U.S. DEPARTMENT OF HOMELAND SECURITY

FEMA

Federal Emergency Management Agency

Quinnipiac River HUC 8 LiDAR FY2010

New Haven County, Connecticut CID 09009C

Middlesex County, Connecticut CID 09007C

Technical Support Data Notebook

Terrain Project Narrative

Elevation Data Acquisition

CASE NO. 11-01-0721S
Contract no. HSFEHQ-09-D-0370
Task Order No. HSFE01-10-J-0005

Date August 31, 2011

Prepared By:

STARR
Strategic Alliance
for Risk Reduction

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ATTACHMENTS:

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1. Introduction

Beginning in Fiscal Year 2010, FEMA initiated a five-year program for Risk Mapping, Assessment, and Planning (Risk MAP). The vision for Risk MAP is to deliver quality data that increases public awareness and leads to action that reduces risk to life and property. In order to realize the Risk MAP vision FEMA is acquiring high resolution terrain elevation and land cover elevation data to increase production efficiencies for NFIP regulatory products and support risk assessment data development. FEMA has made a commitment through Risk MAP to work closely with NDEP (National Digital Elevation Program) partners to obtain and support the collection of terrain data throughout the United States.

Terrain data, collected under the Risk MAP program, will be required to meet minimum specifications outlined in the *Draft Procedure Memorandum No. 61—Standards for LiDAR and Other High Quality Digital Topography dated August 1st, 2010*[1]. FEMA also requires all deliverables for topographic data collection be submitted in accordance with *Appendix M: Data Capture Standards March 2009*[2]. All relevant project materials have been reviewed to insure that these requirements are met.

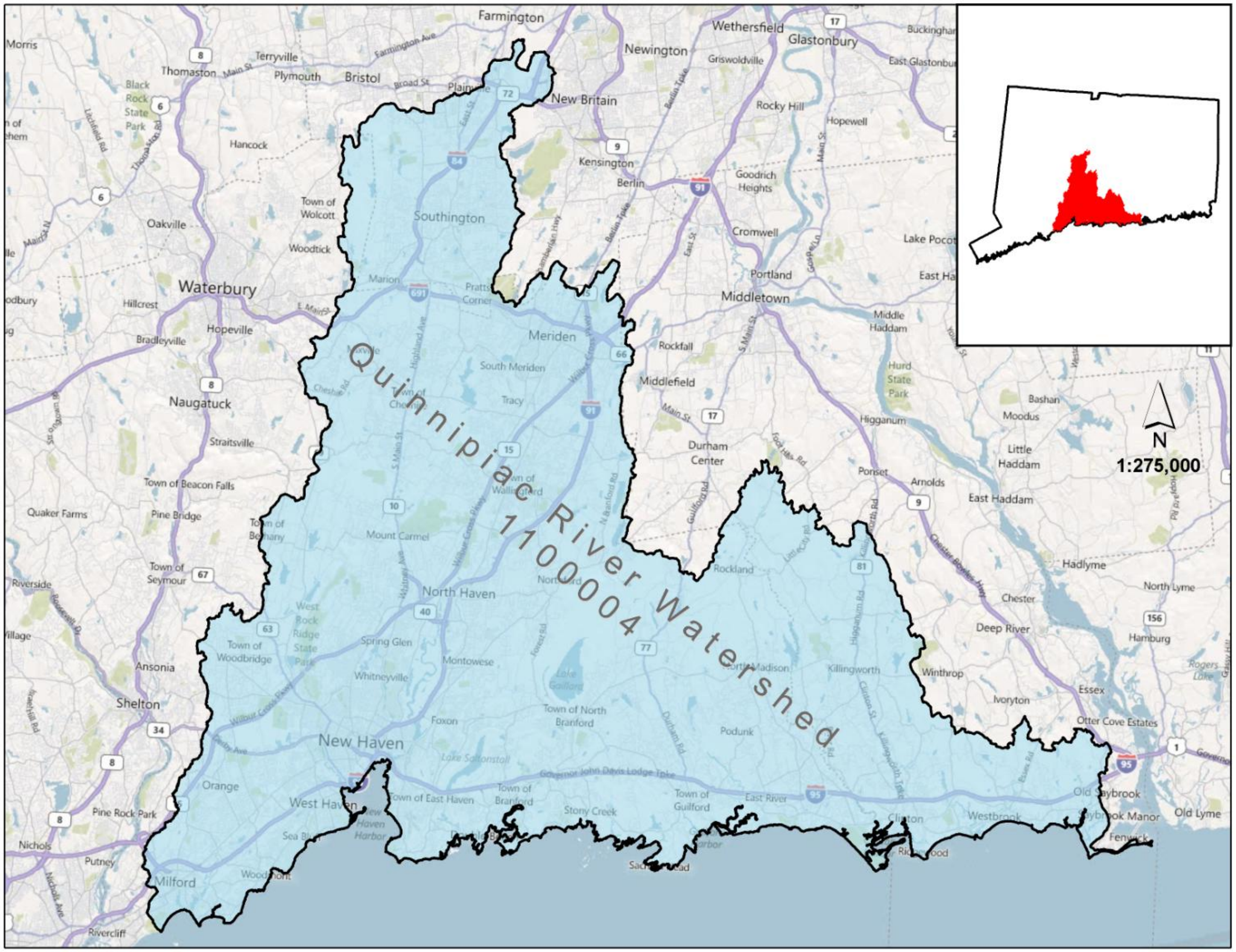
The objectives for elevation data acquisition for the Quinnipiac River watershed are as follows:

1. LAS point cloud files collected for 443 square miles
2. LAS point cloud files captured using the “Highest” vertical accuracy requirements
3. LAS point cloud files collected at equivalent of a 2-foot contour accuracy
4. LAS point cloud files collected using a nominal pulse spacing of 1-meter
5. LAS classified as Bare Earth processed for 443 square miles

Table 1. Vertical Accuracy Requirements

Contour Accuracy	Specification Level	$RMSE_z$	FVA	CVA
2ft	Highest	37.1 cm	24.5 cm	36.3 cm

Figure 1. Quinnipiac Watershed Project Location



The LiDAR Acquisition area for this project covers portions of New Haven County, Middlesex County, and Hartford County, Connecticut. The following communities are either partially or completely included within this Area of Interest:

Communities in New Haven County, Connecticut:

Town of Ansonia
Town of Bethany
Town of Branford
Town of Cheshire
Town of Derby
Town of East Haven
Town of Guilford
Town of Hamden
Town of Madison
Town of Meriden
Town of Milford
Town of New Haven
Town of North Branford
Town of Orange
Town of Prospect
Town of Wallingford
Town of Waterbury
Town of West Haven
Town of Wolcott
Town of Woodbridge

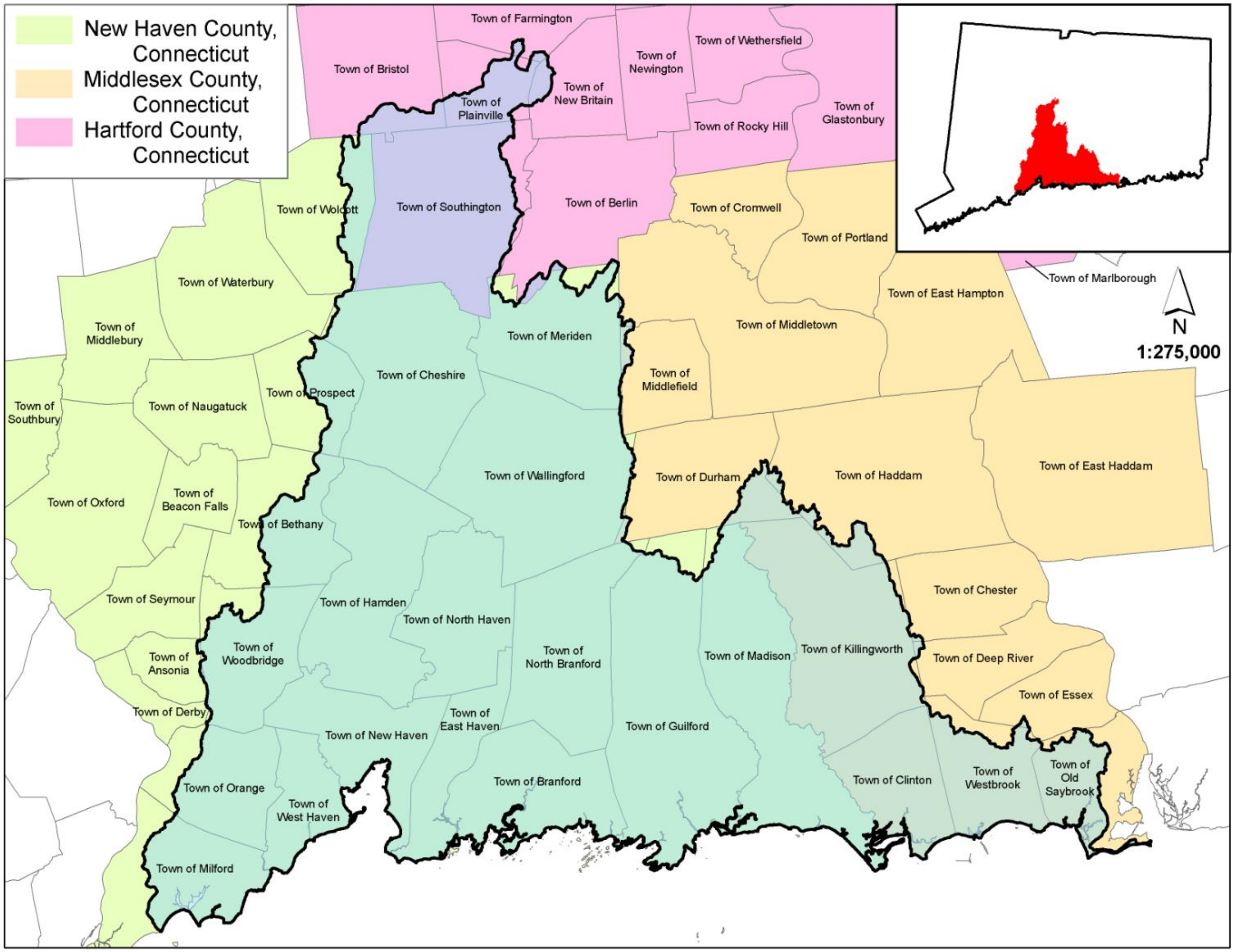
Communities in Middlesex County, Connecticut:

Town of Chester
Town of Clinton
Town of Deep River
Town of Durham
Town of Essex
Town of Haddam
Town of Killingworth
Town of Middlefield
Town of Middletown
Town of Old Saybrook
Town of Westbrook

Communities in Hartford County, Connecticut:

Town of Berlin
Town of Bristol
Town of Farmington
Town of New Britain
Town of Plainville
Town of Southington

Figure 2 Quinnipiac Watershed Communities



2. Scope of Work

Statement of Priorities
PTS Elevation Data Acquisition
STARR – Contract # HSFEHQ-09-D-0370

The contractor shall acquire elevation data to support flood hazard data updates based on the minimum requirements shown of the attached ordering sheet. Elevation data shall comply with the draft FEMA Procedure Memorandum: Standards for LiDAR and Other High Quality Elevation Data.

The contractor shall respond with pricing for the minimum elevation collections and bare earth processing specified the attached ordering sheet. The contractor's proposal shall identify any breakline creation or other post-processing that is required to use the elevation data for the flood hazard data updates based on the risk, terrain type, anticipated engineering methods and other relevant factors. The proposal must explain the reasons this additional processing is needed.

The contractor will also be responsible for performing QA of the elevation data as specified in the Standards for LiDAR and Other High Quality Elevation Data procedure memo.

The contractor shall also propose collection and processing alternatives that group the collections into larger, more cost effective collection blocks or other collection and processing alternatives that may be more advantageous for the government as an alternative option.

Scope Details:

All data collected under this task order will adhere to the FEMA Procedure Memorandum No. 61 – Standards for LiDAR and Other High Quality Digital Topography.

STARR will be responsible for all phases of LiDAR collection (including ground control, acquisition, post-processing, and accuracy assessment of the data) as described below:

STARR is responsible for the collection of ground control required to control the LiDAR data and points to support a vertical test. These points must be located only in open terrain, where there is a high probability that the sensor will have detected the ground surface without influence from surrounding vegetation.

Checkpoints must be located on flat or uniformly sloping terrain and will be at least five (5) meters away from any break line where there is a change in slope. This criterion applies for all QA points for the Fundamental Vertical Accuracy (FVA) Assessment as well.

STARR will be responsible for the collection of blind vertical QA points for the Consolidated Accuracy Check (CVA). These points must be collected randomly across the three predominant land use types using the ASPRS NSSDA land cover types. The points will be located in flat areas with no substantial elevation breaks within a 3-5 meter radius. The CVA assessment may incorporate a representative sample of the FVA assessment into the dataset to save on the total number of points collected. A CVA point should not be collected for any land class comprising less than 10% of the total project area.

At least 20 points for the FVA and 15 additional points for the CVA in vegetated classes, supplemented by five FVA points to achieve 20 in total in the CVA must be collected. This number of points will give STARR the required RMSE to generate the 95% confidence required by the FEMA guidelines. All ground control points must have digital photos and a sketch (if practical) for each point. This collateral data may help with any discrepancies without further field work.

STARR must provide proof that the vertical accuracy assessment of the LiDAR data was a blind test via an independent check report. The spreadsheet with X and Y coordinates for at least 20 FVA and 15 CVA points, the elevation of each coordinate found in the LiDAR data, the comparison with the accuracy check point, the calculated difference and the overall RMSE must be included in this report. Independent check or calibration points will be three times as accurate as the surface being checked. Therefore, in order to validate a 24.5 cm surface, STARR must collect control data to 8 cm.

LiDAR acquisition of the Quinnipiac River Watershed, consisting of 443 square miles, captured to the “Highest” vertical accuracy requirement. This collection specification is the equivalent of a 2-foot contour accuracy and must be collected with a nominal pulse spacing of 1-meters. The entire area will be post processed to bare earth.

DELIVERABLES

STARR will deliver the following:

- Ground control spreadsheet in x,y,z format, digital photograph and sketch of area (if practical) for each collected point.
- FVA Report. Assessment of initial vertical accuracy of point cloud to ensure that data has successfully completed preliminary processing. The data will be validated for positional accuracy using USGS LiDAR Guidelines and Base Specifications v13. Fundamental checkpoints will only consist of open area or bare earth areas (short grass, dirt, or rock).

  Listing of checkpoints will include any digital photographs and/or sketches for each point.
- CVA Report. Assessment of final vertical accuracy of LiDAR data to ensure that data has successfully completed bare earth processing. The data will be validated for positional accuracy using USGS LiDAR Guidelines and Base Specifications v13. Consolidated checkpoints will be collected over the five major ASPRS Land Classes.

  Listing of checkpoints will include any digital photographs and/or sketches for each point.
- Pre-Flight Operations Plan. MS Word file or PDF document that details planned flight lines, planned GPS stations, planned control, planned airport locations, calibration plans, quality procedures for flight crews, planned scanset, type of aircraft, re-flight procedures, and considerations for terrain, cover and weather in the project. This document is to be provided in accordance with the FEMA Procedure Memorandum No. 61– Standards for LiDAR and Other High Quality Digital Topography.
- Post Flight Aerial Acquisition Report. MS Excel, MS Word, and ESRI Shapefile formats (as appropriate) that details actual GPS base station information, GPS/IMU processing summary, coverage, flight data (as flown), flight logs, ground control to be used, and results of data verification (QC) process. This document is to be provided in accordance with the FEMA Procedure Memorandum No. 61 – Standards for LiDAR and Other High Quality Digital Topography.
- LAS Point Cloud Data. The initial processing and analysis of laser data (GPS/IMU/laser ranges) to fully calibrated point clouds in a mutually agreed upon tile format. This format will be proposed by Tuck Mapping to STARR. Consideration of optimum processing and use by floodplain modeling staff will be a basis for the format.   All LiDAR data will be set to ASPRS LAS Class 1 (unclassified).
- LAS Bare Earth Data. The final processing and classification of LiDAR to the required ASPRS LAS classes in a mutually agreed upon tile format and compliant with USGS LiDAR Guidelines and Base Specifications v13, except as noted in the FEMA Procedure Memorandum No. 61 – Standards for LiDAR and Other

High Quality Digital Topography.

- LAS Model Key Points (ASPRS Class 8). LAS Bare Earth Data thinned to an average density of approximately 3-meter post spacing.
- Metadata. Metadata will be delivered for LAS Bare Earth Data using FGDC standards compliant with FEMA Procedure Memorandum N. 61 – Standards for LiDAR and Other High Quality Digital Topography, Attachment 2.

All data will be referenced to the NAD83 horizontal datum. The vertical datum will be referenced to NAVD88. Geoid 09 model for the National Geodetic Survey will be used to perform conversions from ellipsoidal heights to orthometric heights. The standard coordinate reference system and units will be UTM (meters).

A Certification of Compliance is also required. The Certification shall meet FEMA TSDN (Technical Support Data Notebook) requirements as stated in FEMA Guidelines and Specifications, Appendix M.

3. Issues

A. Special Problem Reports

None

B. Project Modifications

None

4. Information for the Next Mapping Partner

The Quinnipiac Watershed LiDAR collection Area of Interest (AOI) consists of one large functional area that covers 443 square miles. This area only covers all of the Quinnipiac Watershed. This project included both LiDAR point cloud development and Bare Earth post processing. The Point Cloud LiDAR data for this project are 666 partially classified LAS 1.2 binary files. The 666 Bare Earth LiDAR LAS 1.2 binary files for this project have been classified using ASPRS LiDAR classifications. Bare Earth classified as class 2 is considered to be Bare Earth and points classified as class 8 are Model Key. All data for this project has been collected using the following spatial reference information:

Projection: Universal Transverse Mercator
UTM Zone: 18
Linear units: Meter
Horizontal Datum: North American Datum 1983
Vertical Datum: North American Vertical Datum of 1988
Vertical units: Meters

LAS point files are named according to the UTM Coordinates at the southwest corner of the tile, following the zz_0xxxyyy convention, where z is the UTM zone number, x and y are the UTM coordinates.

Details about the storage of this dataset can be found within Appendix G of this document.

Ground control and quality control checkpoints were collected by CompassData, Inc. Photo Science, Inc. performed LiDAR acquisition flights, automated processing and Bare Earth manual edits. Independent QC of the point cloud and bare earth surface was performed by CompassData, Inc. Quality Assurance testing was conducted by Greenhorne & O'Mara, Inc. All firms were under contract to STARR, A Joint Venture which held the FEMA Professional Technical Services contract and task order for this work. All contact information for the project team can be found in Appendix A of this document.

A. Ground Control Survey

Ground Control is collected throughout the AOI for use in the processing of LiDAR data to ensure data accurately represents the ground surface. QA/QC checkpoints, also collected throughout the AOI, are used for independent quality checks of the processed LiDAR data.

GPS based surveys were utilized to support both processing and testing of LiDAR data within FEMA designated Areas of Interest (AOIs). Geographically distinct ground points were surveyed using GPS technology throughout the AOIs to provide support for three distinct tasks.

Task 1 was to provide Vertical Ground Control to support the aerial acquisition and subsequent bare earth model processing. To accomplish this, survey-grade Trimble R-8 GPS receivers were used to collect a series of control points located on open areas, free of excessive or significant slope, and at least 5 meters away from any significant terrain break. Most if not all control points were collected at street/road intersections on bare level pavement.

Task 2 was to collect Fundamental Vertical Accuracy (FVA) checkpoints to evaluate the initial quality of the collected point cloud and to ensure that the collected data was satisfactory for further processing to meet FEMA specifications. The FVA points were collected in identical fashion to the Vertical Ground Control Points, but segregated from the point pool to ensure independent quality testing without prior knowledge of FVA locations by the aerial vendor.

Task 3 was to collect Consolidated Vertical Accuracy (CVA) checkpoints to allow vertical testing of the bare-earth processed LiDAR data in different classes of land cover, including: Open (pavement, open dirt, short grass), High Grass and Crops, Brush and Low Trees, Forest, Urban. CVA points were collected in similar fashion as Control and FVA points with emphasis on establishing point locations within the predominant land cover classes within each AOI or Functional AOI Group. In order to successfully collect the Forest land cover class, it was necessary to establish a Backsight and Initial Point with the R8 receiver, and then employ a Nikon Total Station to observe a retroreflective prism stationed under tree canopy. This was necessary due to the reduced GPS performance and degradation of signal under tree canopy. The R-8 receivers were equipped with cellular modems to receive real-time correction signals from the Keystone Precision Virtual Reference Station (VRS) network encompassing the Region 1 AOIs. Use of the VRS network allowed rapid collection times (~3 minutes/point) at 2.54 cm (1 inch) initial accuracy.

All points collected were below the 8 cm specification for testing 24.5 cm, Highest category LiDAR data. To ensure valid in-field collections, an NGS monument with suitable vertical reporting was measured using the same equipment and procedures used for Control, FVA and CVA points on a daily basis. The measurement was compared to the NGS published values to ensure that the GPS collection schema was producing valid data and as a physical proof point of quality of collection. Those monument measurements are summarized in the Accuracy report included in the data delivered to FEMA.

In order to meet FEMA budgetary requirements, AOIs were consolidated into Functional Groups: if AOIs were contiguous, they were treated as one large AOI to allow collection of 20 FVA points and 15 additional CVA points across the group of AOIs. 20 FVA points are necessary to allow testing to CE95 – 1 point out of 20 may fail vertical testing and still allow the entire dataset to meet 95% accuracy requirements. In similar fashion, 20 CVA points are necessary to test to CE95 as discussed above. 15 CVA points were collected with the intention at the outset that 5 of the collected FVAs would perform double –duty as Open-class CVA points, to total 20 CVAs.

The following software packages and utilities were used to control the GPS receiver in the field during data collection, and then ingest and export the collected GPS data for all points:

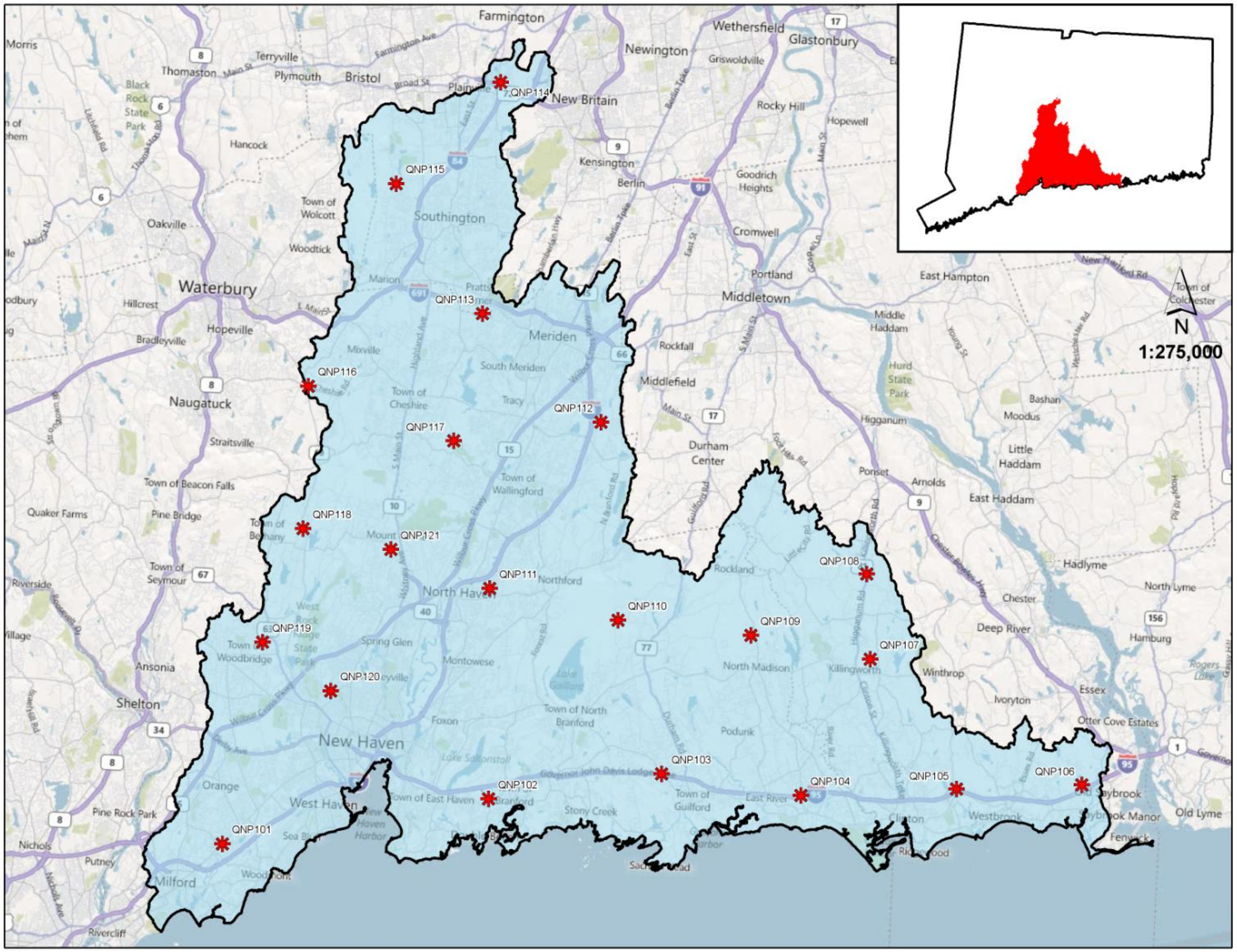
- Trimble Survey Controller
- Trimble Pathfinder Office

The following software utilities were used to translate the collected Latitude/Longitude Decimal Degree HAE GPS data for all points into Latitude/Longitude Degrees/Minutes/Seconds for checking the collected monument data against the published NGS Datasheet Lat/Long DMS values and into UTM NAD83 Northings/Eastings:

- U.S. Army Corps of Engineers CorpsCon
- National Geodetic Survey Geoid09NAVD88

MSL values were determined using the most recent NGS-approved geoid model to generate geoid separation values for each Lat/Long coordinate pair. In this fashion, Orthometric heights were determined for each Control, FVA and CVA point by subtracting the generated Geoid Separation value from the Ellipsoidal Height (HAE) for publication and use as MSL NAVD88(09).

Figure 3. Quinnipiac Watershed Ground Control Survey Coverage



B. Data Acquisition

LiDAR acquisition products include Pre- and Post- flight reports which contain information on the flight lines, equipment parameters, and other pertinent acquisition details. The LiDAR product is considered to be point cloud data and consists of 1500mx1500m tiles of LAS points which are partially classified such that the bare earth points can be calibrated to the ground surface and tested via the independent QC to ensure the ground surface is accurately represented.

Using an Optech Gemini LiDAR system, a total 101 flightlines of Highest density (Nominal pulse Spacing of 1.0m) were collected over the Quinnipiac area. A total of 443 square miles was collected. A total of 10 missions were flown between December 11, 2011 and May 27, 2011. One airborne global positioning system (GPS) base station was used to support the LiDAR data acquisition: MMK A-AI5589. Coordinates are available in the Post-Flight Aerial Acquisition Report.

Leica IPAS and Applanix software was used in the post-processing of the airborne GPS and inertial data that is critical to the positioning and orientation of the sensor during all flights. This software suite includes the IPAS from Leica and Applanix POSPac and Waypoint's GrafNav solutions. Pairing the aircraft's raw trajectory data with the stationary GPS base station data, the IPAS and POPSac software yields the smoothed best estimate of trajectory (SBET) that is necessary for Leica's post processor to develop the point cloud from the LiDAR missions. The point cloud is the mathematical three dimensional collections of all returns from all laser pulses as determined from the aerial mission. At this point this data is ready for analysis, classification, and filtering to generate a bare earth surface model in which the above ground features are removed from the data set. GeoCue was used in the creation of some files needed in downstream processing, as well as in the tiling of the dataset into more manageable file sizes. The TerraScan and TerraModeler software packages are then used for the automated data classification, manual cleanup, and bare earth generation from this data. Project specific macros are created to classify the ground and to remove the side overlap between parallel flight lines.

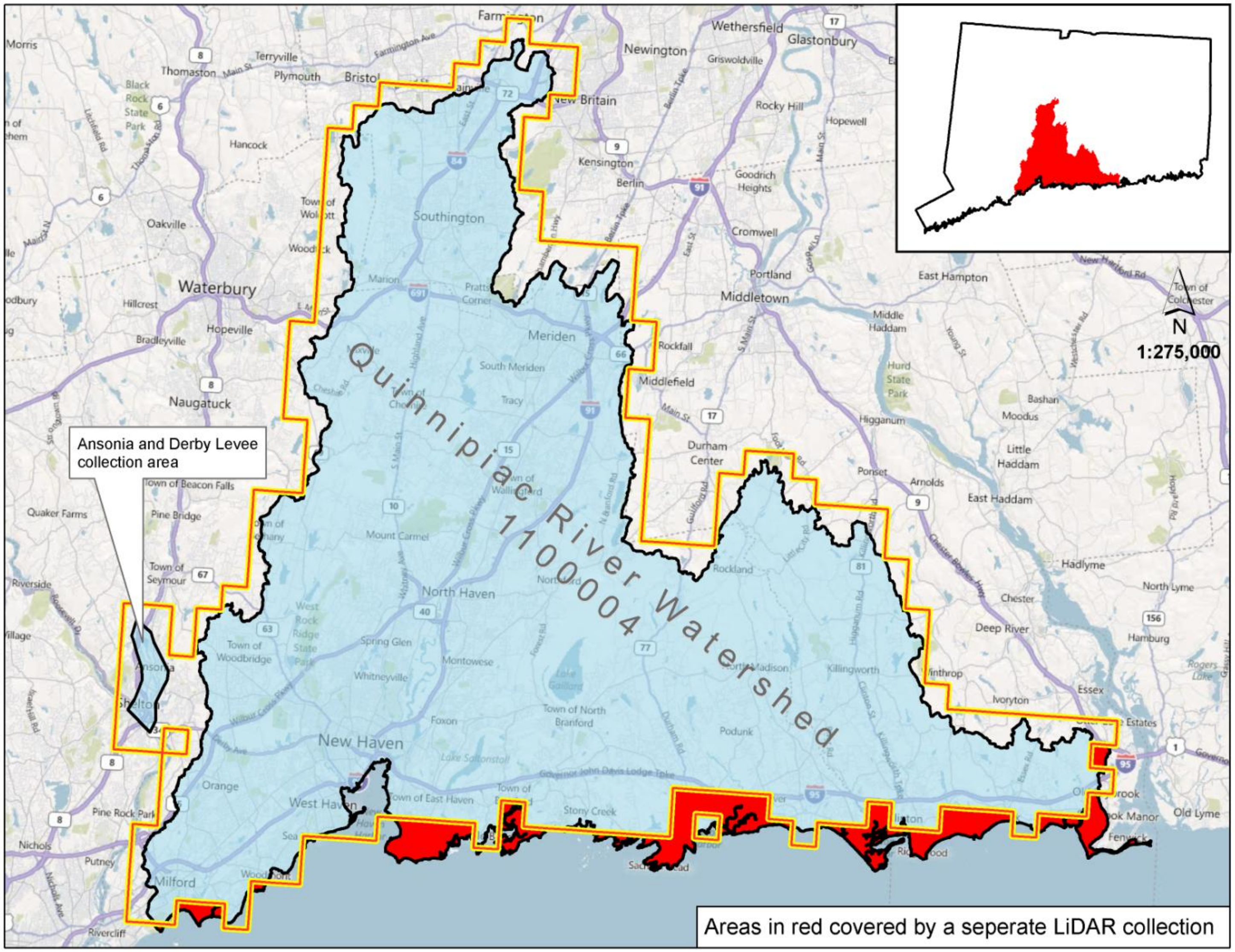
C. Post Processing

Point Cloud data is manually reviewed and any remaining artifacts are removed using functionality provided within the TerraScan and TerraModeler software packages. Additional project specific macros are created and run within GeoCue/TerraScan to ensure correct LAS classification prior to project delivery.

All points were placed in one of the following categories: 1 Unclassified, 2 Ground, 7 Noise, and 12 Overlap Points. Model Key points were then generated from the Ground points and placed in Category 8.

Final Classified LAS tiles are created within GeoCue to confirm correct LAS versioning and header information. In-house software is then used to check LAS header information and final LAS classification prior to delivery. LAS Class 2 is used to check the independent QC points against the Triangulated LiDAR surface.

Figure 4. Quinnipiac Watershed Point Cloud and Post Processing Areas



Ansonia and Derby Levee collection area

Areas in red covered by a seperate LiDAR collection

D. Quality Control

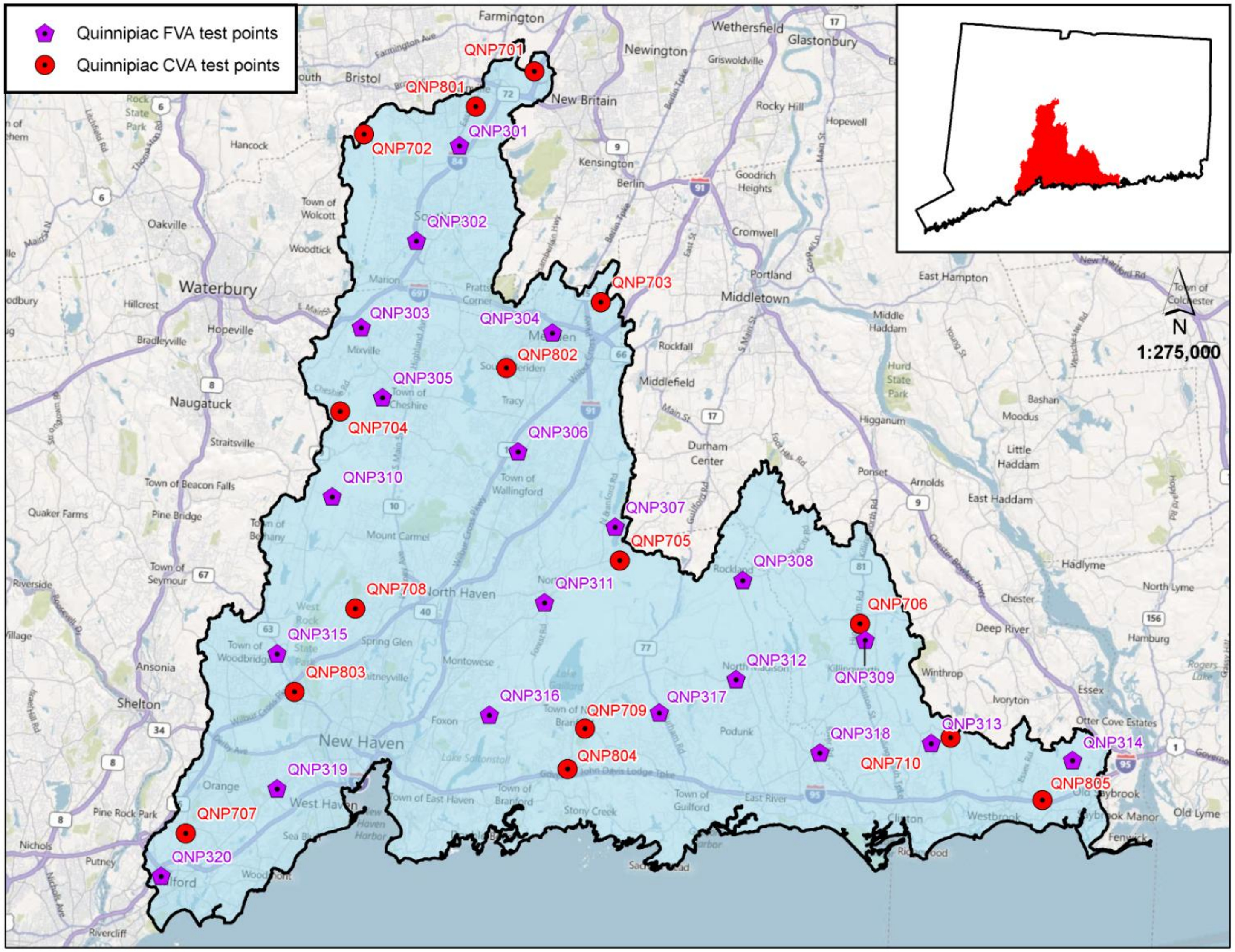
Fundamental Vertical Accuracy (FVA) checkpoints are located only in open terrain, where there is a high probability that the sensor will have detected the ground surface without influence from surrounding vegetation and/or buildings. Checkpoints are located on flat or uniformly sloping terrain and at least five (5) meters away from any break line where there is a change in slope. Checkpoints are located randomly across the acquisition area. At least 20 FVA points were collected for each test.

Consolidated Vertical Accuracy (CVA) checkpoints are collected randomly across different land use types using the ASPRS NSSDA land cover types. The points are located in flat areas with no substantial elevation breaks within a five meter radius. The CVA assessment incorporates a representative sample of the FVA assessment points into the dataset to save on the total number of points collected. CVA points were not collected for any land class comprising less that 10% of the total project area; this may have resulted in less than 4 land classes being collected in a particular area. At least 15 CVA points were collected and 5 FVA points used, for a total of at least 20 points for the CVA testing.

All checkpoints were collected by CompassData to ensure the 'independence' of the quality control check. All points were collected at three times the accuracy of the surface being checked. Thus to check a 24.5 cm surface the points were collected accurate to 8 cm.

Tests were conducted when processing by the LiDAR vendor was complete and points were called for. CompassData provided the point coordinates in an excel spreadsheet to the LiDAR vendor. The LiDAR vendor found the corresponding elevation from a surface created from the LiDAR points, filled in the spreadsheet and returned it to CompassData. CompassData compared the elevation of the LiDAR data with that of the accuracy check point, calculated the difference and reported their findings both in terms of $RMSE_z$ and at the 95% confidence level (computed as $RMSE_z$ x 1.9600). LiDAR datasets passing the quality control checks were delivered to STARR for quality assurance approval.

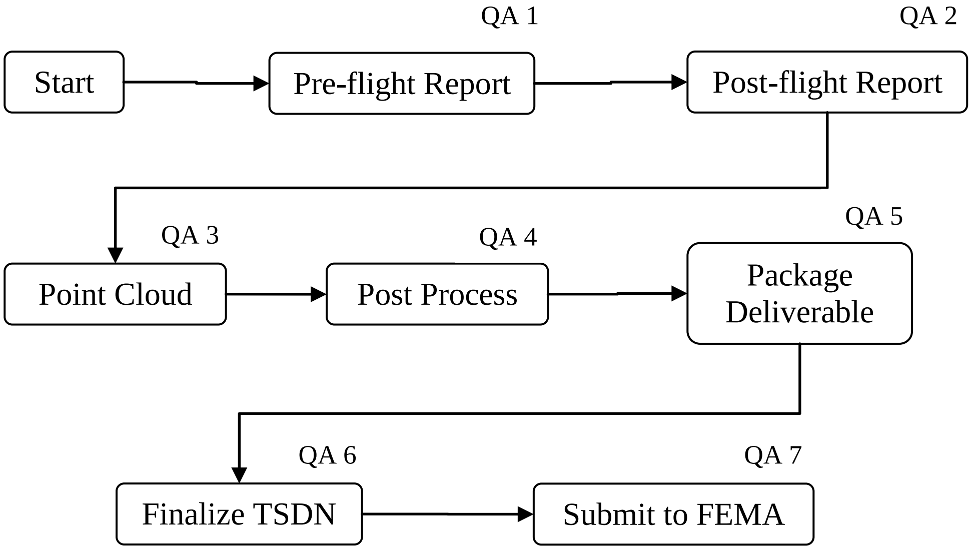
Figure 5. Quinnipiac Watershed FVA and CVA Points



E. Quality Assurance

Quality assurance for all elevation data collected for this project has been completed using *FEMA Draft PM61*[1], *FEMA Appendix M*[2], *USGS LiDAR Guidelines and Base Specifications v13*[3], and *FEMA Appendix A*[4] as guidance. Products generated during this project are checked for conformance to the aforementioned guidance and specifications before submittal to FEMA.

Figure 6. Quality Assurance Workflow



QA1: Preflight Planning and Reporting

Project preflight operations planning were delivered as a report. This report was reviewed for completeness based on: *Table 4.1 and checklists provided in section 4.2.1in PM61*[1]. The report was reviewed and is compliant with FEMA guidance and specifications. This report is included within Appendix C of this document. Appendix G contains information about the location of report data on the MIP.

QA2: Post flight Report

Post flight reporting for this project has been reviewed for both content and completeness based upon: *Table 4.2 and checklists provided in section 4.2.1in PM61*[1]. The report is included with Appendix E of this document. The report is complete and all content meets the guidance and specifications.

QA3: Raw Point Cloud Review

Fully calibrated raw point cloud data has been reviewed at both a macro and micro level using *Table 4.3 and checklists provided in section 4.2.1in PM61*[1], and USGS *LiDAR Guidelines and Base Specifications v13*[3]. 5% of the total number of project tiles was reviewed for compliance with USGS and FEMA specifications. All tiles reviewed for this project passed both the macro and micro reviews. Quality assurance results for the point cloud are contained within Appendix F of this document.

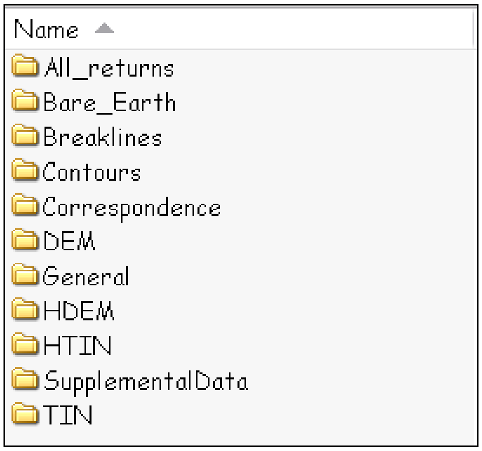
QA4: Bare Earth Review

Post-processed data has been reviewed at both a macro and micro level using *Table 4.4 and checklists provided in section 4.2.1in PM61*[1], and USGS *LiDAR Guidelines and Base Specifications v13*[3]. 10% of the total number of project tiles was reviewed for compliance with USGS and FEMA specifications. All tiles reviewed for this project passed both the macro and micro reviews. Quality assurance results for the bare earth are contained within Appendix F of this document.

QA5: Create Delivery Package

All deliverables have been organized in accordance with Appendix M: Data Capture Standards March 2009 Section M.4.2.8[2].

Figure 7. Terrain Deliverable Directory Structure



Name
All_returns
Bare_Earth
Breaklines
Contours
Correspondence
DEM
General
HDEM
HTIN
SupplementalData
TIN

QA6: Finalization of Deliverables and TSDN

All data to be submitted for delivery has been reviewed for completeness based on the map activity statement, scope of work, and FEMA deliverable requirements. Quality assurance checklists are included in Appendix F of this document.

QA7: FEMA submission

All data for the elevation data acquisition task was delivered to FEMA on August 31, 2011. A transmittal of this submission is included in Appendix G of this document.

5. References

1. Draft Procedure Memorandum 61 included in Appendix H
2. FEMA Appendix M section M.4 included in Appendix H
3. USGS LiDAR Guidelines and Base Specifications v13 included in Appendix H
4. Appendix A: Guidance for Aerial Mapping and Surveying [includes guidance on Light Detection and Ranging Systems (LIDAR)] http://www.fema.gov/library/viewRecord.do?id=2206

Appendix A: Contact Information

STARR Contacts:

Project Management and Quality Assurance

Company	Greenhorne & O'Mara, Inc.
Name	Diane Rogers
Email	drogers@g-and-o.com
Phone	301-982-2800
Mailing Address	5565 Centerview Drive, Suite 107 Raleigh, NC 27606

LiDAR ground control and QC survey

Company	Compass Data, Inc.
Name	Hayden Howard
Email	haydenh@compassdatainc.com
Phone	303-627-4058
Mailing Address	12353 East Easter Avenue, Suite 200 Centennial, CO 80112

LiDAR data acquisition and Post Processing

Company	Photo Science, Inc
Name	Paul Bishop
Email	bishop@photoscience.com
Phone	859-277-8700
Mailing Address	2670 Wilhite Drive Lexington, KY 40503

Appendix B: FEMA Compliance Forms and Metadata

Project Name:	**Region 1: Quinnipiac, Connecticut – Elevation Data Acquisition**
Statement of Work No.:	FEMA TASK ORDER NUMBER: HSFEHQ-10-J-0005 WORK ORDER NUMBER: CP HQ 10 001
Interagency Agreement No.:	STARR PROJECT NUMBER: 400000058 STARR PARTNER TRACKING NUMBER: CP HQ 10 001
CTP Agreement No.:	N/A
Statement/Agreement Date:	10/10/10
Certification Date:	8/23/11

	Tasks/Activities Covered by This Certification (Check All That Apply)
☐	Base Map
☐	Topographic Data Development
X	Survey: Including Ground Control Points (GCPs), Fundamental Vertical Accuracy Testing (FVA), and Consolidated Vertical Accuracy Testing (CVA).
☐	Hydrologic Analysis
☐	Hydraulic Analysis
☐	Alluvial Fan Analysis
☐	Coastal Analysis
☐	Floodplain Mapping

This is to certify that the work summarized above was completed in accordance with the statement/agreement cited above and all amendments thereto, together with all such modifications, either written or oral, as the Regional Project Officer and/or Assistance Officer or their representative have directed, as such modifications affect the statement/agreement, and that all such work has been accomplished in accordance with the provisions contained in *Guidelines and Specifications for Flood Hazard Mapping Partners* cited in the contract document, and in accordance with sound and accepted engineering practices within the contract provisions for respective phases of the work. This is also to certify that data files submitted for the work summarized above are complete and final. Any revisions made to the already submitted data are included in the final submittal.

Name:	Philipp H. Hummel, PLS
Title:	Professional Land Surveyor, Geodesist
Firm Represented:	Compass Data, Inc.
Registration No.:	38155
Signature:	Philipp Hummel

COLORADO LICENSED PROFESSIONAL LAND SURVEYOR
PHILIPP H. HUMMEL
38155
August 23, 2011

For and on behalf of Compass Data, Inc.
Job. No.: 1508

This form must be signed by a representative of the firm or agency contracted to perform the work, who must be a registered or certified professional in the area of work performed, in compliance with Federal and State regulations.

Project Name:	Quinnipiac Watershed, LiDAR Acquisition
Statement of Work No.:	HSFE01-10-J-0006
Interagency Agreement No.:	N/A
CTP Agreement No.:	N/A
Statement/Agreement Date:	N/A
Certification Date:	August 10, 2011
	Tasks/Activities Covered by This Certification (Check All That Apply)
☐	Base Map
☒	Topographic Data Development
☐	Survey
☐	Hydrologic Analysis
☐	Hydraulic Analysis
☐	Alluvial Fan Analysis
☐	Coastal Analysis
☐	Floodplain Mapping
	This is to certify that the work summarized above was completed in accordance with the statement/agreement cited above and all amendments thereto, together with all such modifications, either written or oral, as the Regional Project Officer and/or Assistance Officer or their representative have directed, as such modifications affect the statement/agreement, and that all such work has been accomplished in accordance with the provisions contained in *Guidelines and Specifications for Flood Hazard Mapping Partners* cited in the contract document, and in accordance with sound and accepted engineering practices within the contract provisions for respective phases of the work. This is also to certify that data files submitted for the work summarized above are complete and final. Any revisions made to the already submitted data are included in the final submittal.
Name:	Mark E. Meade, PE, PLS, CP
Title:	Senior Vice President
Firm/Agency Represented:	Photo Science
Registration No.:	R1050
Signature:	
	This form must be signed by a representative of the firm or agency contracted to perform the work, who must be a registered or certified professional in the area of work performed, in compliance with Federal and State regulations.

American Society for Photogrammetry and Remote Sensing
MARK E. MEADE
CERTIFIED
PHOTOGRAMMETRIST
(ASPRS) No. 1050
Exp. 03/21/12

```
Identification_Information:
  Citation:
    Citation_Information:
      Originator: Federal Emergency Management Agency
      Publication_Date: 20110823
      Title: TERRAIN, Naragansett, Massachusetts
      Geospatial_Data_Presentation_Form: FEMA-DCS-Terrain
      Publication_Information:
        Publication_Place: Washington, DC
        Publisher: Federal Emergency Management Agency
      Online_Linkage: http://hazards.fema.gov
      Larger_Work_Citation:
        Citation_Information:
           Originator: Federal Emergency Management Agency
           Publication_Date: 20110823
        Title: FEMA CASE 11-01-0721S
  Description:
    Abstract: The Quinnipiac AOI consists of one 443 square mile area.
Ground Control is collected throughout the AOI for use in the processing
of LiDAR data to ensure data accurately represents the ground surface.
QA/QC checkpoints, (FVA and CVA - see Ground Control process step for
further information) also collected throughout the AOI, are used for
independent quality checks of the processed LiDAR data.
LiDAR acquisition products include Pre- and Post- flight reports which
contain information on the flightlines, equipment parameters, and other
pertinant acquisition details.  The LiDAR product is considered to be
point cloud data and consists of 1500mx1500m tiles of LAS points which
are partially classified such that the bare earth points can be
calibrated to the ground surface and tested via the independent QC to
ensure the ground surface is accurately represented.
The Bare Earth deliverables consists of tiles of fully classified LAS
points.  A full narrative accompanies this deliverable, as well as the
independent QC report
    Purpose: Provide high resolution terrain elevation and land cover
elevation data. Terrain data is used to represent the topography of a
watershed and/or floodplain environment and to extract useful information
for hydraulic and hydrologic models.

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    Time_Period_Information:
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    Maintenance_and_Update_Frequency: Unknown
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  Access_Constraints: None
  Use_Constraints: Acknowledgement of FEMA would be appreciated in
products derived from these data.  This digital data is produced for the
purposes of updating/creating a DFIRM database.
  Data_Set_Credit:   Ground control and quality control checkpoints were
collected by CompassData, Inc.  LiDAR was acquired and processed by Photo
Science, Inc. Quality Control testing was performed by CompassData, Inc.
Quality Assurance testing was conducted by Greenhorne & O'Mara, Inc.  All
firms were under contract to STARR, A Joint Venture which held the FEMA
contract and task order for this work.
Data_Quality_Information:
  Logical_Consistency_Report: Survey data have been confirmed to be in
proper units, coordinate systems and format. The terrain data have been
confirmed as complete LAS format data files.  Header files are in proper
LAS format with content as specified by FEMA Procedural Memo No. 61.
  Completeness_Report: Survey data have been checked for completeness,
points have been collected in correct vegetation units, and distributed
throughout the AOI. The terrain data have been checked for completeness
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against AOI polygons.  No gaps as defined by FEMA Procedural Memo No. 61
are known to exist within the dataset.

  Positional_Accuracy:
    Vertical_Positional_Accuracy:
      Vertical_Positional_Accuracy_Report: Deliverables were tested by
for both vertical and horizontal accuracy.  The vertical unit of the data
file is in meters with 2-decimal point precision.
      Quantitative_Vertical_Positional_Accuracy_Assessment:
        Vertical_Positional_Accuracy_Value: 0.331
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Accuracy (CVA) equal to the 95th percentile confidence level (RMSE[z] x
1.9600) calculated in open terrain.  Reported in meters.

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          Publication_Date: 2011
          Title: Ground_Control Quinnipiac
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ground surface.
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          Publication_Date: 2011
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          Publication_Date: 2011
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          Publication_Date: 2011
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and CVA blind check point tests against open area and bare earth surfaces
generated from All Returns and Bare Earth (respectively) LAS points.
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          Publication_Date: 2011
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      Source_Contribution: Contains complete narrative on the acquisition
and processing of the LiDAR dataset, includes area diagrams, reports and
metadata.
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          Originator: STARR
          Publication_Date: 2011
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Process_Step:
  Process_Description: GPS based surveys were utilized to support both
processing and testing of LiDAR data within FEMA designated Areas of
Interest (AOIs).  Geographically distinct ground points were surveyed
using GPS technology throughout the AOIs to provide support for three
distinct tasks.
Task 1 was to provide Vertical Ground Control to support the aerial
acquisition and subsequent bare earth model processing.  To accomplish
this, survey-grade Trimble R-8 GPS receivers were used to collect a
series of control points located on open areas, free of excessive or
significant slope, and at least 5 meters away from any significant
terrain break.  Most if not all control points were collected at
street/road intersections on bare level pavement.
Task 2 was to collect Fundamental Vertical Accuracy (FVA) checkpoints to
evaluate the initial quality of the collected point cloud and to ensure
that the collected data was satisfactory for further processing to meet
FEMA specifications.  The FVA points were collected in identical fashion
to the Vertical Ground Control Points, but segregated from the point pool
to ensure independent quality testing without prior knowledge of FVA
locations by the aerial vendor.
Task 3 was to collect Consolidated Vertical Accuracy CVA) checkpoints to
allow vertical testing of the bare-earth processed LiDAR data in
different classes of land cover, including:  Open (pavement, open dirt,
short grass), High Grass and Crops, Brush and Low Trees, Forest, Urban.
CVA points were collected in similar fashion as Control and FVA points
with emphasis on establishing point locations within the predominant land
cover classes within each AOI or Functional AOI Group.  In order to
successfully collect the Forest land cover class, it was necessary to
establish a Backsight and Initial Point with the R8 receiver, and then
employ a Nikon Total Station to observe a retroreflective prism stationed
under tree canopy. This was necessary due to the reduced GPS performance
and degradation of signal under tree canopy.
The R-8 receivers were equipped with cellular modems to receive real-time
correction signals from the Keystone Precision Virtual Reference Station
(VRS) network encompassing the Region 1 AOIs.  Use of the VRS network
allowed rapid collection times (~3 minutes/point) at 2.54 cm (1 inch)
initial accuracy.
All points collected were below the 8cm specification for testing 24cm,
Highest category LiDAR data.  To ensure valid in-field collections, an
NGS monument with suitable vertical reporting was measured using the same
equipment and procedures used for Control, FVA and CVA points on a daily
basis.  The measurement was compared to the NGS published values to
ensure that the GPS collection schema was producing valid data and as a
physical proof point of quality of collection.  Those monument
measurements are summarized in the Accuracy report included in the data
delivered to FEMA.
In order to meet FEMA budgetary requirements, AOIs were consolidated into
Functional Groups:  if AOIs were contiguous, they were treated as one
large AOI to allow collection of 20 FVA points and 15 additional CVA
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points across the group of AOIs. 20 FVA points are necessary to allow testing to CE95 – 1 point out of 20 may fail vertical testing and still allow the entire dataset to meet 95% accuracy requirements.
In similar fashion, 20 CVA points are necessary to test to CE95 as discussed above. 15 CVA points were collected per AOI or per Functional Group with the intention at the outset that 5 of the collected FVAs would perform double –duty as Open-class CVA points, to total 20 CVAs per AOI or Functional Group.
The Functional Groups are as follows:
Narragansett/Charles/Blackstone(northeast), Nashua, Blackstone(north and west), Quinnipiac, Quincy/Suffolk (while included as part of the FEMA Charles AOI, was physically separated from the Charles AOI polygon and treated as an independent functional area).
The following software packages and utilities were used to control the GPS receiver in the field during data collection, and then ingest and export the collected GPS data for all points: Trimble Survey Controller, Trimble Pathfinder Office.
The following software utilities were used to translate the collected Latitude/Longitude Decimal Degree HAE GPS data for all points into Latitude/Longitude Degrees/Minutes/Seconds for checking the collected monument data against the published NGS Datasheet Lat/Long DMS values and into UTM NAD83 Northings/Eastings: U.S. Army Corps of Engineers CorpsCon, National Geodetic Survey Geoid09NAVD88.
MSL values were determined using the most recent NGS-approved geoid model to generate geoid separation values for each Lat/Long coordinate pair.
In this fashion, Orthometric heights were determined for each Control, FVA and CVA point by subtracting the generated Geoid Separation value from the Ellipsoidal Height (HAE) for publication and use as MSL NAVD88(09).
  Process_Date: 2011
Process_Step:
  Process_Description: Using a Leica ALS60 LiDAR system, 101 flight lines of highest density (Nominal Pulse Spacing of 1.0m) were collected over the Quinnipiac area which encompasses 443 square miles. A total of 10 missions were flown on Dec 11, 2010, Dec 16, 2010, Dec 17, 2010, Dec 18, 2010, March 29, 2011, March 30, 2011, May 6, 2011, May 8, 2011, May 10, 2011, and May 27, 2011. One airborne global positioning system (GPS) base station was used to support the LiDAR data acquisition: MMK-A. Additional information can be found in the Post-Flight Aerial Acquisition Report.
  Process_Date: 2011
Process_Step:
  Process_Description: Leica proprietary software was used in the post-processing of the airborne GPS and inertial data that is critical to the positioning and orientation of the sensor during all flights. Pairing the aircraft’s raw trajectory data with the stationary GPS base station data, this software yields Leica’s IPAS TC (“Inertial Positioning & Attitude Sensor – Tightly Coupled”) smoothed best estimate of trajectory (an “SBET”, in Leica’s .sol file format) that is necessary for Leica’s ALSPP post processing software to develop the resulting geo-referenced point cloud from the LiDAR missions. The point cloud is the mathematical three dimensional composite of all returns from all laser pulses as determined from the aerial mission. At this point this data is ready for analysis,

```
classification, and filtering to generate a bare earth surface model in
which the above-ground features are removed from the data set.
The point cloud was created using Leica’s Post Processor software. GeoCue
was used in the creation of some of the files needed in downstream
processing, as well as in the tiling of the dataset into more manageable
file sizes. The TerraScan and TerraModeler software packages are then
used for the automated data classification, manual cleanup, and bare
earth generation from this data. Project specific macros were used to
classify the ground and to remove the side overlap between parallel
flight lines. All data was manually reviewed and any remaining artifacts
removed using functionality provided by TerraScan and TerraModeler. QT
Modeler was used as a final check of the bare earth dataset. GeoCue was
then used to create the deliverable industry-standard LAS files for both
the All Point Cloud Data and the Bare Earth. In-house software was then
used to perform final statistical analysis of the classes in the LAS
files.
  Process_Date:  2011
Process_Step:
  Process_Description:  Point Cloud data is manually reviewed and any
remaining artifacts are removed using functionality provided within the
TerraScan and TerraModeler software packages.
Additional project specific macros are created and run within
GeoCue/TerraScan to ensure correct LAS classification prior to project
delivery.
Final Classified LAS tiles are created within GeoCue to confirm correct
LAS versioning and header information.
In-house software is then used to check LAS header information and final
LAS classification prior to delivery.
LAS Class 2 is used to check the independent QC points against the
Triangulated LiDAR surface.
  Process_Date: 2011

Spatial_Reference_Information:
Horizontal_Coordinate_System_Definition:
Planar:
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Grid_Coordinate_System_Name: Universal Transverse Mercator
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UTM_Zone_Number: 18
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   Longitude_of_Central_Meridian: -75.000000
   Latitude_of_Projection_Origin: 0.000000
   False_Easting: 500000.000000
   False_Northing: 0.000000
      Planar_Coordinate_Information:
        Planar_Coordinate_Encoding_Method: coordinate pair
        Coordinate_Representation:
          Abscissa_Resolution: 0.000010
          Ordinate_Resolution: 0.000010
        Planar_Distance_Units: meters
Geodetic_Model:
   Horizontal_Datum_Name: North American Datum 1983
   Ellipsoid_Name:  Geodetic Reference System 80
   Semi-major_Axis: 6378137.00
   Denominator_of_Flattening_Ratio: 298.257222
      Vertical_Coordinate_System_Definition:
        Altitude_System_Definition:
        Altitude_Datum_Name: North American Vertical Datum of 1988
        Altitude_Resolution: 0.01
        Altitude_Distance_Units:  meters
        Altitude_Encoding_Method:  Attribute Values

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Quinnipiac
        Entity_Type_Definition: Ground Control Survey for LiDAR
collection
        Entity_Type_Definition_Source: FEMA Guidelines and Specifications
for Flood Hazard Mapping Partners, Appendix M: Data Capture Standards and
Data Capture Guidelines (available at
http://www.fema.gov/fhm/dl_cgs.shtm)
    Detailed_Description:
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Quinnipiac
        Entity_Type_Definition: Survey for Horizontal and Vertical LiDAR
QC
        Entity_Type_Definition_Source: FEMA Guidelines and Specifications
for Flood Hazard Mapping Partners, Appendix M: Data Capture Standards and
Data Capture Guidelines (available at
http://www.fema.gov/fhm/dl_cgs.shtm)
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Terrain\2142895\SupplementalData\Quinnipiac_Collection_Area
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        Entity_Type_Definition_Source: FEMA Guidelines and Specifications
for Flood Hazard Mapping Partners, Appendix M: Data Capture Standards and
Data Capture Guidelines (available at
http://www.fema.gov/fhm/dl_cgs.shtm)
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        Entity_Type_Label: Terrain\2142895\All_Returns
        Entity_Type_Definition: LAS 1.2 files
        Entity_Type_Definition_Source: FEMA Guidelines and Specifications
for Flood Hazard Mapping Partners, Appendix M: Data Capture Standards and
Data Capture Guidelines (available at
http://www.fema.gov/fhm/dl_cgs.shtm)
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Terrain\2142895\SupplementalData\Quinnipiac_PreFlight Report
        Entity_Type_Definition: Digital Document
        Entity_Type_Definition_Source: FEMA Guidelines and Specifications
for Flood Hazard Mapping Partners, Appendix M: Data Capture Standards and
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Data Capture Guidelines (available at
http://www.fema.gov/fhm/dl_cgs.shtm)
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for Flood Hazard Mapping Partners, Appendix M: Data Capture Standards and
Data Capture Guidelines (available at
http://www.fema.gov/fhm/dl_cgs.shtm)
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Terrain\2142895\SupplementalData\Quinnipiac_Tile_Index
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        Entity_Type_Definition_Source: FEMA Guidelines and Specifications
for Flood Hazard Mapping Partners, Appendix M: Data Capture Standards and
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http://www.fema.gov/fhm/dl_cgs.shtm)
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        Entity_Type_Label: Terrain\2142896\SupplementalData\Region 1
Quinnipiac Testing Results FVA CVA
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        Entity_Type_Definition_Source: FEMA Guidelines and Specifications
for Flood Hazard Mapping Partners, Appendix M: Data Capture Standards and
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http://www.fema.gov/fhm/dl_cgs.shtm)
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        Entity_Type_Label:
Terrain\2142896\SupplementalData\R1_Quinnipiac_Terrain_TSDN
        Entity_Type_Definition: Digital Document
        Entity_Type_Definition_Source: FEMA Guidelines and Specifications
for Flood Hazard Mapping Partners, Appendix M: Data Capture Standards and
Data Capture Guidelines (available at
http://www.fema.gov/fhm/dl_cgs.shtm)
    Detailed_Description:
      Entity_Type:
        Entity_Type_Label: Terrain\2142896\Bare_Earth
        Entity_Type_Definition: LAS 1.2 files
        Entity_Type_Definition_Source: FEMA Guidelines and Specifications
for Flood Hazard Mapping Partners, Appendix M: Data Capture Standards and
Data Capture Guidelines (available at
http://www.fema.gov/fhm/dl_cgs.shtm)
    Overview_Description:
      Entity_and_Attribute_Overview: The Terrain data package is made up
of several data themes containing primarily spatial information. These
data supplement the Elevation datasets by providing additional
information to aid flood risk evaluation and flood hazard area
delineations.
      Entity_and_Attribute_Detail_Citation: Appendix M of FEMA Guidelines
and Specifications for FEMA Flood Hazard Mapping Partners contains a
```

```
detailed description of the data themes and references to other relevant
information.

Distribution_Information:
  Distributor:
    Contact_Information:
      Contact_Organization_Primary:
        Contact_Organization: Federal Emergency Management Agency
Engineering Library
      Contact_Address:
        Address_Type: mailing address
        Address: Marie Sparrow, Zimmerman Associates, Inc.
        Address: 847 South Pickett Street
        City: Alexandria
        State_or_Province: Virginia
        Postal_Code: 22304
        Country: USA
      Contact_Voice_Telephone: 1-877-336-2627
      Contact_Electronic_Mail_Address: miphelp@mapmodteam.com

Distribution_Liability:  No warranty expressed or implied is made by FEMA
regarding the utility of the data on any other system nor shall the act
of distribution constitute any such warranty.
  Standard_Order_Process:
    Digital_Form:
      Digital_Transfer_Information:
        Format_Name: FEMA-DCS-Terrain
      Digital_Transfer_Option:
        Online_Option:
          Computer_Contact_Information:
            Network_Address:
             Network_Resource_Name: http://hazards.fema.gov
    Fees: Contact Distributor

Metadata_Reference_Information:
  Metadata_Date: 20110823
  Metadata_Contact:
    Contact_Information:
      Contact_Person_Primary:
        Contact_Person: FEMA Representative
        Contact_Organization: Federal Emergency Management Agency
      Contact_Address:
        Address_Type: mailing address
        Address: 500 C Street, S.W.
        City: Washington
        State_or_Province: District of Columbia
        Postal_Code: 20472
        Country: USA
      Contact_Voice_Telephone: 1-877-336-2627
      Contact_Electronic_Mail_Address: miphelp@mapmodteam.com
  Metadata_Standard_Name: FGDC Content Standards for Digital Geospatial
Metadata
  Metadata_Standard_Version: FGDC-STD-001-1998
Metadata_Extensions:
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Online_Linkage: http://hazards.fema.gov
Online_Linkage: http://www.epsg.org
Profile_Name: FEMA NFIP Metadata Content and Format Standard
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Appendix C: Pre Flight Planning Report

STARR
Strategic Alliance
for Risk Reduction

Quinnipiac

Pre-Flight Operations Plan

November 2010

Planned Flight Lines

Photo Science has completed preliminary flight planning for Quinnipiac project area. Quinnipiac is scheduled to be acquired this fall when the leaves are off and delivered to FEMA in late spring of 2011. The Quinnipiac area is 443 square miles and initial planning details are depicted in Figure 1 on the following page. This Figure details that STARR expects to collect **93 flight lines covering 1136 flight line miles**. This area warranted a “Highest” vertical accuracy requirement and will be collected with a nominal pulse spacing of 1-meter. Key components of this flight planning include:

- ✓ Generating a plan that takes all specifications into account, and the required Laser settings to meet those specs, review of terrain and water issues, along with potential base station locations at airports with sufficient services available to support the crews.
- ✓ Orientation of flight lines parallel to major terrain features and variation in flight line spacing due to terrain variation (steeper slopes generally require tighter line spacing between adjacent parallel lines to ensure point density and side overlap are maintained)
- ✓ Check Airspace issues, and access issues for Base Stations.
- ✓ Safety considerations, both for flights, and Laser collection.

Acquisition (443 sq. miles @ 1-meter nominal post spacing to meet 24.5 cm FVA, LAS point cloud delivery with metadata, pre-operations flight plan, and post flight aerial acquisition report).

Planned GPS Stations

Normally existing high accuracy monuments at airports are utilized if possible. Typically a Primary Airport Control Monument (or Secondary) is available; otherwise any other high accuracy monument can be used. We typically prefer these on the airport grounds as they can be monitored for security by airport staff. If no monument is available or an existing monument is damaged, we will set a monument with re-bar and use OPUS to control the monument. These are then used for initial field processing of the data.

Planned Control

Twenty-one (21) ground control points will be surveyed to control the LiDAR data and to support a vertical test. Each of these two functions shall remain independent of each other and also be collected by an independent subcontractor (CompassData). Independent check or calibration points will be three times as accurate as the surface being checked. Therefore, in order to validate a 24.5 cm LiDAR surface (consistent with 2 foot contours), STARR will collect elevation control data accurate to 8 cm. This “three times” model for collecting ground control and QA points will be used throughout the task order.

Vertical accuracy checkpoints will be located by another independent STARR contractor (CompassData) to check Photo Science’s work in open terrain, where there is a high probability that the sensor will have detected the ground surface without influence from surrounding vegetation. Checkpoints will be located on flat or uniformly sloping terrain and will be at least five (5) meters away from any break line where there is a change in slope. This criterion applies for all QA points for the Fundamental Vertical Accuracy (FVA) Assessment as well.

Blind vertical QA points for the Consolidated Accuracy Check (CVA) will also be collected by CompassData to check Photo Science’s work randomly across different land use types using the ASPRS NSSDA land cover types. The points will be located in flat areas with no substantial elevation breaks within a 3-5 meter radius. We expect to normally pick one area and get 3-5 different land use classes from a single setup. We expect to normally use GPS to position an occupation and backsight point and then use a total station to get the other classes from that setup. The CVA assessment will incorporate a representative sample of the FVA assessment into the dataset to save on the total number of points collected. Figure 1 below has a location map of the flight lines and ground control points.

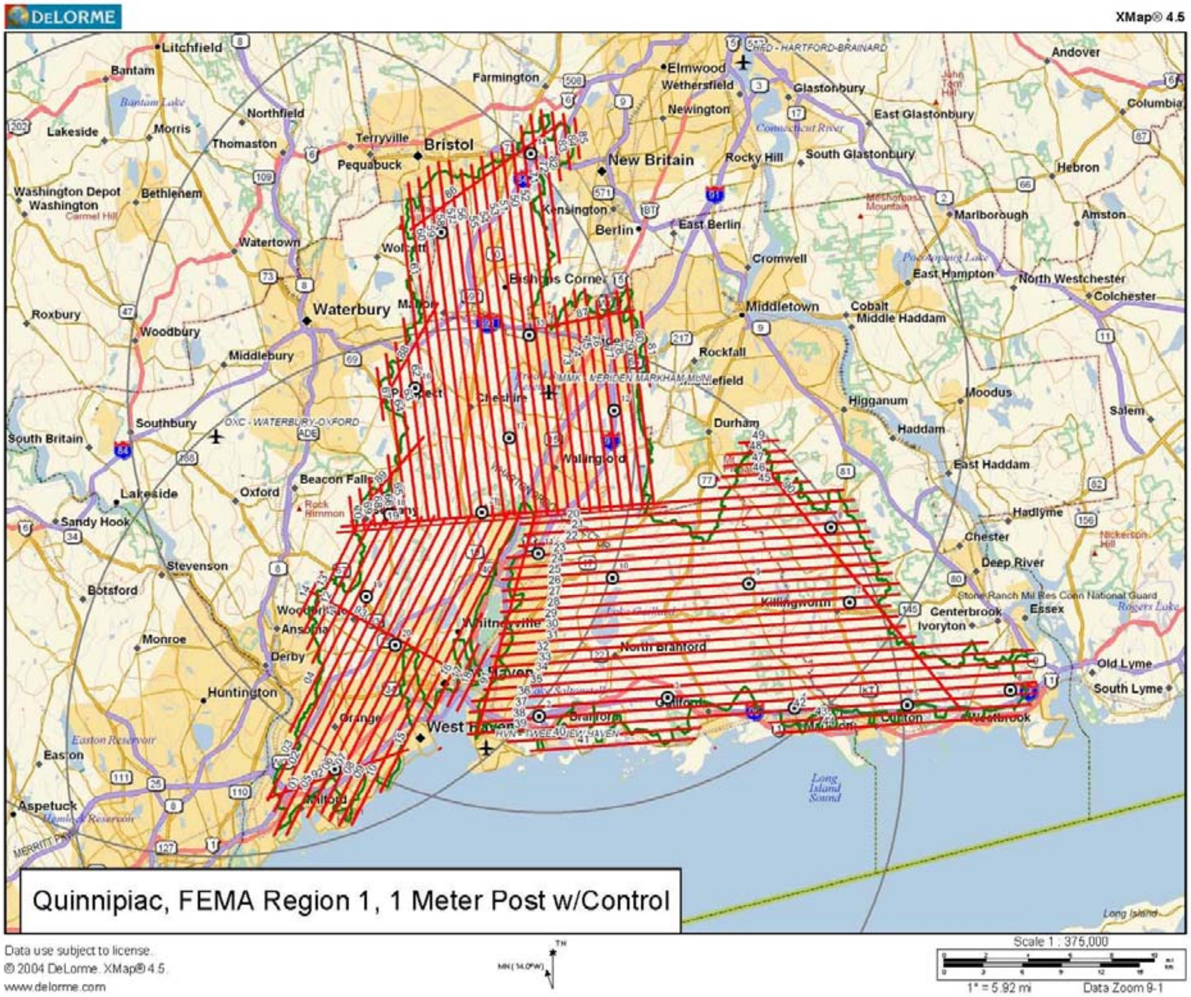


Figure 1-Quinnipiac Flight Lines, Ground Control, and Airport Locations

Planned Airport Locations

Photo Science will be utilizing two airports for Quinnipiac for mobilization and demobilization. As indicated in Figure 1 the two airports will be MMK - Meriden Markham and HVN Tweed New Haven. All base stations used during flights are based at these Airports

Calibration Plans

Periodic detailed boresighting of the LiDAR sensor is performed at a boresight facility established in Lexington, Kentucky for both our LiDAR and imagery platforms. Over 95 high-accuracy control points are located within this facility. The area also has numerous pitched roofs that are necessary in boresighting LiDAR instruments. Local boresights are also carried out at individual project sites. Typically these are established at local airports and consist of opposing and cross flights conducted at multiple flight elevations. The boresight data is processed by our Lead LiDAR Specialist with the results for all boresight parameters applied to the project acquisition. Figure 2 below outlines some of the basic principles that Photo Sciences conducts for LiDAR boresighting.

Figure2

Sensor Calibration Boresighting

- Photo Science routinely performs a Comprehensive Calibration process from our permanent boresighting location at the Capital City Airport in Frankfort, KY, as well as daily, local project specific boresighting locations.
- Photo Science established GPS survey points for LiDAR ground truthing and reflective survey analysis.
- Our calibration methodology adheres to the basic survey principle of *"working for the whole of the parts"* ensuring that residual values of the calibration are reduced, *not* multiplied.
- Photo Science calibration process validates roll, pitch, heading, pitch at swath edge, and torsion.

Calibration – all of our sensors are calibrated by flying lines at multiple altitudes and at varying directions over features on land, typically at the airport where the acquisition is staged. These lines are used to remove angular errors between the IMU and scanning mirror and to determine the precise positioning of the sensor in relationship with the phase center of the GPS antenna mounted on the fuselage of the aircraft.

Calibration of the Elevation Surface – the raw LiDAR surface is compared against ground points that are established for the calibration of the elevation surface. System biases are identified and removed during this calibration. An early statistical analysis takes place that provides an indication of the precision of the acquired data.

Additionally, each lift requires a cross flight over the lines collected during that flight. This also acts as a daily calibration and is used if any anomalies are discovered with processed data.

Quality Control Procedures for Flight Crew

Acquisition Crews

An experienced and knowledgeable acquisition crew is also critical to a successful LiDAR project. We will bring two capable crews to the project site with three more in reserve should any unexpected health issues or similar complications arise.

General Flight Mission Procedures

On a lift by lift basis the flight crew will check cloud conditions, atmospheric conditions (fog or probability of fog) and winds and turbulence. If any of those factors would make acquisition difficult they will wait a few hours and review again.

LiDAR crews can fly at night or during the day. Night flights can be smoother in some cases, but extra care must be used as it is easy to lose orientation with the ground if in very rural areas or over large expanses of water. Additionally, if there are fog probabilities then flights will not take place as fog will block the laser. It must be clear below the aircraft at all times.

The initial item is to set the base station properly over the monument, verify it is secure and running. Prior to setting the crew will have ascertained that it has storage space on the hard drives and full battery life. They will also verify that it is running with proper collection parameters. PDOP is also reviewed as collection will not take place during times of high PDOP.

The LiDAR system (controller hard drives and Laser) is connected to the flight management system and once the project plan is loaded the parameters for collection will load as well. The sensor operator will verify that everything loaded correctly before flight.

Once the LiDAR has been started the crew will taxi to the run up area and wait for the IMU, GPS and the rest of the system level out. They will collect data in a stationary position for about 5-10 minutes until the POS (position and orientation system) provides good level characteristics (Green Lights!).

After this they crew will take off and start collection data, avoiding hard steep turns (banks typically <20 degrees). Collection requires that speeds be maintained, sometimes quite slow depending on the accuracy requirements. Additionally altitudes must be watched closely.

During flights the sensor operator must monitor the laser to sure that temperatures are consistent and within guidelines, that pulsing is taking place correctly and returns are consistent and within guidelines while watching atmospheric conditions, speeds and monitoring the pilot.

Planned ScanSet (Laser Collection Parameters)

Parameters	**15cm RMSE, 1m**
Flying Height	5000
Aircraft Ground Speed (knots)	94
Pulse Rate (KHz)	143.7
Scan Rate (Hz)	48.3
Full Field of View (degrees)	34
Multi-Pulse	Yes
Full Swath Width (meters)	844/961
Swath Overlap (percentage)	30%
Max. Point Spacing Across Track (meters)	1.0
Max. Point Spacing Along Track (meters)	1.0
Across Track/Along Track Ratio	1.0
Average Point Density (M2)	3.10
Average Point Area (M2)	.32
Average Point Spacing (Meters)	.57
Nadir Point Density (pts/m2)	2.00
Illuminated Foot Print Diameter (meters)	.35

Acquisition (443 sq. miles @ 1-meter nominal post spacing to meet 24.5 cm FVA, LAS point cloud delivery with metadata, pre-operations flight plan, and post flight aerial acquisition report)

Type of Aircraft

All of our LiDAR sensors are currently flown in specially modified single-engine Cessna 206 platforms. This platform provides a very stable platform for LiDAR data acquisition, with the ability to easily achieve altitudes and speeds that are most common for LiDAR collection. Achieving an accurate, dense posting of LiDAR returns on the ground is most often associated with altitudes of 2,000 to 7,000 feet above the average terrain height at speeds ranging from 90 to 140 knots. These ranges are ideal for this single-engine platform.

Our platforms also have significant fuel capacity, which allows us considerable time over target for performing data collection. It is also a safe platform, which is important when flying over rugged terrain. The added bonus is this is a very economical platform to fly in terms of operational and maintenance costs. Moreover, that translates to competitive rates for LiDAR data acquisition.

Aircraft Name	**Engine Configuration**	**ABGPS**	**Flight Management System**	**Ceiling Feet**
Cessna U-206G	Single	Yes	Yes	16,700
Cessna U-206G	Single	Yes	Yes	16,700
Cessna U-206H	Single	Yes	Yes	15,700
Cessna U-206H	Single	Yes	Yes	15,700

Procedure for Tracking, Executing, and Checking Re-flights

All daily flights are tracked with specific logs for each area. These include general logs indicating the lines, date flown etc. as well as very specific mission logs concerning the lift, weather conditions, times, speeds and other criteria critical to the performance of the laser. The daily flight logs are faxed to the office on a daily basis and entered into an access database for tracking purposes. This helps determine where next to move crews and overall project status.

After flight each day, the GPS ground base station data is processed and verified and is then is run against the LiDAR POS data in both a forward and reverse sense. The two solutions are then compared against one another for all GPS epochs and the individual differences for the northing, easting, and elevation components are plotted for easy comparison. This data is then run against the LiDAR returns and a point cloud generated. Any anomalies in the data are quickly analyzed, and if required, re-flights take place for the portions of the flight missions that require remediation.

Once the data is checked it is archived, backed up and a set sent to the office via overnight delivery, while the backup copy remains with the crew.

The flight crews do not leave the area of collection until all data has been verified and shipped.

Considerations for Terrain, Cover, and Weather

Terrain is not an issue for flight planning on this project. The area is very flat. Cover has been considered and collection is scheduled for the Fall of 2010 during leaf-off conditions. Traditional LiDAR weather conditions will be observed for this area.

Appendix D: Ground Control Survey and Vertical Testing Quality Control

CompassData

FEMA Region 1 – MA, NH, CT
Ground Control Project Report for Photo Science Inc.

November 22, 2010

Project Information

CDI Project Number:	**FSG1508**
Geographic Location:	**New England; MA, NH, CT**
Number of GCPs Requested:	**86**
Number of GCPs Collected:	**86**

Project Specifications

Precision (Horizontal/Vertical):	**CDI Precision-1 ≤ 8cm H/V**
Coordinate System:	**UTM**
Datum:	**NAD83**
Zone:	**18 & 19**
Altitude Reference:	**HAE (WGS84) and NAVD88 (09)**
Units:	**Meters**

RTK GPS

All Ground Control Points for this project were collected within the boundaries of the Keystone Precision Instruments New England Virtual Reference Station System, which provides continuous real-time broadcast correction signals within a network of 170 base stations encompassing New England and the northern Mid-Atlantic region.

All Control Points were observed for 180 epochs to determine a coordinate location ≤ 8cm in both Horizontal and Vertical to support subsequent LiDAR post-processing and bare earth deliverables generation.

All data collected were well within the confines of the Keystone VRS system with multiple base locations providing position and correction data for each point collected.

Summary

The purpose of this project was to locate and survey photo-identifiable ground control points (GCPs) in multiple areas of interest as defined by FEMA-supplied shape and kml files. The GCP coordinates are to be used to control the vertical aspect of all newly-flown LiDAR data during post-processing and subsequent deliverables creation. CompassData visited the project area, found suitable GCPs, and determined accurate coordinates for each GCP according to the customer's specifications.

Equipment

CompassData used a Trimble R8 to perform the Control survey. This device is accurate to within 1 cm on a position-by-position basis per Trimble specifications. Operating within the VRS network provided accurate coordinate values at or around 5 cm H/V within 3-5 minutes observation times. CompassData has consistently demonstrated this level of accuracy on many GCP collection jobs across North and South America and Africa. Specifications for the Trimble R8 are available upon request.

Survey Methodology

CompassData has met the required precision for this project by using a high-quality GPS receiver with differential corrections provided by a VRS network surrounding the project area. The GPS antenna sat atop a bubble-leveled, fixed-height range pole that was placed over the center of the desired GCP. At least 180 positions (captured at a rate of one per second) were geometrically averaged to calculate a single coordinate for each GCP. All required field documentation was filled out and the points were identified on web-based imagery and diagrammed on the CompassData-supplied sketch sheets. Digital pictures of each GCP location were collected in the field.

Quality Control Procedures

CompassData collects GCPs with an unobstructed view of the sky to ensure proper GPS operation. CompassData works to avoid potential sources of multipath error such as trees, buildings, and fences that may adversely affect the GPS accuracy.

Additional quality control comes from the fact that at least 180 GPS positions are collected for each GCP. While operating within a VRS, valid solutions are reached within seconds; however, we continue to collect additional data to ensure meeting collection specifications. To ensure project integrity, a GCP will be reobserved or moved to a more suitable location if it does not meet project specifications.

In addition to the aforementioned procedures, CompassData "surveys" existing geodetic control monuments to see if our coordinates match the published coordinates to the required accuracy. These monuments are usually established by the National Geodetic Survey (NGS) in the United States. If it is found that our coordinates are outside the acceptable accuracy, the reason for the difference will be found or the GCPs will be reobserved under different GPS constellation constraints. There are certain geodetic considerations that must be taken into account that affect whether a GPS-derived coordinate will line up with a survey monument, especially when these monuments reference local coordinate systems or the systems of another country. Sometimes the published coordinates for a monument are not accurate, although this is very infrequent.

CompassData visited multiple survey monuments during the course of this project. The results of those monument measurements are summarized in the Accuracy Report.

Deliverables

Deliverables for this project include:

- ☐ Coordinates (in spreadsheet format)
- ☐ Image Chips
- ☐ Sketch Sheets
- ☐ Digital Pictures
- ☐ QA/QC Data

Project Notes

All collected points were retrieved from the Trimble Survey Controller in Decimal Degrees, NAD83, HAE Meters.

CorpsCon was used to generate files in the following format:

Degrees Minutes Decimal Seconds, NAD83 HAE (QC purposes)
UTM Meters, NAD83 HAE

Geoid09 was then used to generate the geoid separation at every Lat/Long location. NAVD88(09) orthometric heights were then generated in spreadsheet form using the formula HAE - Geoid = Orthometric Height. Those values were then included into the final delivery coordinate CSV files and have been tested against NGS monuments collected during the course of this survey and are showing millimeter-level agreement.

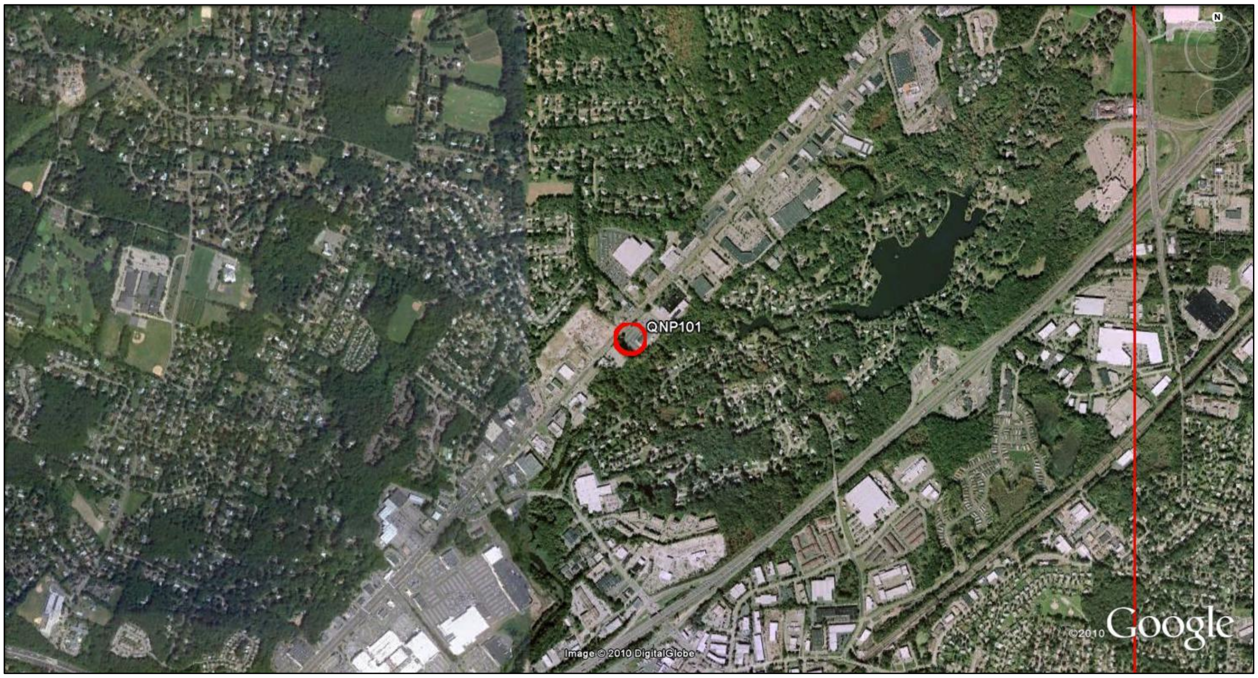
The Horizontal and Vertical accuracies reported in the Final Coordinates file were obtained from the Survey Report generated by Trimble Survey Controller. The report contains all points collected during each daily survey deployment, including CVAs, FVAs and Ground Control. Copies of these reports can be provided upon request once the CVA and FVA data has been redacted.

Contact Information

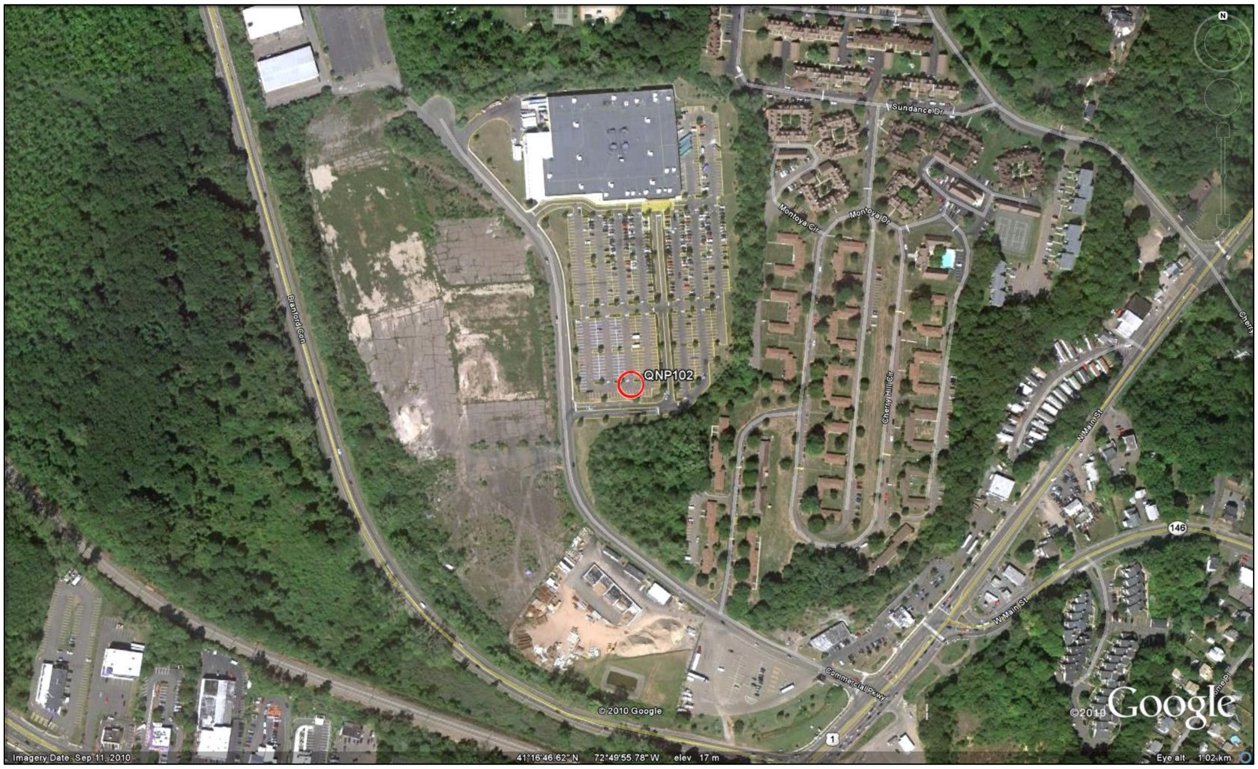
Hayden Howard Phone: (303) 627-4058 E-mail: haydenh@compassdatainc.com

Quinnipiac, Connecticut										
GCP	**Date**	**Vert_Prec**	**Horz_Prec**	**Latitude**	**Longitude**	**Easting**	**Northing**	**HAE**	**GEOID09 Separation**	**NAVD88**
QNP101	10/20/2010	0.0128	0.0101	41.24795703	-73.02402157	665562.815	4568165.935	-22.71831367	-29.781	7.062686333
QNP102	11/18/2010	0.01	0.007	41.27937285	-72.83063764	41.27937285	-72.83063764	-9.477	-29.945	20.468
QNP103	10/20/2010	0.0085	0.0061	41.29735703	-72.70443931	692196.631	4574309.094	-20.08514117	-30.01	9.924858826
QNP104	10/20/2010	0.0091	0.0052	41.28870908	-72.60176728	700820.061	4573581.46	-14.01016016	-30.162	16.15183984
QNP105	10/20/2010	0.0104	0.0067	41.29574022	-72.48802483	710322.657	4574631.608	-14.11805958	-30.276	16.15794042
QNP106	10/20/2010	0.0137	0.0088	41.30086694	-72.39620218	717994.379	4575427.51	-25.34386615	-30.384	5.040133855
QNP107	10/20/2010	0.0113	0.0076	41.36563856	-72.55507753	704489.181	4582231.965	76.37541353	-30.001	106.3764135
QNP108	10/20/2010	0.0088	0.0061	41.41269822	-72.56006536	703924.77	4587445.231	127.6127013	-29.882	157.4947013
QNP109	10/20/2010	0.0085	0.004	41.37601342	-72.64334823	697074.493	4583179.297	81.19583522	-29.847	111.0428352
QNP110	10/20/2010	0.0067	0.0046	41.38128103	-72.74118726	688876.922	4583546.189	65.66228159	-29.733	95.39528159
QNP111	10/19/2010	0.007	0.0049	41.39567172	-72.83643591	680872.037	4584940.64	-10.35864882	-29.624	19.26535118
QNP112	10/19/2010	0.0079	0.0052	41.49041583	-72.76019667	686904.24	4595755.557	92.56002126	-29.504	122.0640213
QNP113	10/20/2010	0.0073	0.0055	41.54741136	-72.85090749	679243.465	4601757.917	72.69220292	-29.312	102.0042029
QNP114	10/19/2010	0.0076	0.0046	41.67563136	-72.84501896	679378.873	4616006.517	38.07477814	-29.172	67.24677814
QNP115	10/19/2010	0.0076	0.0052	41.6171515	-72.91857687	673412.468	4609362.871	38.71638343	-29.13	67.84638343
QNP116	10/19/2010	0.0091	0.0061	41.50301008	-72.97643668	668888.723	4596575.148	223.4039139	-29.195	252.5989139
QNP117	10/19/2010	0.0073	0.0046	41.47652672	-72.86774888	678032.953	4593852.85	65.17521021	-29.381	94.55621021
QNP118	10/20/2010	0.0091	0.0061	41.42413336	-72.97544085	669176.825	4587819.64	158.8815866	-29.322	188.2035866
QNP119	10/20/2010	0.0098	0.0064	41.36034386	-73.00139682	667171.188	4580686.962	93.20254095	-29.472	122.674541
QNP120	10/20/2010	0.0119	0.0073	41.33518813	-72.94980821	671552.55	4577994.831	-11.46477025	-29.624	18.15922975
QNP121	10/20/2010	0.0125	0.007	41.41488244	-72.91039565	674637.243	4586921.714	98.22595985	-29.449	127.6749598
Survey Control										
NGS_AI5590	10/18/2010	0.0067	0.0049	41.51051804	-72.83083879	681020.240	4597703.530	0.77114555	-29.386	30.15714555
NGS_LX6301	10/20/2010	0.0073	0.0043	41.44670608	-72.67332528	694356.550	4594863.551	4590960.47	-29.667	194.9353786
NGS_DE7815	10/20/2010	0.0173	0.0094	41.51127305	-72.82884545	681184.500	4602597.598	4597791.53	-29.388	30.185968
Metadata										
UTM 18 North, NAD83, NAVD88										
All units in meters where applicable.										
HAE - GEOID09 = NAVD88										

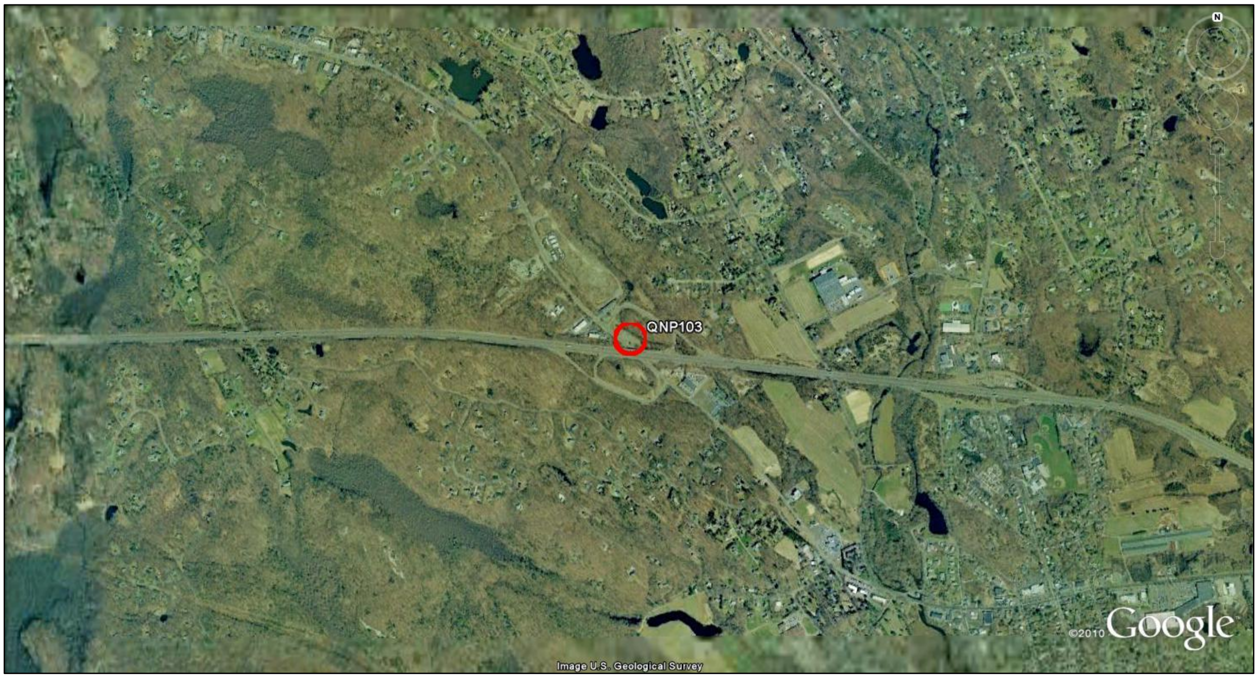
QNP101_C



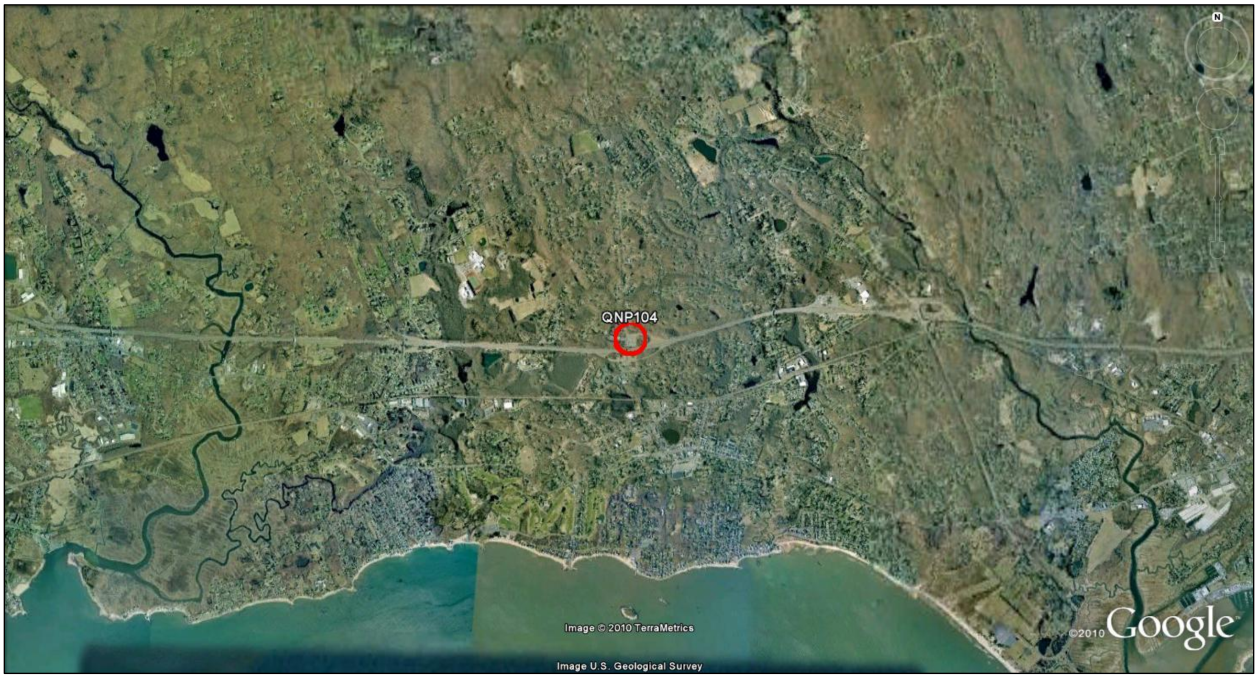
QNP102_C


N
QNP102
Sundance Dr
Montoya Cir
Montoya Dr
Cherry Hill Cir
Branford Con
W Main St
146
Commercial Pkwy
1
© 2010 Google
©2010 Google
Imagery Date: Sep 11, 2010
41°16'46.62" N 72°49'55.78" W elev 17 m
Eye alt 1.02 km

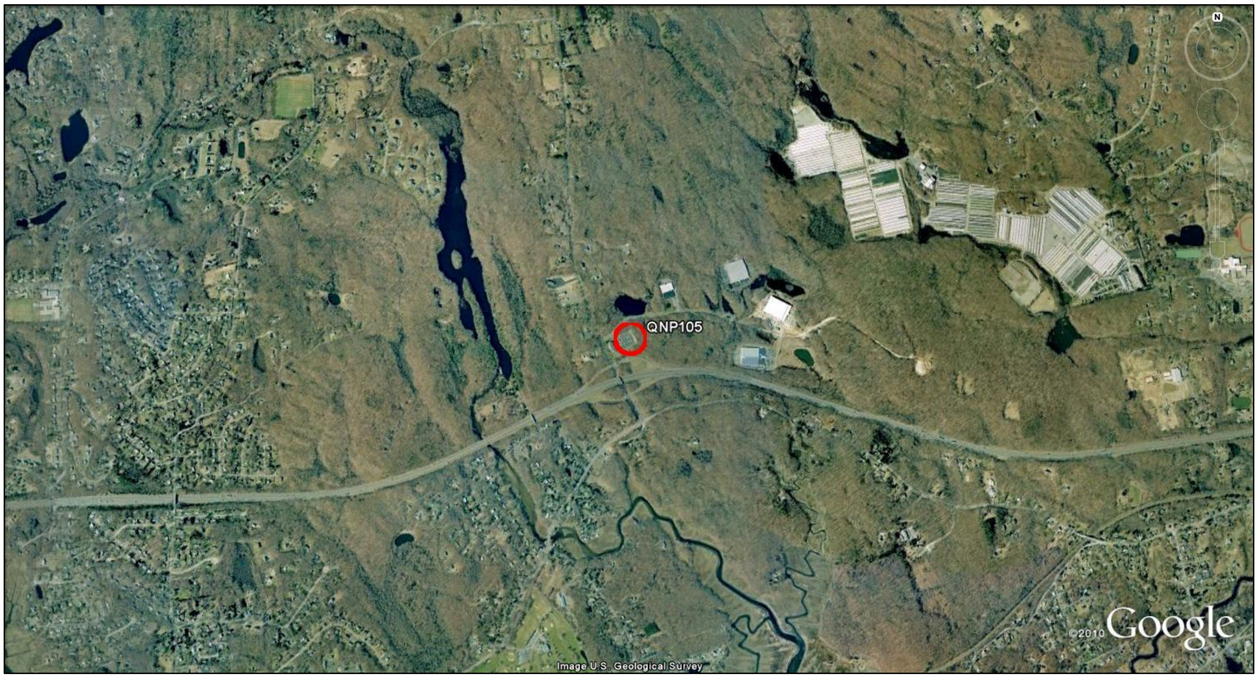
QNP103_C



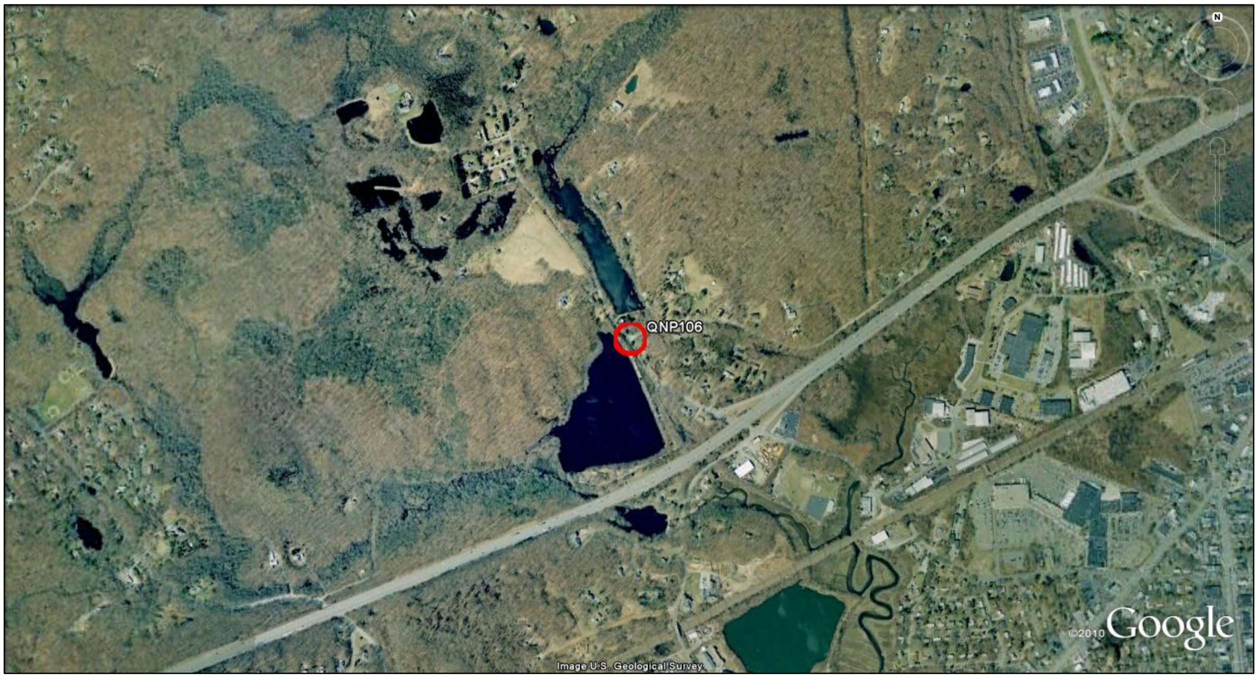
QNP104_C


QNP104
Image © 2010 TerraMetrics
Image U.S. Geological Survey
©2010 Google
N

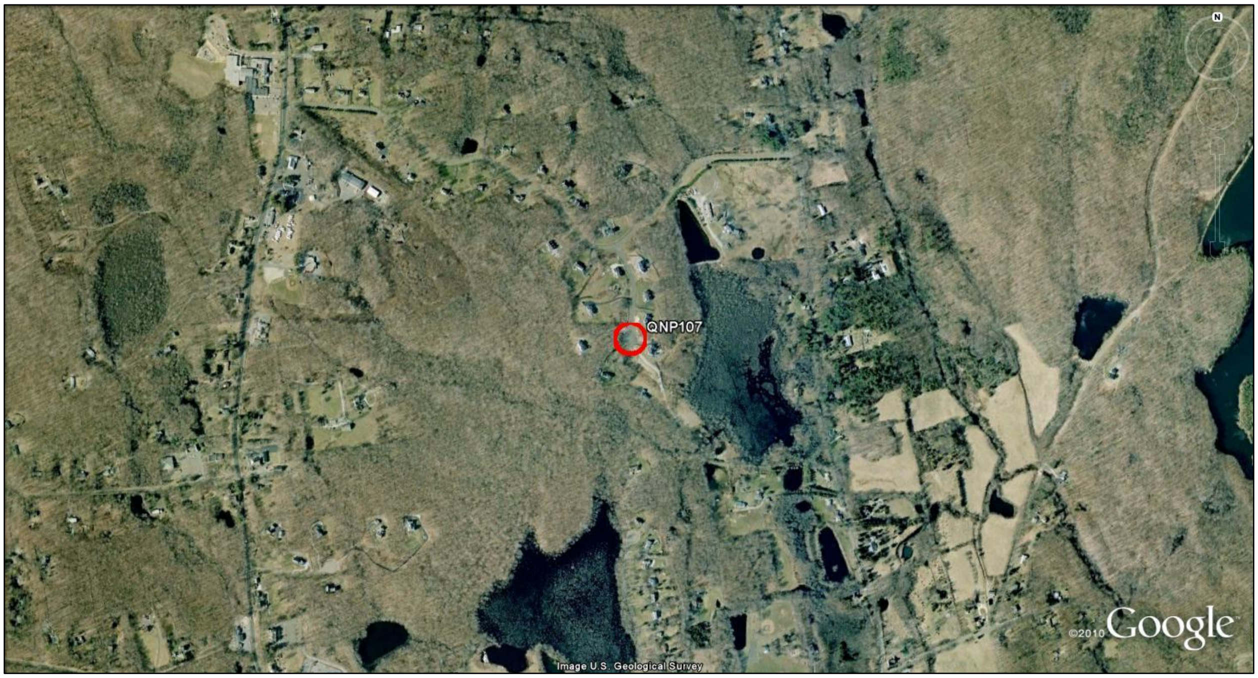
QNP105_C



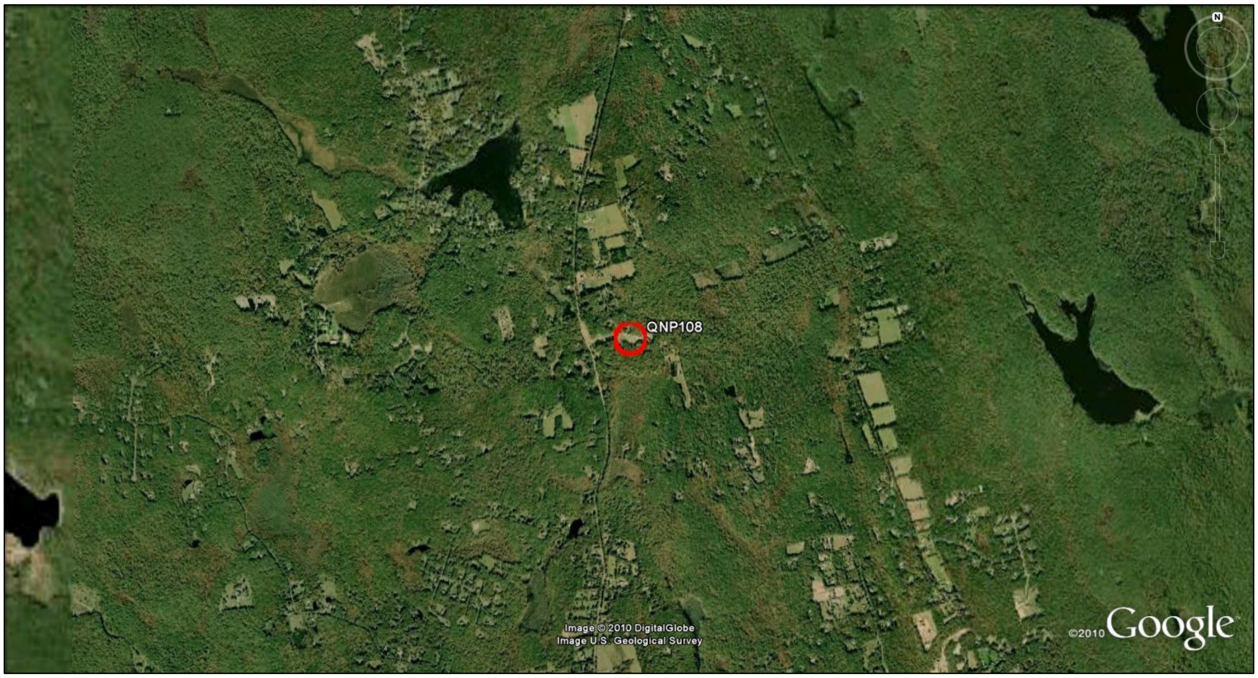
QNP106_C



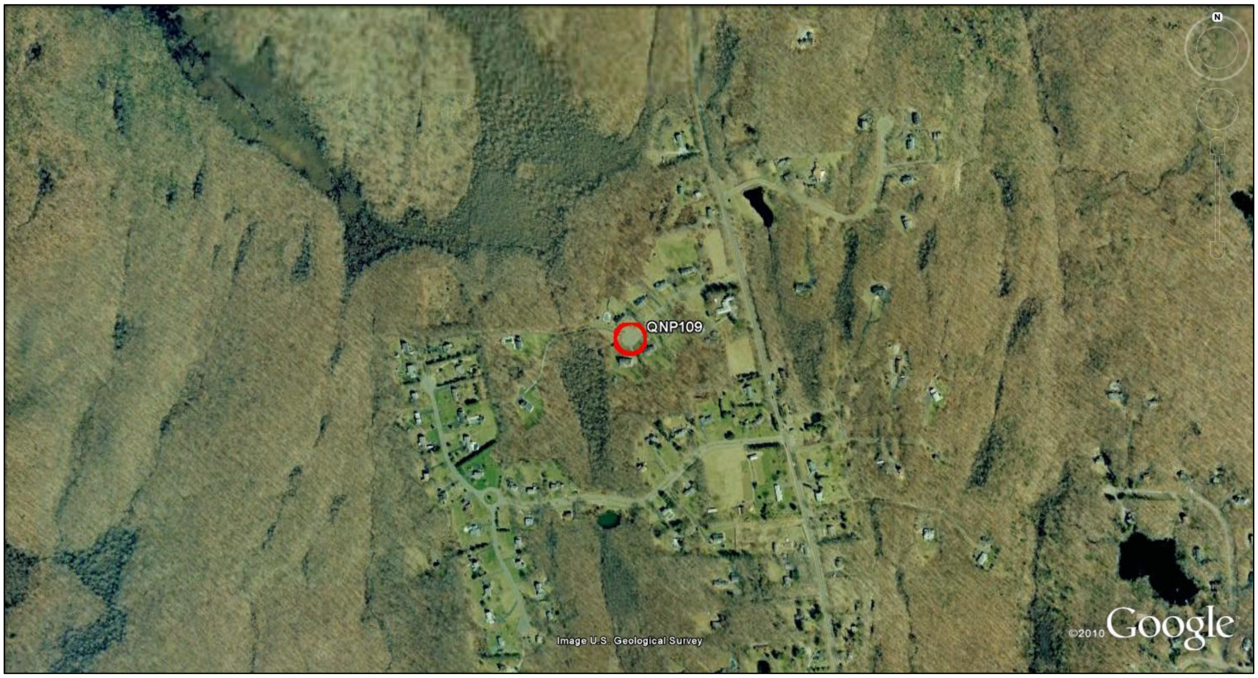
QNP107_C



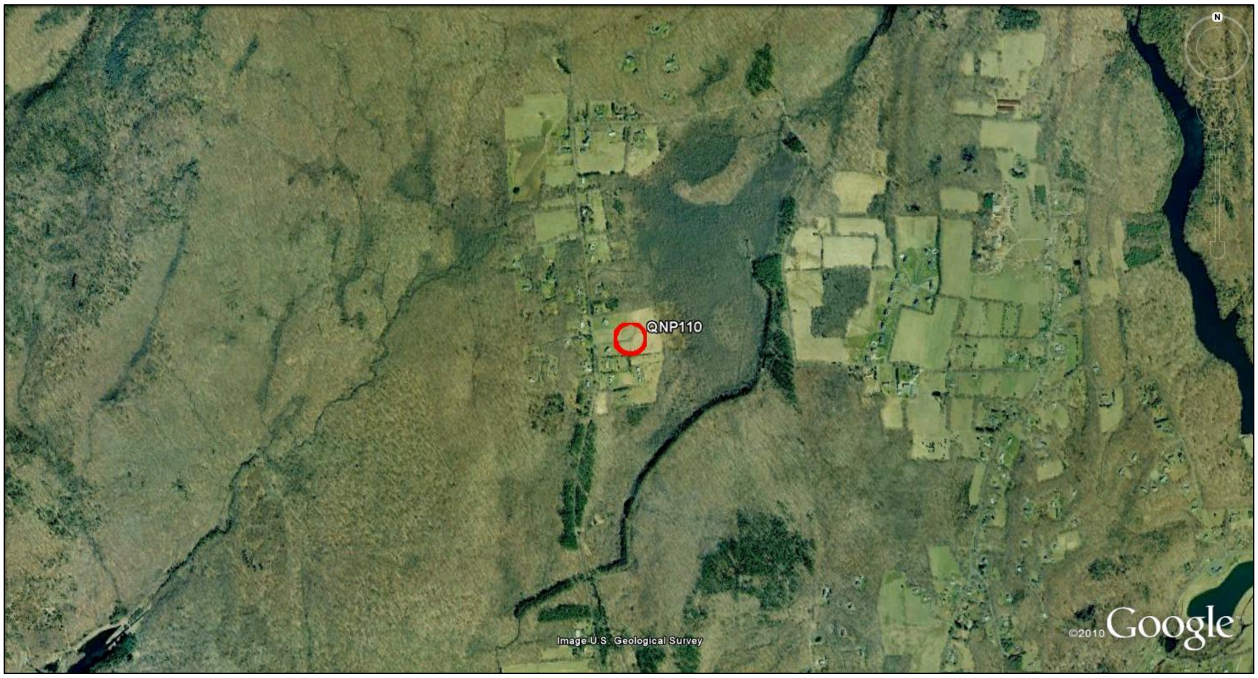
QNP108_C


QNP108
N
Image © 2010 DigitalGlobe
Image U.S. Geological Survey
©2010 Google

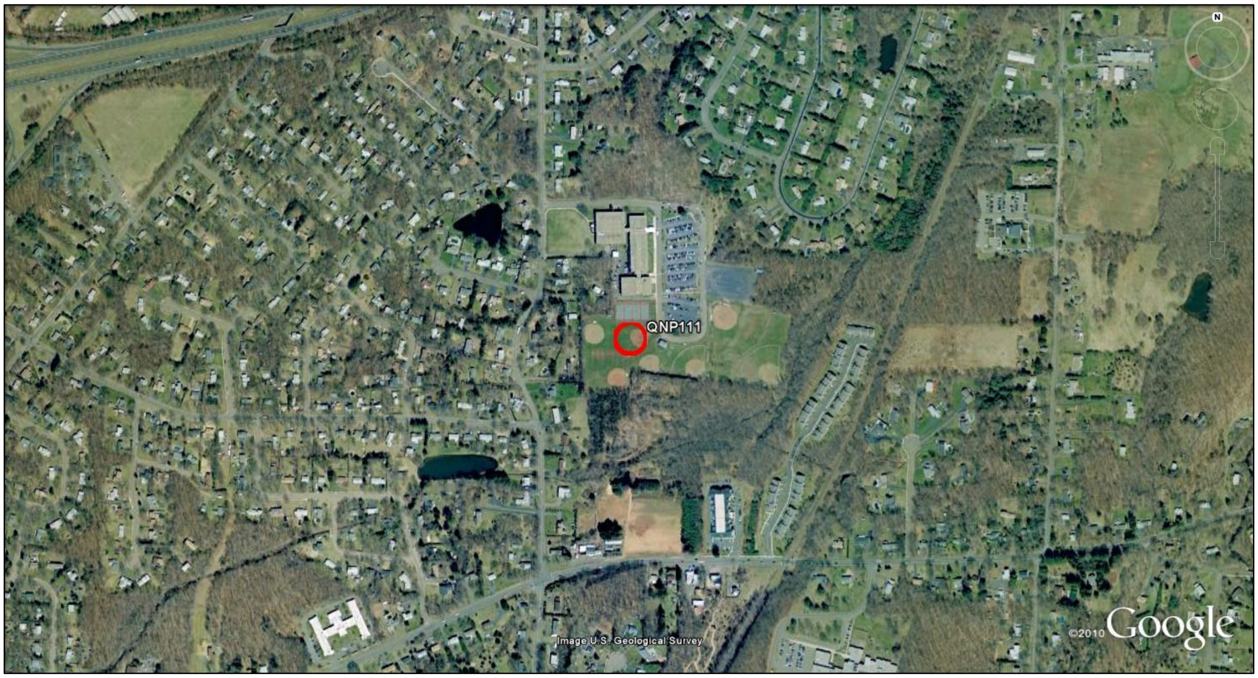
QNP109_C



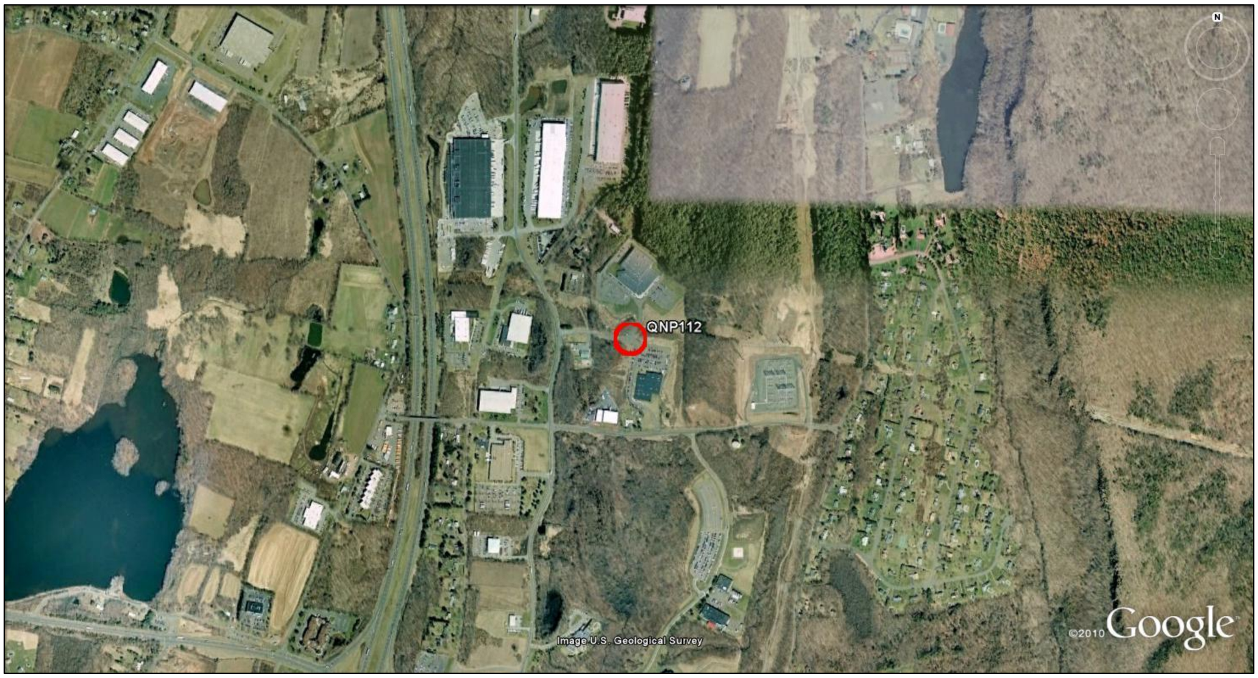
QNP110_C



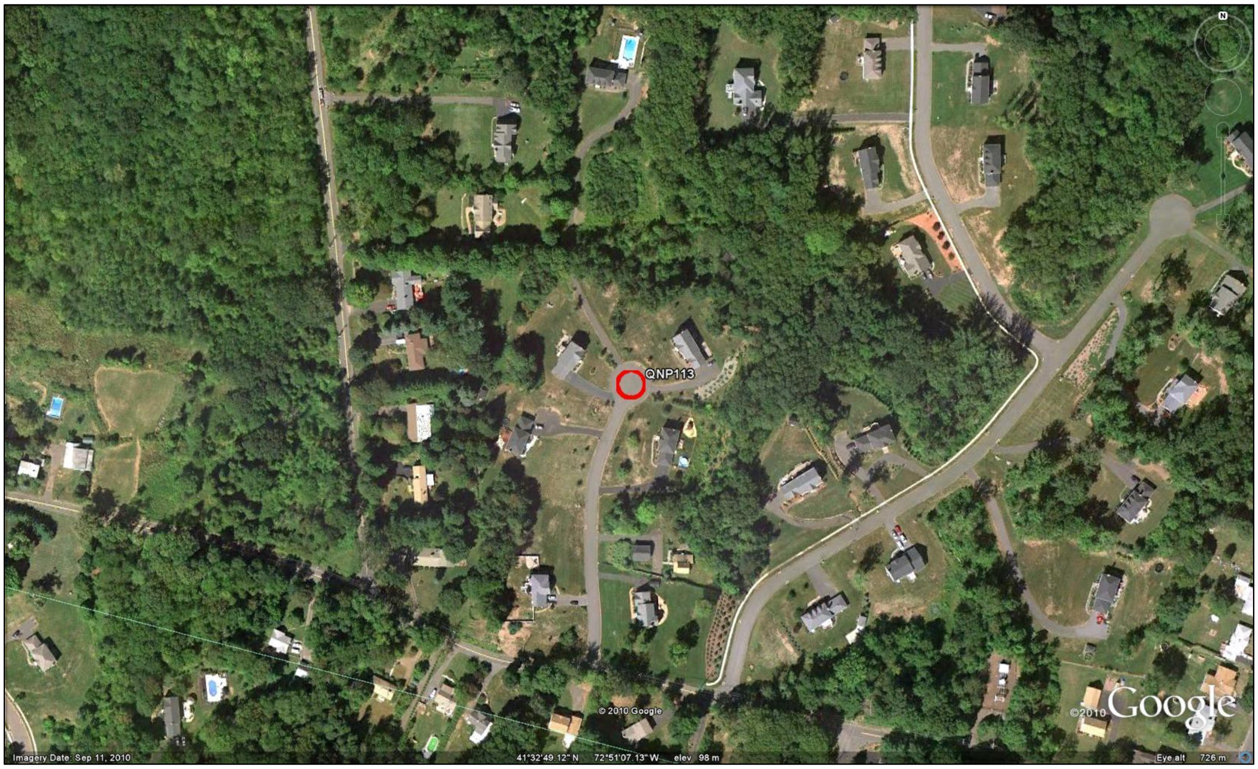
QNP111_C



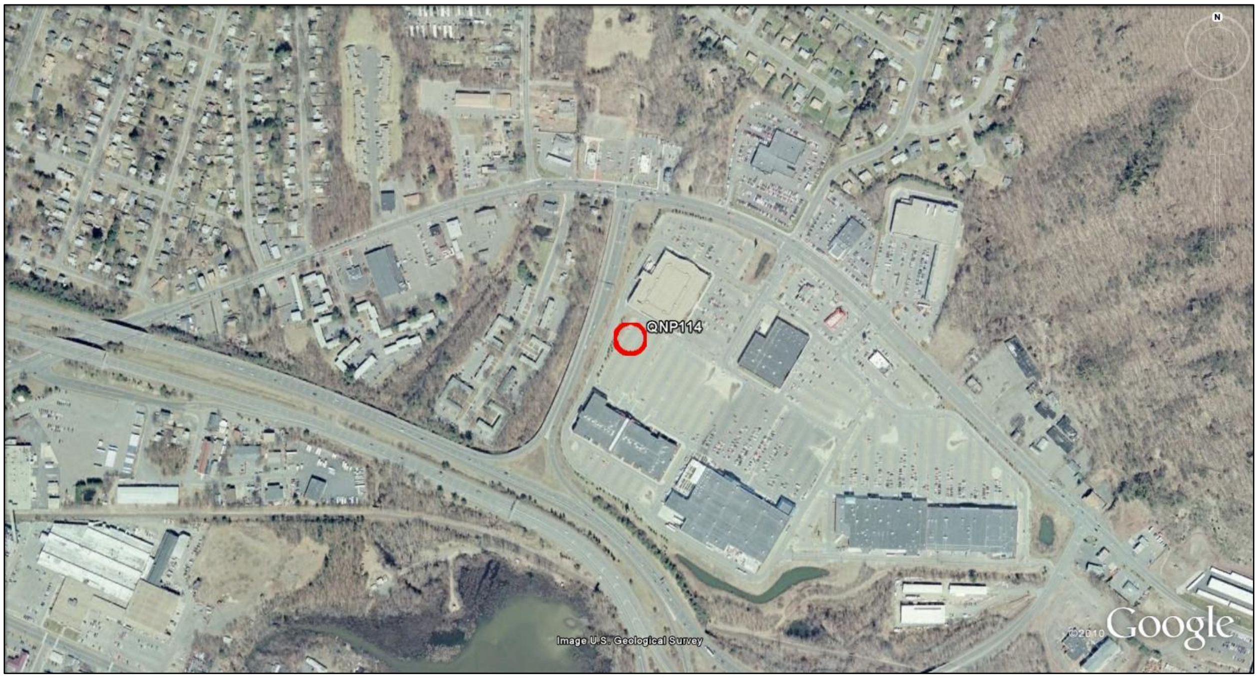
QNP112_C



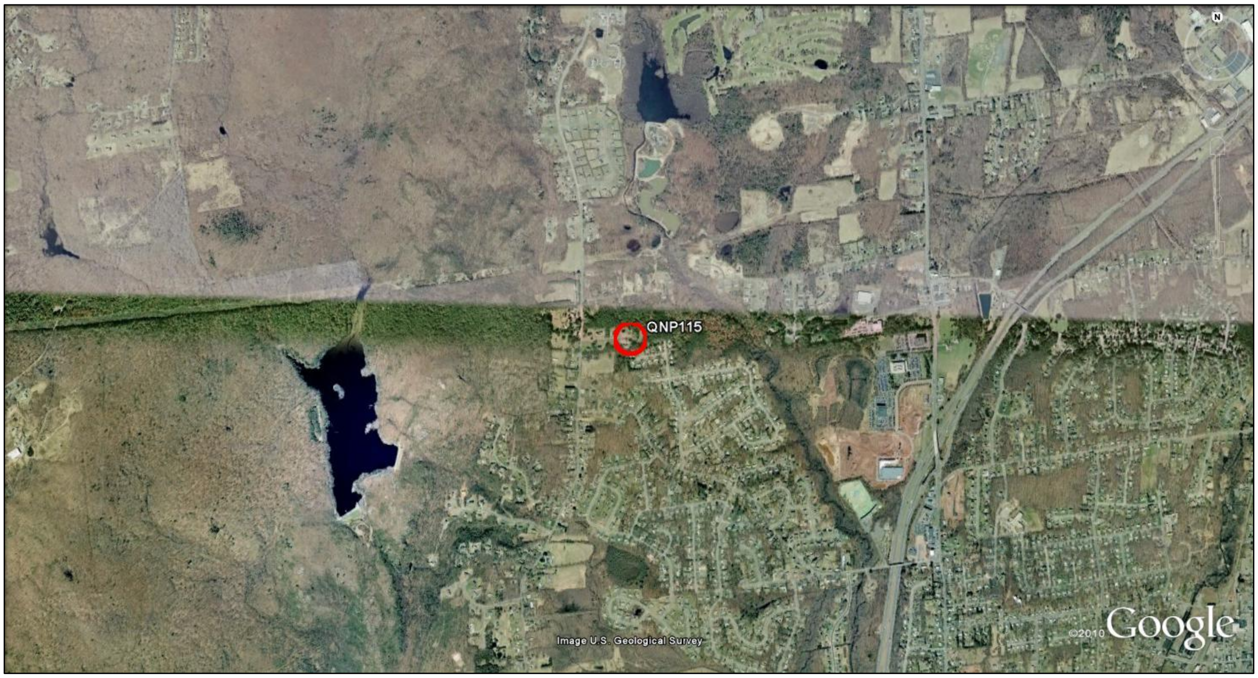
QNP113_C


N
QNP113
© 2010 Google
©2010 Google
Imagery Date: Sep 11, 2010
41°32'49.12" N 72°51'07.13" W elev 98 m
Eye alt 726 m

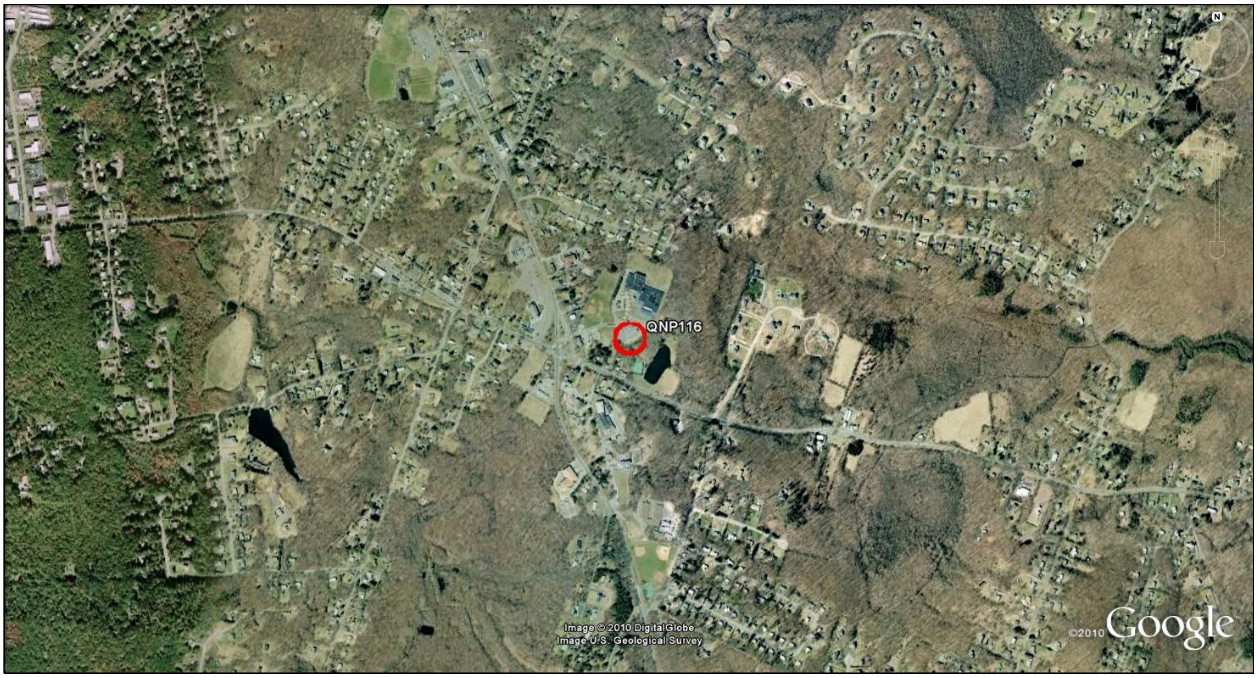
QNP114_C



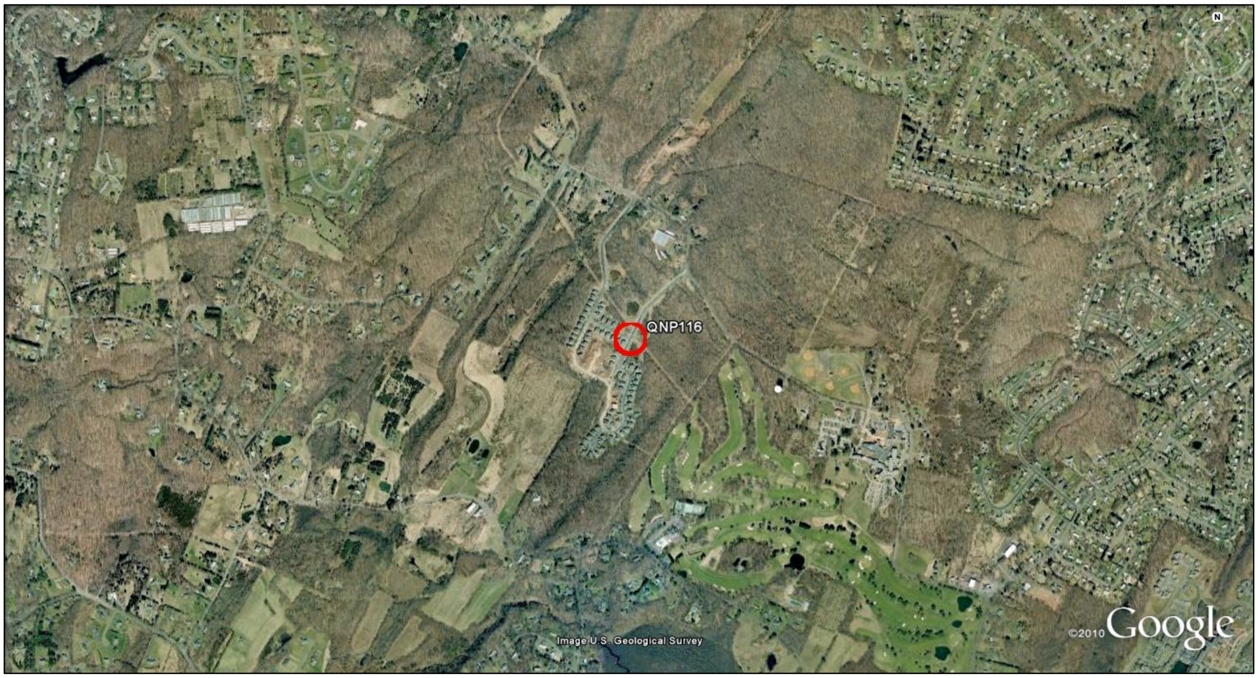
QNP115_C



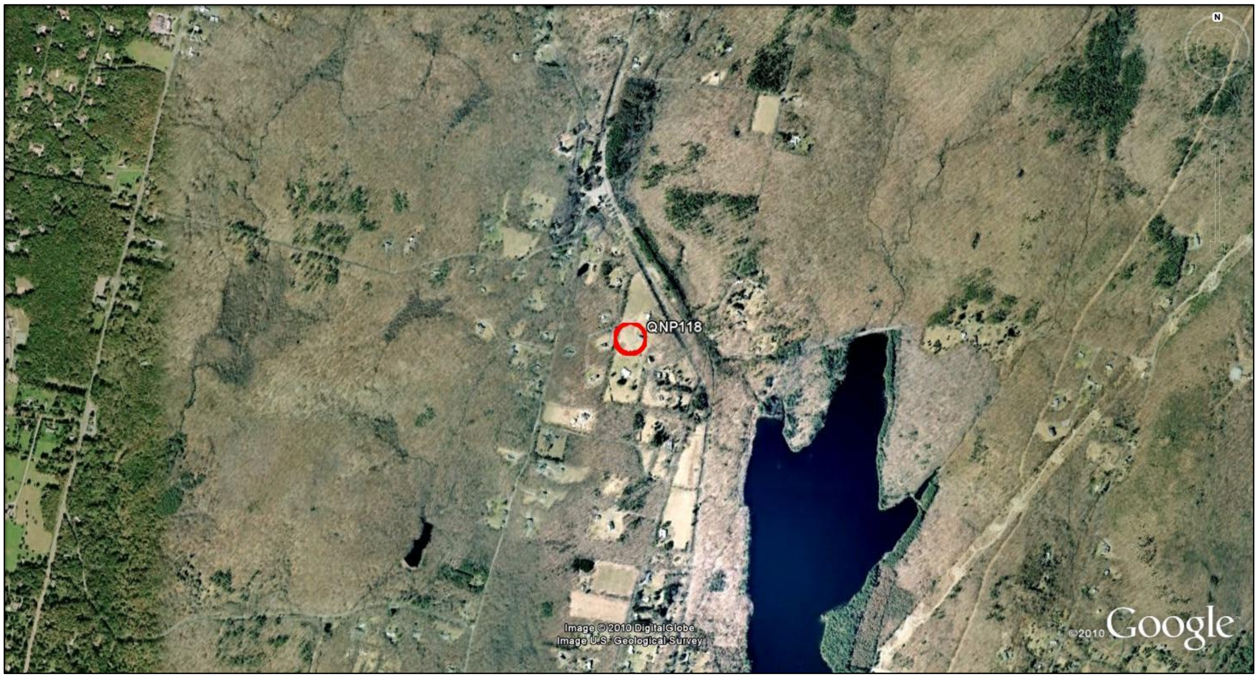
QNP116_C


QNP116
Image © 2010 DigitalGlobe
Image U.S. Geological Survey
©2010 Google
N

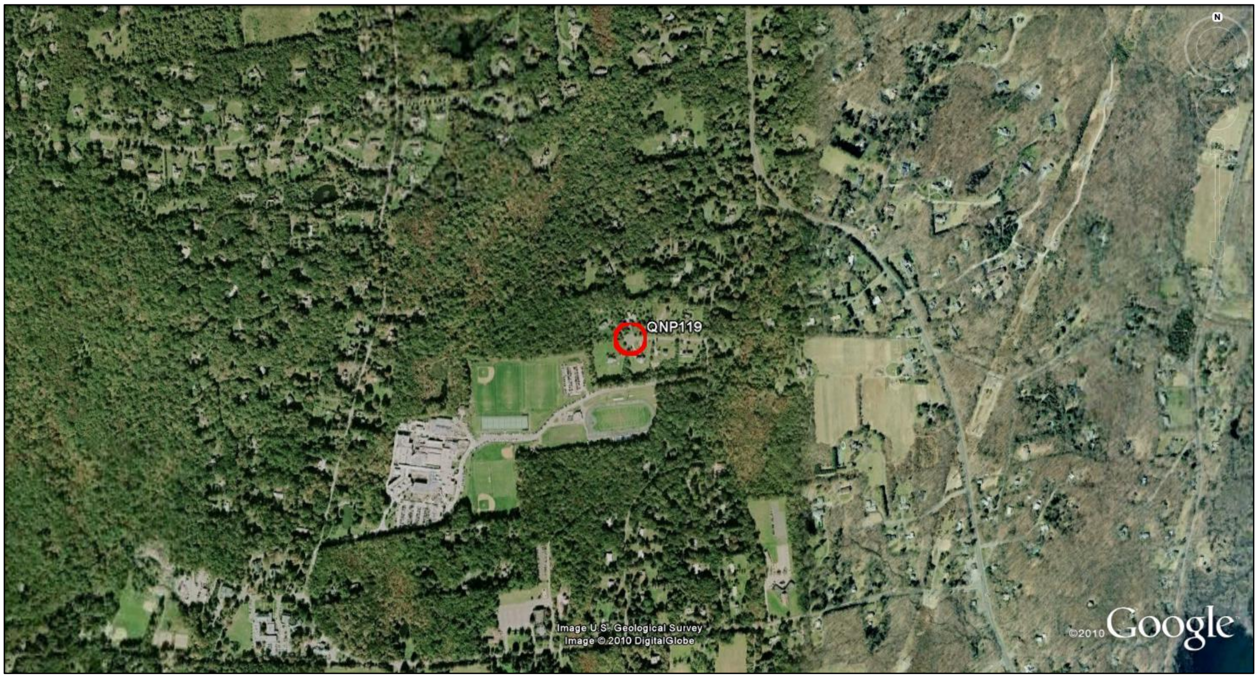
QNP117_C



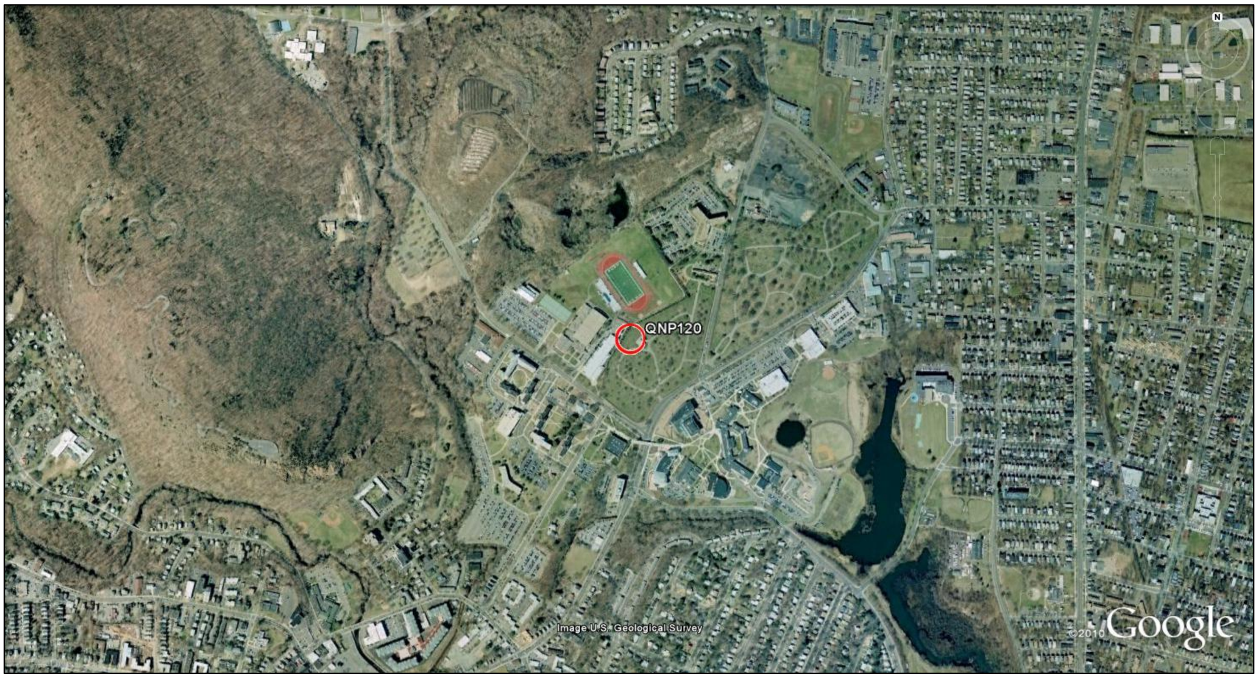
QNP118_C


QNP118
N
Image © 2010 DigitalGlobe
Image U.S. Geological Survey
©2010 Google

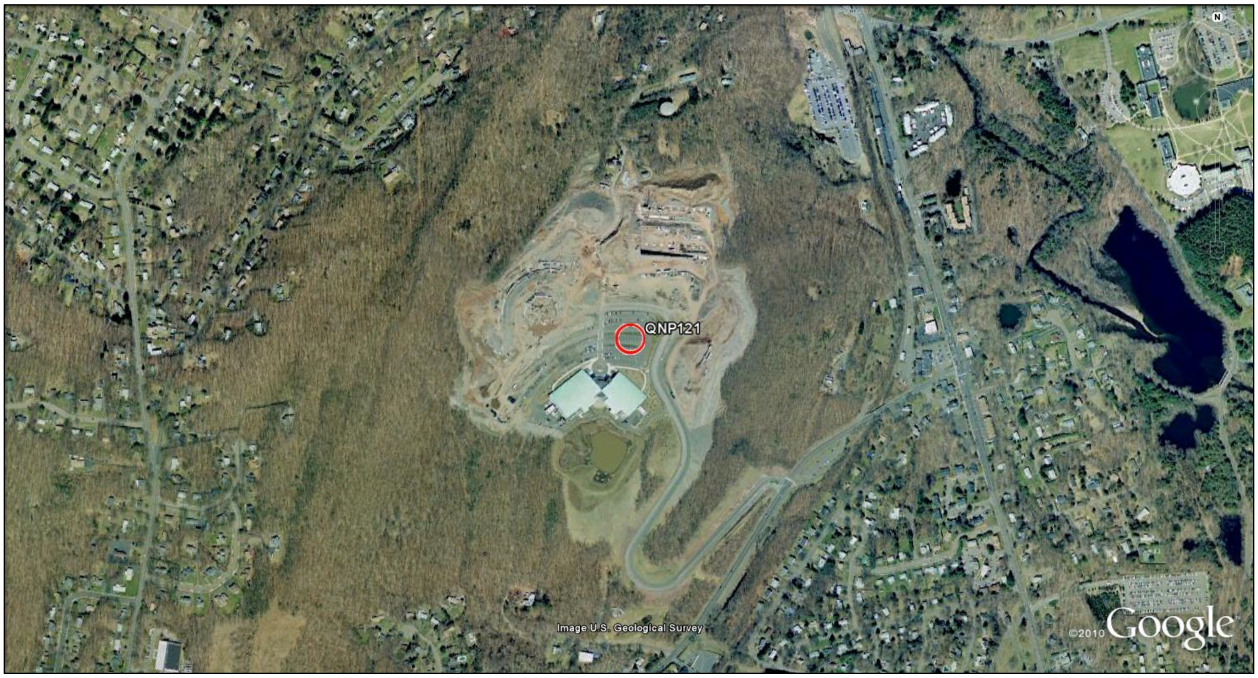
QNP119_C


N
QNP119
Image U.S. Geological Survey
Image © 2010 DigitalGlobe
©2010 Google

QNP120_C



QNP121_C



QNP101

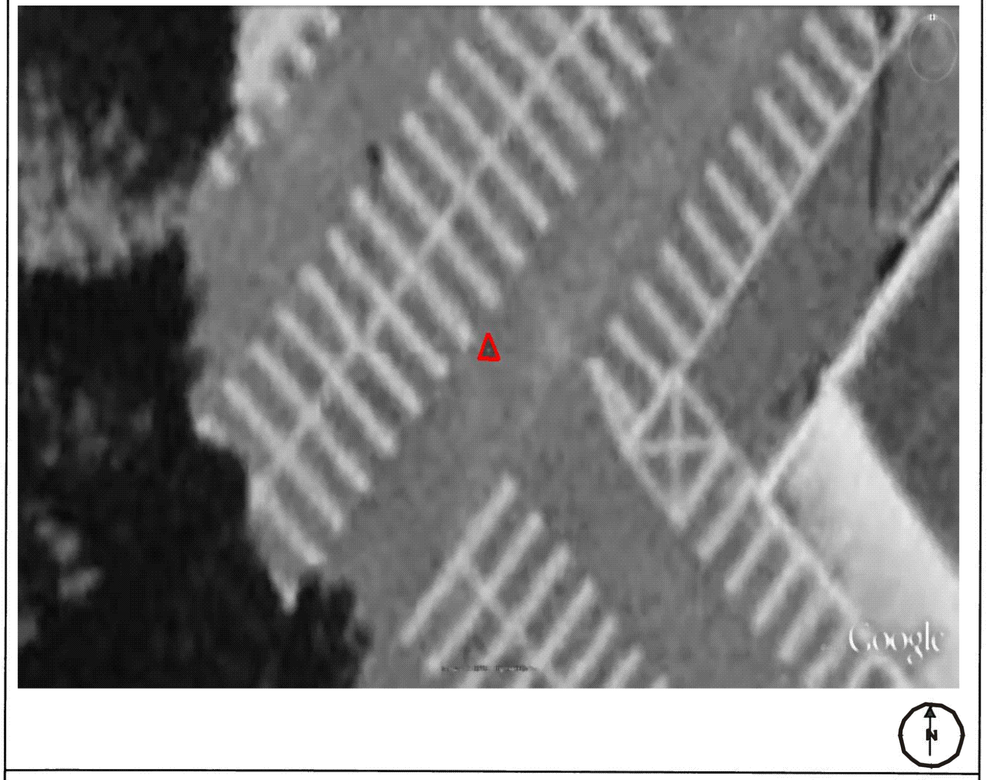
CompassData

GCP Station Diagram for LiDAR

LiDAR

LiDAR

Project Name: Quinnipiac	**GCP Number:** QNP101
CDI Project Number: 1508	**Date:** 10/20/2010



GPS Antenna Height: 2m

Comments:

Point taken in parking lot, east of the AMF Milford Lanes building
off of Boston Post Rd.
New Haven County, Connecticut

Disk (Roll) / Frame Number:	**Sketch** 1 **of** 1
Collected By: Nate Yannacone	**Checked By:**

CompassData, Inc., 12353 E. Easter Ave., Suite 200, Centennial, CO 80112 CDIGCP-01/04

QNP102

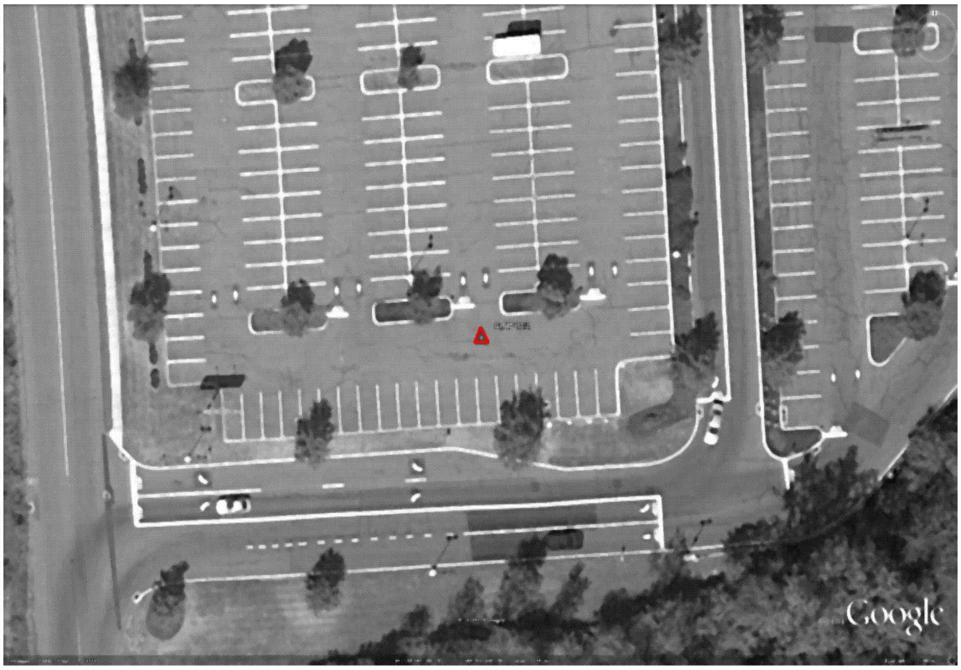
CompassData

GCP Station Diagram for LiDAR

LiDAR

LiDAR

Project Name: Quinnipiac	**GCP Number:** QNP102
CDI Project Number: 1508	**Date:** 11/18/2010



GPS Antenna Height: 2m

Comments:

Point taken in Southern portion of parking lot, South of building,
North of entry drive and East of Commercial Pkwy.
Town of Branford, New Haven County, Ct

Disk (Roll) / Frame Number:	**Sketch** 1 **of** 1
Collected By: Bryan Frazier	**Checked By:**

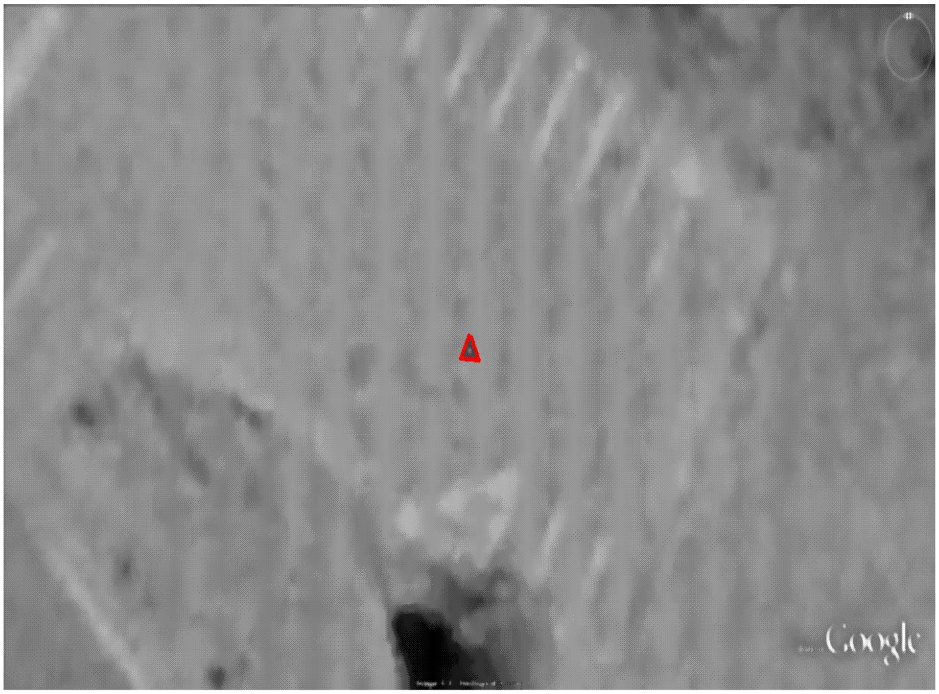
CompassData, Inc., 12353 E. Easter Ave., Suite 200, Centennial, CO 80112 CDIGCP-01/04

QNP103

CompassData

GCP Station Diagram for LiDAR

Project Name: Quinnipiac	**GCP Number:** QNP103
CDI Project Number: 1508	**Date:** 10/20/2010



GPS Antenna Height: 2m

Comments:

Point taken in the south eastern portion of the parking lot off of
Boston Post Rd and Interstate Highway 95.
New Haven County, Connecticut

Disk (Roll) / Frame Number:	**Sketch** 1 **of** 1
Collected By: Bryan Frazier	**Checked By:**

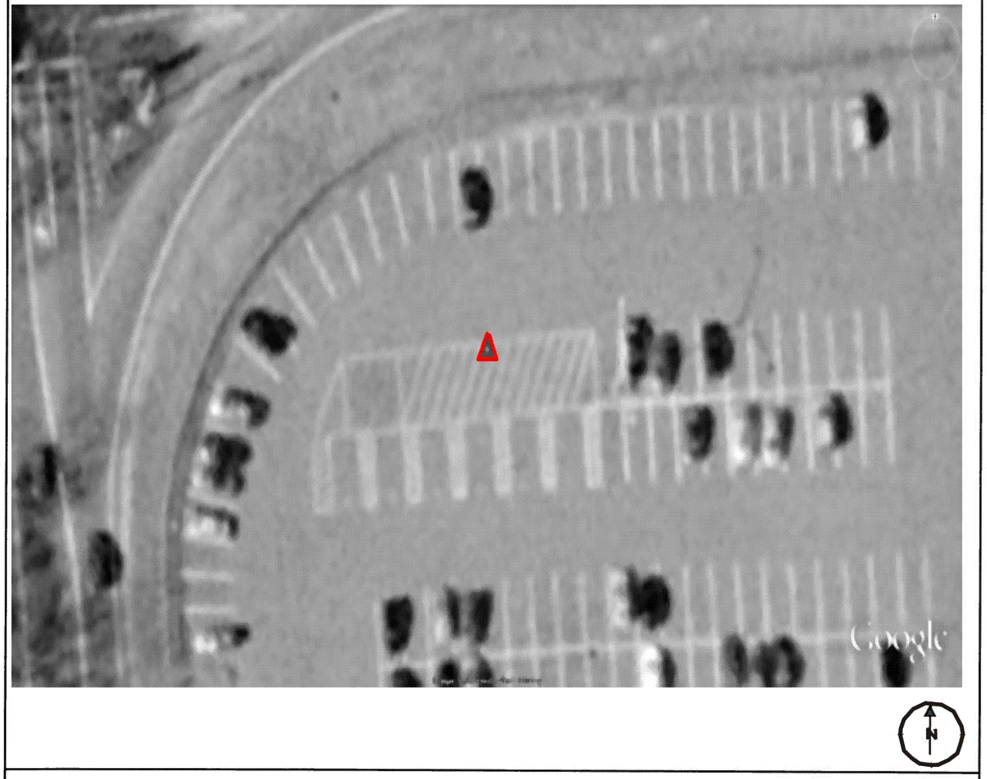
QNP104

CompassData

GCP Station Diagram for LiDAR

LiDAR

Project Name: Quinnipiac	**GCP Number:** QNP104
CDI Project Number: 1508	**Date:** 10/20/2010



LiDAR

GPS Antenna Height: 2m

Comments:

Point taken in parking lot off of State Highway 79 and
Interstate Highway 95.
New Haven County, Connecticut

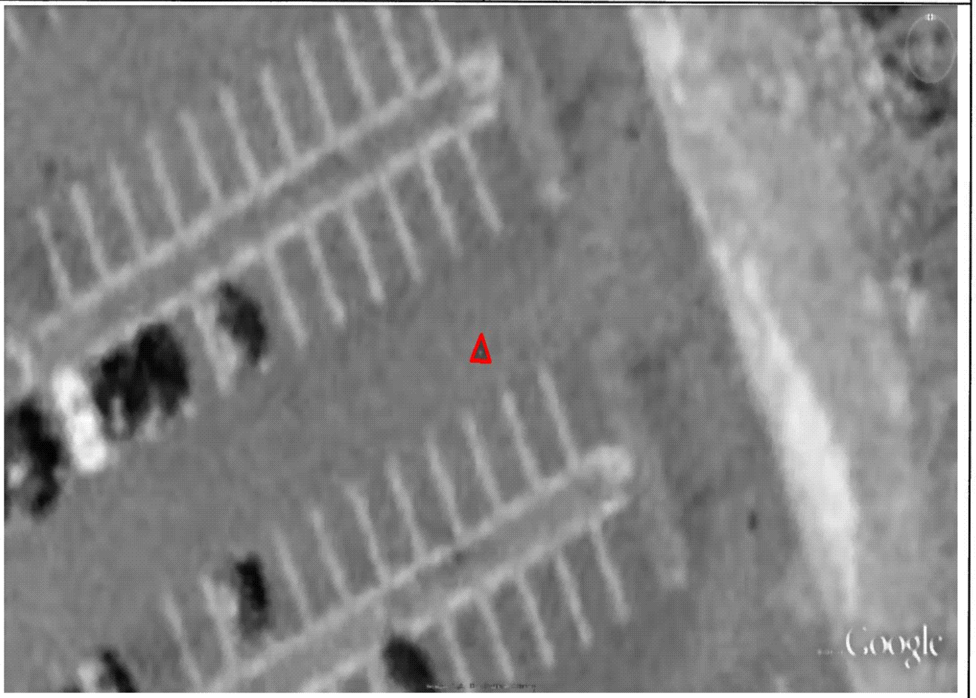
Disk (Roll) / Frame Number:	**Sketch** 1 **of** 1
Collected By: Bryan Frazier	**Checked By:**

QNP105

CompassData

GCP Station Diagram for LiDAR

Project Name: Quinnipiac	**GCP Number:** QNP105
CDI Project Number: 1508	**Date:** 10/20/2010



GPS Antenna Height: 2m

Comments:

Point taken in parking lot of Orthopedic Doctors Office
Middlesex County, Connecticut

Disk (Roll) / Frame Number:	**Sketch** 1 **of** 1
Collected By: Bryan Frazier	**Checked By:**

QNP106

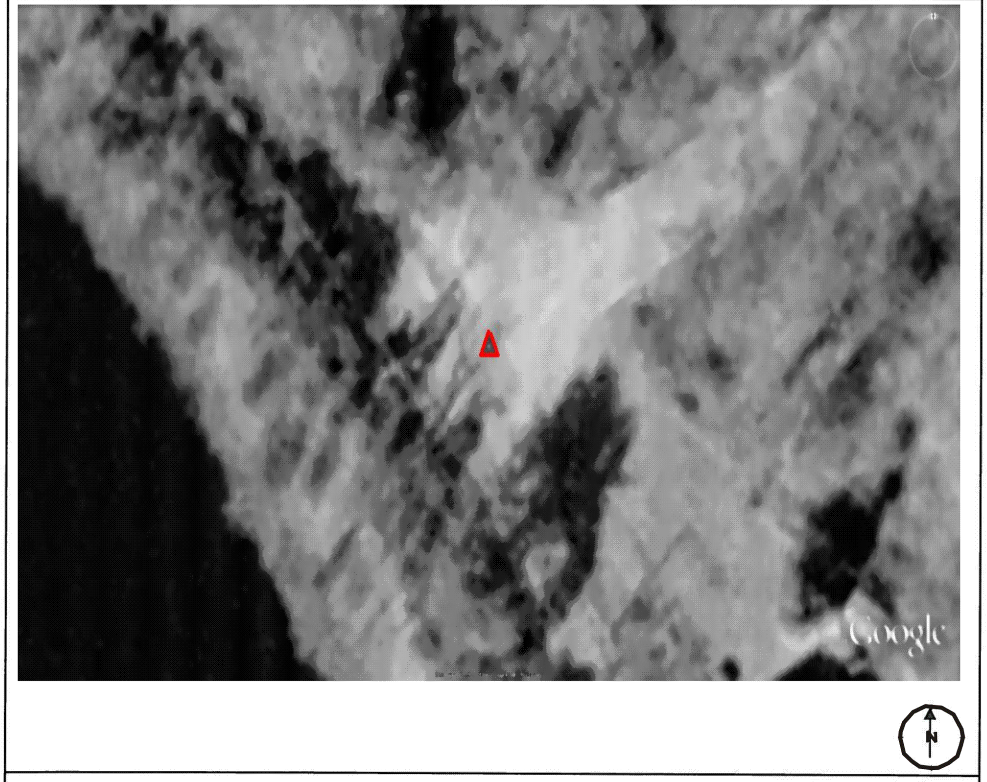
CompassData

GCP Station Diagram for LiDAR

LiDAR

LiDAR

Project Name: Quinnipiac	**GCP Number:** QNP106
CDI Project Number: 1508	**Date:** 10/20/2010



GPS Antenna Height: 2m

Comments:

Point taken at intersection of Ingham Hill Rd and Mill Rock Rd W.
Middlesex County, Connecticut

Disk (Roll) / Frame Number:	**Sketch** 1 **of** 1
Collected By: Bryan Frazier	**Checked By:**

CompassData, Inc., 12353 E. Easter Ave., Suite 200, Centennial, CO 80112 CDIGCP-01/04

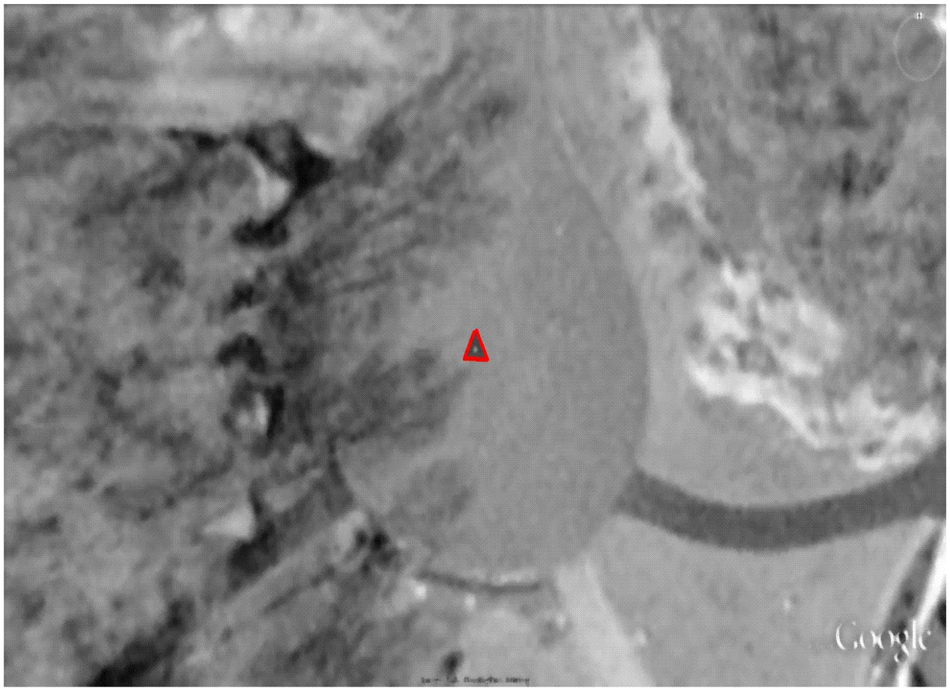
QNP107

CompassData

GCP Station Diagram for LiDAR

LiDAR

Project Name: Quinnipiac	**GCP Number:** QNP107
CDI Project Number: 1508	**Date:** 10/20/2010



N

GPS Antenna Height: 2m

Comments:

Point taken in center of culdesac.
Middlesex County, Connecticut

Disk (Roll) / Frame Number:	**Sketch** 1 **of** 1
Collected By: Bryan Frazier	**Checked By:**

LiDAR

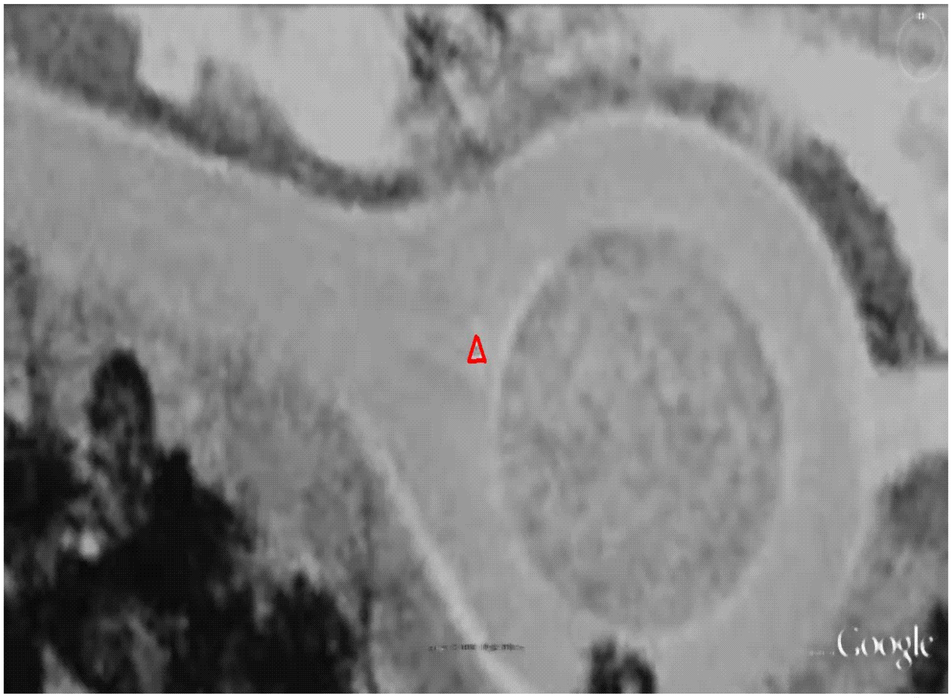
QNP108

CompassData

GCP Station Diagram for LiDAR

LiDAR

Project Name: Quinnipiac	**GCP Number:** QNP108
CDI Project Number: 1508	**Date:** 10/20/2010



GPS Antenna Height: 2m

Comments:

Point taken on road.
Middlesex County, Connecticut

Disk (Roll) / Frame Number:	**Sketch** 1 **of** 1
Collected By: Bryan Frazier	**Checked By:**

LiDAR

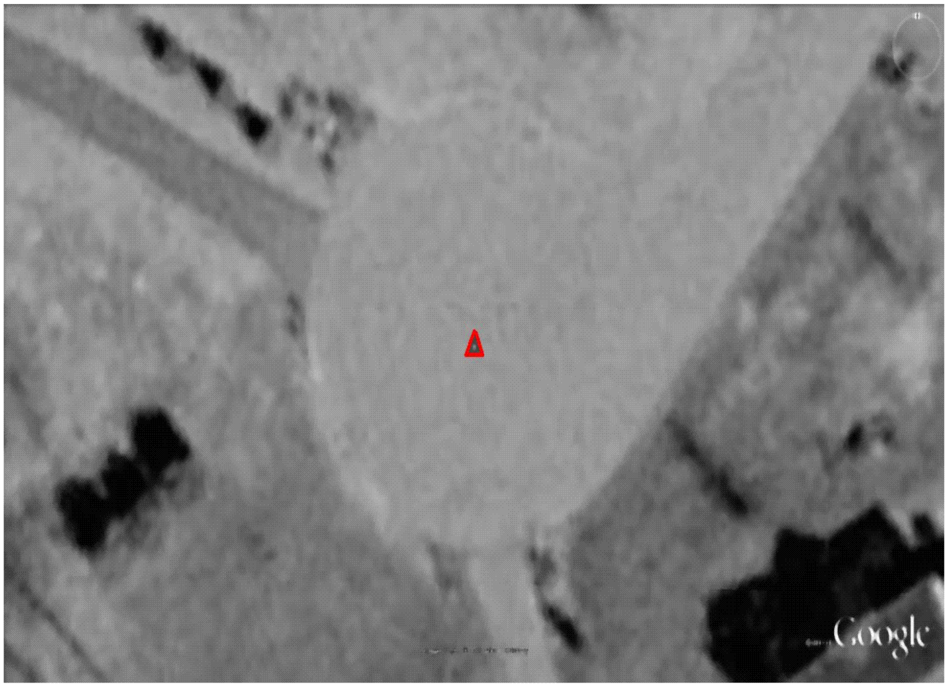
QNP109

CompassData

GCP Station Diagram for LiDAR

LiDAR

Project Name: Quinnipiac	**GCP Number:** QNP109
CDI Project Number: 1508	**Date:** 10/20/2010



N

GPS Antenna Height: 2m

Comments:

Point taken on Eagle Meadow Rd in center of culdesac.
Middlesex County, Connecticut

Disk (Roll) / Frame Number:	**Sketch** 1 **of** 1
Collected By: Bryan Frazier	**Checked By:**

LiDAR

QNP110

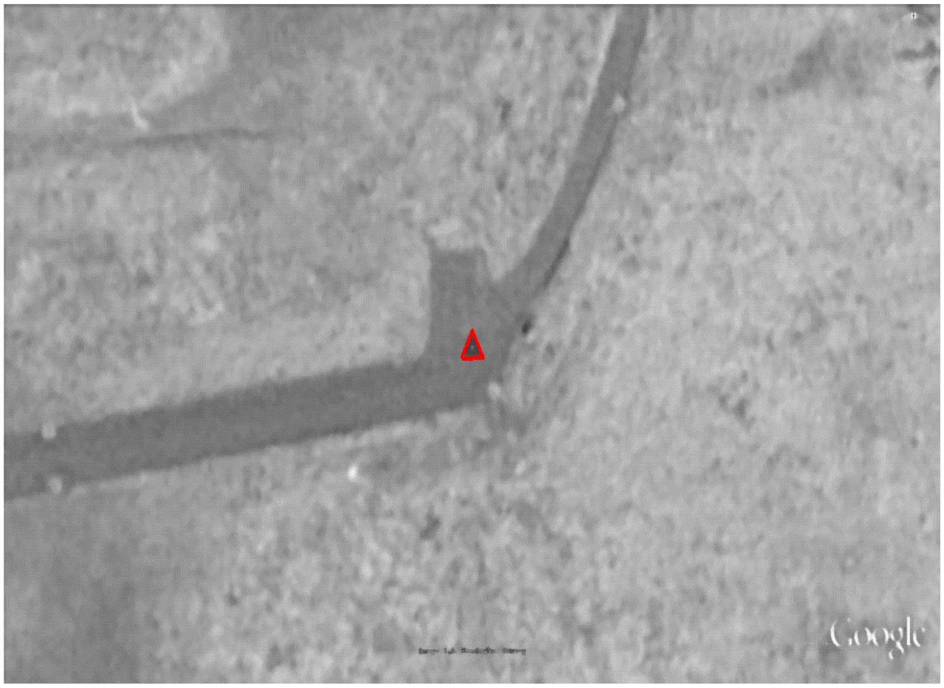
CompassData

GCP Station Diagram for LiDAR

LiDAR

LiDAR

Project Name: Quinnipiac	**GCP Number:** QNP110
CDI Project Number: 1508	**Date:** 10/20/2010



N

GPS Antenna Height: 2m

Comments:

Point taken on road at curve.
New Haven County, Connecticut.

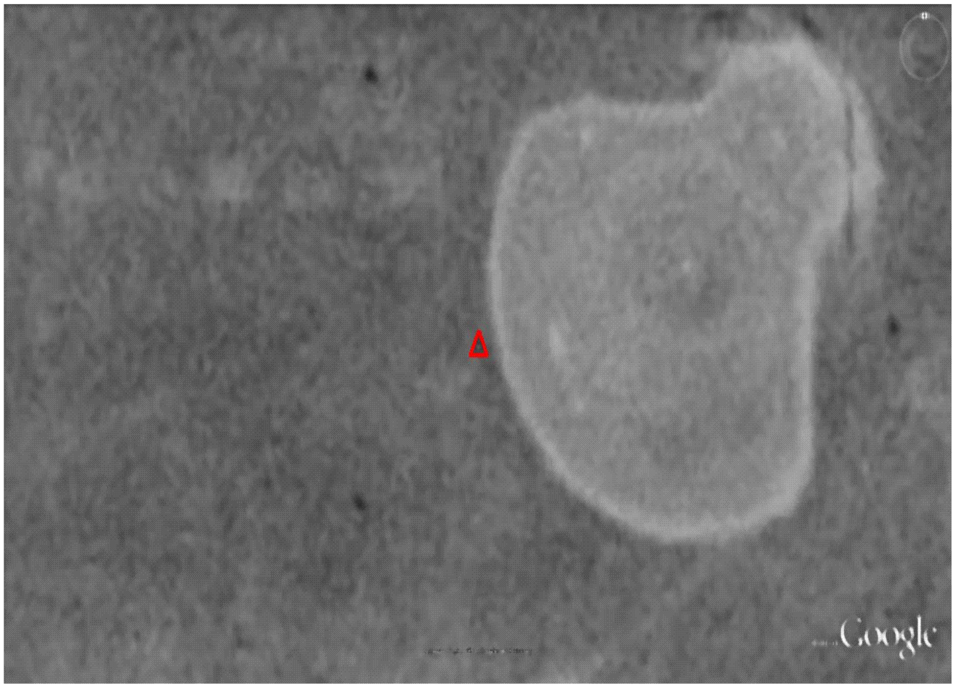
Disk (Roll) / Frame Number:	**Sketch** 1 **of** 1
Collected By: Bryan Frazier	**Checked By:**

QNP111

CompassData

GCP Station Diagram for LiDAR

Project Name: Quinnipiac	**GCP Number:** QNP111
CDI Project Number: 1508	**Date:** 10/19/2010



GPS Antenna Height: 2m

Comments:

Point taken in field near where grass meets the baseball infield dirt line.
New Haven County, Connecticut

Disk (Roll) / Frame Number:	**Sketch** 1 **of** 1
Collected By: Bryan Frazier	**Checked By:**

CompassData, Inc., 12353 E. Easter Ave., Suite 200, Centennial, CO 80112 CDIGCP-01/04

LiDAR

LiDAR

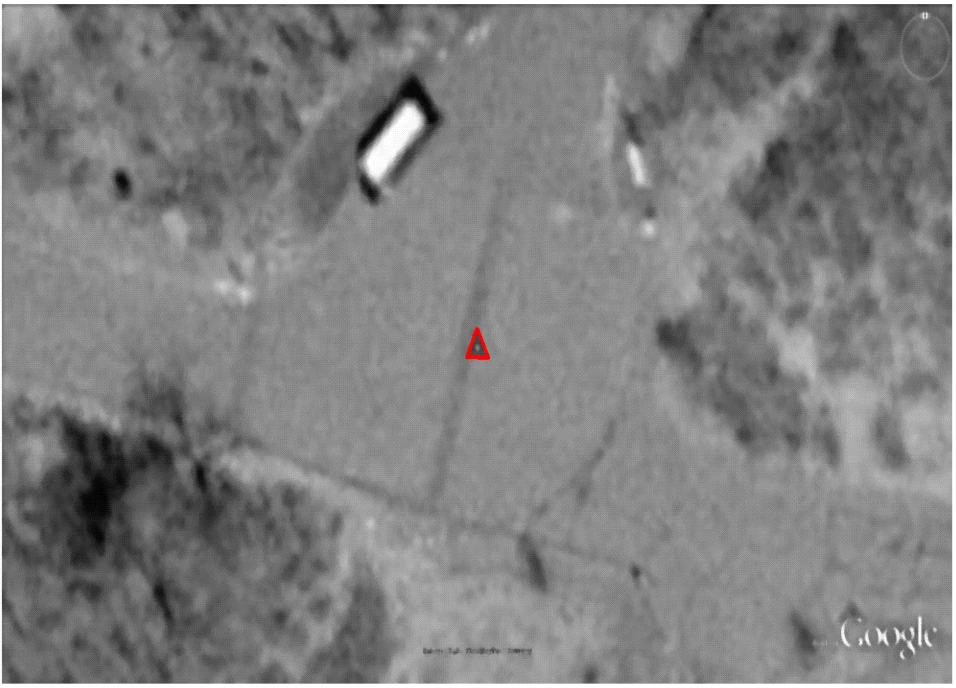
QNP112

CompassData

GCP Station Diagram for LiDAR

LiDAR

Project Name: Quinnipiac	**GCP Number:** QNP112
CDI Project Number: 1508	**Date:** 10/19/2010



GPS Antenna Height: 2m

Comments:

Point taken at intersection of Technology Dr.
New Haven County, Connecticut.

Disk (Roll) / Frame Number:	**Sketch** 1 **of** 1
Collected By: Bryan Frazier	**Checked By:**

LiDAR

QNP113

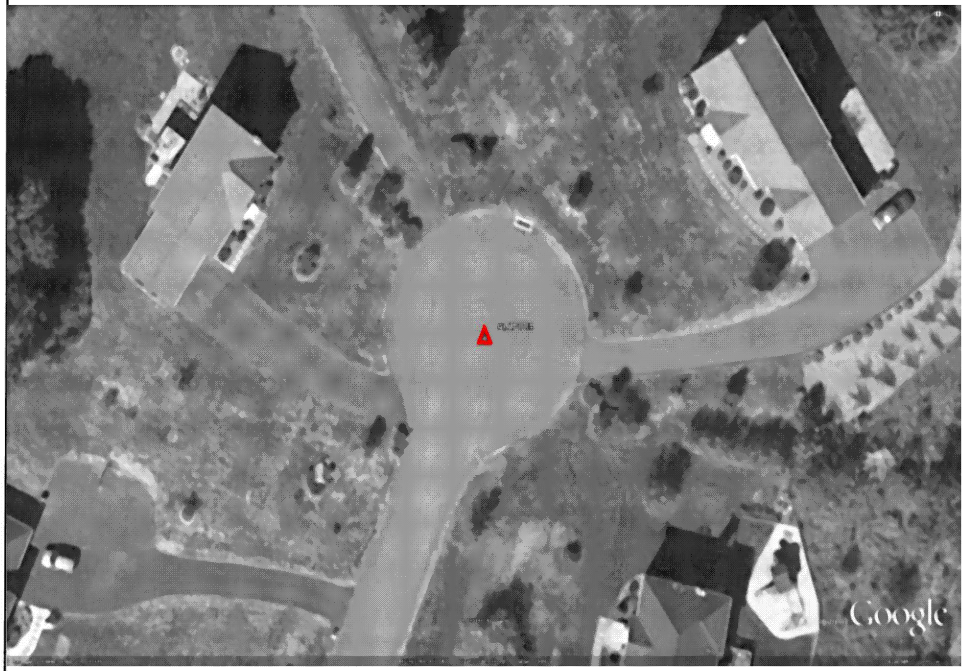
CompassData

GCP Station Diagram for LiDAR

LiDAR

LiDAR

Project Name: Quinnipiac	**GCP Number:** QNP113
CDI Project Number: 1508	**Date:** 10/20/2010



GPS Antenna Height: 2m

Comments:

Point was taken in cul-de-sac at the northern end of Richmond Ct.
Hartford County, Connecticut

Disk (Roll) / Frame Number:	**Sketch** 1 **of** 1
Collected By: Bryan Frazier	**Checked By:**

QNP114

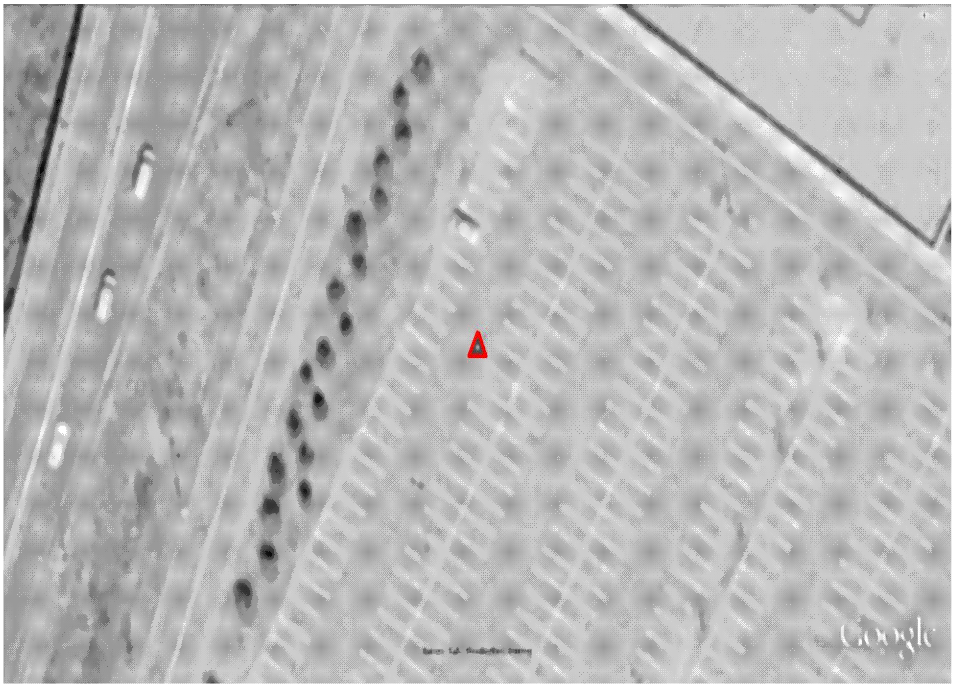
CompassData

GCP Station Diagram for LiDAR

LiDAR

LiDAR

Project Name: Quinnipiac	**GCP Number:** QNP114
CDI Project Number: 1508	**Date:** 10/19/2010



GPS Antenna Height: 2m

Comments:

Point taken at NW corner of shopping center parking lot.
HartfordCounty, Connecticut.

Disk (Roll) / Frame Number:	**Sketch** 1 **of** 1
Collected By: Bryan Frazier	**Checked By:**

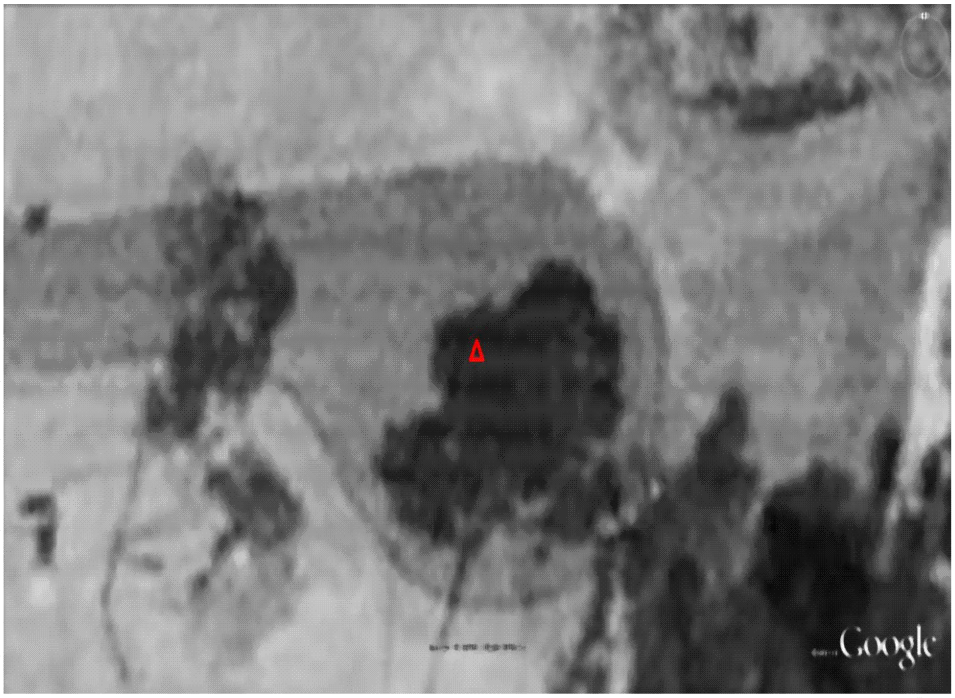
CompassData, Inc., 12353 E. Easter Ave., Suite 200, Centennial, CO 80112   CDIGCP-01/04

QNP115

CompassData

GCP Station Diagram for LiDAR

Project Name: Quinnipiac	**GCP Number:** QNP115
CDI Project Number: 1508	**Date:** 10/19/2010



GPS Antenna Height: 2m

Comments:

Point taken at center of culdesac of Acre Way.
Hartford County, Connecticut.

Disk (Roll) / Frame Number:	**Sketch** 1 **of** 1
Collected By: Bryan Frazier	**Checked By:**

CompassData, Inc., 12353 E. Easter Ave., Suite 200, Centennial, CO 80112 CDIGCP-01/04

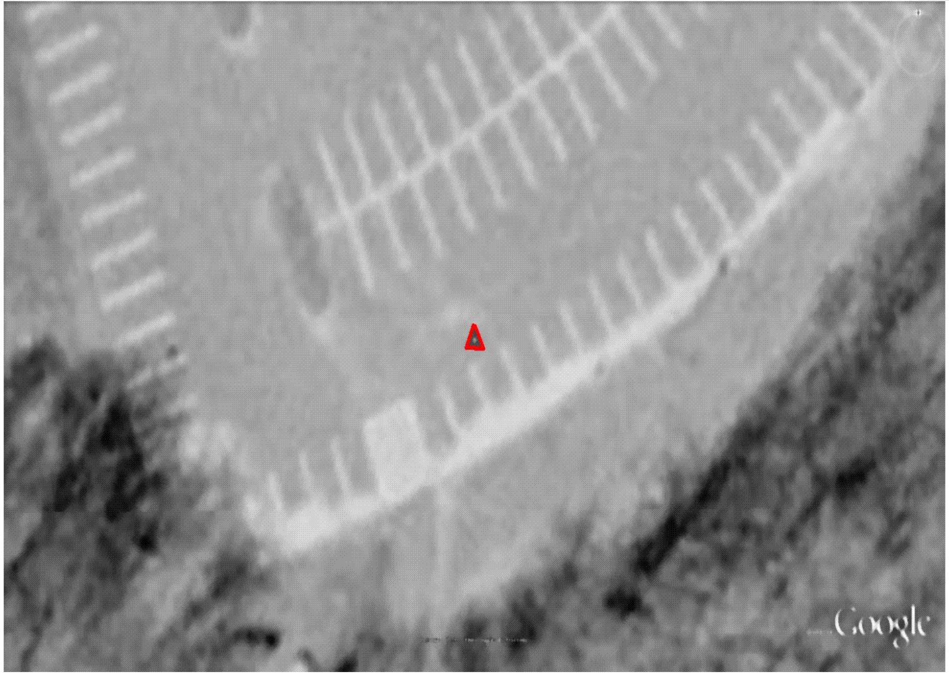
QNP116

CompassData

GCP Station Diagram for LiDAR

LiDAR

Project Name: Quinnipiac	**GCP Number:** QNP116
CDI Project Number: 1508	**Date:** 10/19/2010



N

GPS Antenna Height: 2m	

Comments:

Point taken at SW corner of the parking lot of Long River Middle School.
New Haven County, Connecticut.

Disk (Roll) / Frame Number:	**Sketch** 1 **of** 1
Collected By: Bryan Frazier	**Checked By:**

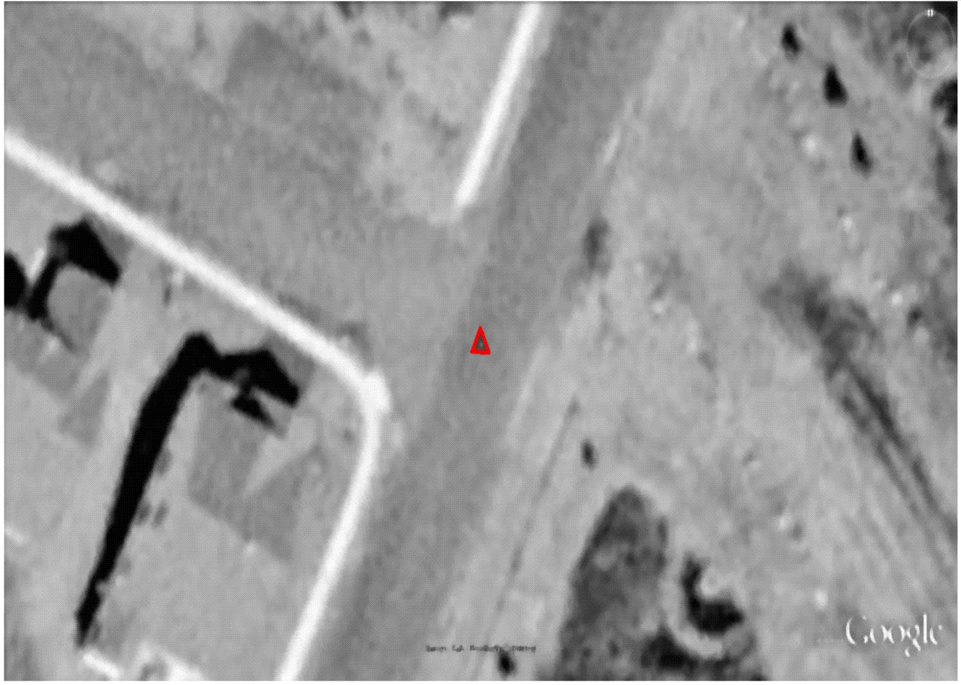
QNP117

CompassData

GCP Station Diagram for LiDAR

LiDAR

Project Name: Quinnipiac	**GCP Number:** QNP117
CDI Project Number: 1508	**Date:** 10/19/2010



N

GPS Antenna Height: 2m

Comments:

Point taken on road at intersection.
New Haven County, Connecticut.

Disk (Roll) / Frame Number:	**Sketch** 1 **of** 1
Collected By: Bryan Frazier	**Checked By:**

LiDAR

QNP118

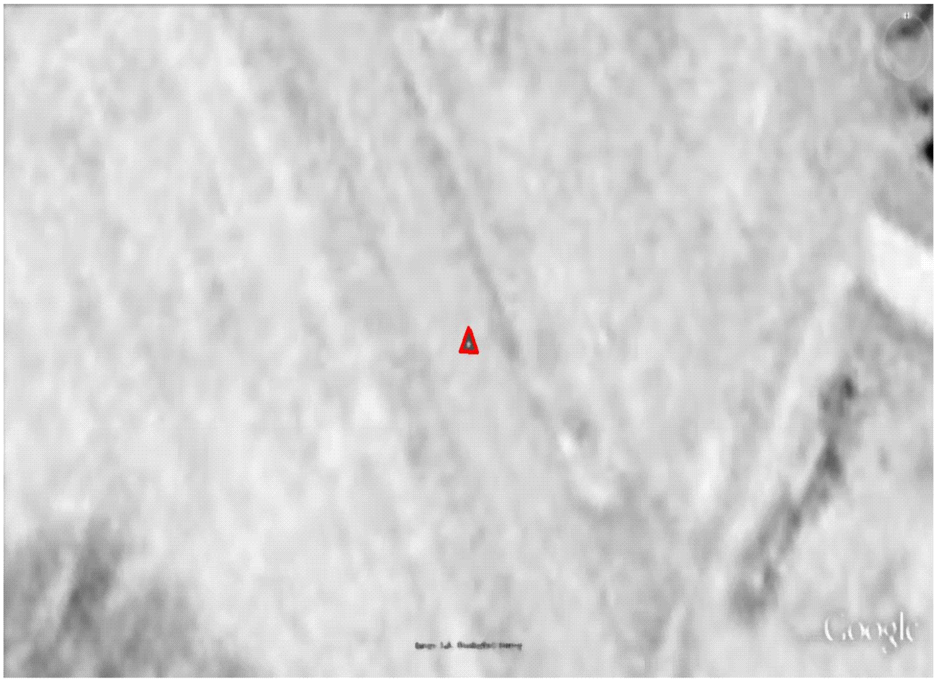
CompassData

GCP Station Diagram for LiDAR

LiDAR

LiDAR

Project Name: Quinnipiac	**GCP Number:** QNP118
CDI Project Number: 1508	**Date:** 10/20/2010



GPS Antenna Height: 2m

Comments:

Point taken on Hiltop Rd.
New Haven County, Connecticut.

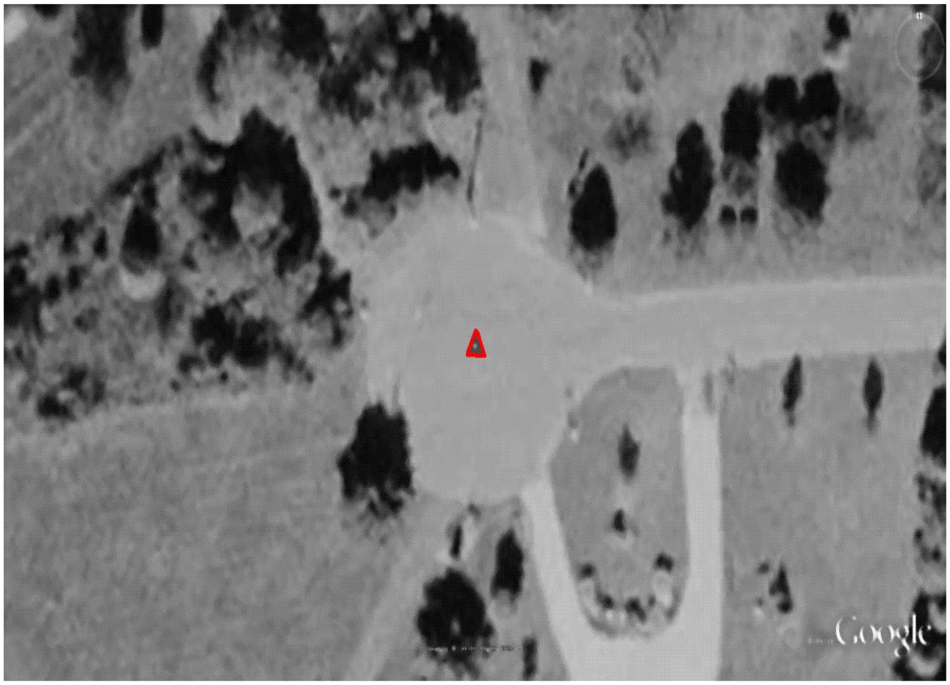
Disk (Roll) / Frame Number:	**Sketch** 1 **of** 1
Collected By: Bryan Frazier	**Checked By:**

QNP119

CompassData

GCP Station Diagram for LiDAR

Project Name: Quinnipiac	**GCP Number:** QNP119
CDI Project Number: 1508	**Date:** 10/20/2010



GPS Antenna Height: 2m

Comments:

Point taken in culdesac of Cornfield Ln.
New Haven County, Connecticut.

Disk (Roll) / Frame Number:	**Sketch** 1 **of** 1
Collected By: Bryan Frazier	**Checked By:**

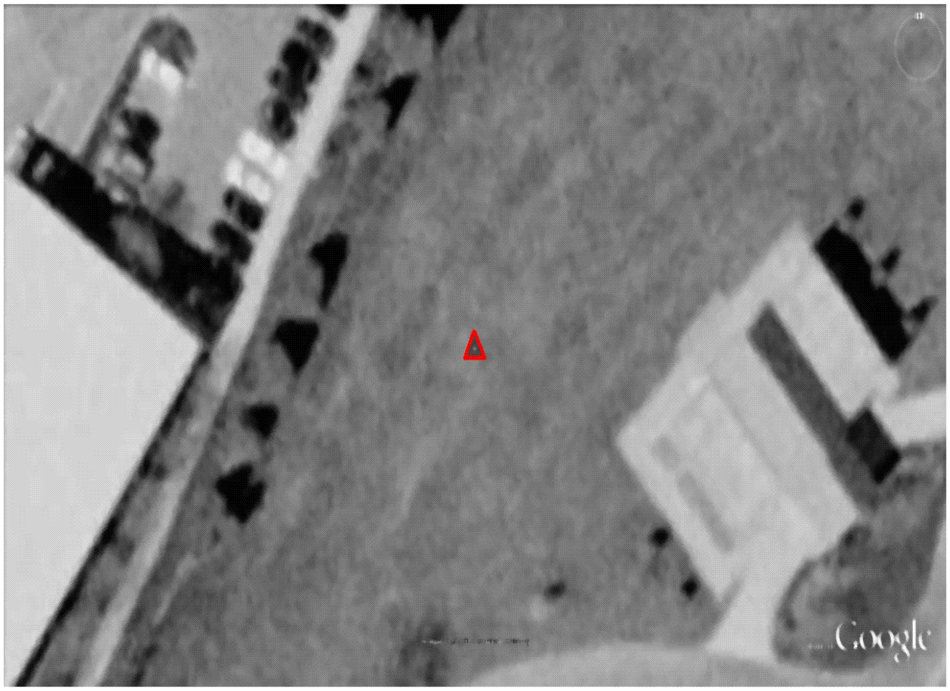
CompassData, Inc., 12353 E. Easter Ave., Suite 200, Centennial, CO 80112 CDIGCP-01/04

QNP120

CompassData

GCP Station Diagram for LiDAR

Project Name: Quinnipiac	**GCP Number:** QNP120
CDI Project Number: 1508	**Date:** 10/20/2010



GPS Antenna Height: 2m

Comments:

Point taken in field. South of Jess Field and east of Moore Fieldhouse. Southern Connecticut State University New Haven County, Connecticut.

Disk (Roll) / Frame Number:	**Sketch** 1 **of** 1
Collected By: Bryan Frazier	**Checked By:**

QNP121

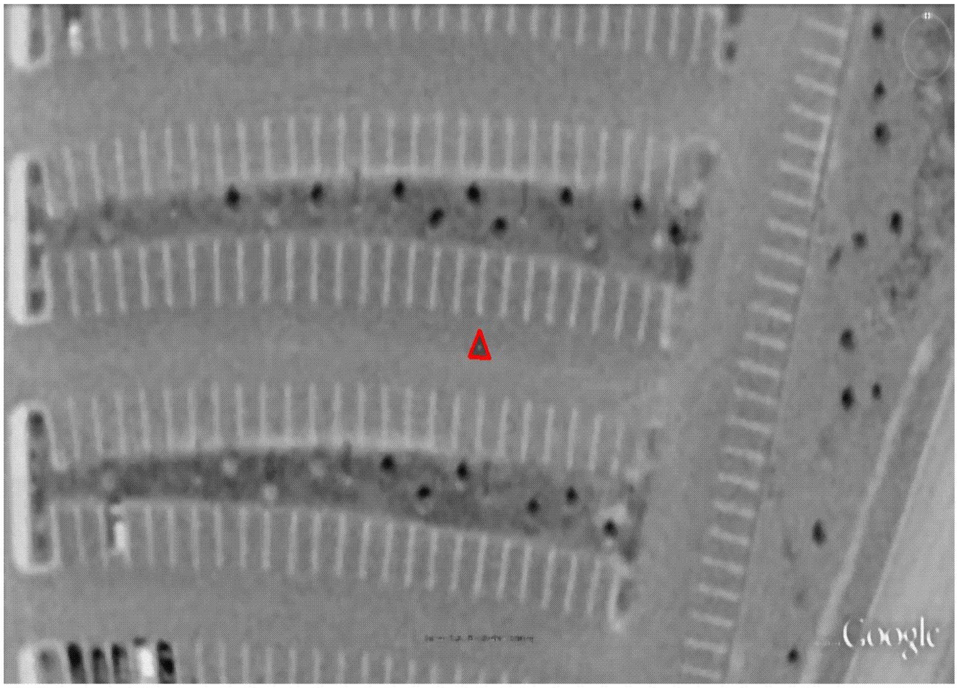
CompassData

GCP Station Diagram for LiDAR

LiDAR

LiDAR

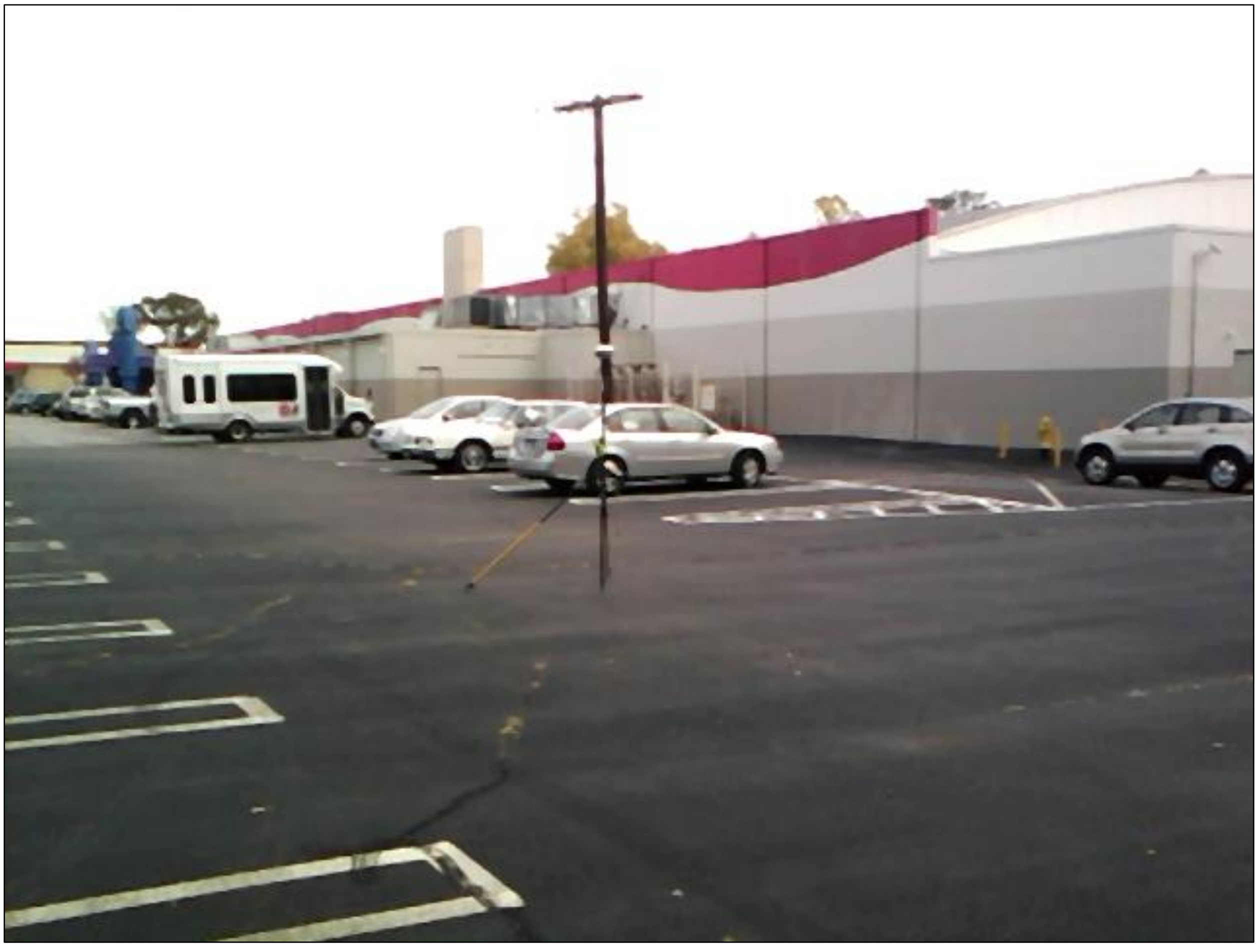
Project Name: Quinnipiac	**GCP Number:** QNP121
CDI Project Number: 1508	**Date:** 10/20/2010



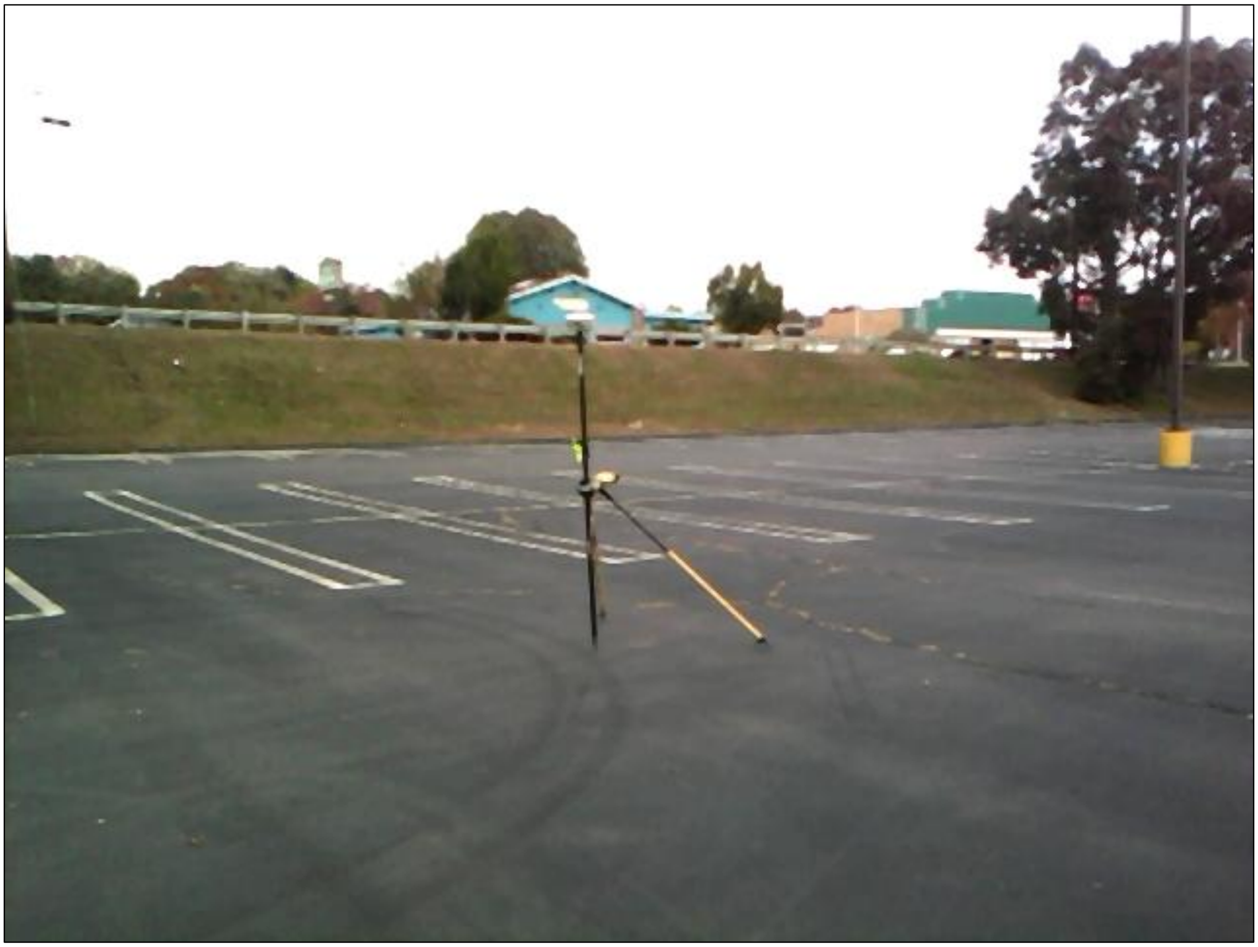
GPS Antenna Height: 2m
Comments: Point taken in parking lot New Haven County, Connecticut.

Disk (Roll) / Frame Number:	**Sketch** 1 **of** 1
Collected By: Bryan Frazier	**Checked By:**

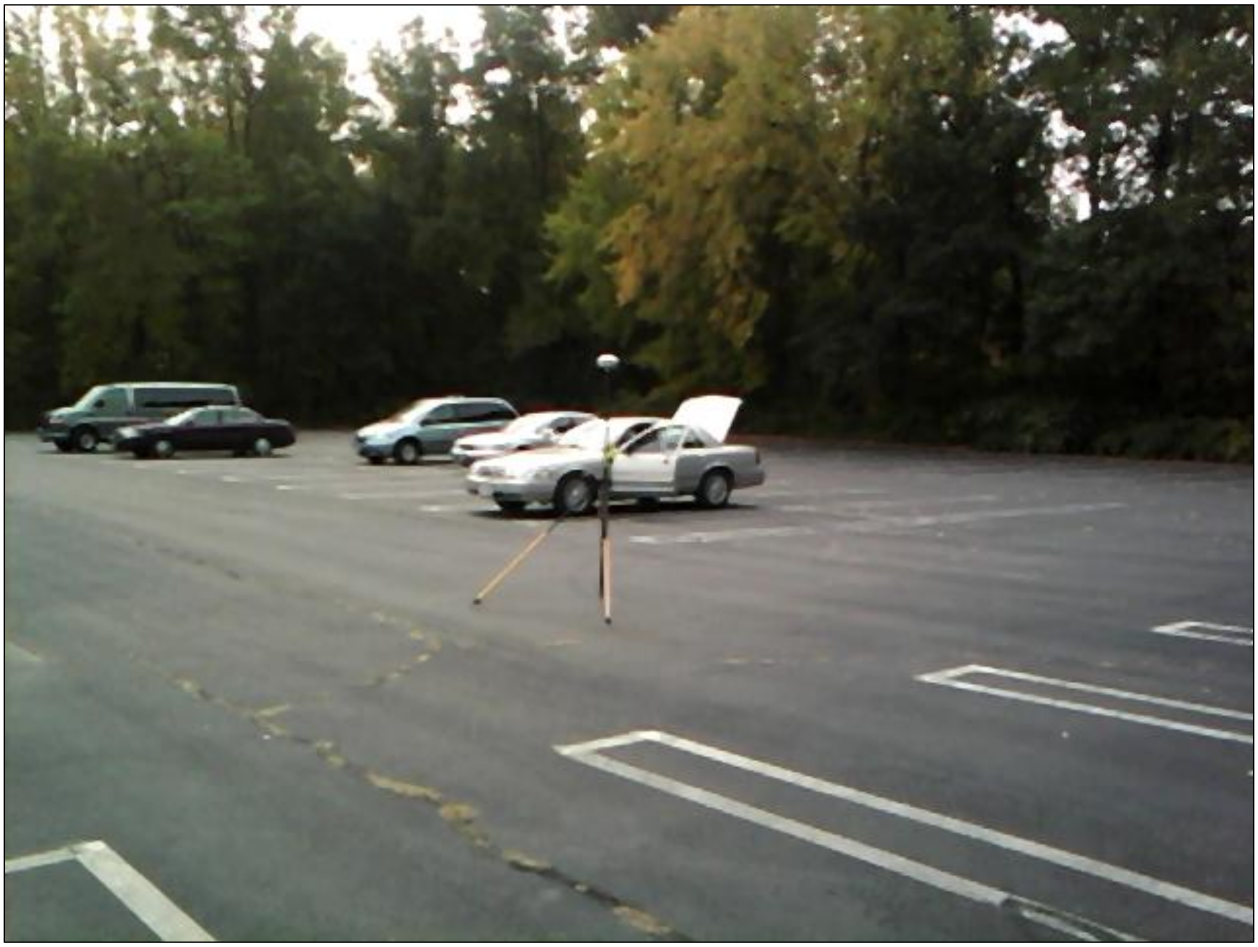
QNP101_E



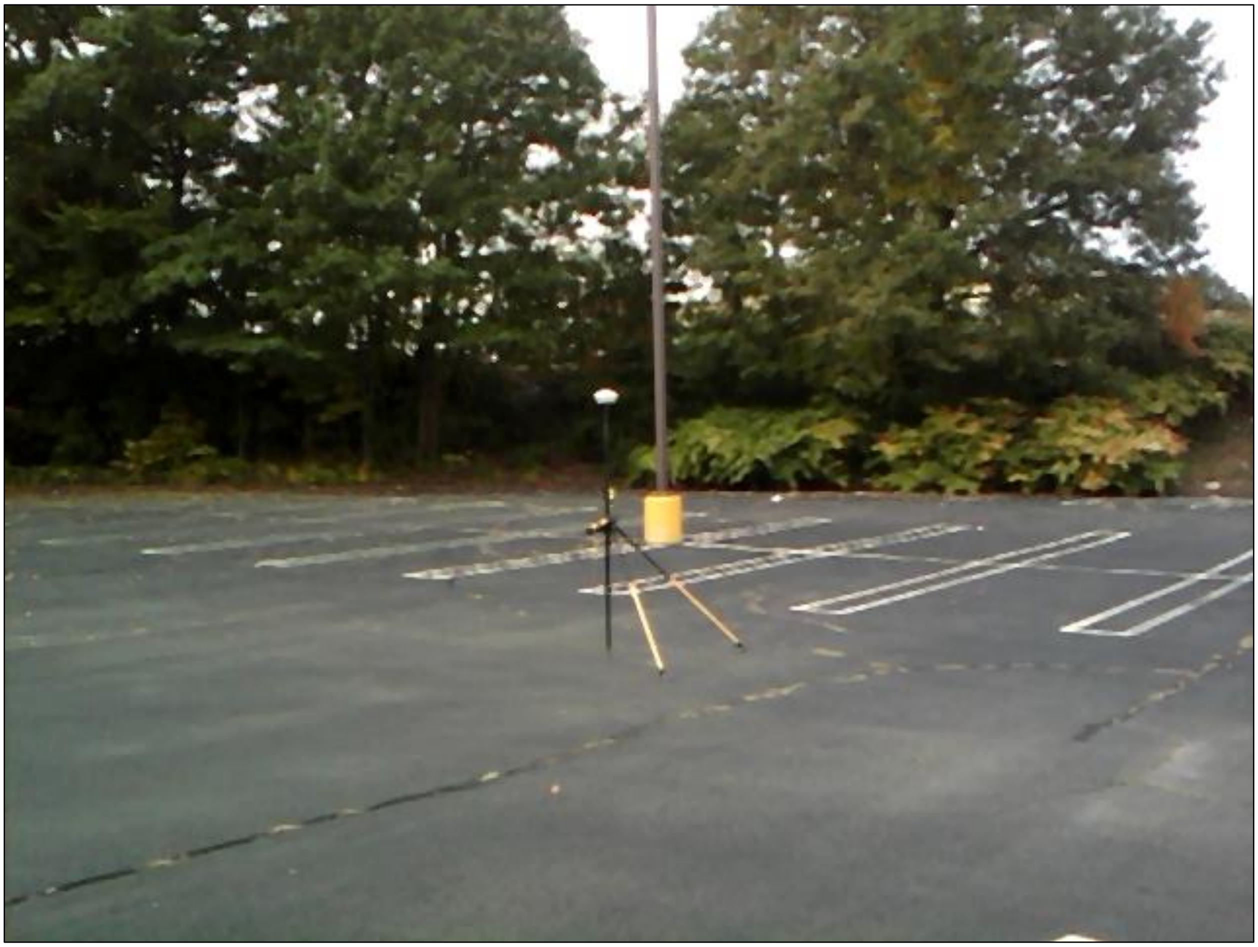
QNP101_N



QNP101_S



QNP101_W



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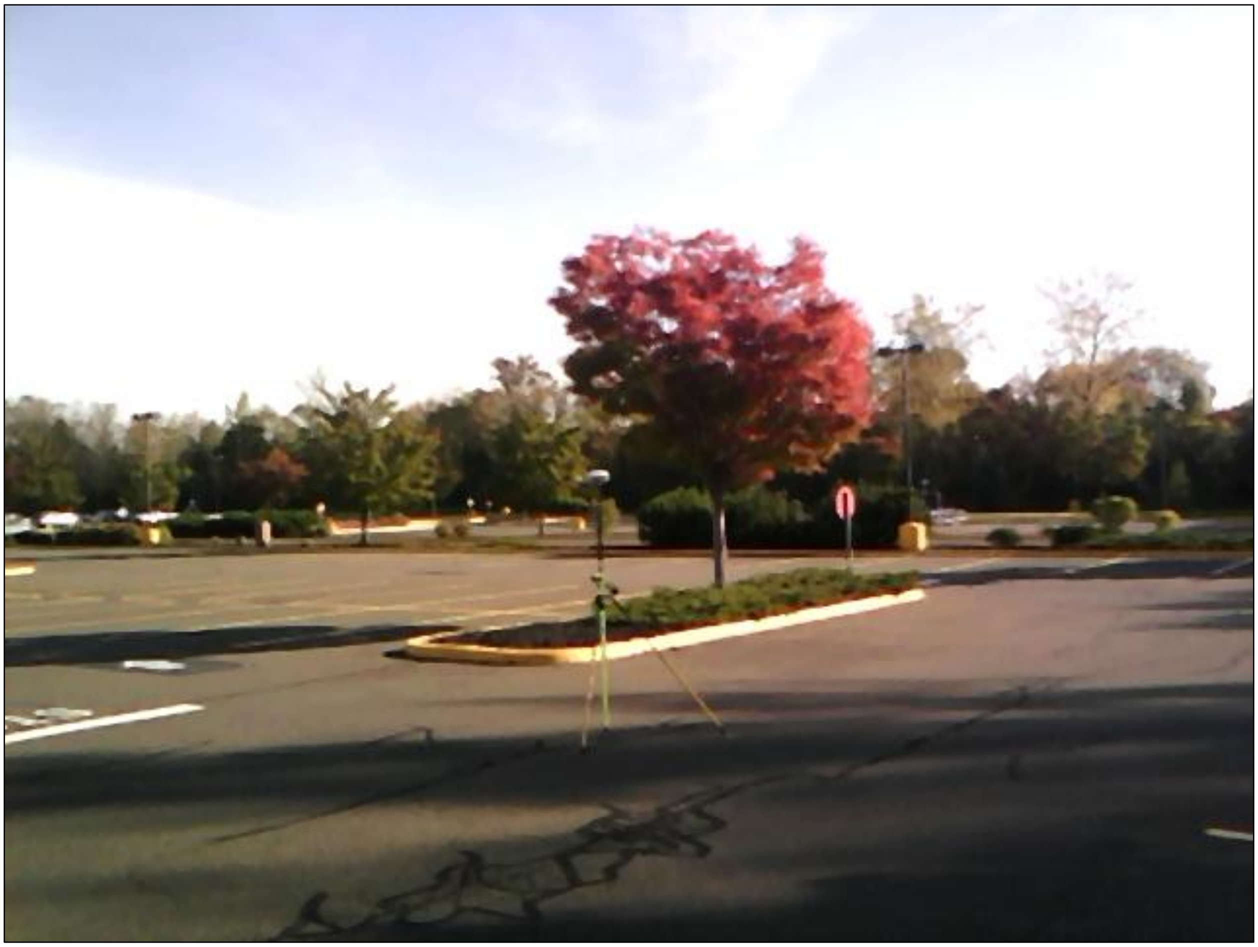

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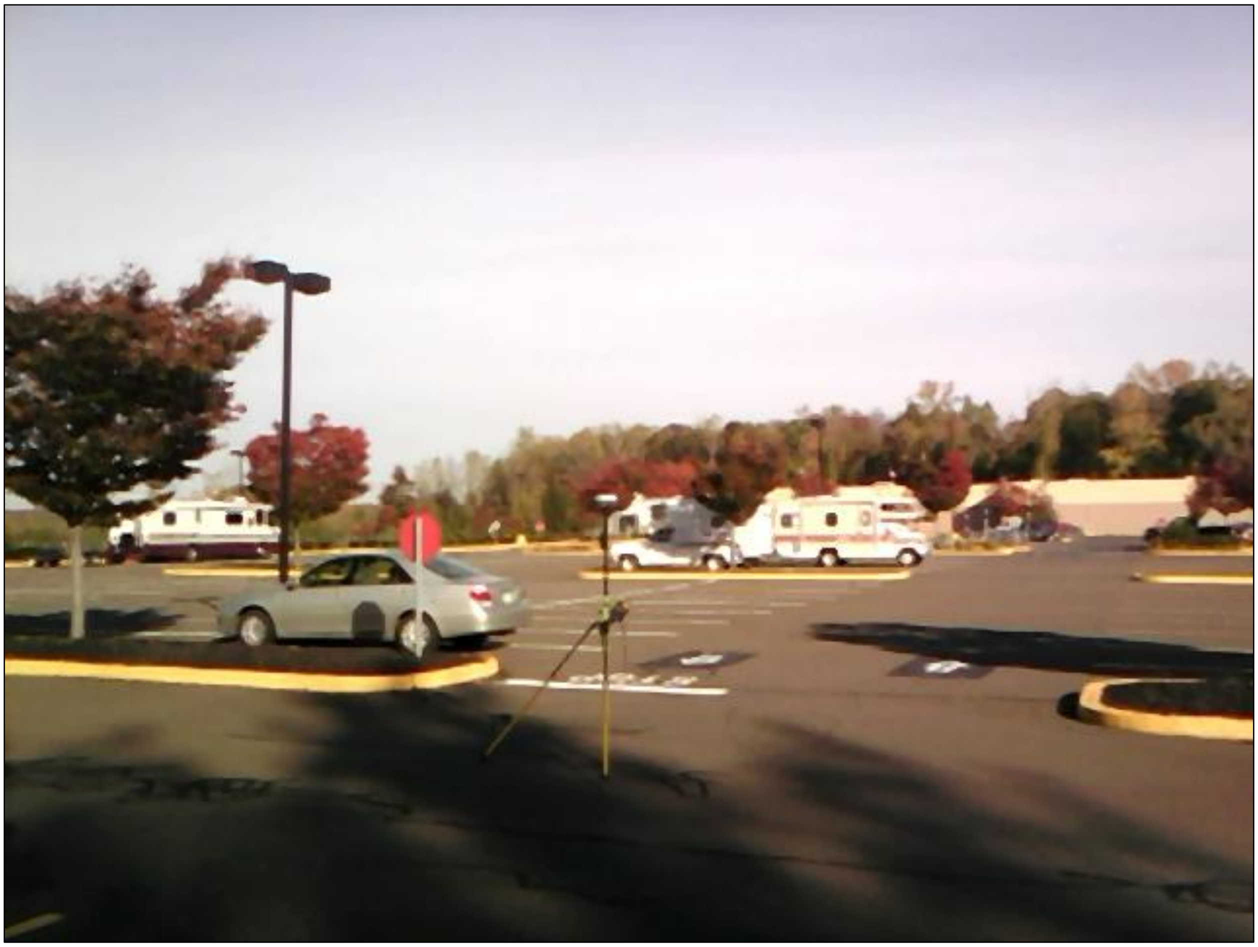

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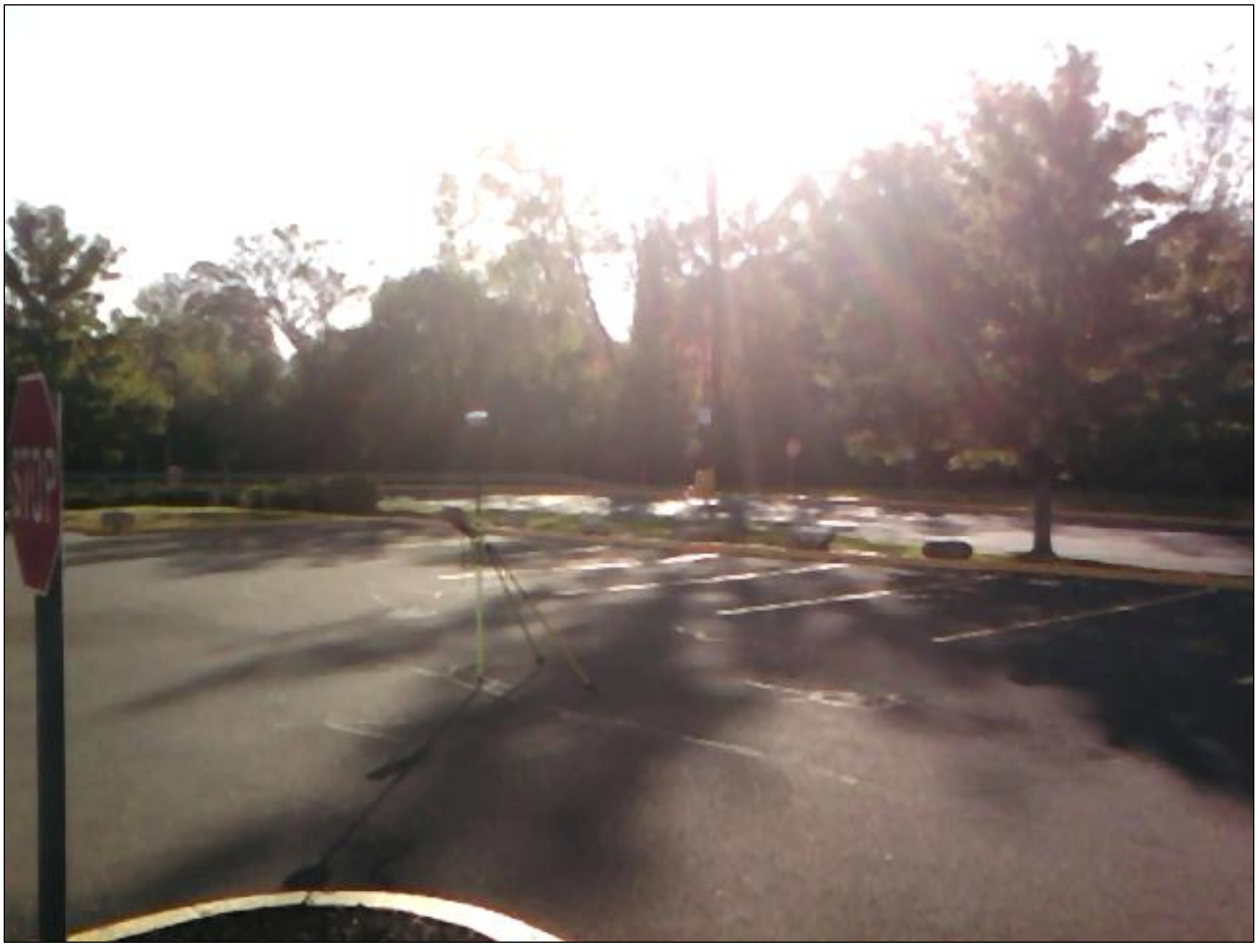

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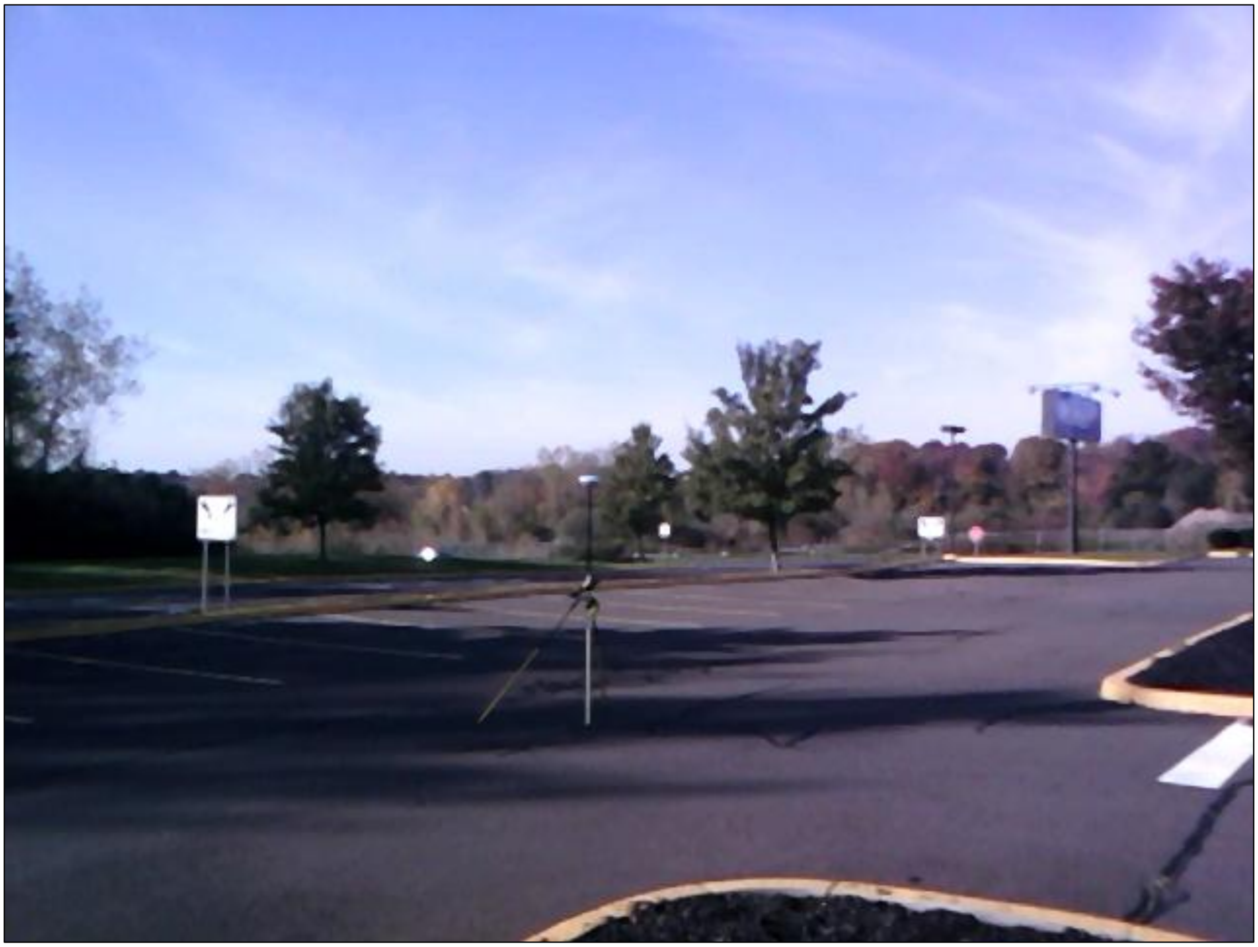
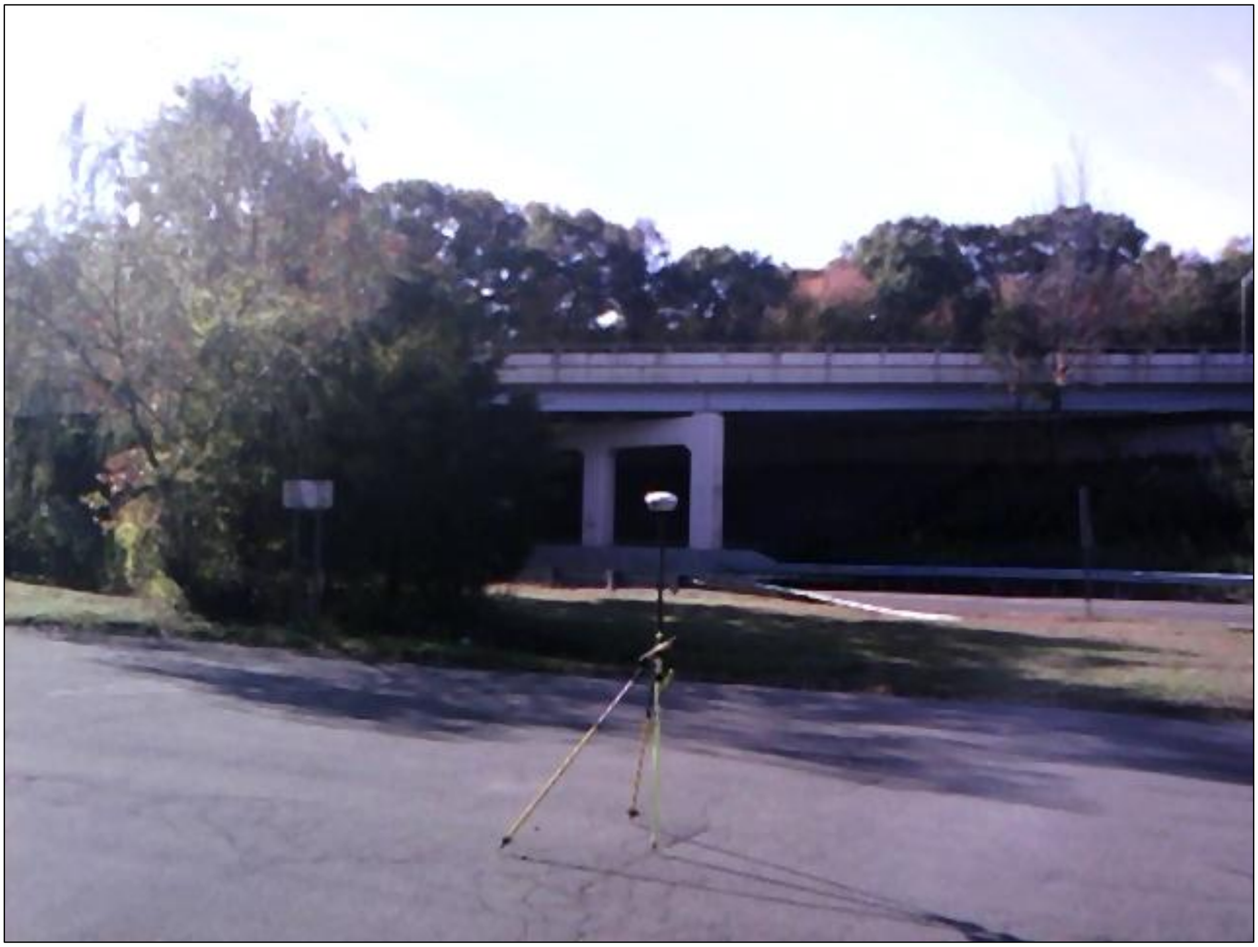


QNP103_E

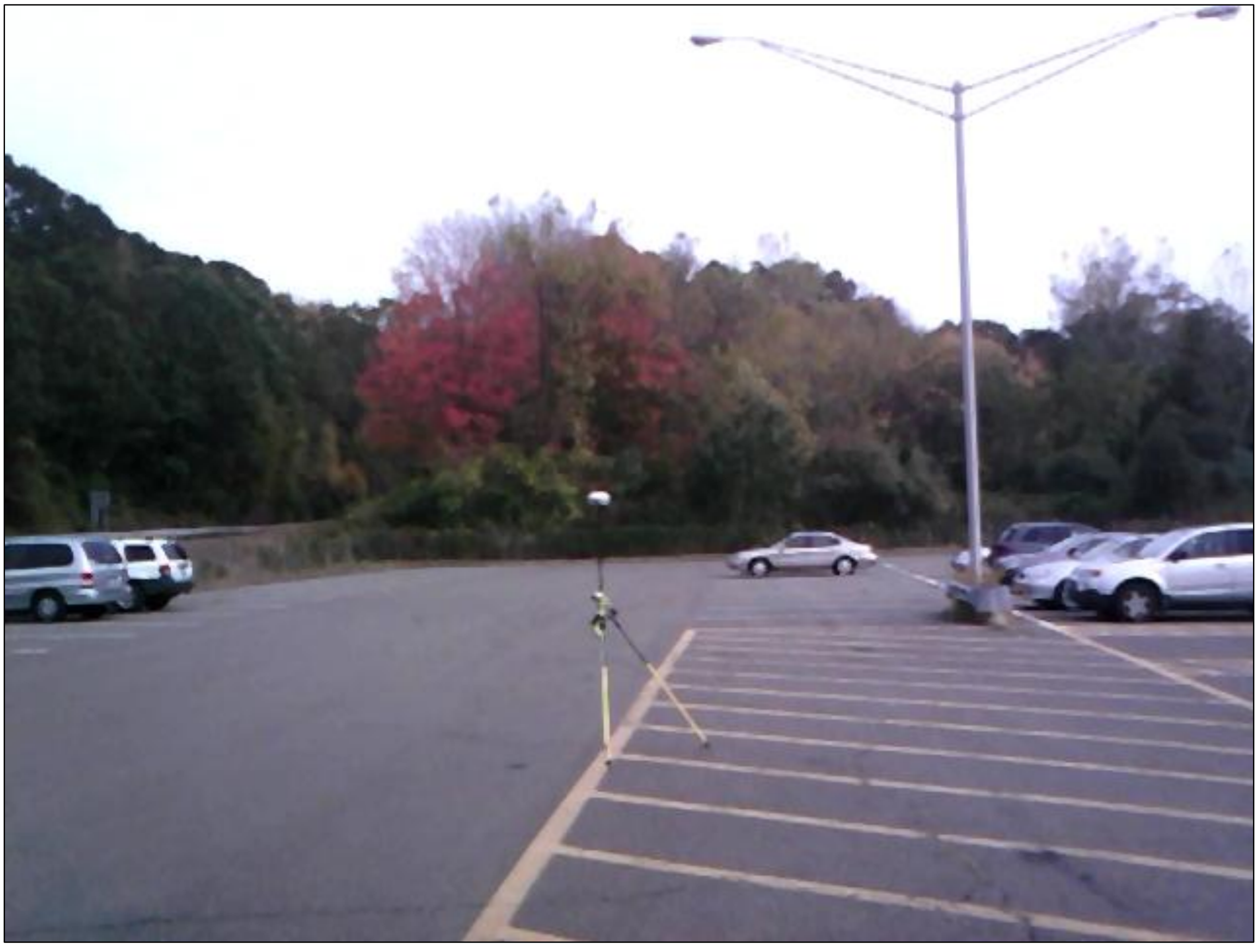
QNP103_N

QNP103_S



QNP103_W

QNP104_E



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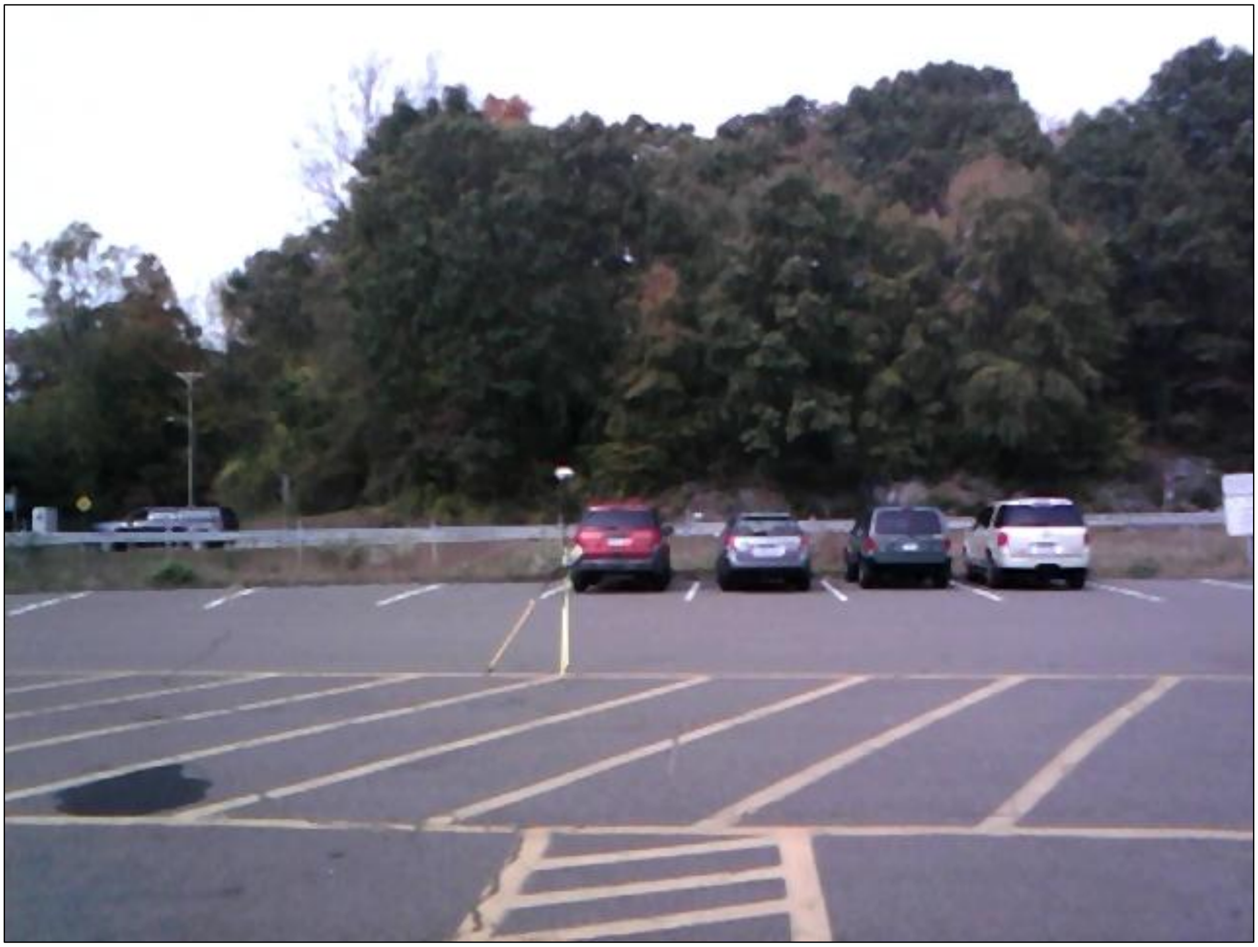

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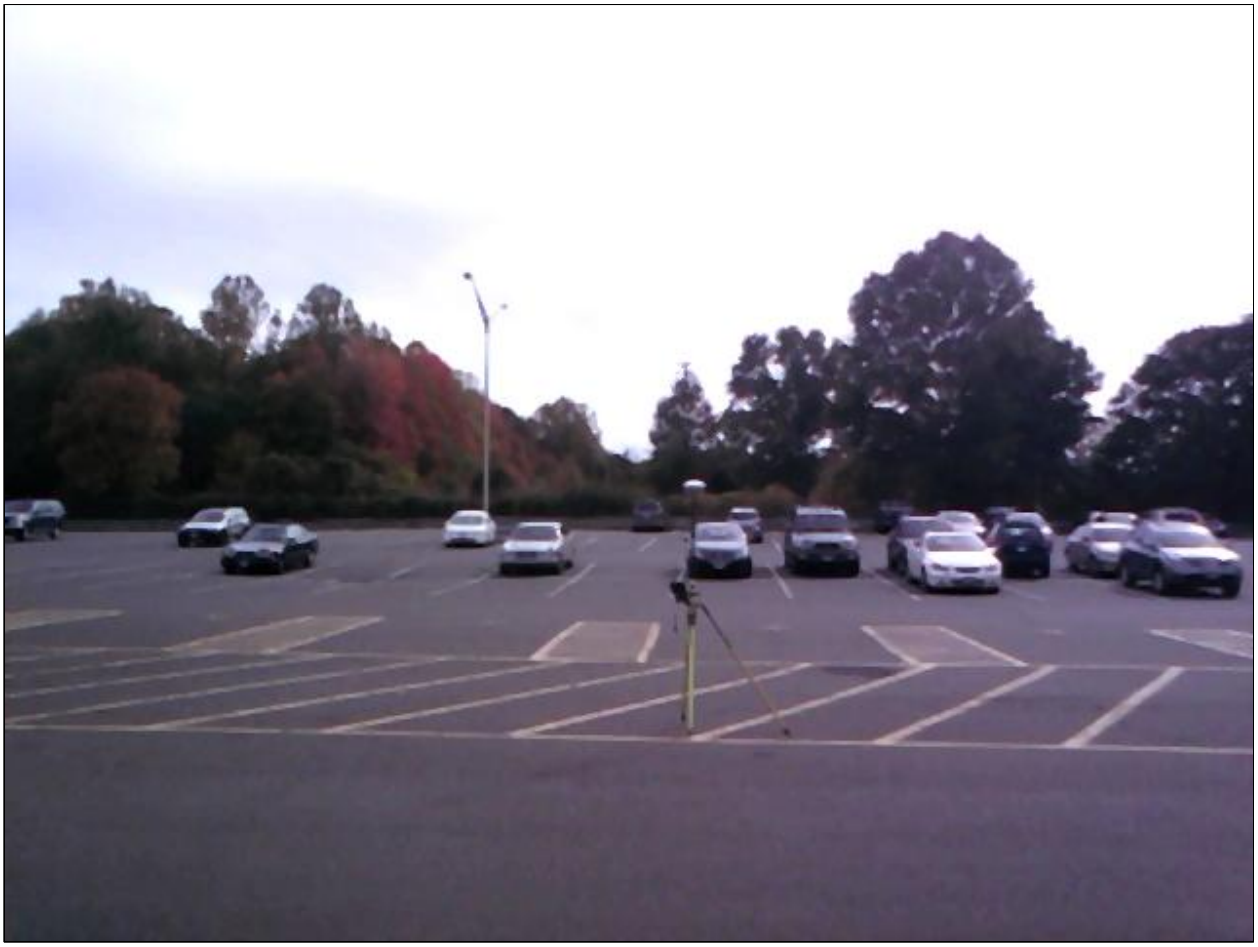

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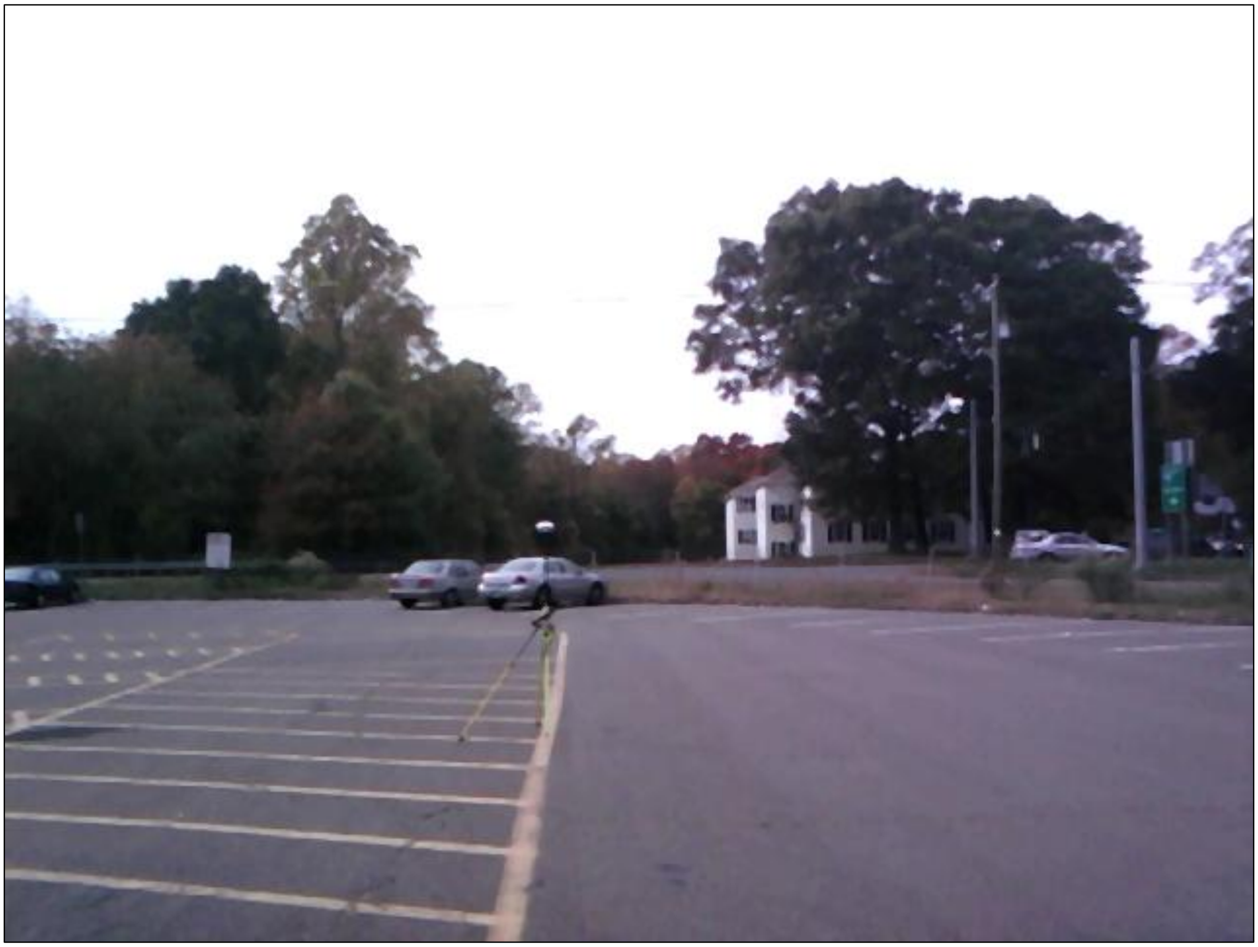

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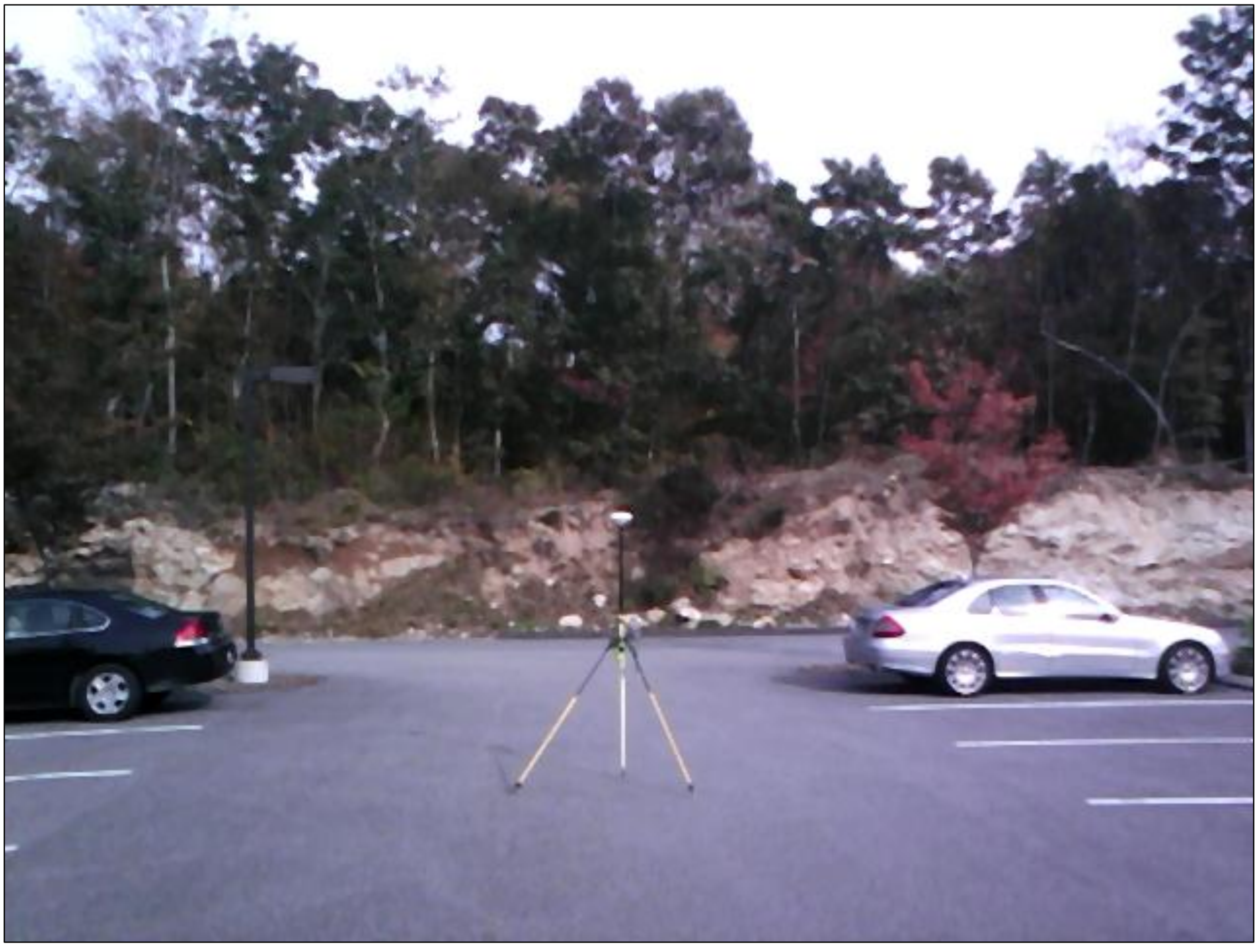

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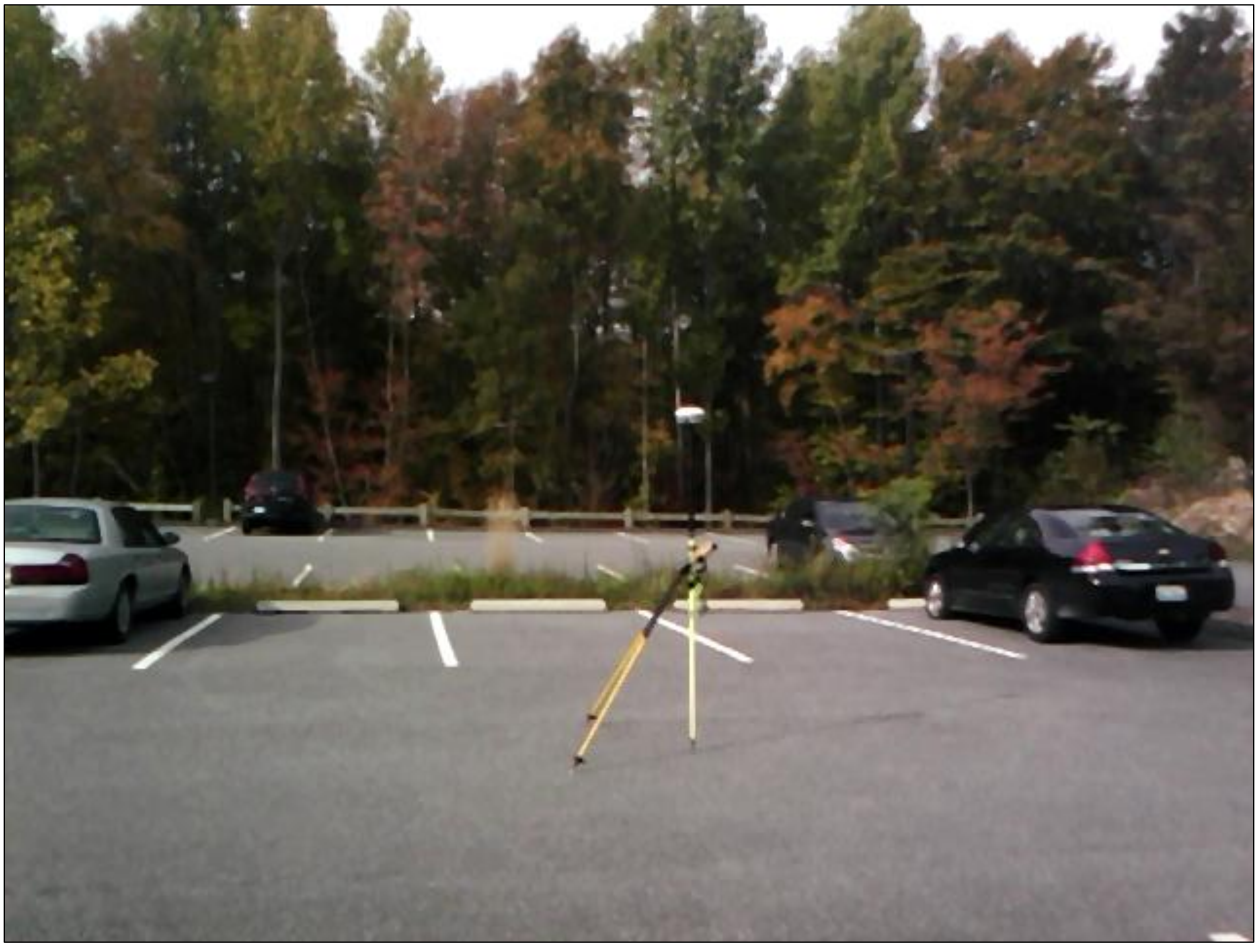

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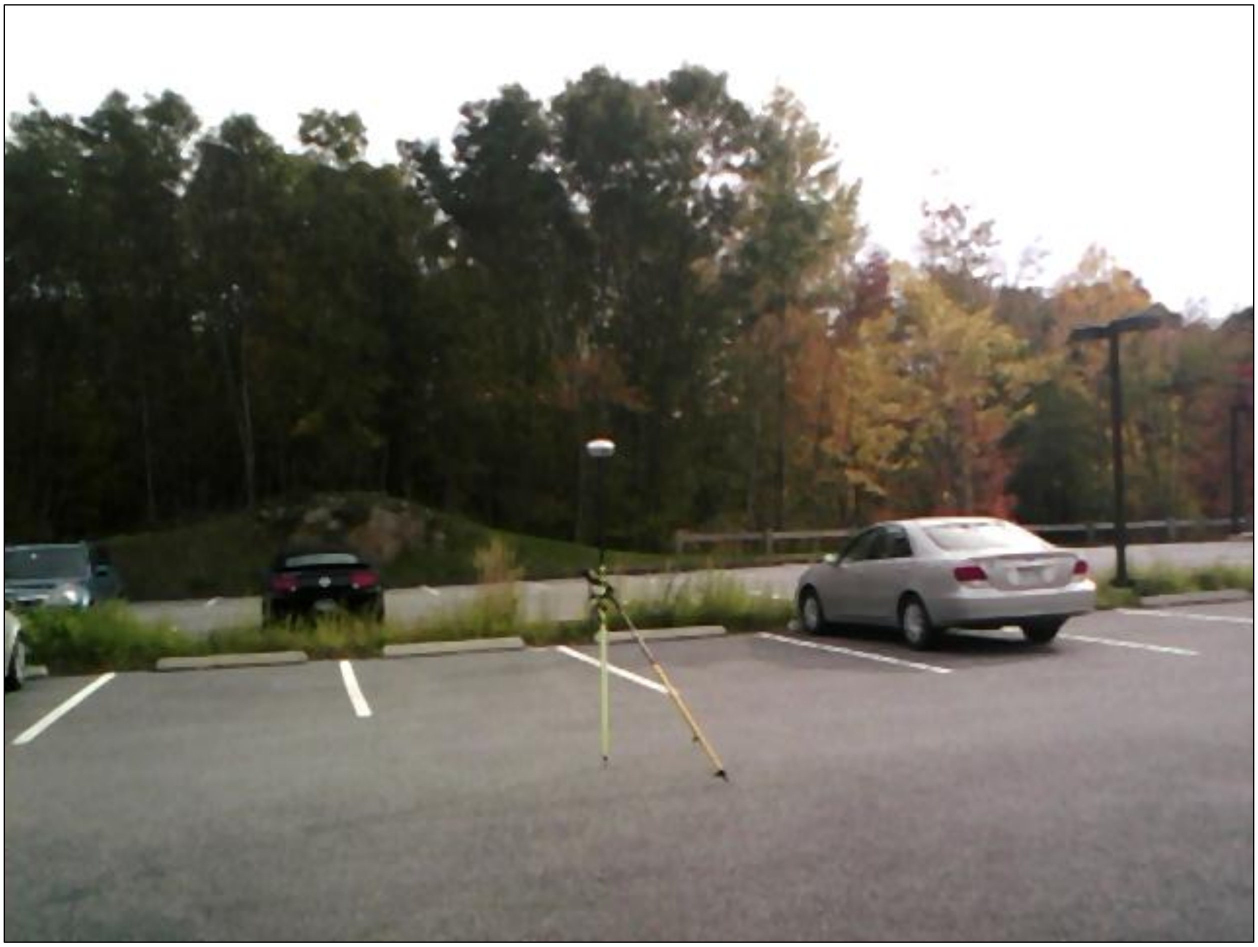

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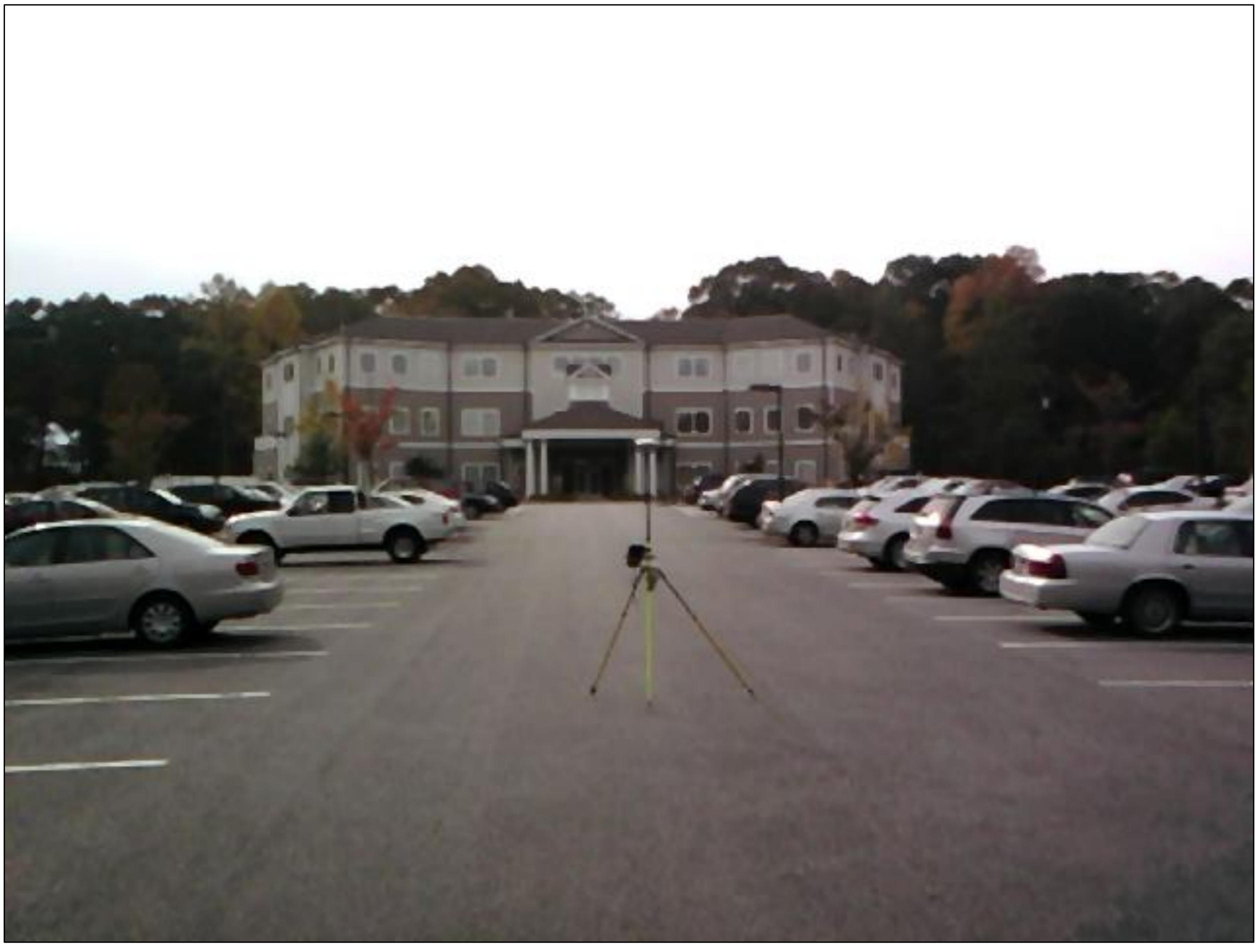

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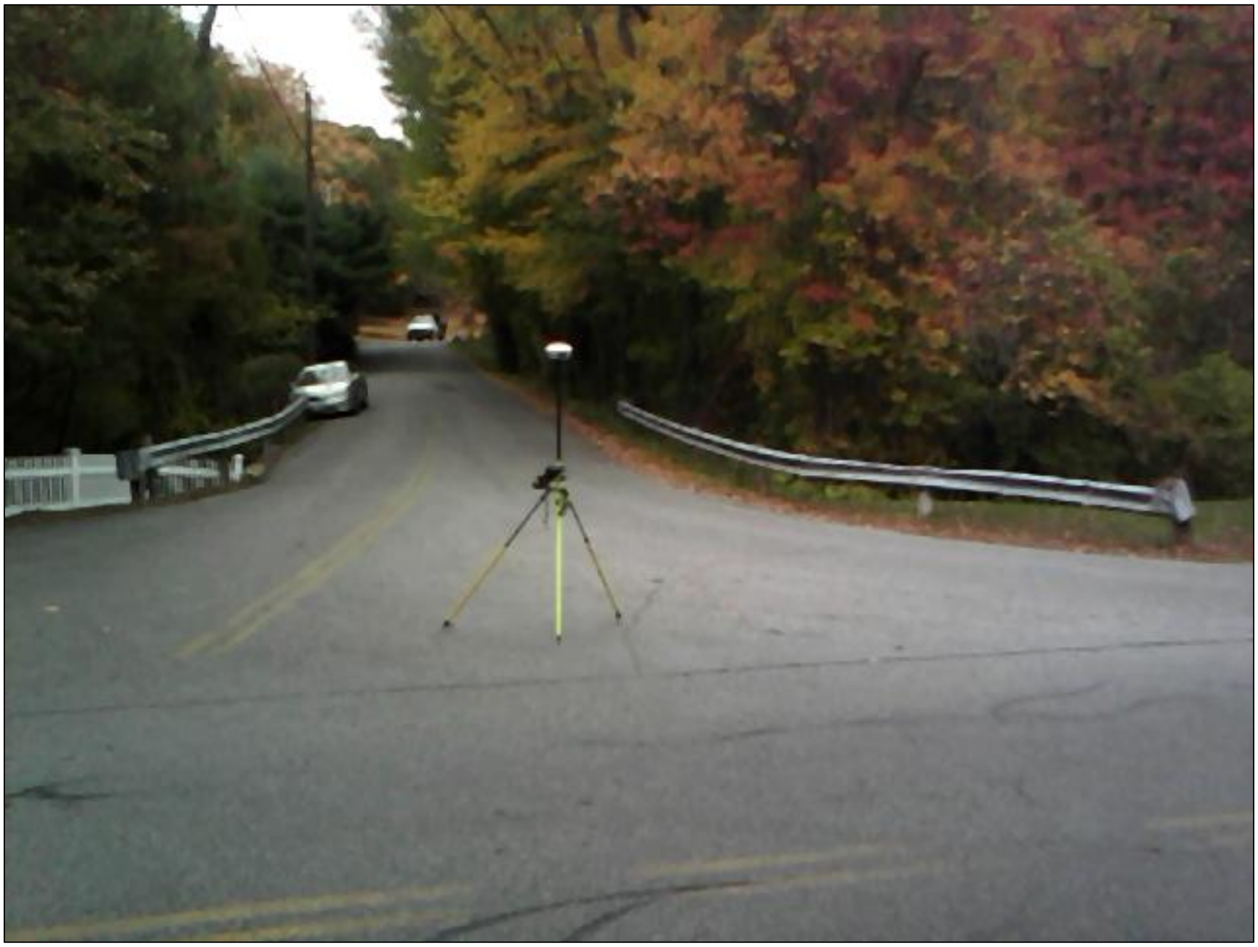

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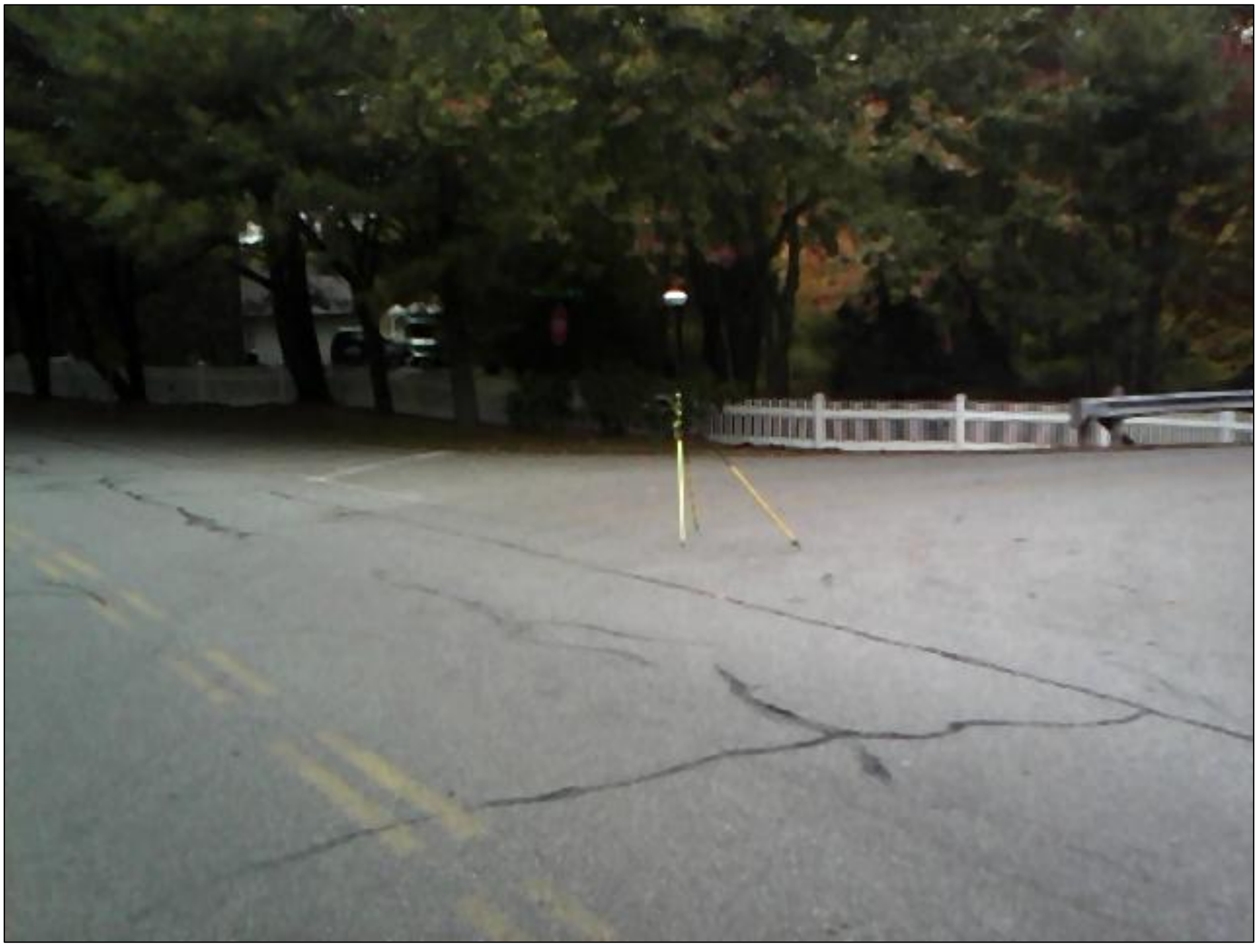

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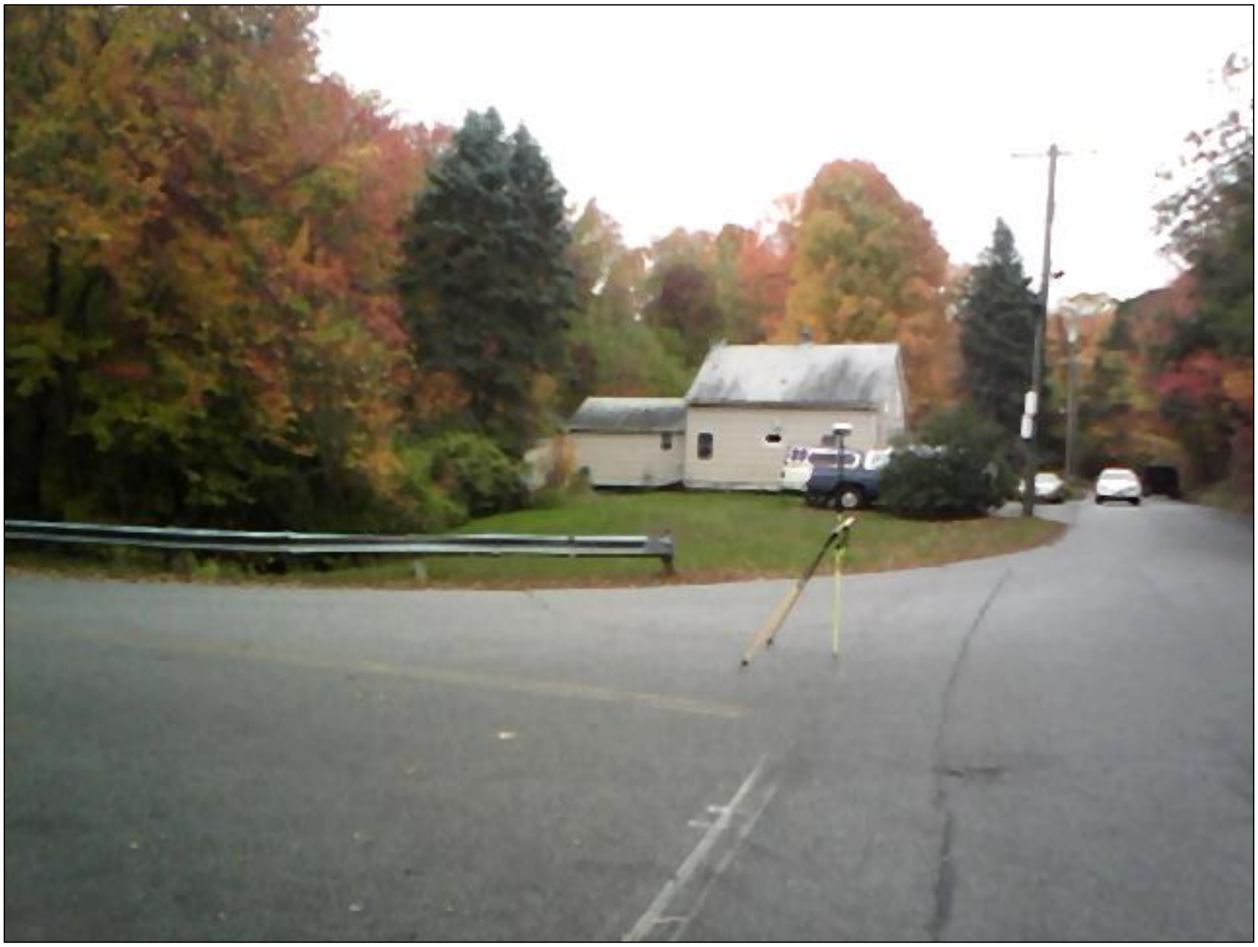

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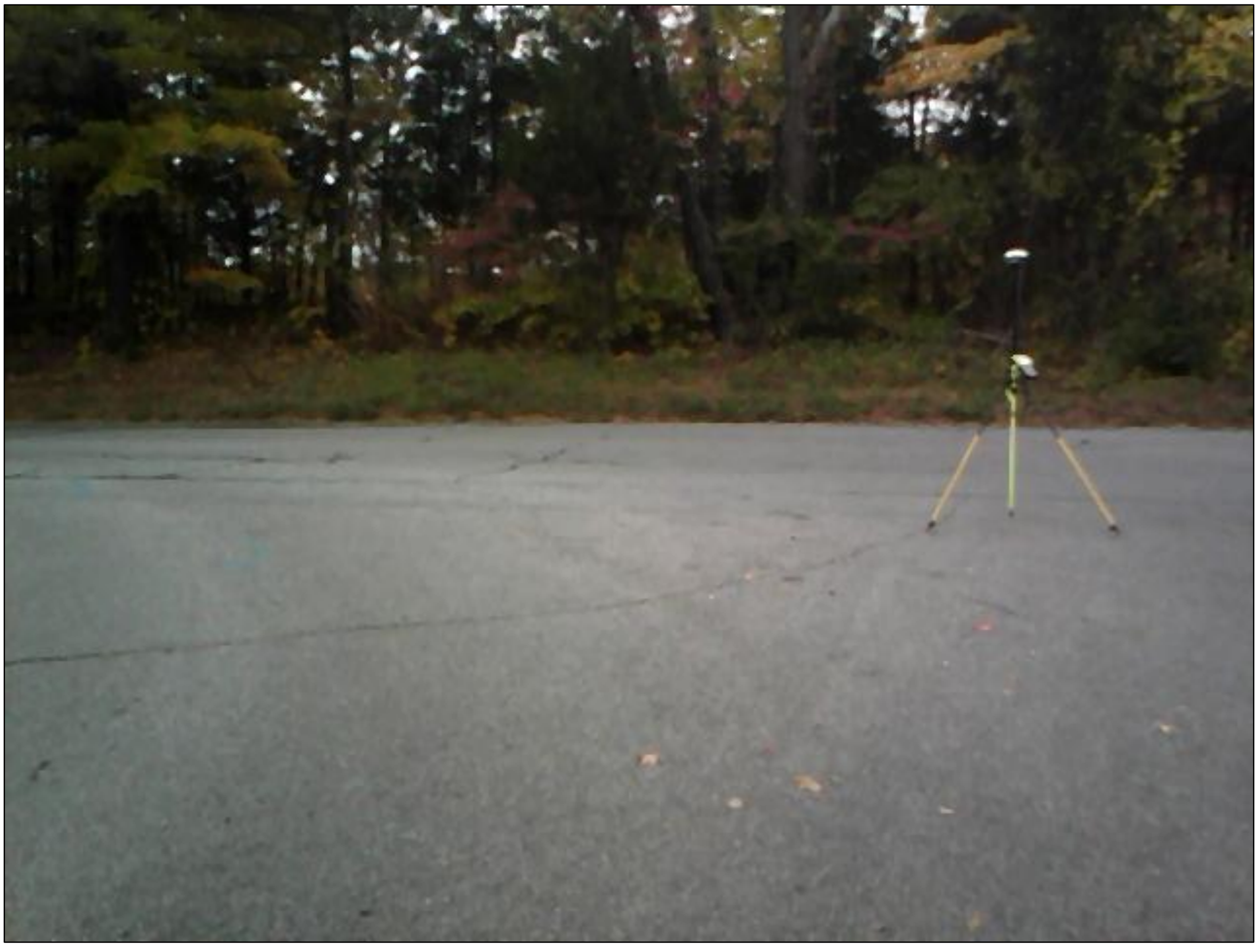

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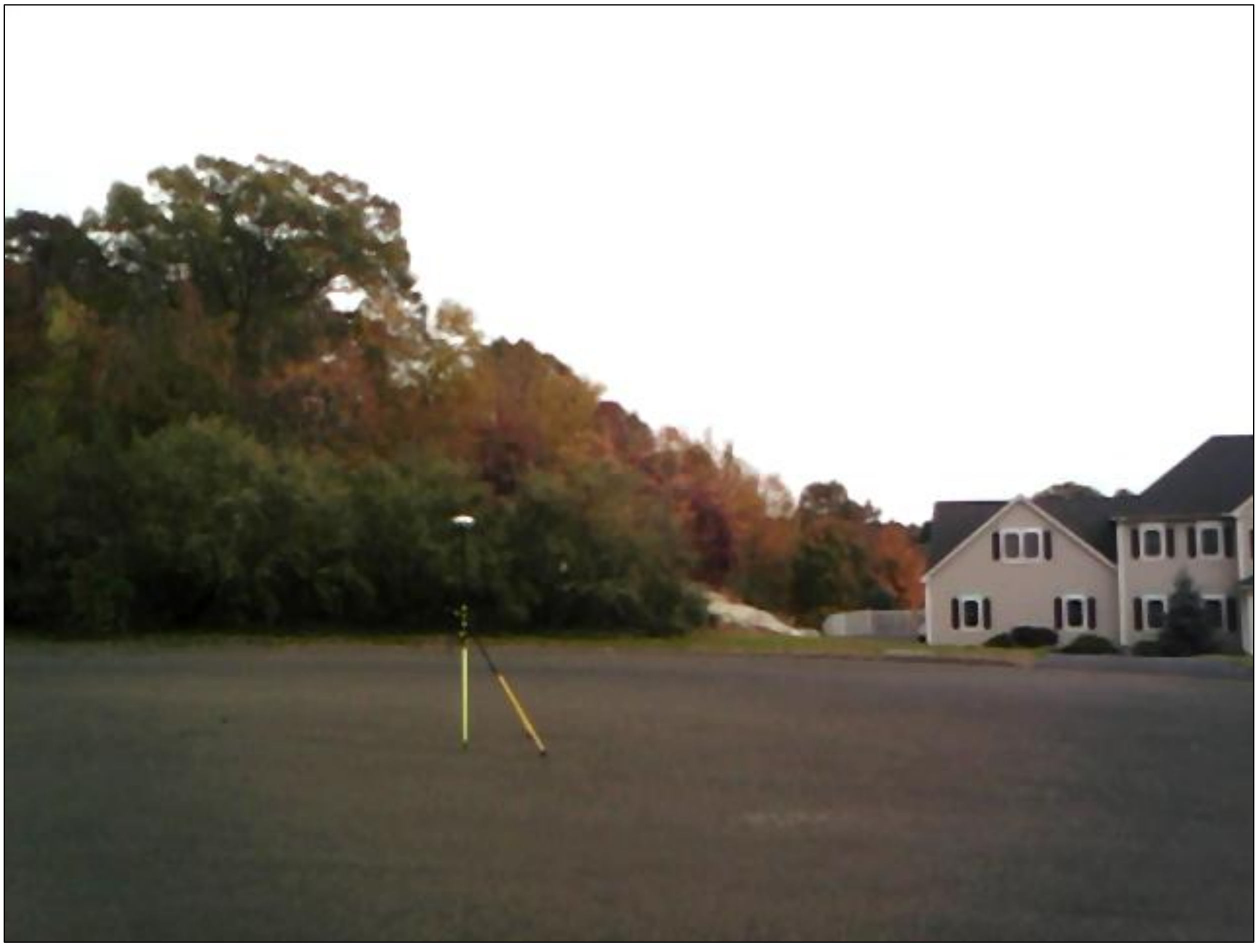

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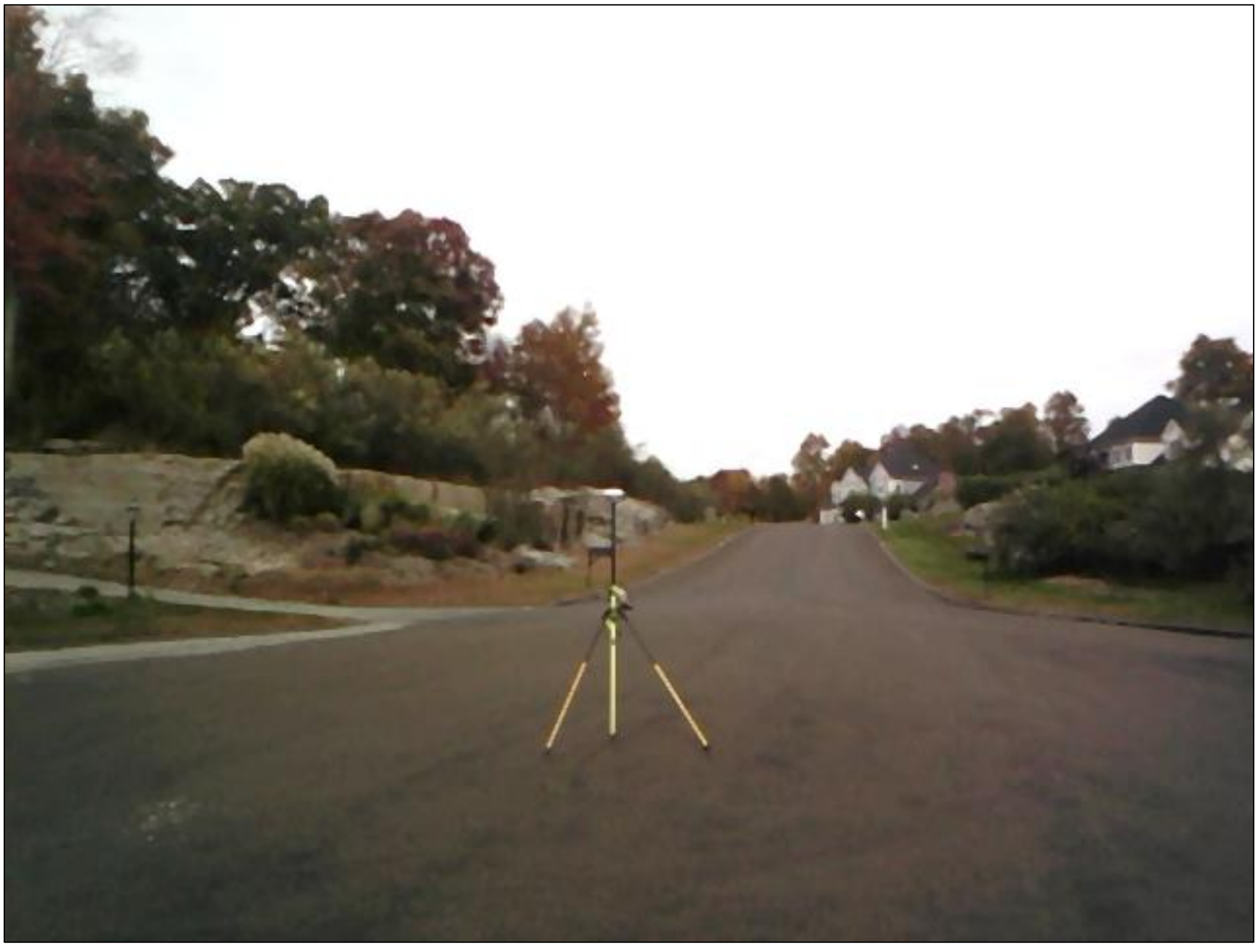

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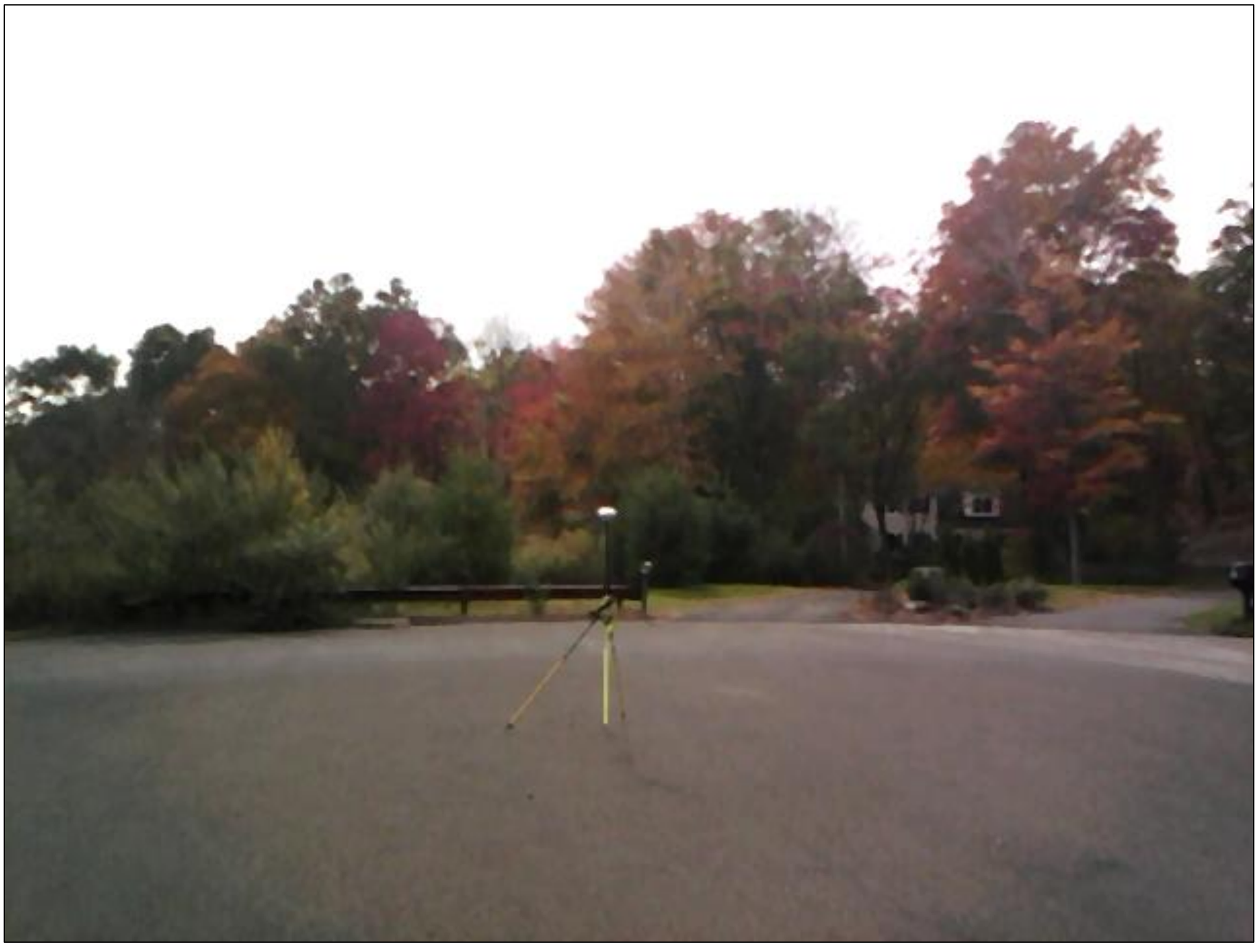

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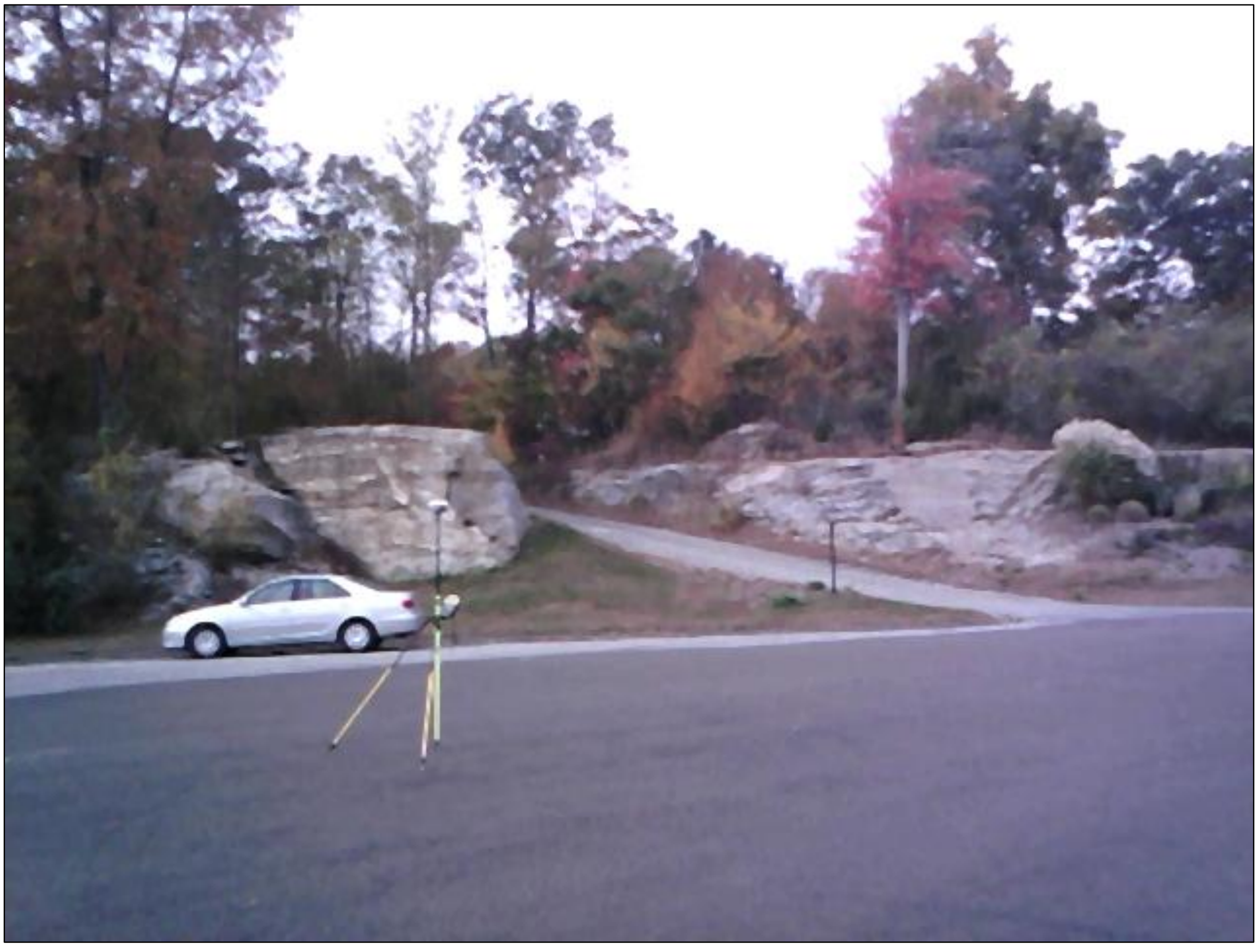

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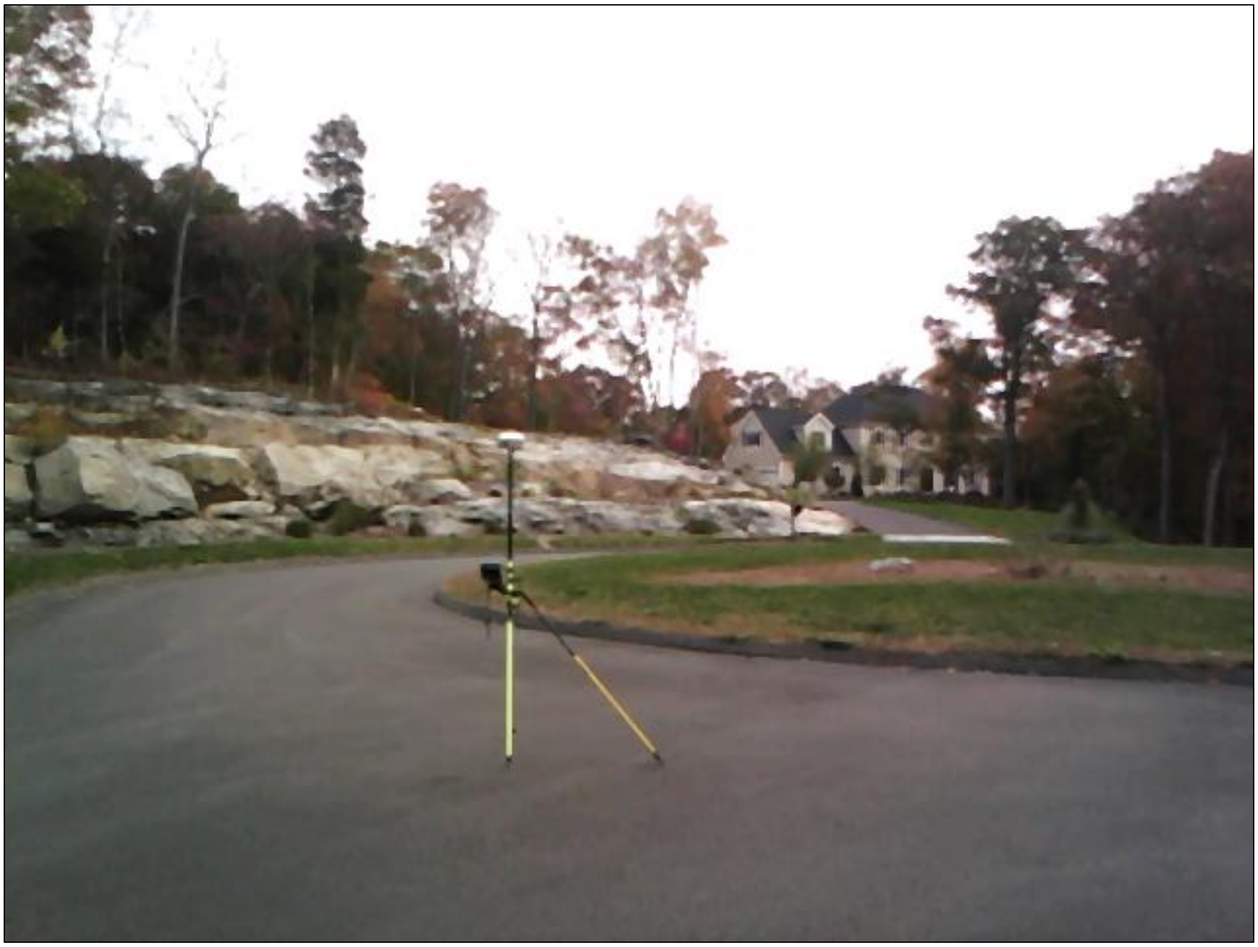

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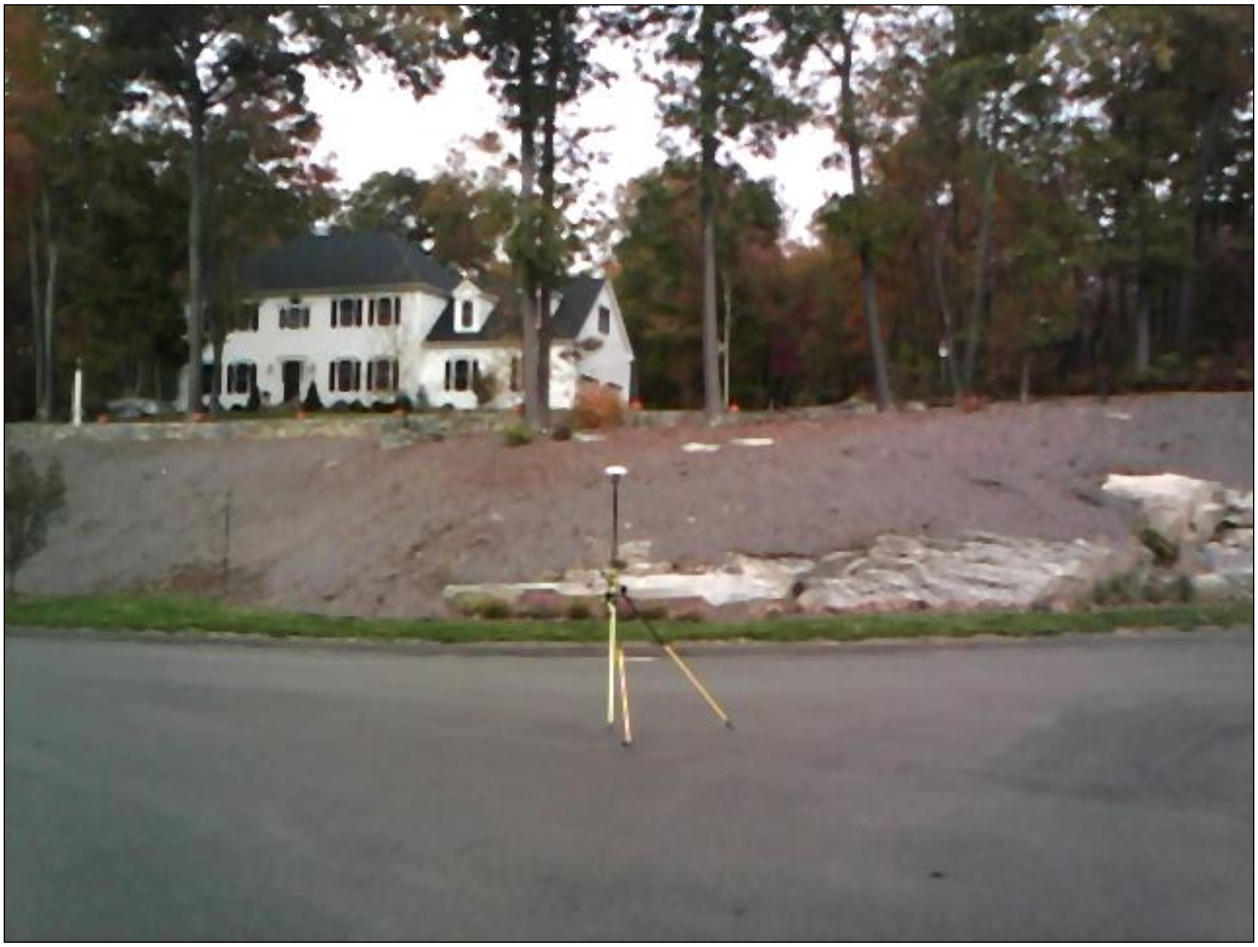

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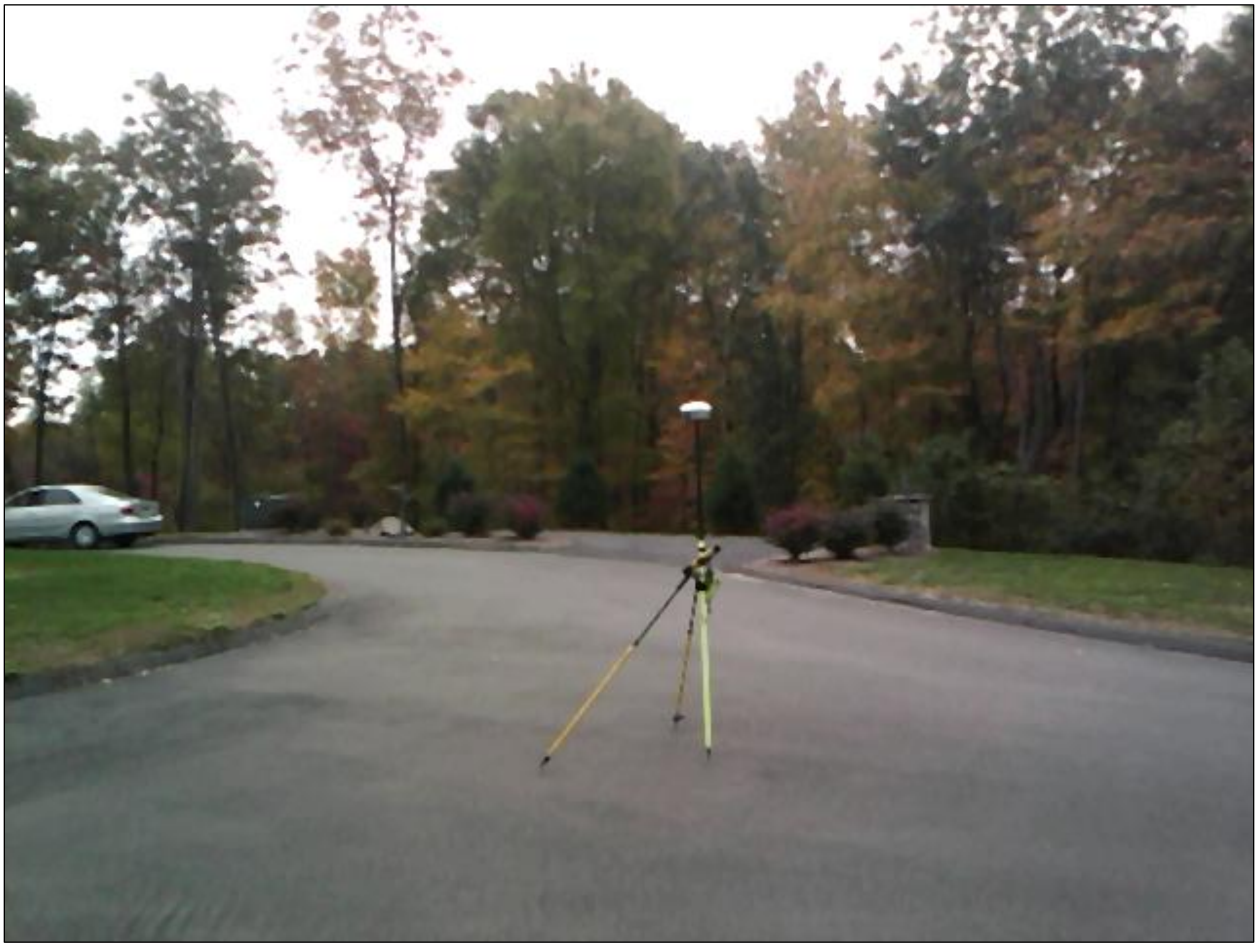

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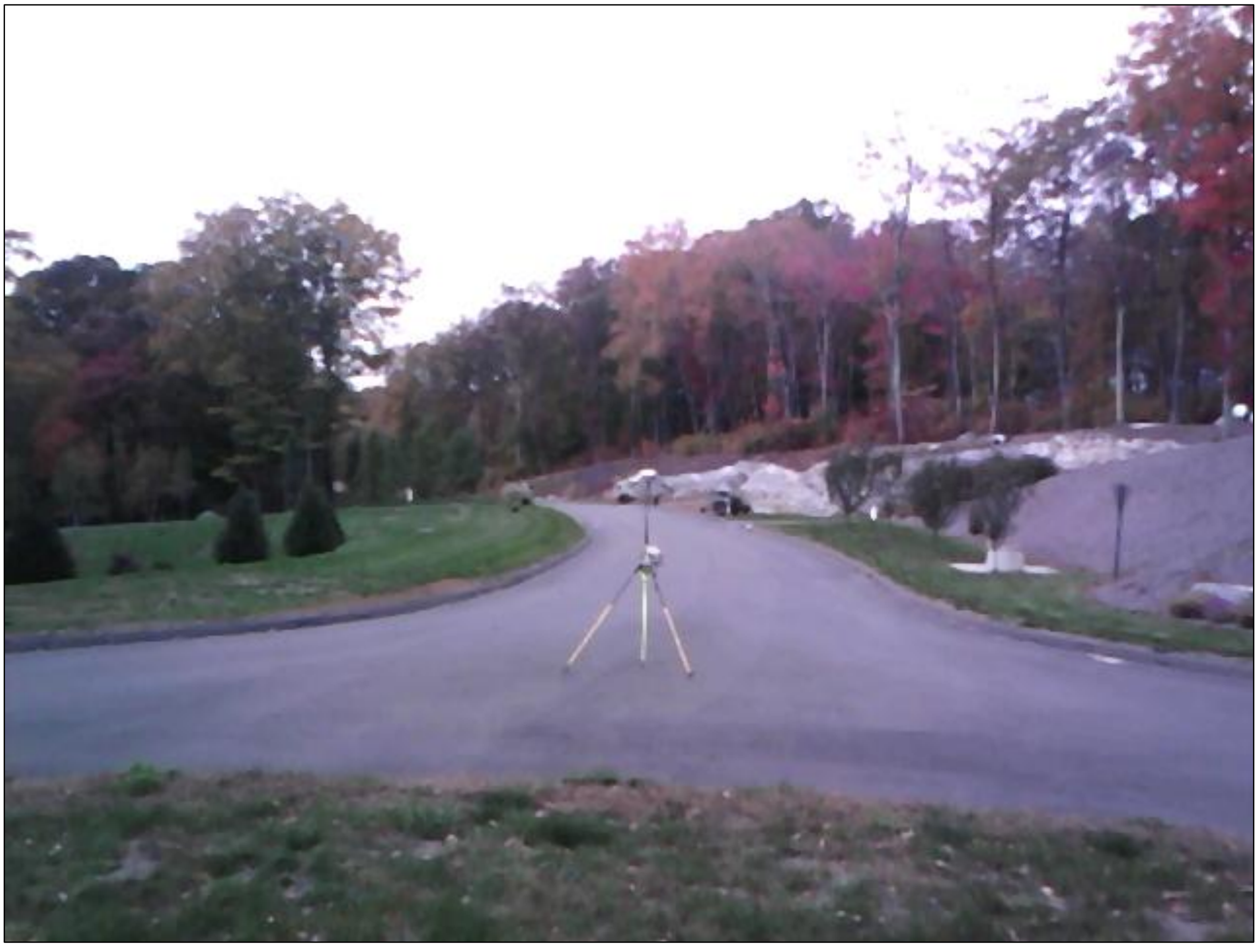

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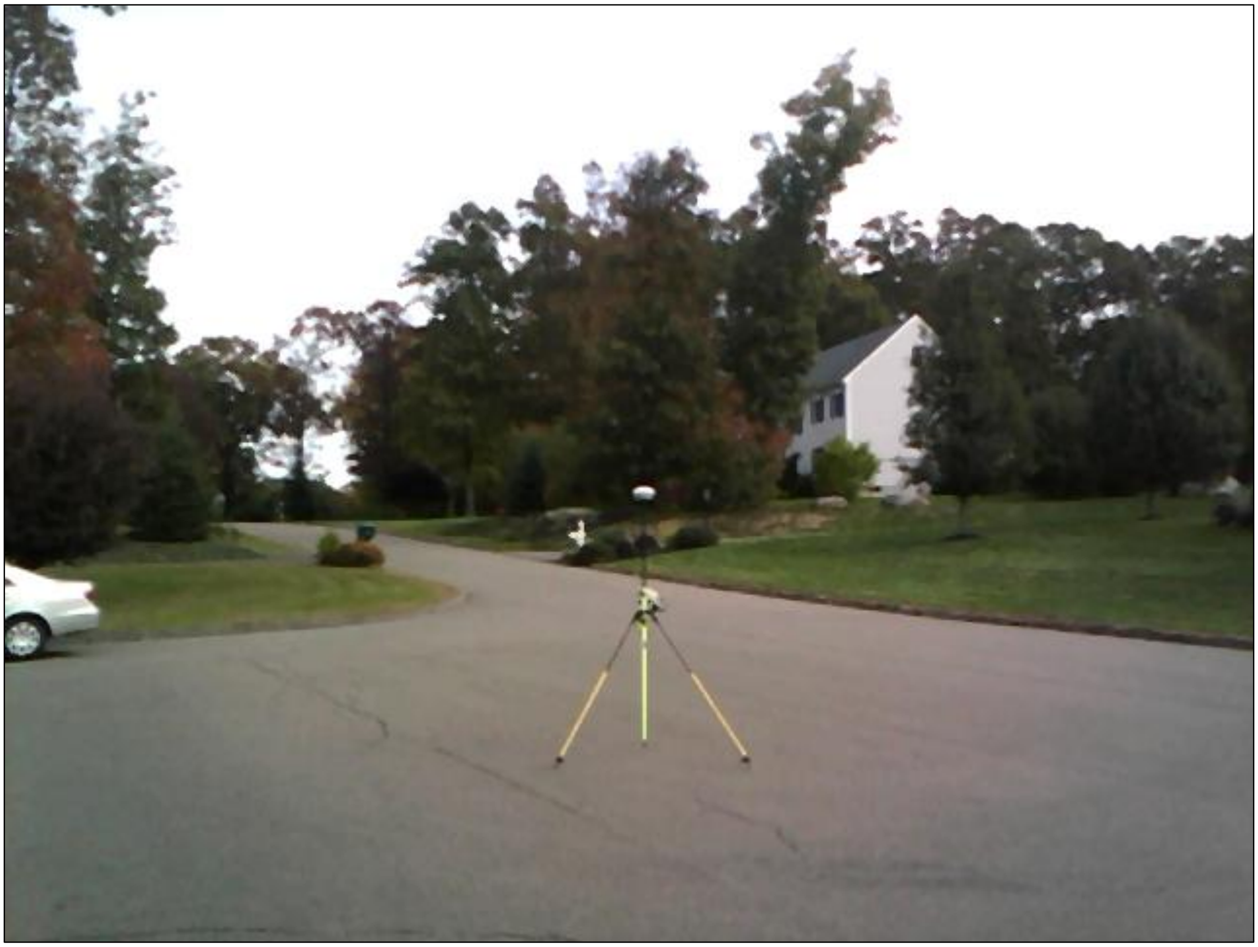

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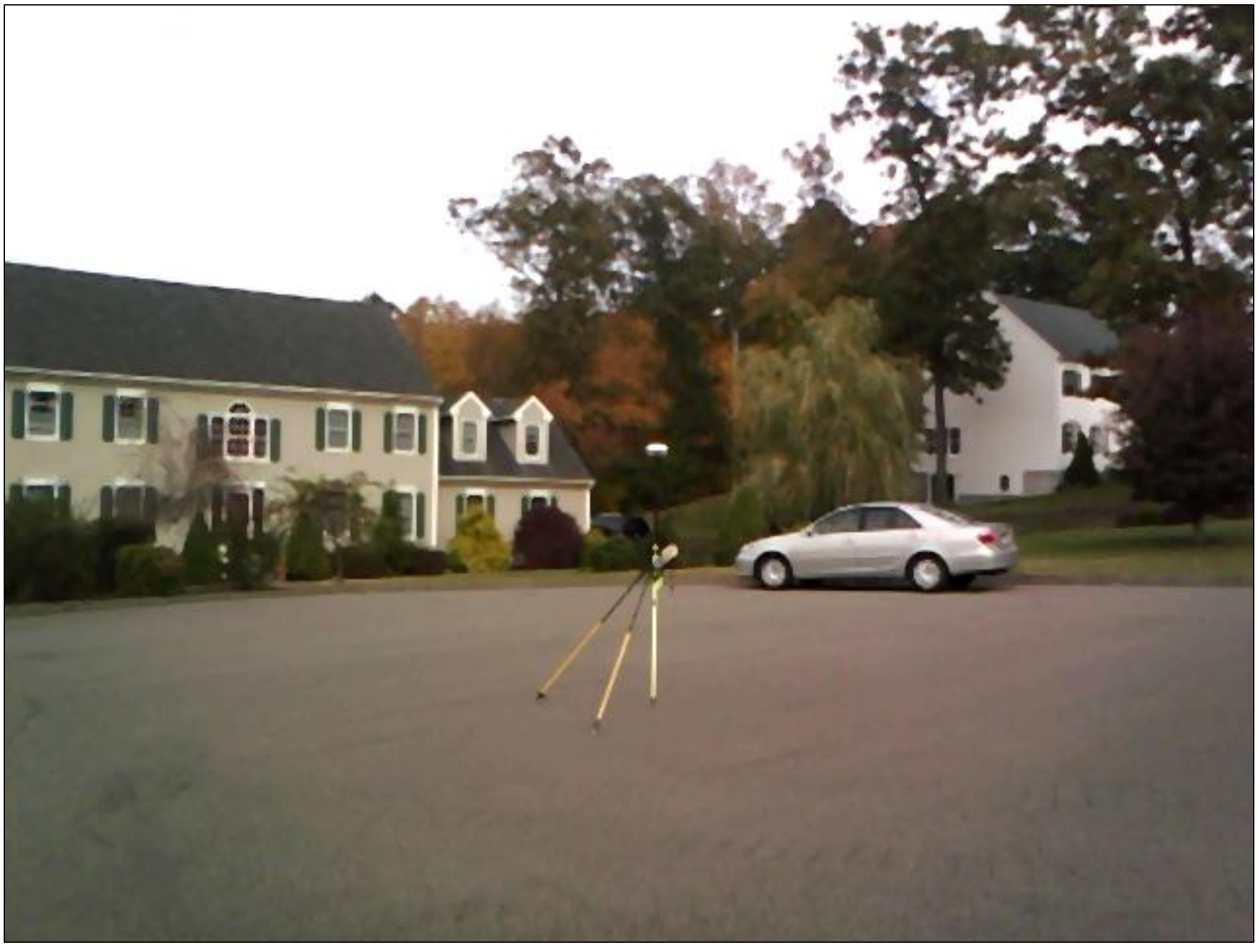

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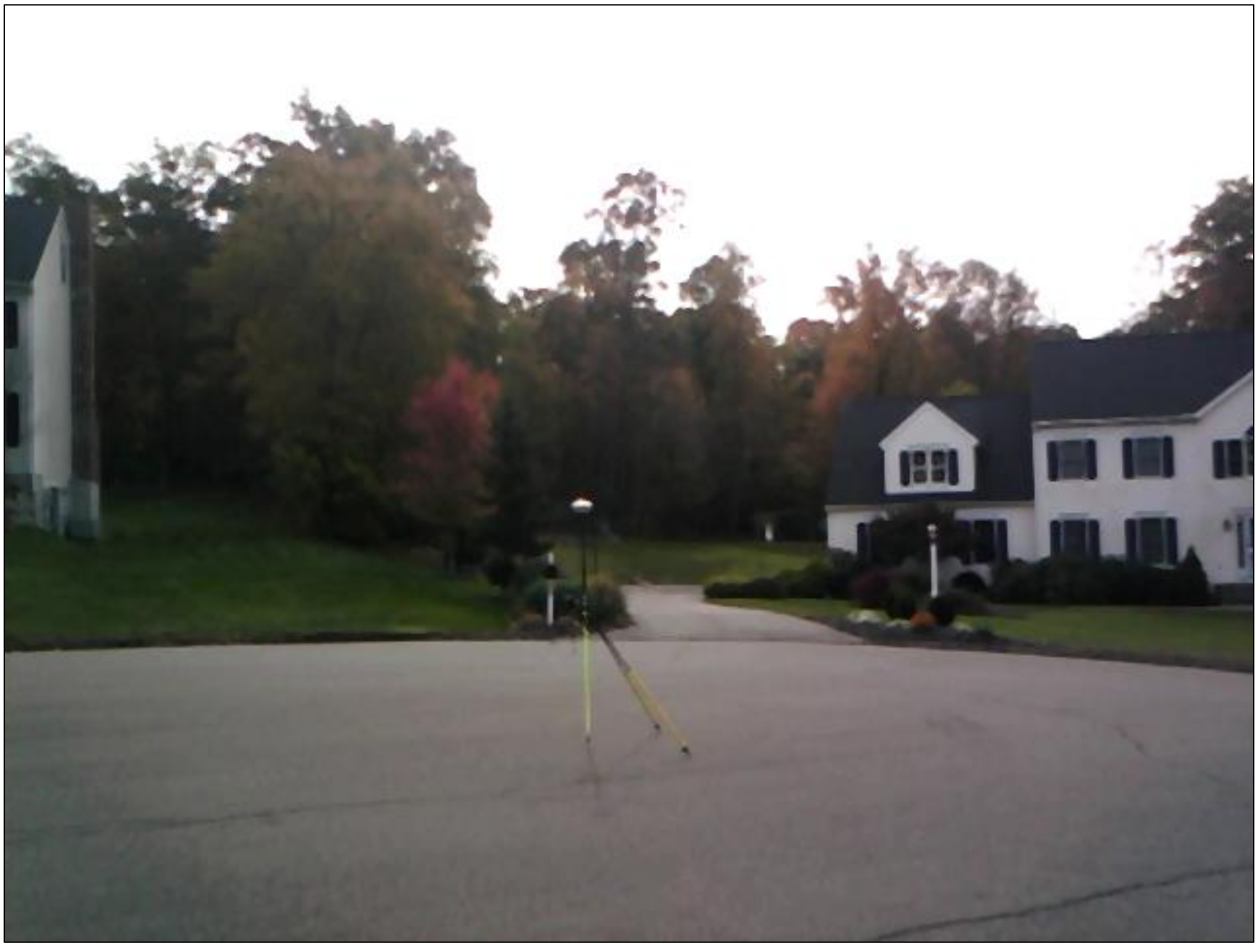

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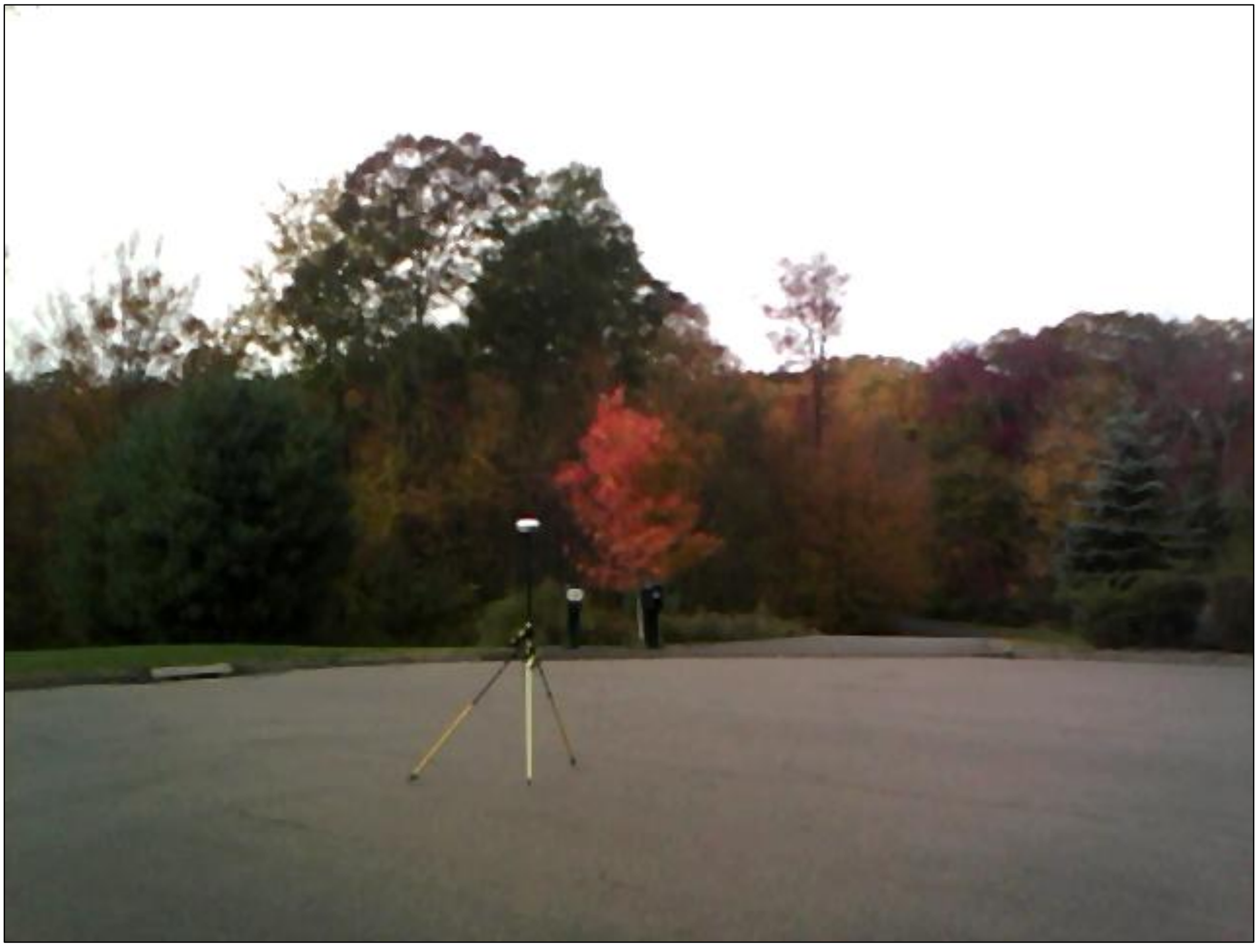

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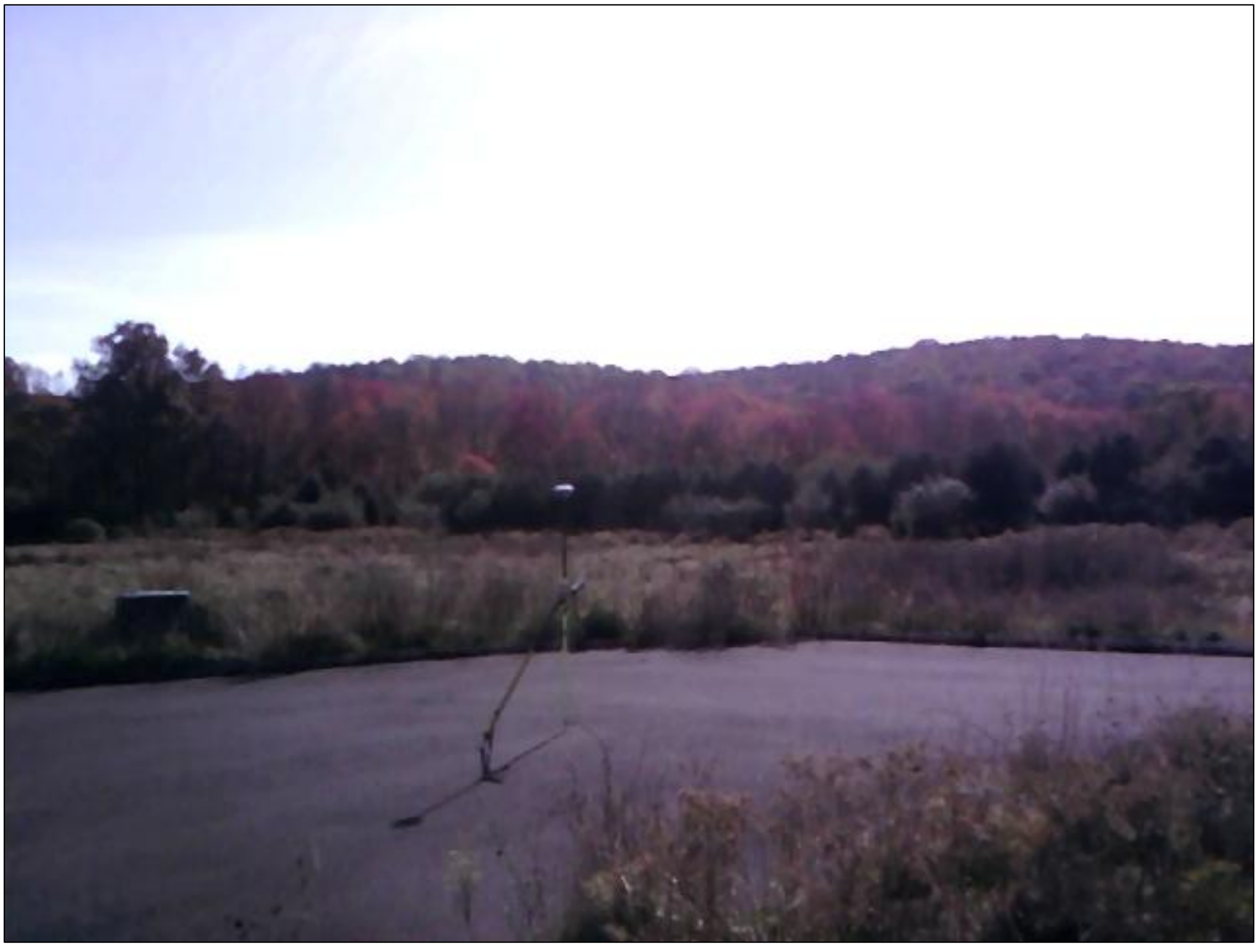

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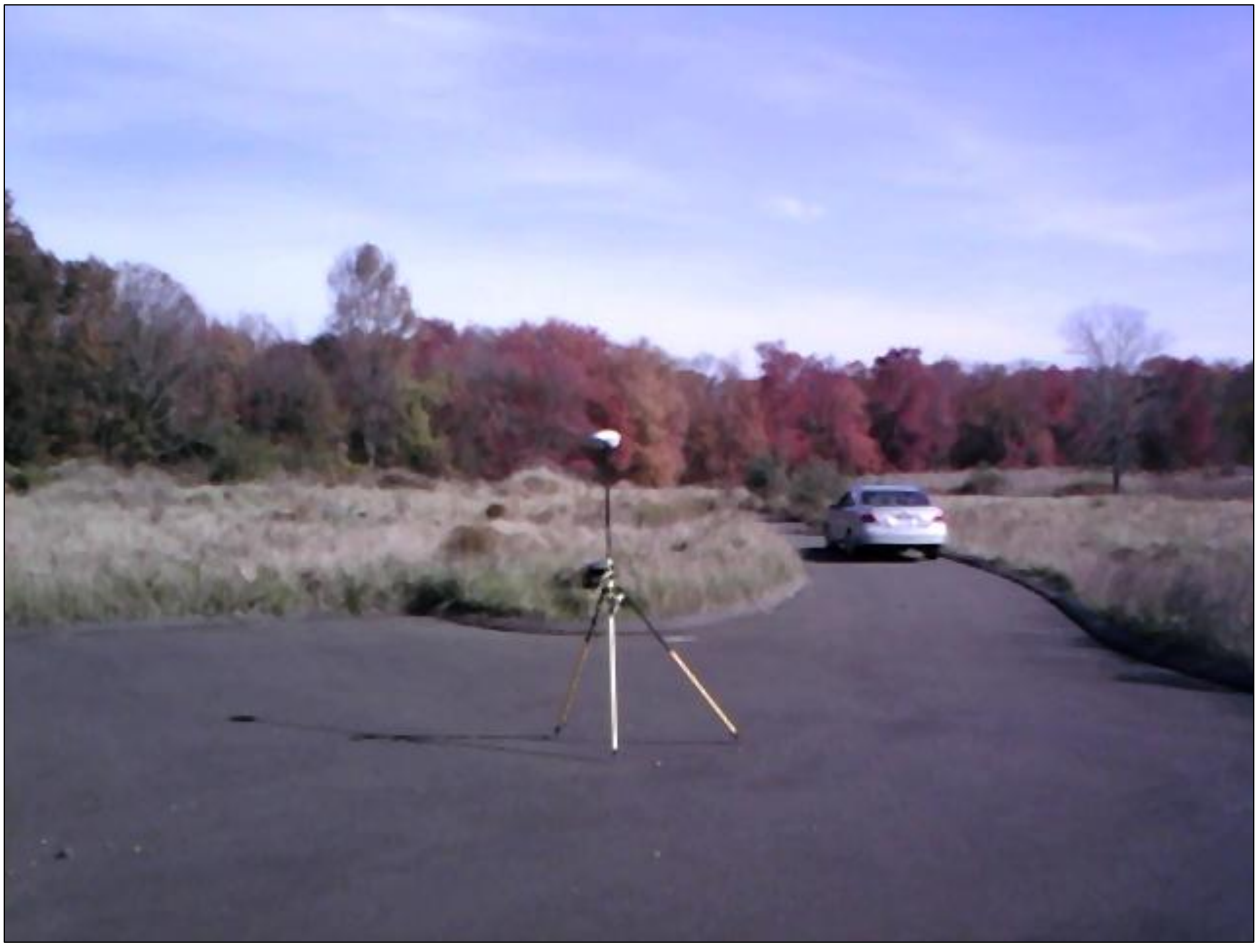

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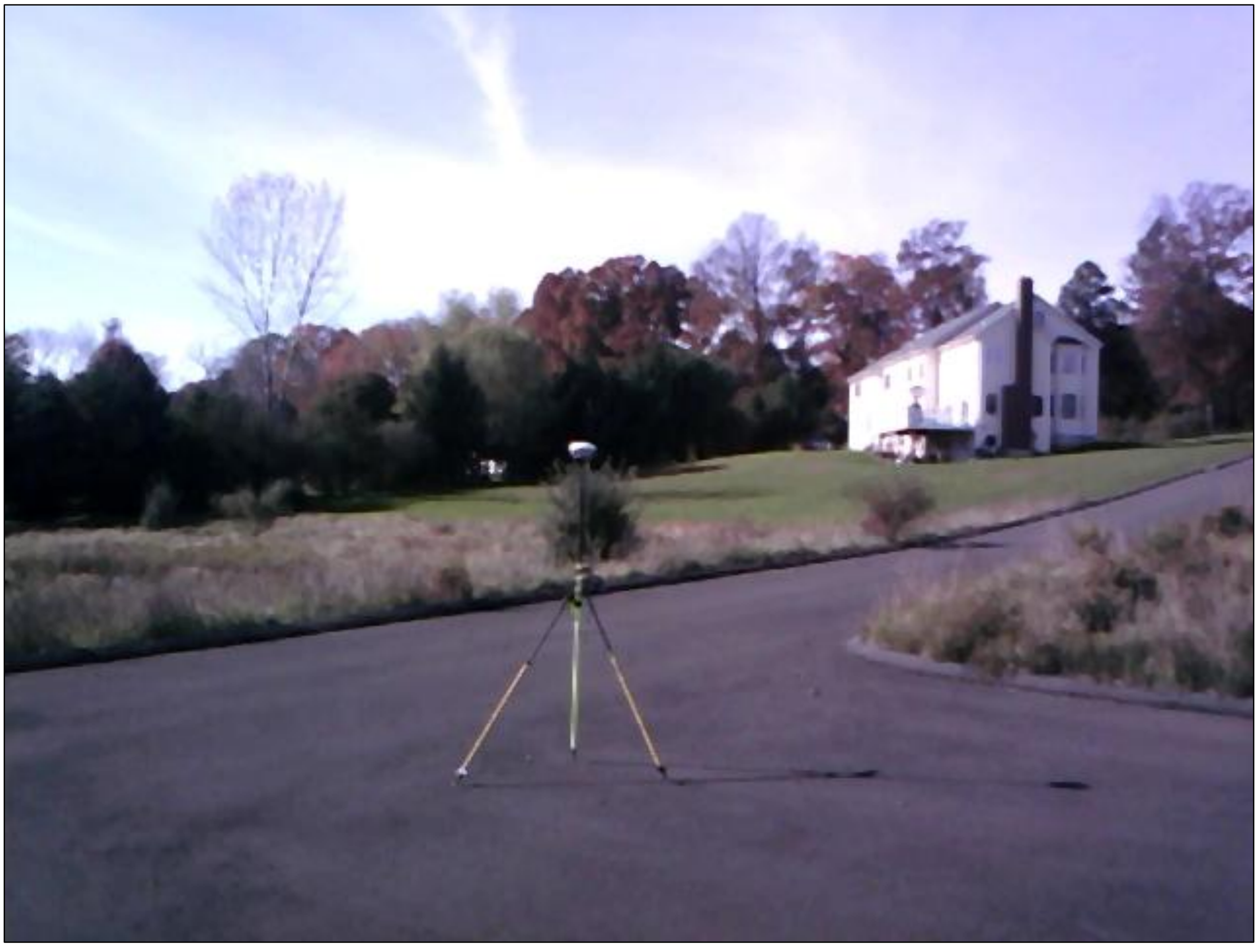

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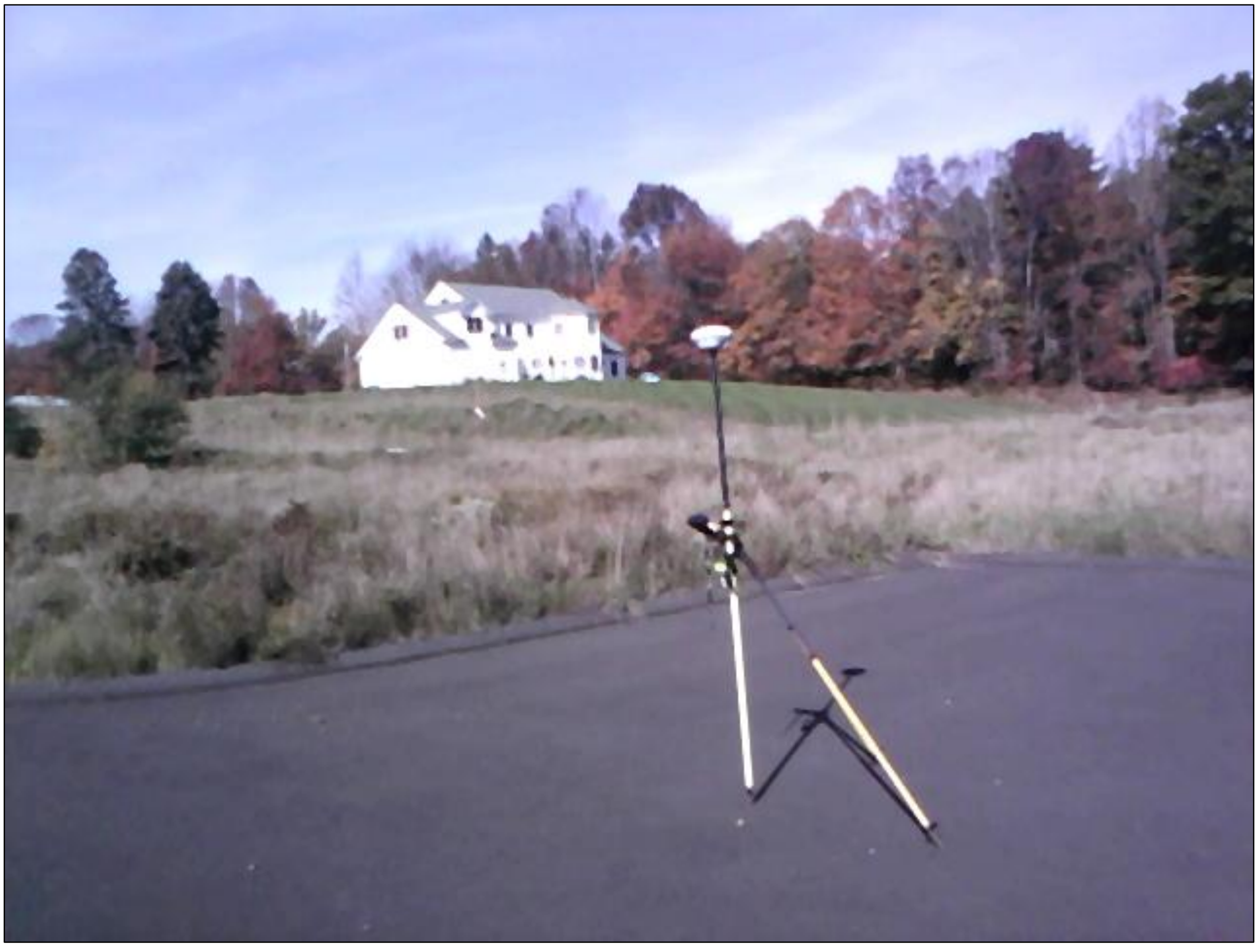
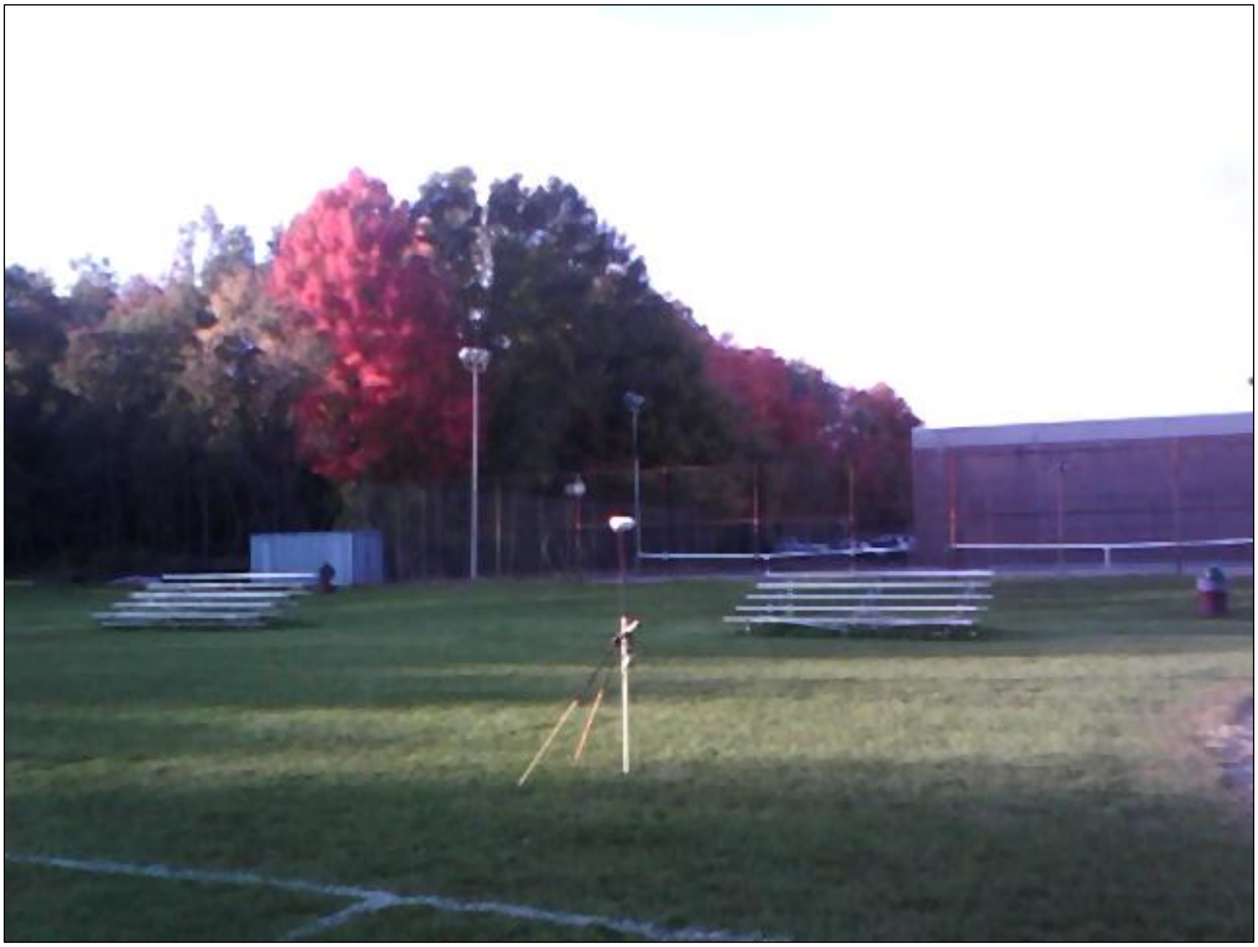


QNP111_E

QNP111_N



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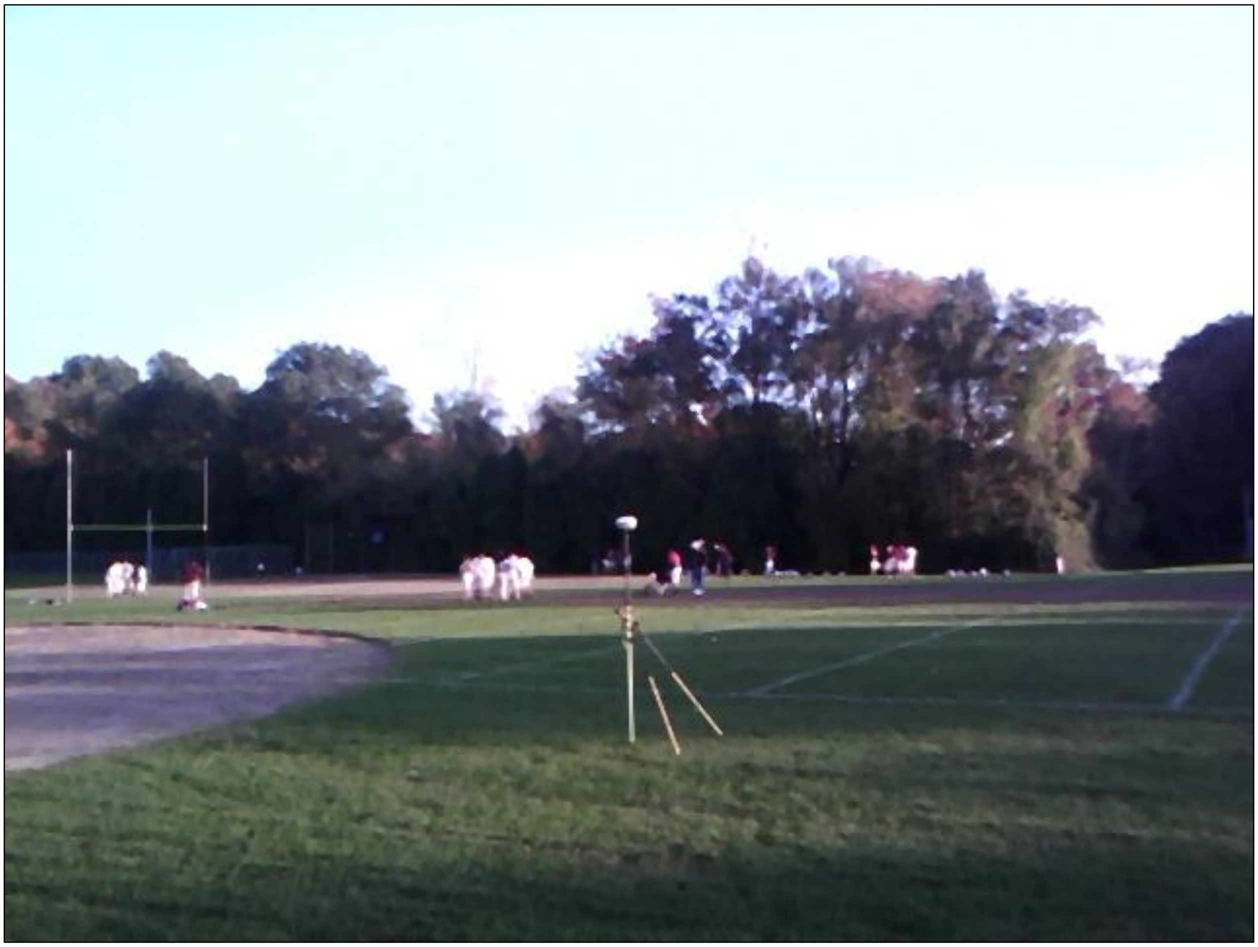
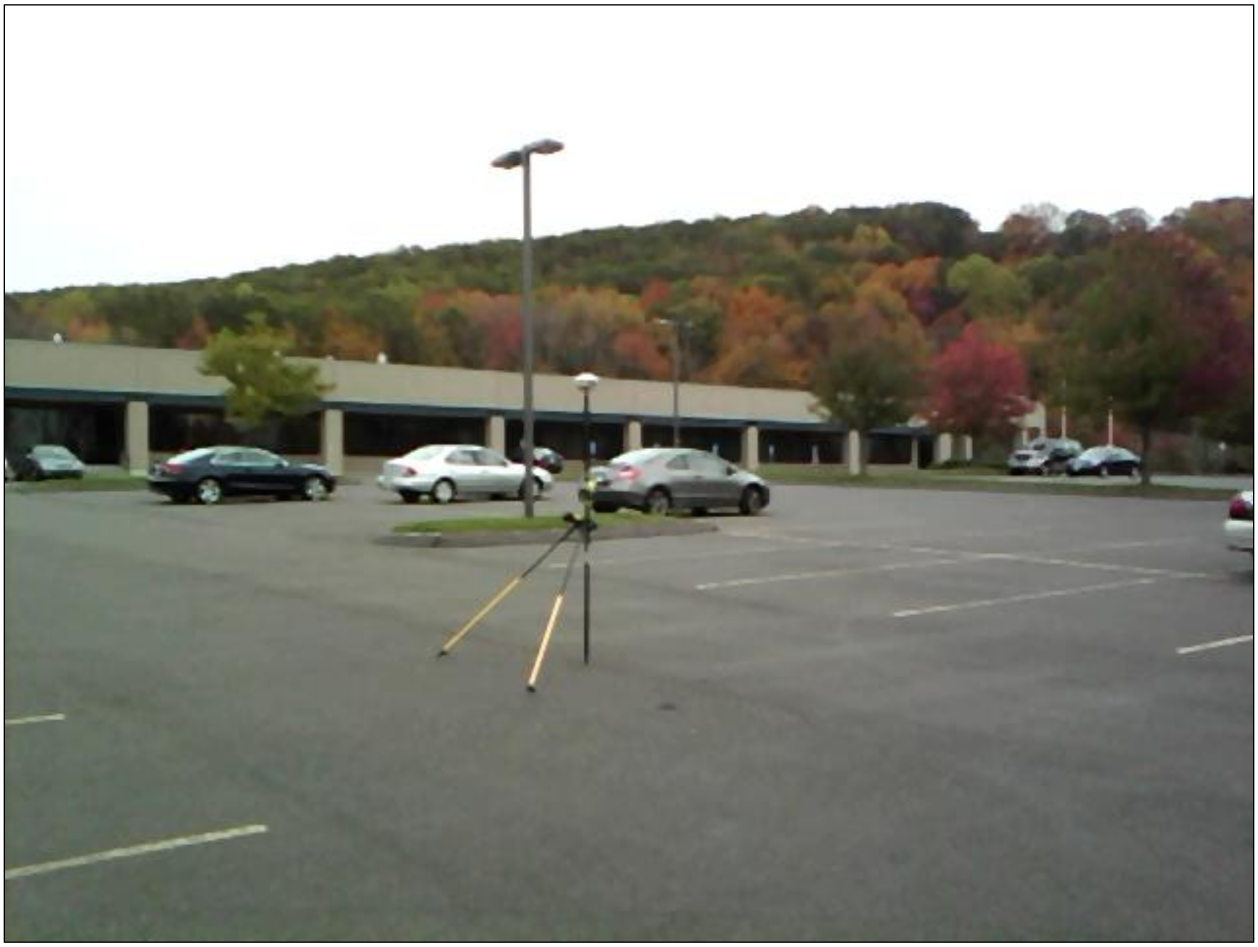


QNP111_W

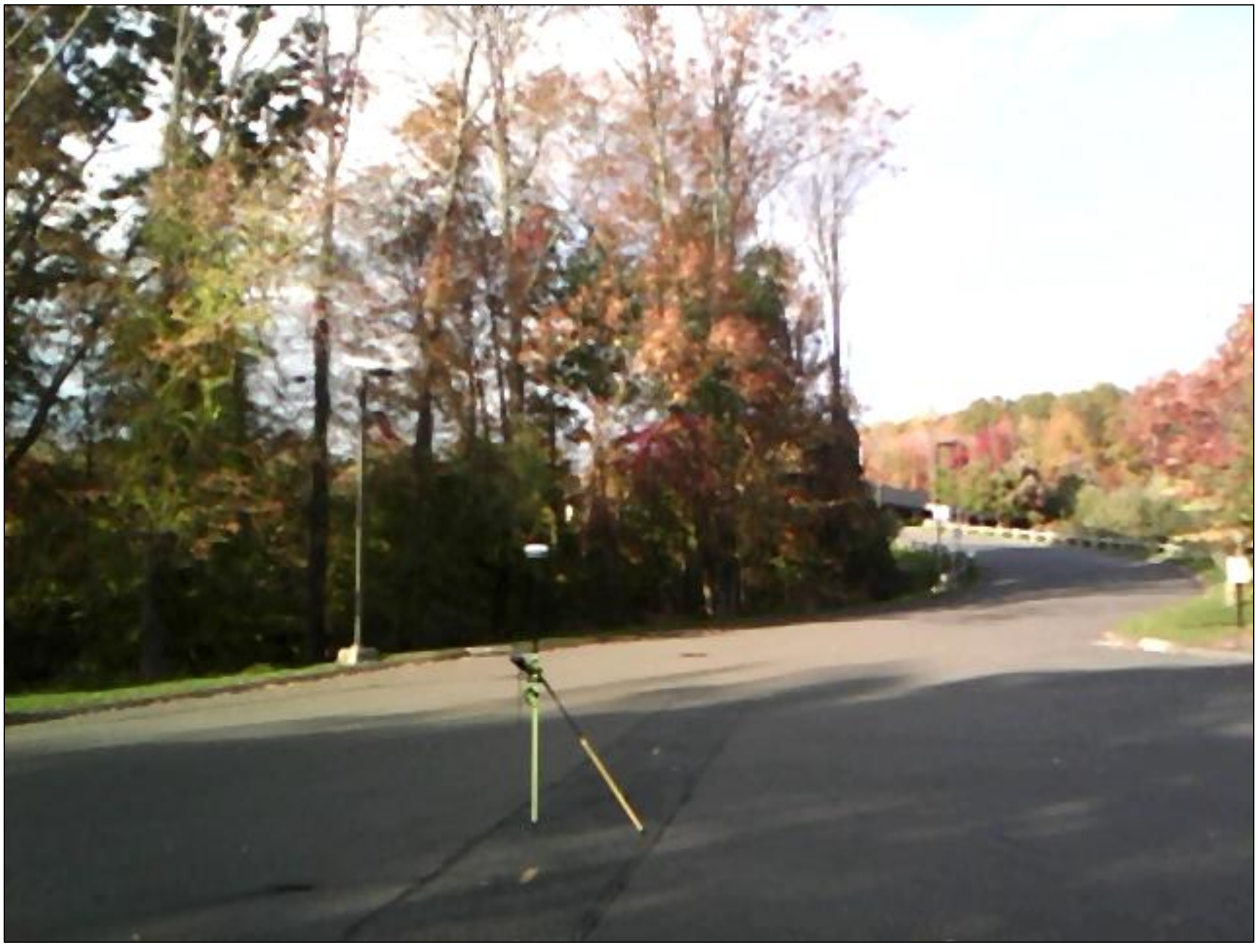
QNP112_E (2)



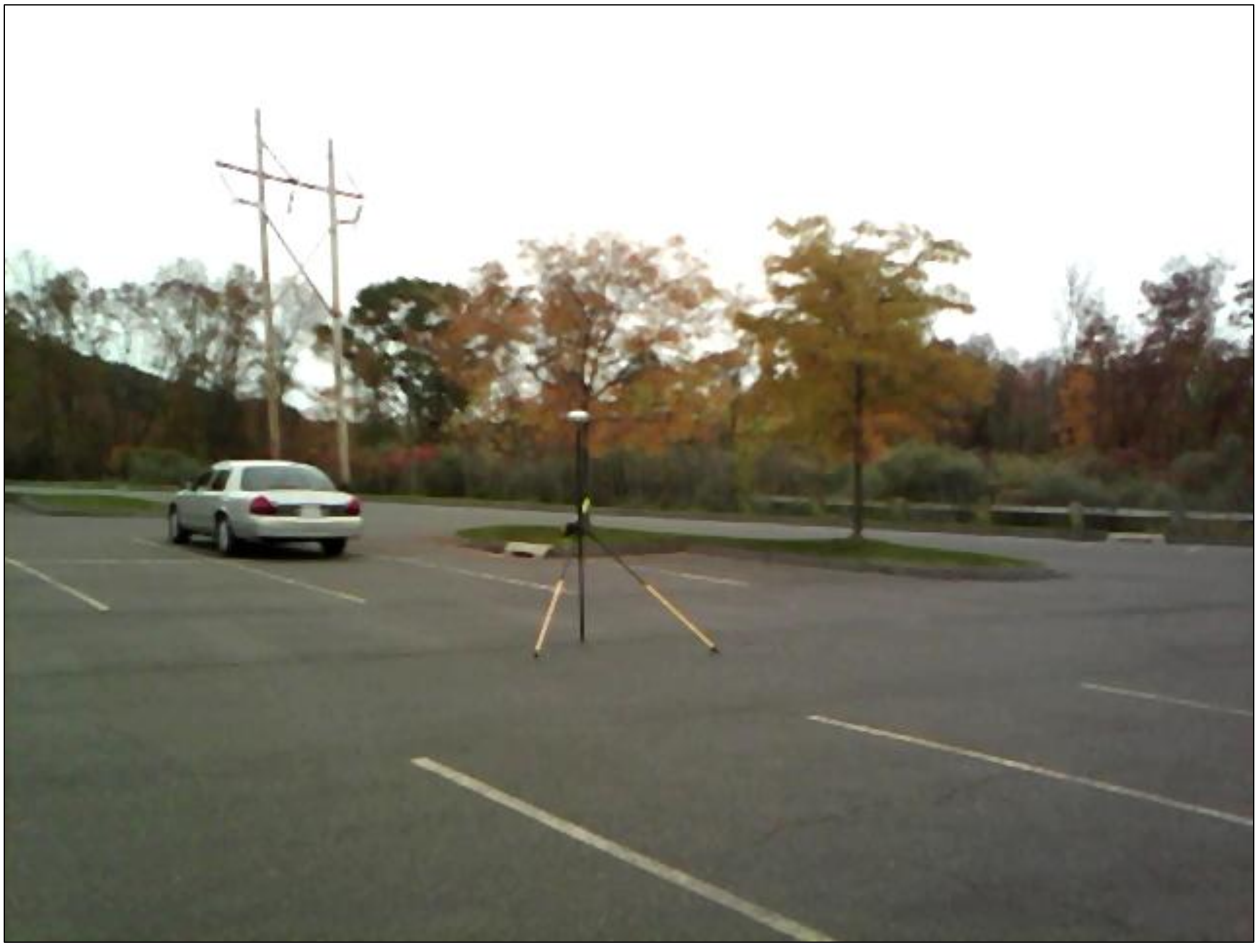
QNP112_E

QNP112_N (2)

QNP112_N

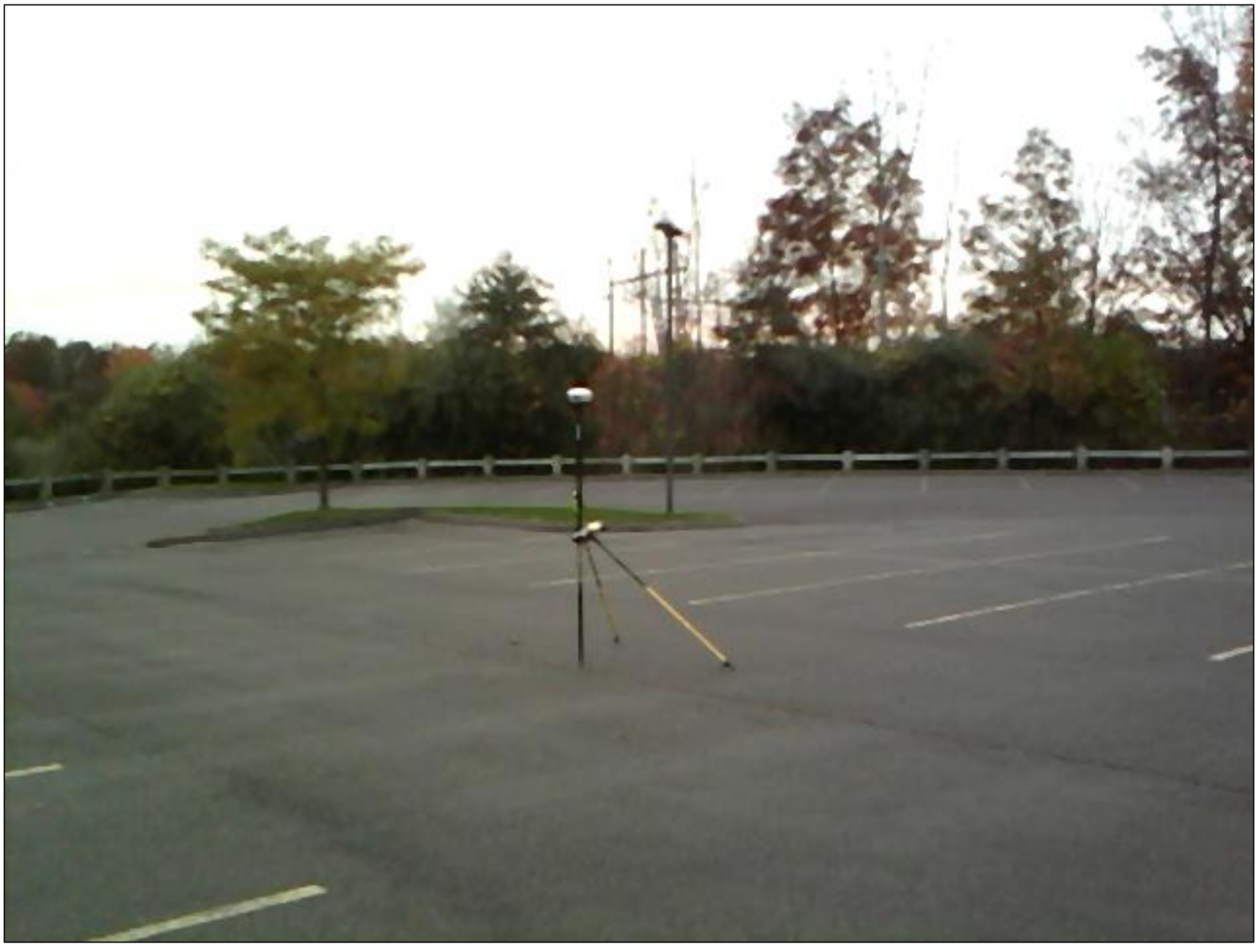


QNP112_S (2)



QNP112_S

QNP112_W (2)



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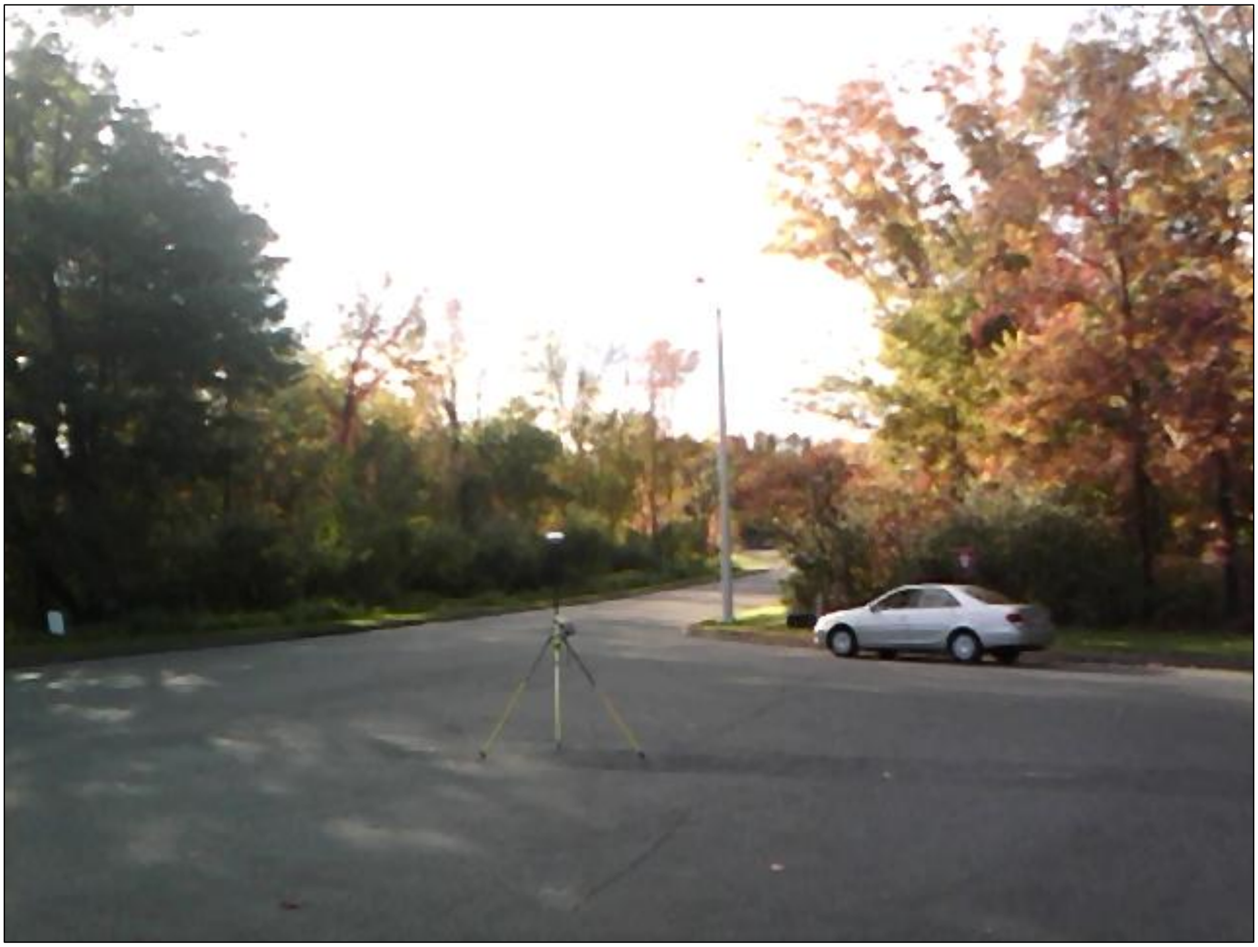

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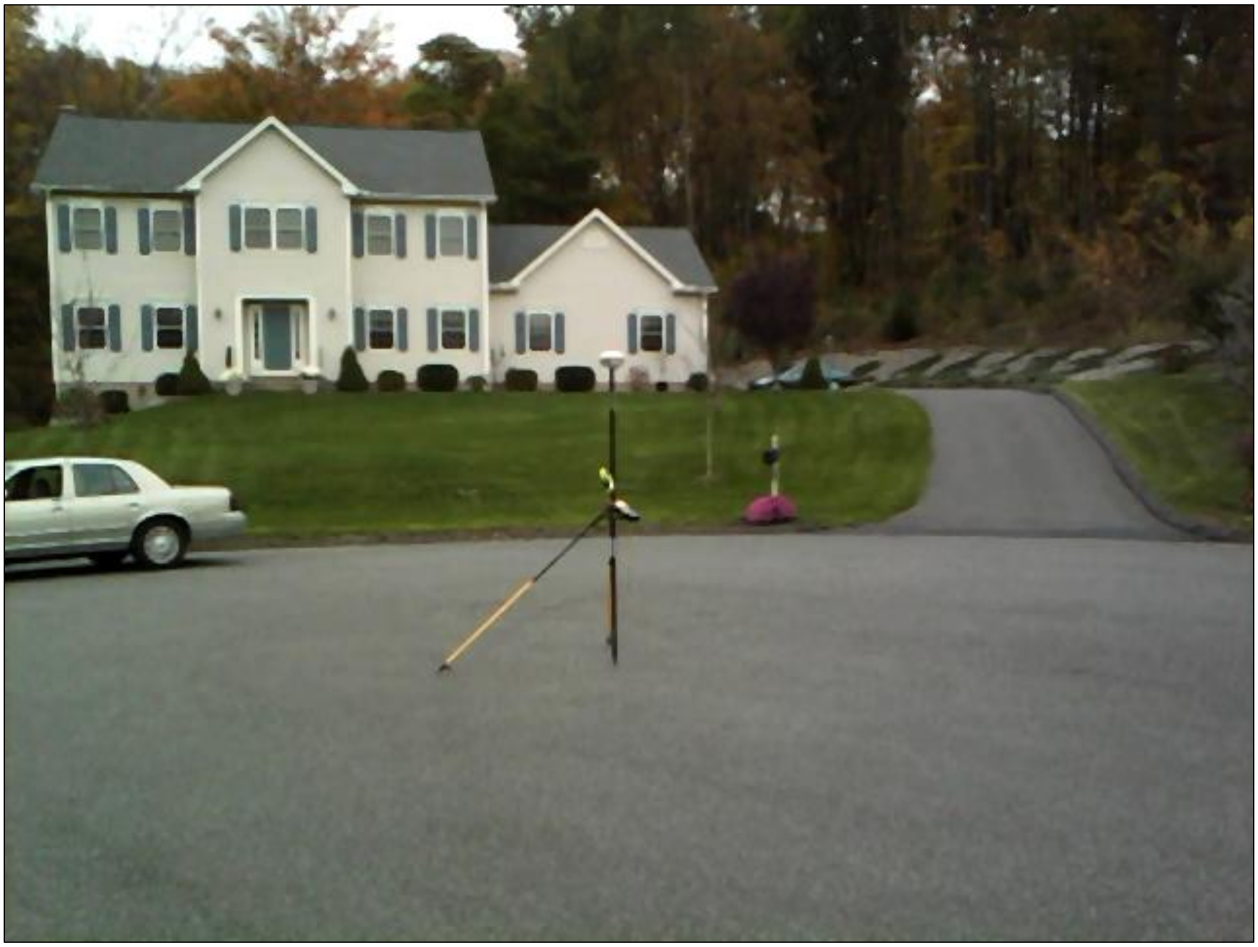

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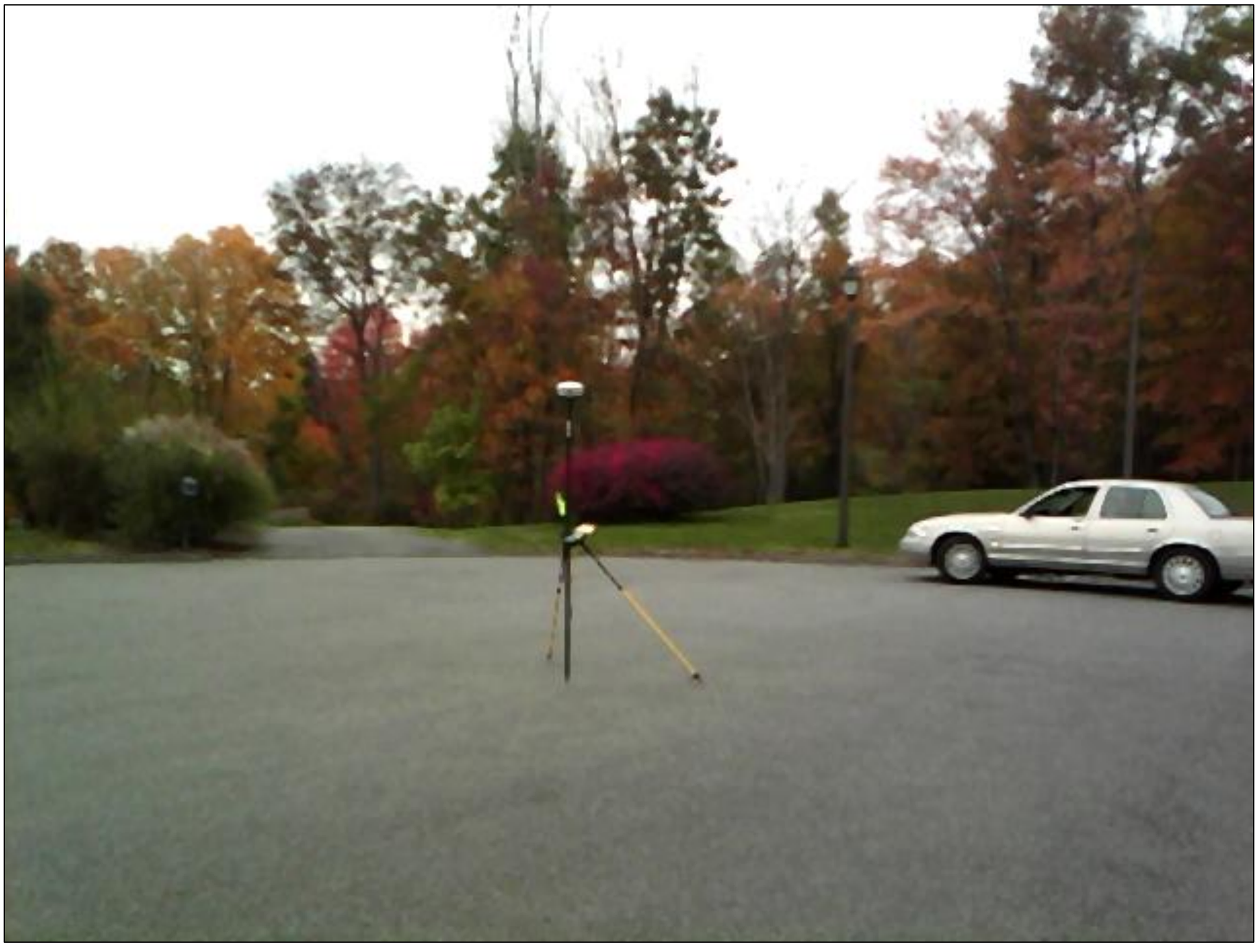

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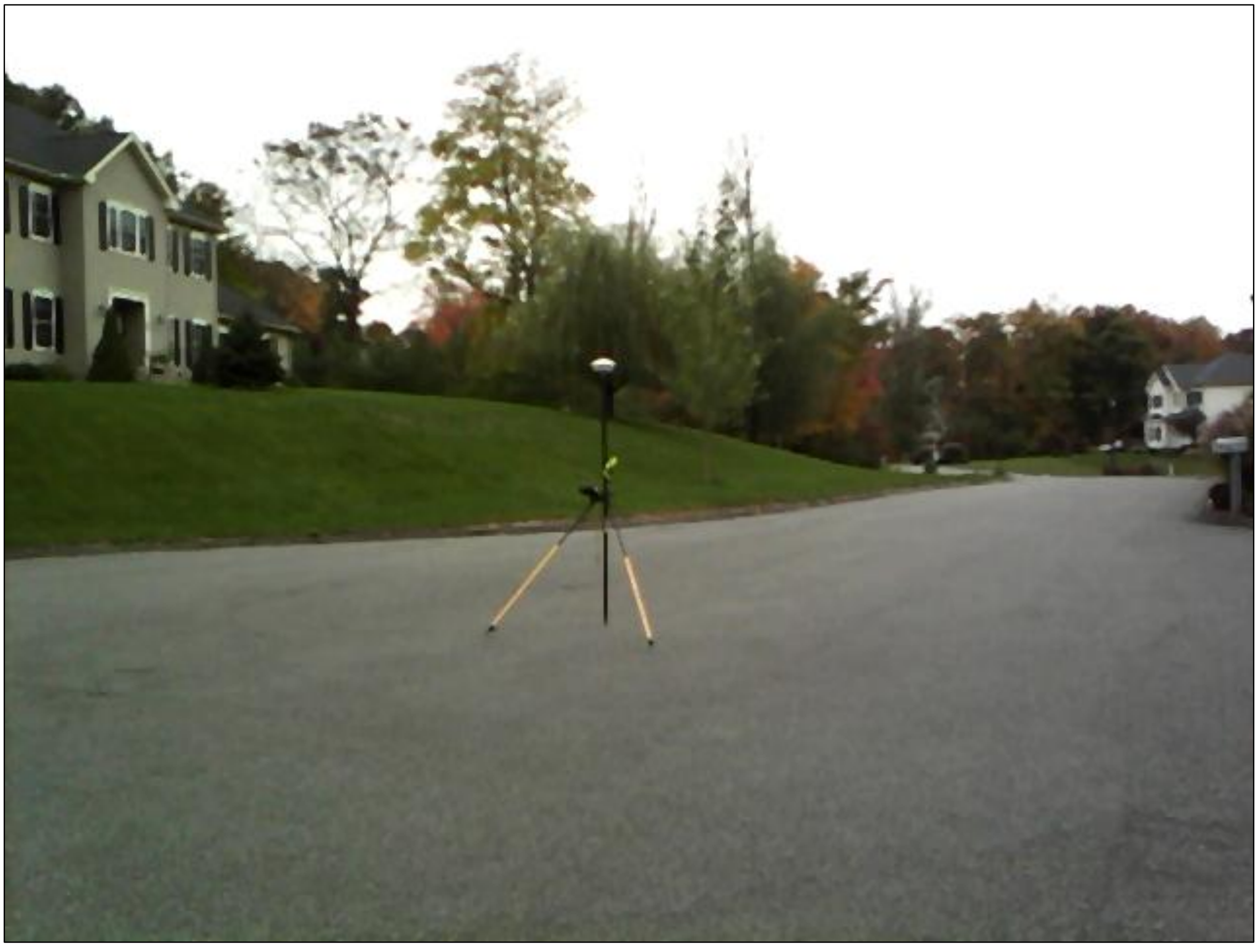

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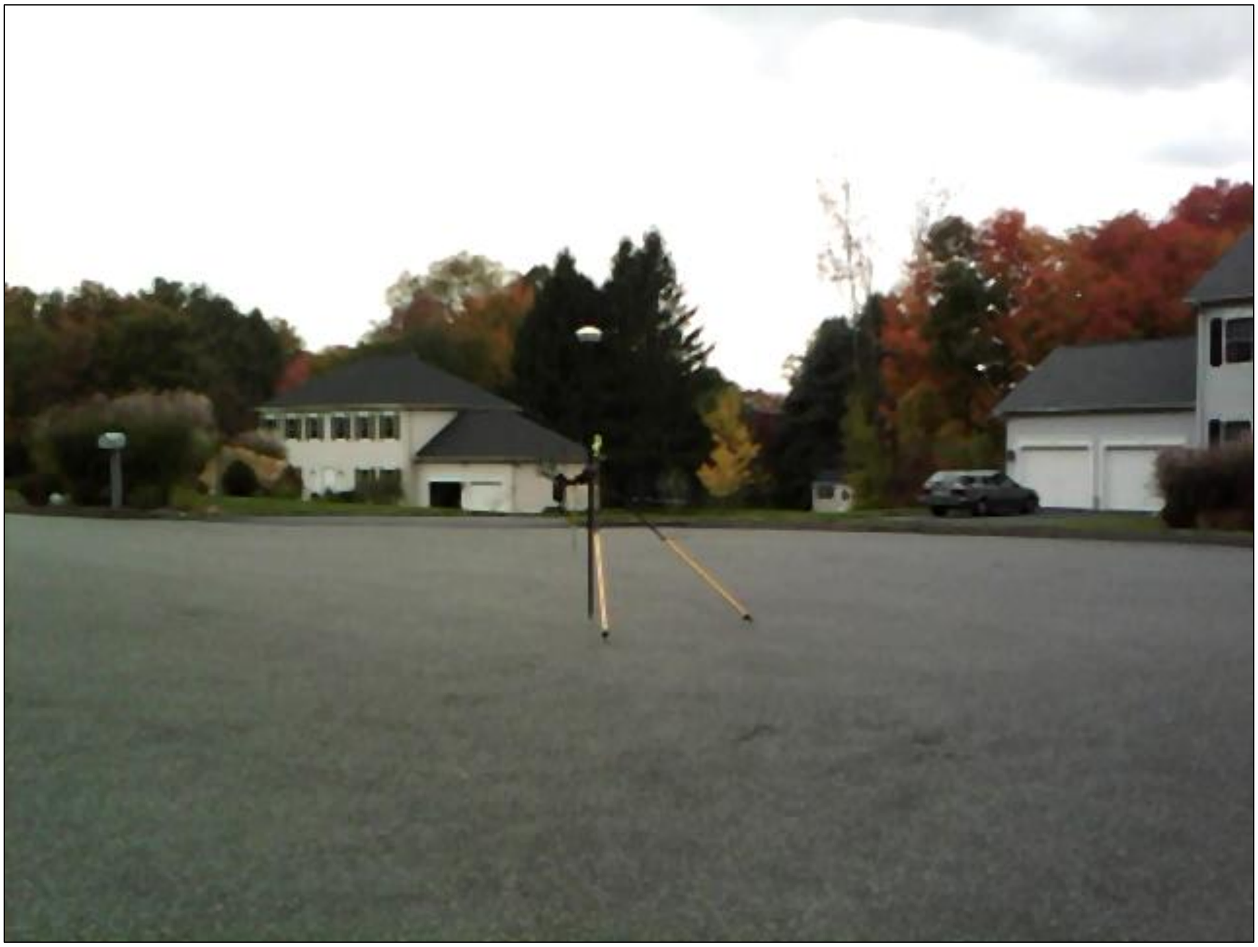

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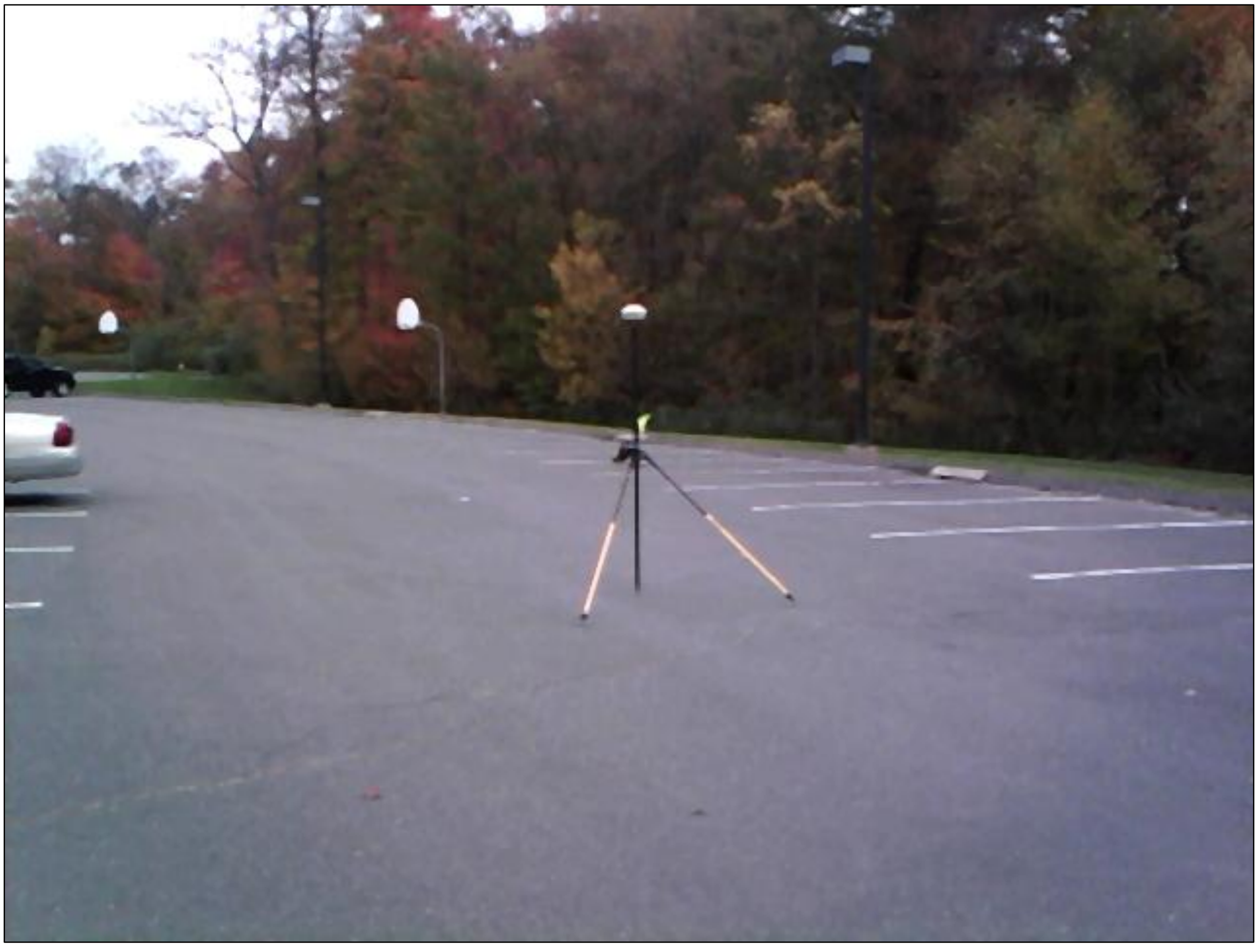

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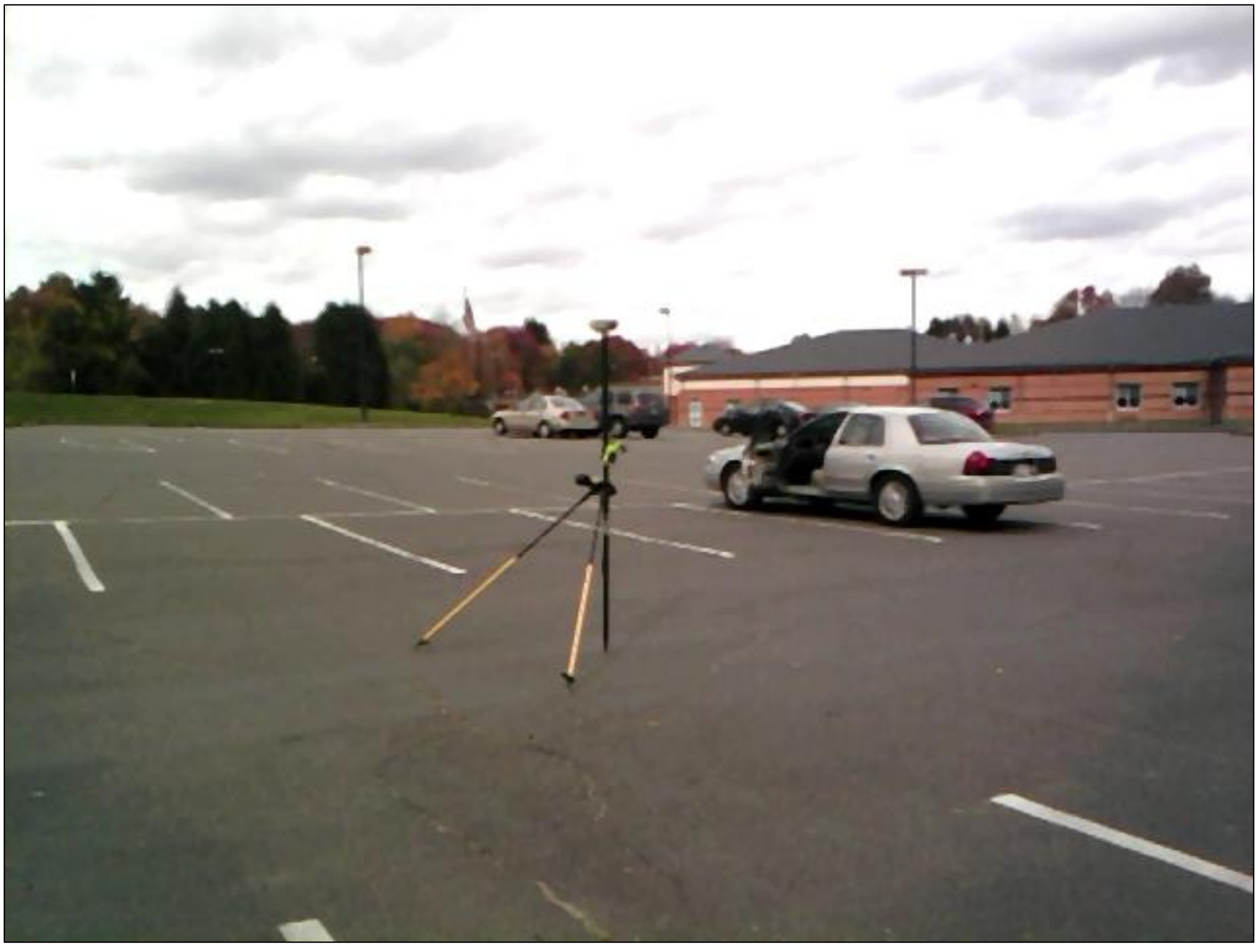

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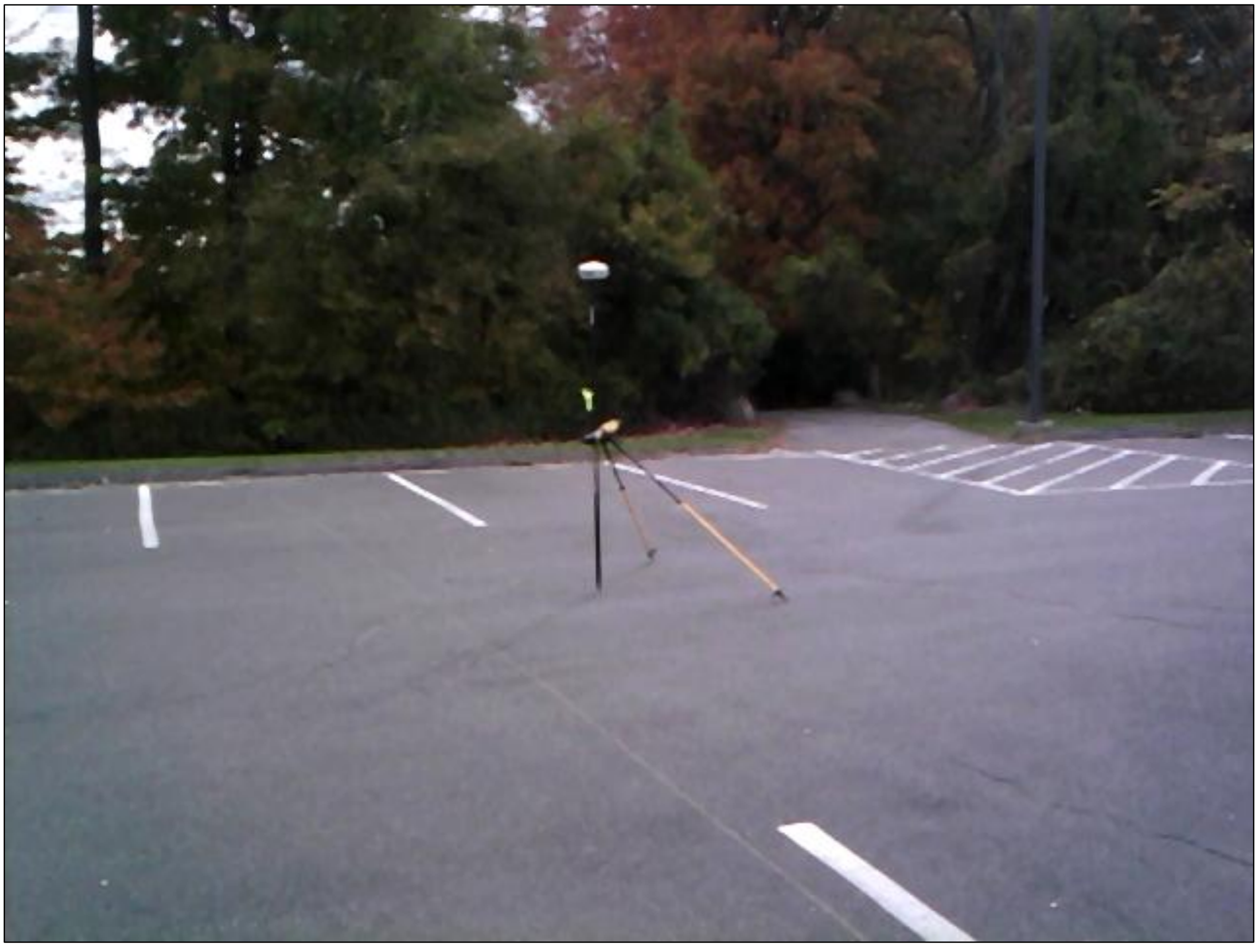

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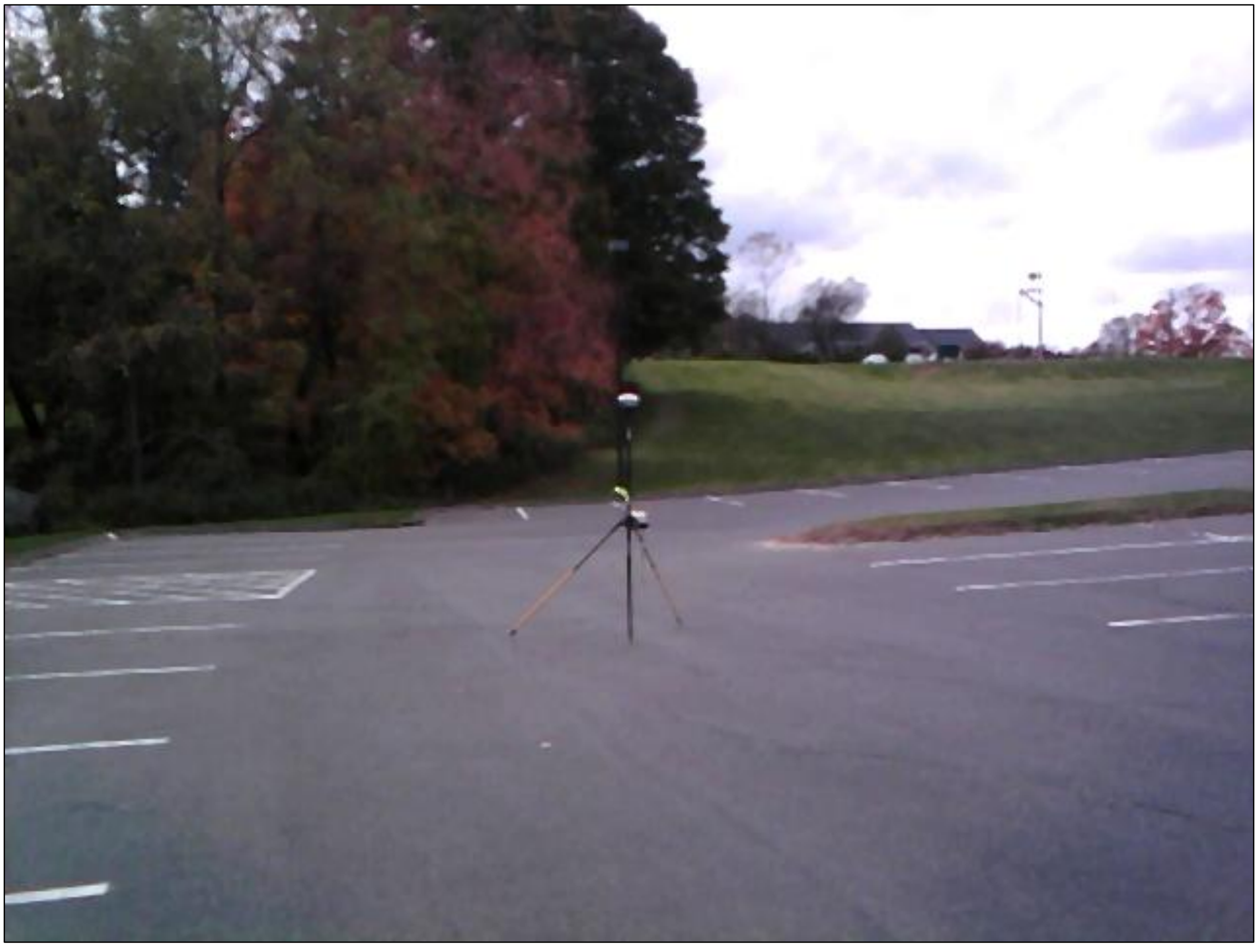

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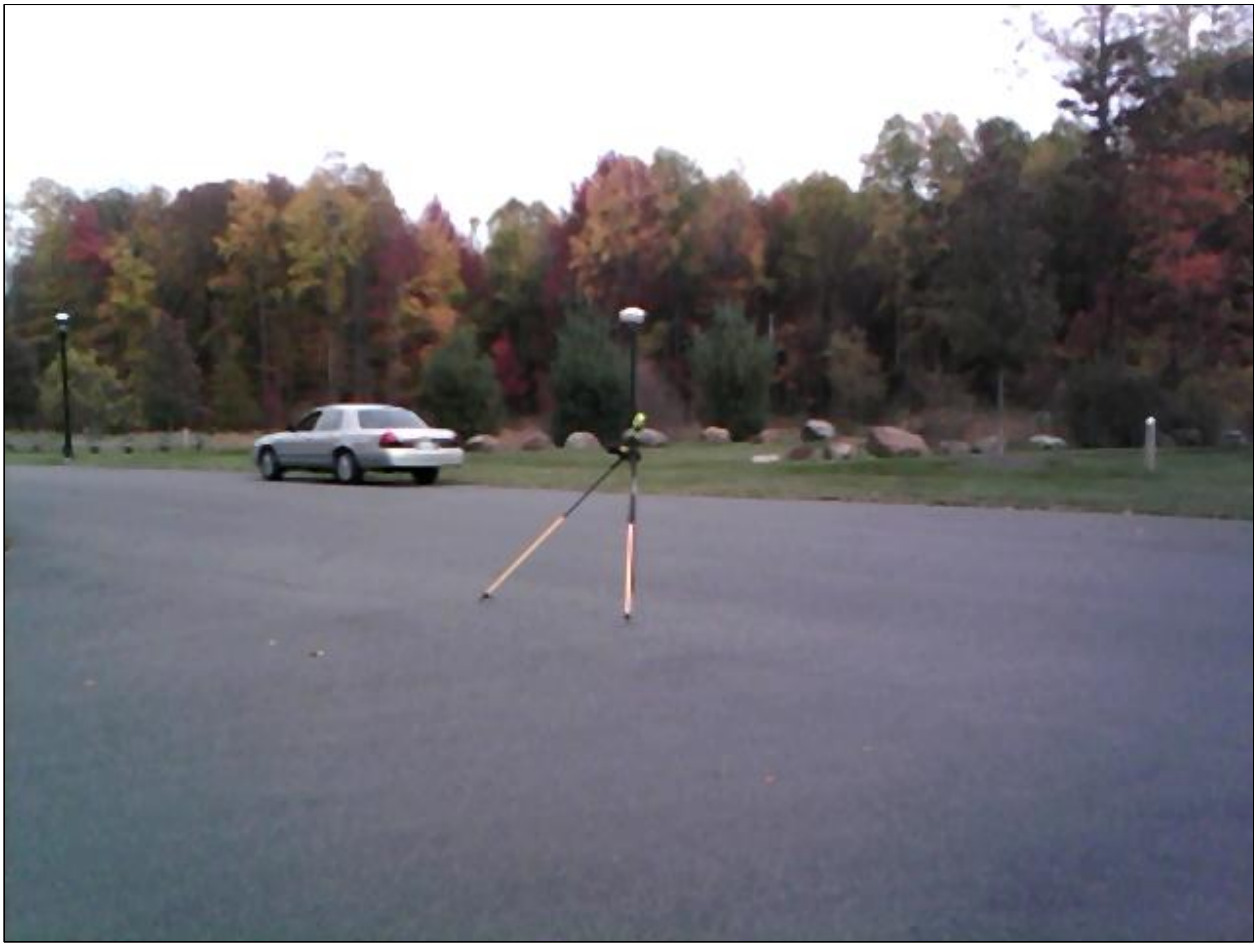

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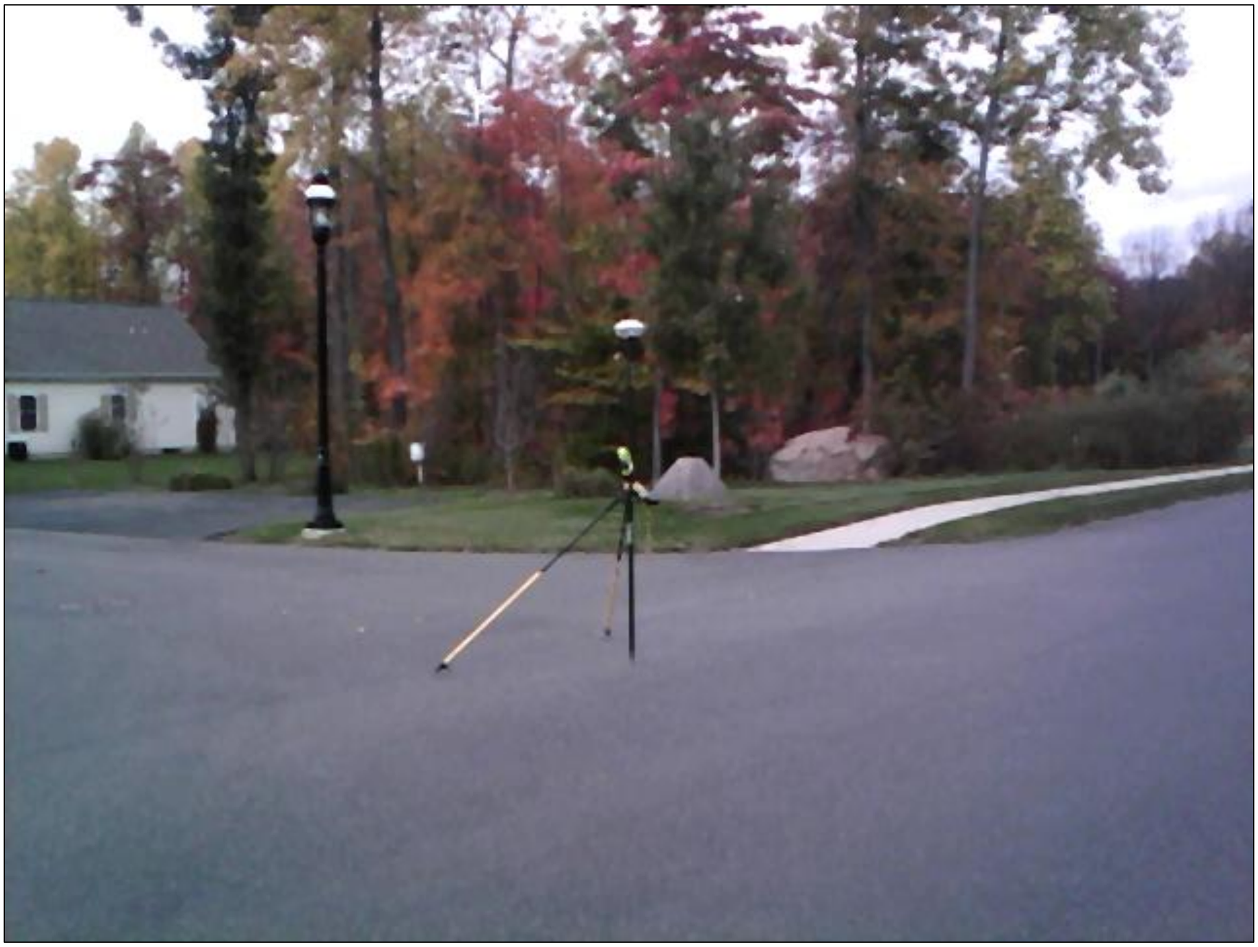

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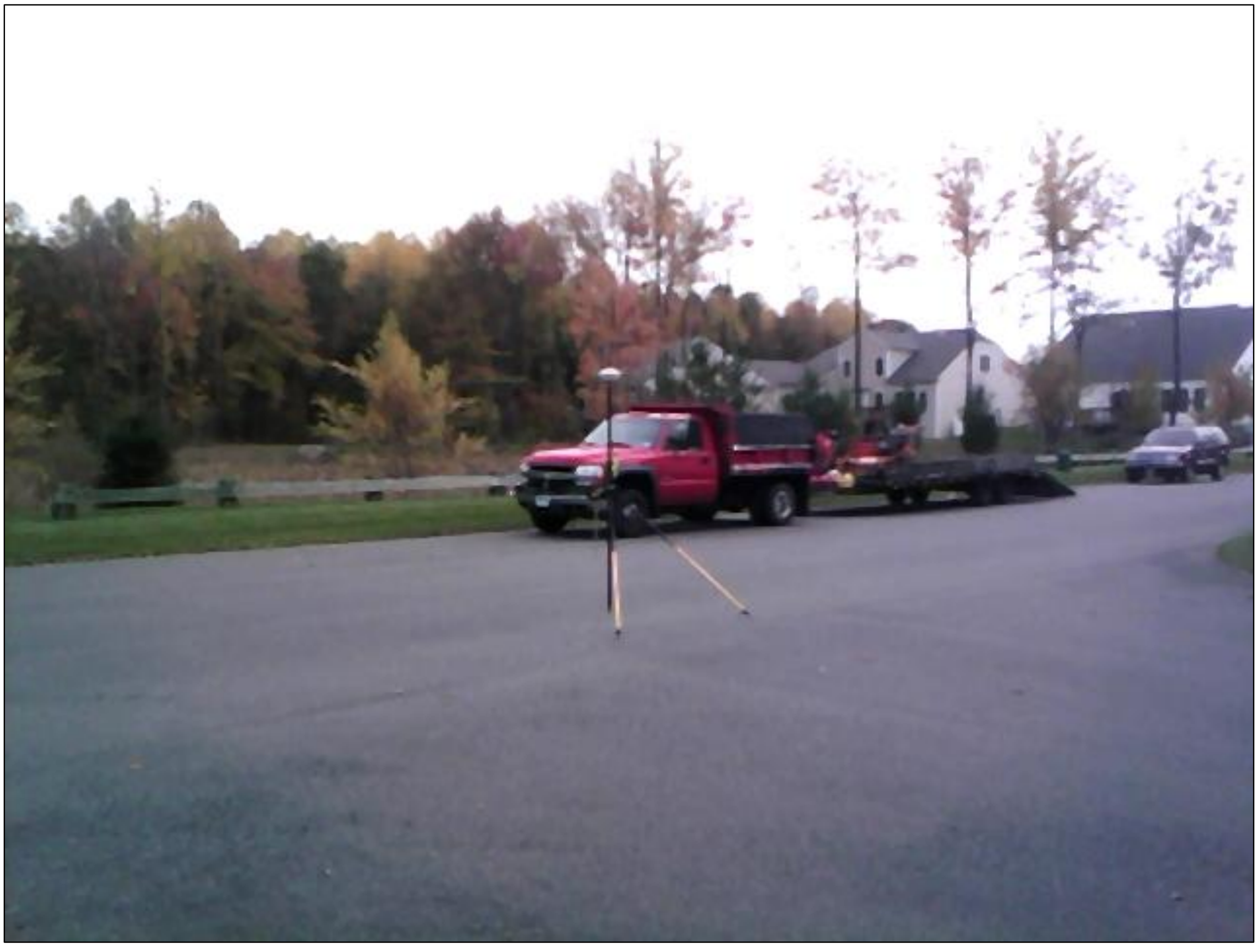

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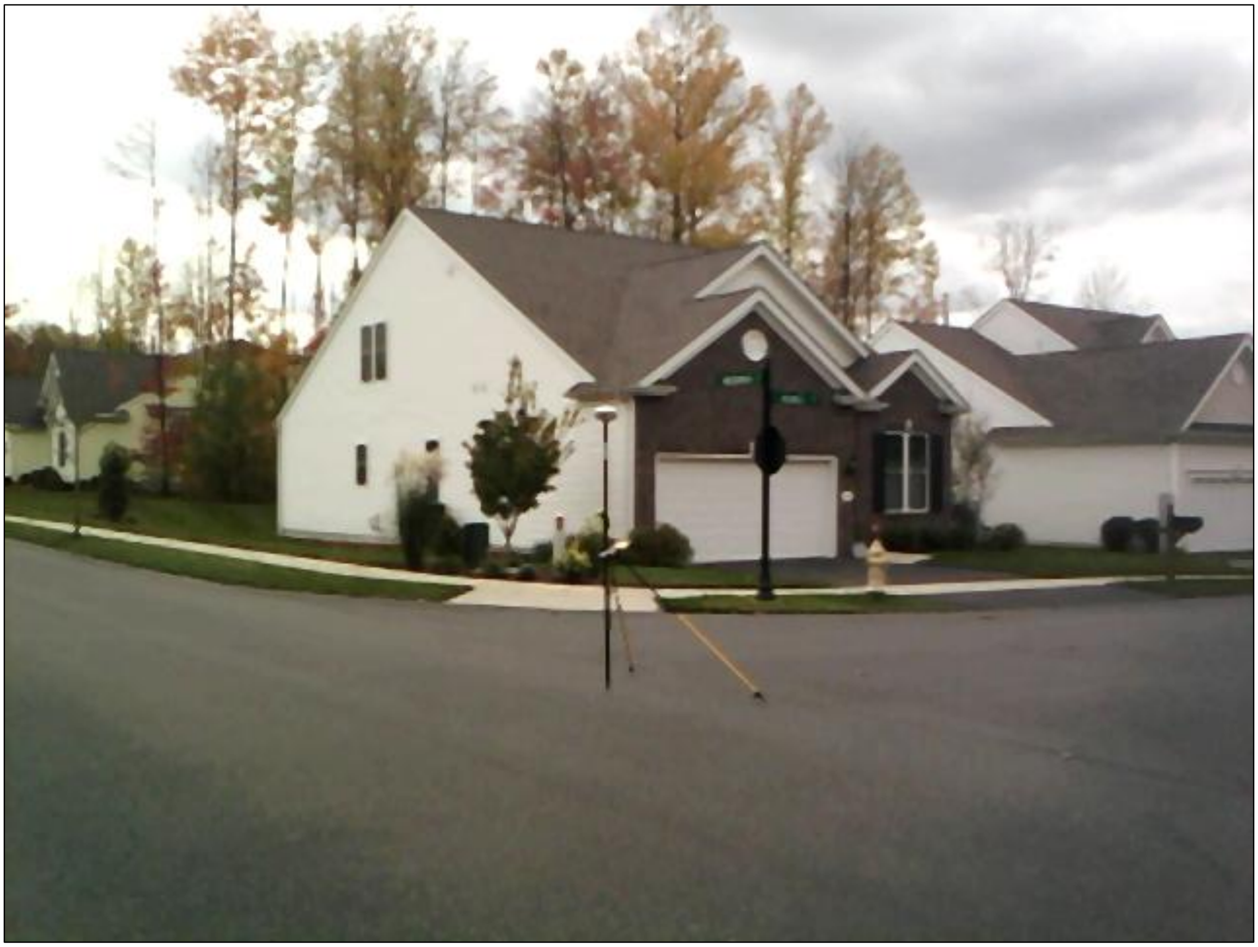
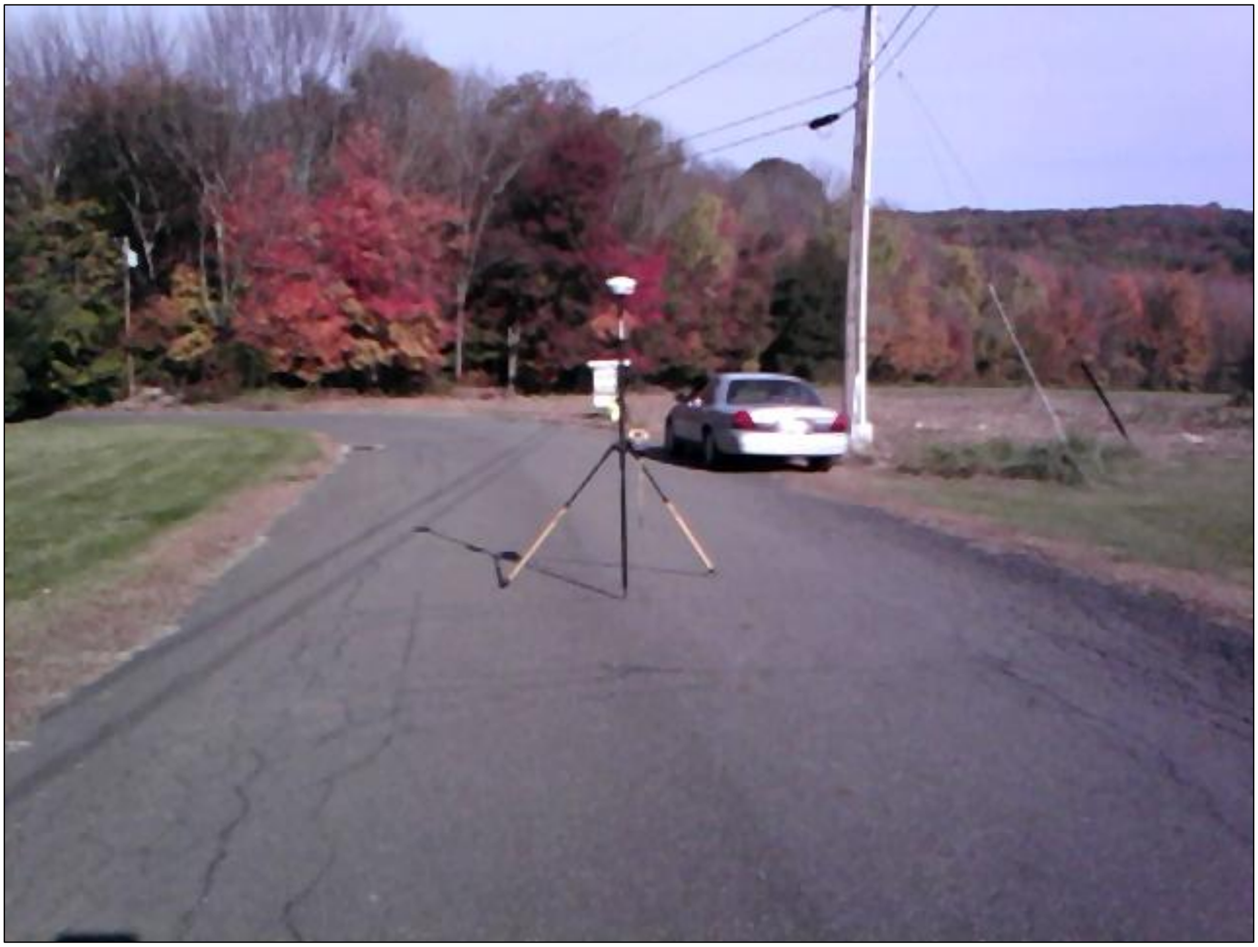


QNP118_E

QNP118_N



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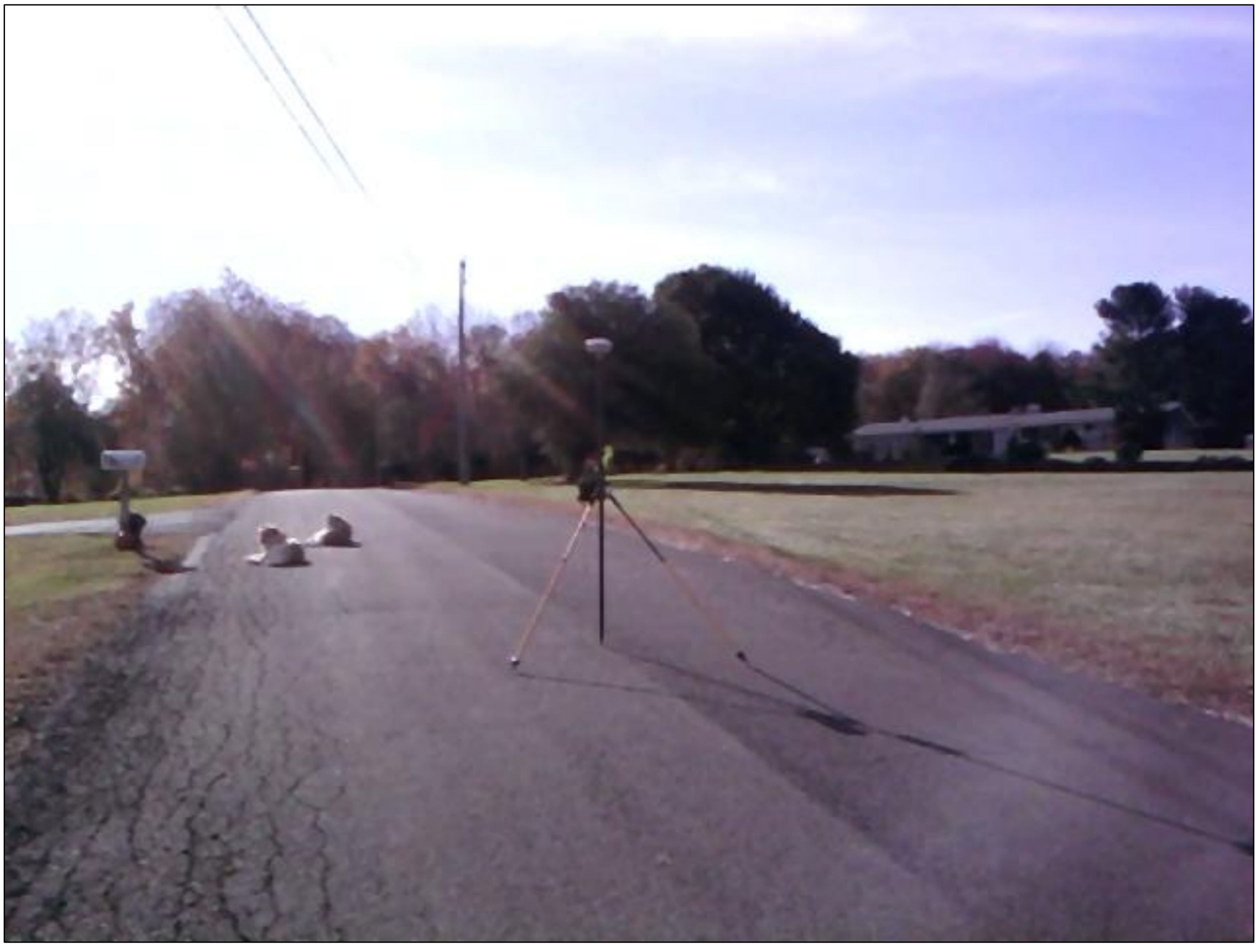

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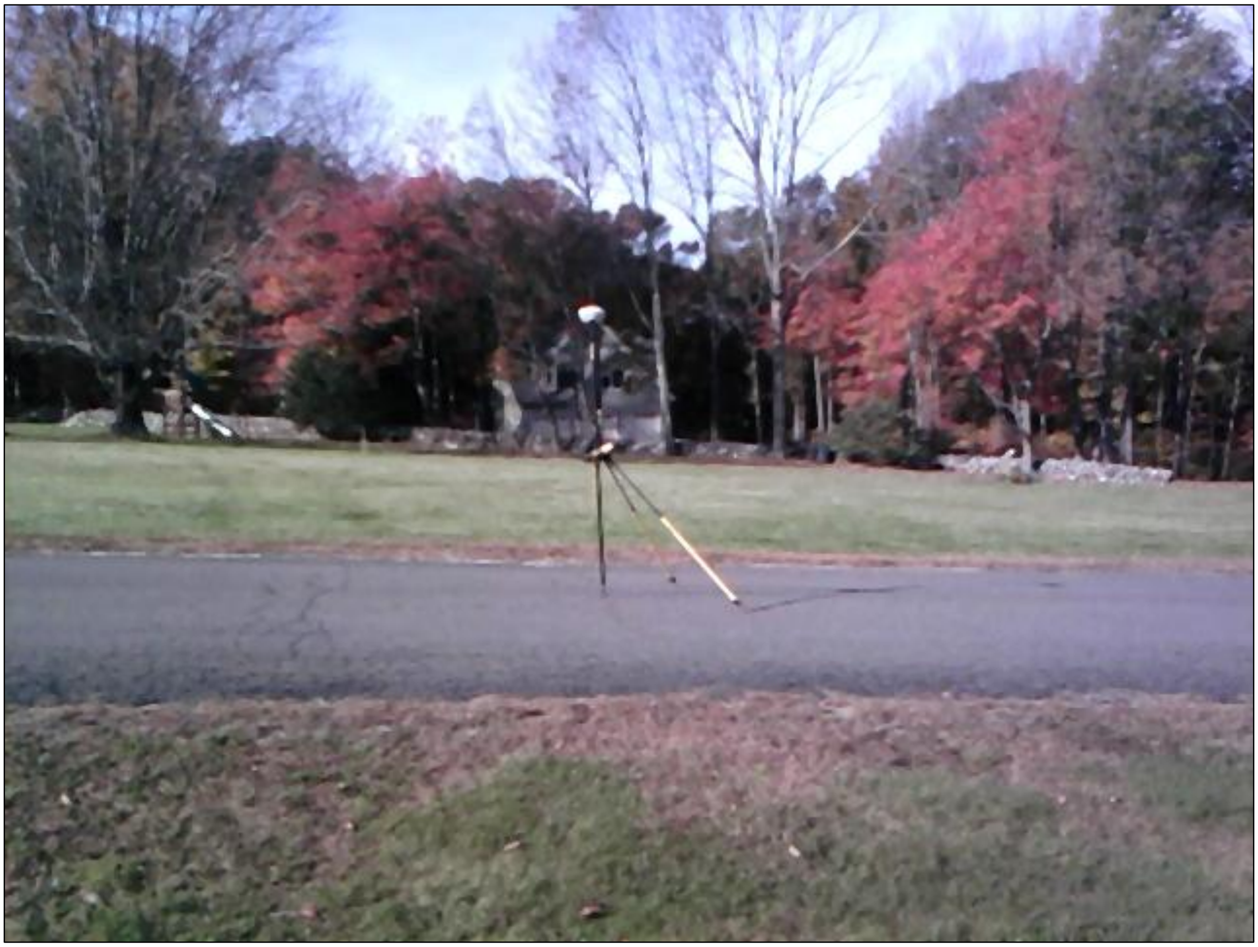

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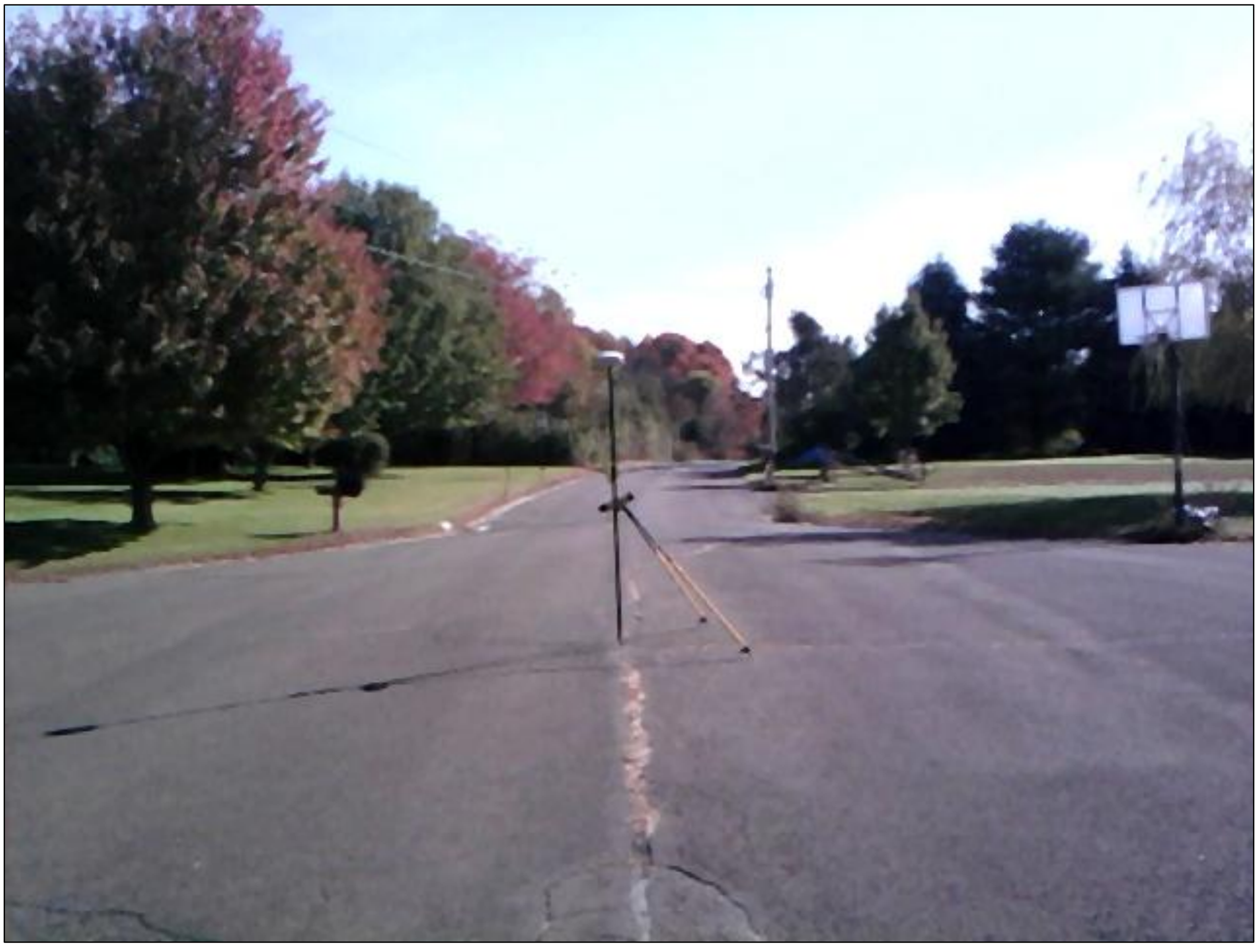

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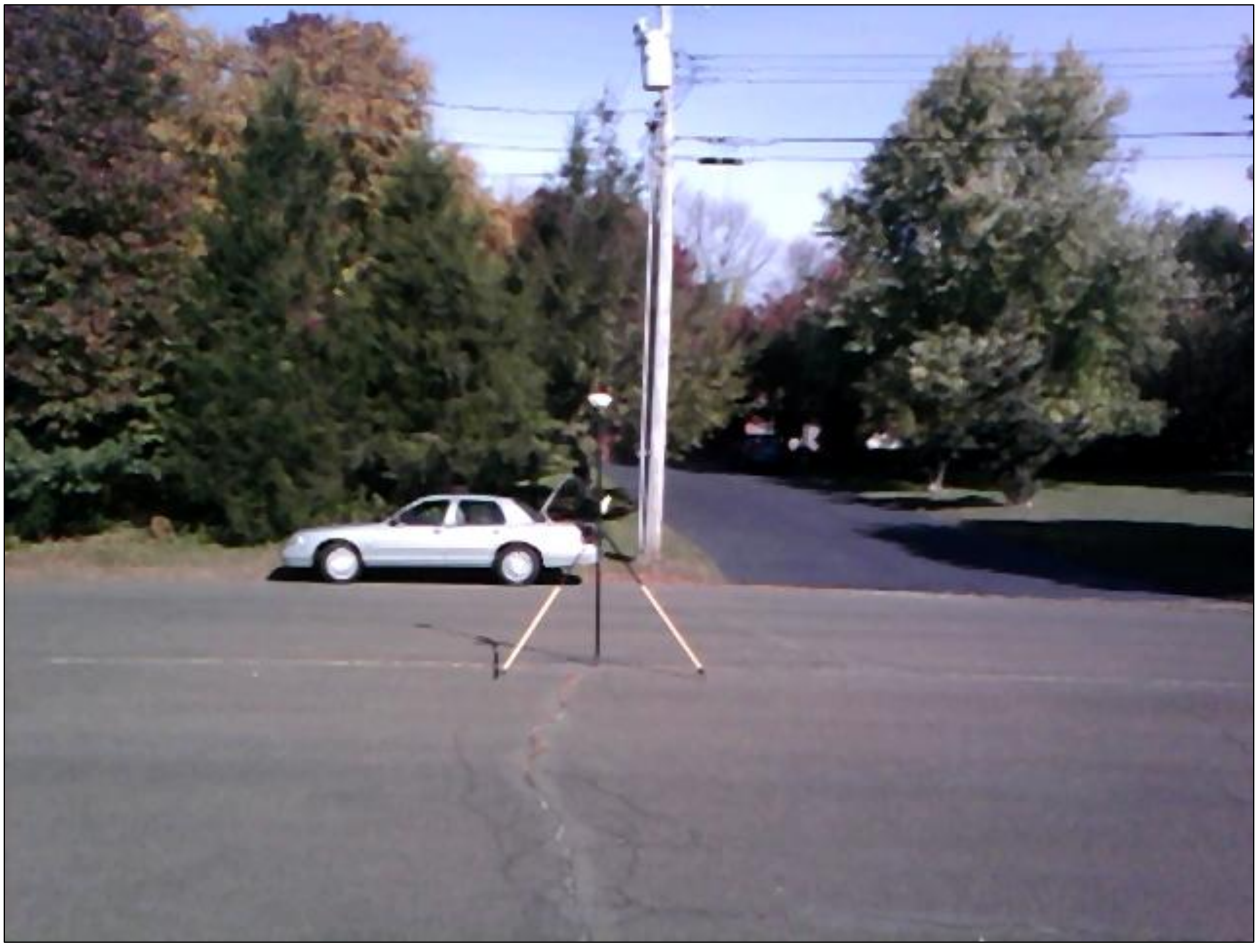

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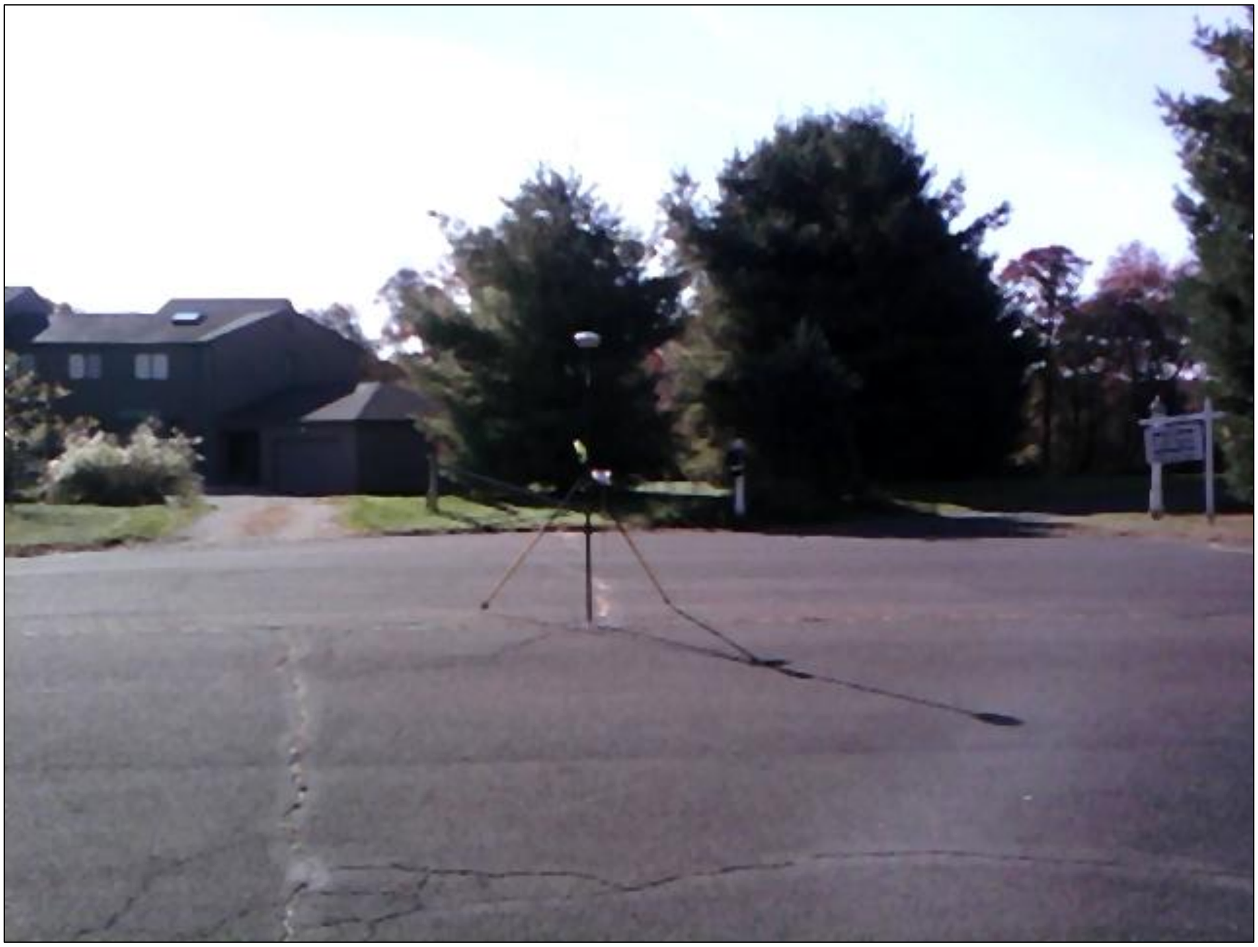

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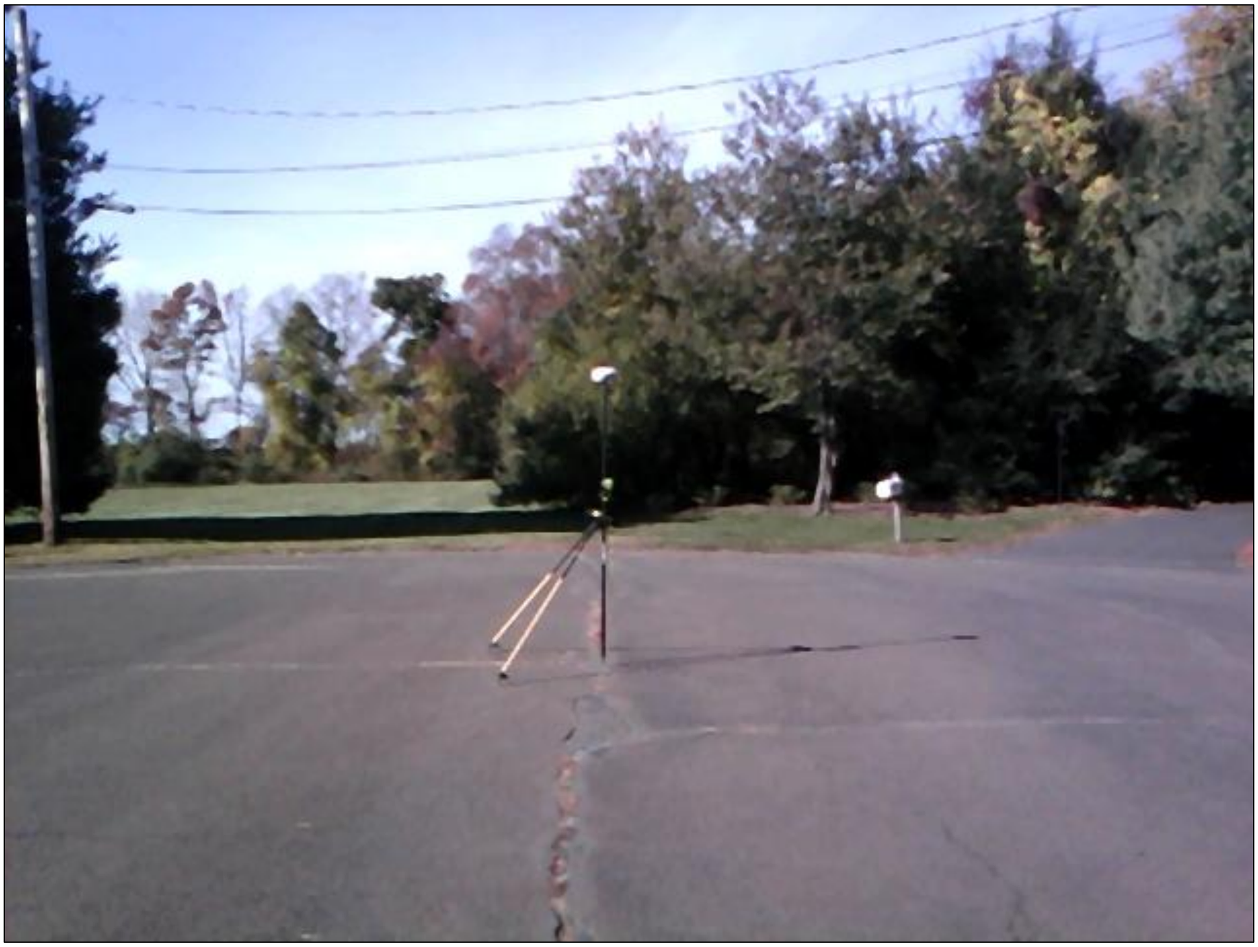

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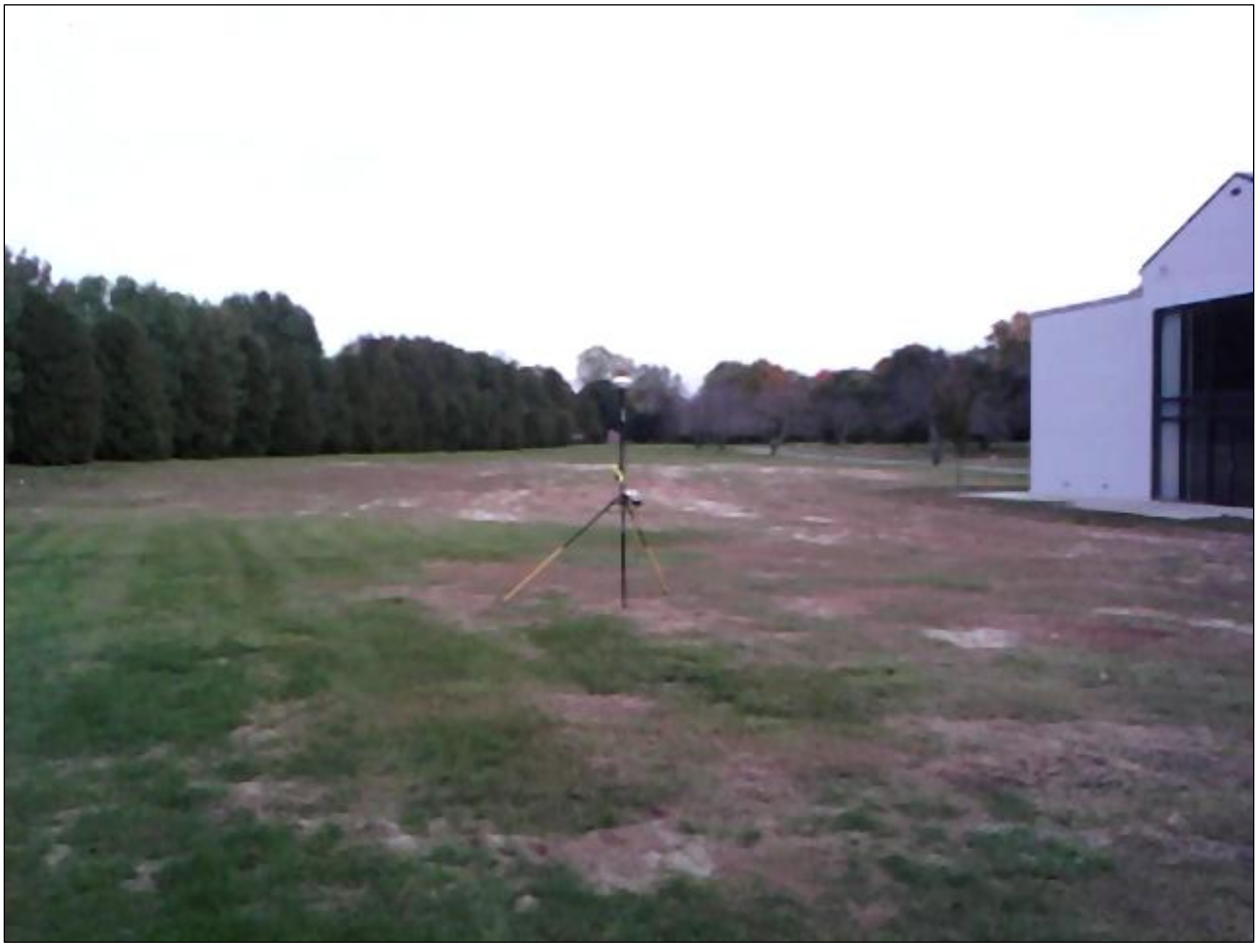

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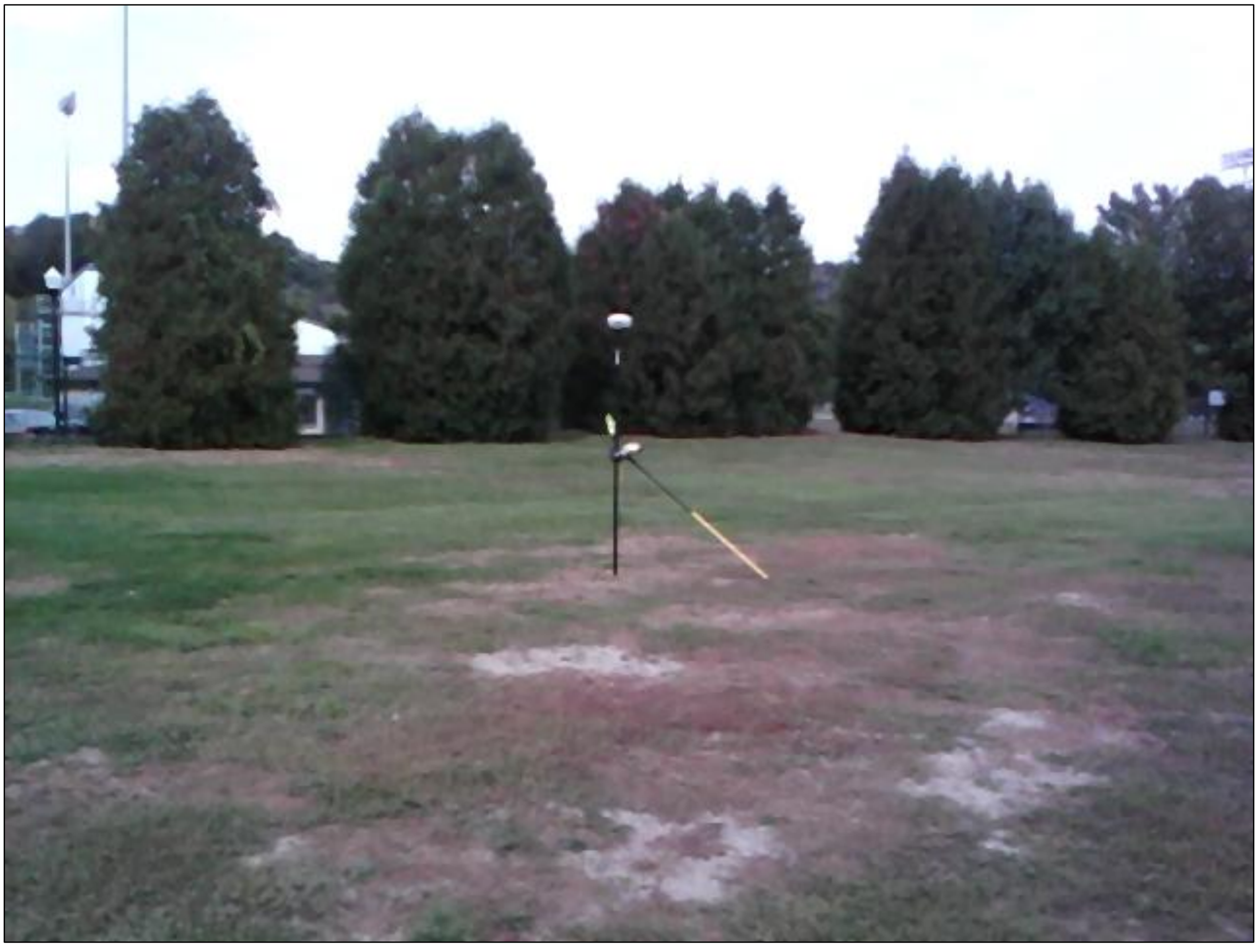
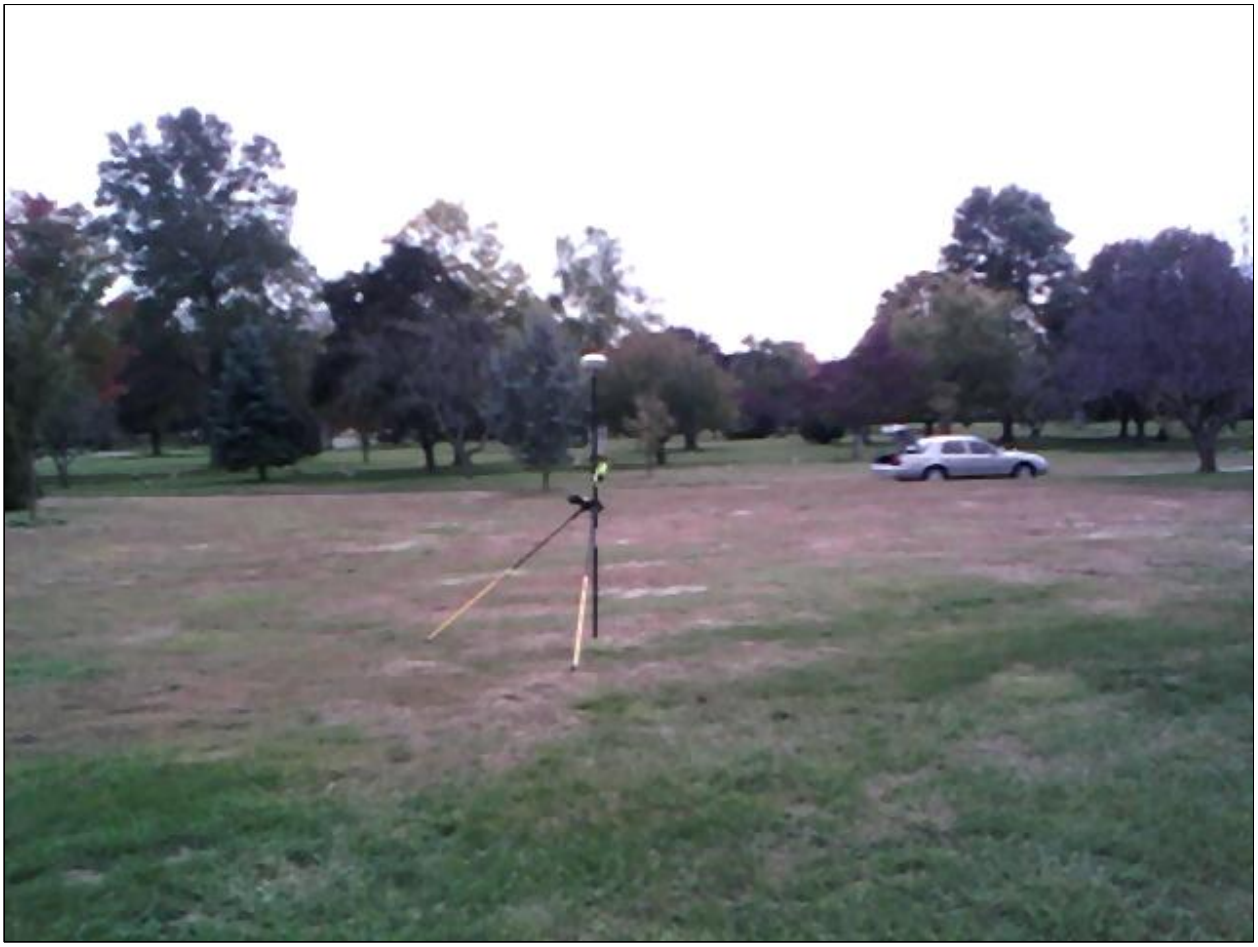


QNP120_S



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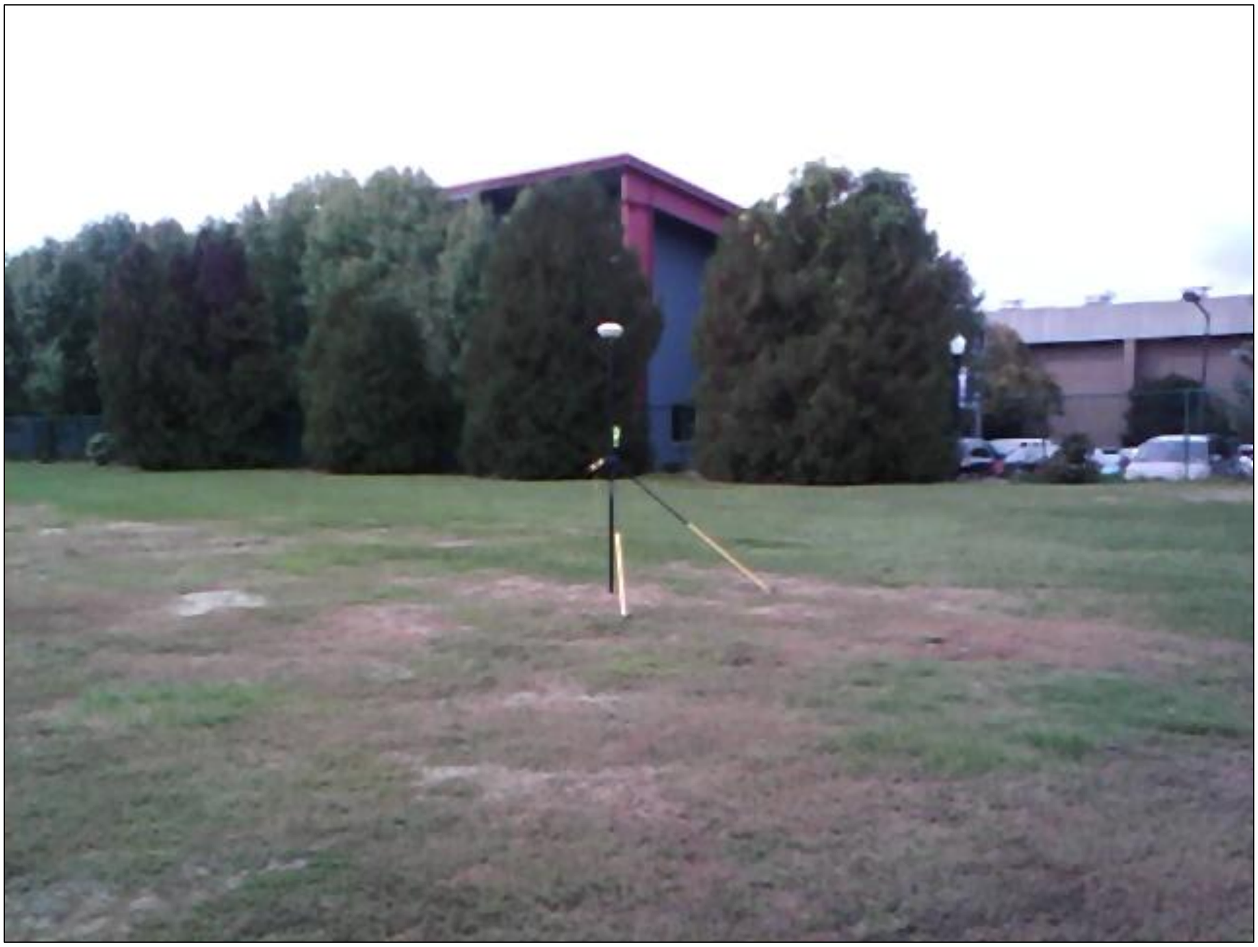
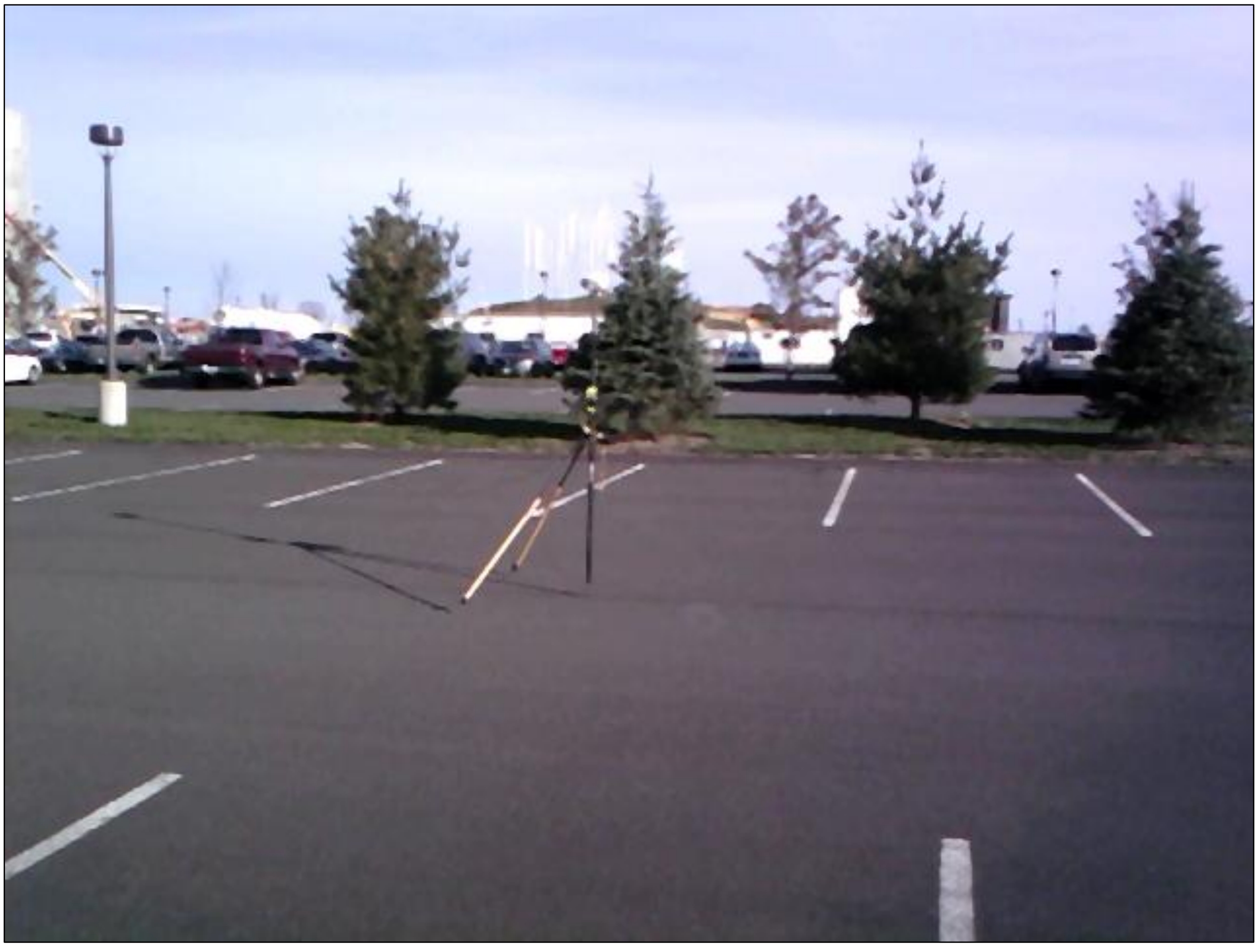


QNP121_E

QNP121_N



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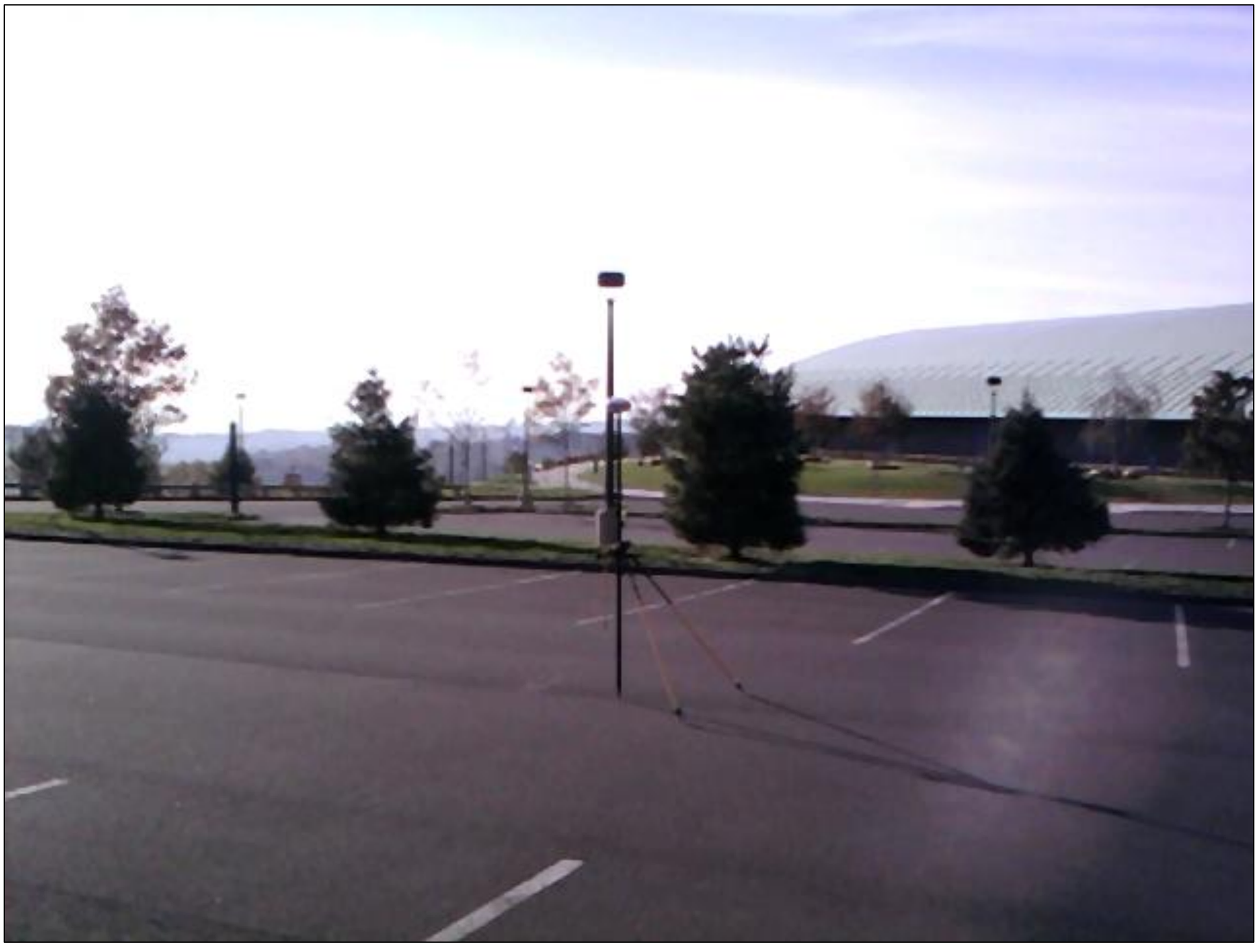

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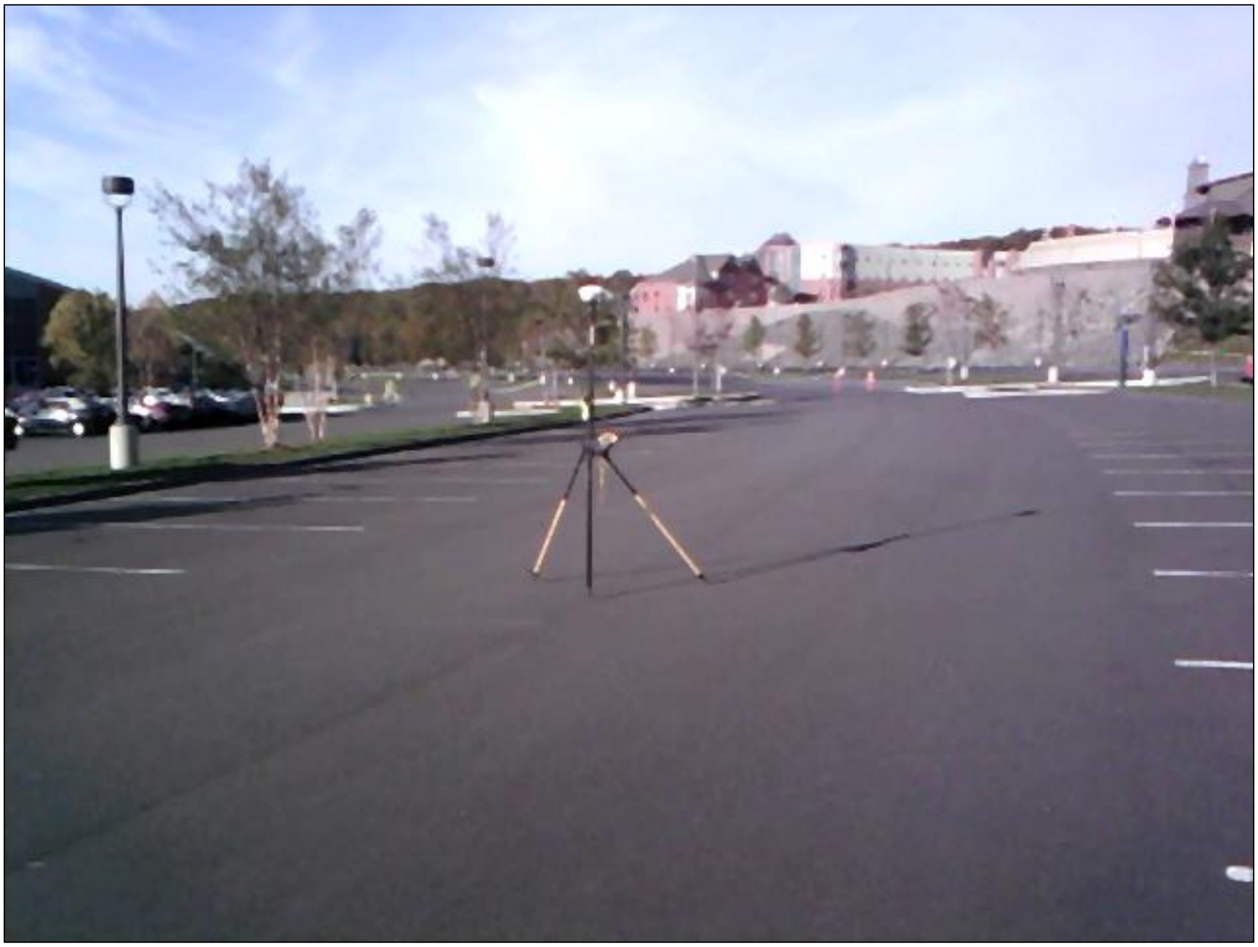
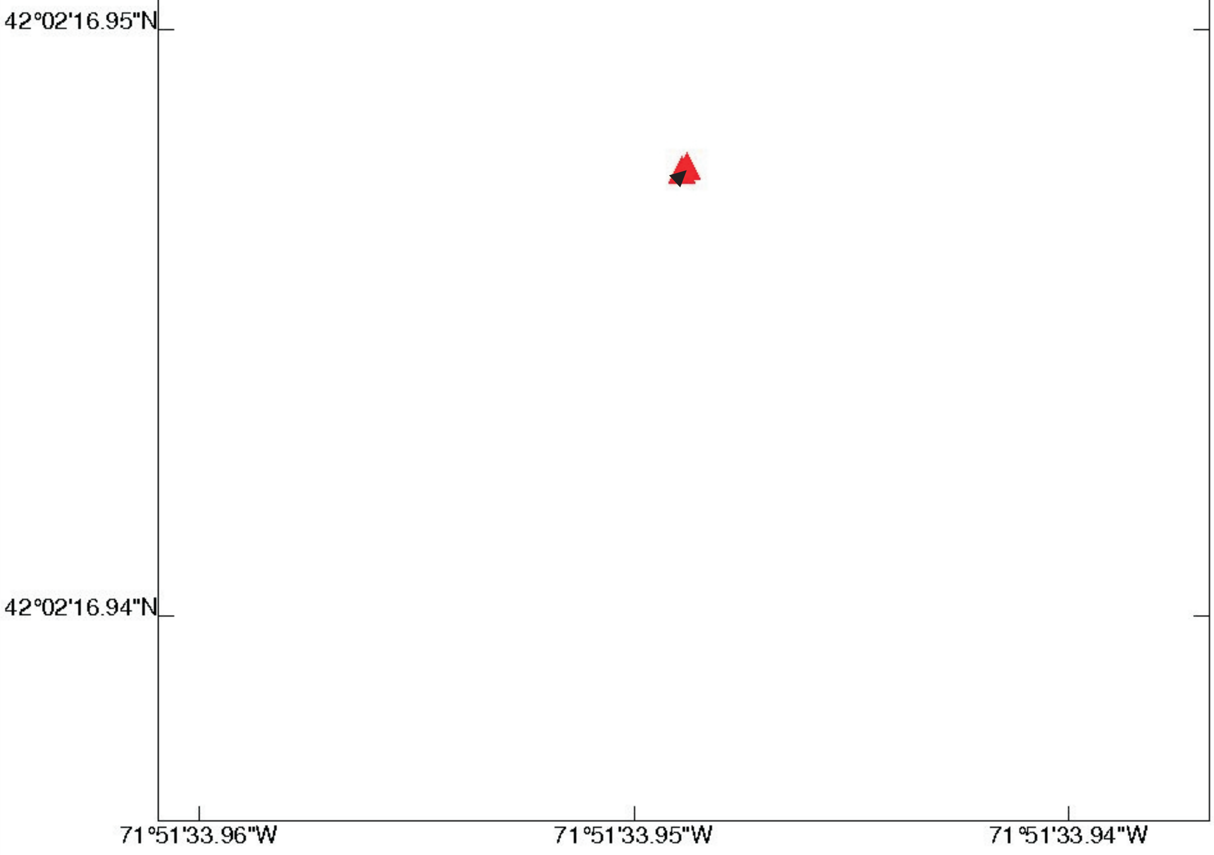


Accuracy Report

ΔH = 0.004m
ΔV = 0.020m



NGS_MY5929 10_19_2010

Lat/Long
WGS 1984

N ↑

Scale 1:4.00
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Meters

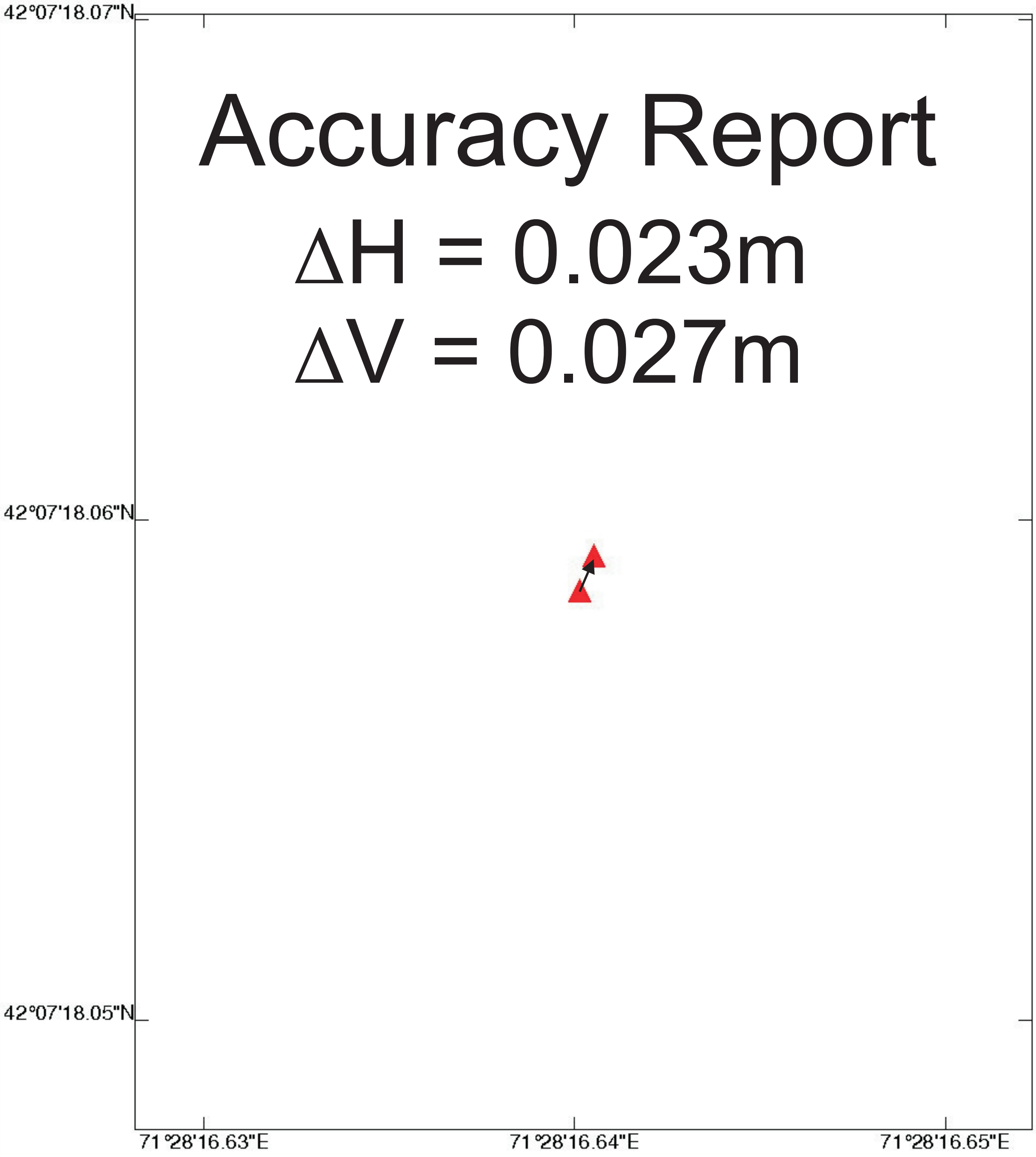
10/28/2010

GPS Pathfinder™ Office
Trimble

Accuracy Report

ΔH = 0.023m

ΔV = 0.027m



NGS_AI5590 10_19_2010

Lat/Long
WGS 1984

N

Scale 1:4.00

0 0.150

Meters

10/28/2010

GPS Pathfinder™ Office

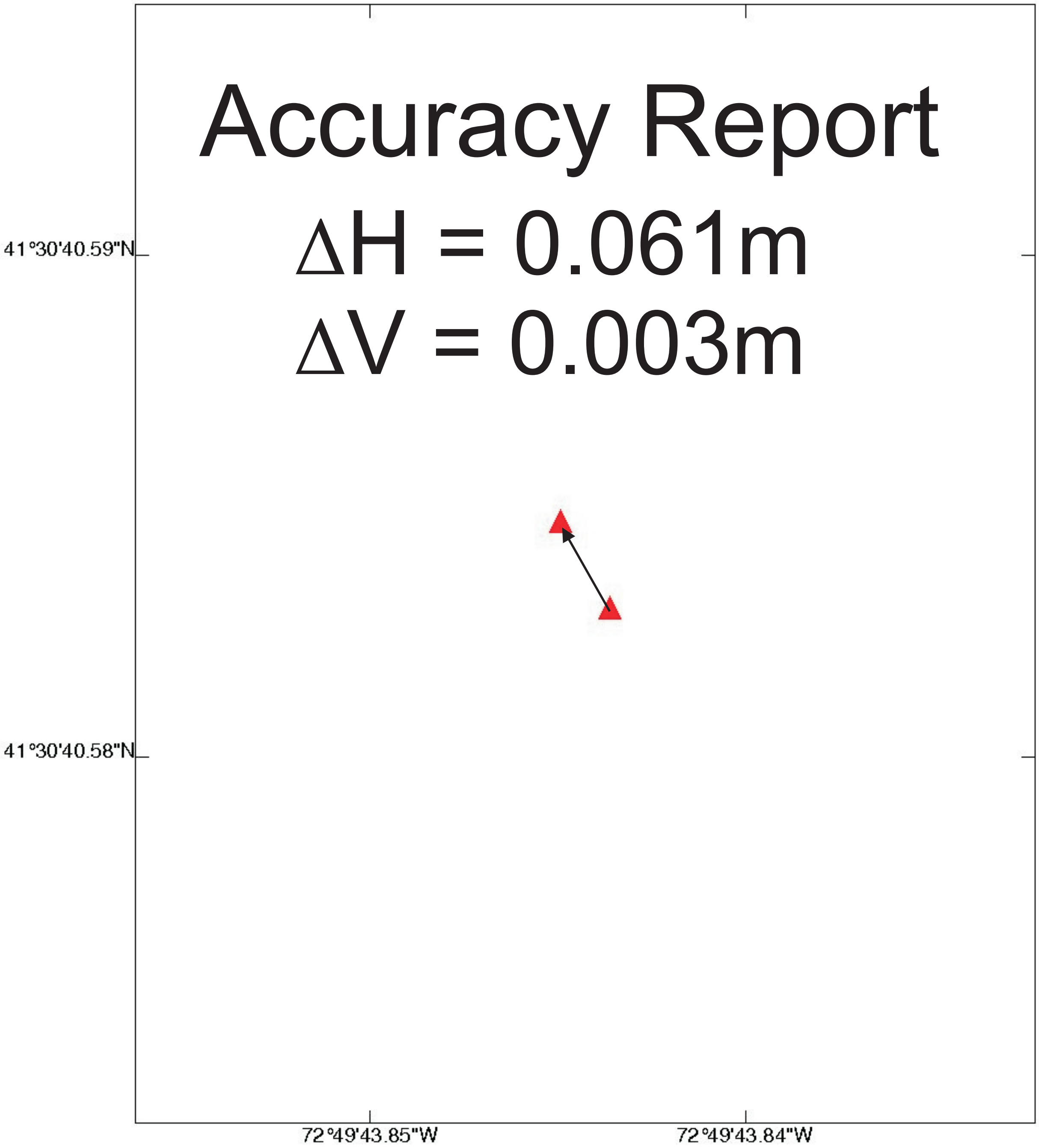
Trimble

CompassData

Accuracy Report

$\Delta H = 0.061m$

$\Delta V = 0.003m$



NGS_DE7815 10_20_2010

Lat/Long
WGS 1984

Scale 1:4.00

10/28/2010

GPS Pathfinder Office

Trimble

FEMA Region 1 – MA, NH, CT
FVA and CVA Project Report for FEMA
Inc. Narragansett, Charles, Concord, Blackstone, Nashua & Quinnipiac

Project Information

CDI Project Number:	**FSG1508**
Geographic Location:	**New England; MA, NH, CT**
Number of FVA/CVAs Requested:	**210**
Number of GCPs Collected:	**210**

Project Specifications

Precision (Horizontal/Vertical):	**CDI Precision-1 ≤ 8cm H/V**
Coordinate System:	**UTM**
Datum:	**NAD83**
Zone:	**18 & 19**
Altitude Reference:	**HAE (WGS84) and NAVD88 (09)**
Units:	**Meters**

RTK GPS

All FVA and CVA Quality Assurance Points for this project were collected within the boundaries of the Keystone Precision Instruments New England Virtual Reference Station System, which provides continuous real-time broadcast correction signals within a network of 170 base stations encompassing New England and the northern Mid-Atlantic region.

All QA Points were observed for 180 epochs to determine a coordinate location ≤ 8cm in both Horizontal and Vertical to support subsequent LiDAR post-processing and bare earth deliverables generation.
All data collected were well within the confines of the Keystone VRS system with multiple base locations providing position and correction data for each point collected.

Summary

The purpose of this project was to locate and survey photo-identifiable QA test points (FVA/CVAs) in multiple areas of interest as defined by FEMA-supplied shape and kml files. The QA coordinates are to be used to test the vertical aspect of all newly-flown LiDAR data during post-processing and subsequent deliverables creation. CompassData visited the project area, found suitable FVA and CVA locations, and determined accurate coordinates for each point according to the customer's specifications.

Equipment

CompassData used a Trimble R8 to perform the Control survey. This device is accurate to within 1 cm on a position-by-position basis per Trimble specifications. Operating within the VRS network provided accurate coordinate values at or around 5 cm H/V within 3-5 minutes observation times. CompassData has consistently demonstrated this level of accuracy on many GCP collection jobs across North and South America and Africa. Specifications for the Trimble R8 are available upon request.

Survey Methodology

CompassData has met the required precision for this project by using a high-quality GPS receiver with differential corrections provided by a VRS network surrounding the project area. The GPS antenna sat atop a bubble-leveled, fixed-height range pole that was placed over the center of the desired QA point. At least 180 positions (captured at a rate of one per second) were geometrically averaged to calculate a single coordinate for each FVA/CVA point. All required field documentation was filled out and the points were identified on web-based imagery and diagrammed on the CompassData-supplied sketch sheets (FVA points only). Digital pictures of each GCP location were collected in the field.

Quality Control Procedures

CompassData collects QA points with an unobstructed view of the sky to ensure proper GPS operation. CompassData works to avoid potential sources of multipath error such as trees, buildings, and fences that may adversely affect the GPS accuracy.

Additional quality control comes from the fact that at least 180 GPS positions are collected for each point. While operating within a VRS, valid solutions are reached within seconds; however, we continue to collect additional data to ensure meeting collection specifications. To ensure project integrity, an FVA or CVA will be reobserved or moved to a more suitable location if it does not meet project specifications.

In addition to the aforementioned procedures, CompassData "surveys" existing geodetic control monuments to see if our coordinates match the published coordinates to the required accuracy. These monuments are usually established by the National Geodetic Survey (NGS) in the United States. If it is found that our coordinates are outside the acceptable accuracy, the reason for the difference will be found or the GCPs will be reobserved under different GPS constellation constraints. There are certain geodetic considerations that must be taken into account that affect whether a GPS-derived coordinate will line up with a survey monument, especially when these monuments reference local coordinate systems or the systems of another country. Sometimes the published coordinates for a monument are not accurate, although this is very infrequent.

CompassData visited multiple survey monuments during the course of this project. The results of those monument measurements are summarized in the Accuracy Report.

Deliverables

Deliverables for this project include:

- ☐ Coordinates (in spreadsheet format)
- ☐ Image Chips
- ☐ Sketch Sheets (FVA points only)
- ☐ Digital Pictures
- ☐ QA/QC Data

Project Notes

All collected points were retrieved from the Trimble Survey Controller in Decimal Degrees, NAD83, HAE Meters.

CorpsCon was used to generate files in the following format:

Degrees Minutes Decimal Seconds, NAD83 HAE (QC purposes)
UTM Meters, NAD83 HAE

Geoid09 was then used to generate the geoid separation at every Lat/Long location. NAVD88(09) orthometric heights were then generated in spreadsheet form using the formula HAE - Geoid = Orthometric Height. Those values were then included into the final delivery coordinate CSV files and have been tested against NGS monuments collected during the course of this survey and are showing millimeter-level agreement.

The Horizontal and Vertical accuracies reported in the Final Coordinates file were obtained from the Survey Report generated by Trimble Survey Controller. The report contains all points collected during each daily survey deployment, including CVAs, FVAs and NGS Monuments.

Contact Information

Hayden Howard Phone: (303) 627-4058 E-mail: haydenh@compassdatainc.com

December 29, 2010

Quinnipiac, Connecticut										
CVAs/FVAs	Date	Vert_Prec	Horz_Prec	Latitude	Longitude	Easting	Northing	HAE	GEOID09 Separation	NAVD88
QNP301	10/19/2010	0.0073	0.0049	41.64021025	-72.87330348	677121.439	4612015.144	24.34899695	-29.173	53.52199695
QNP302	10/19/2010	0.0067	0.0055	41.58638121	-72.90189407	674885.56	4605980.129	30.53340138	-29.191	59.72440138
QNP303	10/20/2010	0.0082	0.0058	41.53720673	-72.93983468	671853.19	4600444.123	76.57444833	-29.195	105.7694483
QNP304	10/18/2010	0.004	0.003	41.53891968	-72.79857424	683632.576	4600925.052	9.346405988	-29.39	38.73640599
QNP305	10/19/2010	0.0159	0.0116	41.49891356	-72.92169578	673468.638	4596228.743	24.71201448	-29.259	53.97101448
QNP306	10/19/2010	0.0082	0.0052	41.47241018	-72.81999966	682031.548	4593495.217	-12.94274842	-29.465	16.52225158
QNP307	10/19/2010	0.0082	0.0052	41.43311569	-72.74616556	688310.808	4589290.458	99.23698348	-29.618	128.8549835
QNP308	10/20/2010	0.0137	0.0076	41.40670732	-72.65068956	696368.087	4586570.533	85.04851496	-29.764	114.812515
QNP309	10/20/2010	0.0107	0.0073	41.37645944	-72.55875277	704147.912	4583424.734	85.62855053	-29.969	115.5975505
QNP310	10/20/2010	0.0131	0.0076	41.44282797	-72.95530428	670810.535	4589934.796	130.1084087	-29.301	159.4094087
QNP311	10/19/2010	0.0082	0.0052	41.38965375	-72.79567602	684296.746	4584358.412	18.81838983	-29.678	48.49638983
QNP312	10/20/2010	0.0229	0.0095	41.35159651	-72.65248406	696383.899	4580447.581	48.63124256	-29.905	78.53624256
QNP313	10/20/2010	0.0116	0.0073	41.32076407	-72.5069946	708654.373	4577364.169	3.804826048	-30.183	33.98782605
QNP314	10/20/2010	0.0213	0.0125	41.31446301	-72.40279913	717396.82	4576920.528	-0.206350015	-30.338	30.13164999
QNP315	10/20/2010	0.0101	0.0064	41.35477221	-72.99072792	668077.964	4580089.002	46.12913433	-29.501	75.63013433
QNP316	10/20/2010	0.0125	0.0058	41.32604918	-72.83256933	681388.62	4577218.763	-11.13345198	-29.809	18.67554802
QNP317	10/20/2010	0.0073	0.0055	41.33139586	-72.70774966	691819.579	4578080.999	-5.316941888	-29.9	24.58305811
QNP318	10/20/2010	0.0088	0.0064	41.31311831	-72.58857786	701849.258	4576322.18	-23.26390676	-30.103	6.83909324
QNP319	10/20/2010	0.0122	0.0073	41.27994458	-72.98602716	668664.089	4571790.425	20.63134387	-29.735	50.36634387
QNP320	10/20/2010	0.0137	0.0101	41.22881531	-73.0683004	661899.851	4565957.323	-4.522936292	-29.794	25.27106371
QNP701	12/3/2010			41.68286267	-72.82060407	681390.945	4616860.564	76.15693097	-29.191	105.347931
QNP701_BK	12/3/2010	0.006	0.004	41.68308787	-72.82031538	681414.341	4616886.177	76.218	-29.191	105.409
QNP701_TP	12/3/2010	0.007	0.005	41.68305056	-72.82065151	681386.468	4616881.326	77.26	-29.191	106.451
QNP702	12/3/2010			41.64390933	-72.94430395	671198.079	4612282.378	244.9763645	-29.072	274.0483645
QNP702_BK	12/3/2010	0.008	0.005	41.64346579	-72.94438428	671192.563	4612232.972	244.04	-29.072	273.112
QNP702_TP	12/3/2010	0.008	0.005	41.64355853	-72.94406384	671219.005	4612243.906	244.517	-29.073	273.59
QNP703	12/3/2010			41.55677916	-72.76387215	686476.085	4602982.373	65.83732507	-29.415	95.25232507
QNP703_BK	12/3/2010	0.006	0.004	41.55636698	-72.76405352	686462.144	4602936.217	66.1	-29.416	95.516
QNP703_BK1	12/3/2010	0.008	0.005	41.5564587	-72.76410895	686457.258	4602946.281	66.368	-29.416	95.784
QNP703_TP	12/3/2010	0.006	0.004	41.55653857	-72.76389197	686475.124	4602955.618	65.603	-29.416	95.019
QNP704	12/3/2010			41.48992085	-72.95257097	670915.108	4595168.793	161.1468907	-29.227	190.3738907
QNP704_BK	12/3/2010	0.009	0.007	41.49000336	-72.95275502	670899.526	4595177.59	161.616	-29.227	190.843
QNP704_TP	12/3/2010	0.009	0.006	41.48979515	-72.95268892	670905.592	4595154.604	161.323	-29.227	190.55
QNP705	12/3/2010			41.41443838	-72.74179253	688730.308	4587226.268	61.94569054	-29.66	91.60569054
QNP705_BK	12/3/2010	0.009	0.006	41.41029765	-72.76150098	687094.95	4586723.749	48.793	-29.654	78.447
QNP705_BK1	12/3/2010	0.022	0.014	41.41460895	-72.74163607	688742.891	4587245.548	63.301	-29.66	92.961
QNP705_TP	12/3/2010	0.012	0.008	41.40998891	-72.76175764	687074.383	4586688.916	48.058	-29.655	77.713

QNP705_TP1	12/3/2010	0.014	0.009	41.41452137	-72.7418847	688722.364	4587235.282	63.339	-29.66	92.999
QNP706	12/3/2010			41.38514112	-72.56320555	703748.405	4584378.173	116.3559789	-29.941	146.2969789
QNP706_BK	12/3/2010	0.008	0.006	41.38548722	-72.56361902	703712.75	4584415.628	117.626	-29.939	147.565
QNP706_TP	12/3/2010	0.008	0.006	41.38537182	-72.56332738	703737.497	4584403.501	117.226	-29.94	147.166
QNP707	12/3/2010			41.2527705	-73.0516274	663237.678	4568648.09	-2.693699243	-29.735	27.04130076
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QNP707_TP	12/3/2010	0.011	0.009	41.25292447	-73.05120787	663272.445	4568665.973	-2.128	-29.735	27.607
QNP708	12/3/2010			41.38143944	-72.93461074	672701.923	4583160.094	-0.494820889	-29.503	29.00817911
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QNP709	12/3/2010			41.32064428	-72.76189899	687318.772	4576768.906	4.912722731	-29.876	34.78872273
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QNP709_TP	12/3/2010	0.013	0.012	41.32085146	-72.76191102	687317.171	4576791.883	5.426	-29.876	35.302
QNP710	12/3/2010			41.32424146	-72.49315538	709801.594	4577783.656	38.53666135	-30.191	68.72766135
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QNP710_TP	12/3/2010	0.008	0.006	41.32439096	-72.49326616	709791.842	4577799.986	38.72	-30.19	68.91
QNP801	12/3/2010	0.007	0.004	41.66200669	-72.86262424	677950.879	4614457.232	26.532	-29.165	55.697
QNP802	12/3/2010	0.008	0.005	41.51814097	-72.83147593	680945.829	4598548.56	1.533	-29.375	30.908
QNP803	12/3/2010	0.011	0.007	41.33377236	-72.9765647	669317.211	4577785.054	-7.681	-29.585	21.904
QNP804	12/3/2010	0.011	0.008	41.29785953	-72.77350353	686412.387	4574214.199	-22.418	-29.936	7.518
QNP805	12/3/2010	0.009	0.006	41.29172858	-72.42370374	715721.827	4574344.13	-22.085	-30.37	8.285
Survey Control										
NGSAI5590	10/18/2010	0.0067	0.0049	41.51051804	-72.83083879	681020.24	4597703.53	0.77114555	-29.386	30.15714555
NGS_LX6301	10/20/2010	0.0073	0.0043	41.44670608	-72.67332528	694356.55	4590960.47	165.2683786	-29.667	194.9353786
NGS_DE7815	10/20/2010	0.0174	0.0094	41.51127305	-72.82884545	681184.5	4597791.53	0.797968004	-29.388	30.185968
Metadata										
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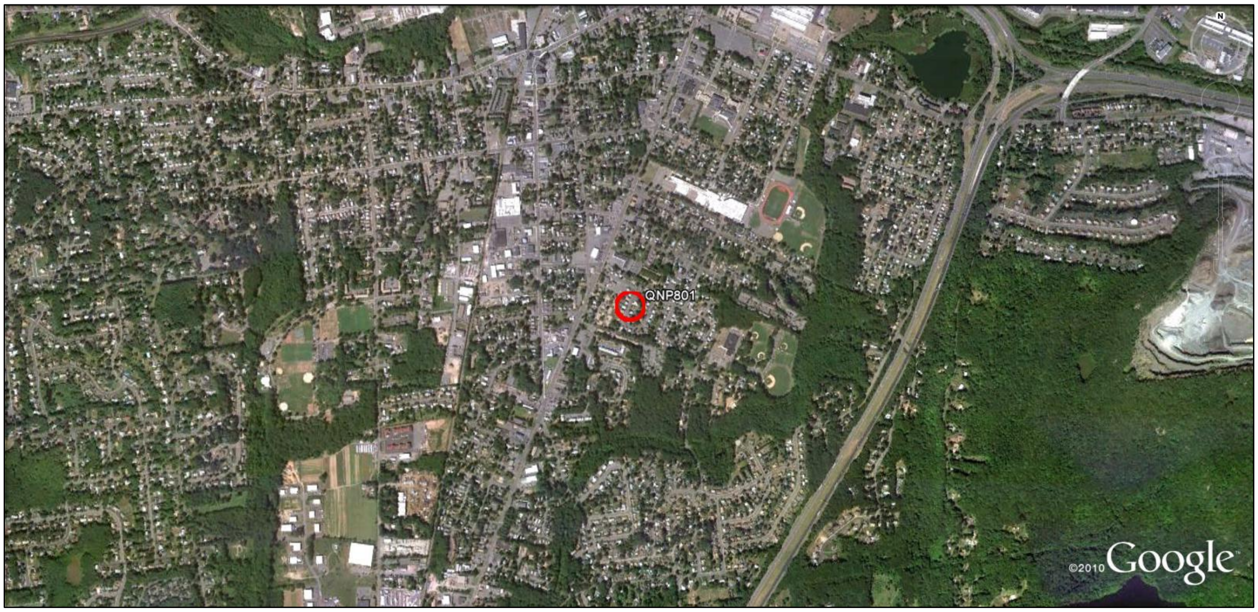
All units in meters where applicable.										
HAE - GEOID09 = NAVD88										

QNP801_C



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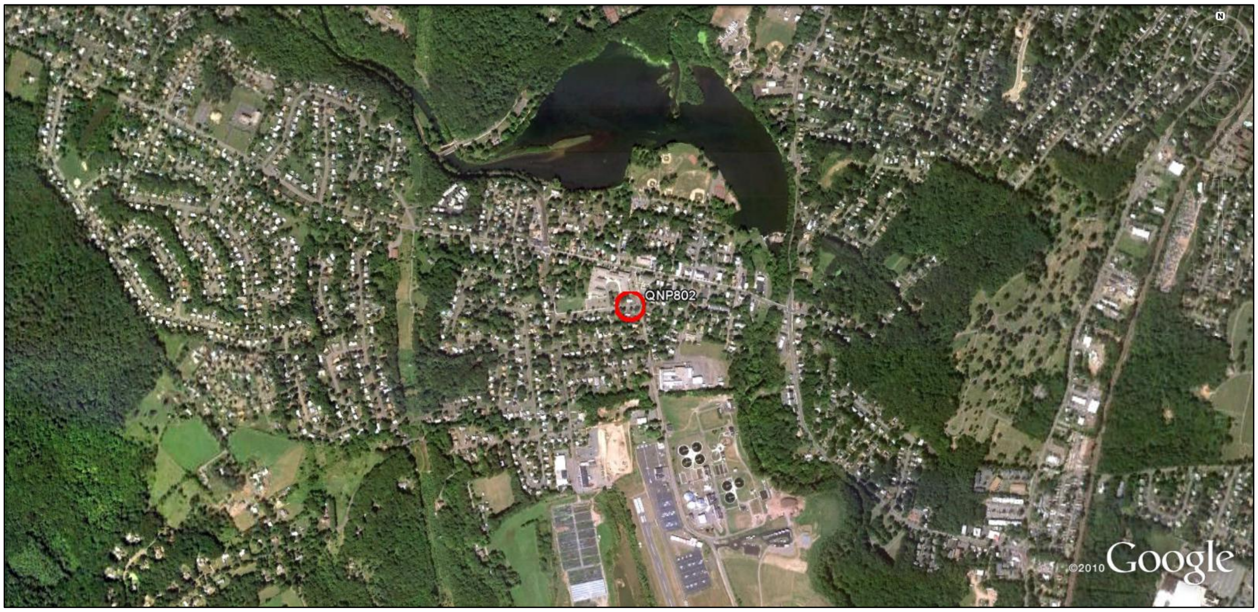

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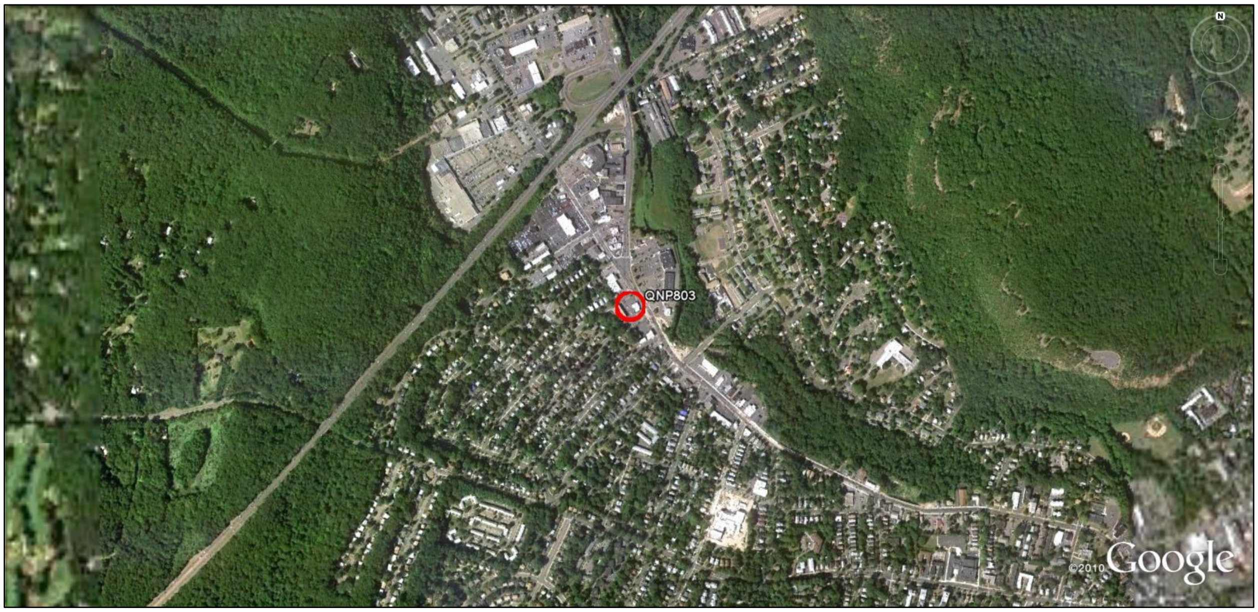

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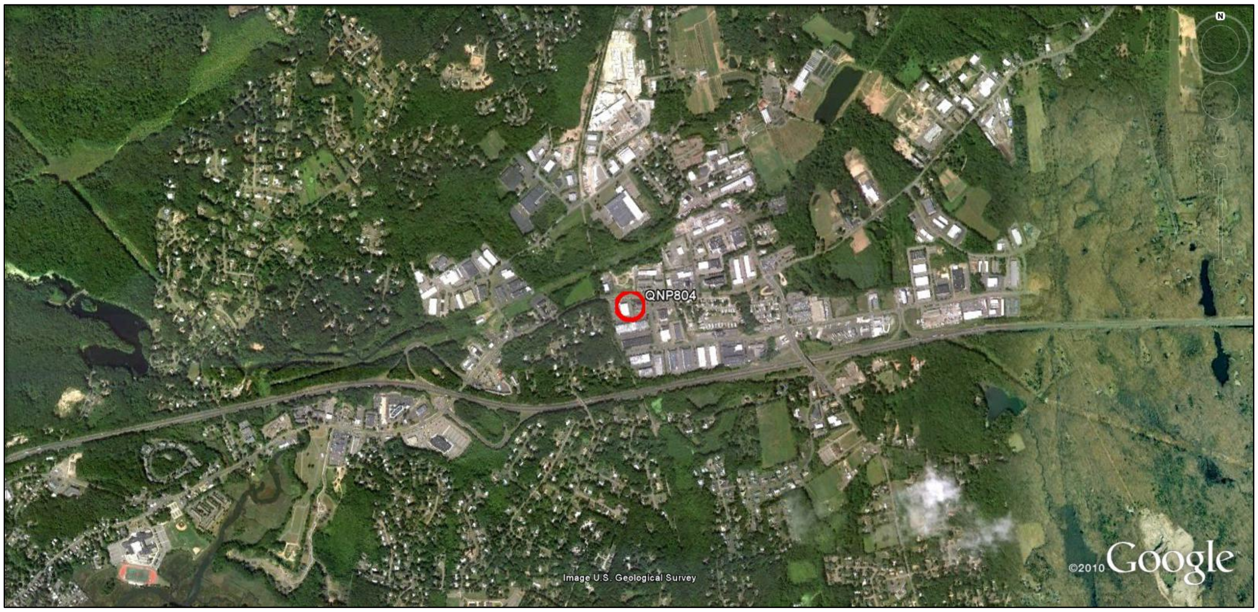

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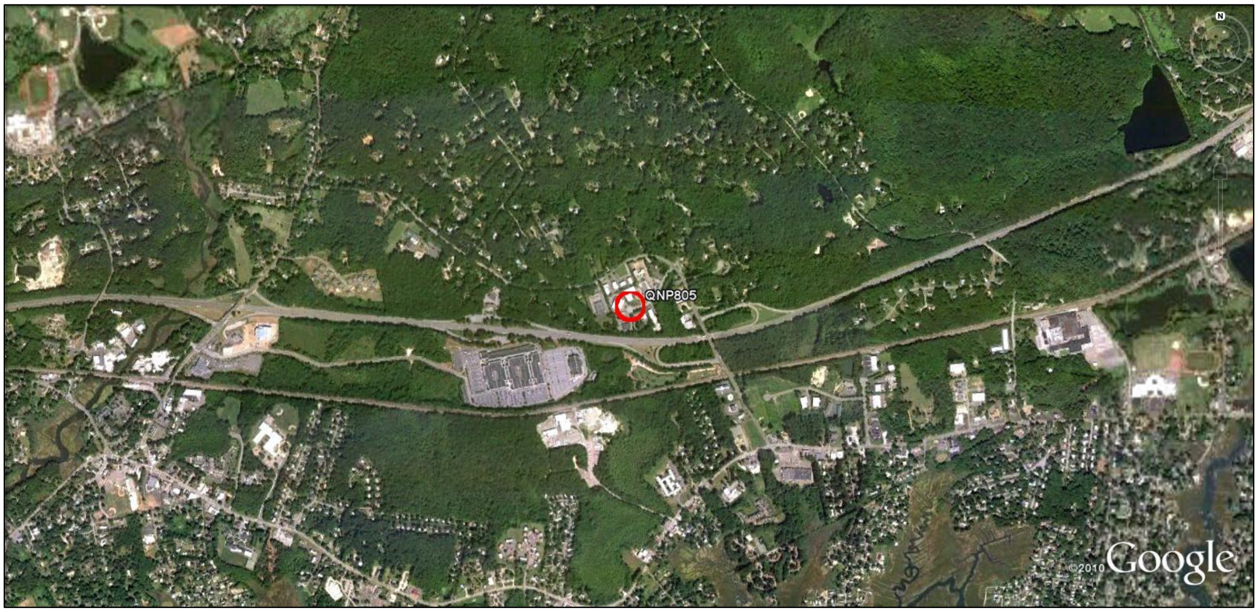

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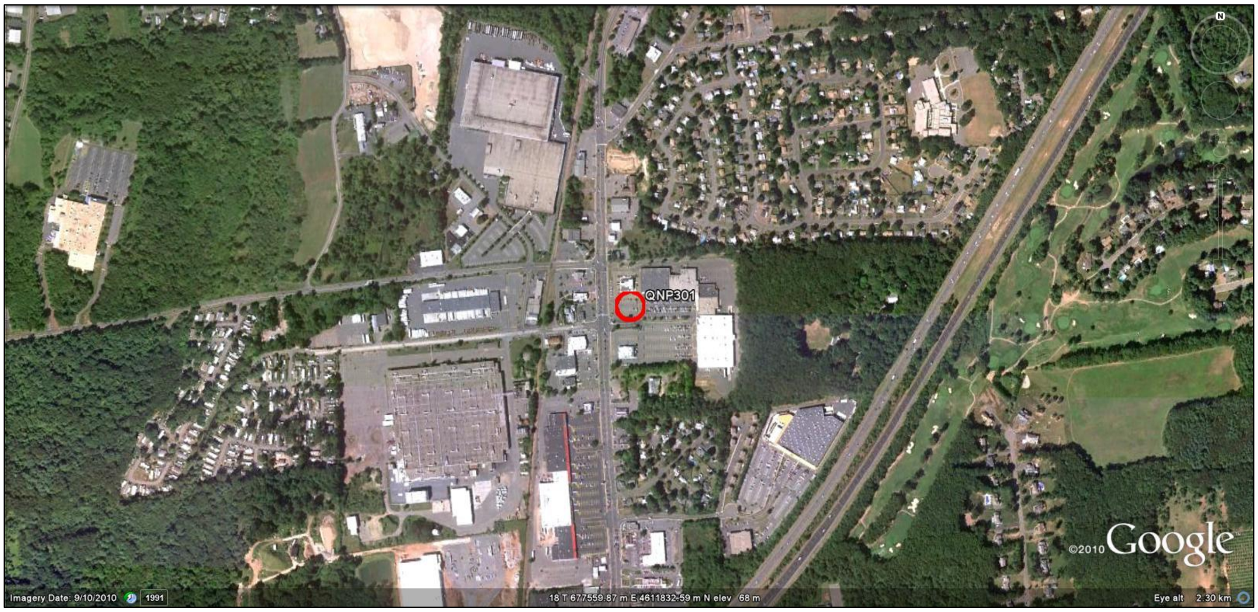
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QNP301
©2010 Google
Imagery Date: 9/10/2010
1991
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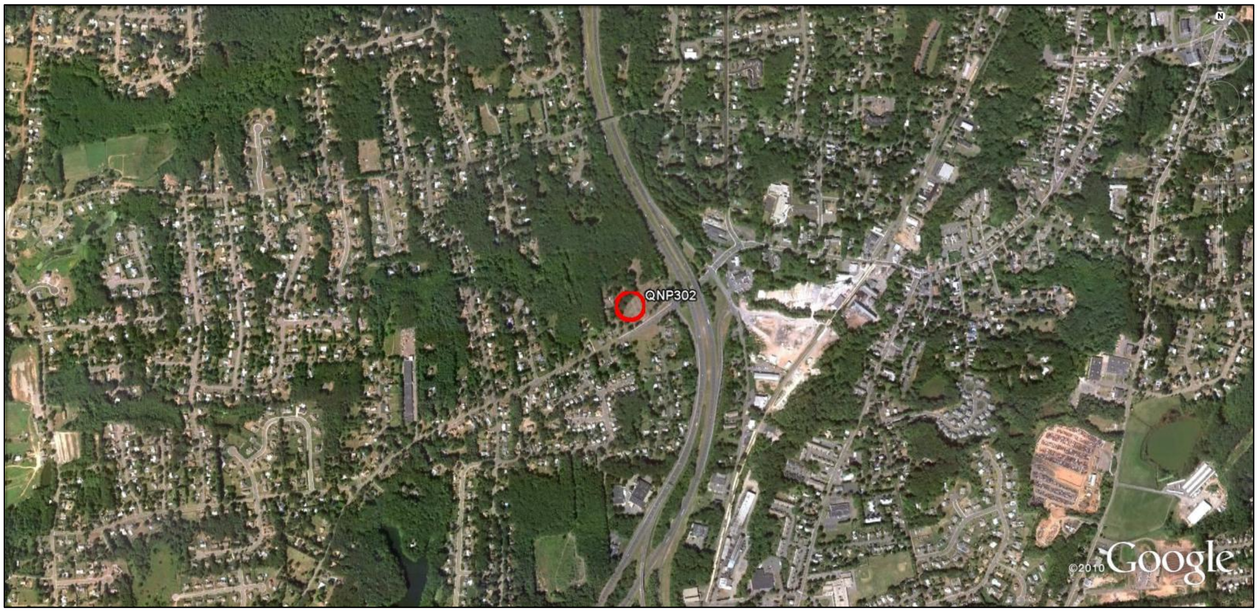
Eye alt 2.30 km

QNP302_C



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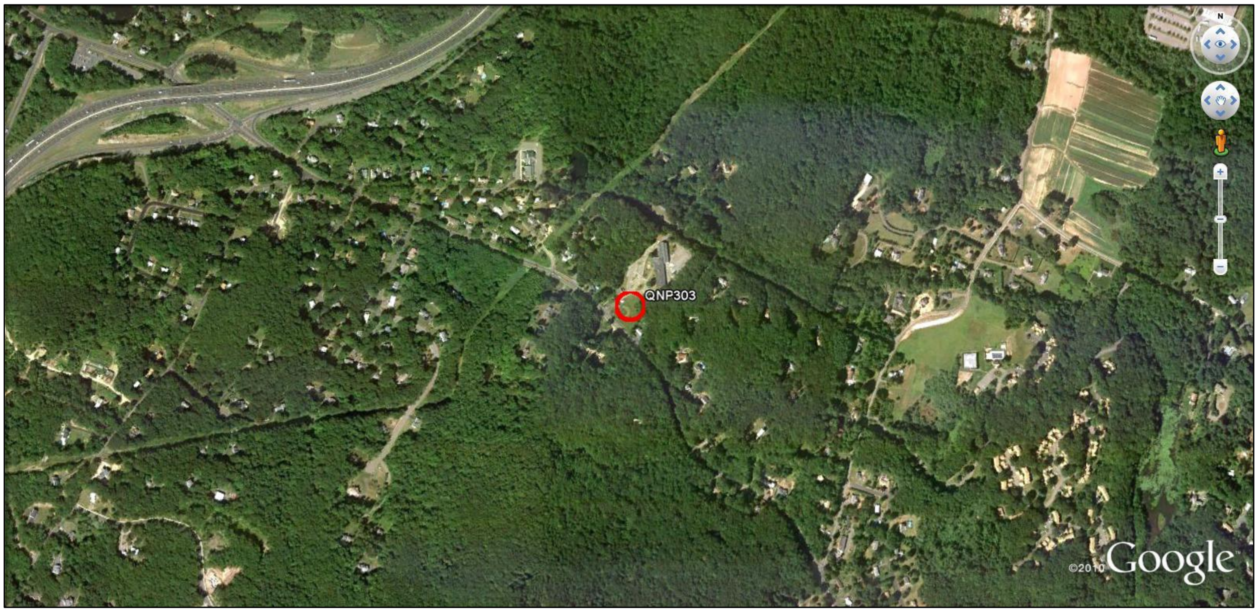

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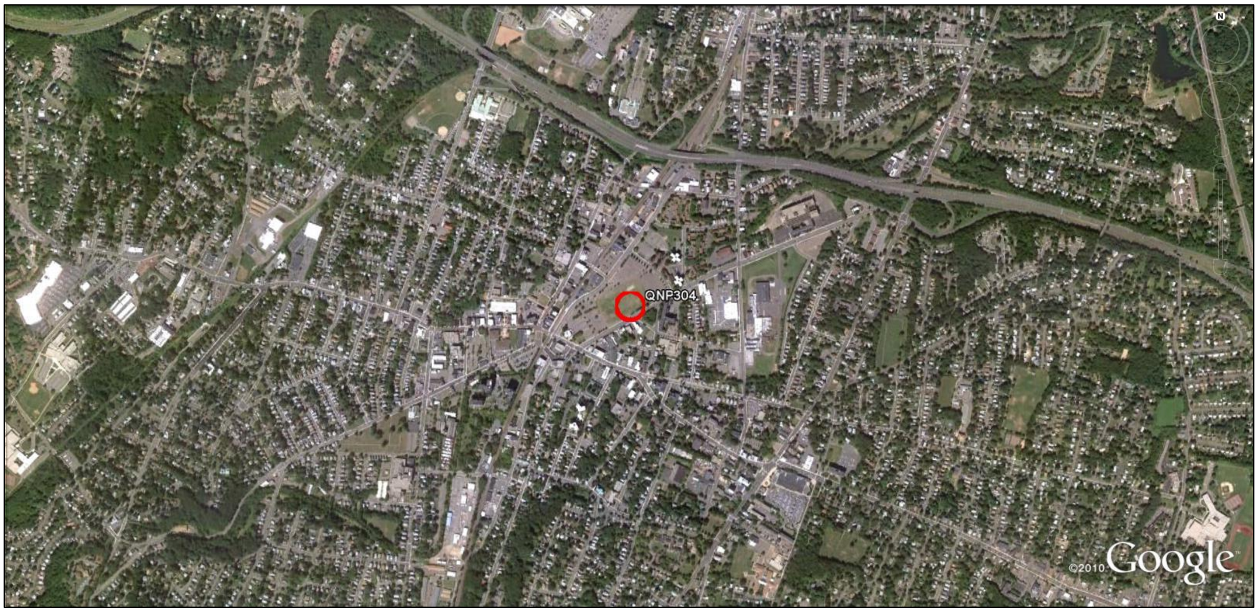

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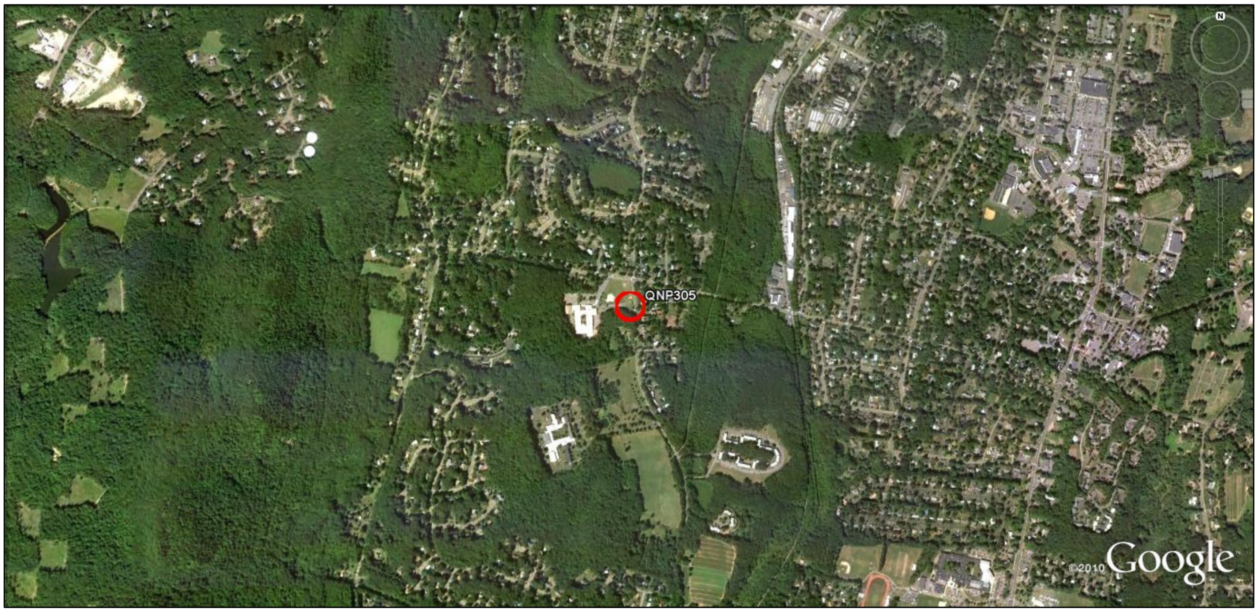

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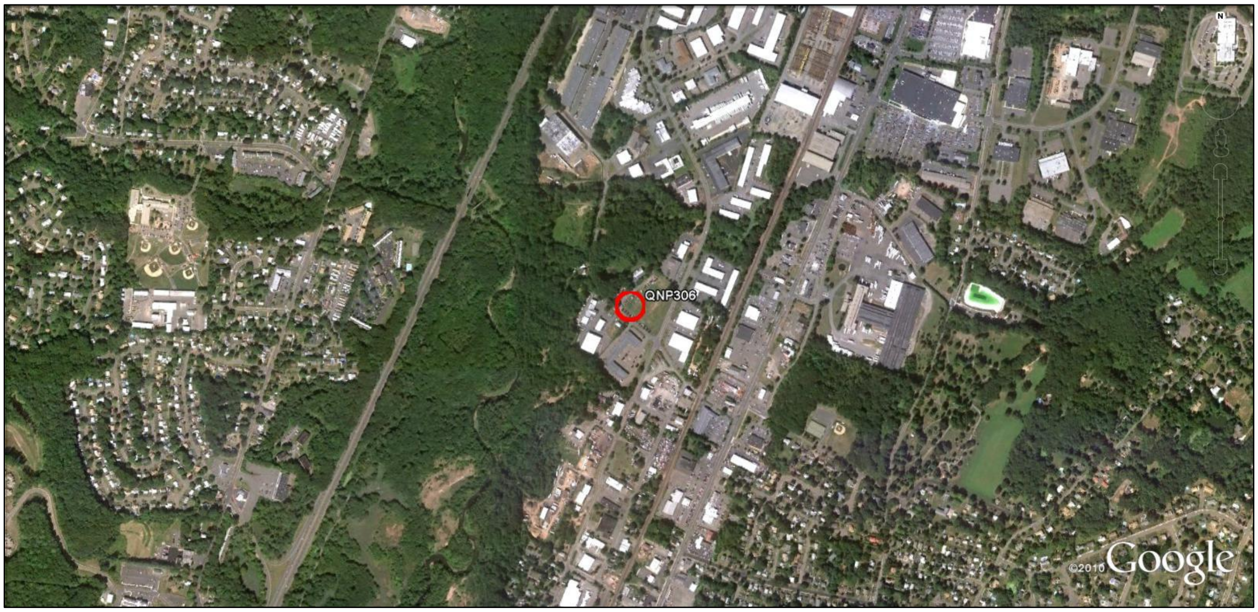

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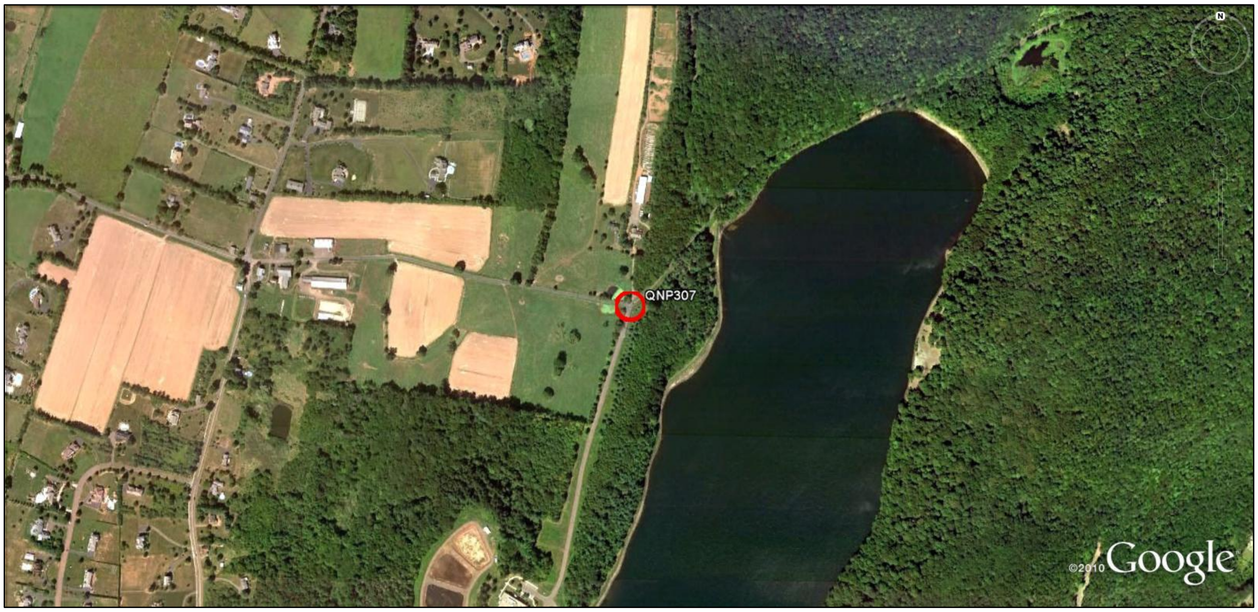

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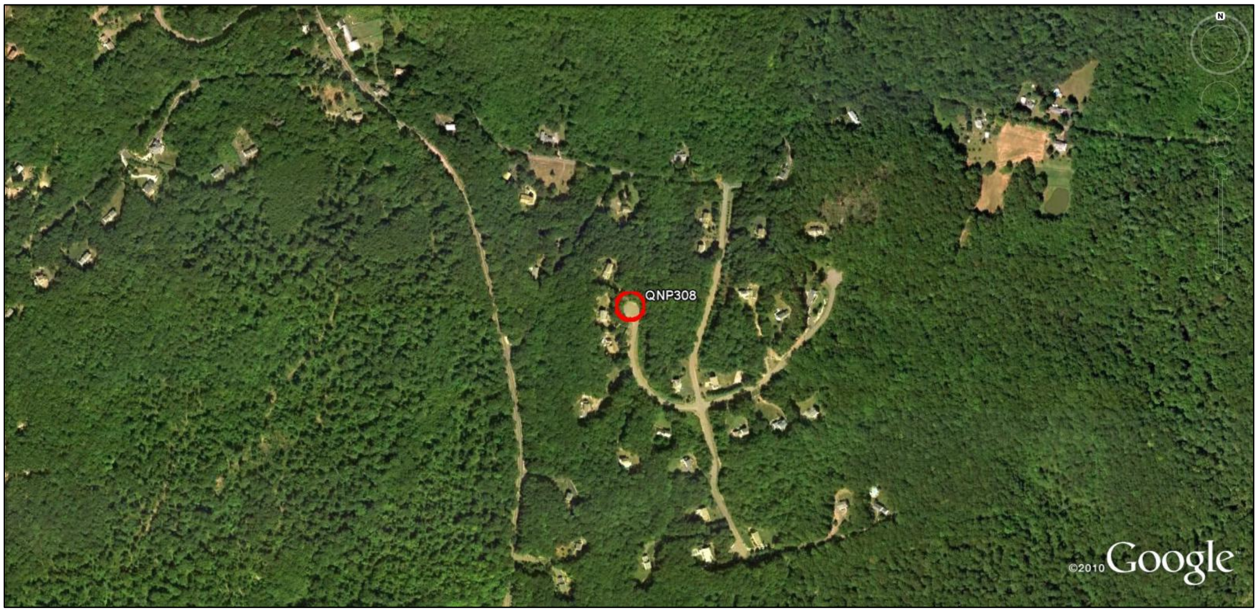

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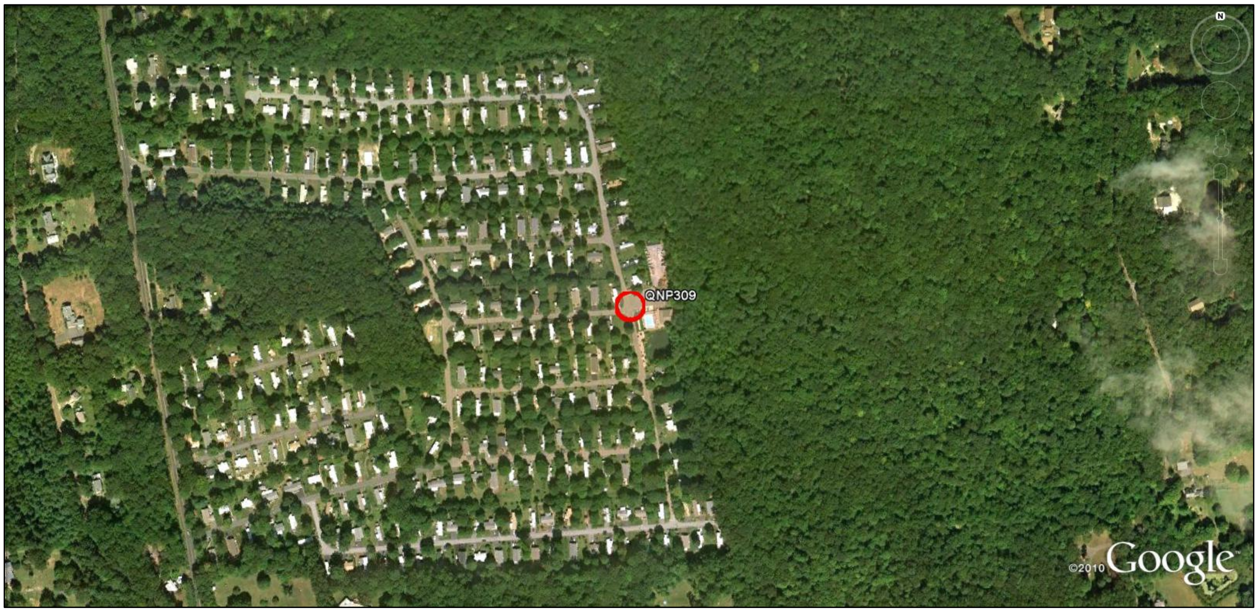

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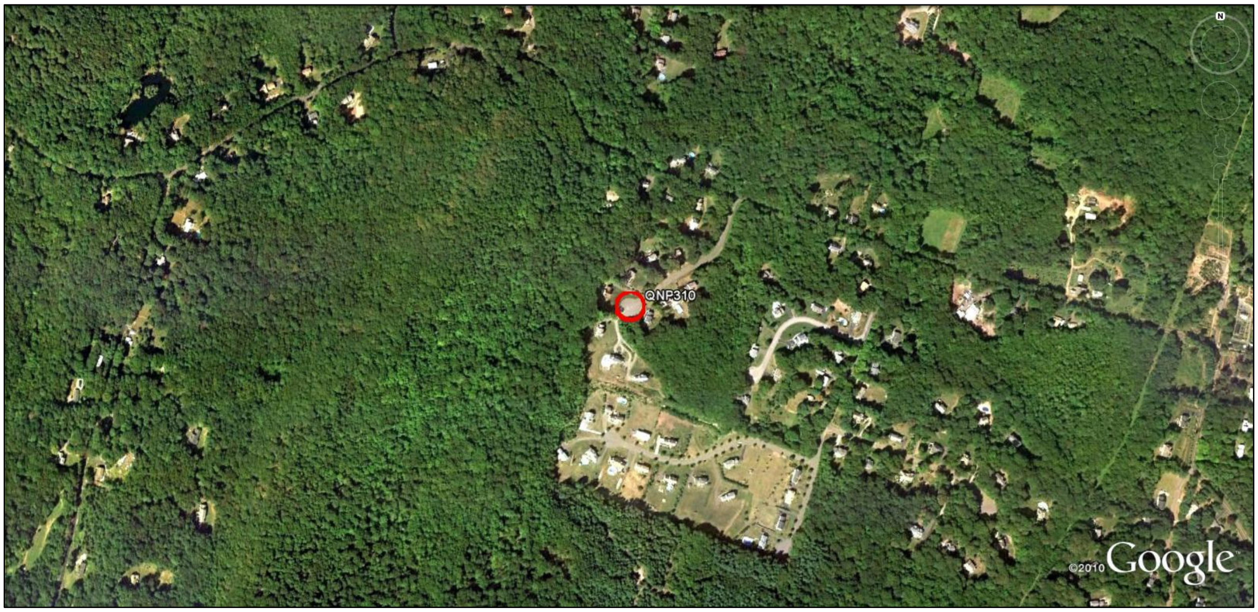
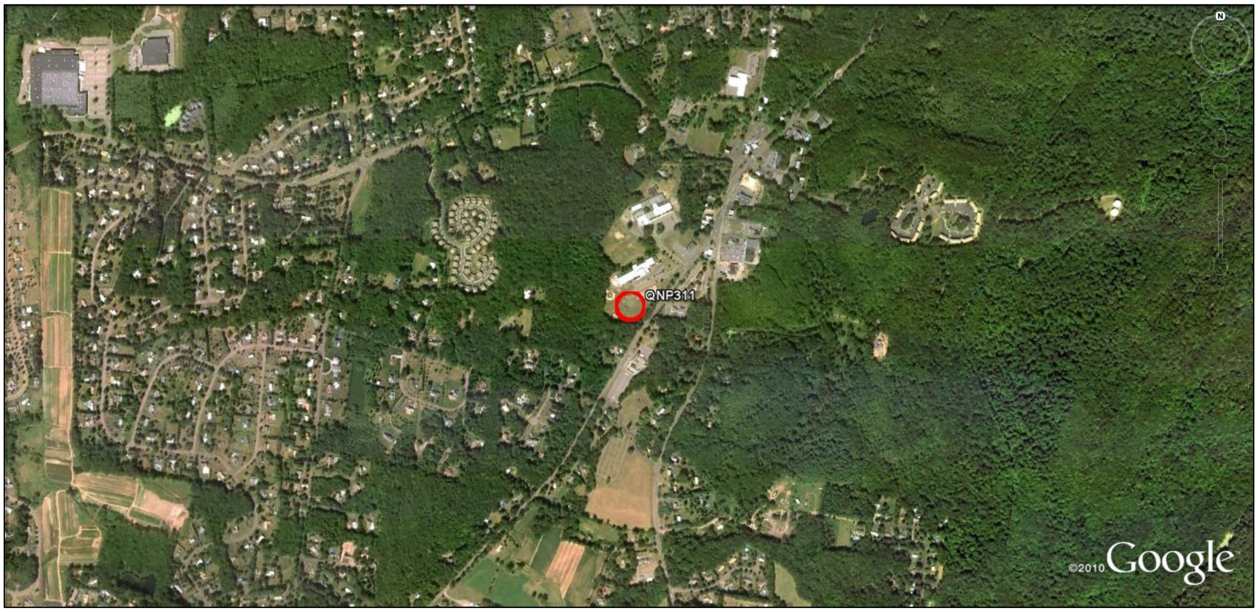
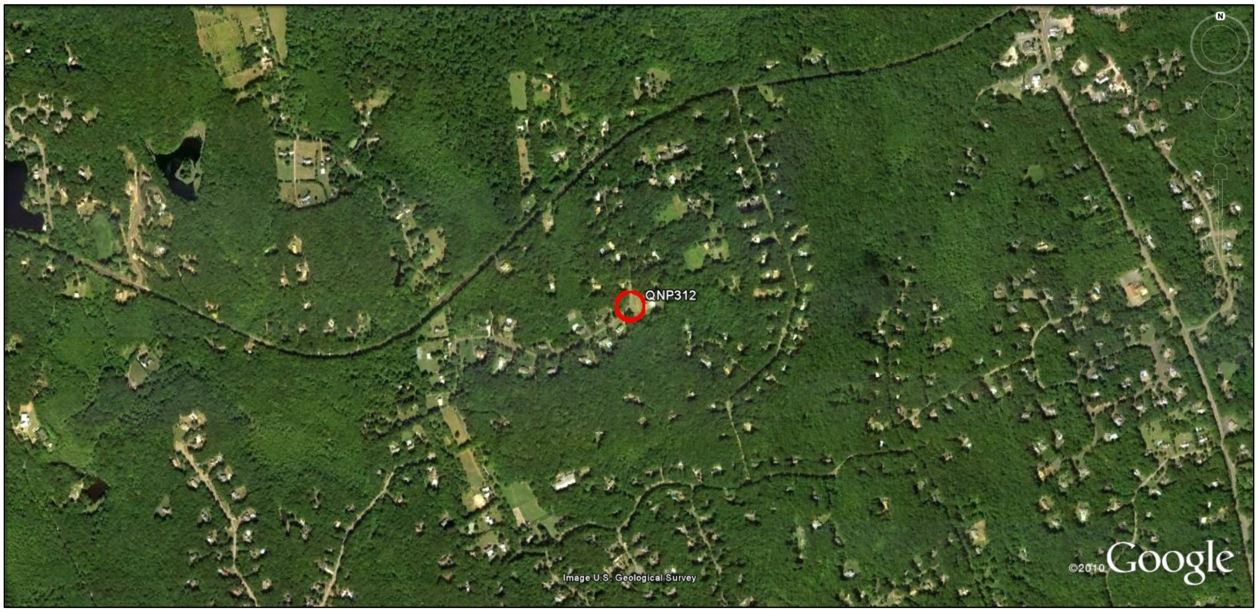


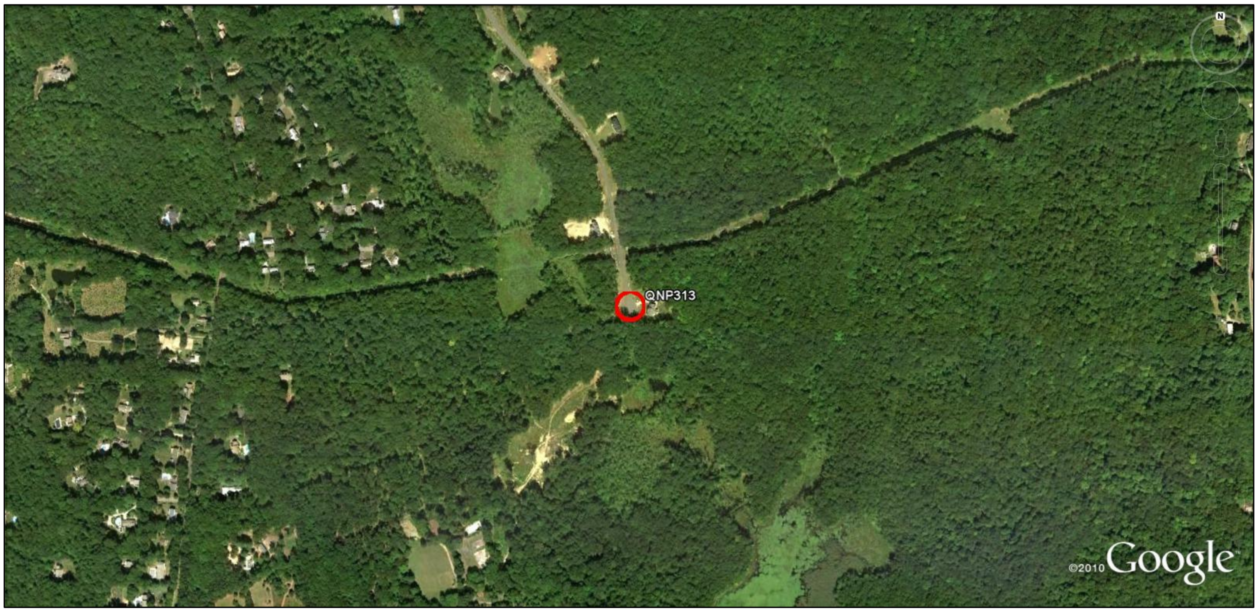
QNP311_C



QNP312_C



QNP313_C



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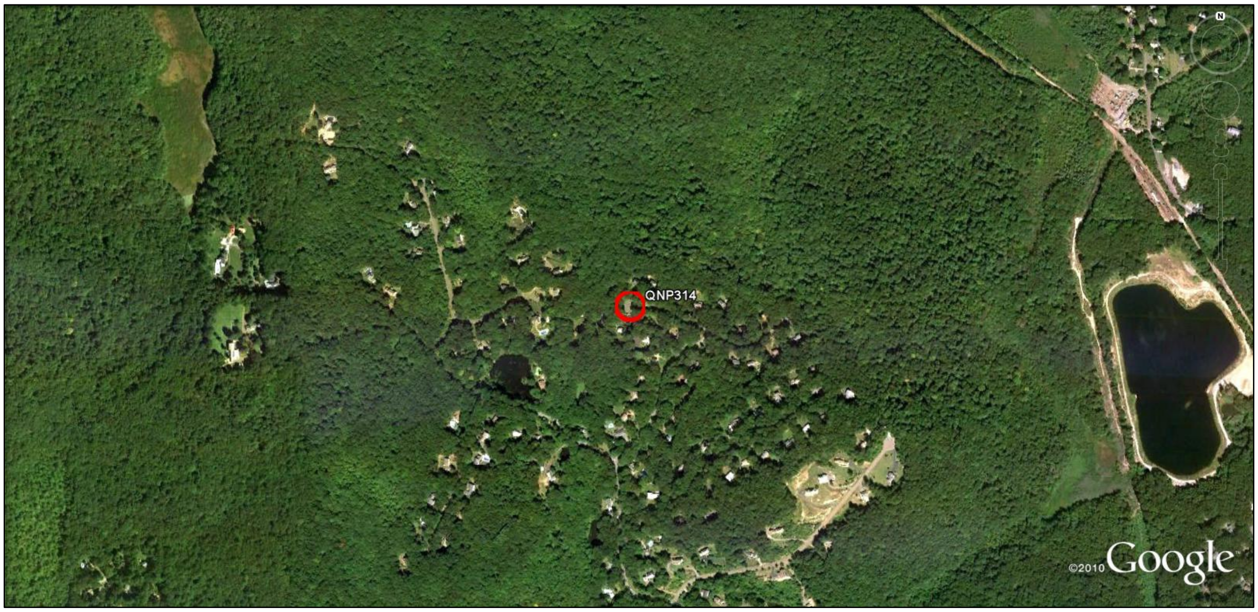
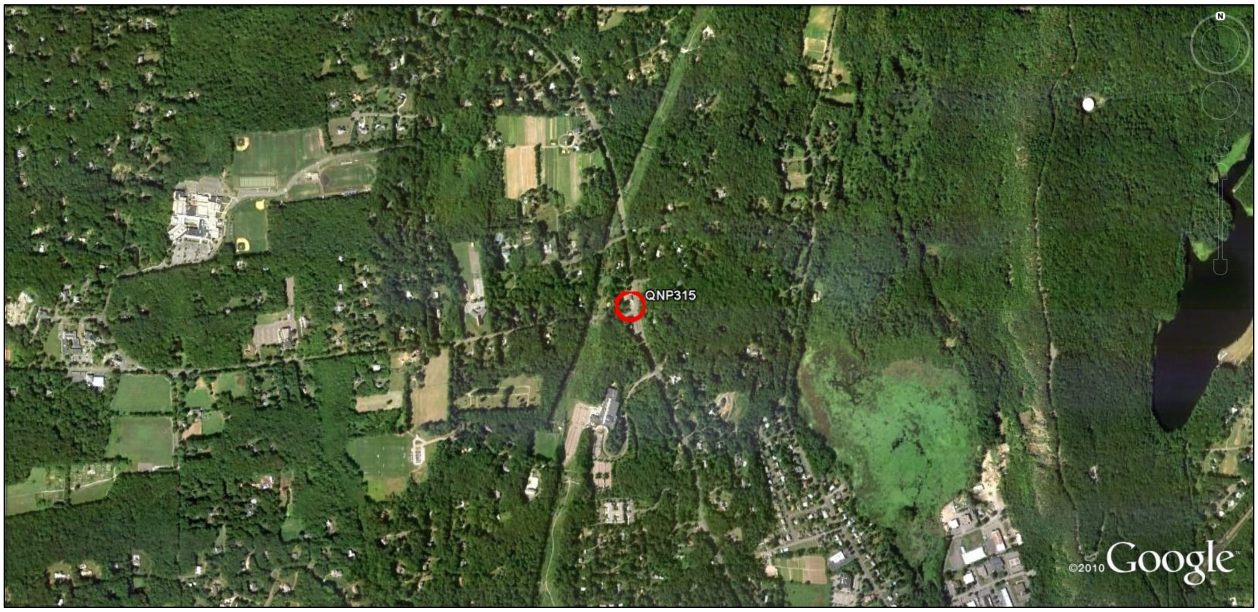
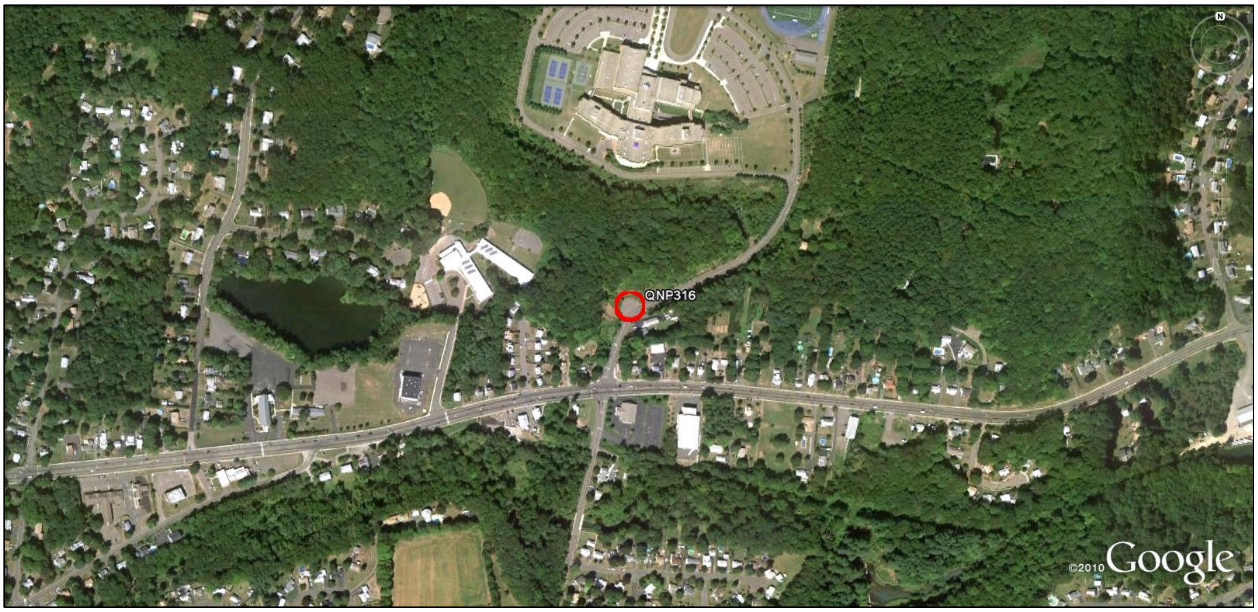


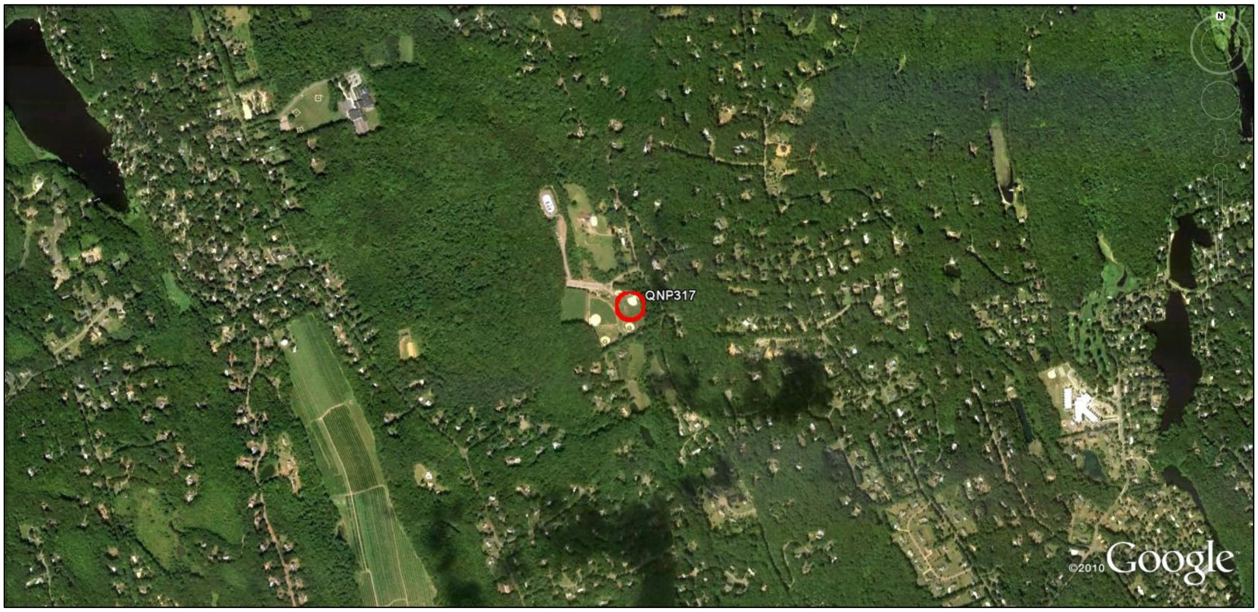
QNP315_C



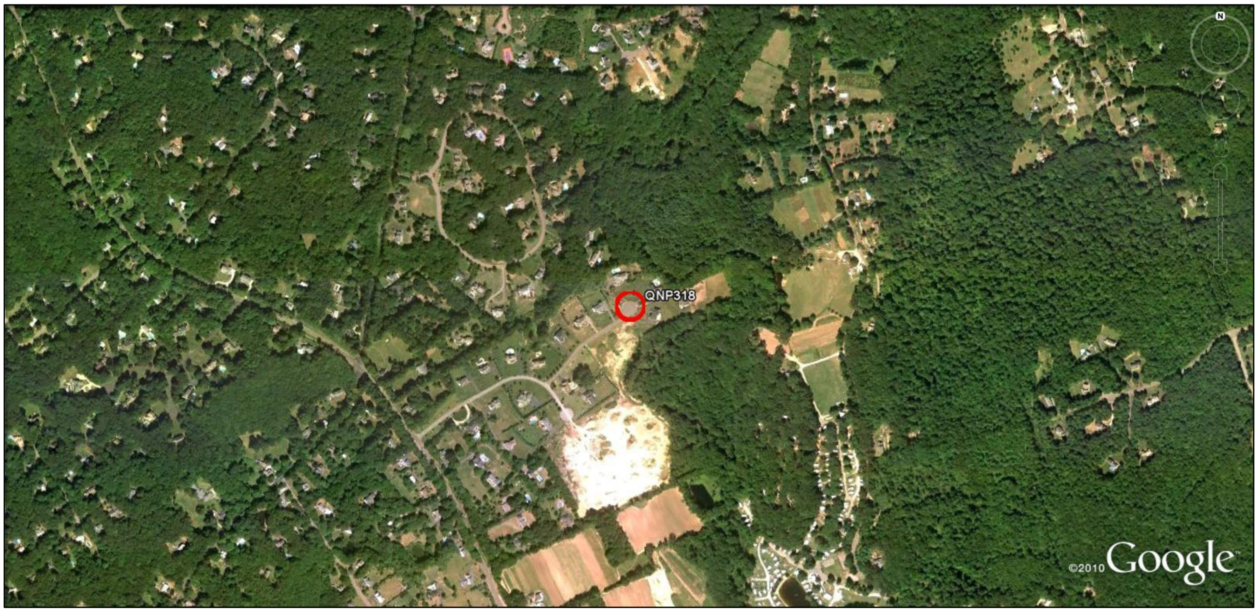
QNP316_C



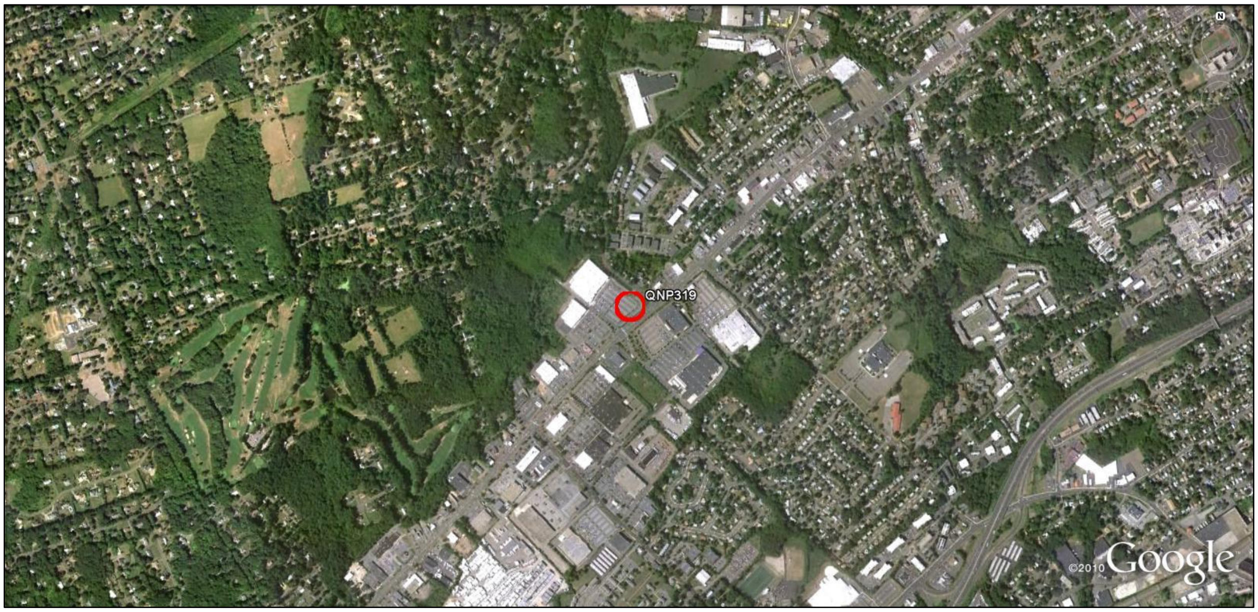
QNP317_C



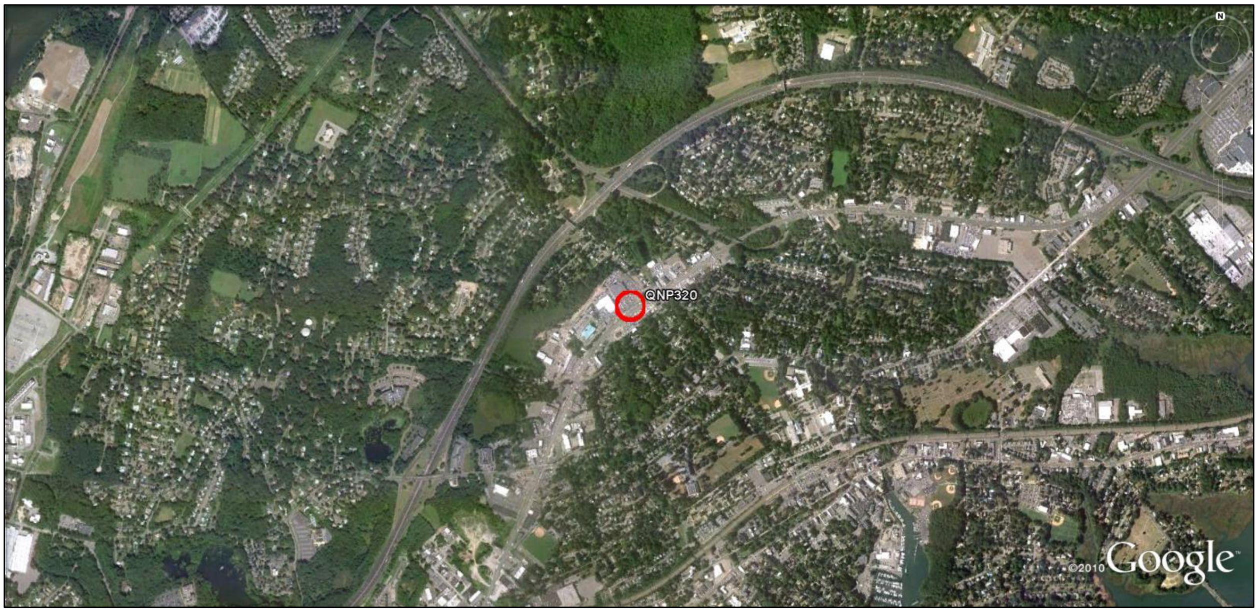
QNP318_C



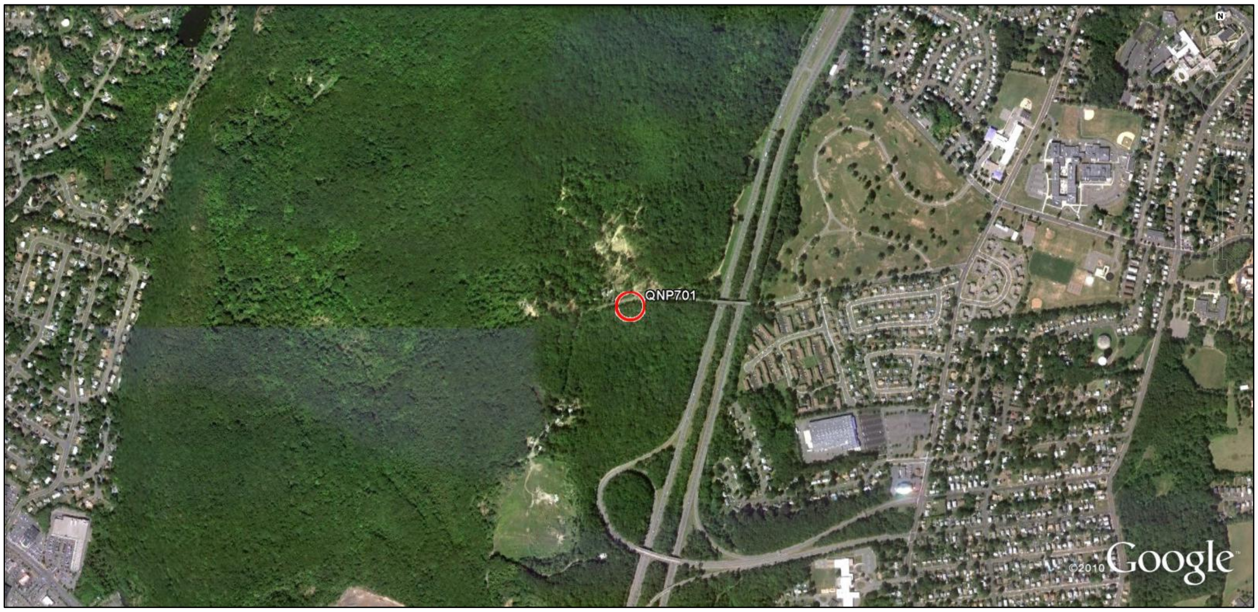
QNP319_C



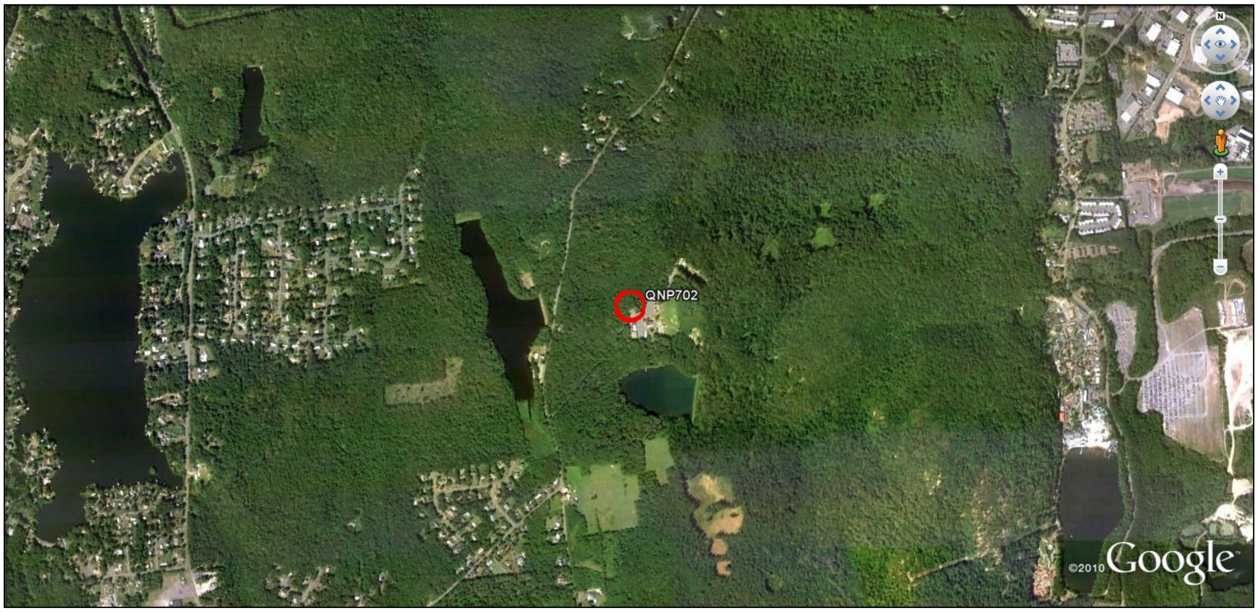
QNP320_C



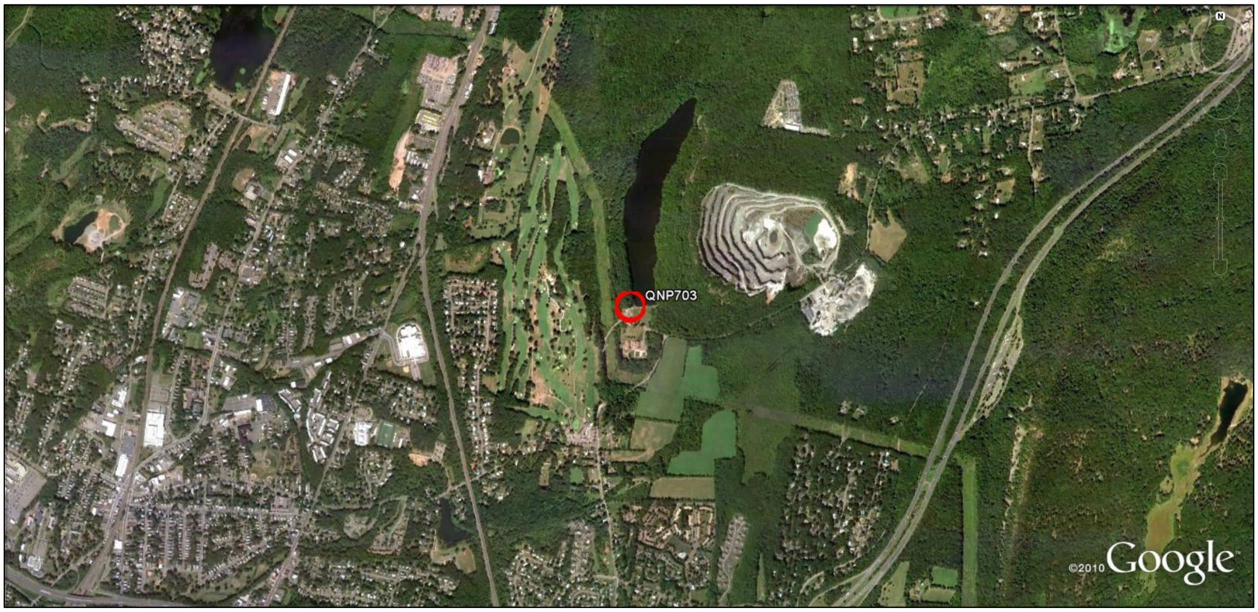
QNP701_C



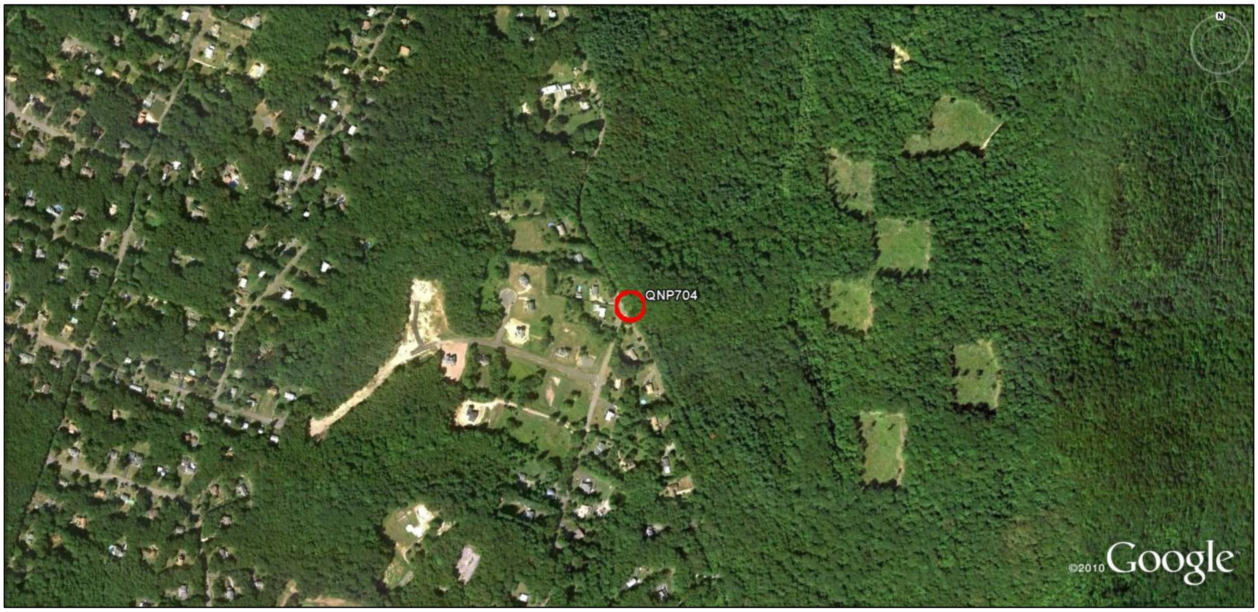
QNP702_C



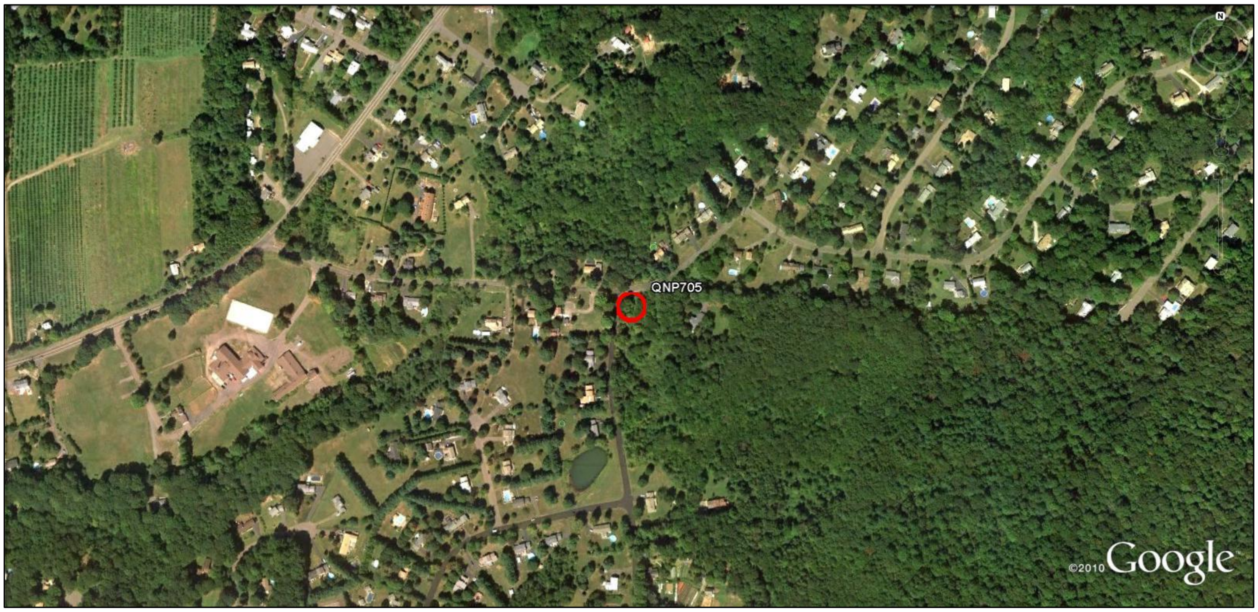
QNP703_C



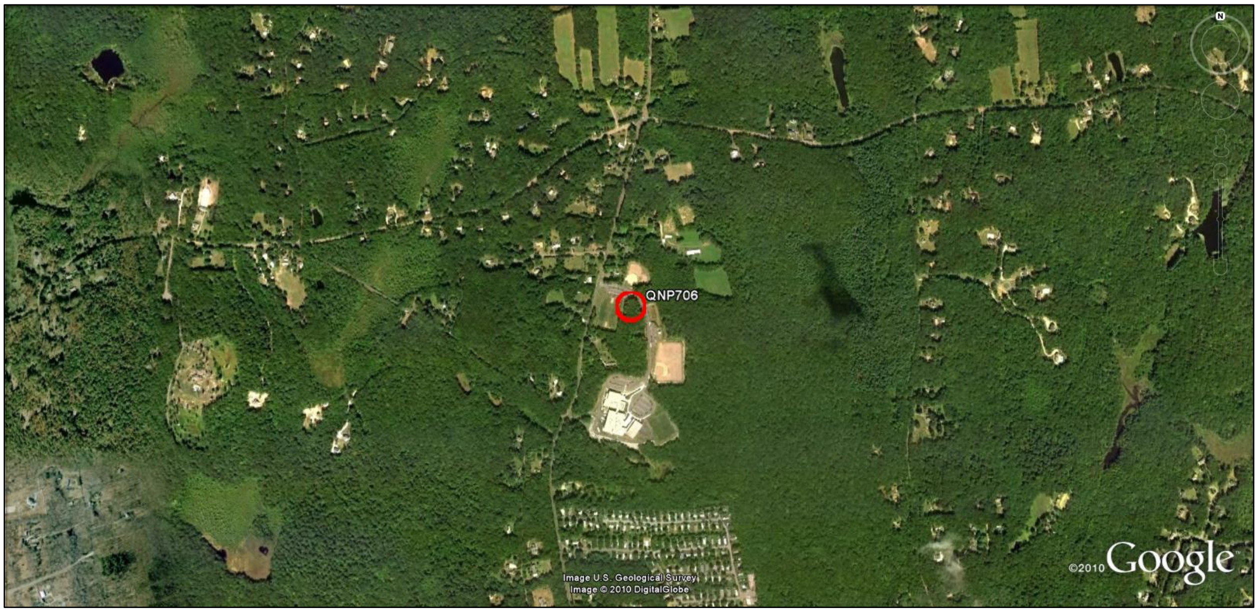
QNP704_C



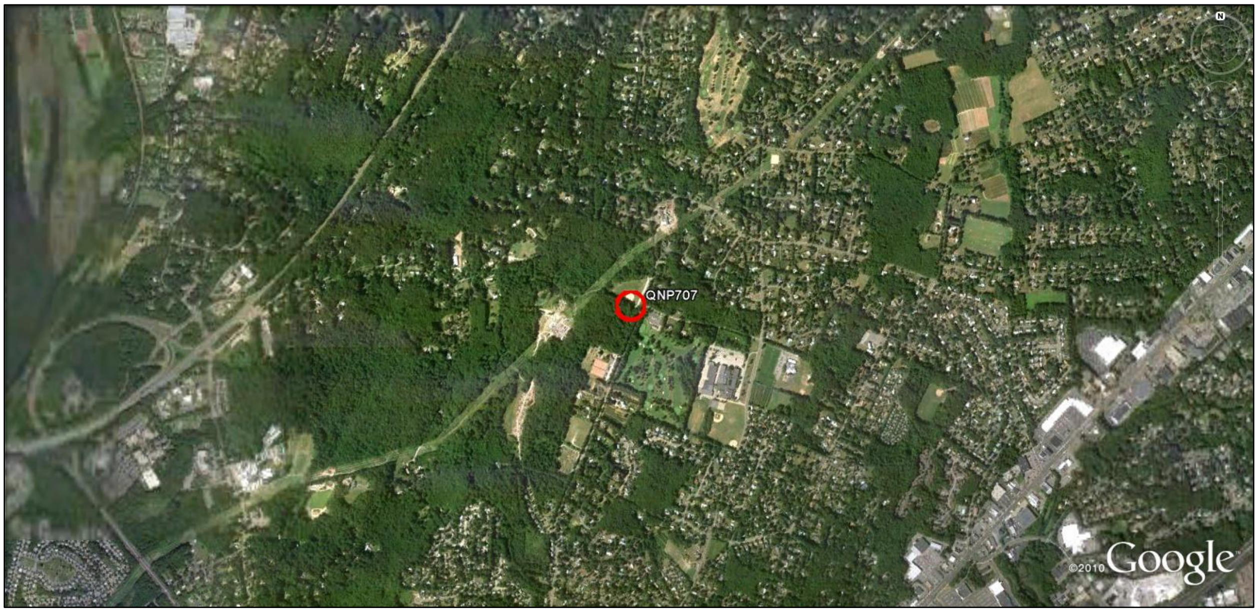
QNP705_C



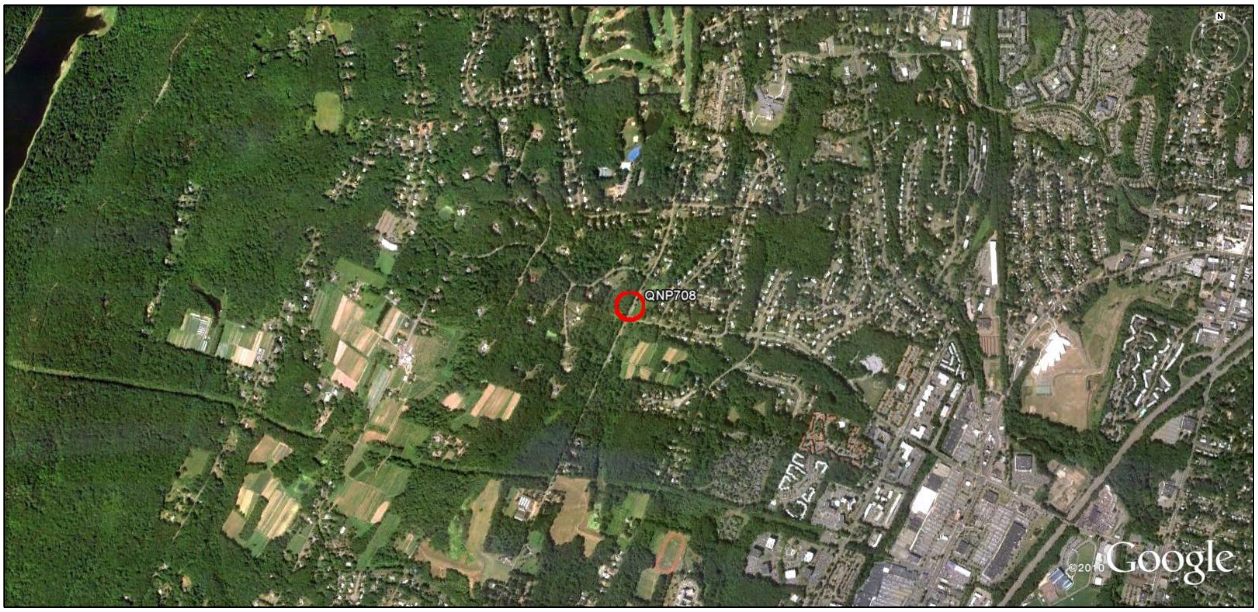
QNP706_C


QNP706
N
Image U.S. Geological Survey
Image © 2010 DigitalGlobe
©2010 Google

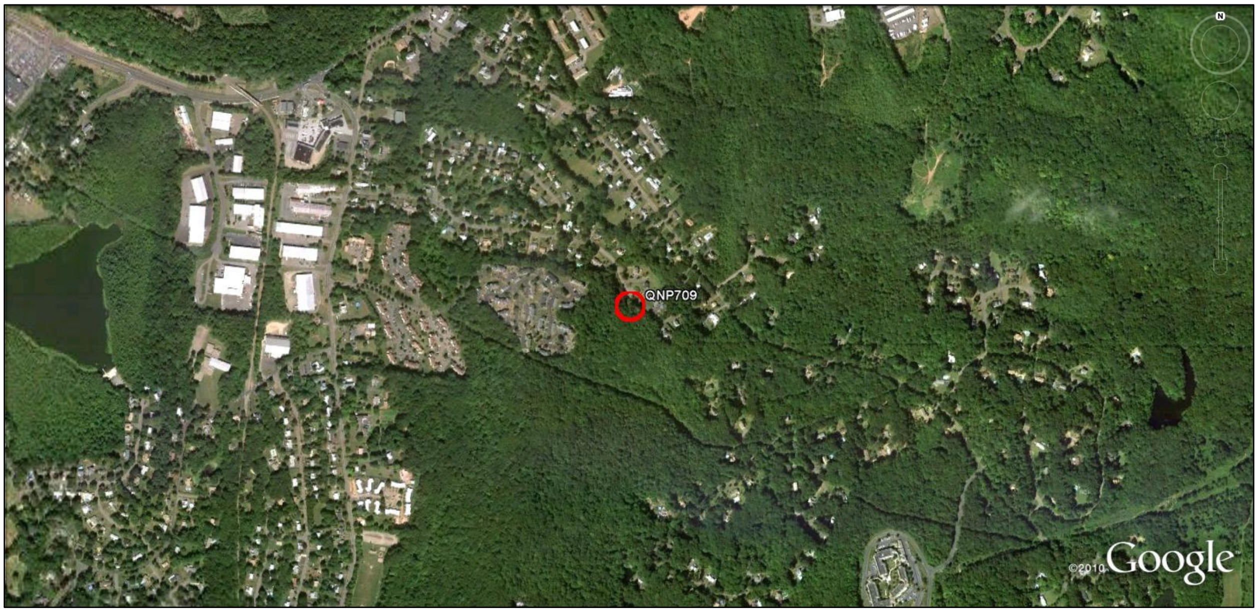
QNP707_C



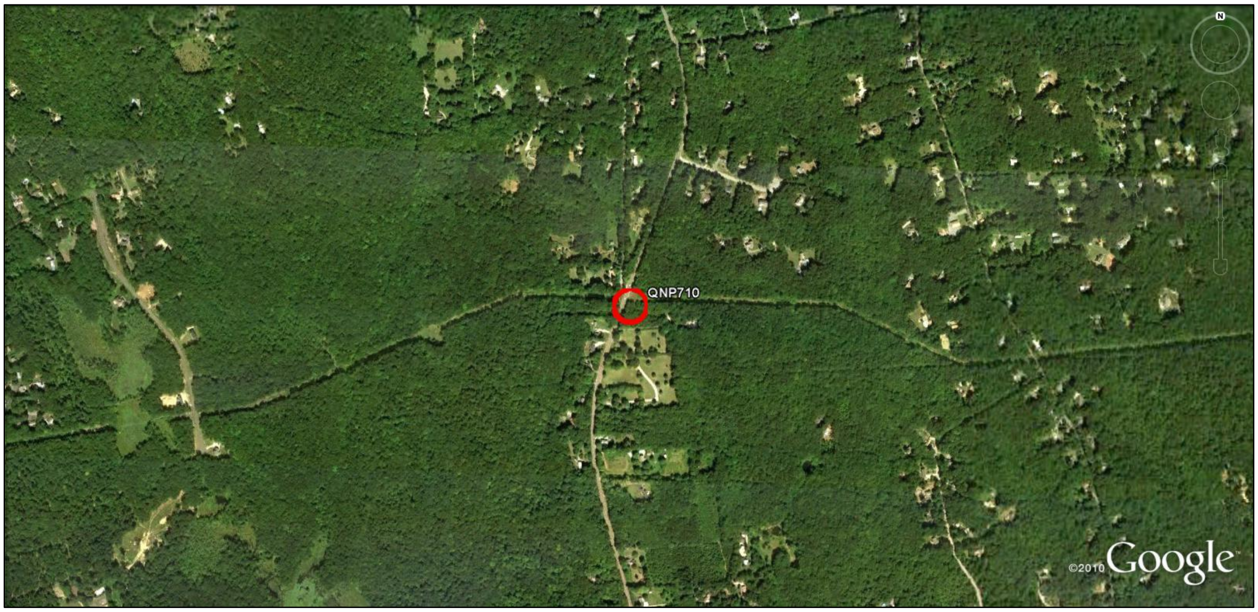
QNP708_C



QNP709_C



QNP710_C

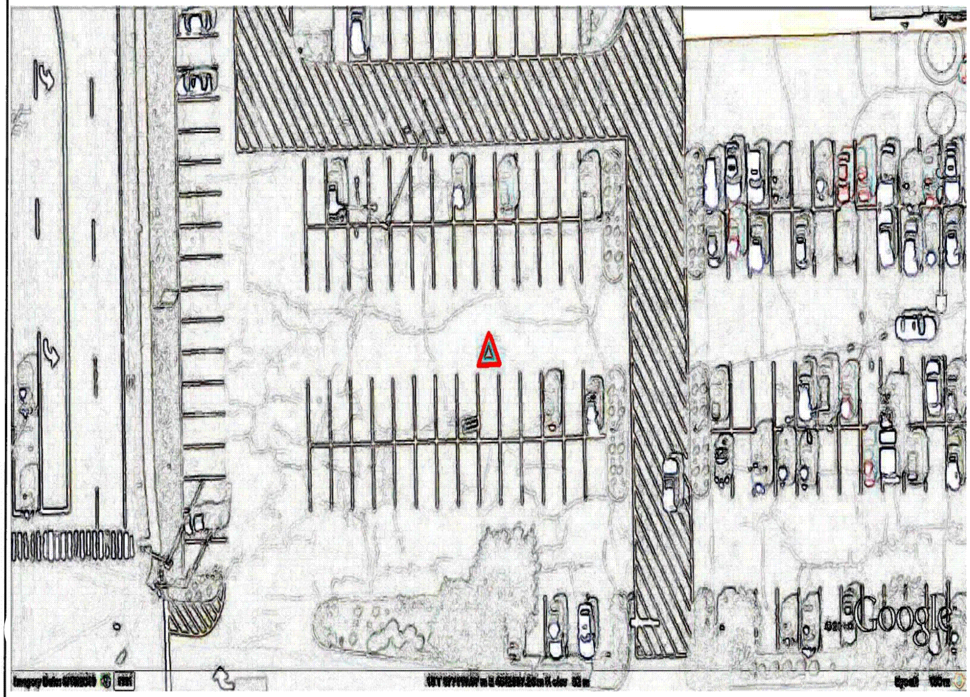


QNP301

CompassData

GCP Station Diagram for LiDAR

Project Name: Quinnipiac	**GCP Number:** QNP301
CDI Project Number: 1508	**Date:** 10/19/2010



GPS Antenna Height: 2m

Comments:

Point taken in parking lot S of building and E of Queen St.
Hartford County, CT

Disk (Roll) / Frame Number:	**Sketch** 1 **of** 1
Collected By: Bryan Frazier	**Checked By:**

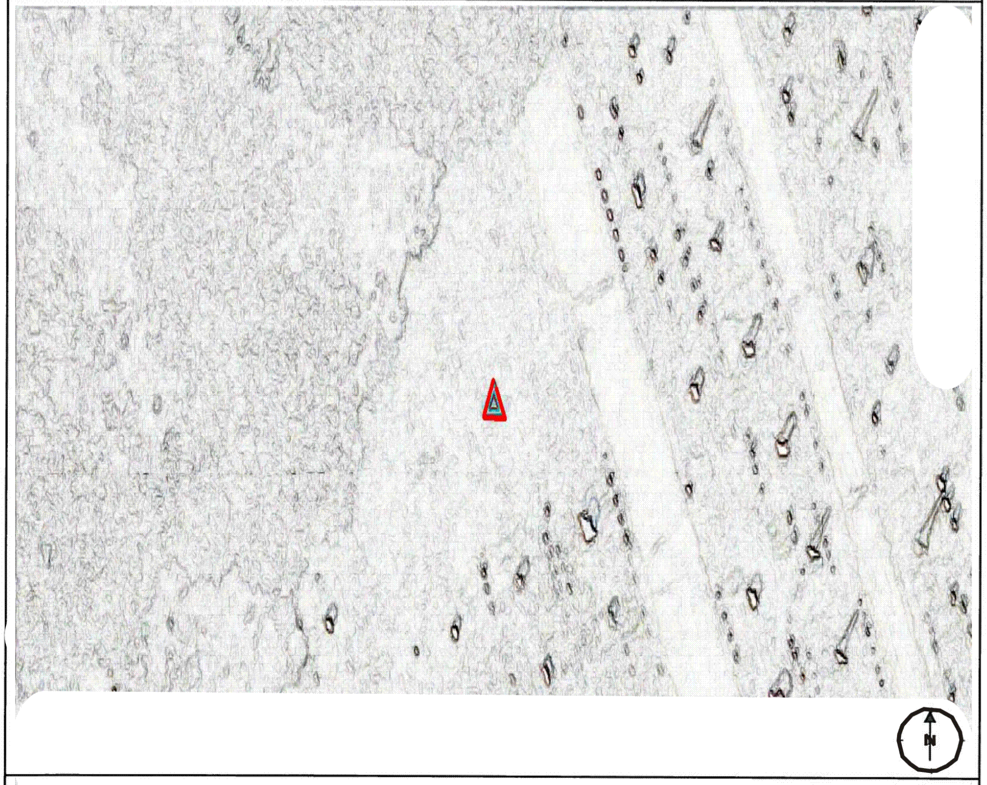
CompassData, Inc., 12353 E. Easter Ave., Suite 200, Centennial, CO 80112 CDIGCP-01/04

QNP302

CompassData

GCP Station Diagram for LiDAR

Project Name: Quinnipiac	**GCP Number:** QNP302
CDI Project Number: 1508	**Date:** 10/20/2010



GPS Antenna Height: 2m

Comments:

Point taken in SW part of cemetery NW of Marion Ave.
Hartford County, CT

Disk (Roll) / Frame Number:	**Sketch** 1 **of** 1
Collected By: Bryan Frazier	**Checked By:**

CompassData, Inc., 12353 E. Easter Ave., Suite 200, Centennial, CO 80112 CDIGCP-01/04

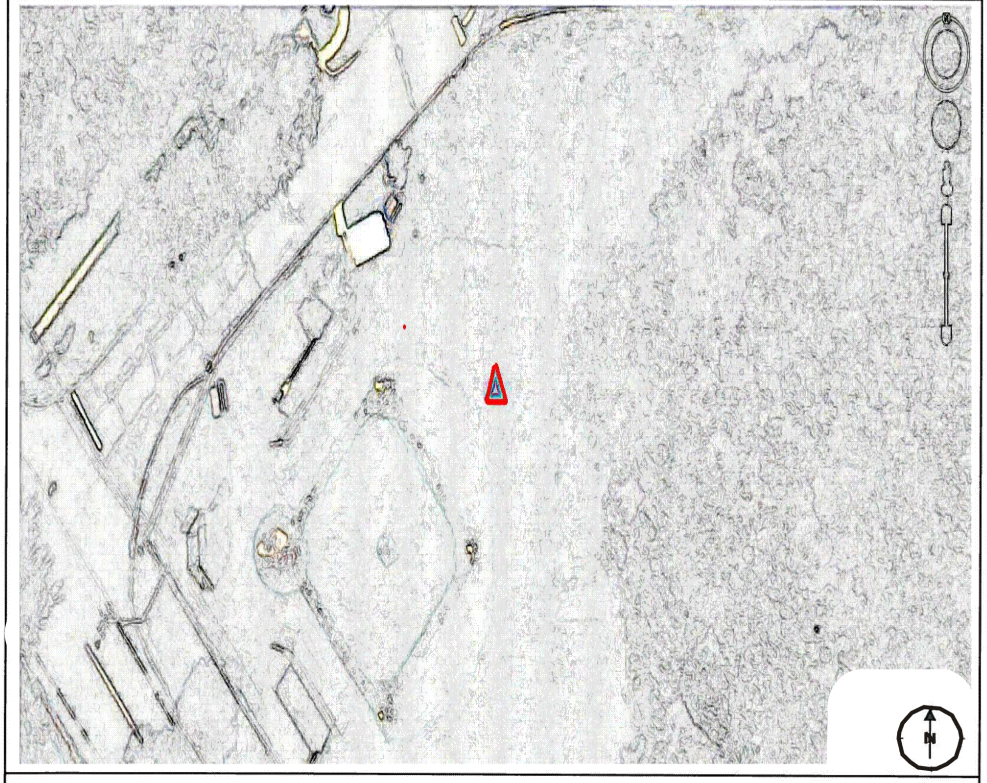
LiDAR

LiDAR

QNP303

GCP Station Diagram for LiDAR

Project Name: Quinnipiac	**GCP Number:** QNP303
CDI Project Number: 1508	**Date:** 10/20/2010



GPS Antenna Height: 2m

Comments:

Point taken in NE part of baseball field.
New Haven County, CT

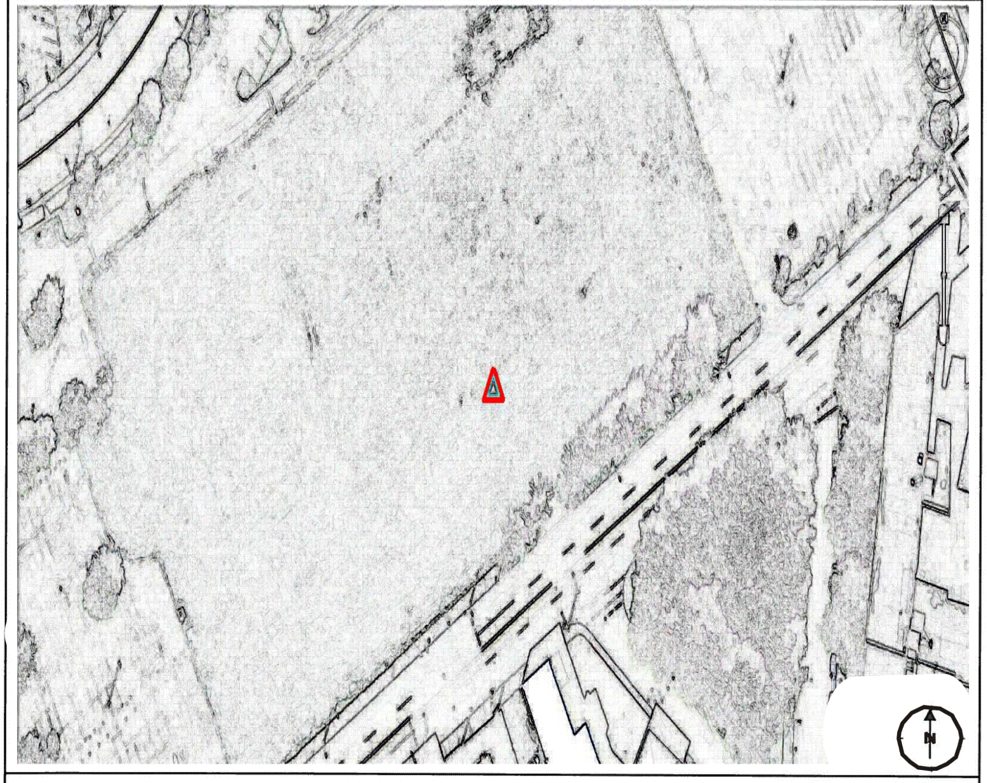
Disk (Roll) / Frame Number:	**Sketch** 1 **of** 1
Collected By: Bryan Frazier	**Checked By:**

QNP304

CompassData

GCP Station Diagram for LiDAR

Project Name: Quinnipiac	**GCP Number:** QNP304
CDI Project Number: 1508	**Date:** 10/18/2010



GPS Antenna Height: 2m

Comments:

Point taken in field NW of Pratt St, SE of State St, SW of Mill St.
New Haven County, CT

Disk (Roll) / Frame Number:	**Sketch** 1 **of** 1
Collected By: Bryan Frazier	**Checked By:**

QNP305

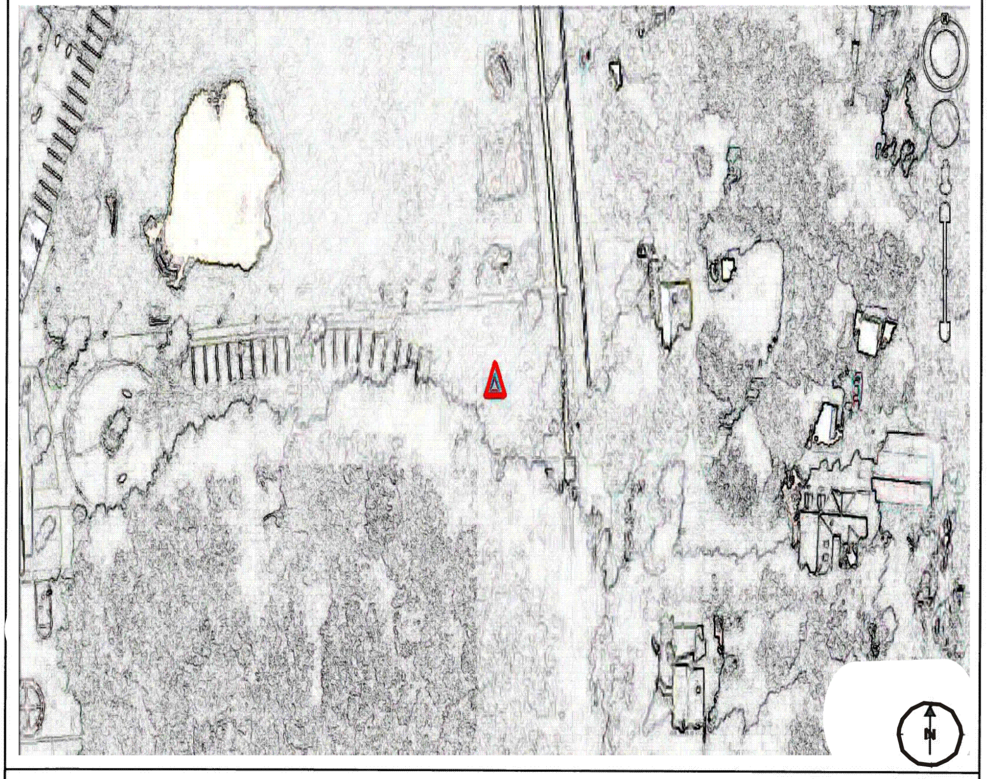
CompassData

GCP Station Diagram for LiDAR

LiDAR

LiDAR

Project Name: Quinnipiac	**GCP Number:** QNP305
CDI Project Number: 1508	**Date:** 10/19/2010



GPS Antenna Height: 2m

Comments:

Point taken in field E of Doolittle School and parking lot,
W of Oak Ave. and S of Cornwall Ave.
New Haven County, CT

Disk (Roll) / Frame Number:	**Sketch** 1 **of** 1
Collected By: Bryan Frazier	**Checked By:**

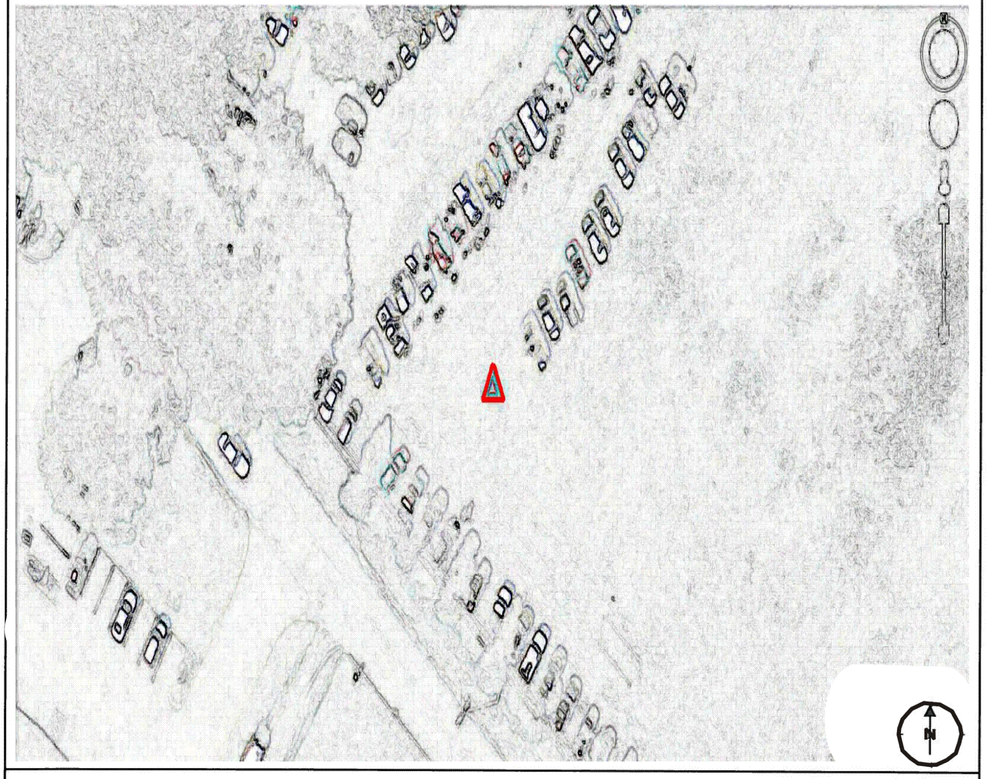
CompassData, Inc., 12353 E. Easter Ave., Suite 200, Centennial, CO 80112 CDIGCP-01/04

QNP306

CompassData

GCP Station Diagram for LiDAR

Project Name: Quinnipiac	**GCP Number:** QNP306
CDI Project Number: 1508	**Date:** 10/20/2010



GPS Antenna Height: 2m

Comments:

Point taken in E corner field, NE of N. Plains Hwy. and NW of
N. Plains Industrial Rd.
New Haven County, CT

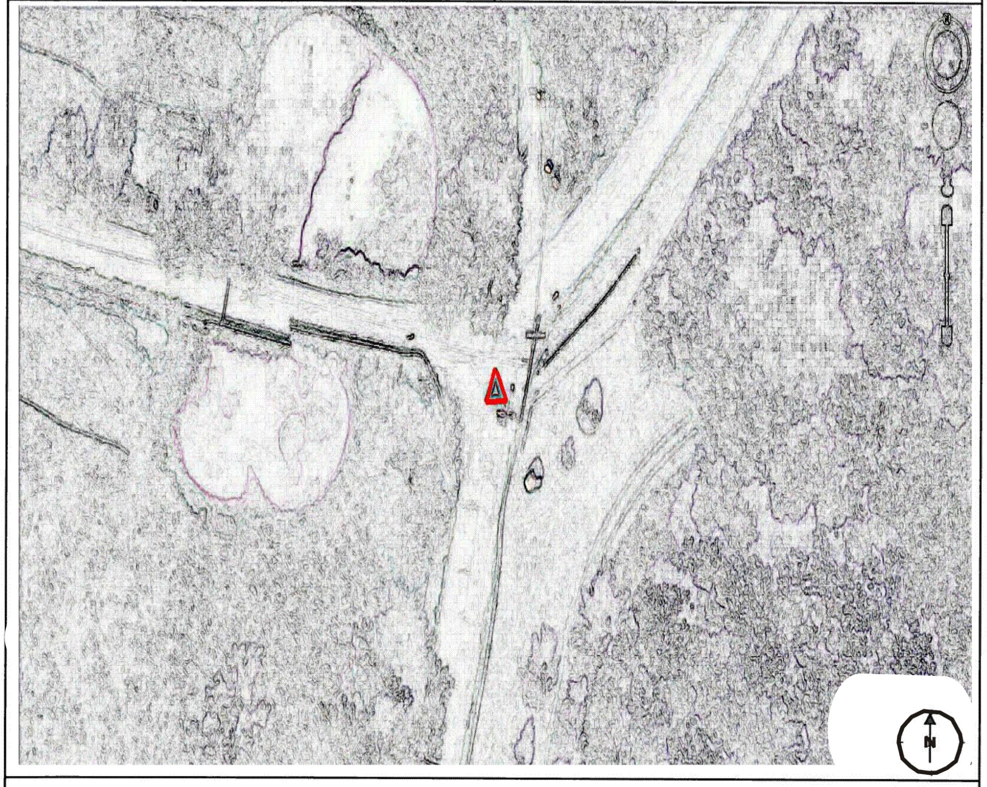
Disk (Roll) / Frame Number:	**Sketch** 1 **of** 1
Collected By: Bryan Frazier	**Checked By:**

QNP307

CompassData

GCP Station Diagram for LiDAR

Project Name: Quinnipiac	**GCP Number:** QNP307
CDI Project Number: 1508	**Date:** 10/19/2010



GPS Antenna Height: 2m

Comments:

Point taken at intersection of Whirlwind Hill Rd and a private business drive.
New Haven County, CT

Disk (Roll) / Frame Number:	**Sketch** 1 **of** 1
Collected By: Bryan Frazier	**Checked By:**

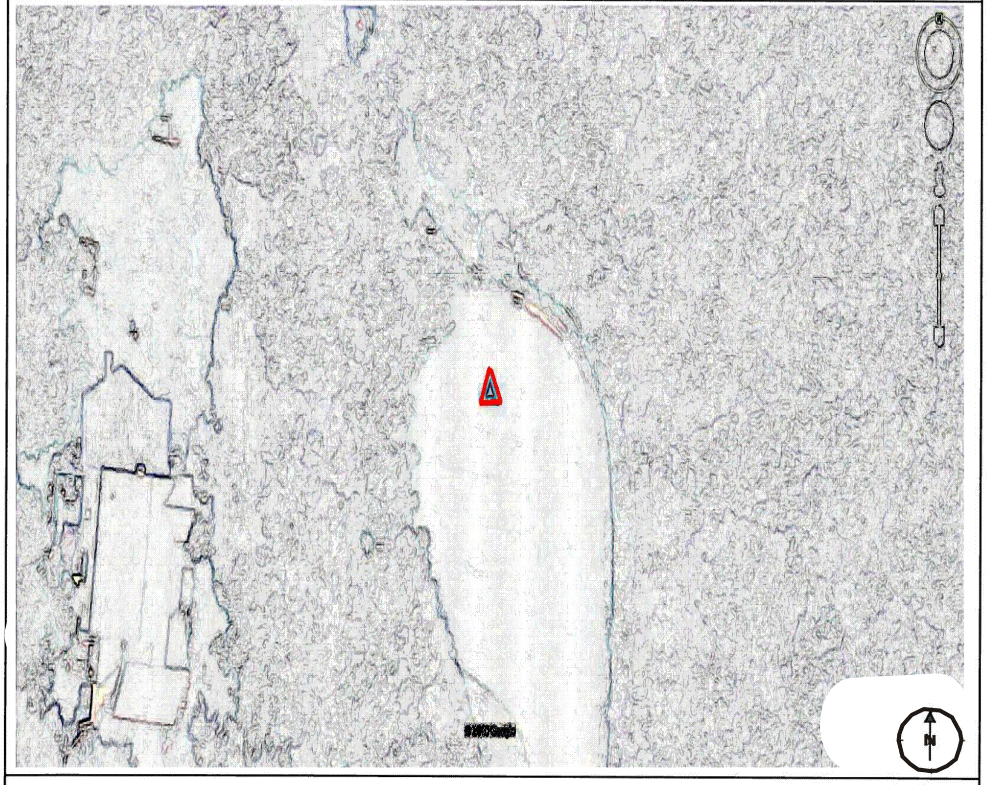
QNP308

CompassData

GCP Station Diagram for LiDAR

Project Name: Quinnipiac	**GCP Number:** QNP308
CDI Project Number: 1508	**Date:** 10/20/2010

LiDAR



LiDAR

GPS Antenna Height: 2m

Comments:

Point taken at N end of culdesac of new road that branches off of Suffolk Dr.
New Haven County, CT

Disk (Roll) / Frame Number:	**Sketch** 1 **of** 1
Collected By: Bryan Frazier	**Checked By:**

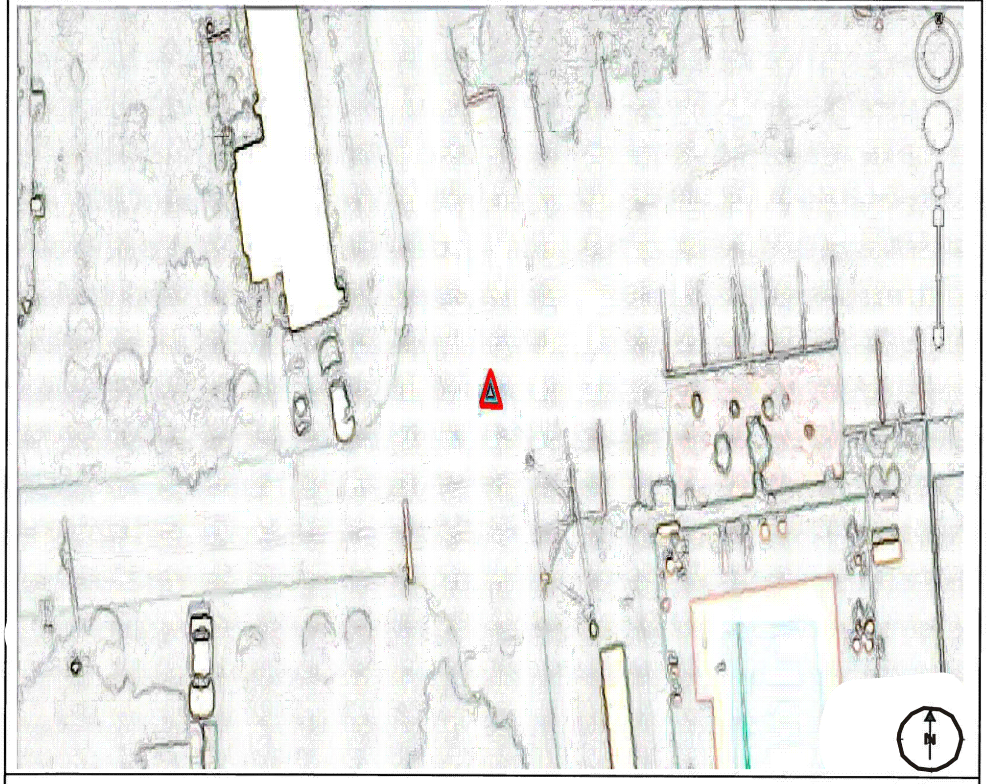
QNP309

CompassData

GCP Station Diagram for LiDAR

LiDAR

Project Name: Quinnipiac	**GCP Number:** QNP309
CDI Project Number: 1508	**Date:** 10/20/2010



GPS Antenna Height: 2m

Comments:

Point taken at intersection of Pleasant Trail and Swan lake Trail.
Middlesex County, CT

Disk (Roll) / Frame Number:	**Sketch** 1 **of** 1
Collected By: Bryan Frazier	**Checked By:**

LiDAR

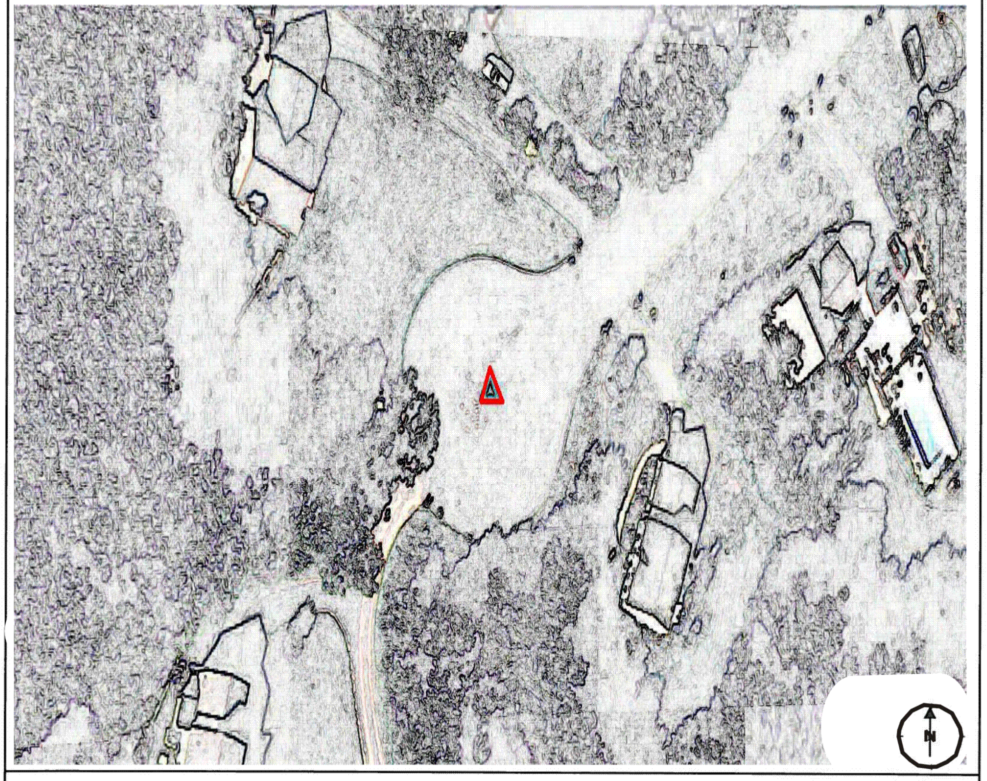
QNP310

CompassData

GCP Station Diagram for LiDAR

LiDAR

Project Name: Quinnipiac	**GCP Number:** QNP310
CDI Project Number: 1508	**Date:** 10/20/2010



GPS Antenna Height: 2m

Comments:

Point taken at the culdesac of Deer Pond Trail.
New Haven County, CT

Disk (Roll) / Frame Number:	**Sketch** 1 **of** 1
Collected By: Bryan Frazier	**Checked By:**

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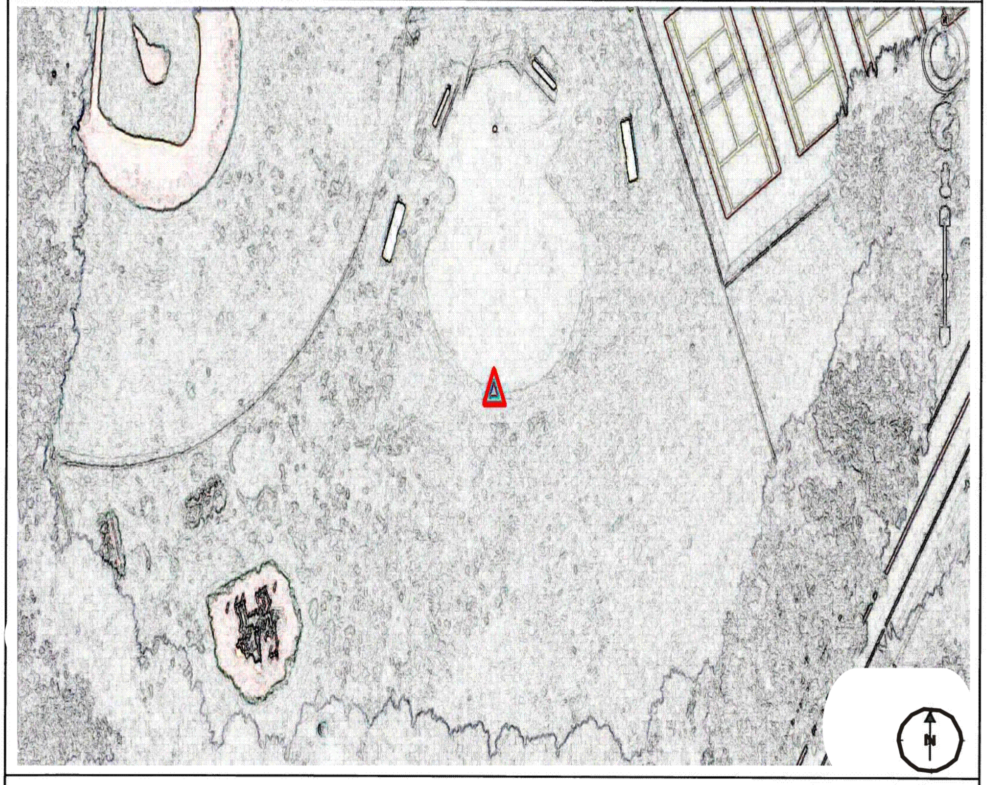
LiDAR

QNP311

CompassData

GCP Station Diagram for LiDAR

Project Name: Quinnipiac	**GCP Number:** QNP311
CDI Project Number: 1508	**Date:** 10/19/2010



GPS Antenna Height: 2m

Comments:

Point taken in athletic field S of Stanely T. Williams School.
New Haven County, CT

Disk (Roll) / Frame Number:	**Sketch** 1 **of** 1
Collected By: Bryan Frazier	**Checked By:**

CompassData, Inc., 12353 E. Easter Ave., Suite 200, Centennial, CO 80112 CDIGCP-01/04

QNP312

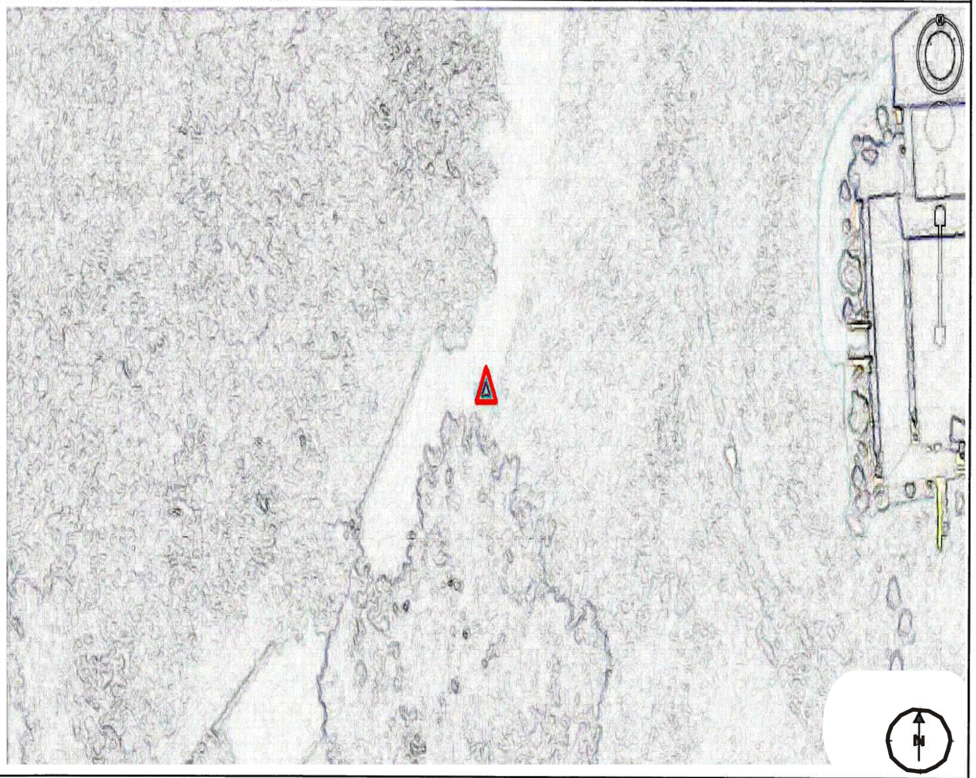
CompassData

GCP Station Diagram for LiDAR

LiDAR

LiDAR

Project Name: Quinnipiac	**GCP Number:** QNP312
CDI Project Number: 1508	**Date:** 10/20/2010



GPS Antenna Height: 2m

Comments:

Point taken on curve of Hickory Ln road.
New Haven County, CT

Disk (Roll) / Frame Number:	**Sketch** 1 **of** 1
Collected By: Bryan Frazier	**Checked By:**

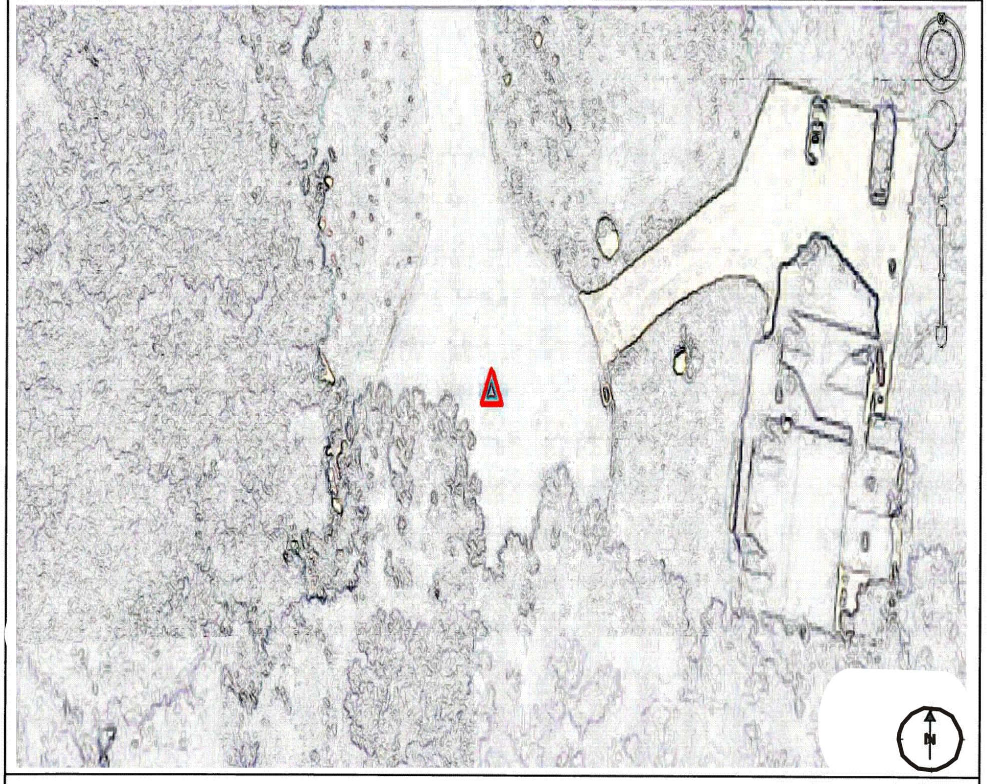
CompassData, Inc., 12353 E. Easter Ave., Suite 200, Centennial, CO 80112 CDIGCP-01/04

QNP313

CompassData

GCP Station Diagram for LiDAR

Project Name: Quinnipiac	**GCP Number:** QNP313
CDI Project Number: 1508	**Date:** 10/20/2010



GPS Antenna Height: 2m

Comments:

Point taken in center of culdesac of Lindera Ln.
Middlesex County, CT

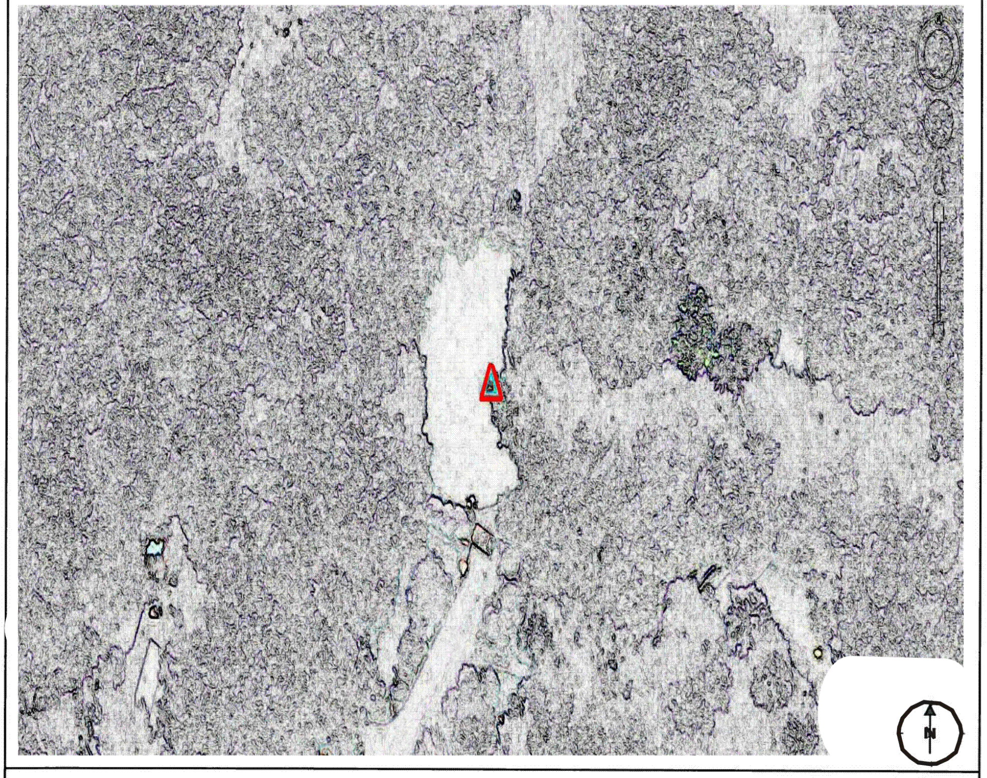
Disk (Roll) / Frame Number:	**Sketch** 1 **of** 1
Collected By: Bryan Frazier	**Checked By:**

QNP314

CompassData

GCP Station Diagram for LiDAR

Project Name: Quinnipiac	**GCP Number:** QNP314
CDI Project Number: 1508	**Date:** 10/20/2010



GPS Antenna Height: 2m

Comments:

Point taken in center of culdesac of Wild Apple Ln.
Middlesex County, CT

Disk (Roll) / Frame Number:	**Sketch** 1 **of** 1
Collected By: Bryan Frazier	**Checked By:**

CompassData, Inc., 12353 E. Easter Ave., Suite 200, Centennial, CO 80112 CDIGCP-01/04

LiDAR

LiDAR

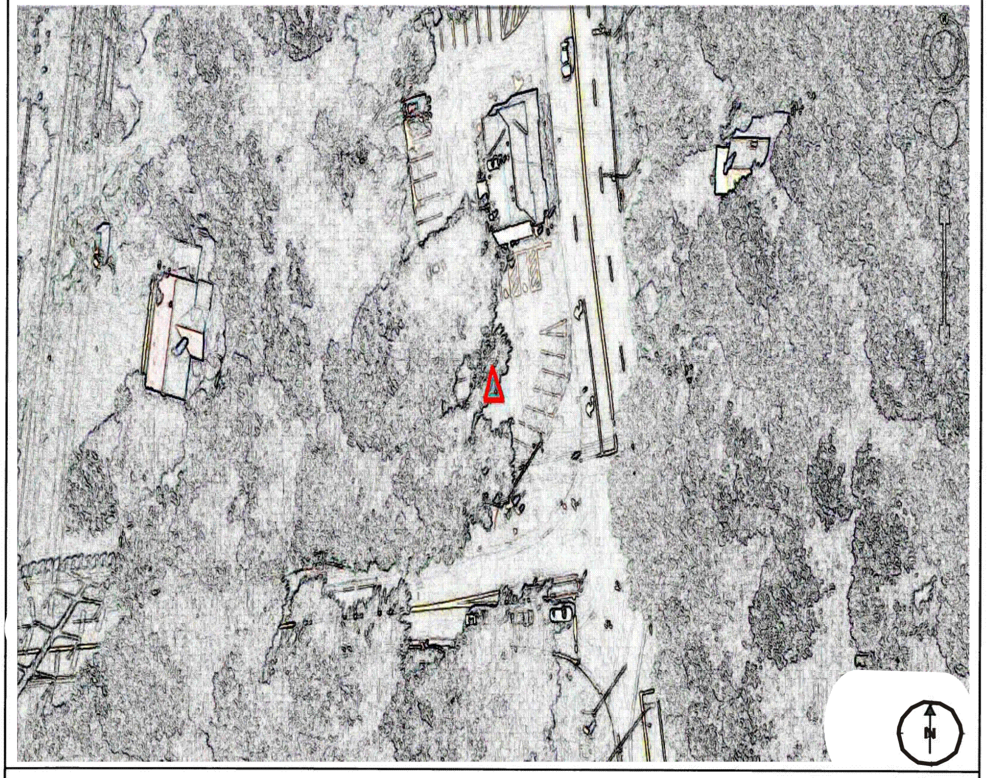
QNP315

CompassData

GCP Station Diagram for LiDAR

LiDAR

Project Name: Quinnipiac	**GCP Number:** QNP315
CDI Project Number: 1508	**Date:** 10/20/2010



GPS Antenna Height: 2m

Comments:

Point taken in S part of parkling lot, S of building and N of Center Rd and W of Amity Rd.
New Haven County, CT

Disk (Roll) / Frame Number:	**Sketch** 1 **of** 1
Collected By: Bryan Frazier	**Checked By:**

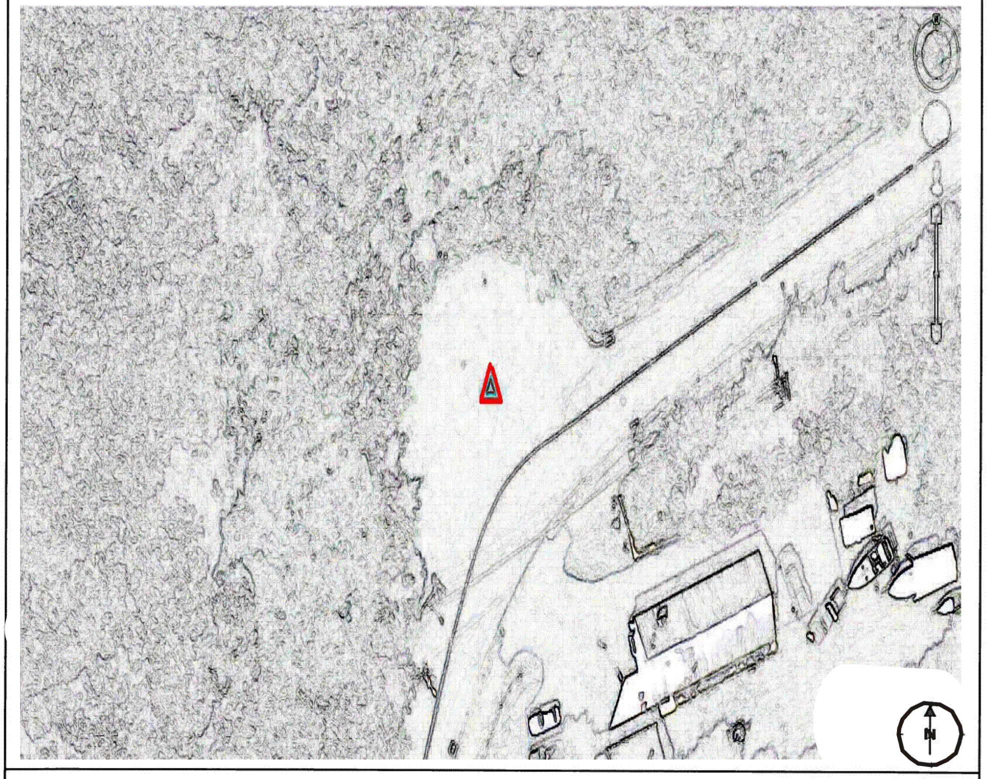
LiDAR

QNP316

CompassData

GCP Station Diagram for LiDAR

Project Name: Quinnipiac	**GCP Number:** QNP316
CDI Project Number: 1508	**Date:** 10/20/2010



GPS Antenna Height: 2m

Comments:

Point taken in culdesac off of Foxon Rd.
New Haven County, CT

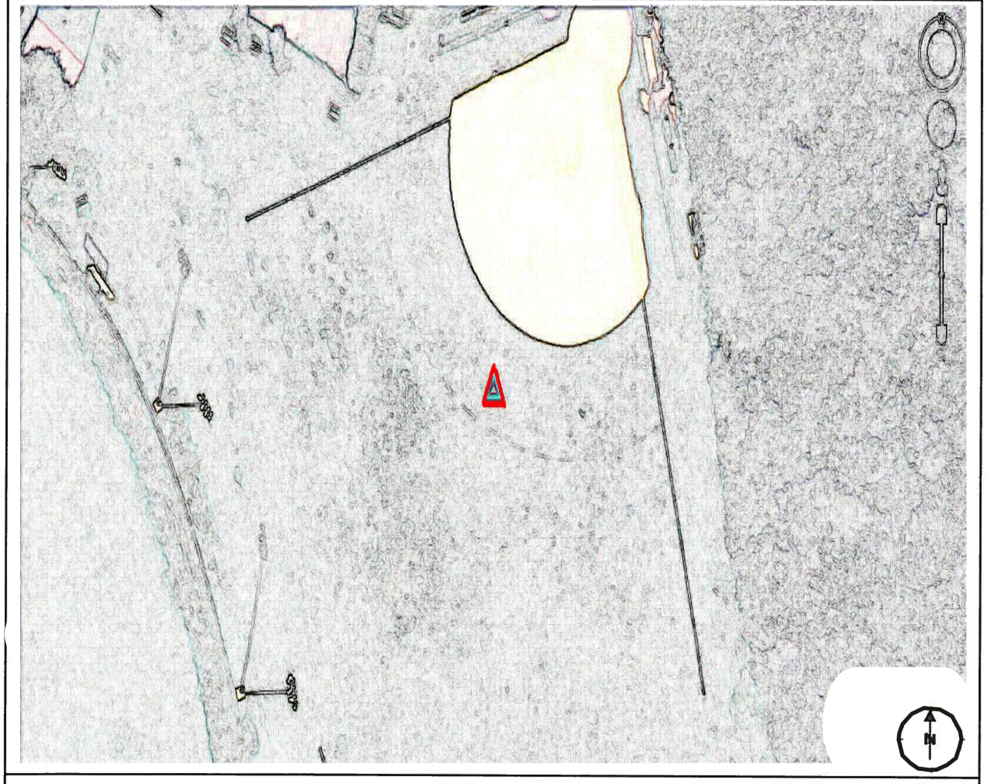
Disk (Roll) / Frame Number:	**Sketch** 1 **of** 1
Collected By: Bryan Frazier	**Checked By:**

QNP317

CompassData

GCP Station Diagram for LiDAR

Project Name: Quinnipiac	**GCP Number:** QNP317
CDI Project Number: 1508	**Date:** 10/20/2010



GPS Antenna Height: 2m

Comments:

Point taken in baseball field just S of the dirt diamond.
New Haven County, CT

Disk (Roll) / Frame Number:	**Sketch** 1 **of** 1
Collected By: Bryan Frazier	**Checked By:**

CompassData, Inc., 12353 E. Easter Ave., Suite 200, Centennial, CO 80112 CDIGCP-01/04

LiDAR

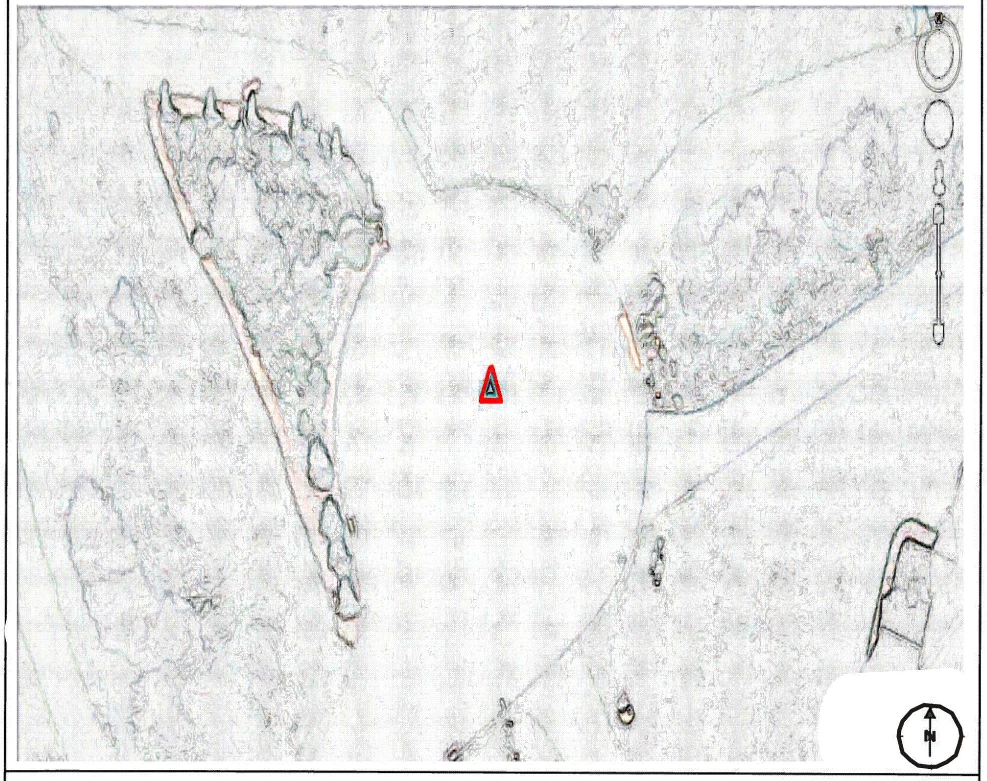
LiDAR

QNP318

CompassData

GCP Station Diagram for LiDAR

Project Name: Quinnipiac	**GCP Number:** QNP318
CDI Project Number: 1508	**Date:** 10/20/2010



GPS Antenna Height: 2m

Comments:

Point taken in culdesac of Creamery Ln.
New Haven County, CT

Disk (Roll) / Frame Number:	**Sketch** 1 **of** 1
Collected By: Bryan Frazier	**Checked By:**

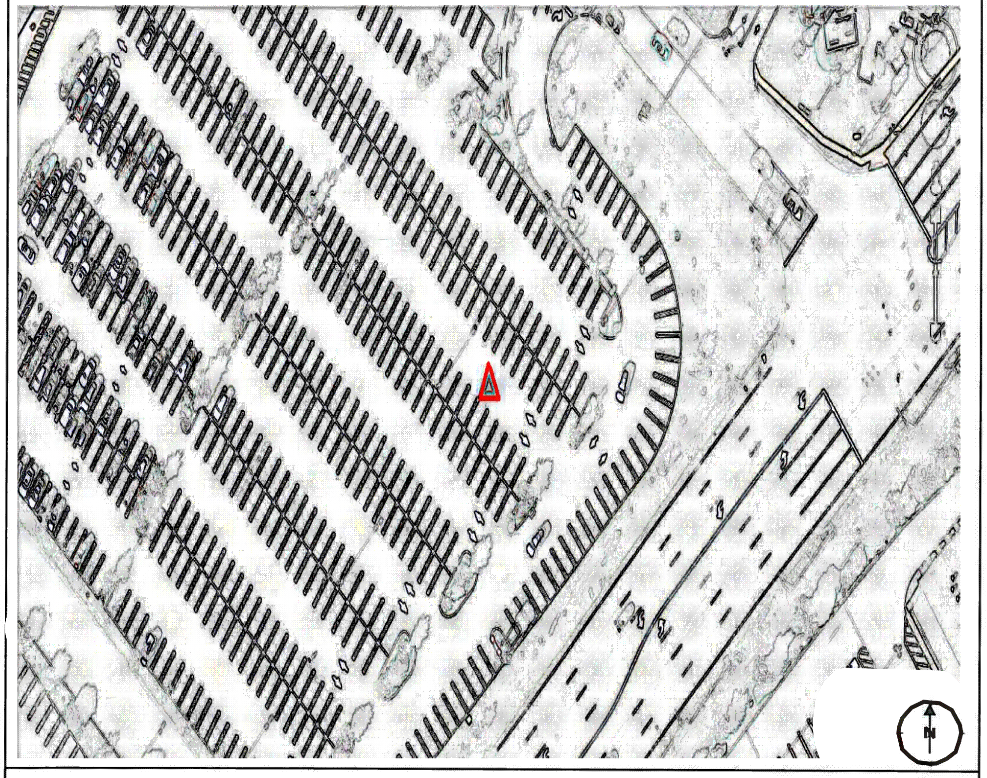
CompassData, Inc., 12353 E. Easter Ave., Suite 200, Centennial, CO 80112 CDIGCP-01/04

QNP319

CompassData

GCP Station Diagram for LiDAR

Project Name: Quinnipiac	**GCP Number:** QNP319
CDI Project Number: 1508	**Date:** 10/20/2010



LiDAR

LiDAR

GPS Antenna Height: 2m

Comments:

Point taken in E part of parking lot, SW of Dogburn Rd and
NW of Boston Post Rd.
New Haven County, CT

Disk (Roll) / Frame Number:	**Sketch** 1 **of** 1
Collected By: Bryan Frazier	**Checked By:**

CompassData, Inc., 12353 E. Easter Ave., Suite 200, Centennial, CO 80112 CDIGCP-01/04

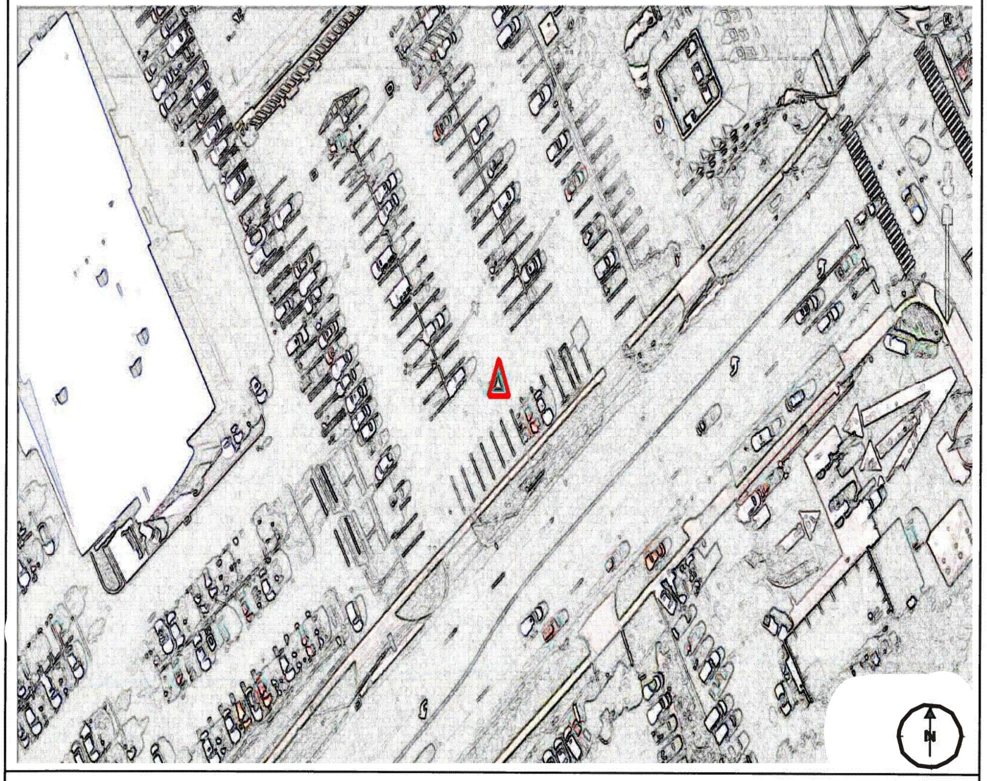
QNP320

CompassData

GCP Station Diagram for LiDAR

LiDAR

Project Name: Quinnipiac	**GCP Number:** QNP31920
CDI Project Number: 1508	**Date:** 10/20/2010



LiDAR

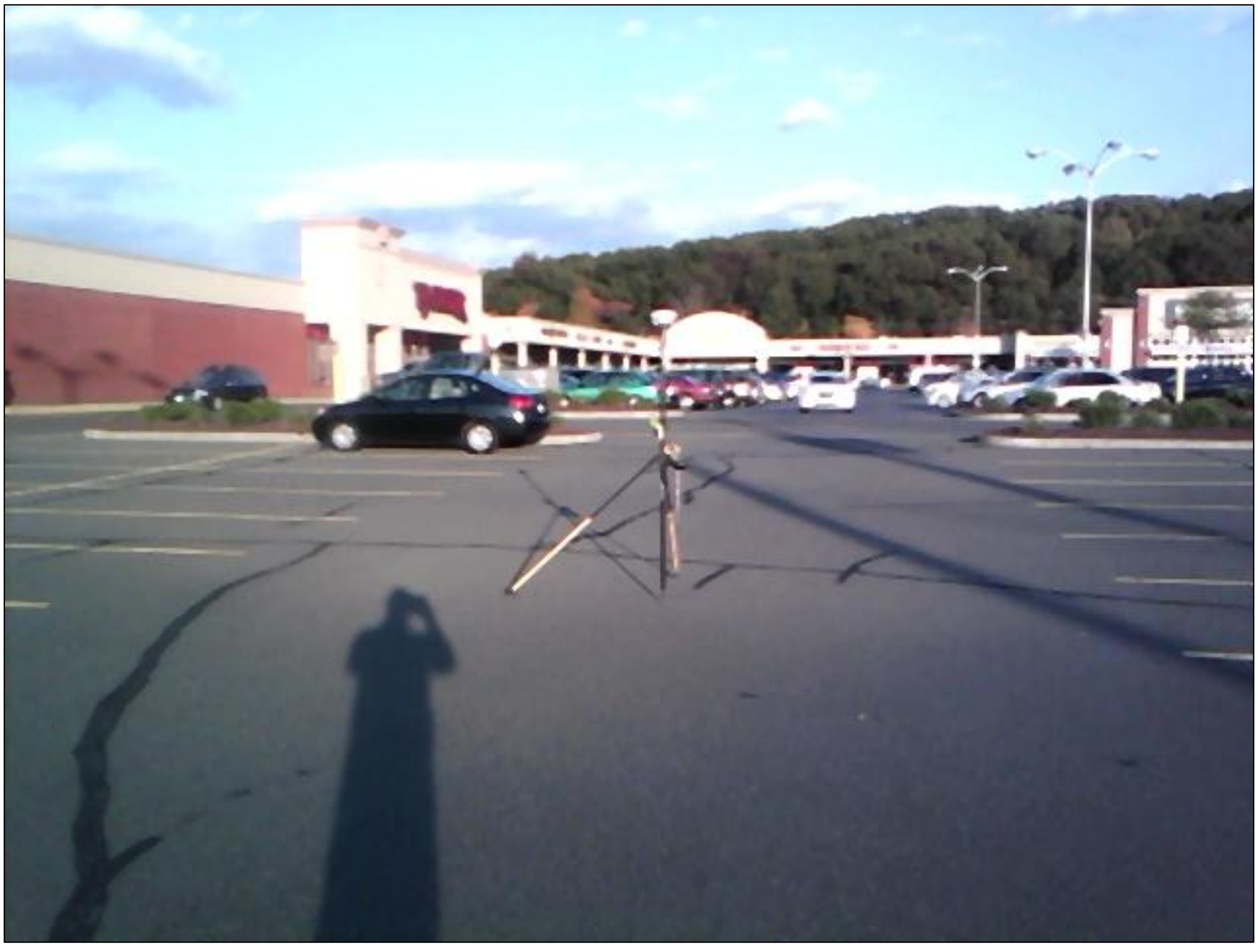
GPS Antenna Height: 2m

Comments:

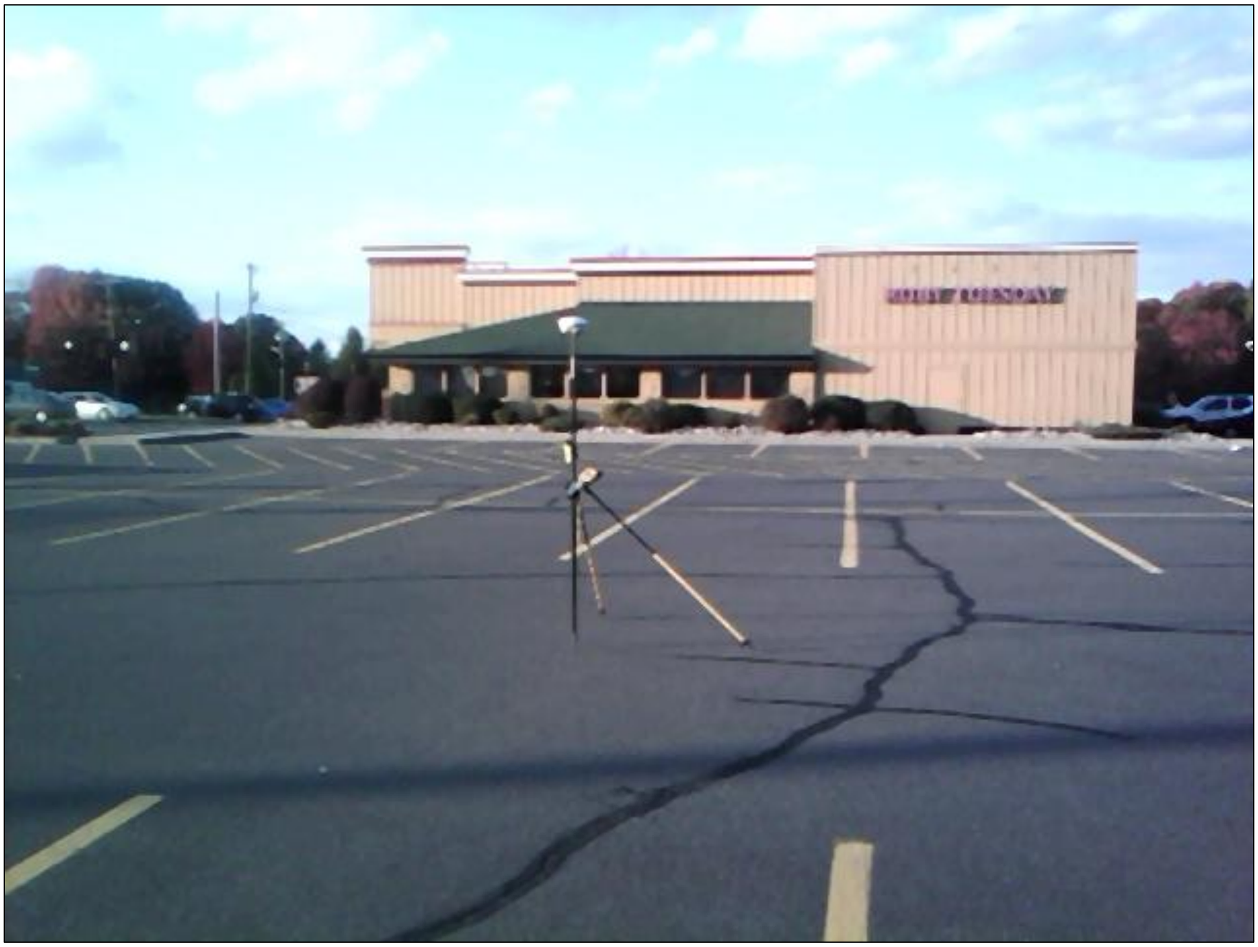
Point taken in SE part of parking lot, SW of High St. and
NW of Boston Post Rd.
New Haven County, CT

Disk (Roll) / Frame Number:	**Sketch** 1 **of** 1
Collected By: Bryan Frazier	**Checked By:**

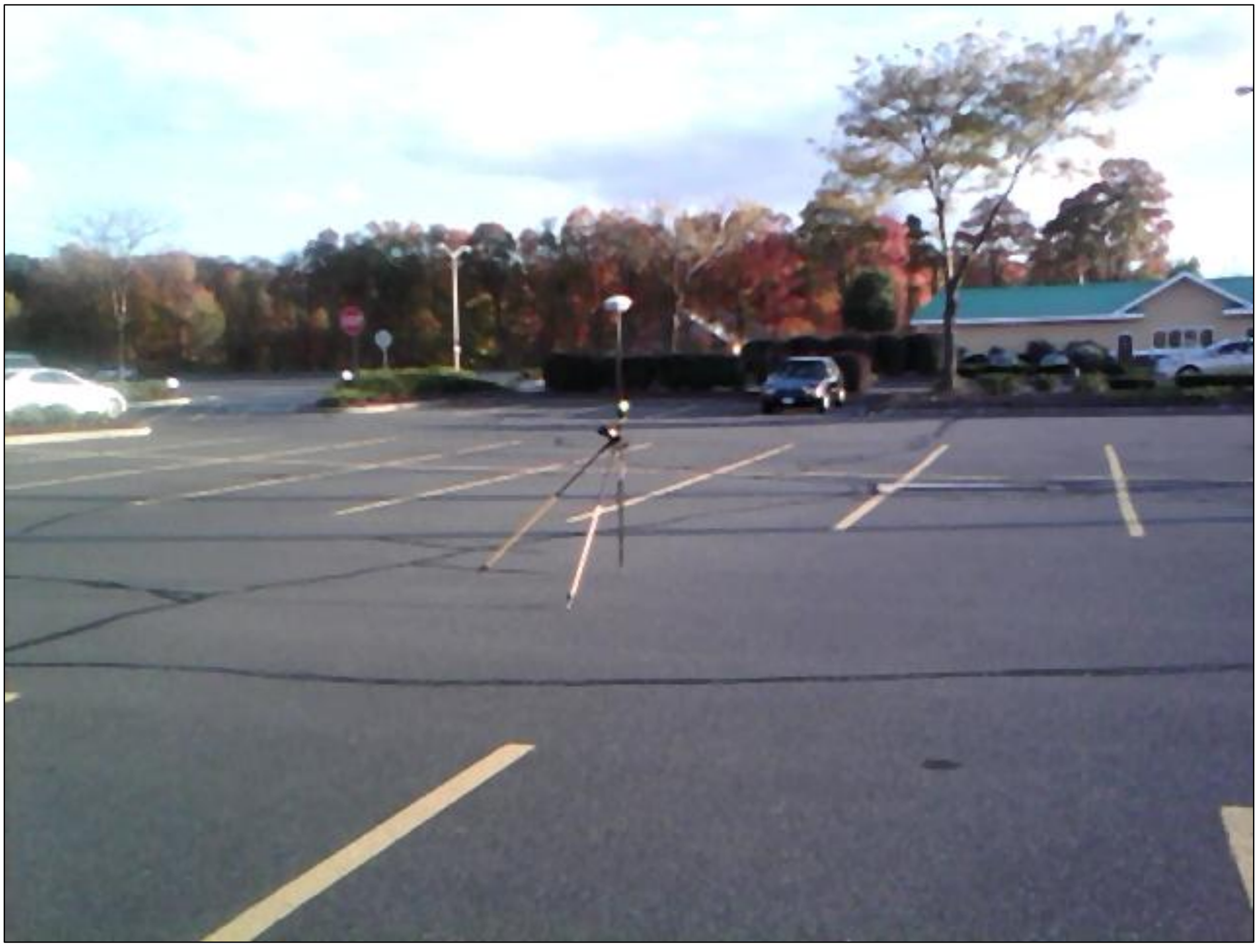
QNP301_E



QNP301_N

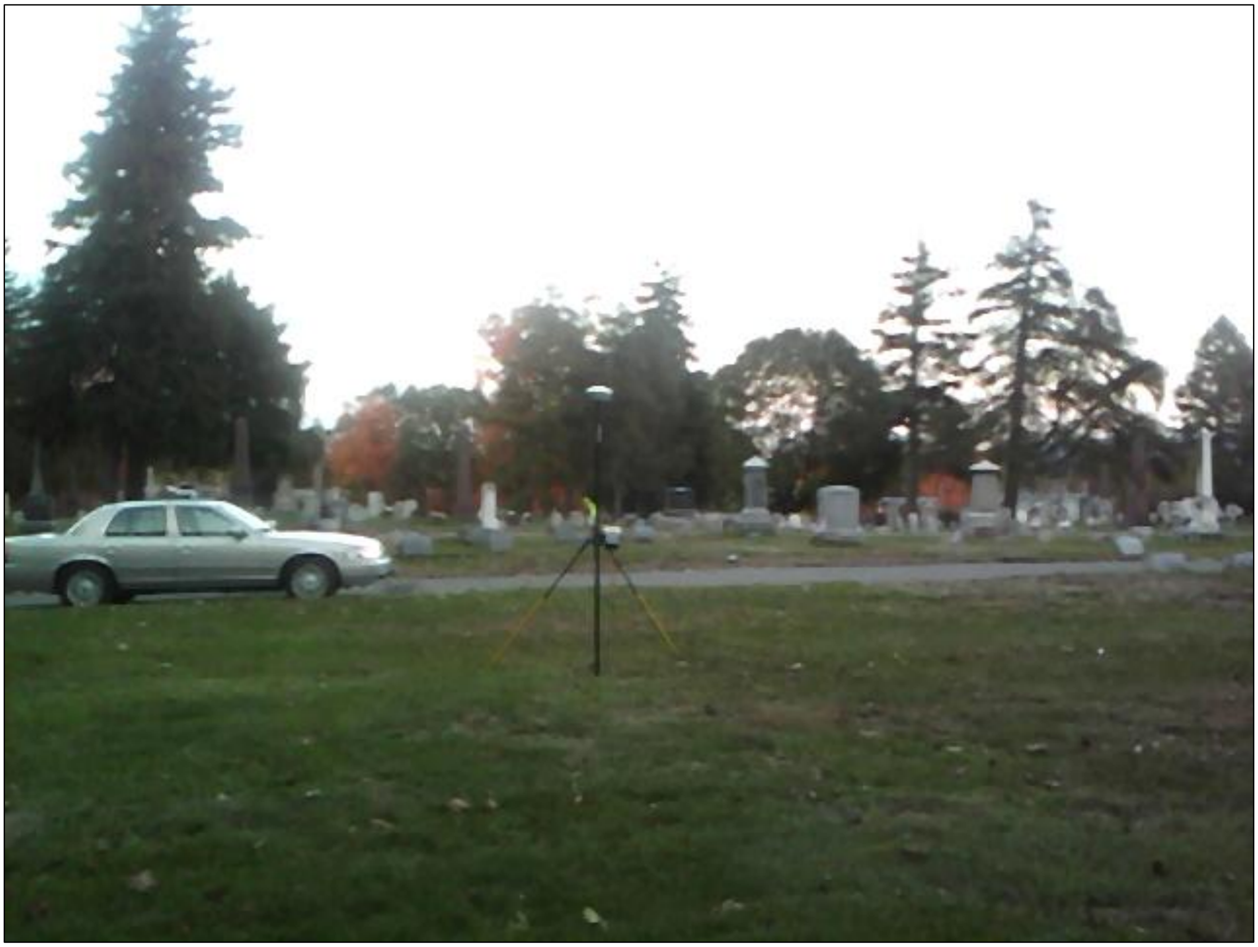


QNP301_S

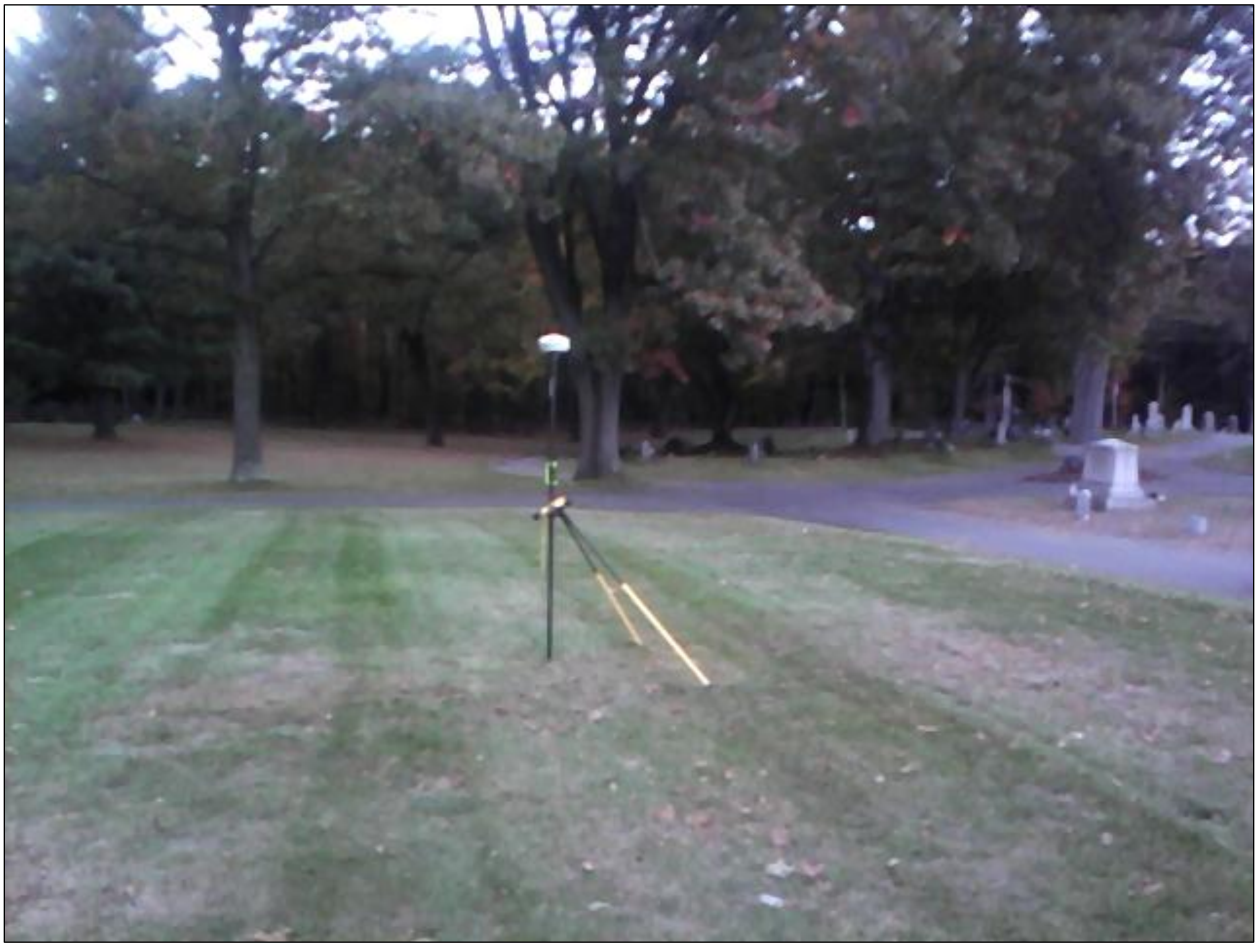


QNP301_W

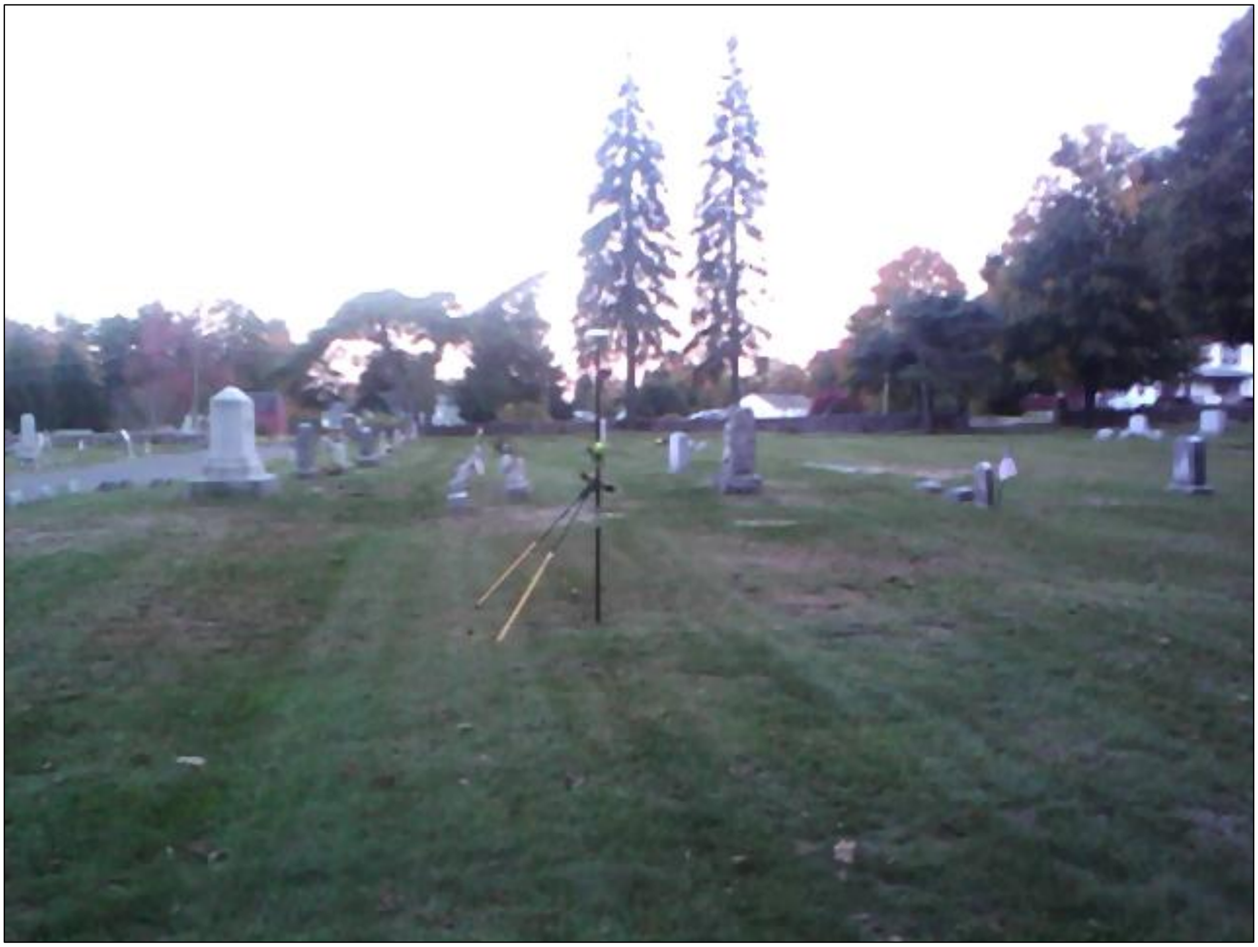
QNP302_E



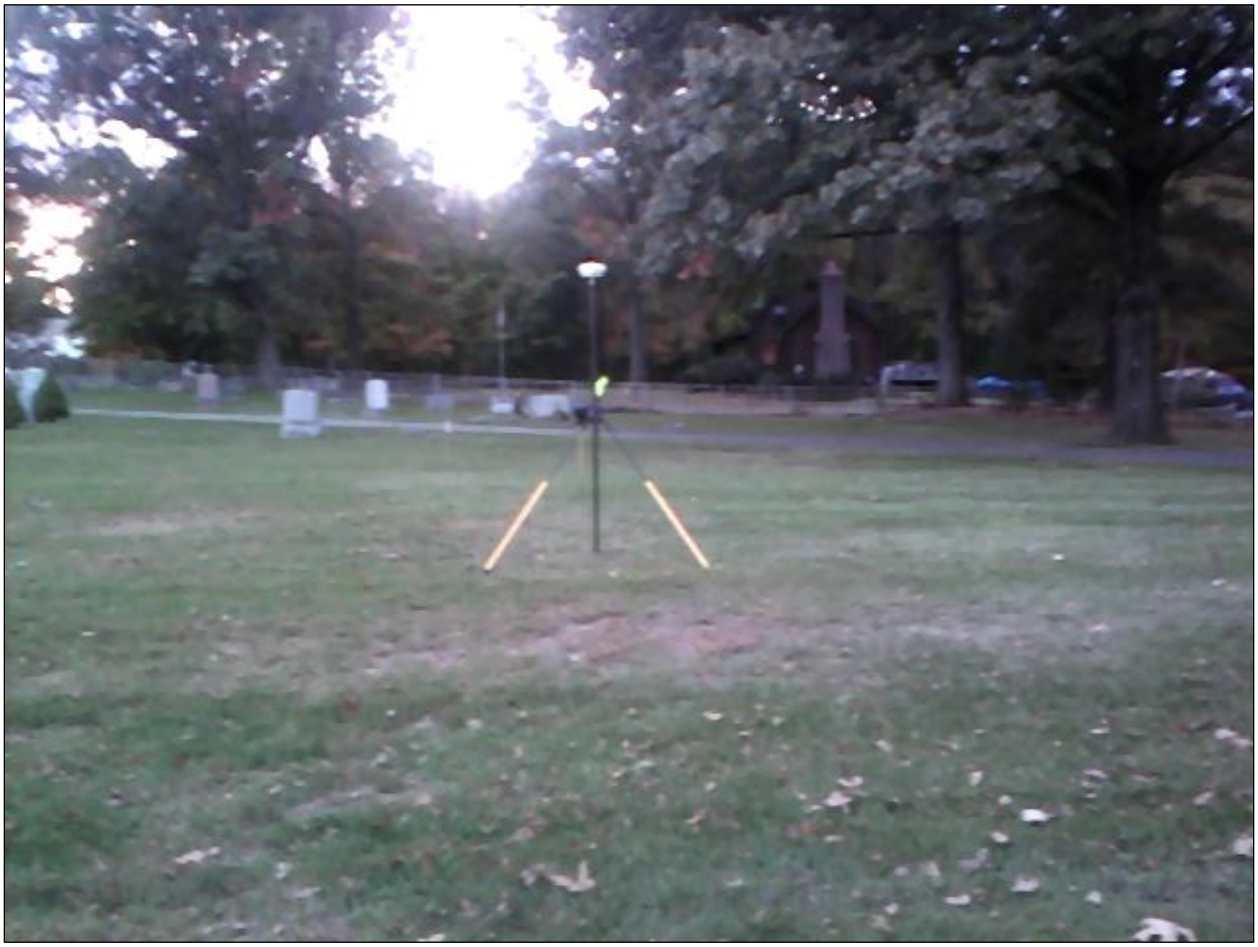
QNP302_N



QNP302_S



QNP302_W



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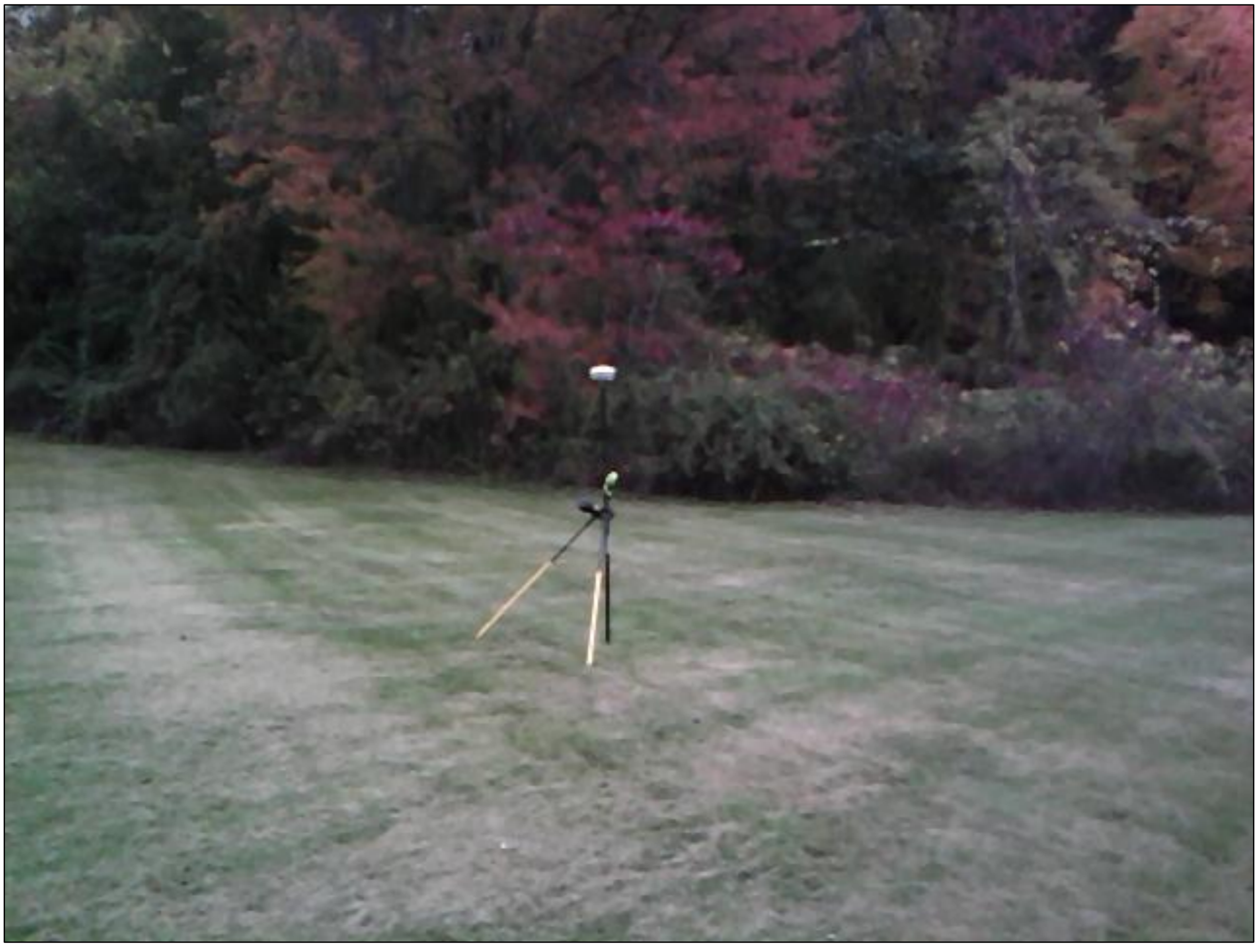

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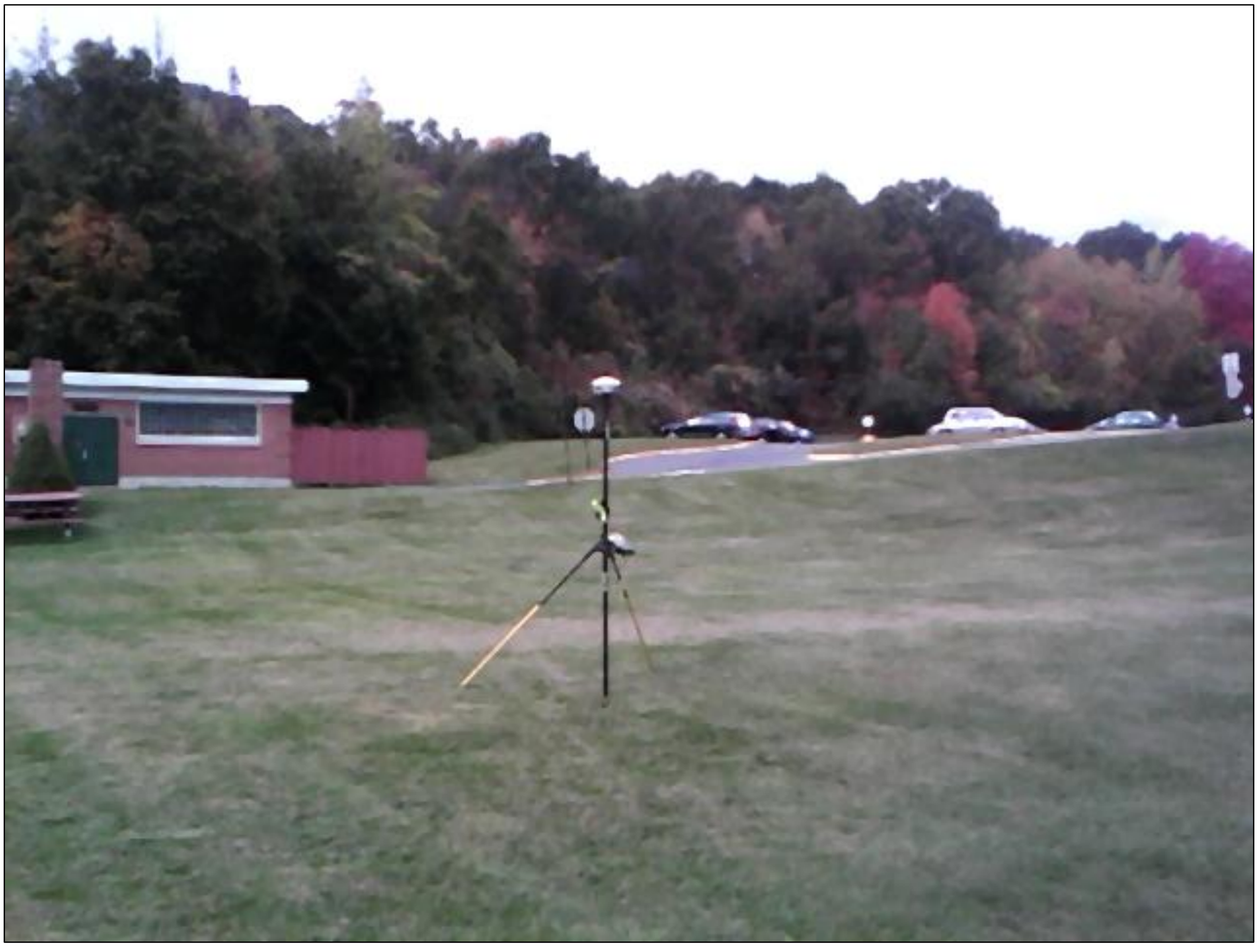

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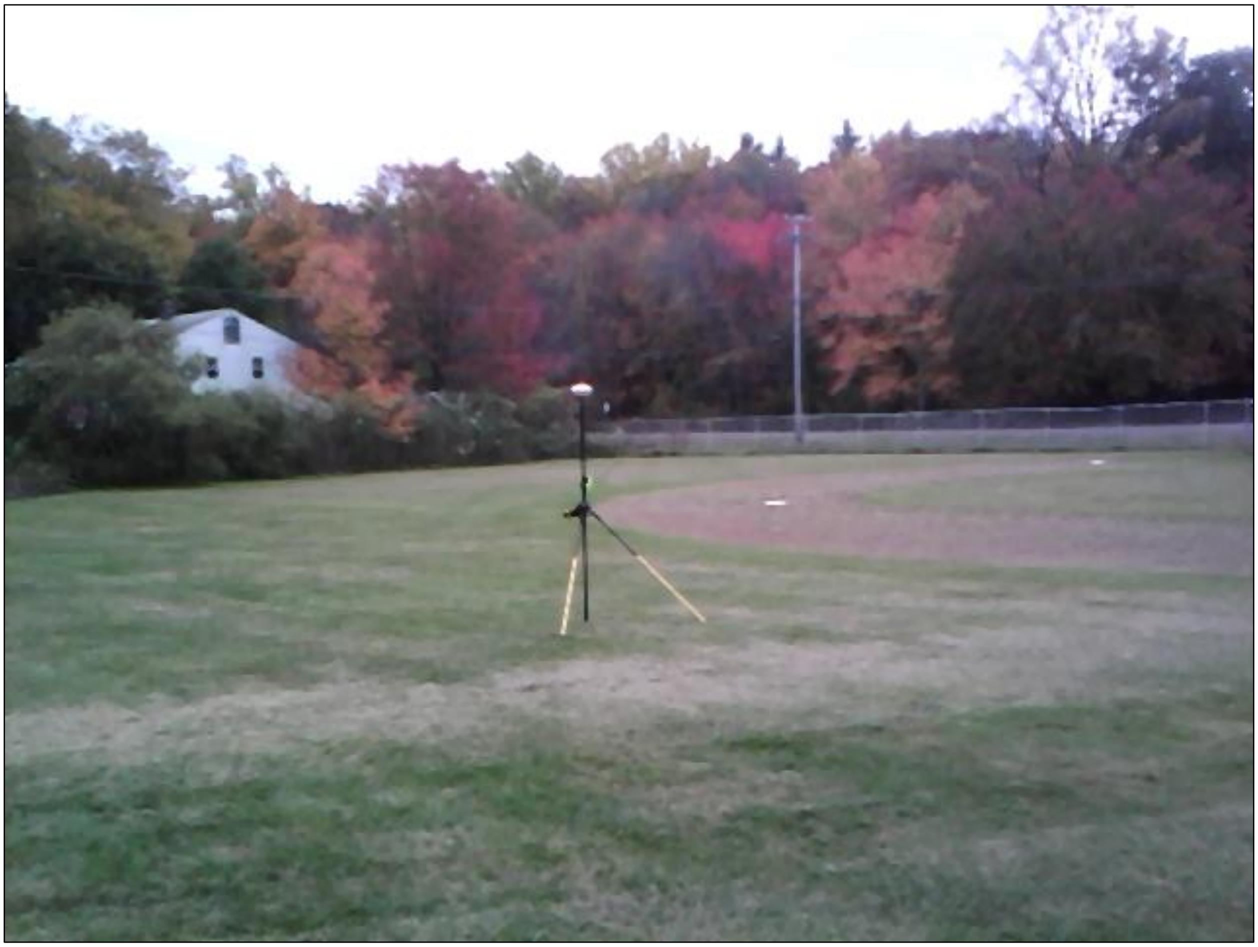

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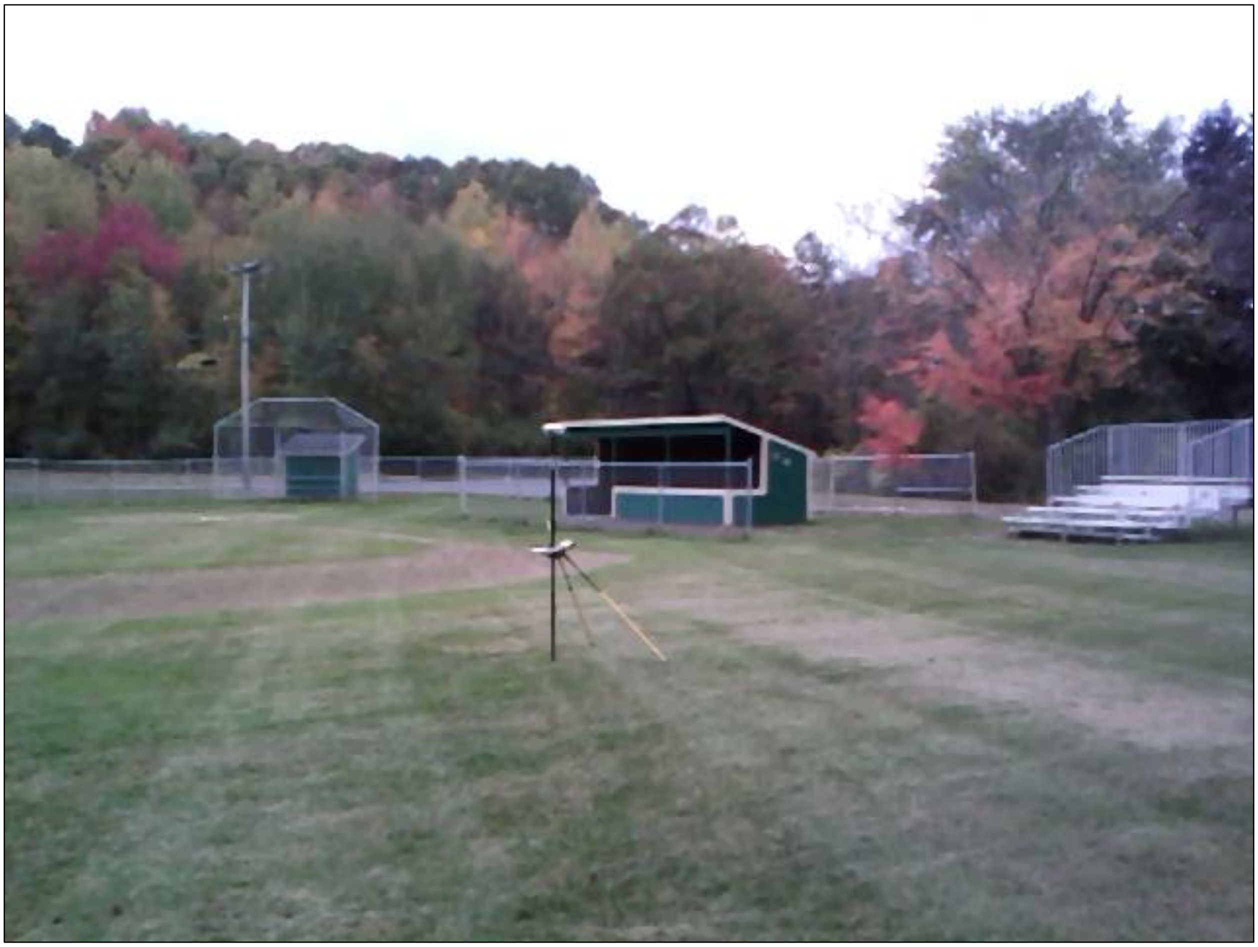

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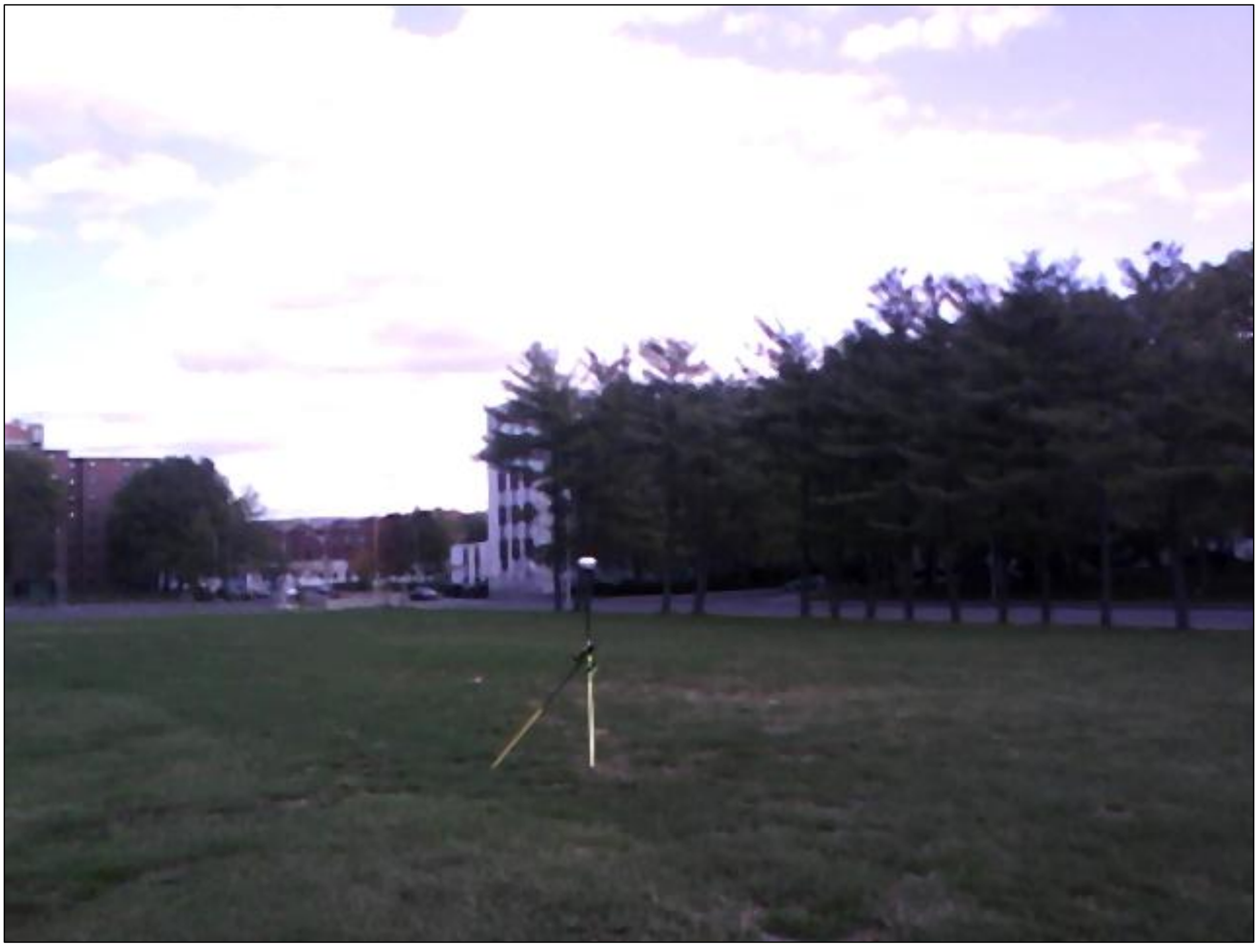

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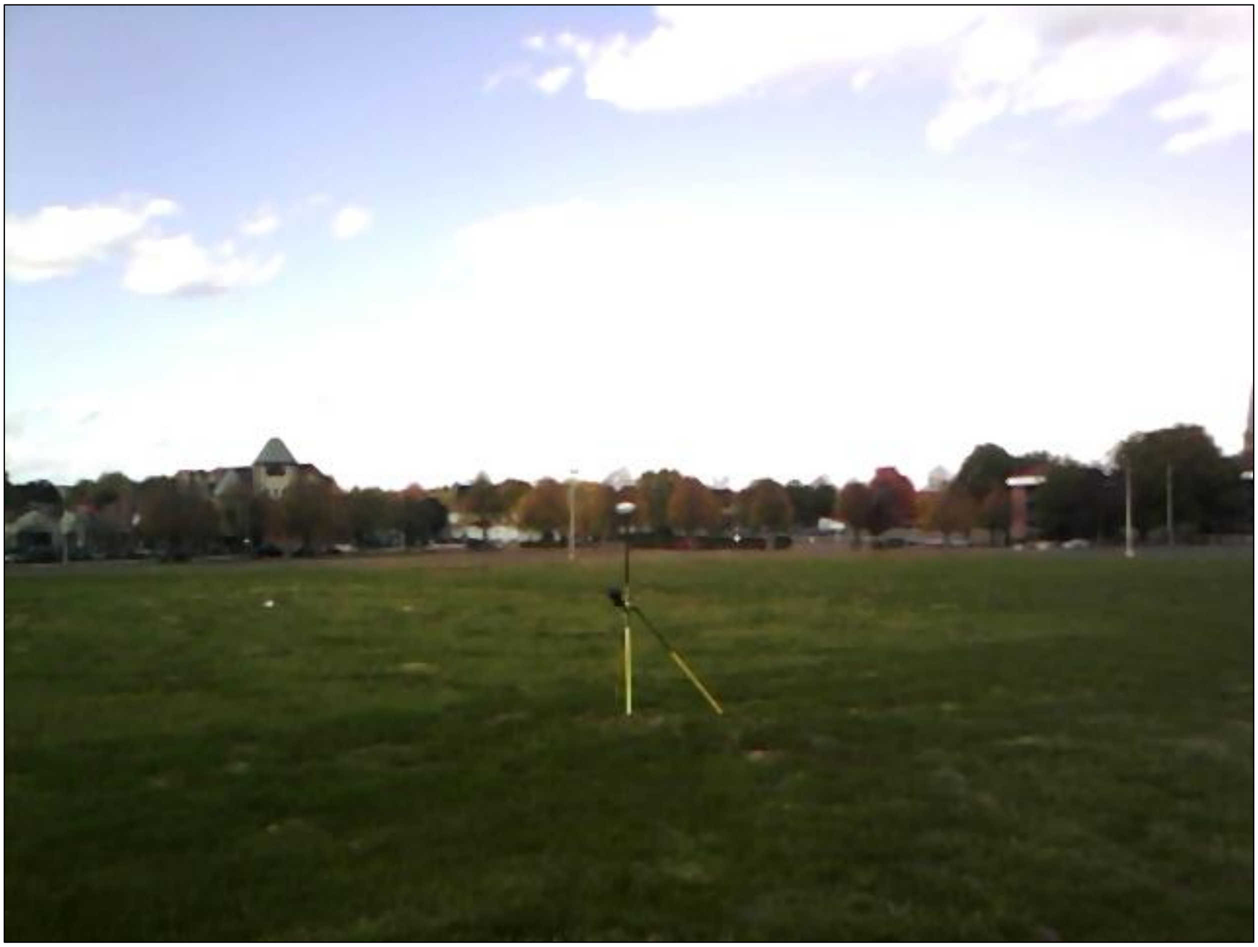

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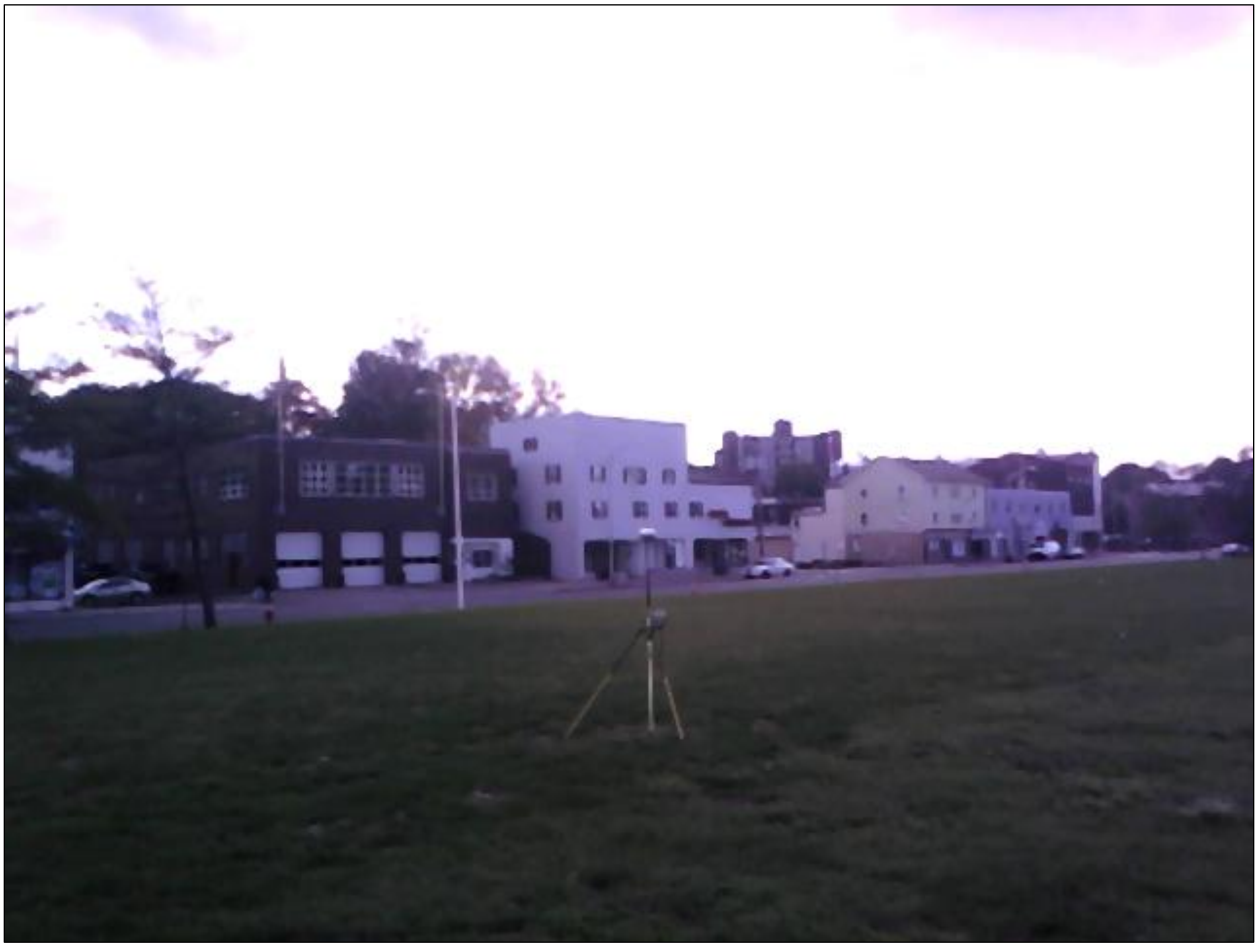

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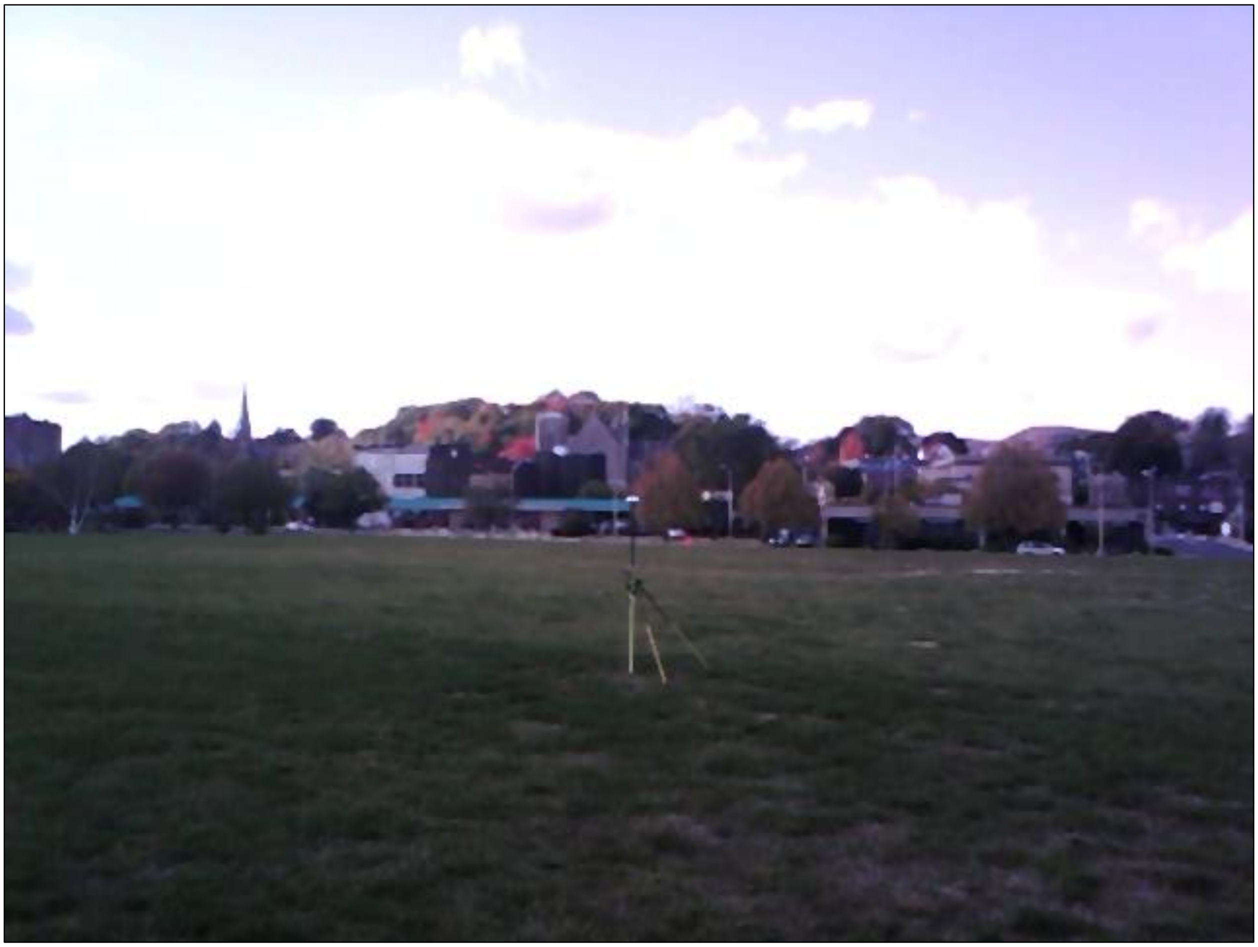

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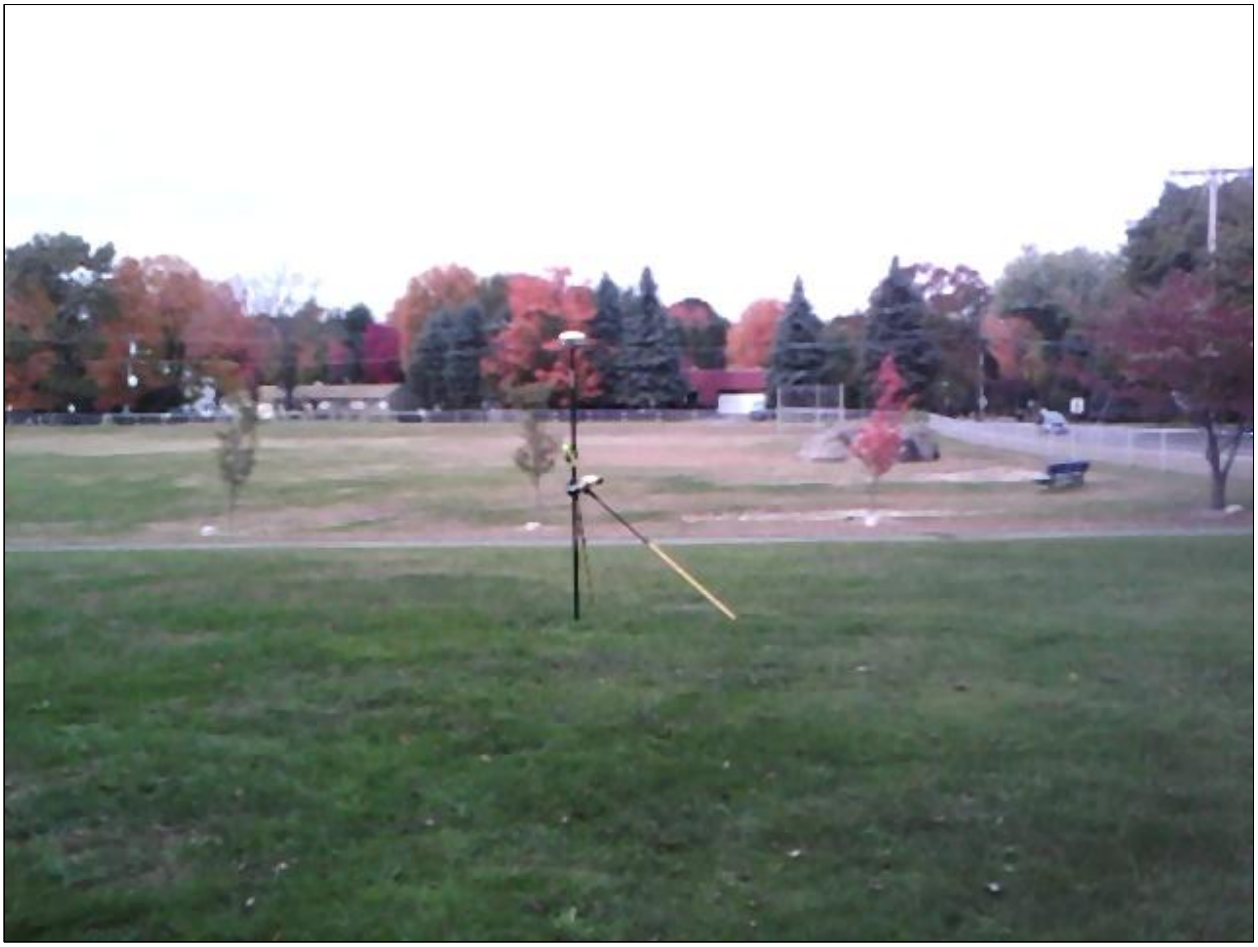

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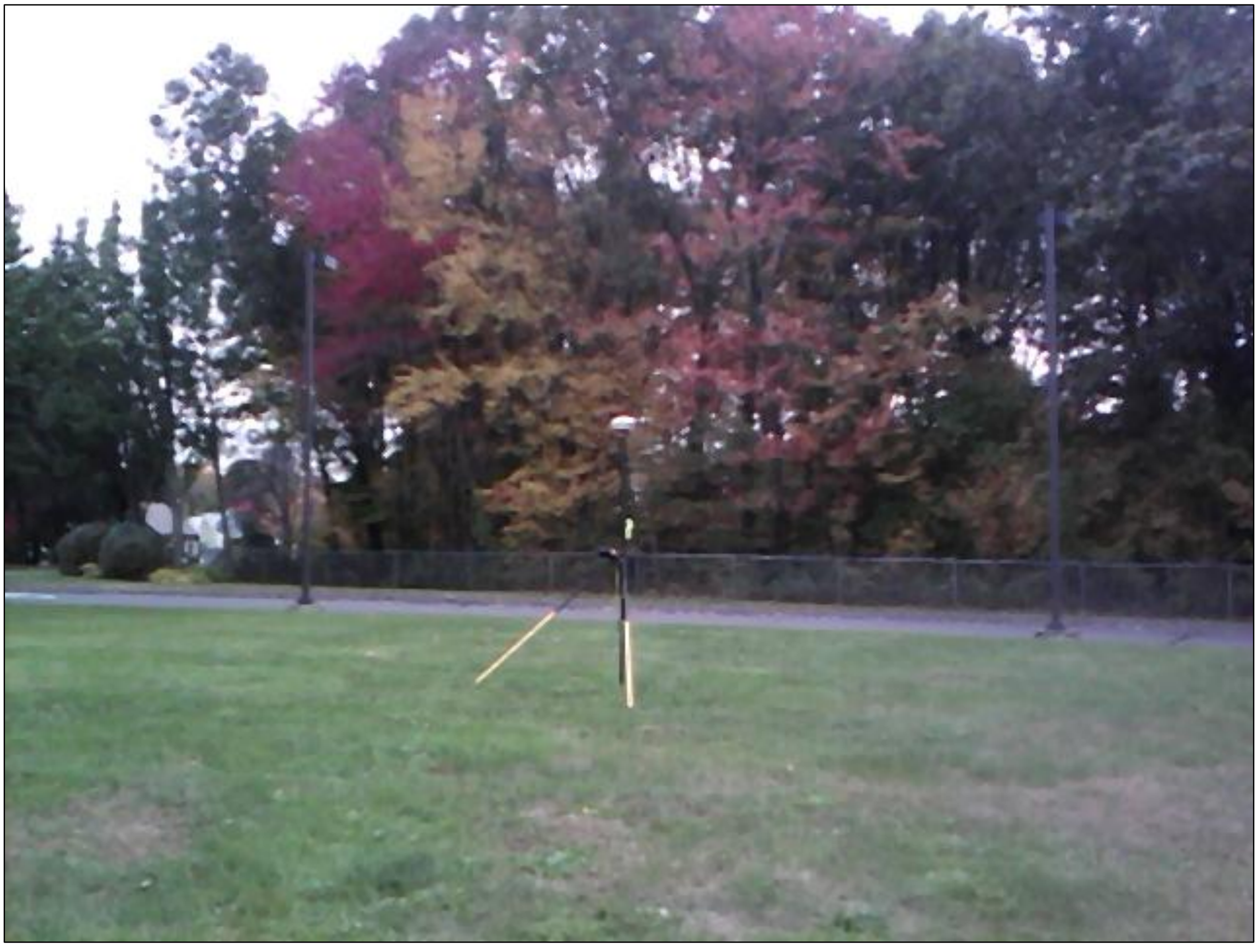

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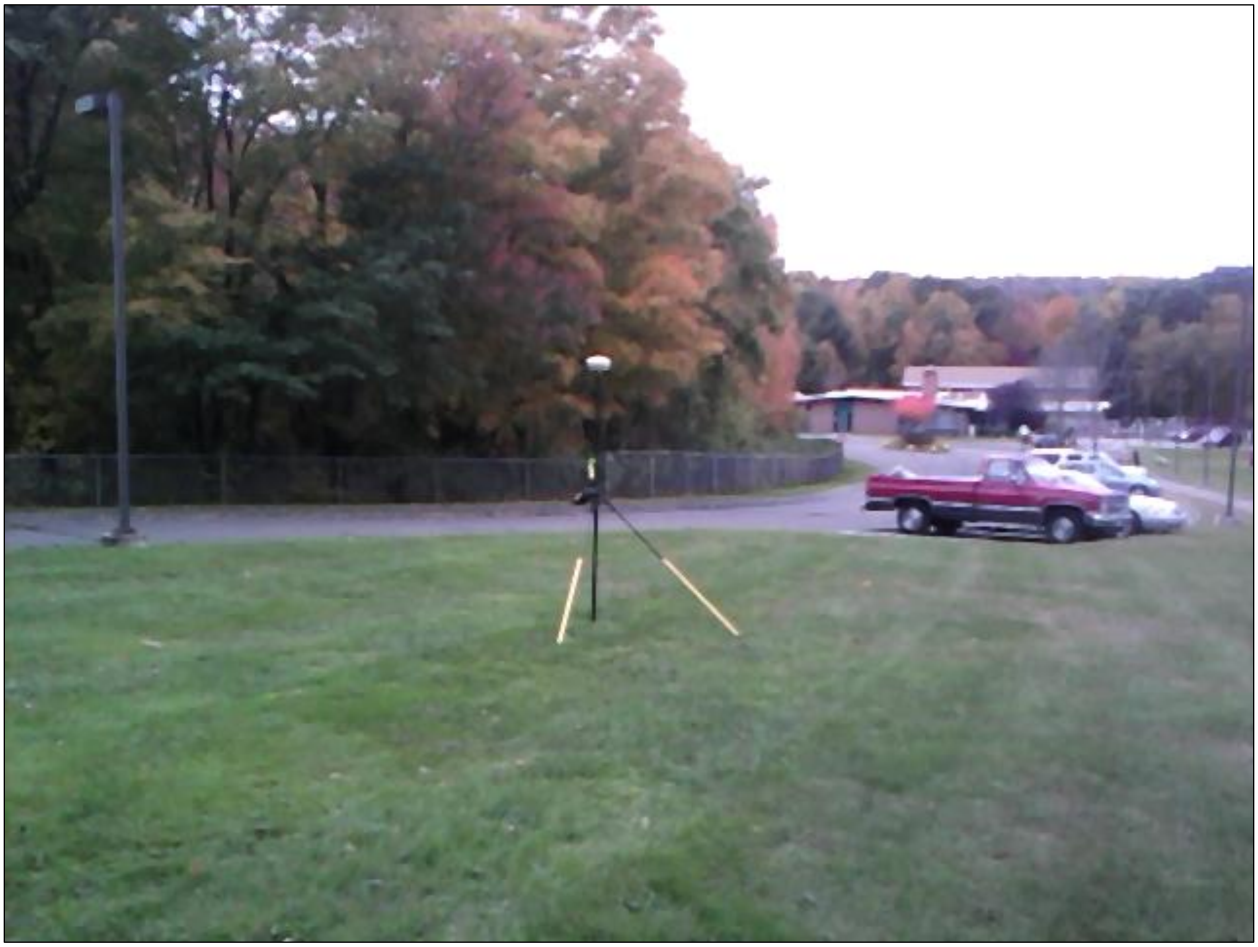

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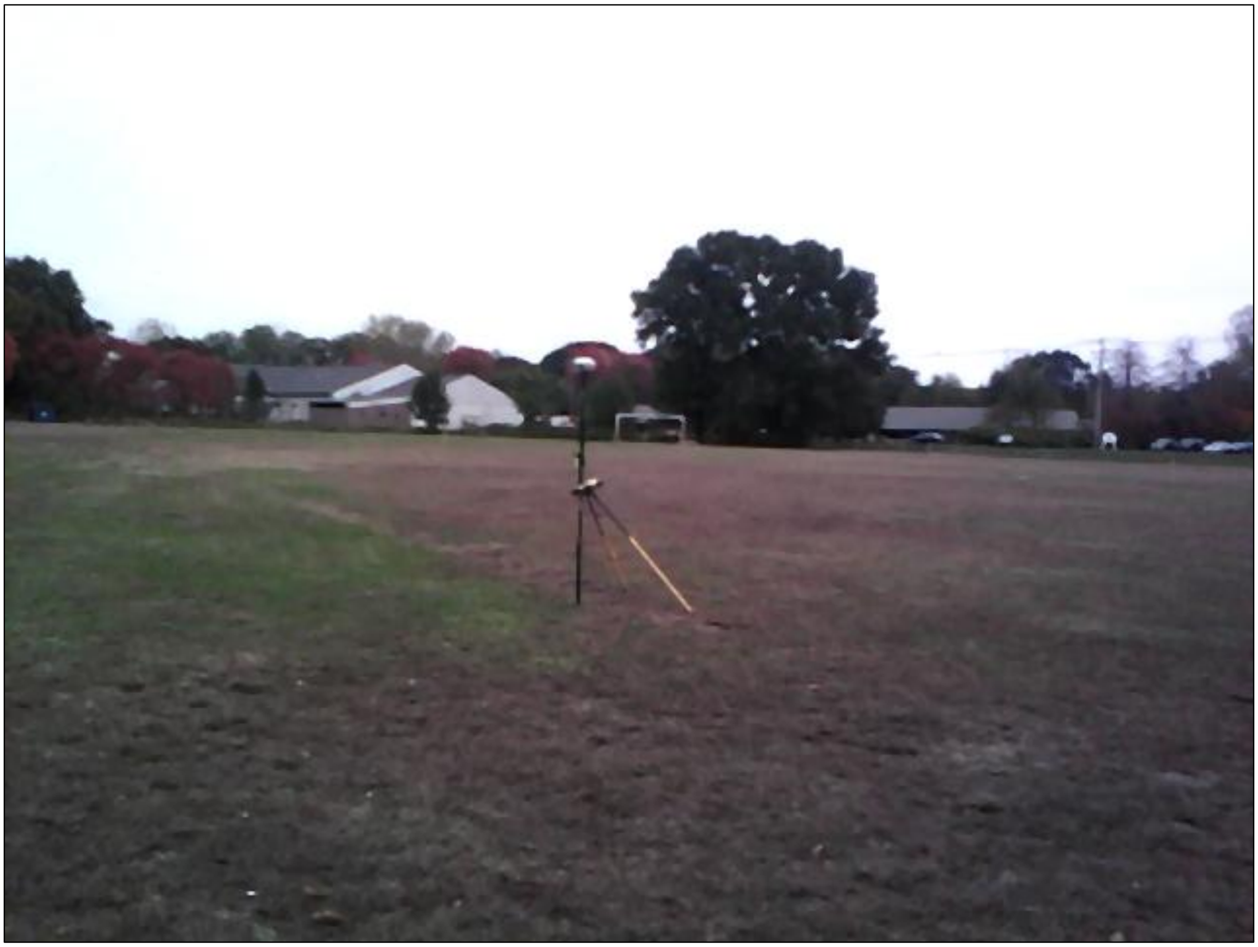

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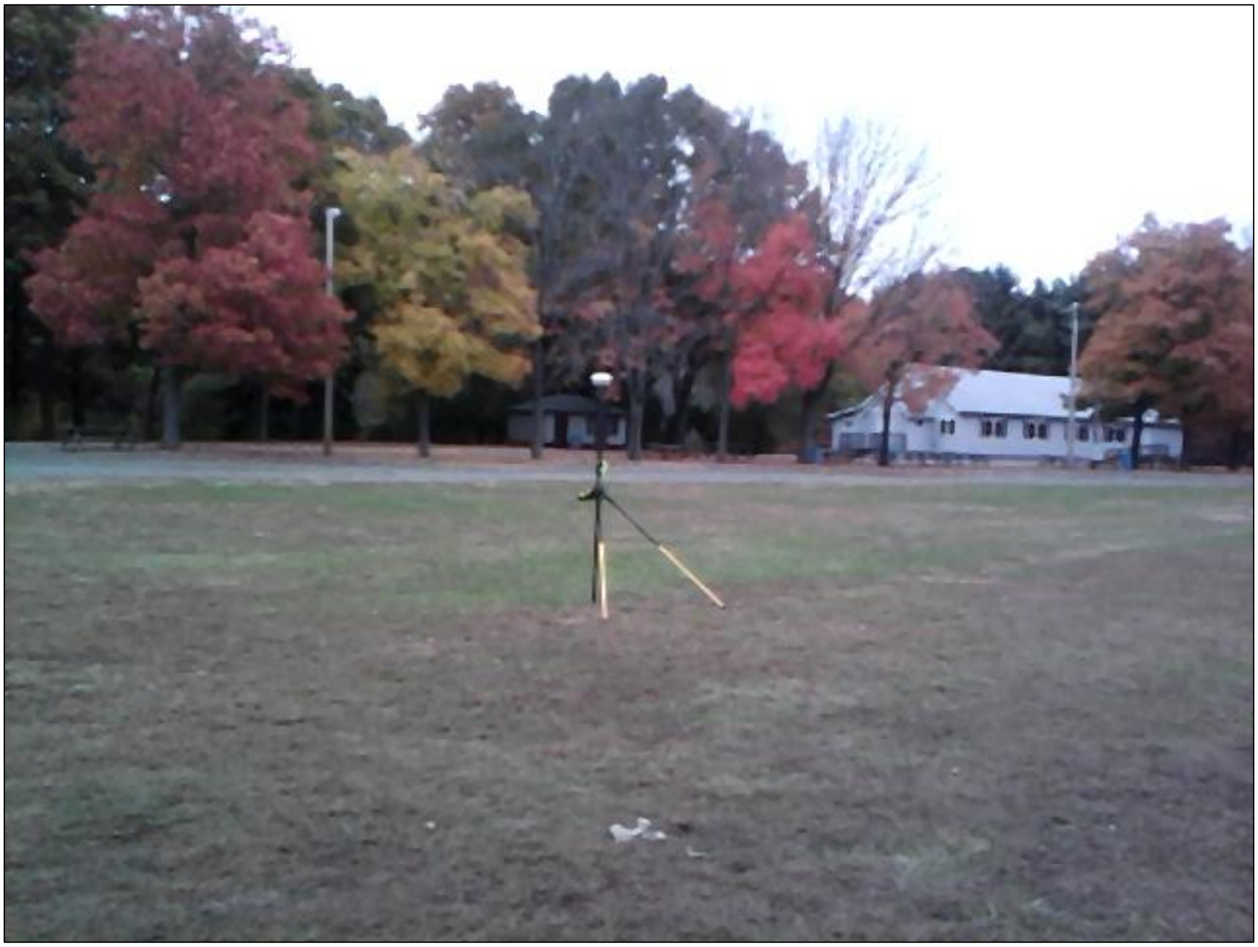

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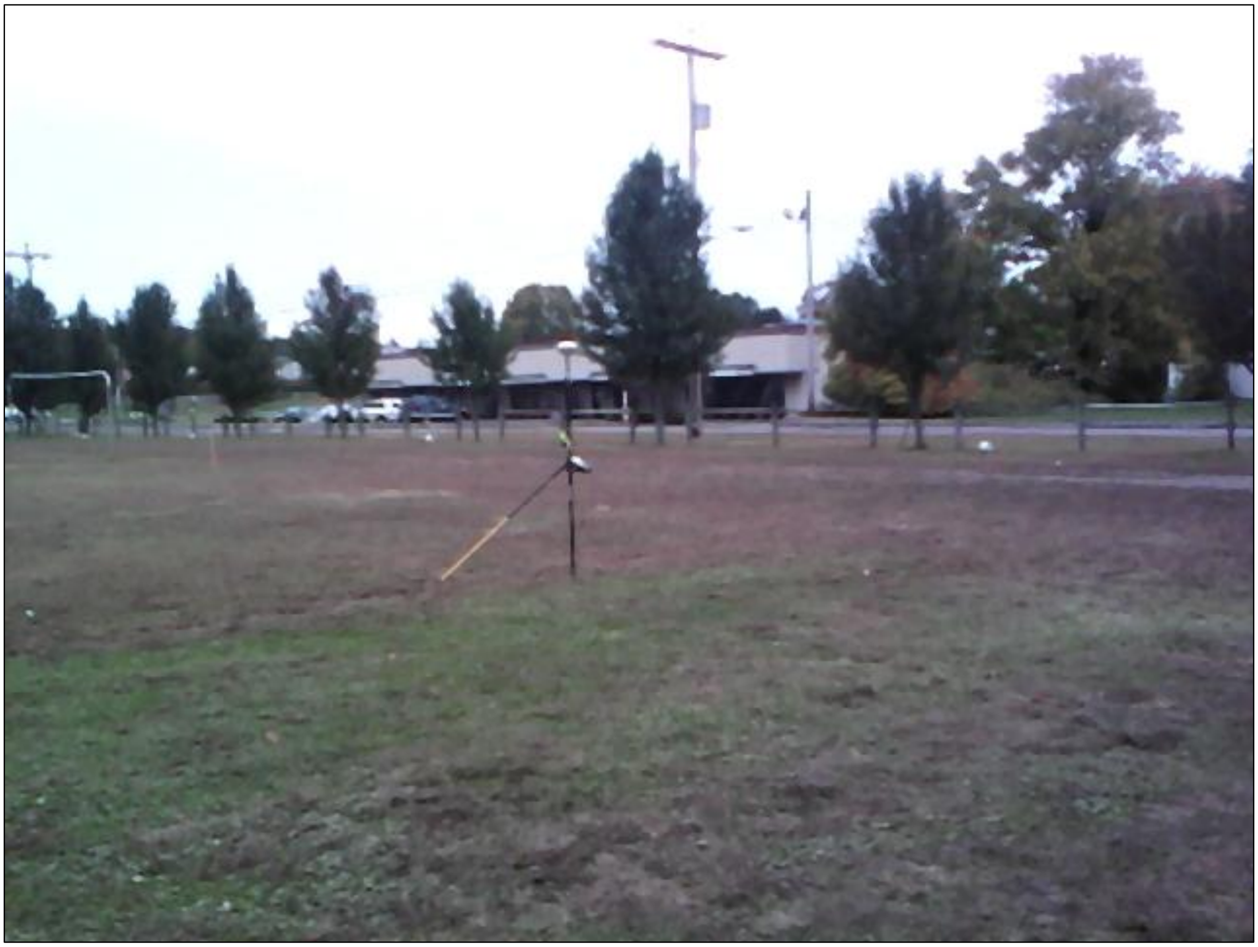

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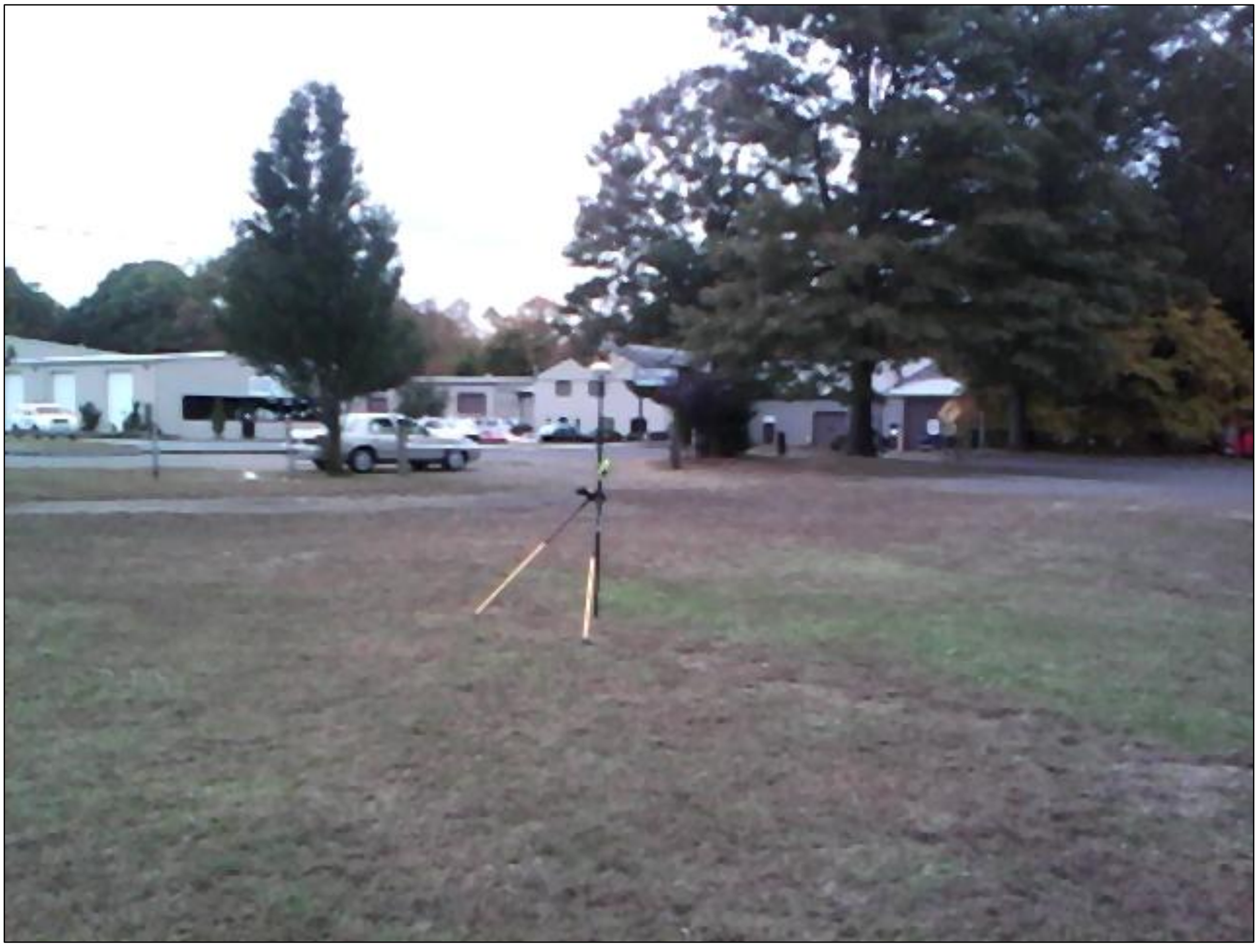

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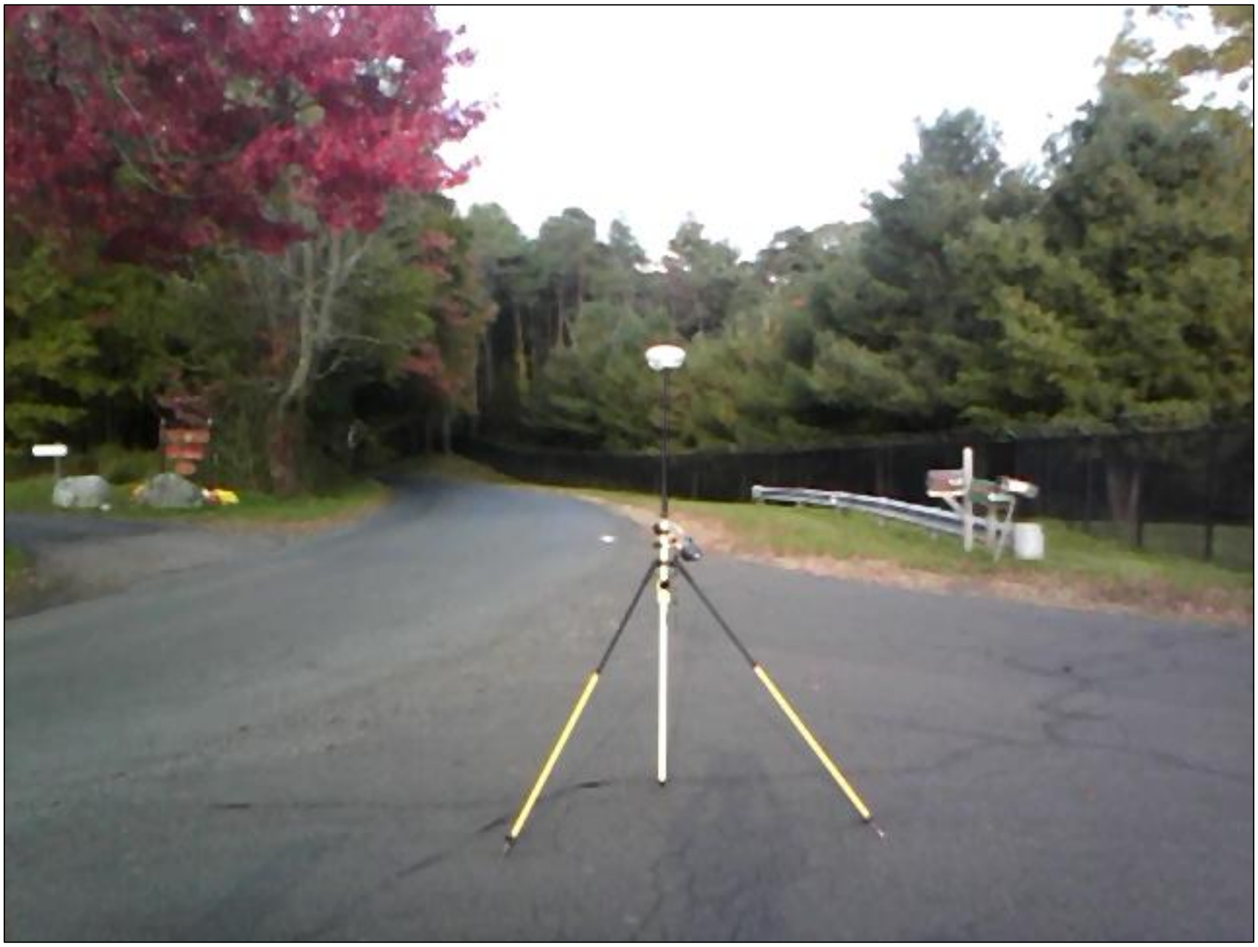

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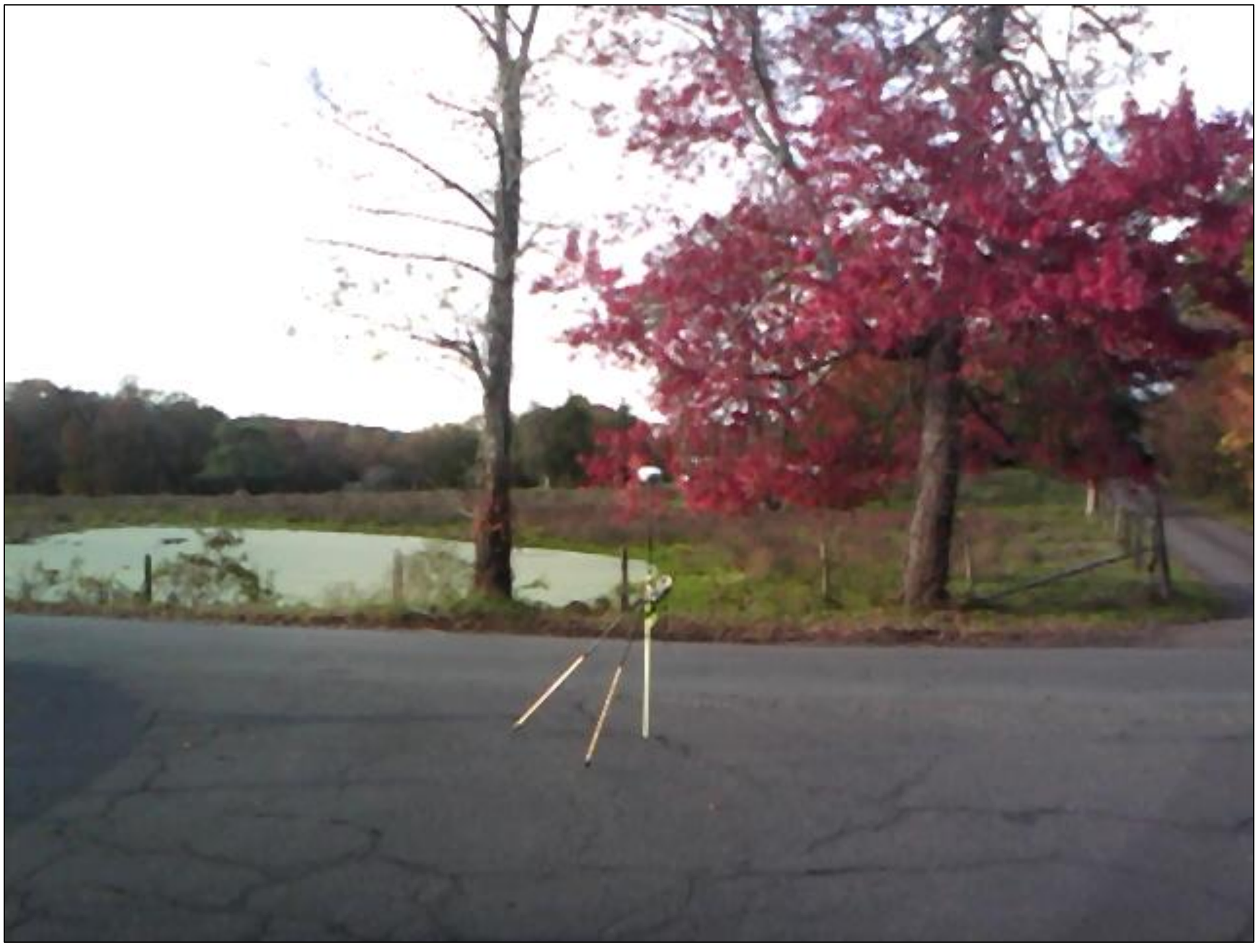

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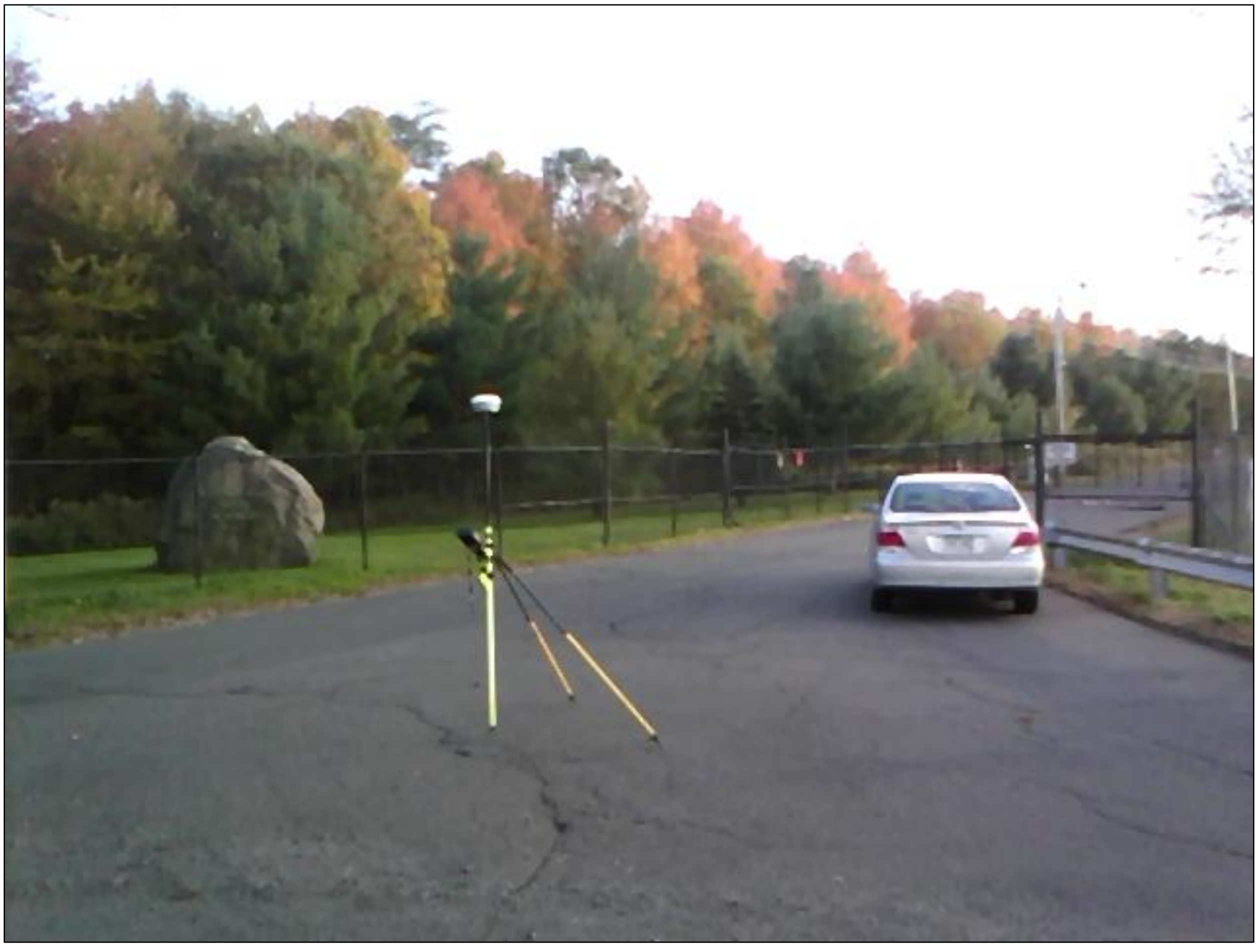

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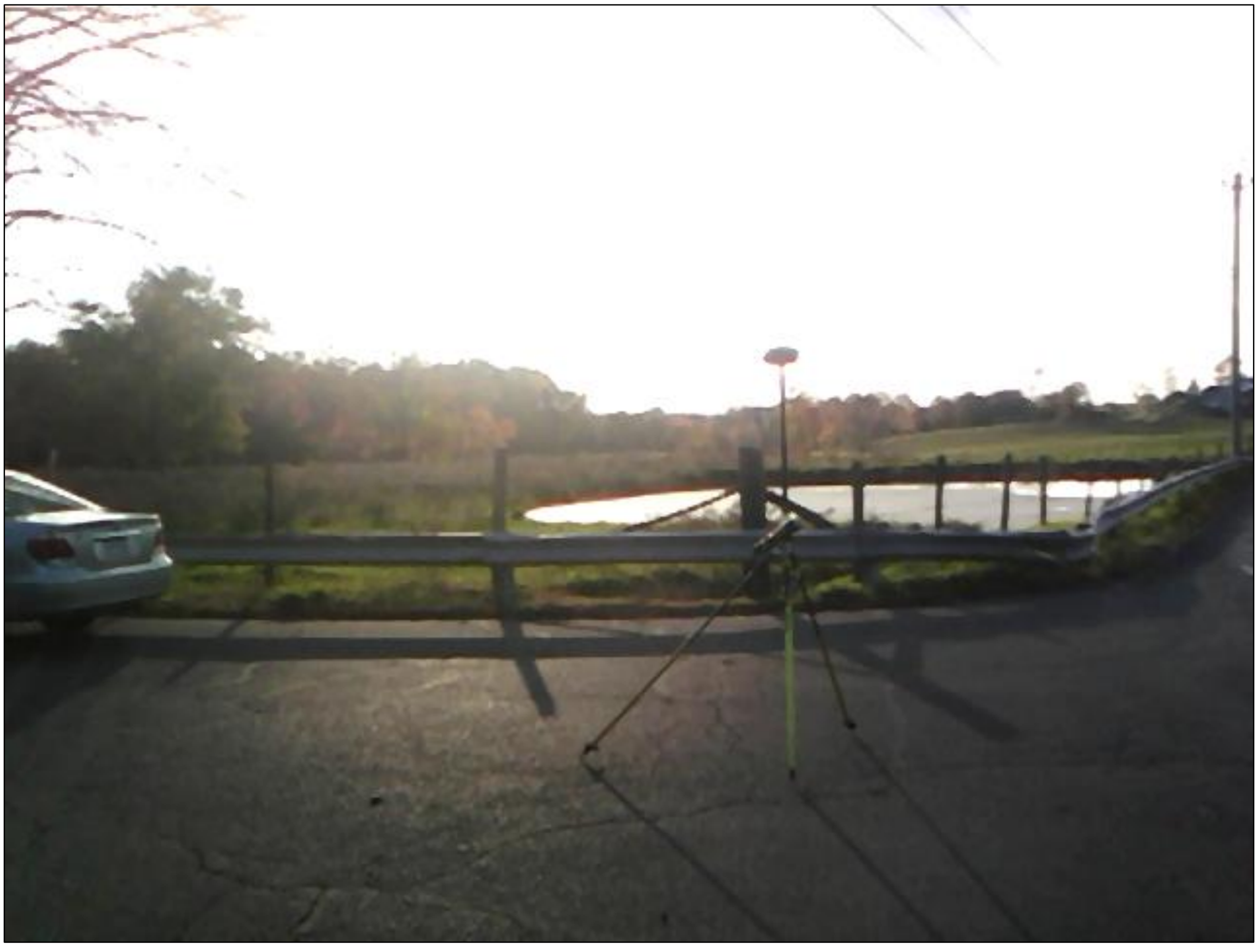

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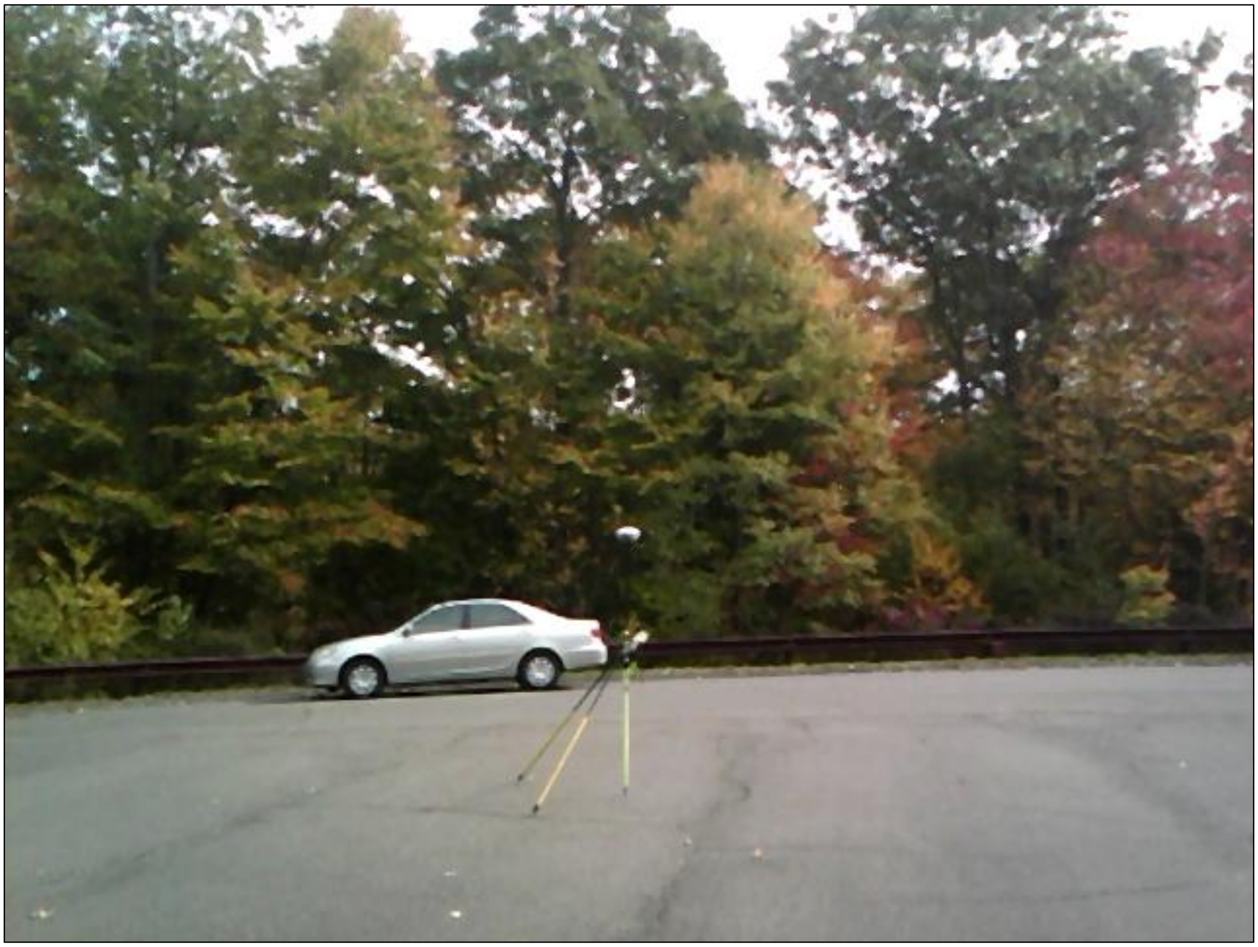

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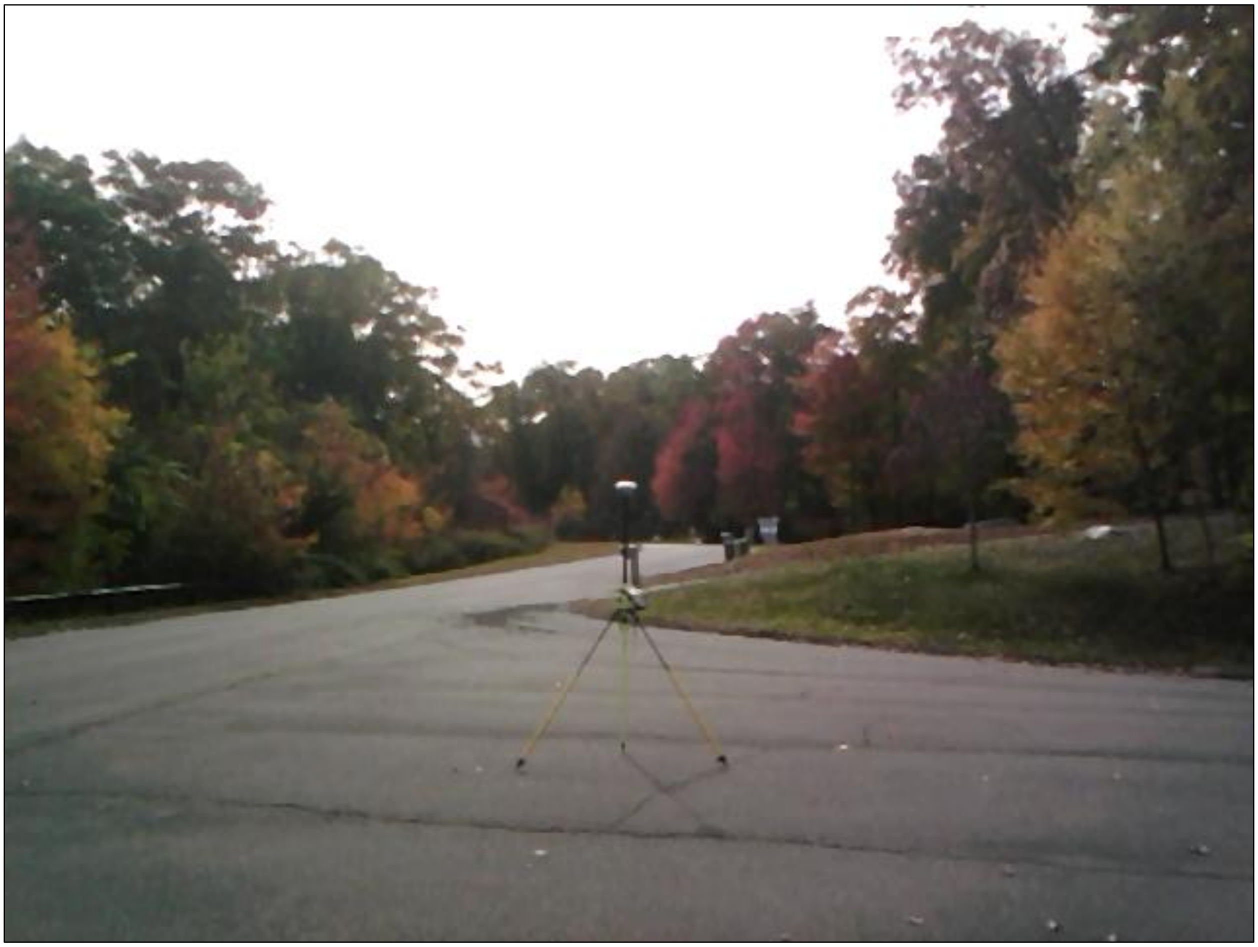

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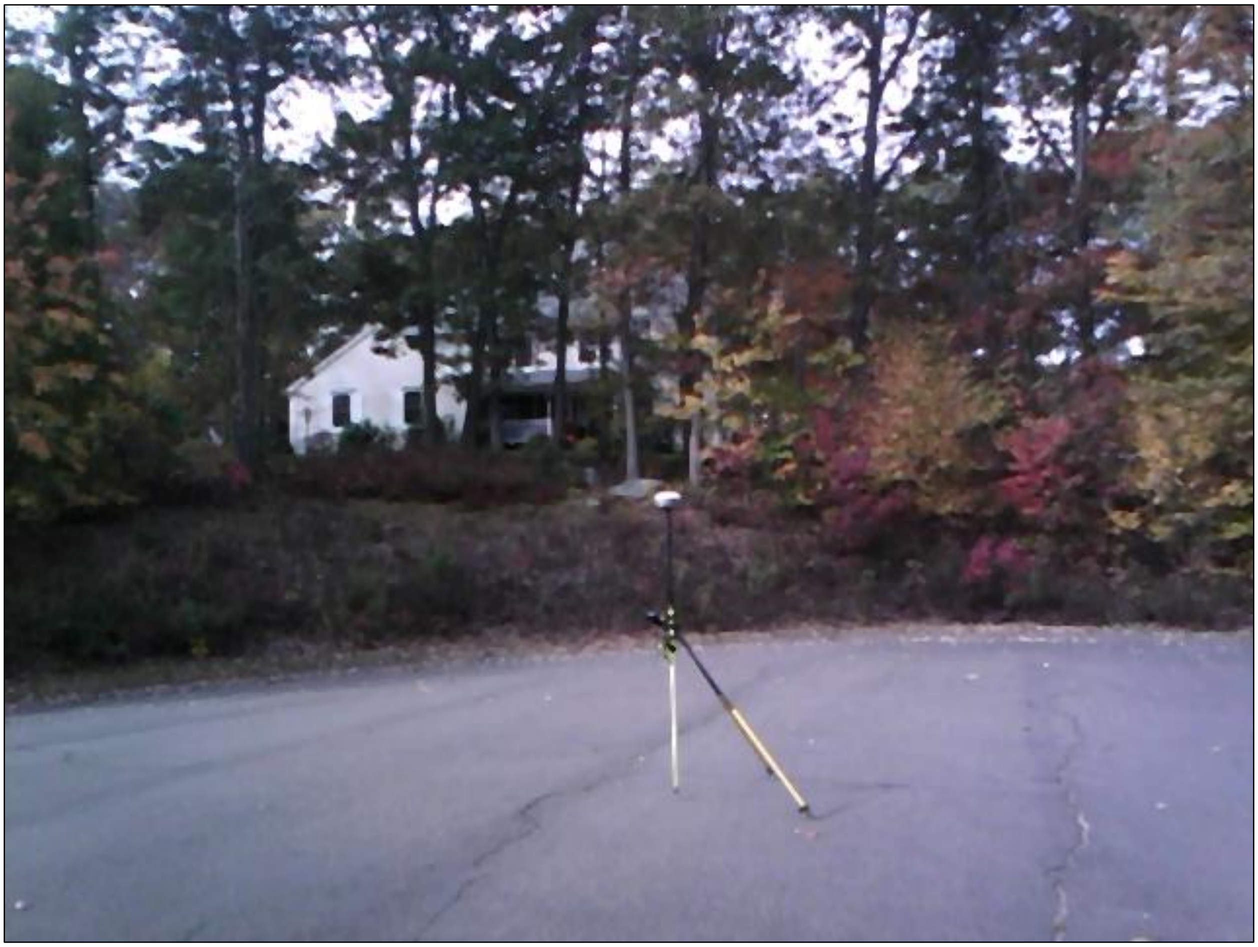

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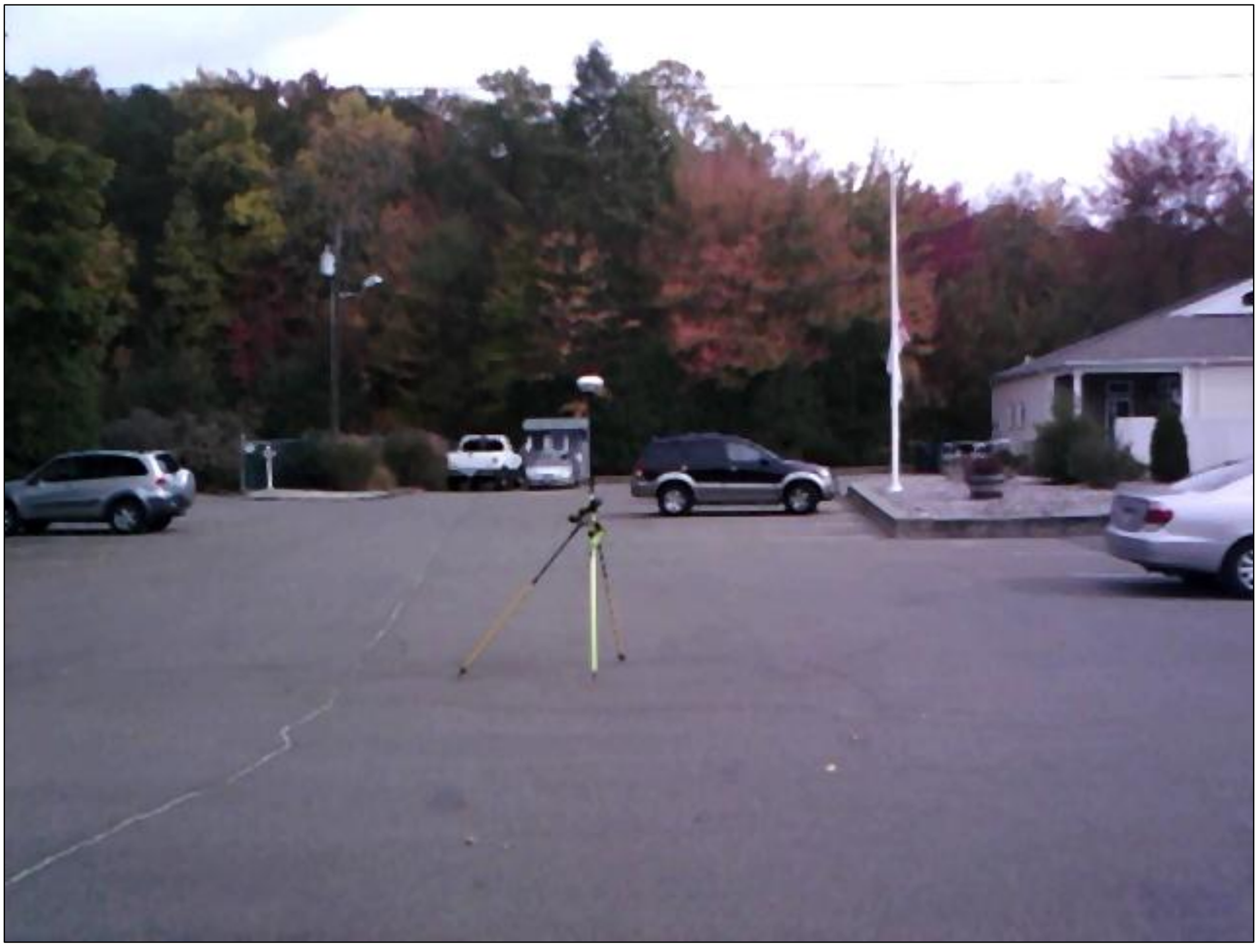

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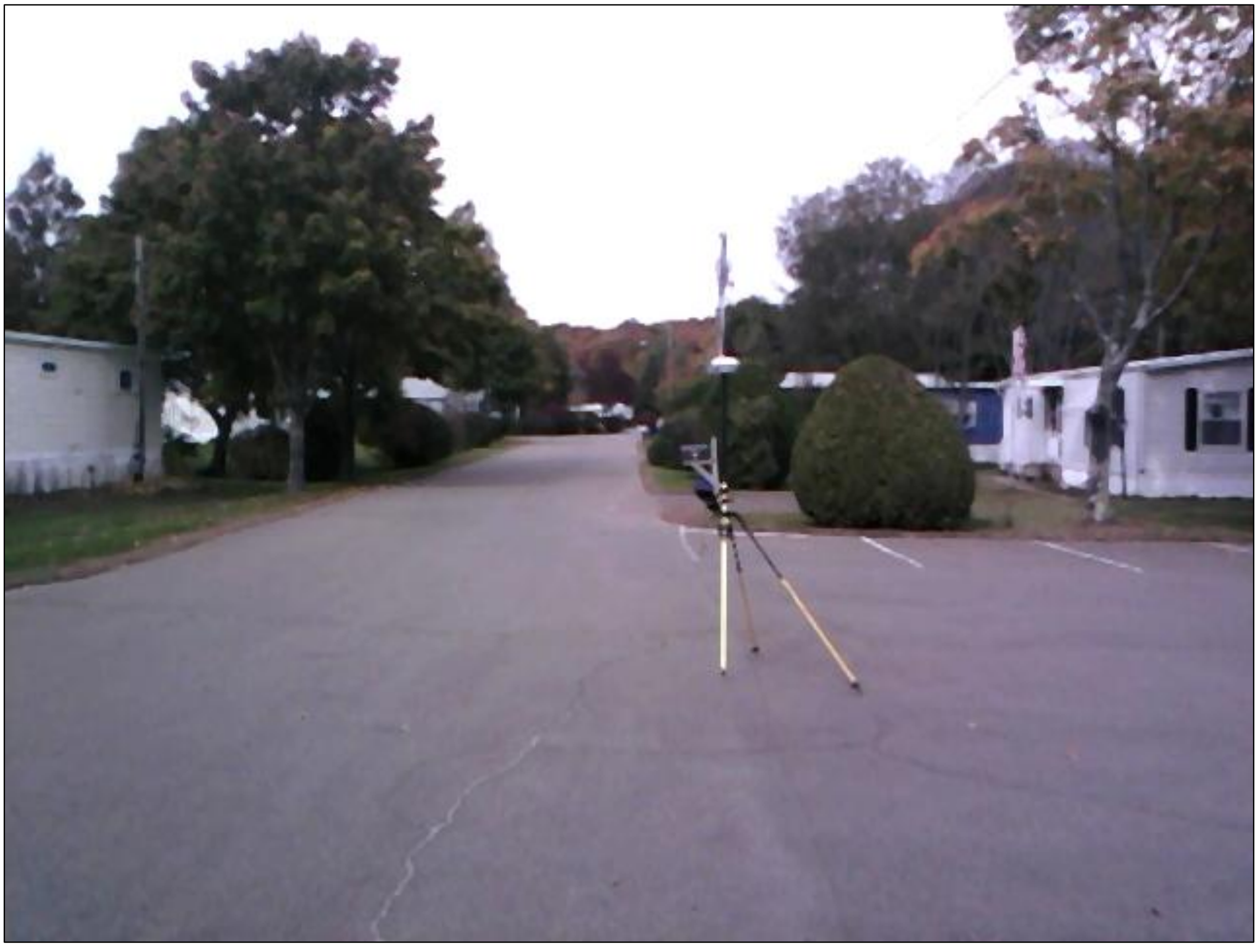

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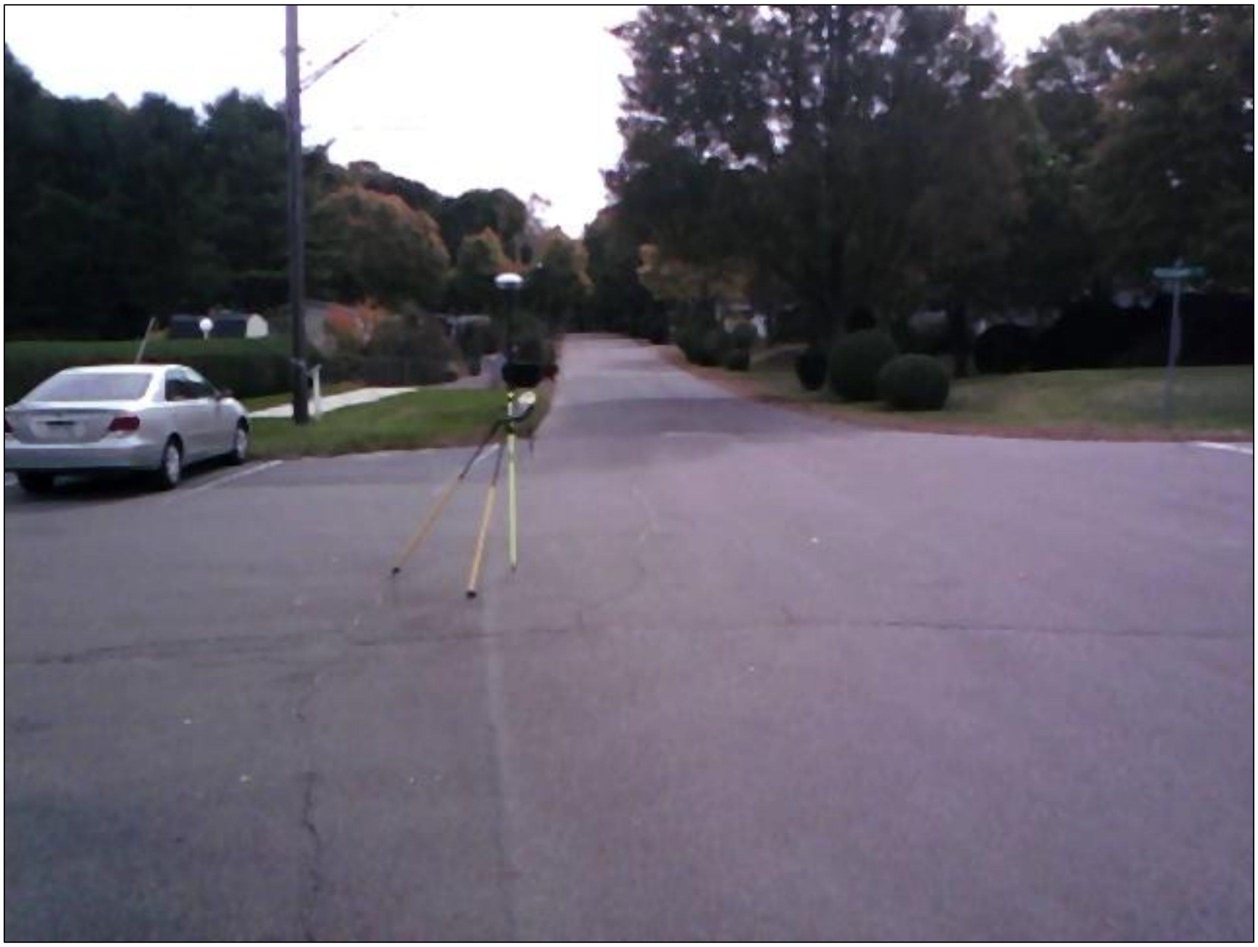

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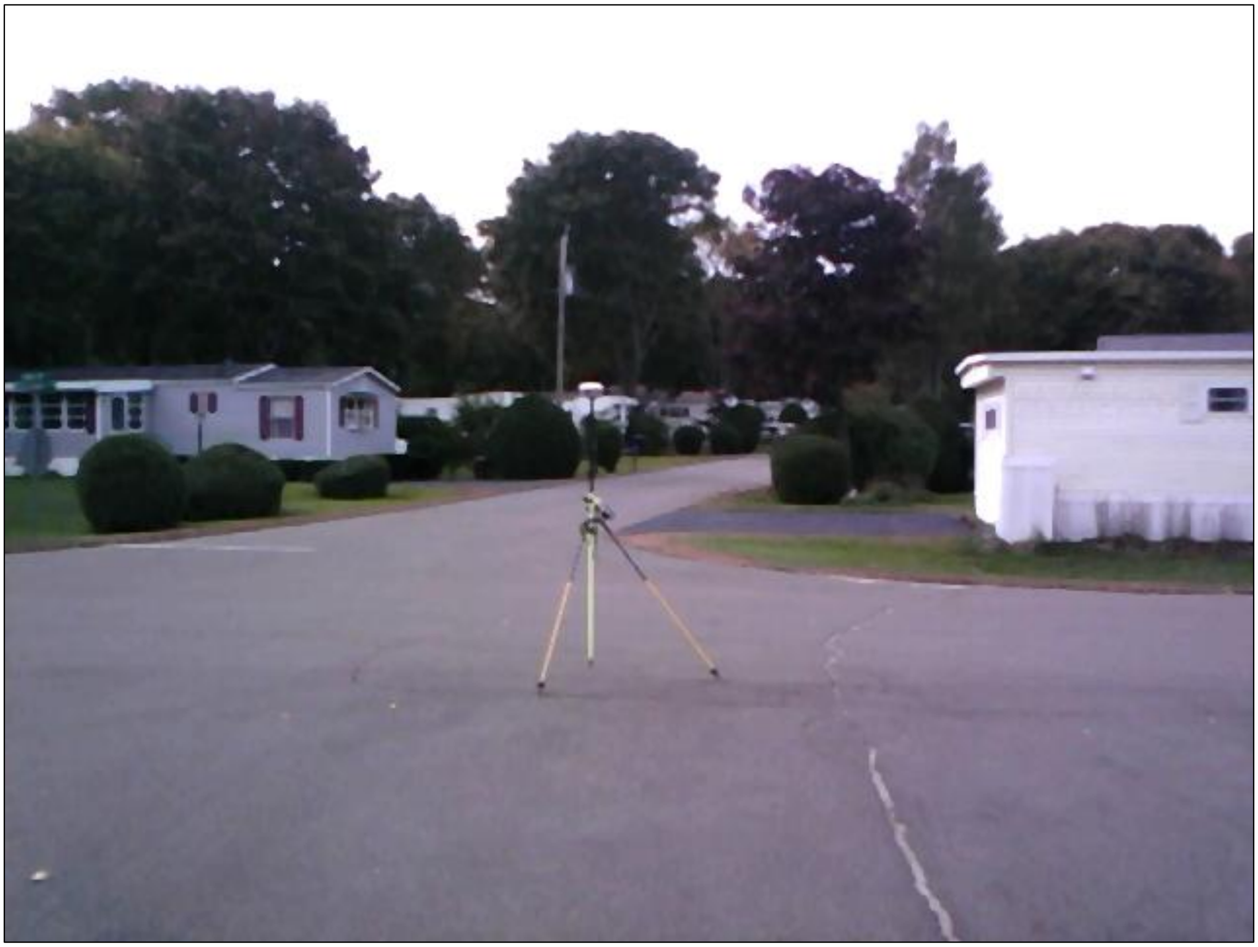

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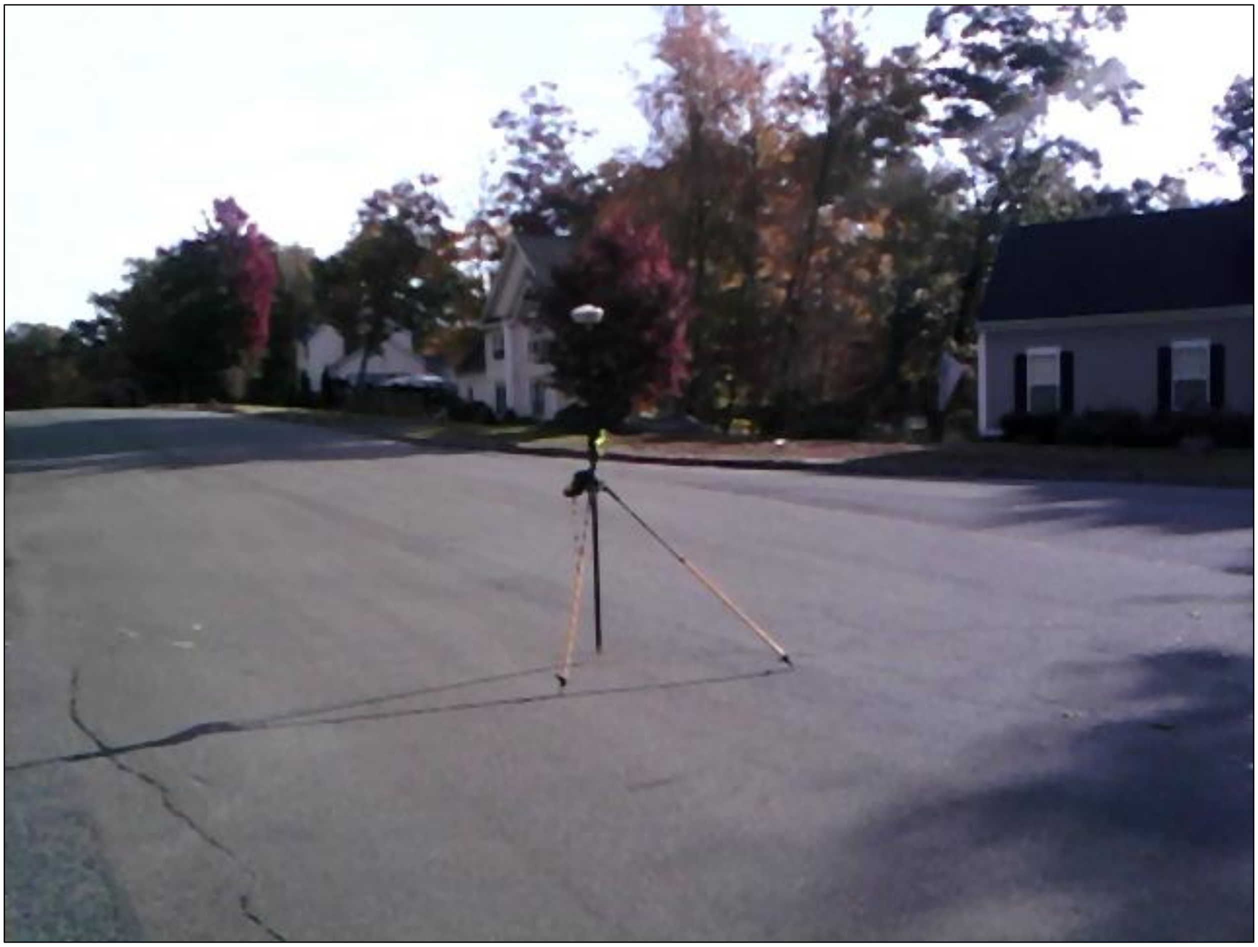

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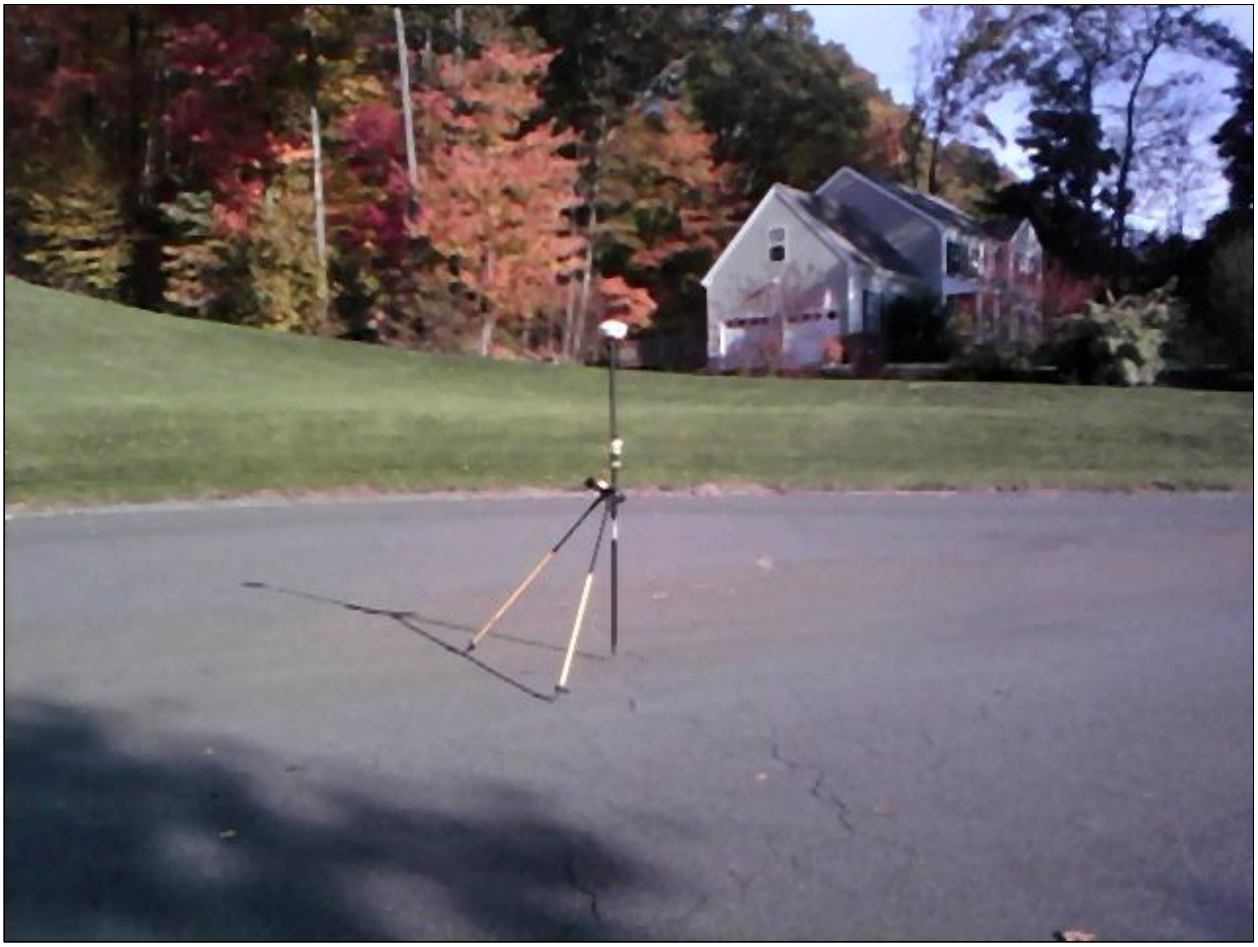

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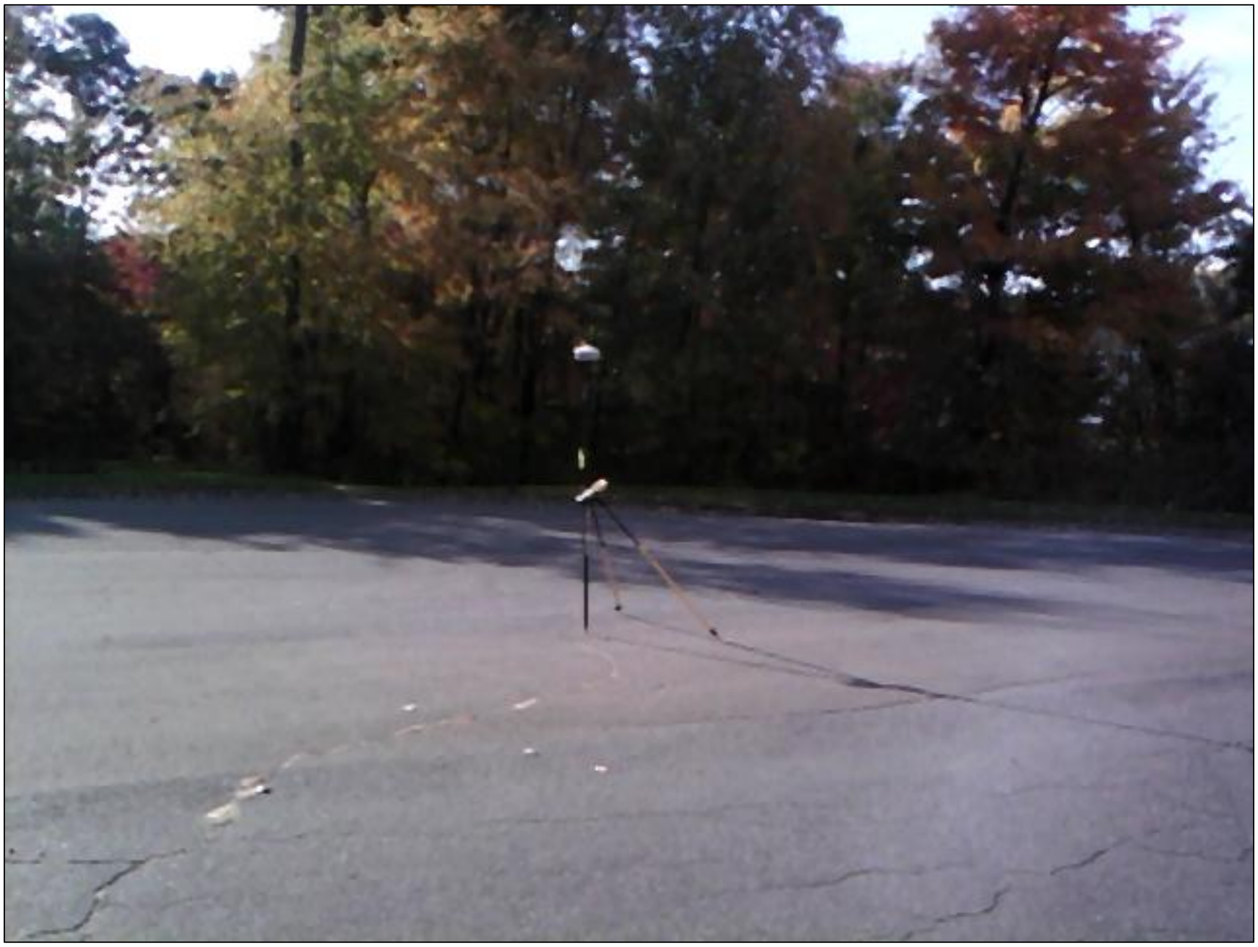

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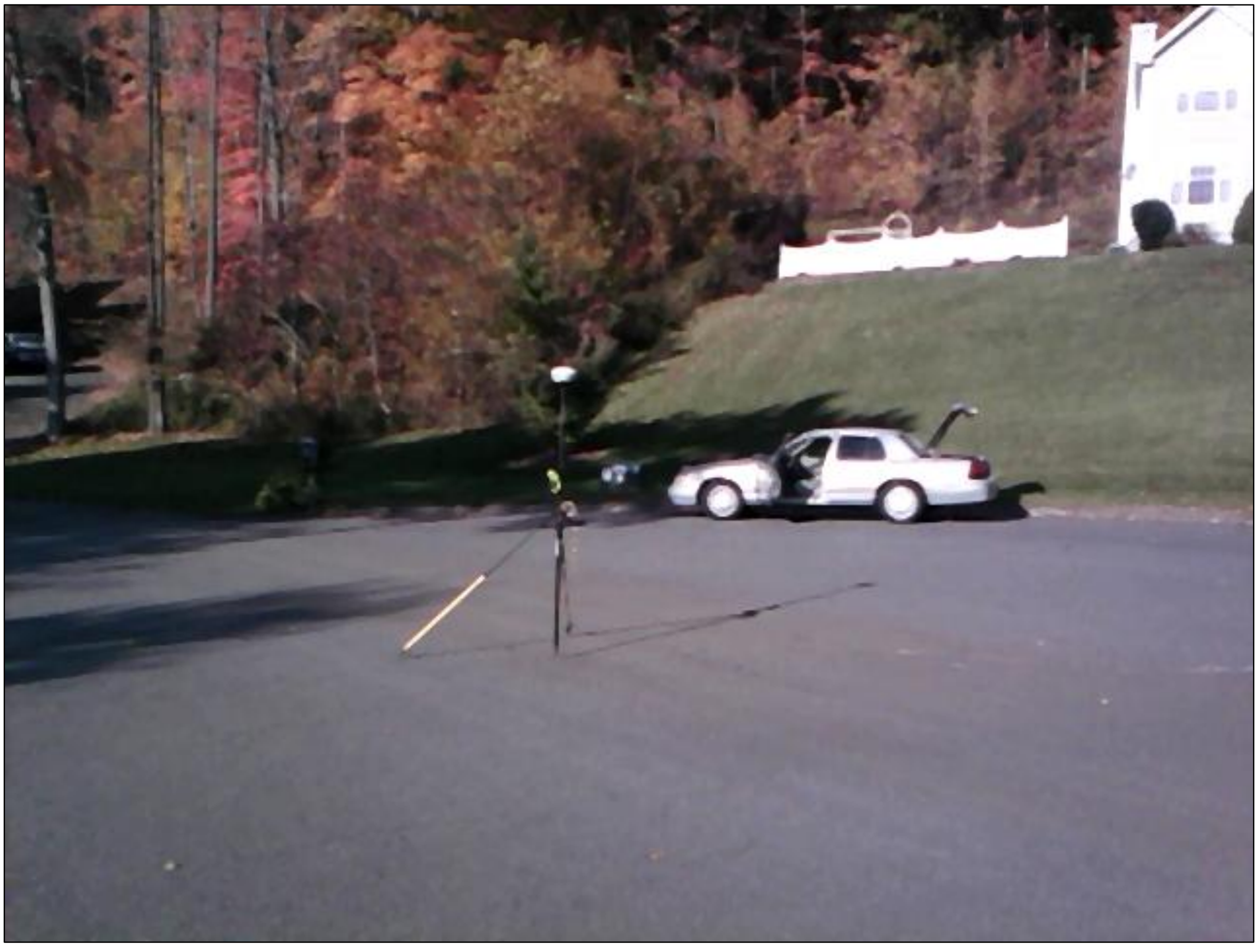

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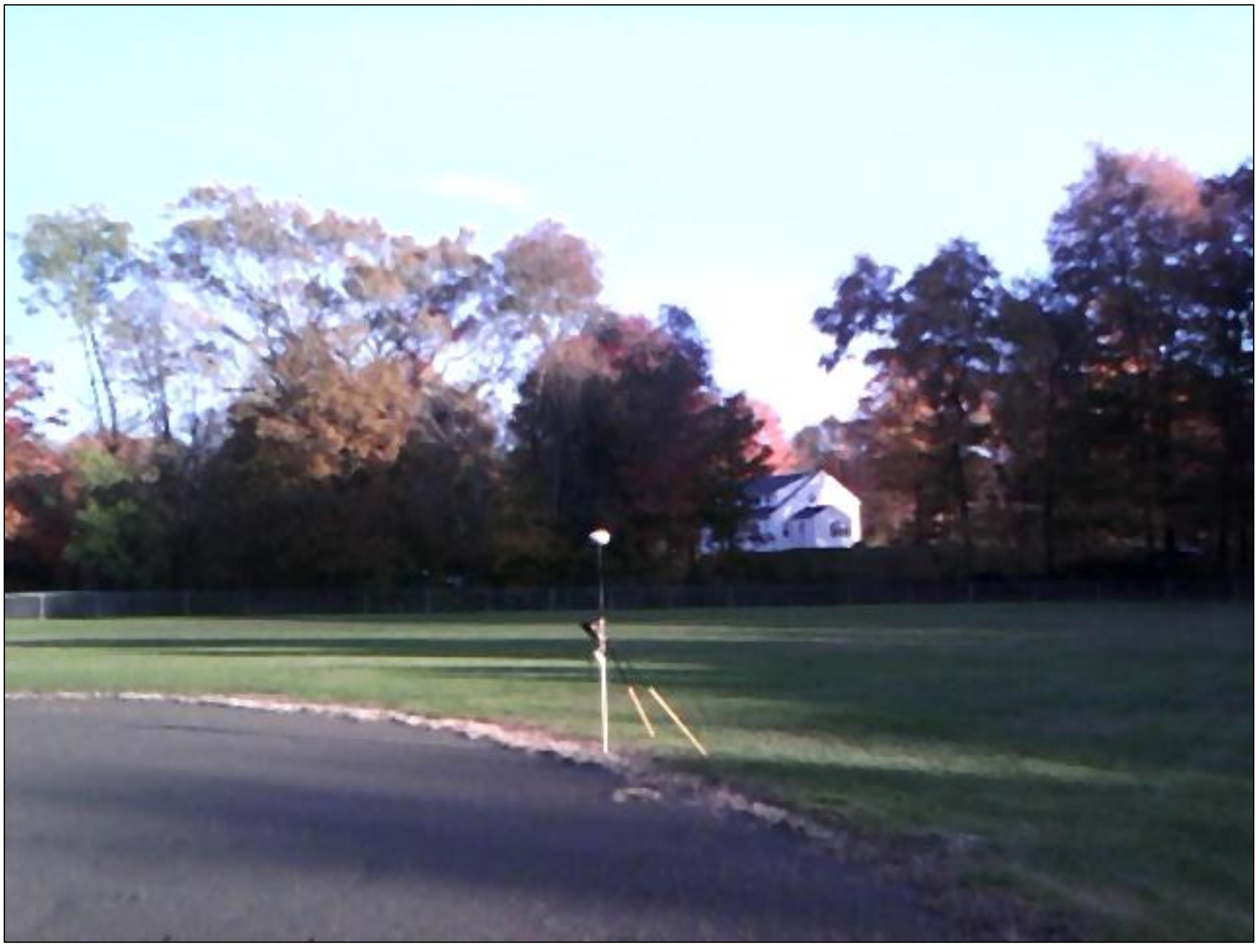

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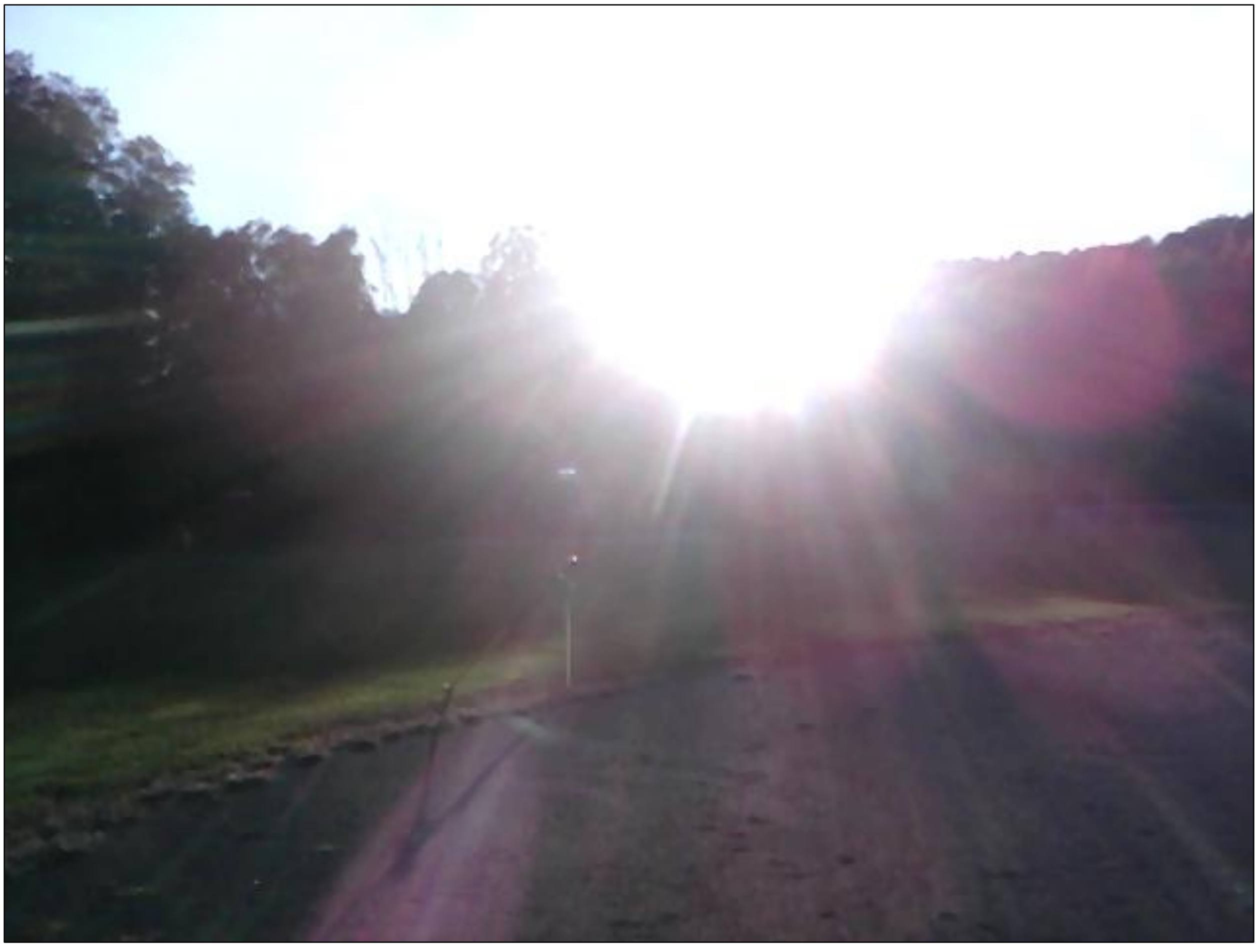

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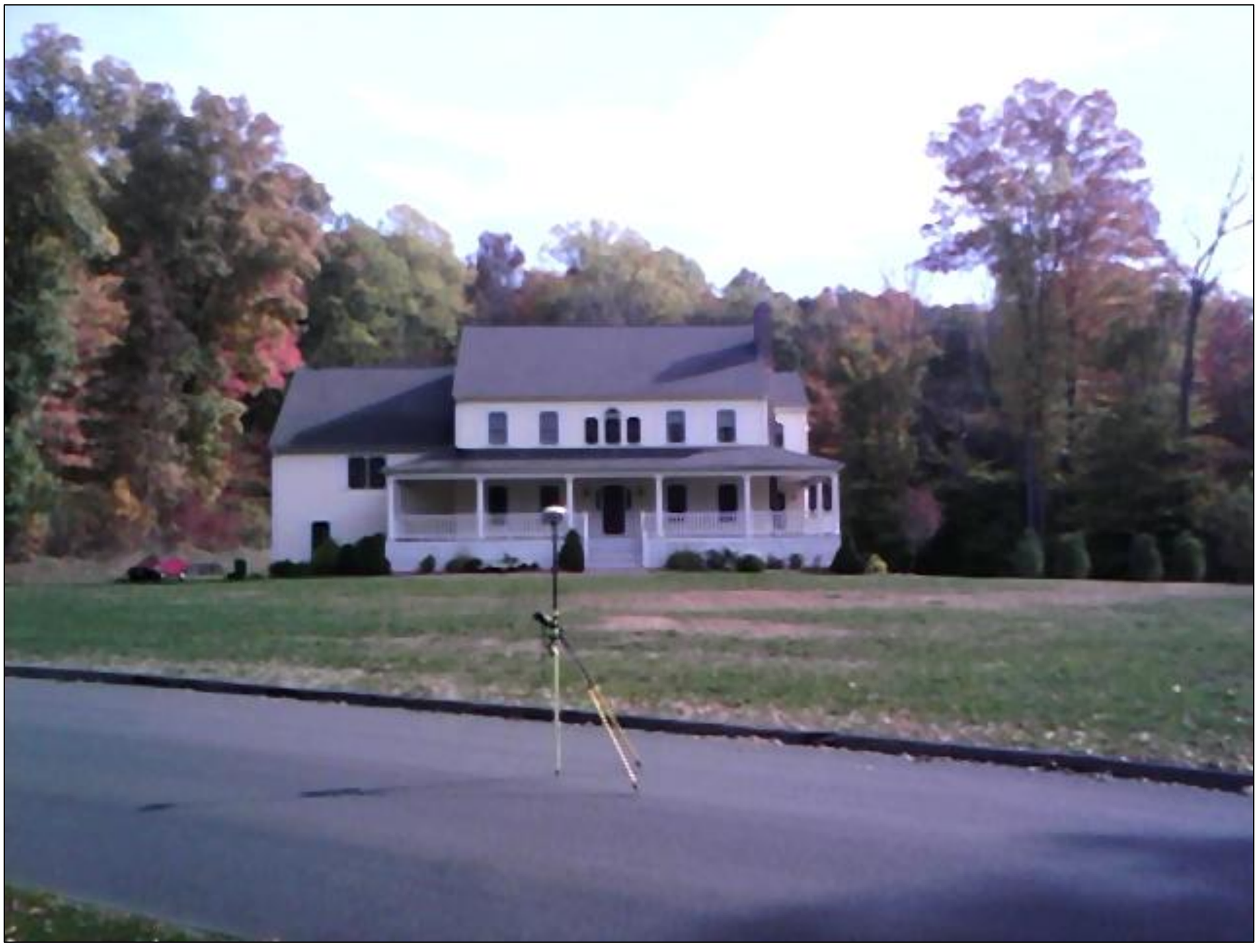

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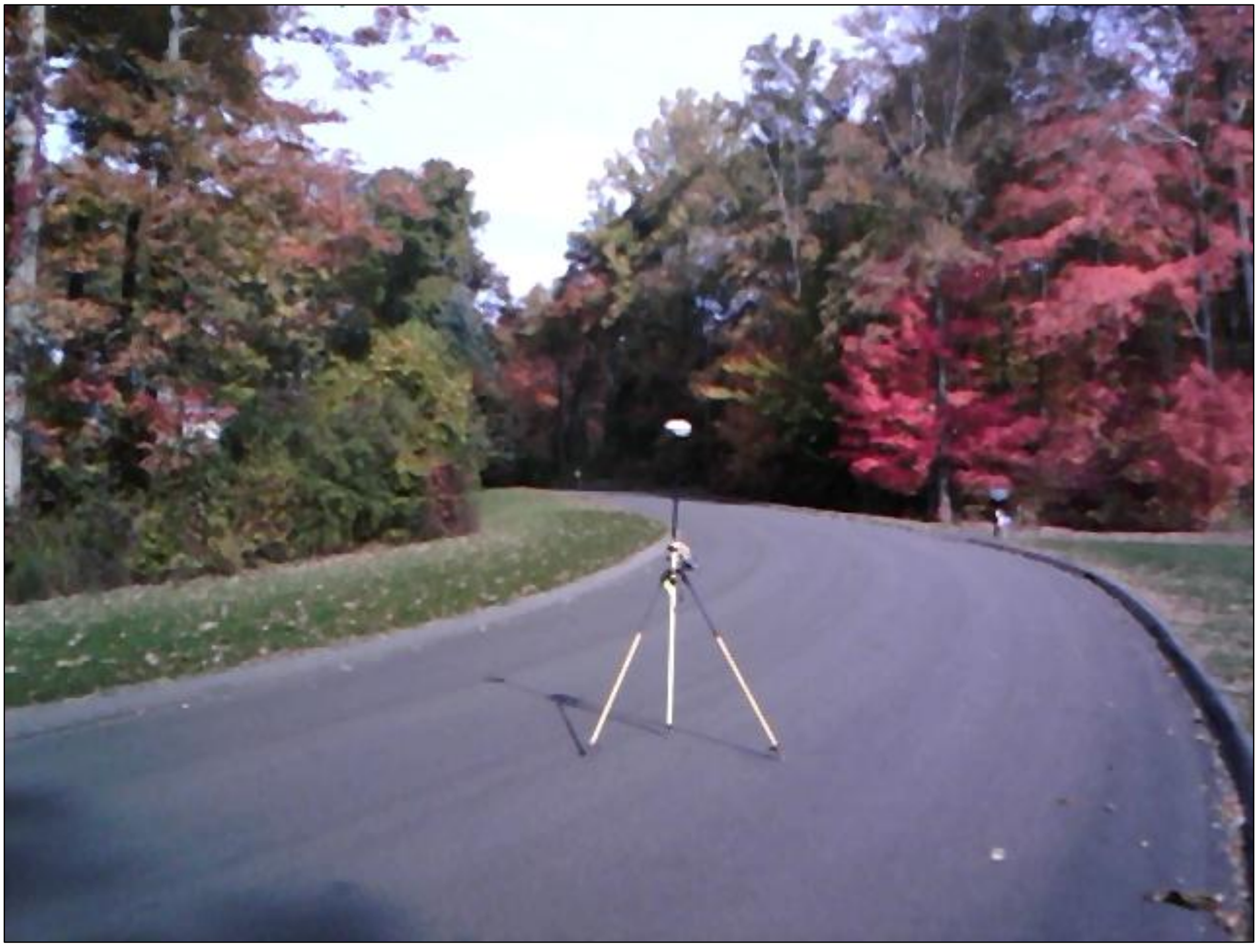

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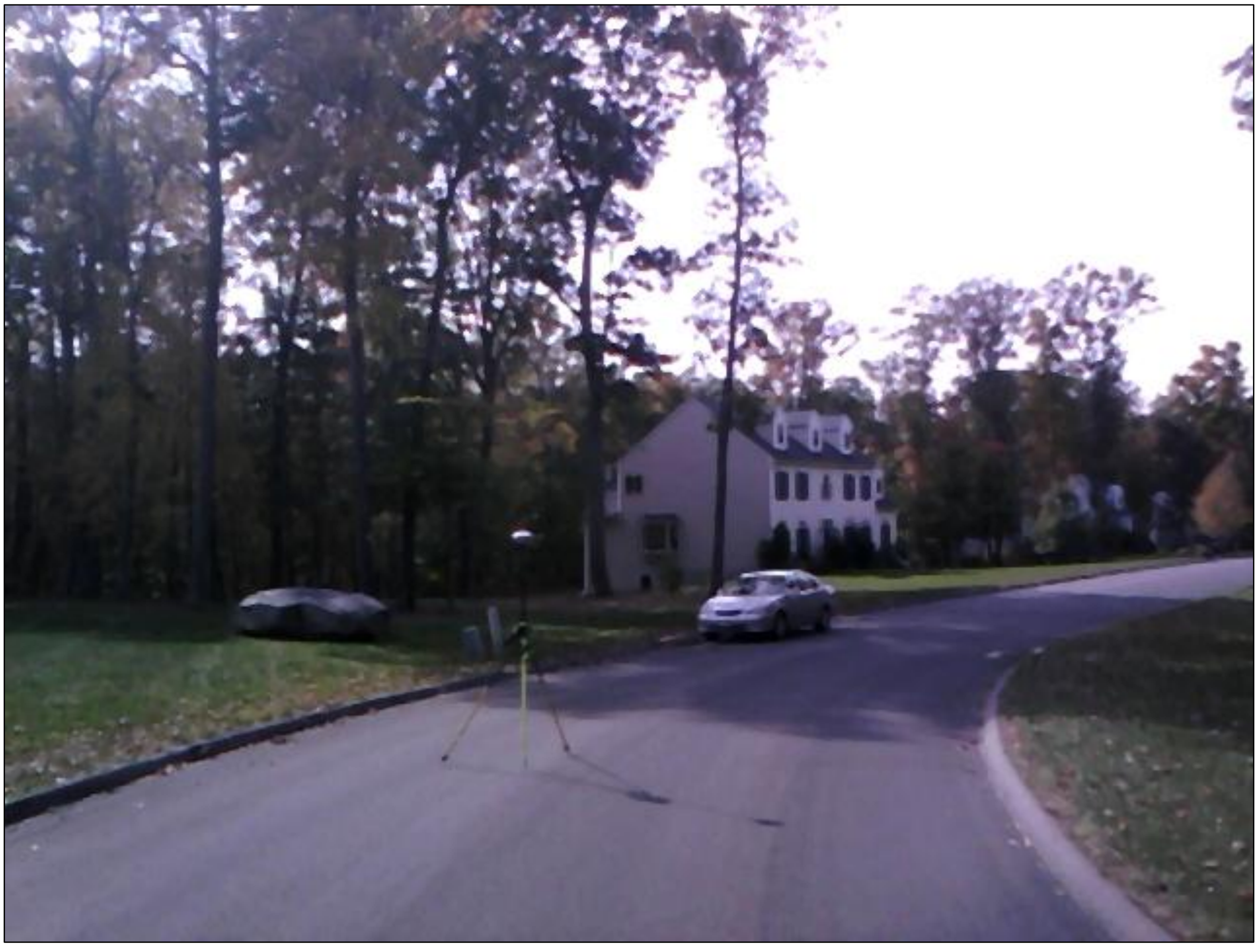

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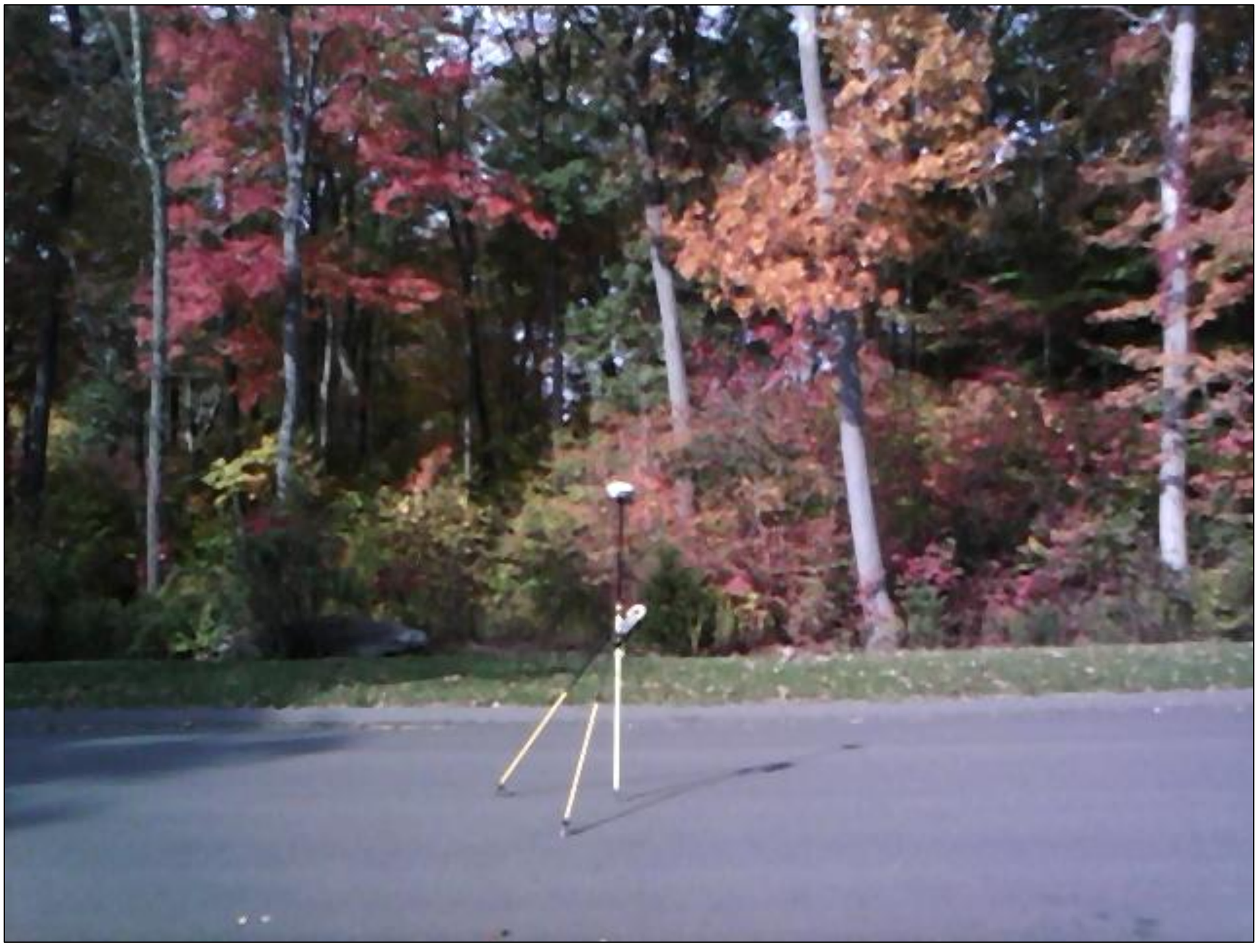

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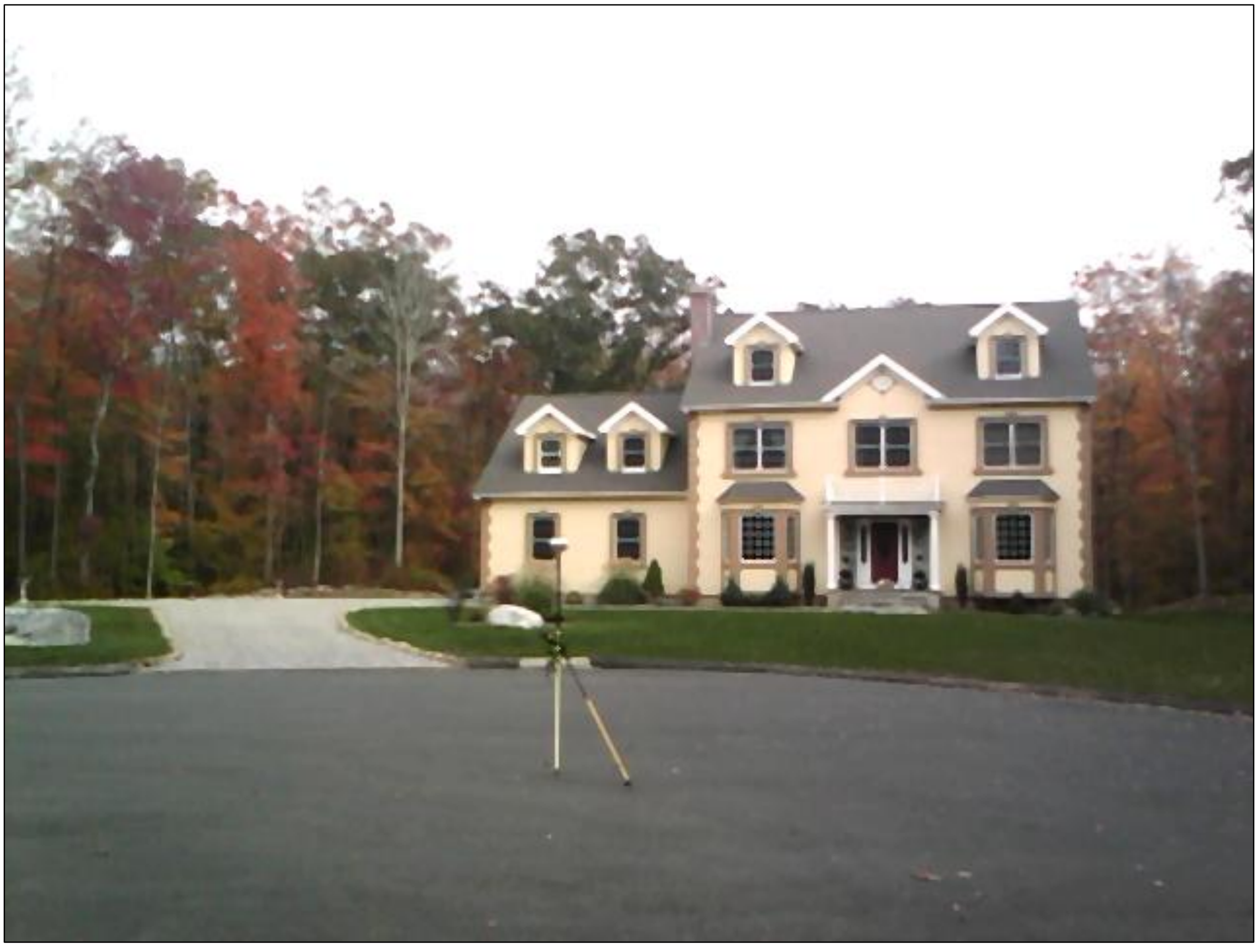

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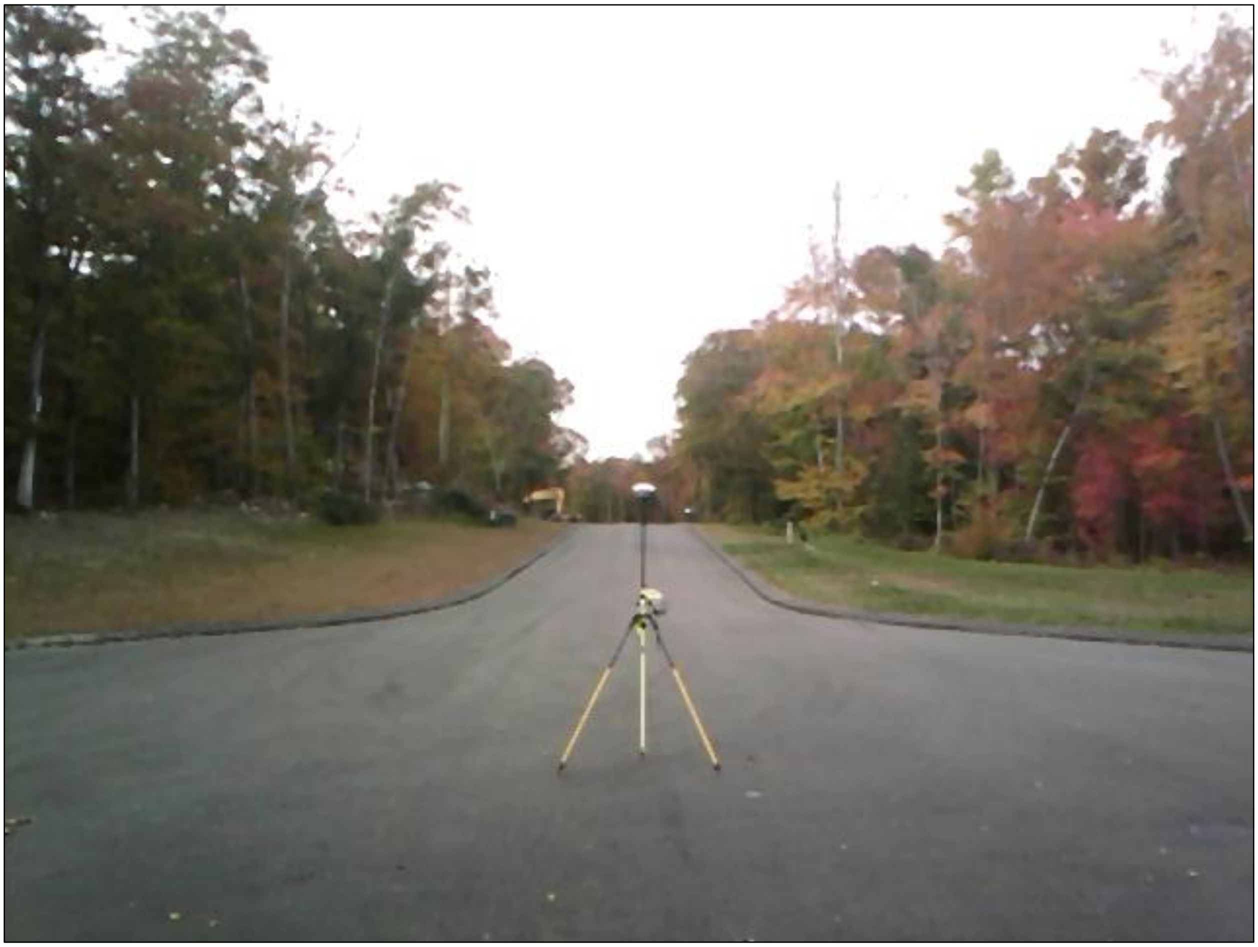

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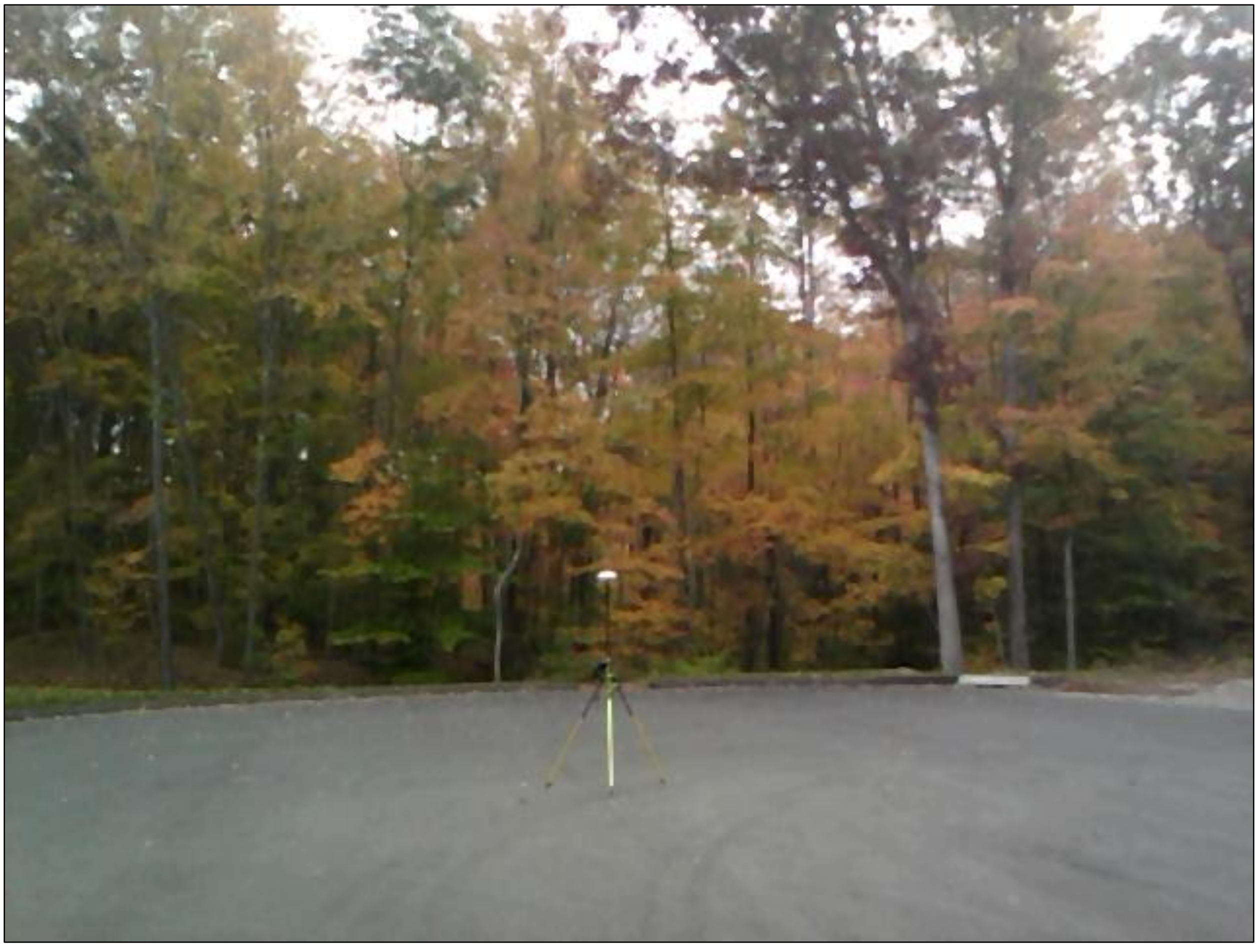

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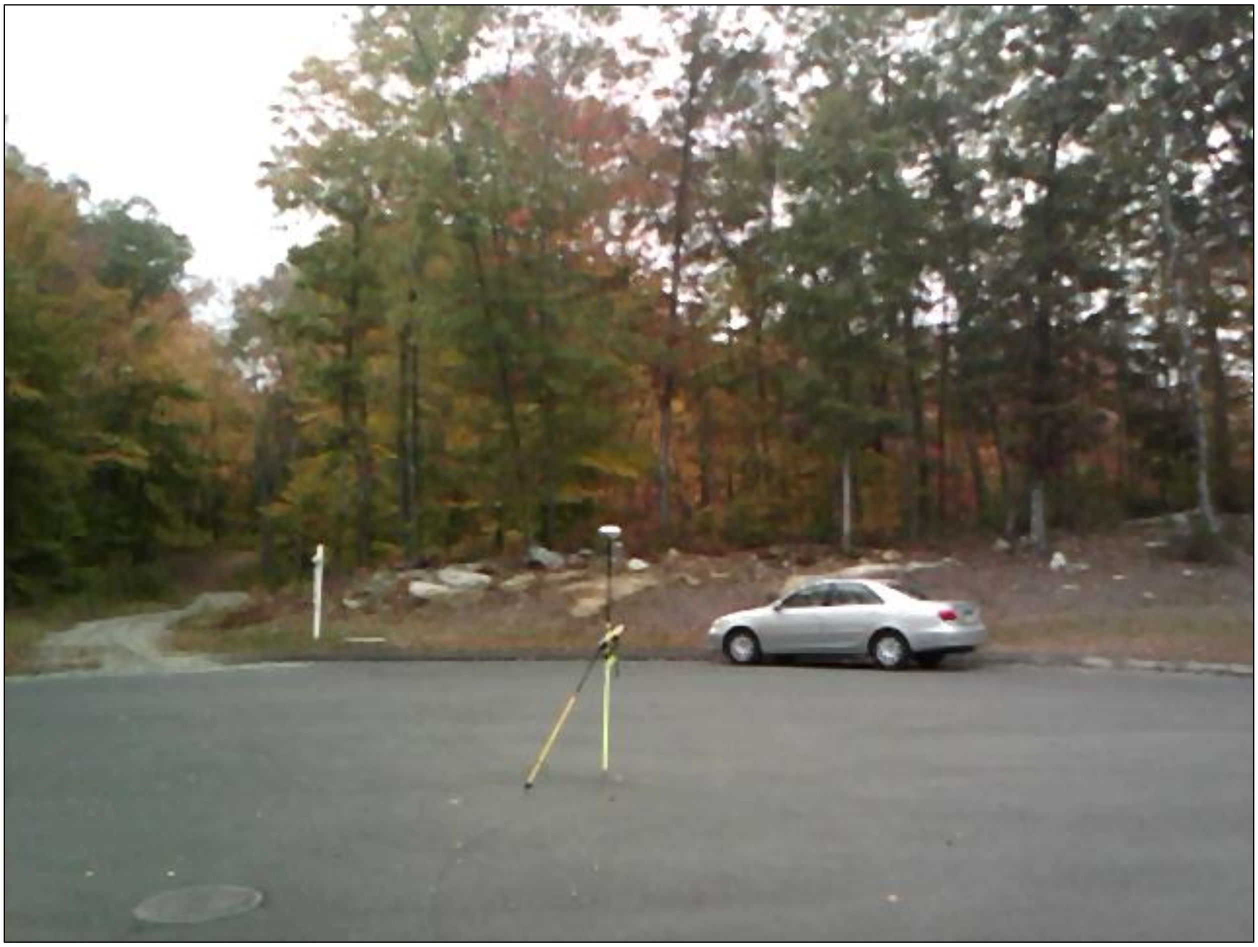

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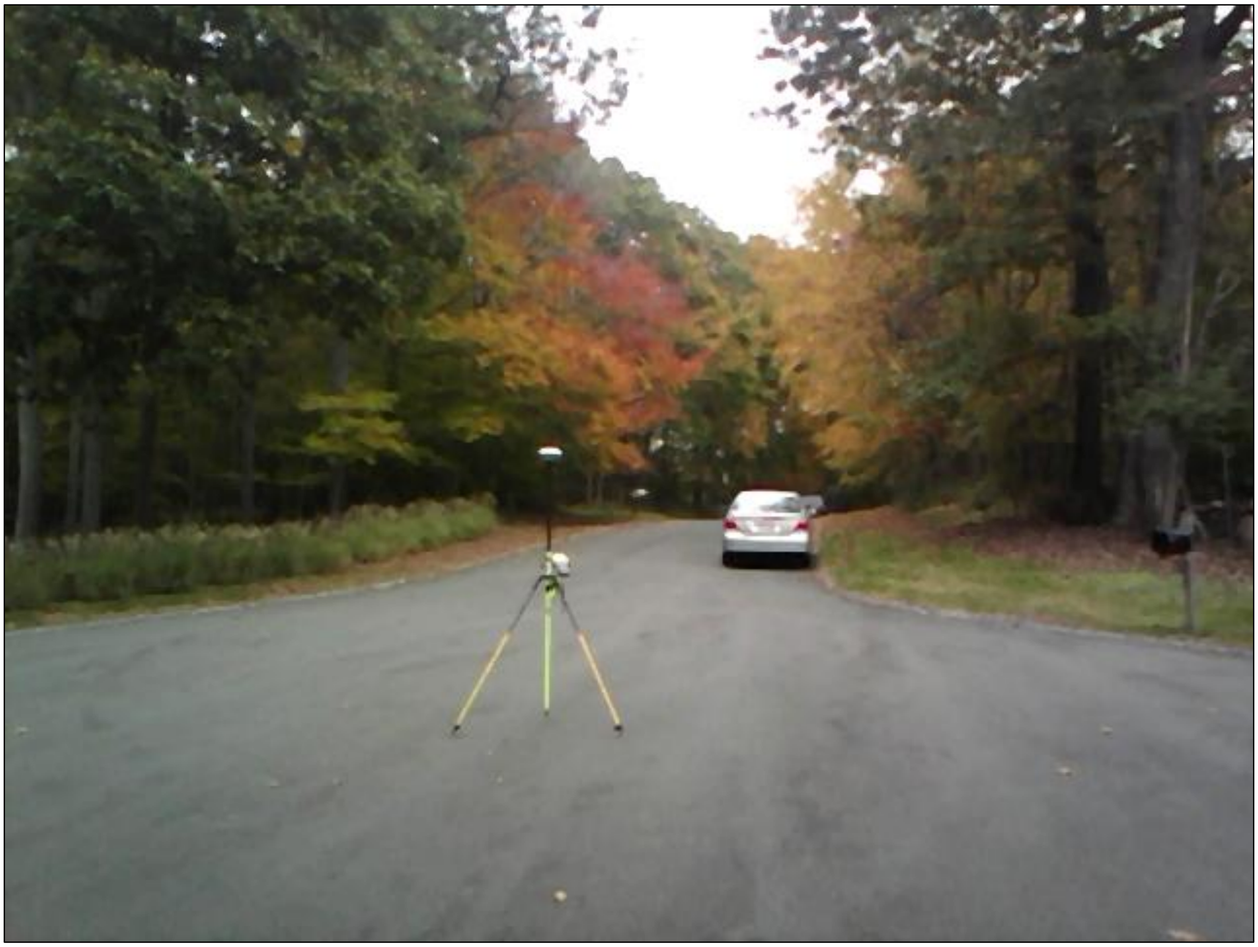

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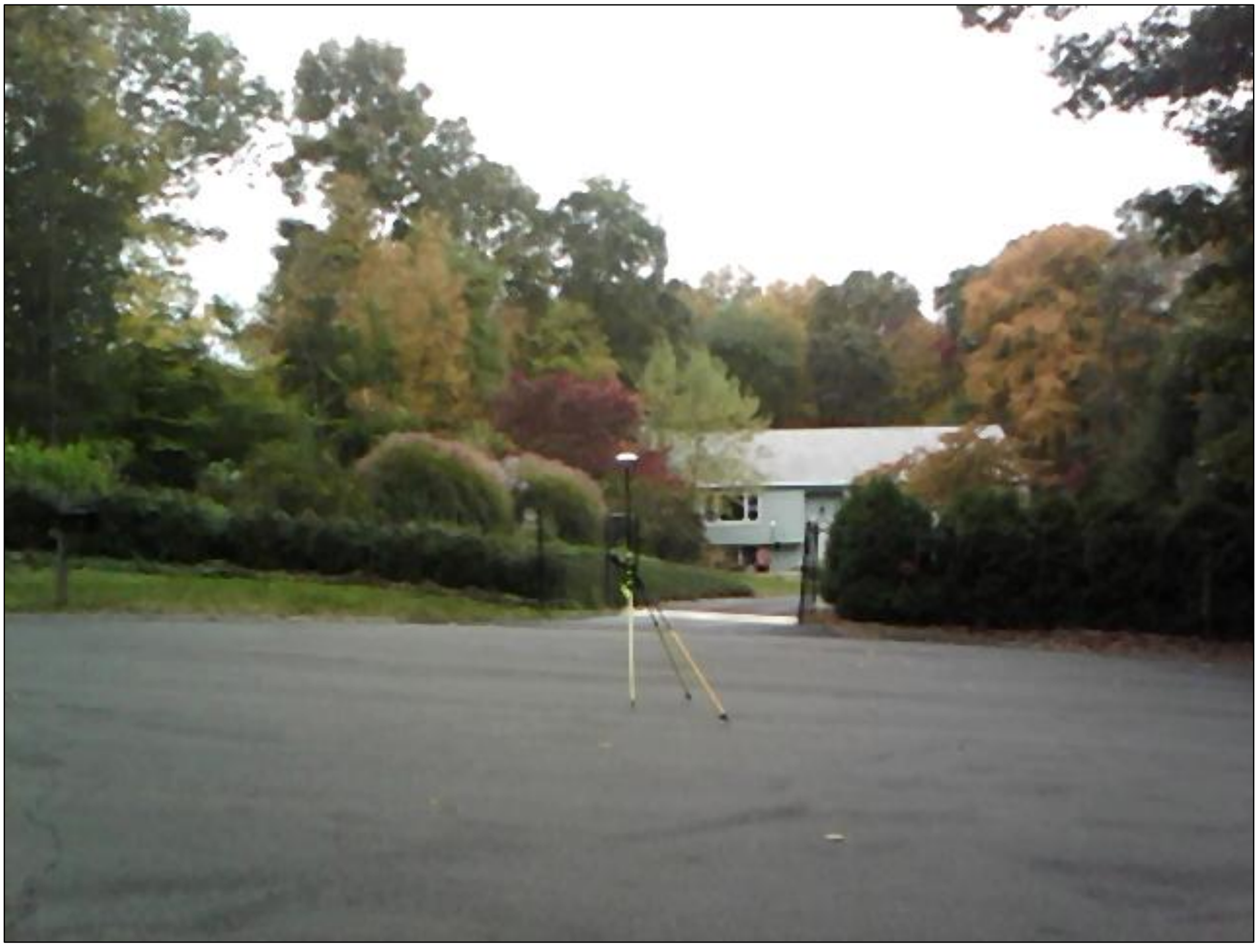

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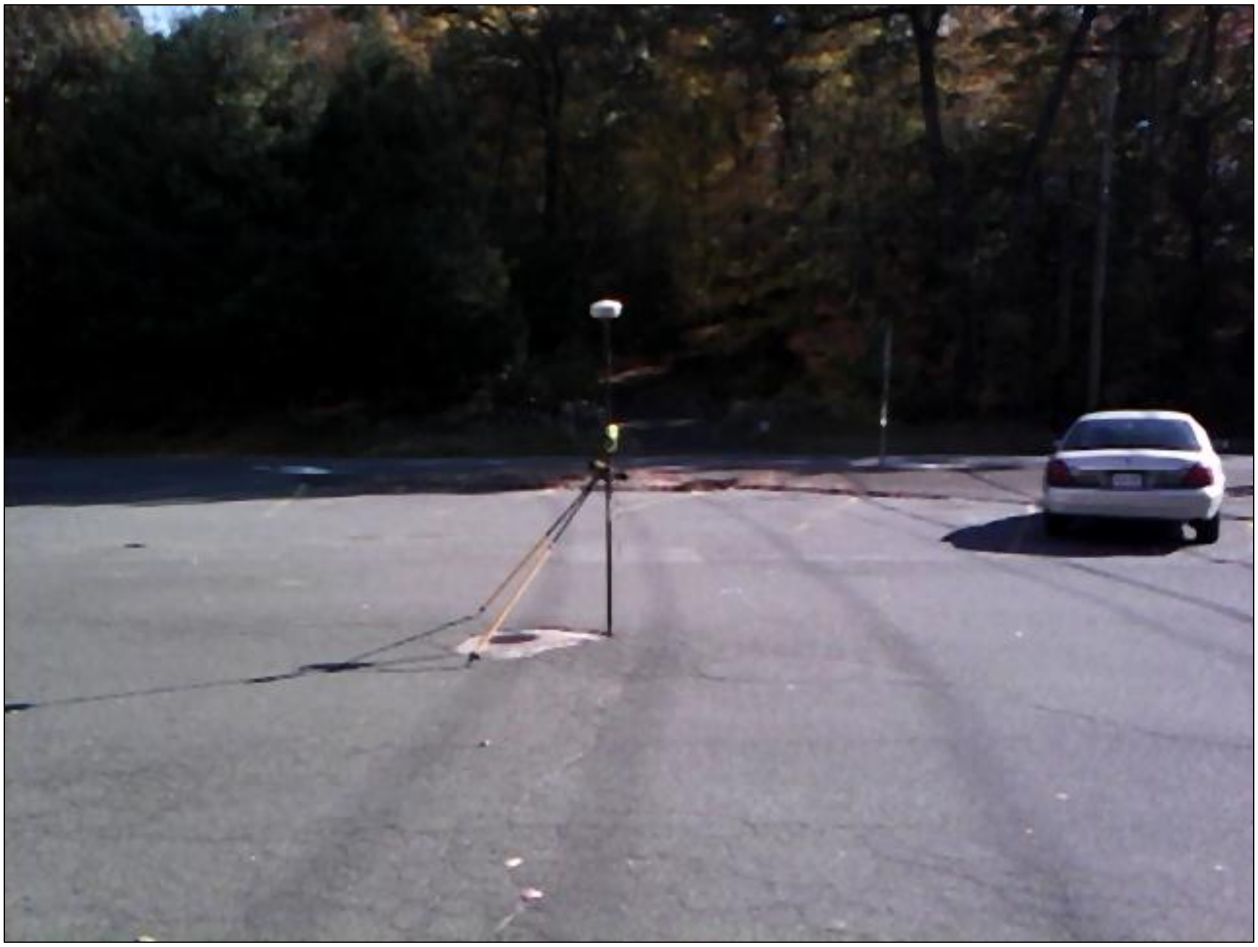

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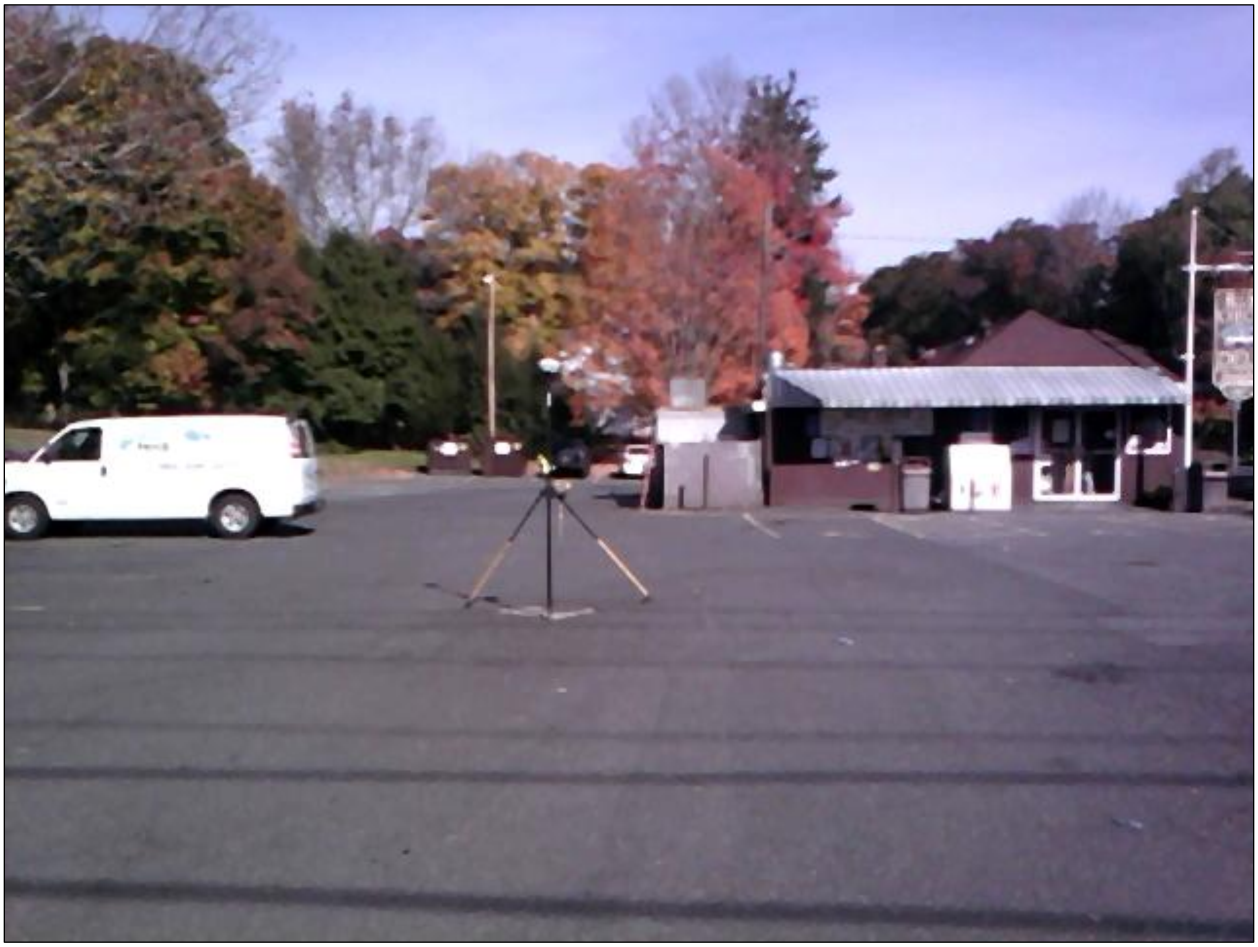

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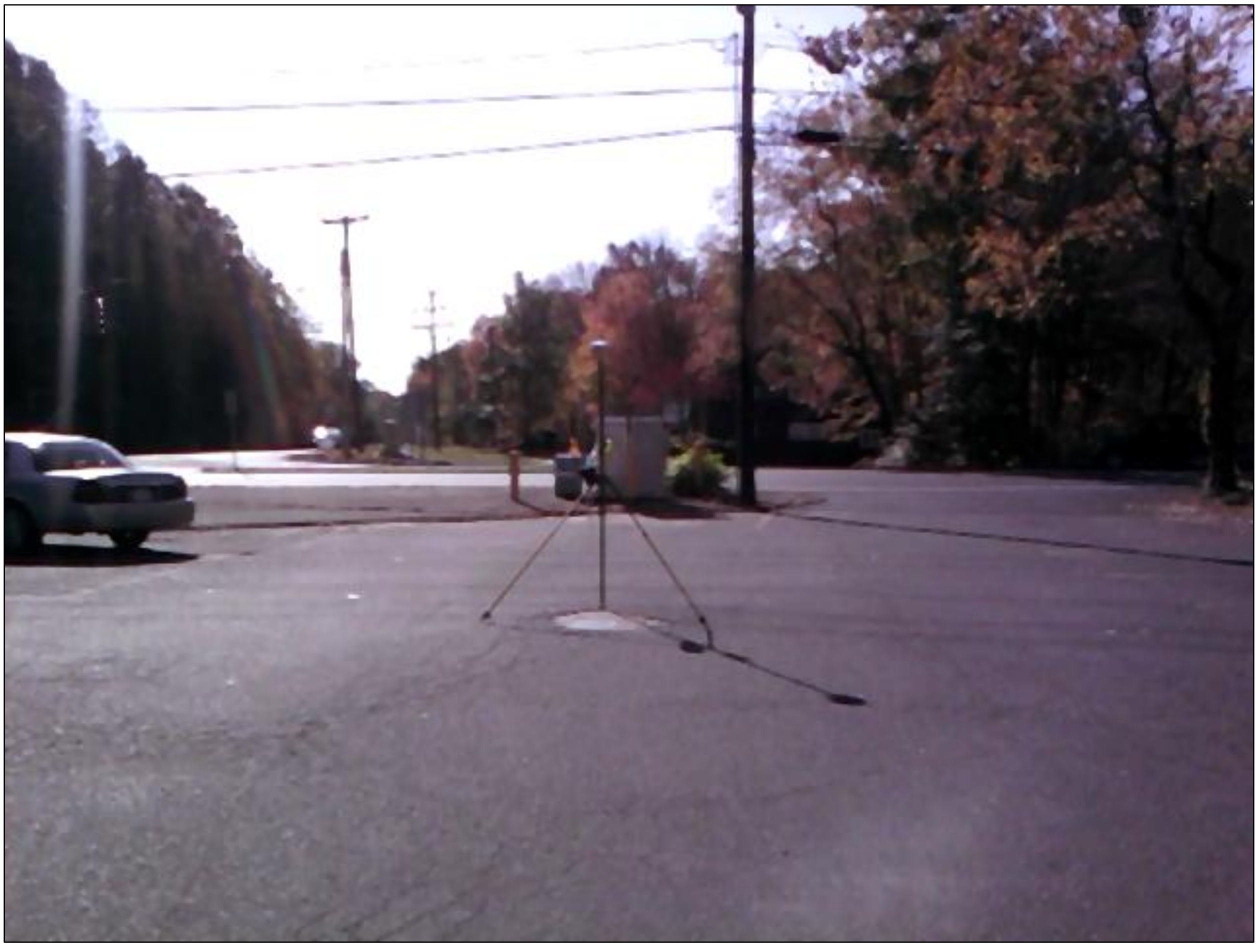

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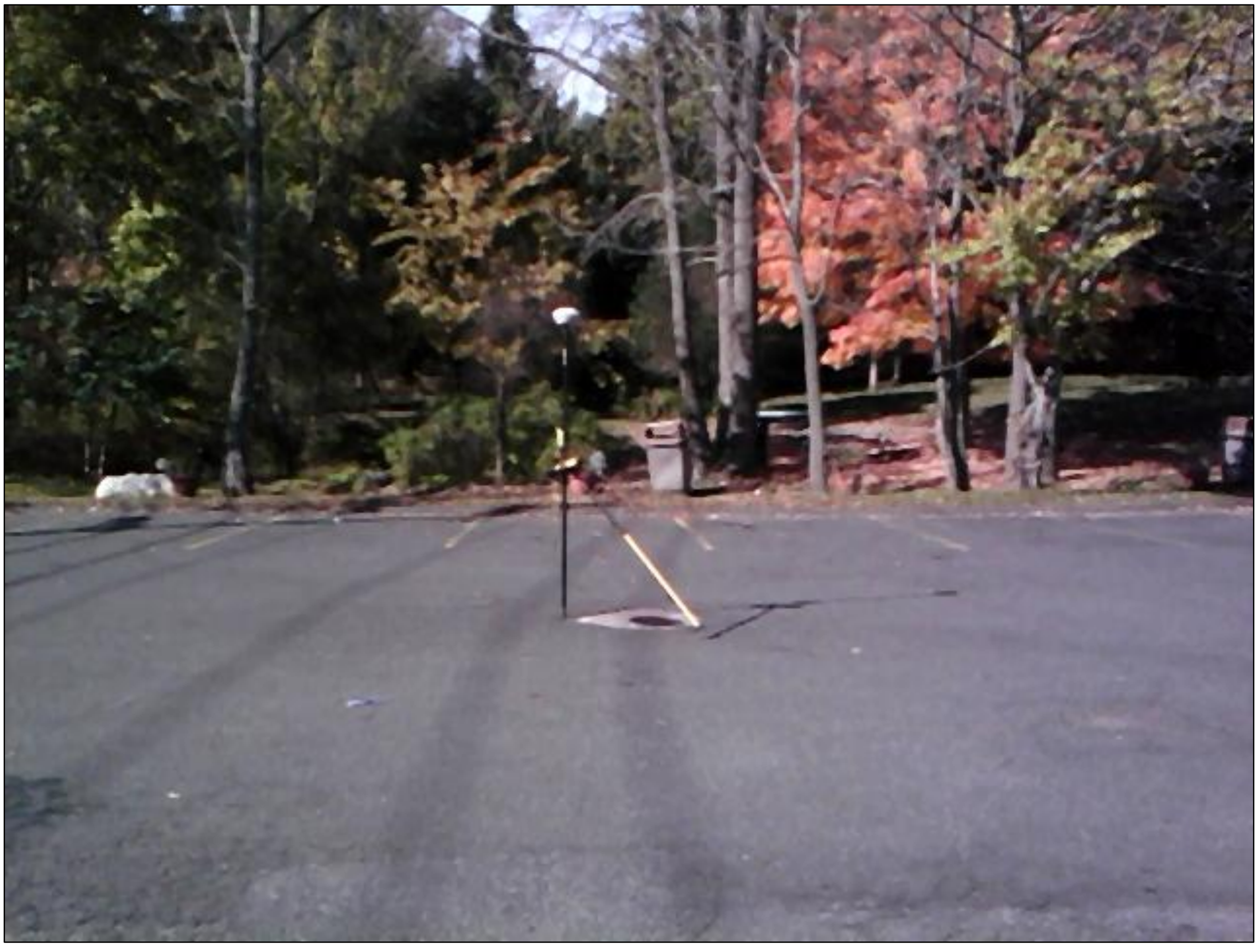

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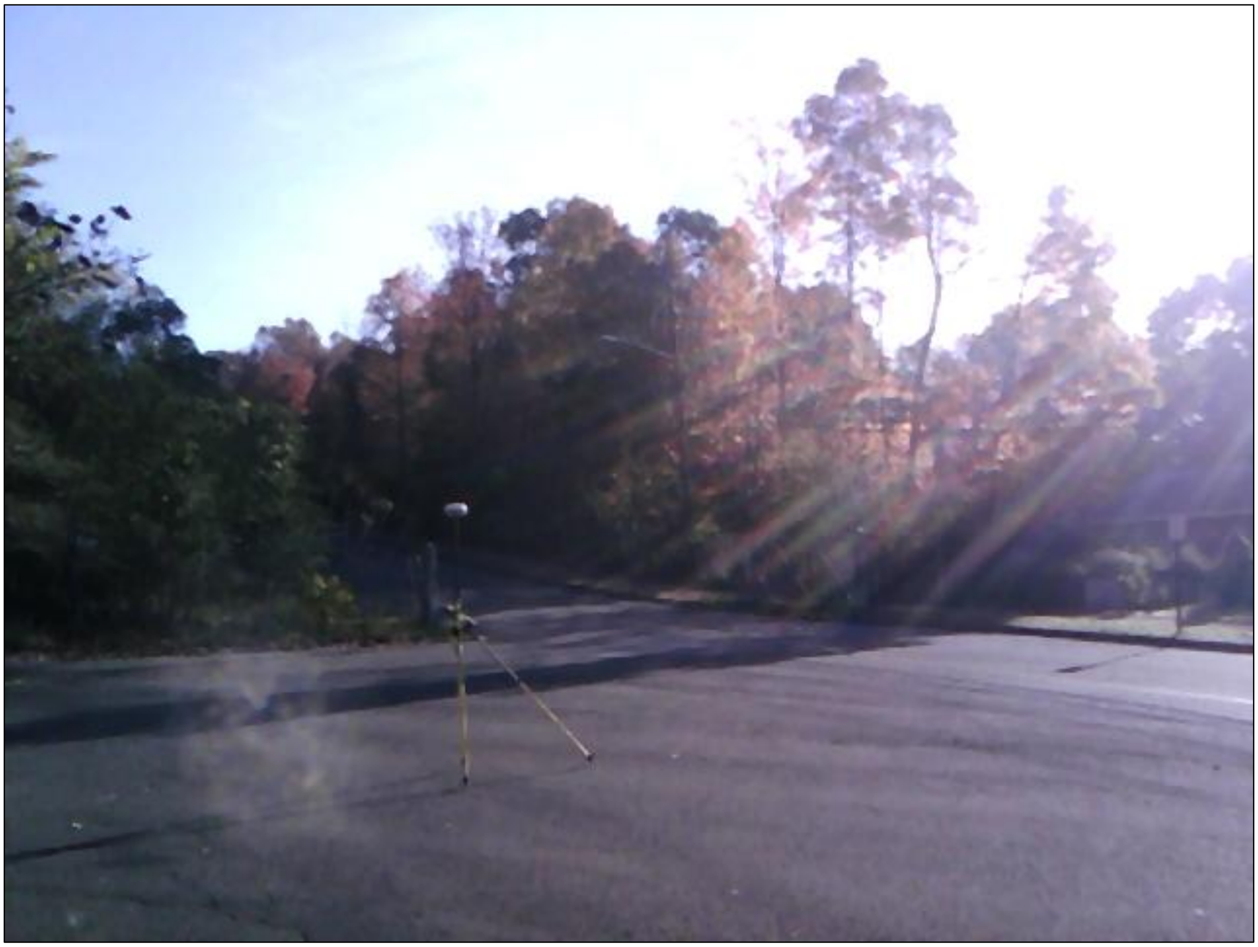

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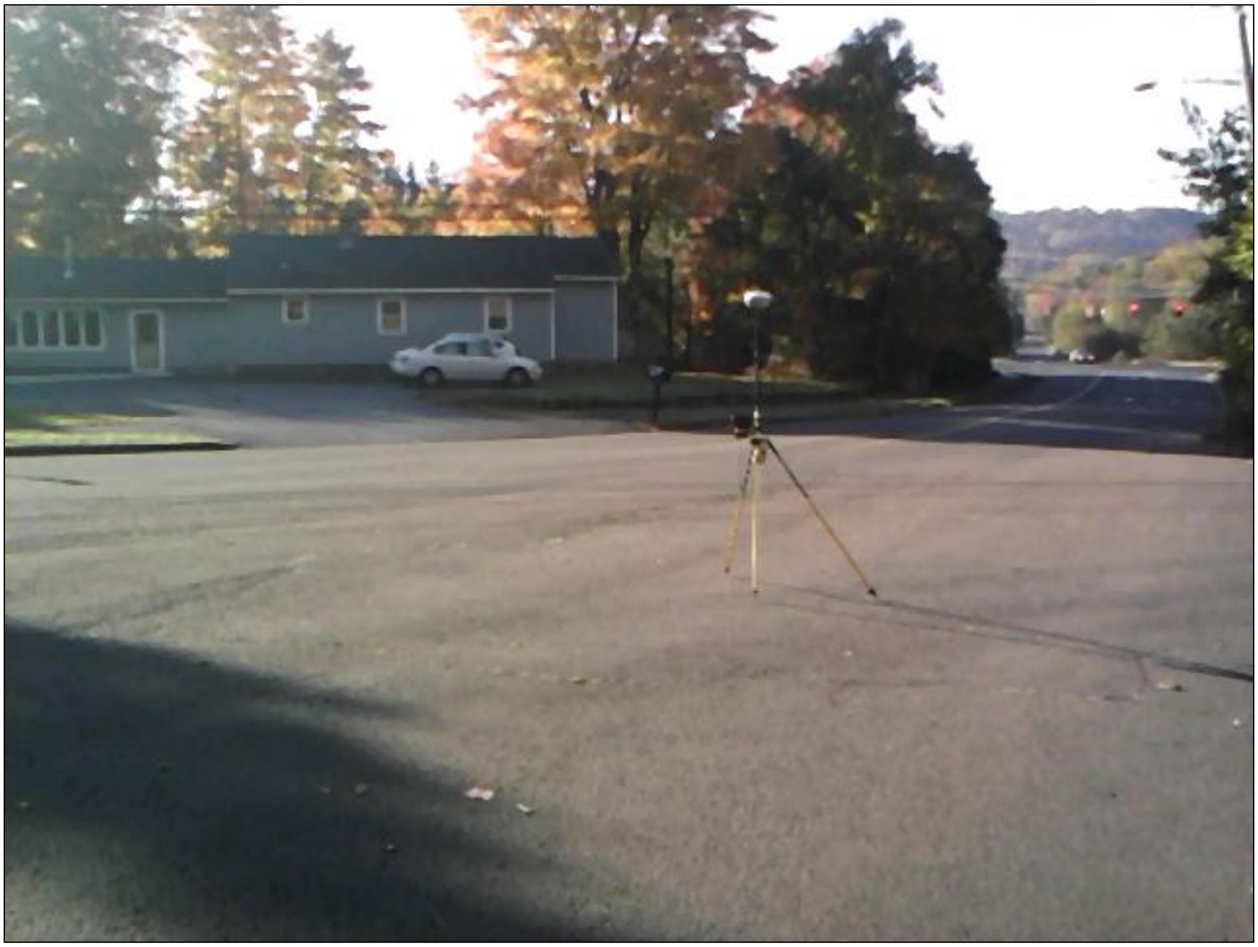

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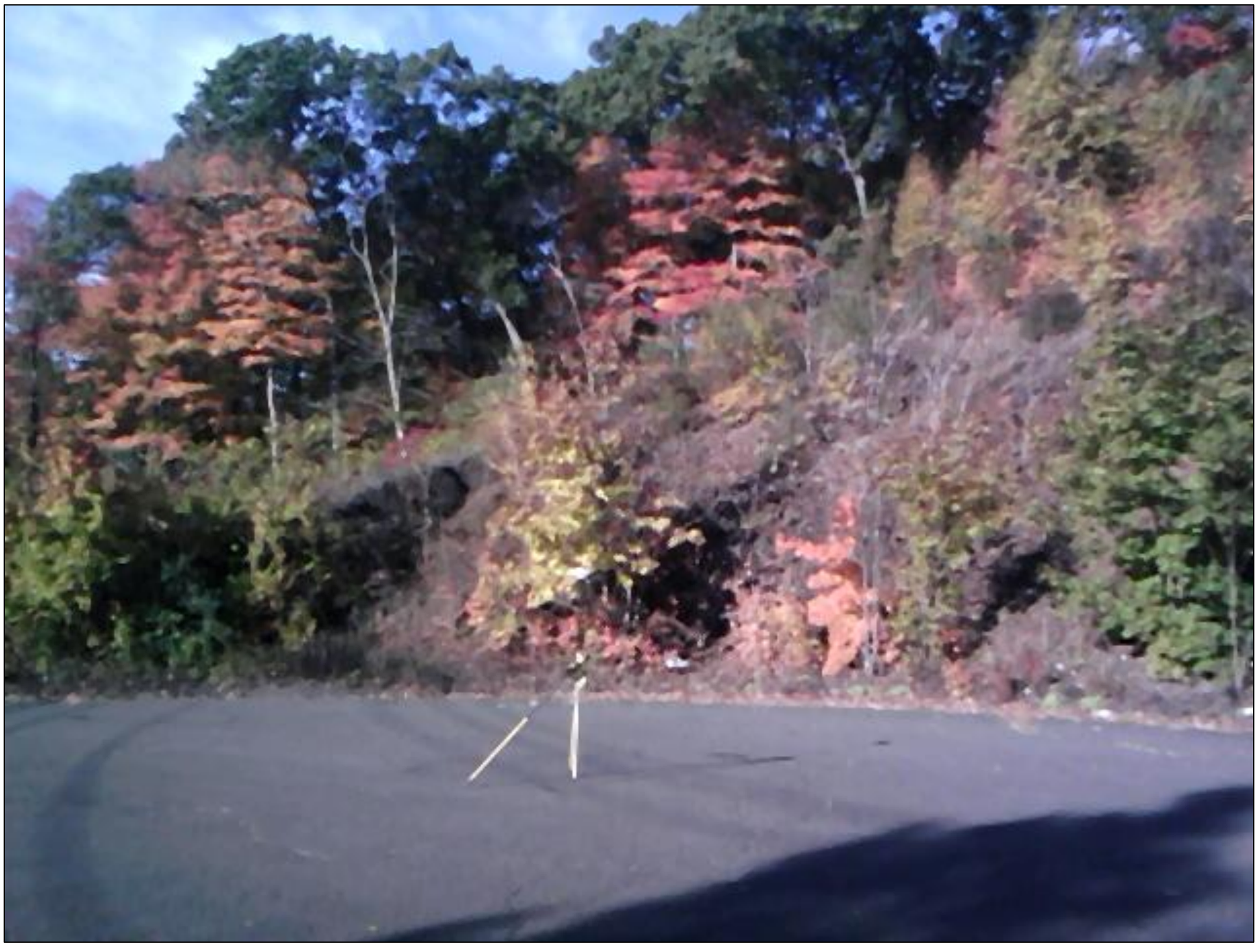

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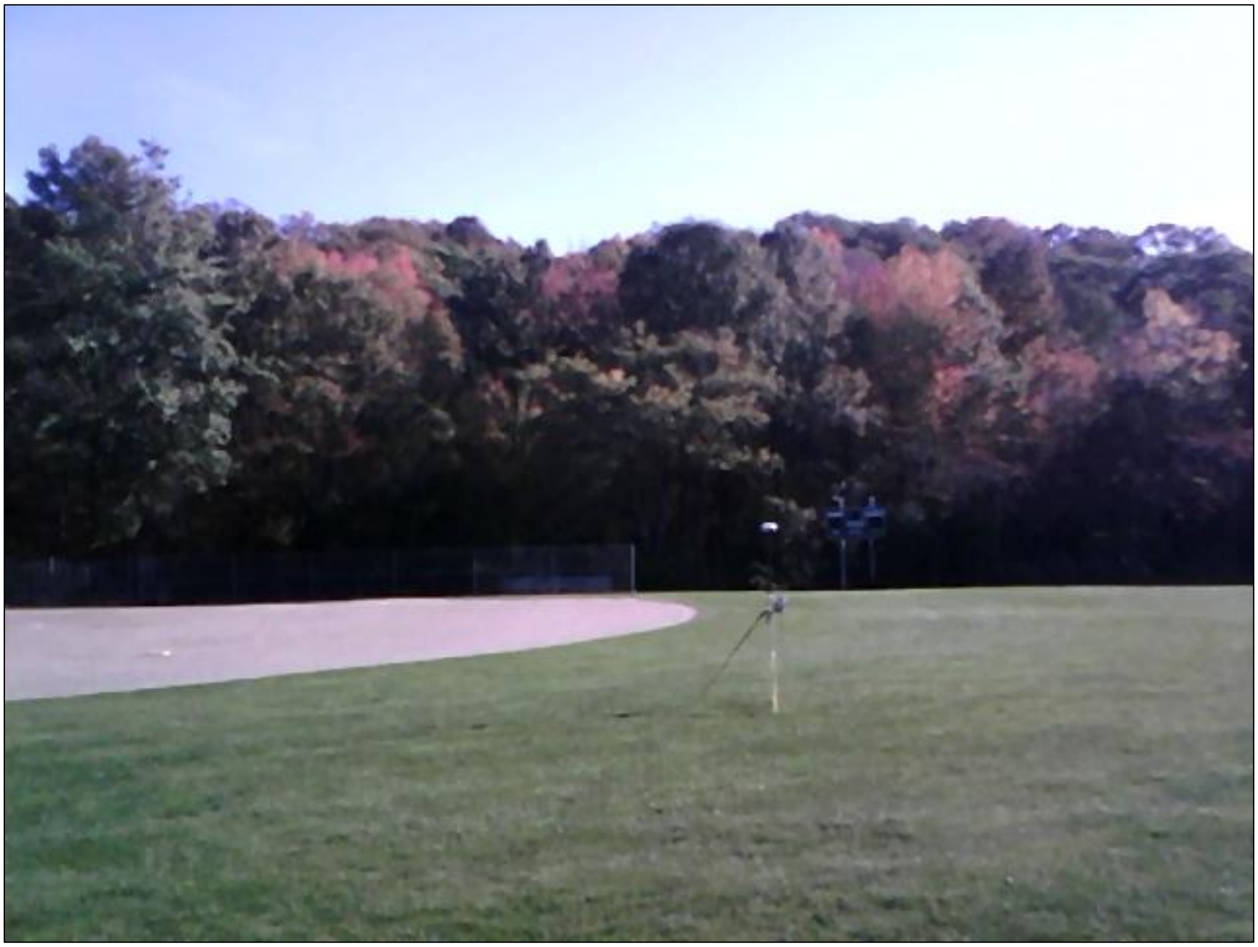

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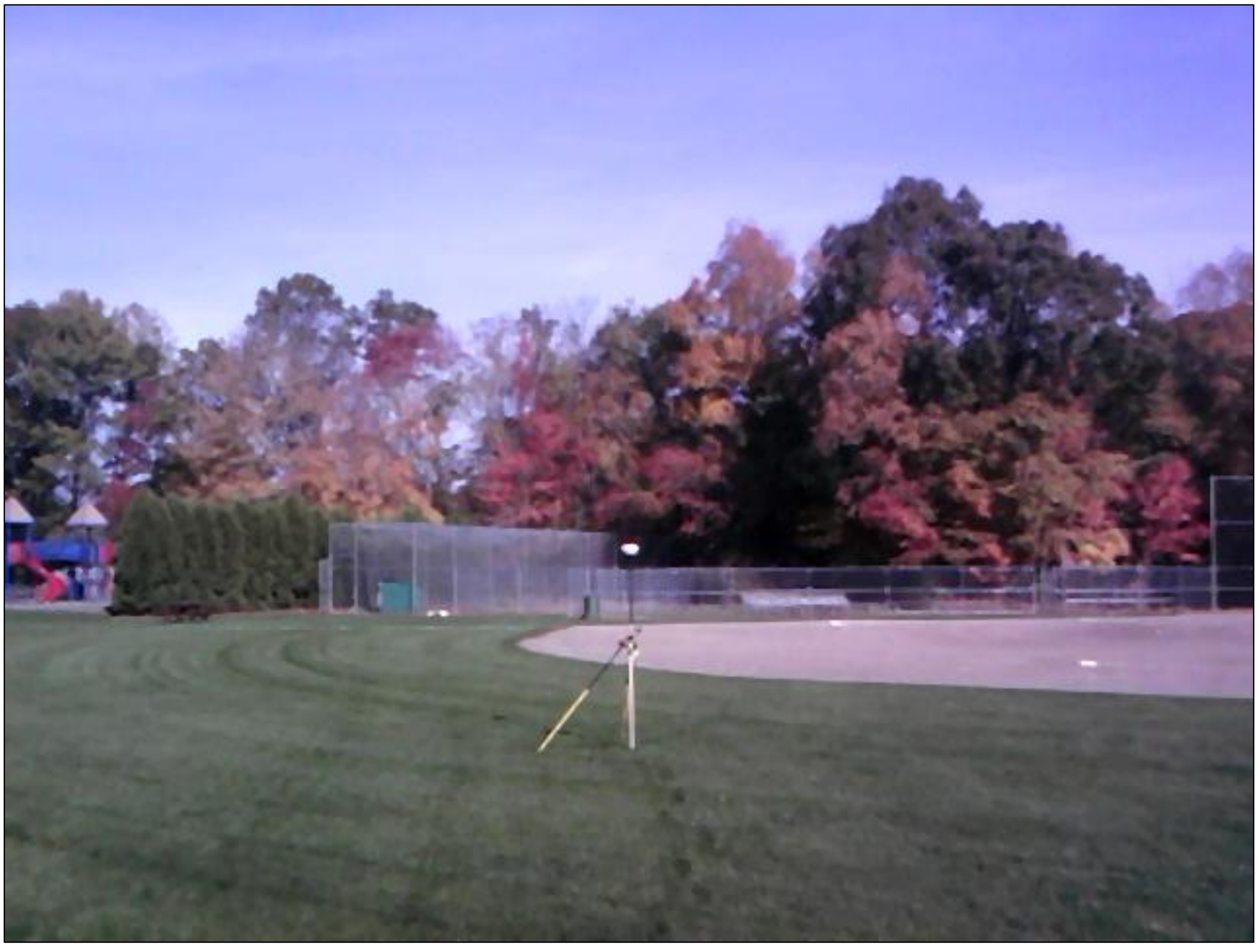

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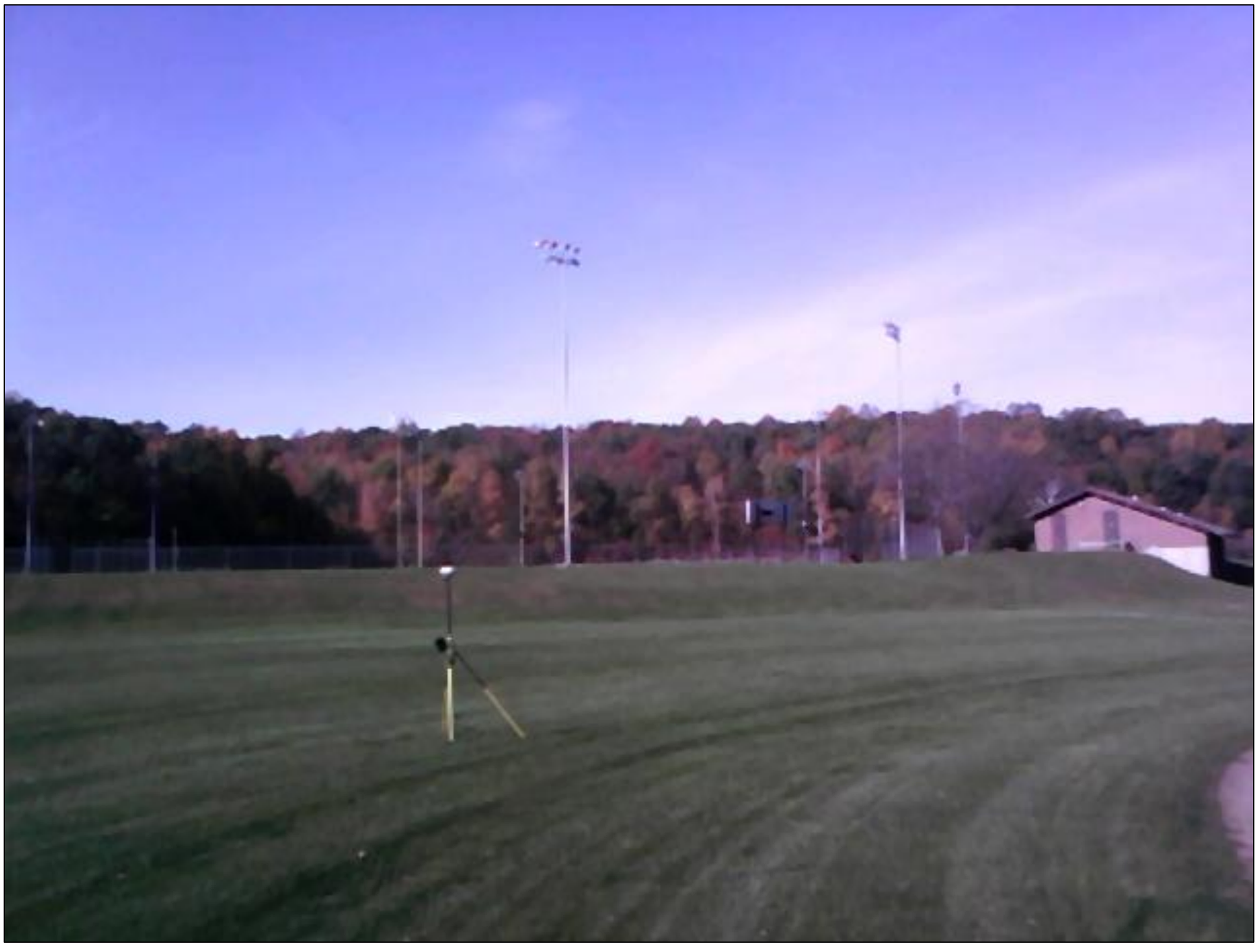

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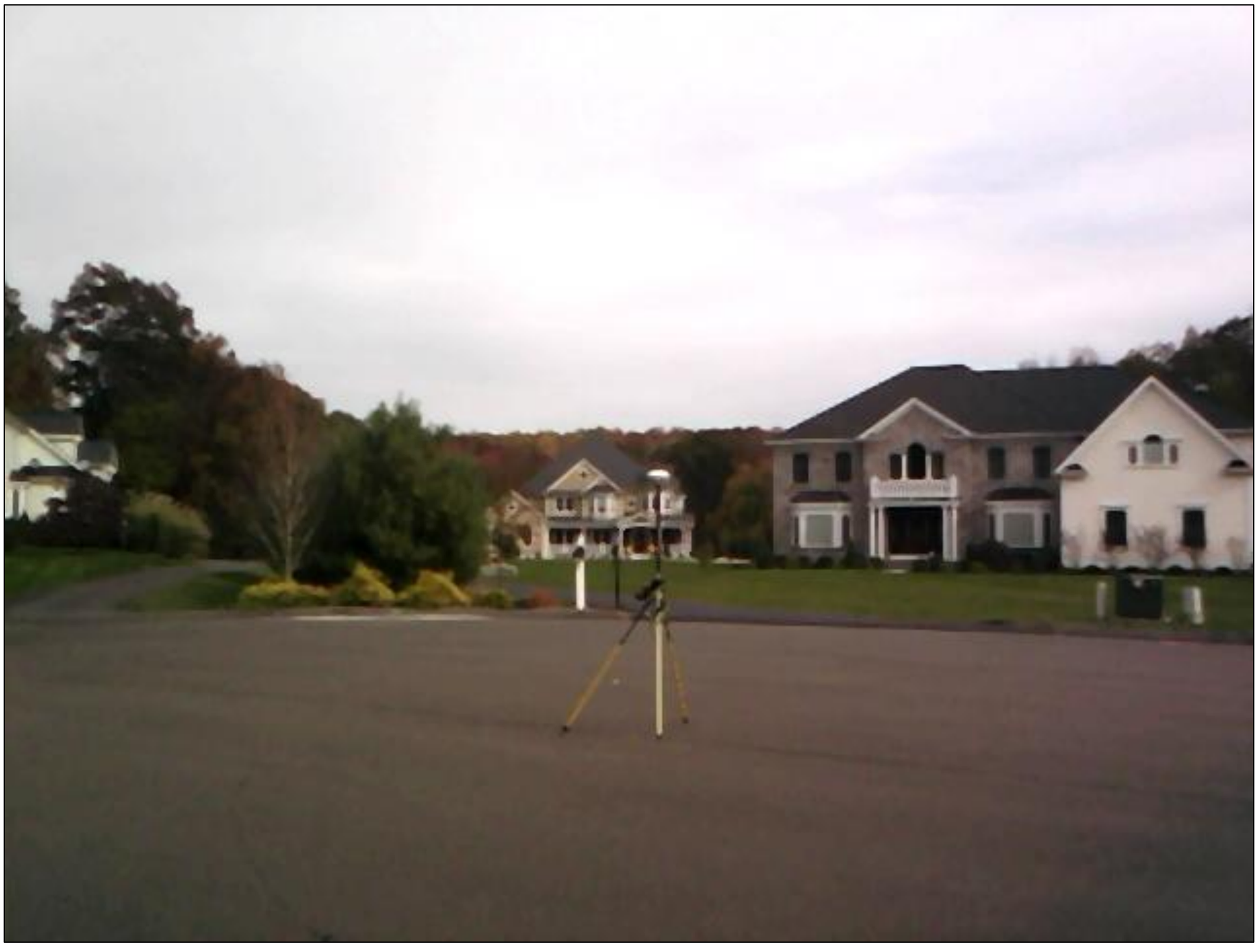

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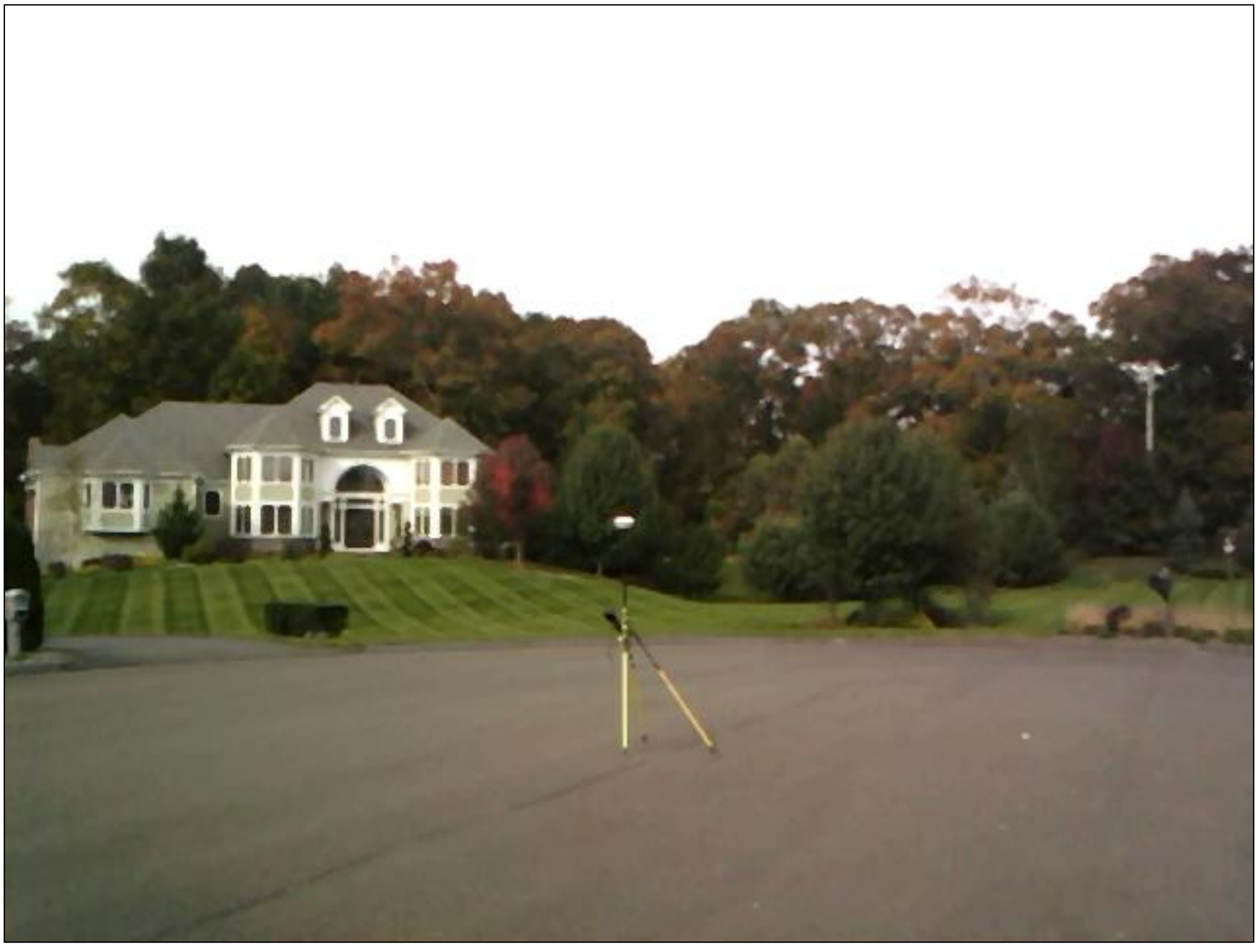

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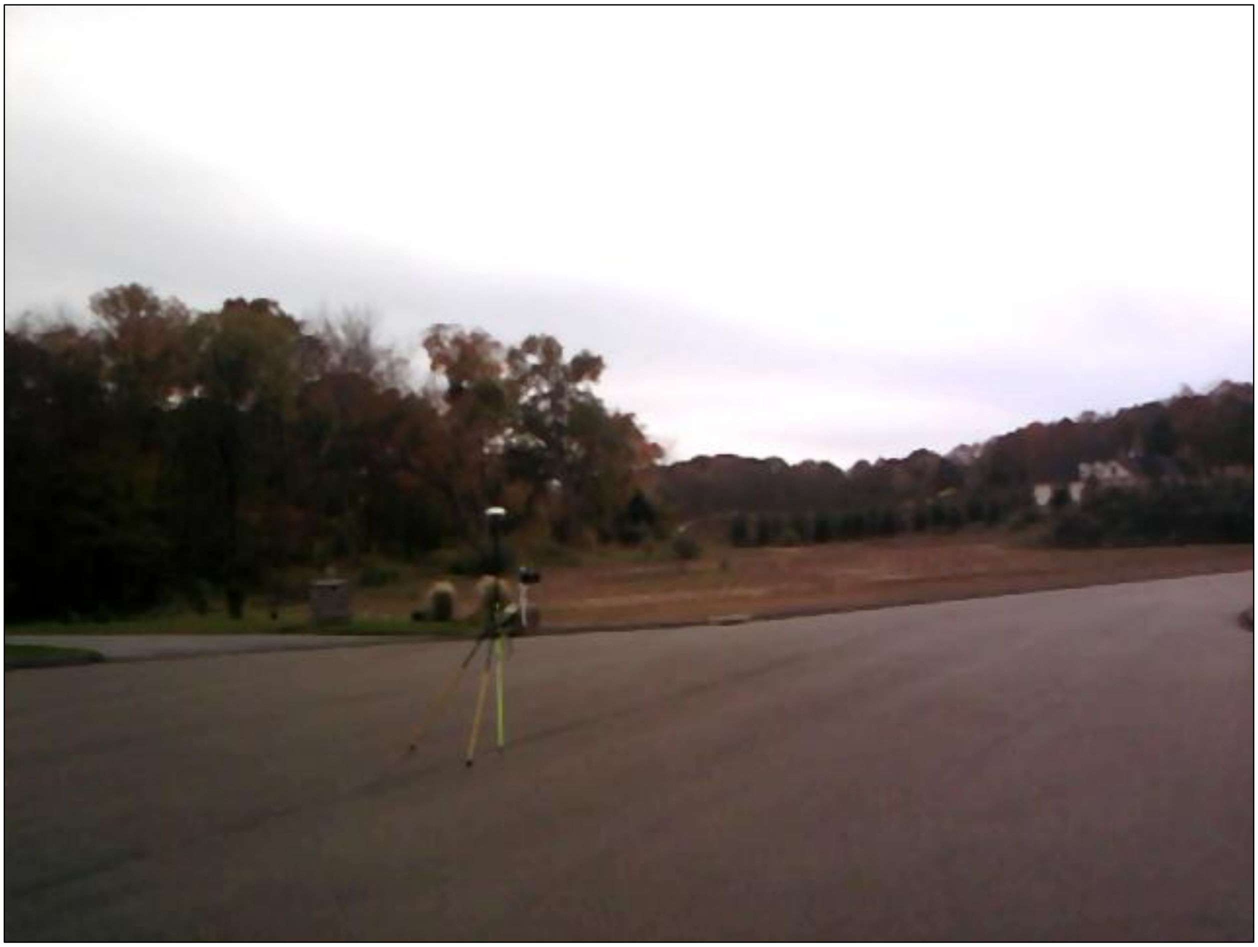

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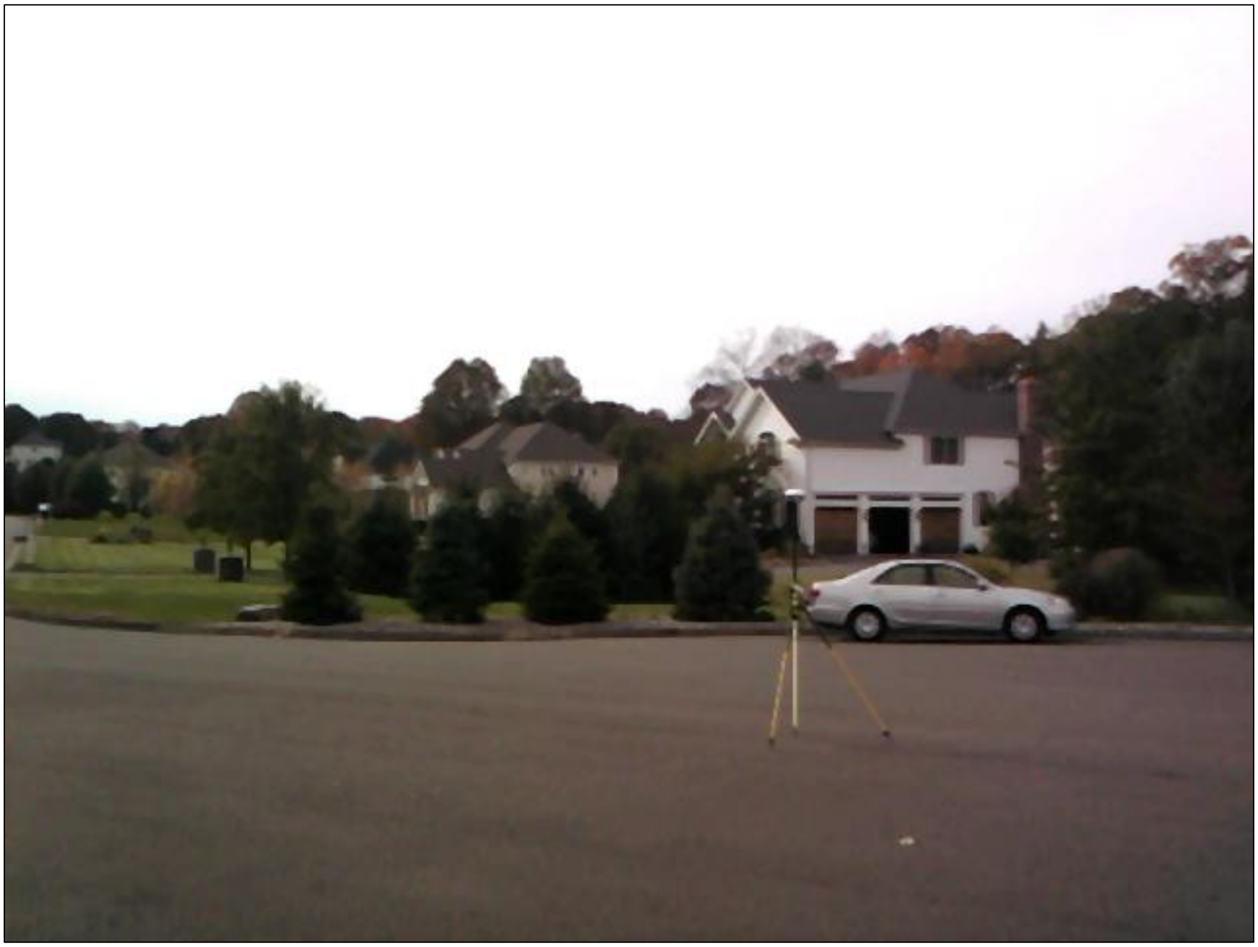

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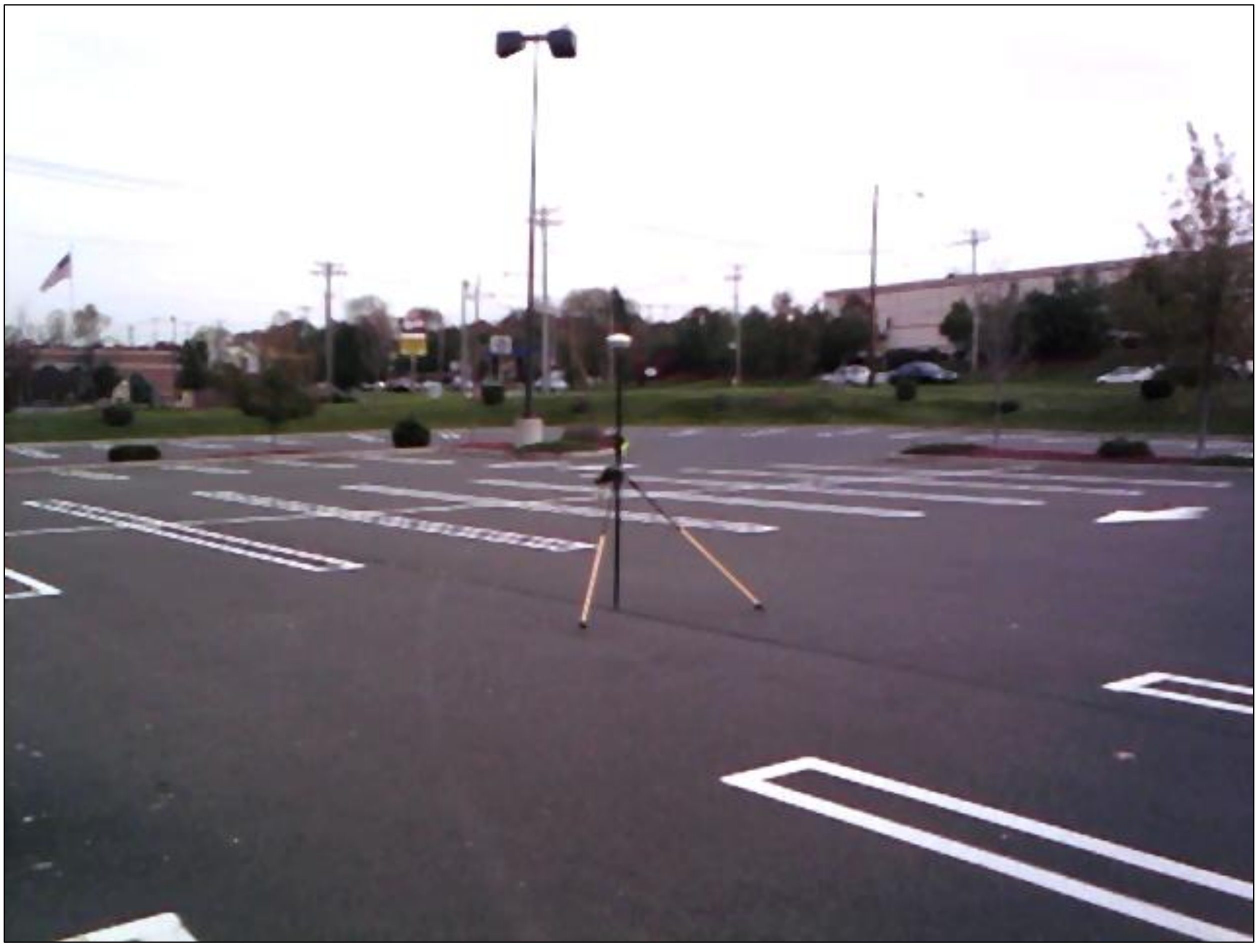

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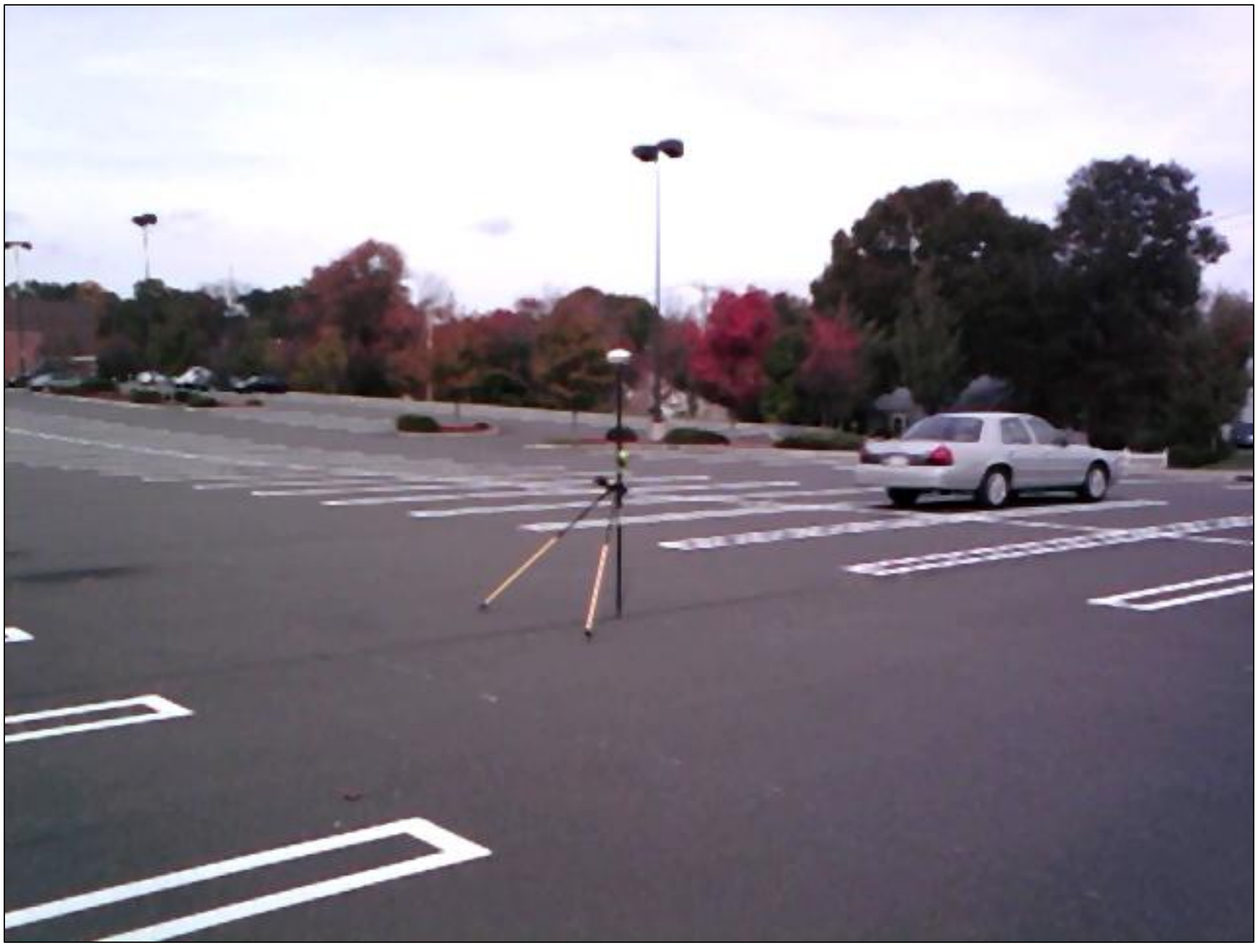

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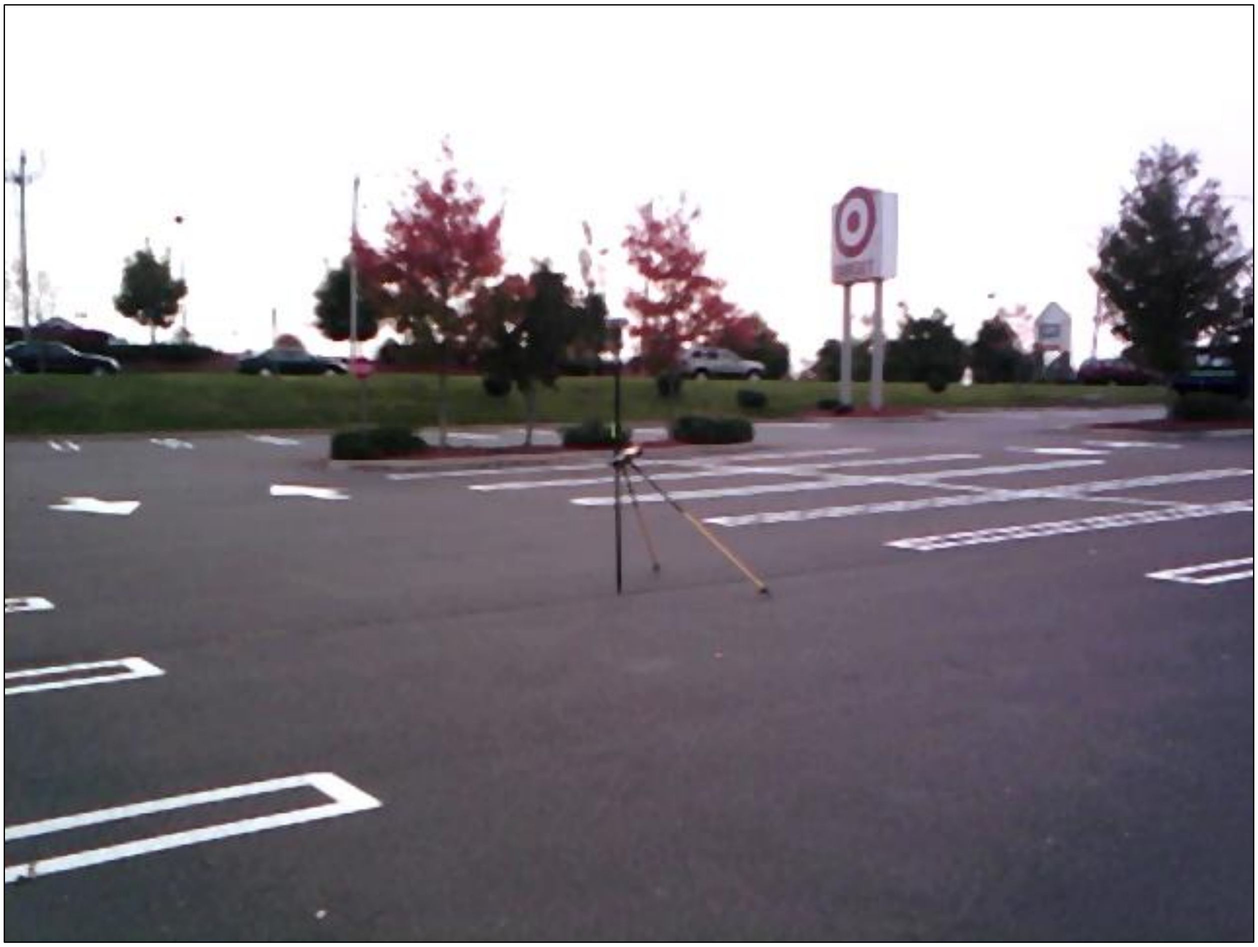

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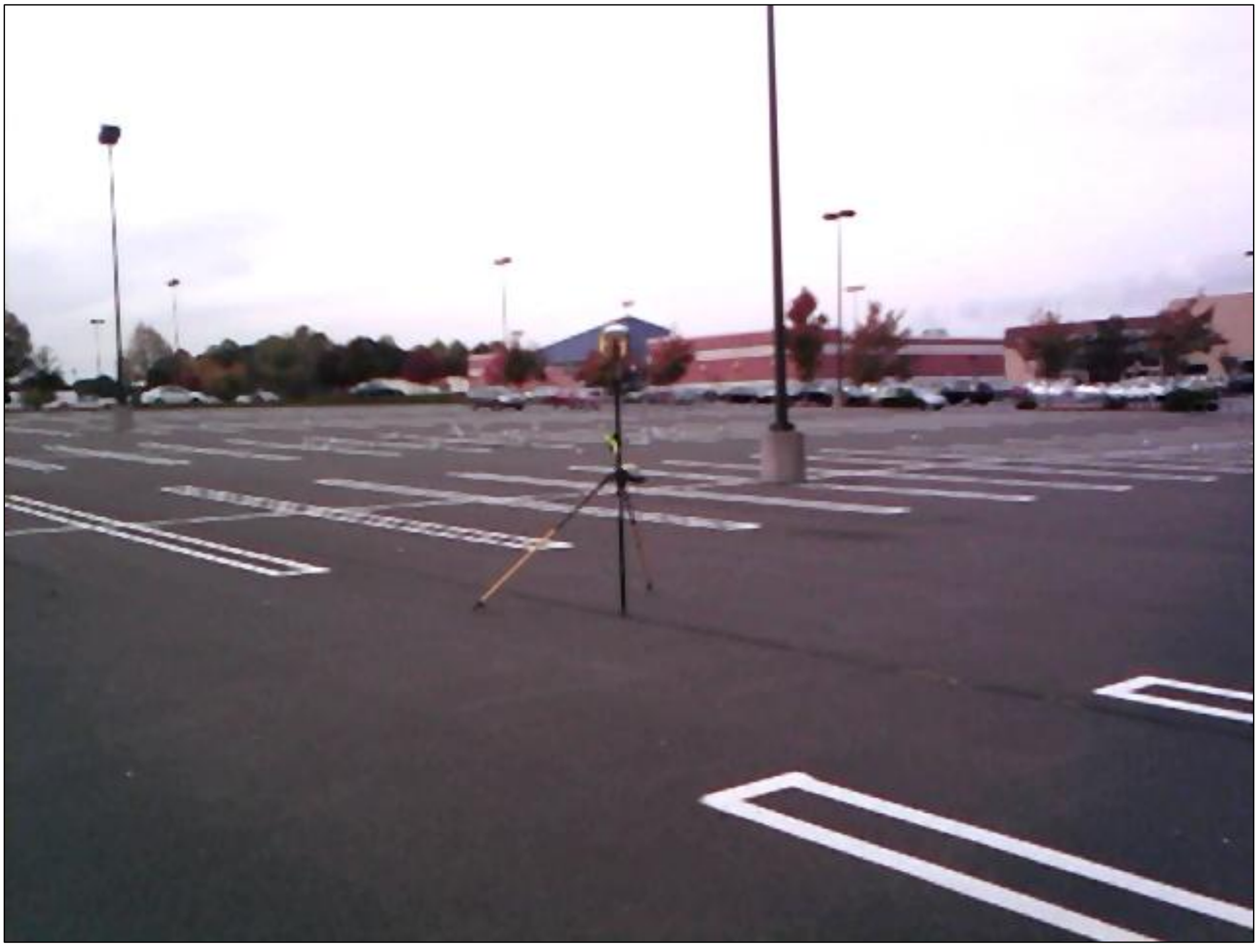

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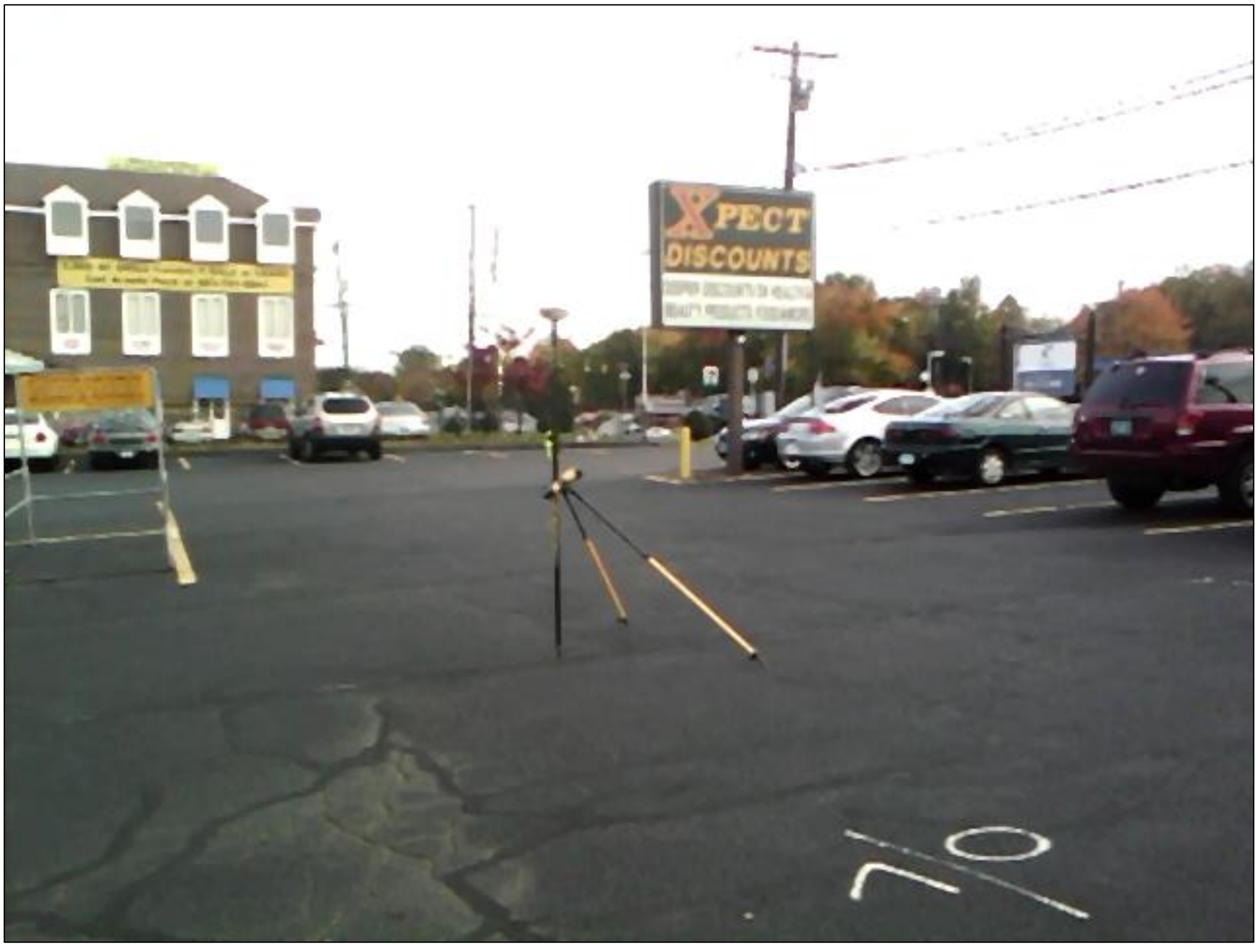

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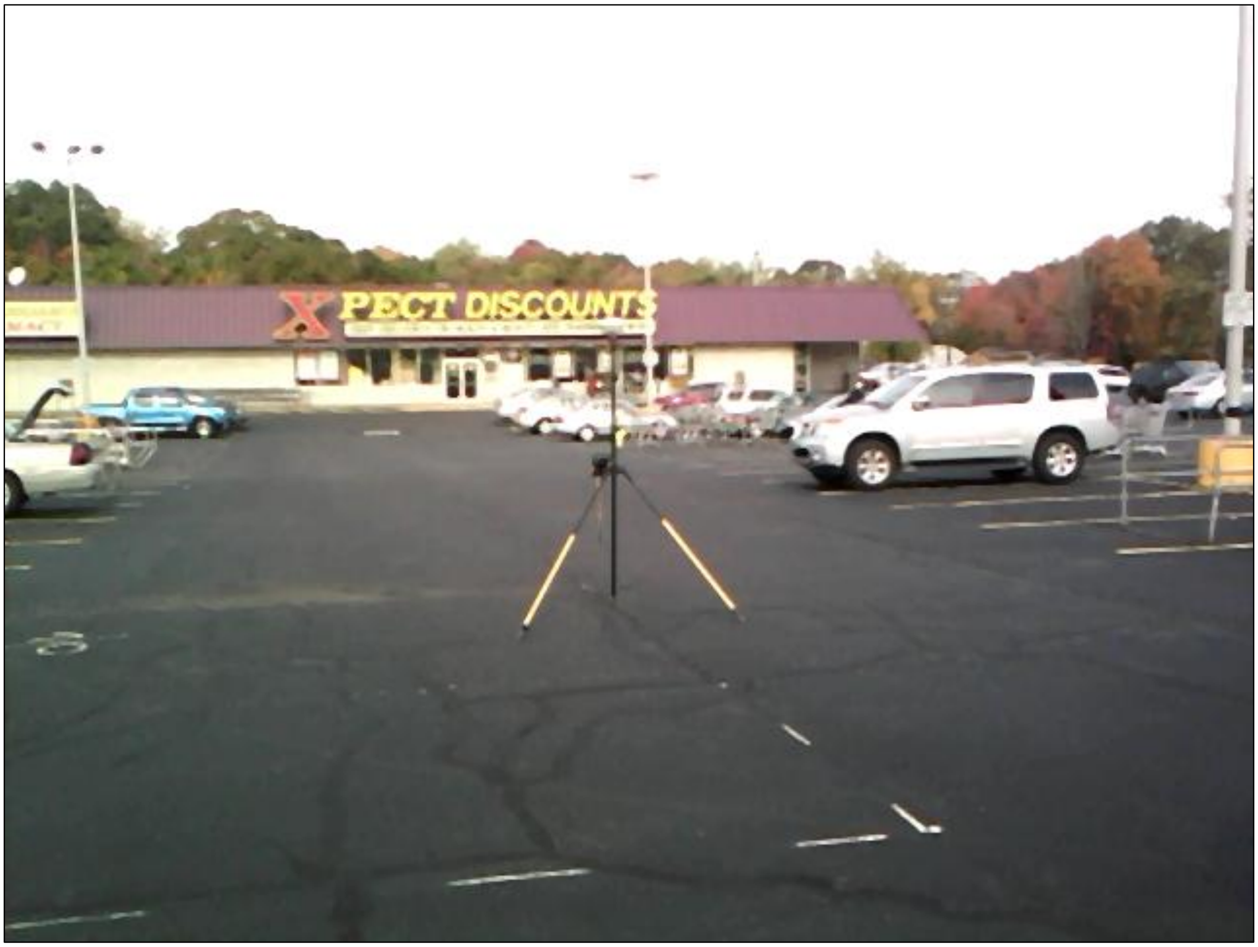

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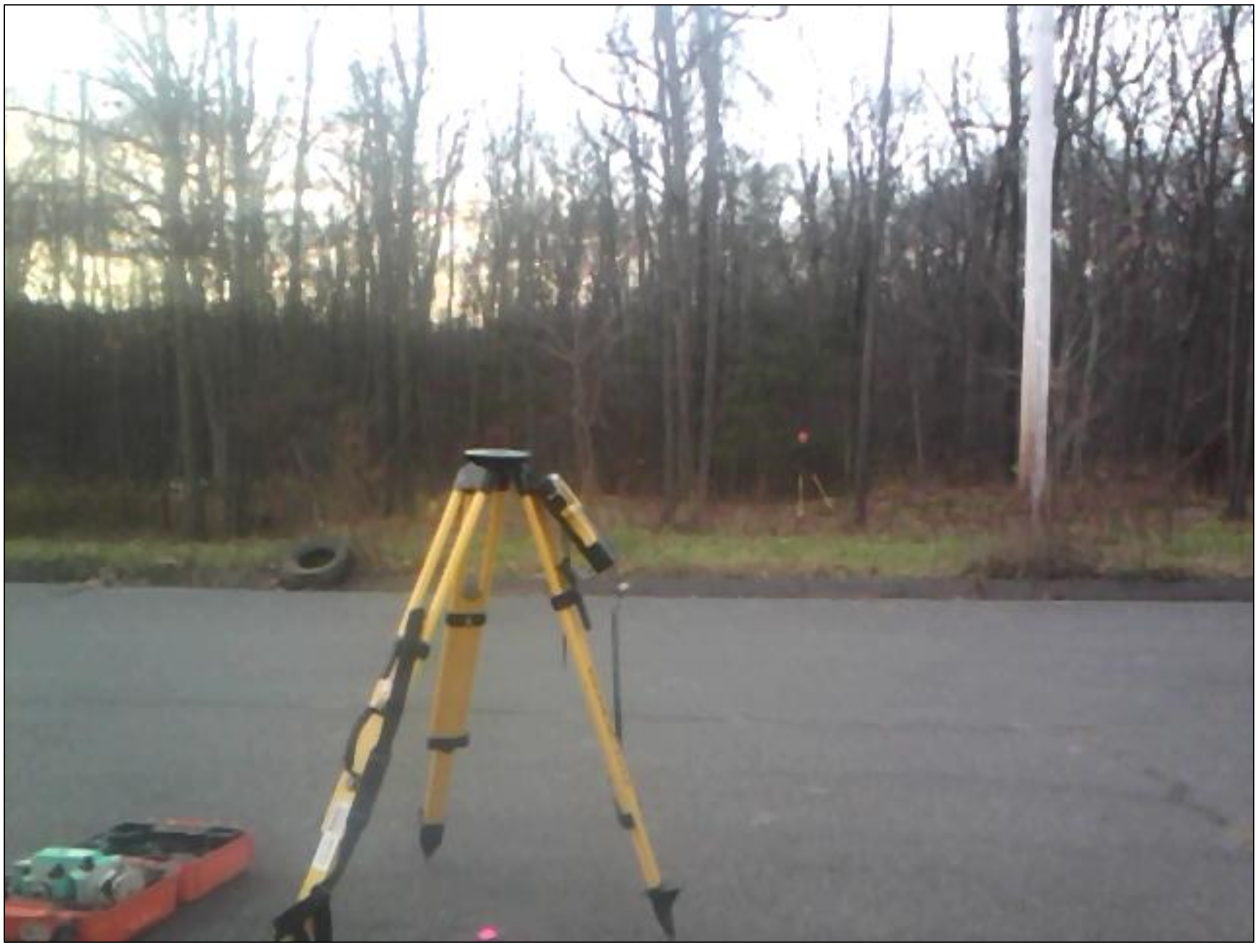

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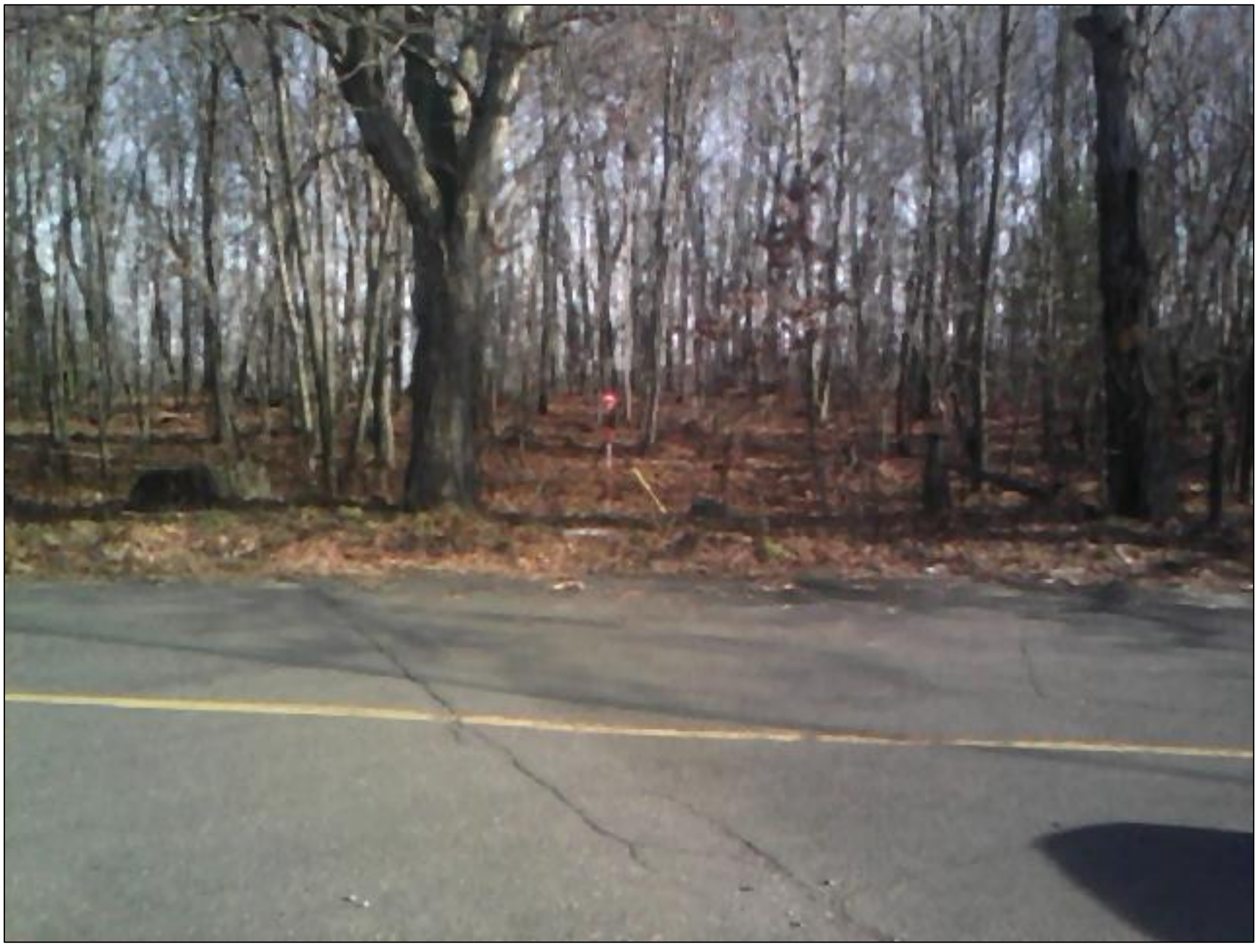

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QNP708

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QNP710

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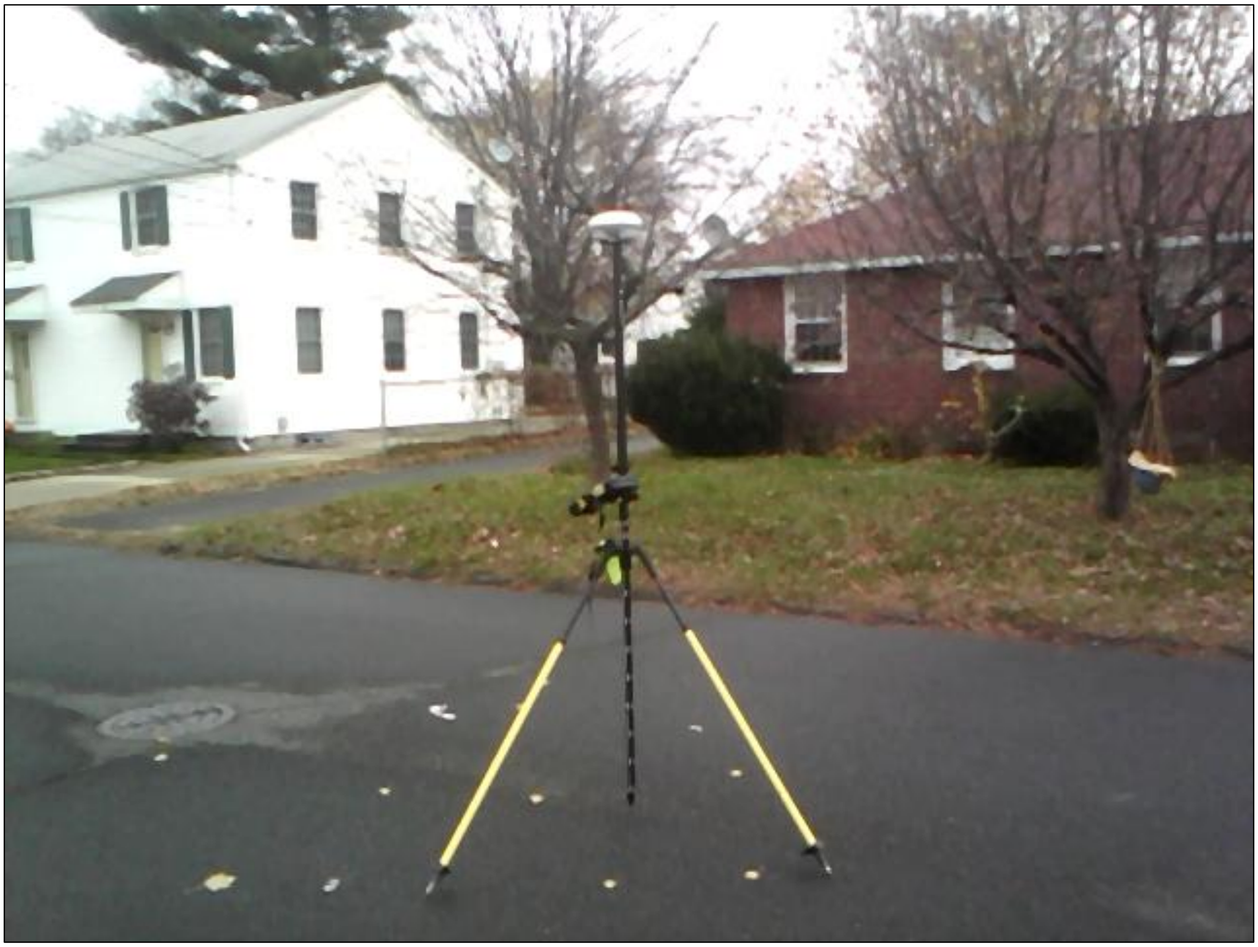

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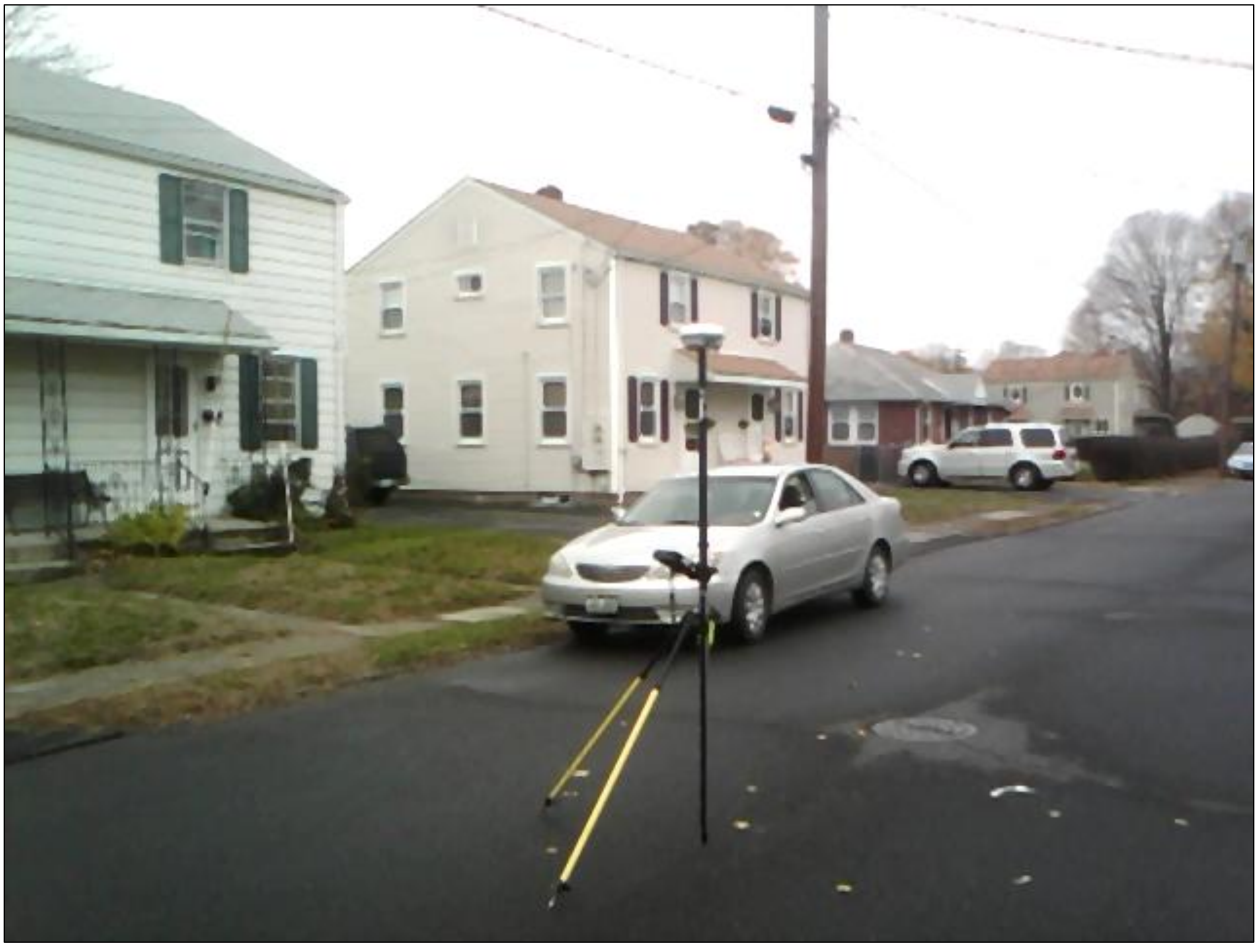

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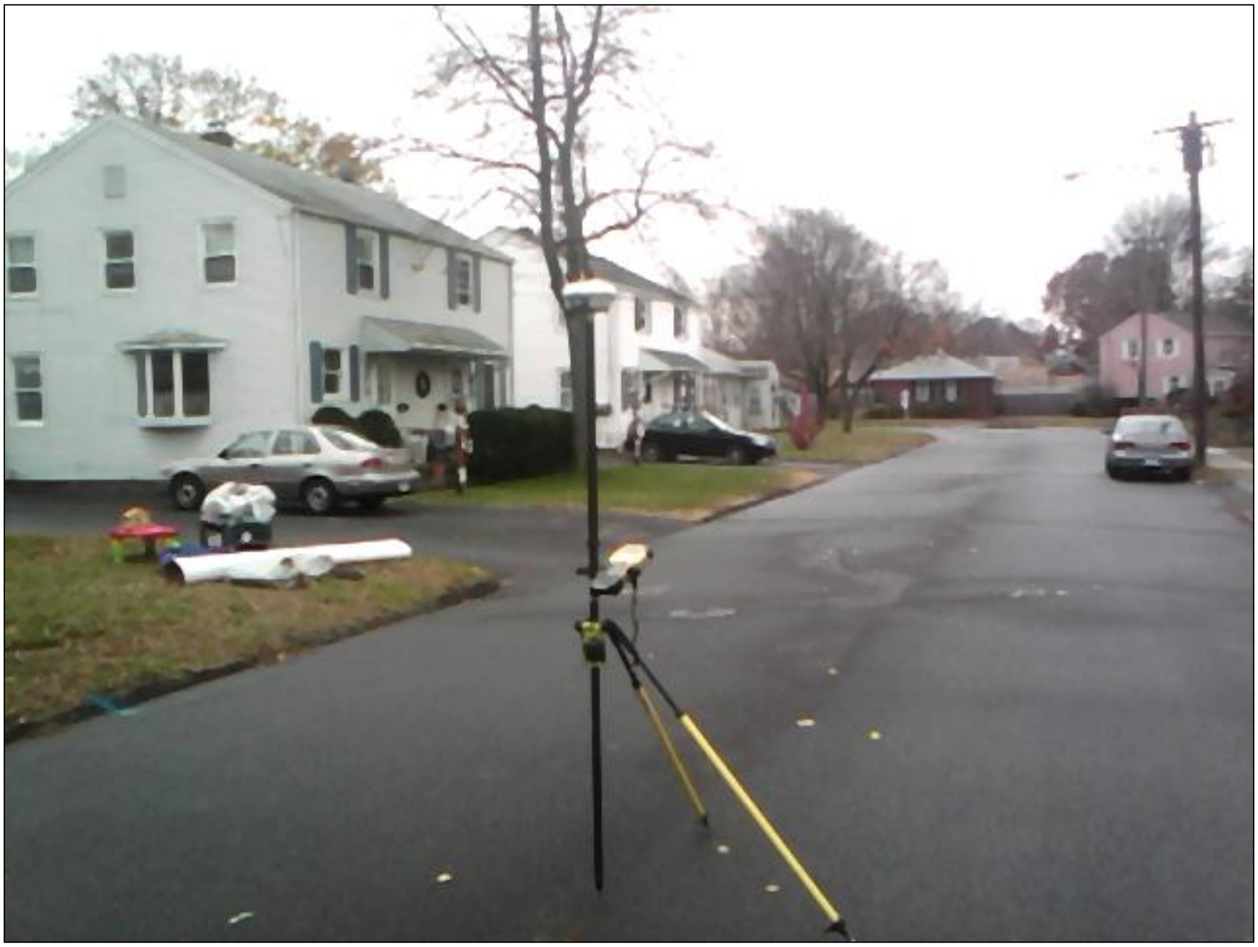

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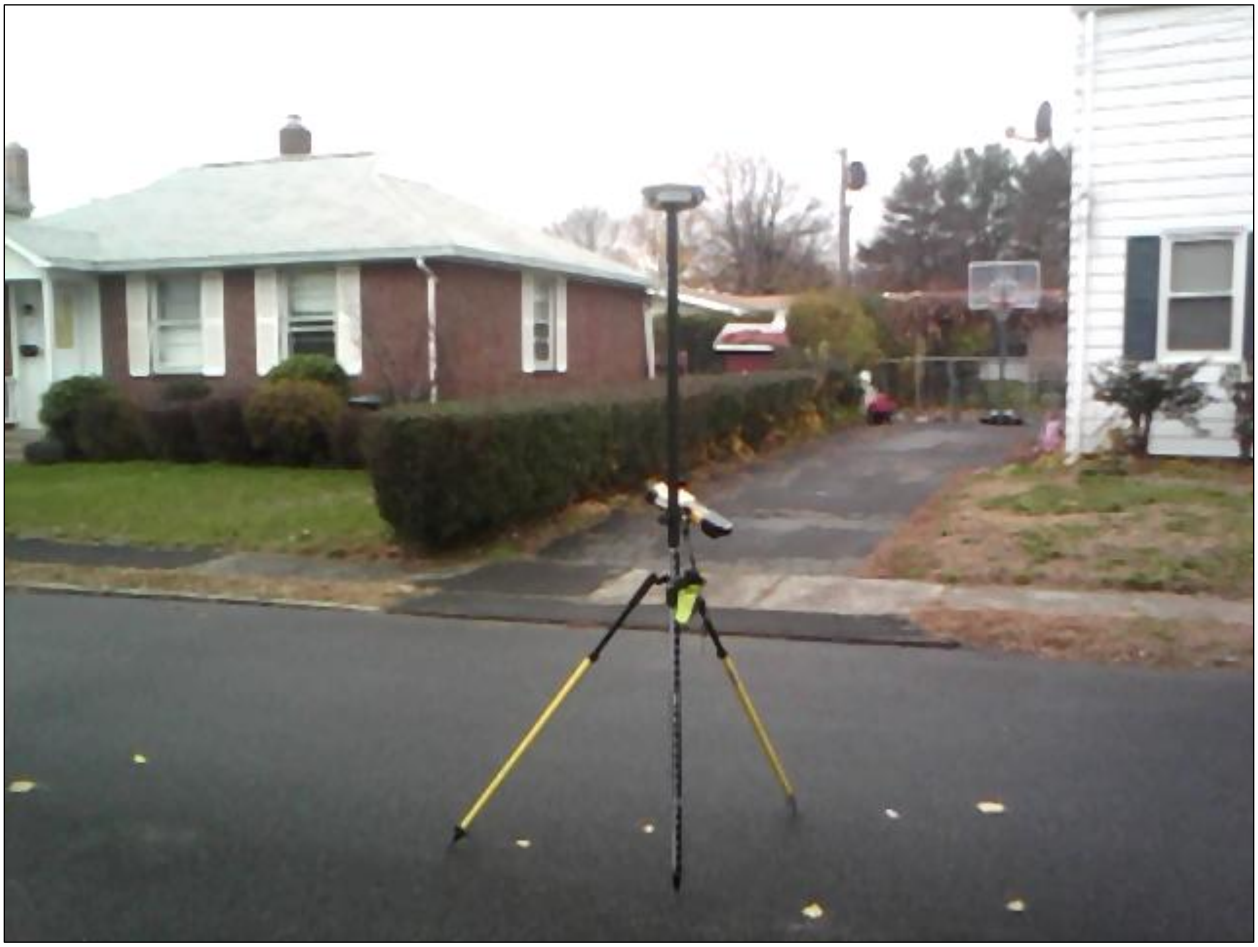

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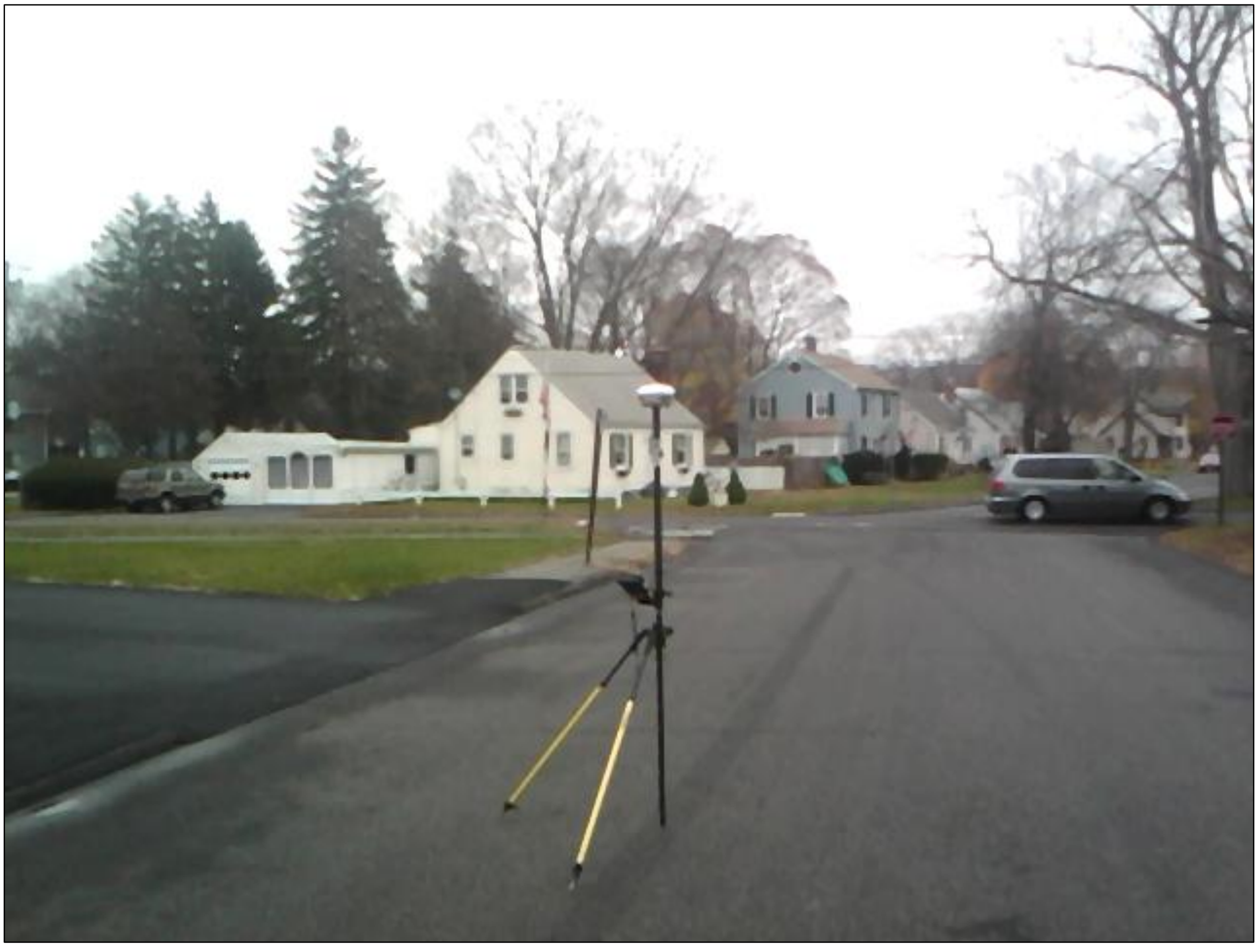

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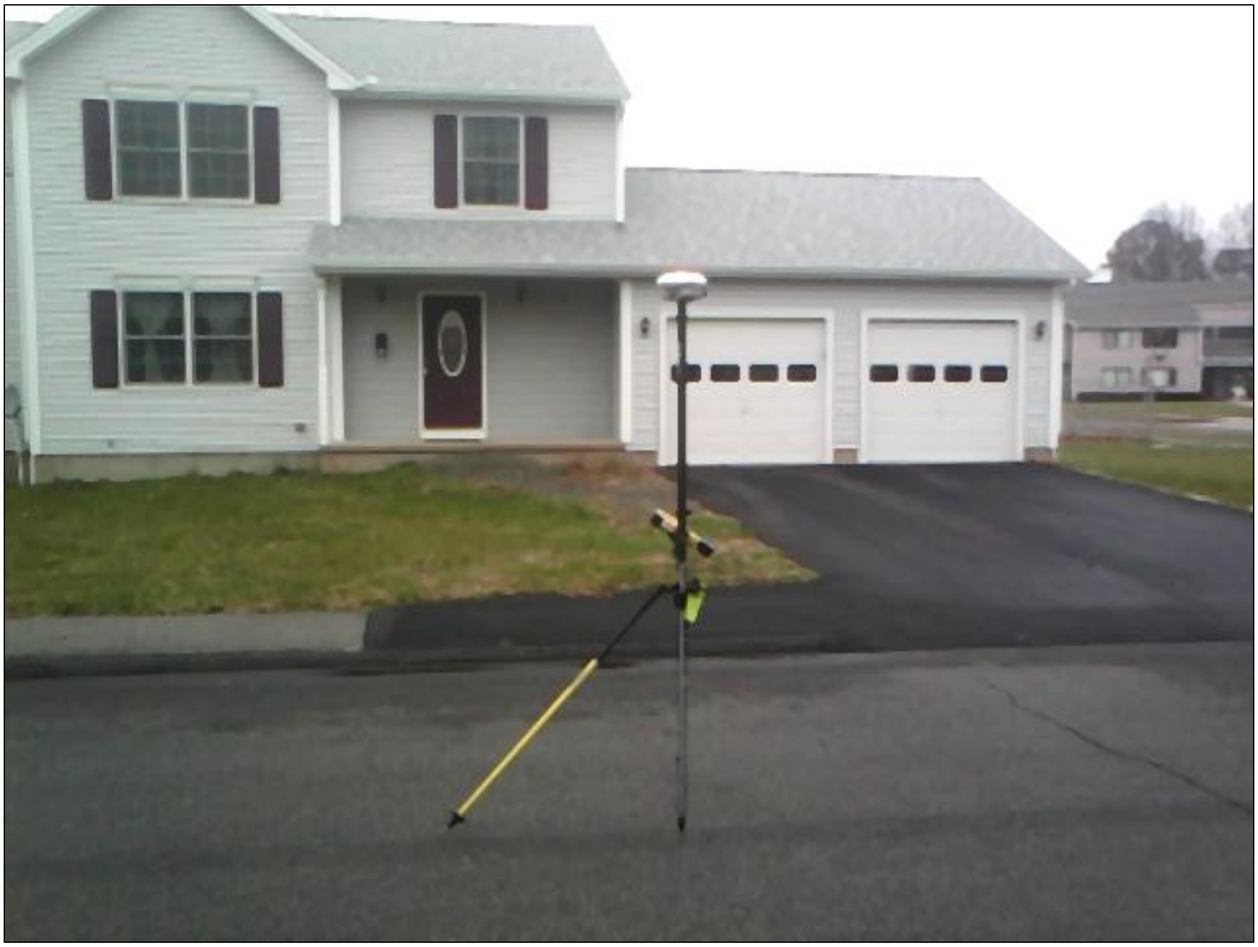

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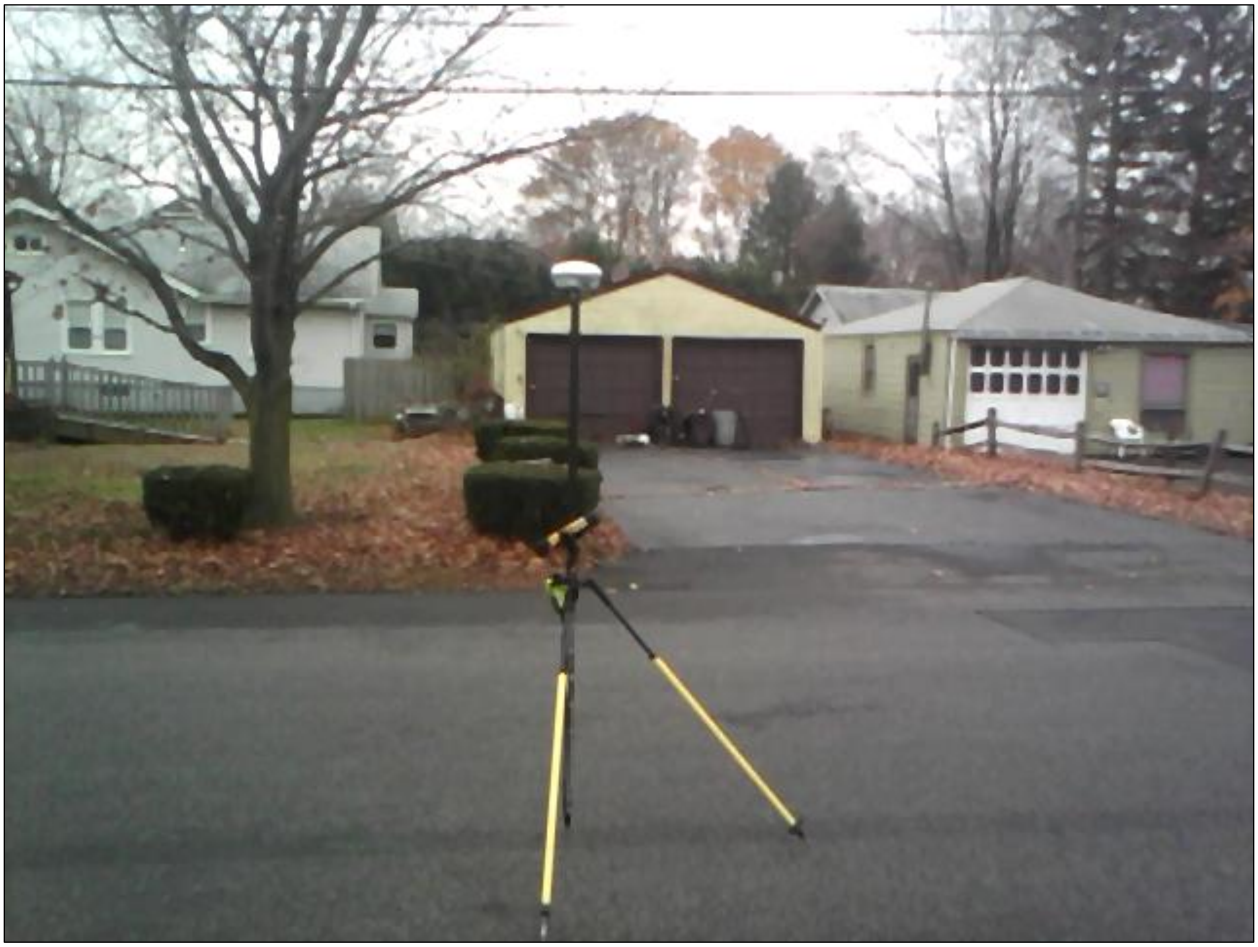

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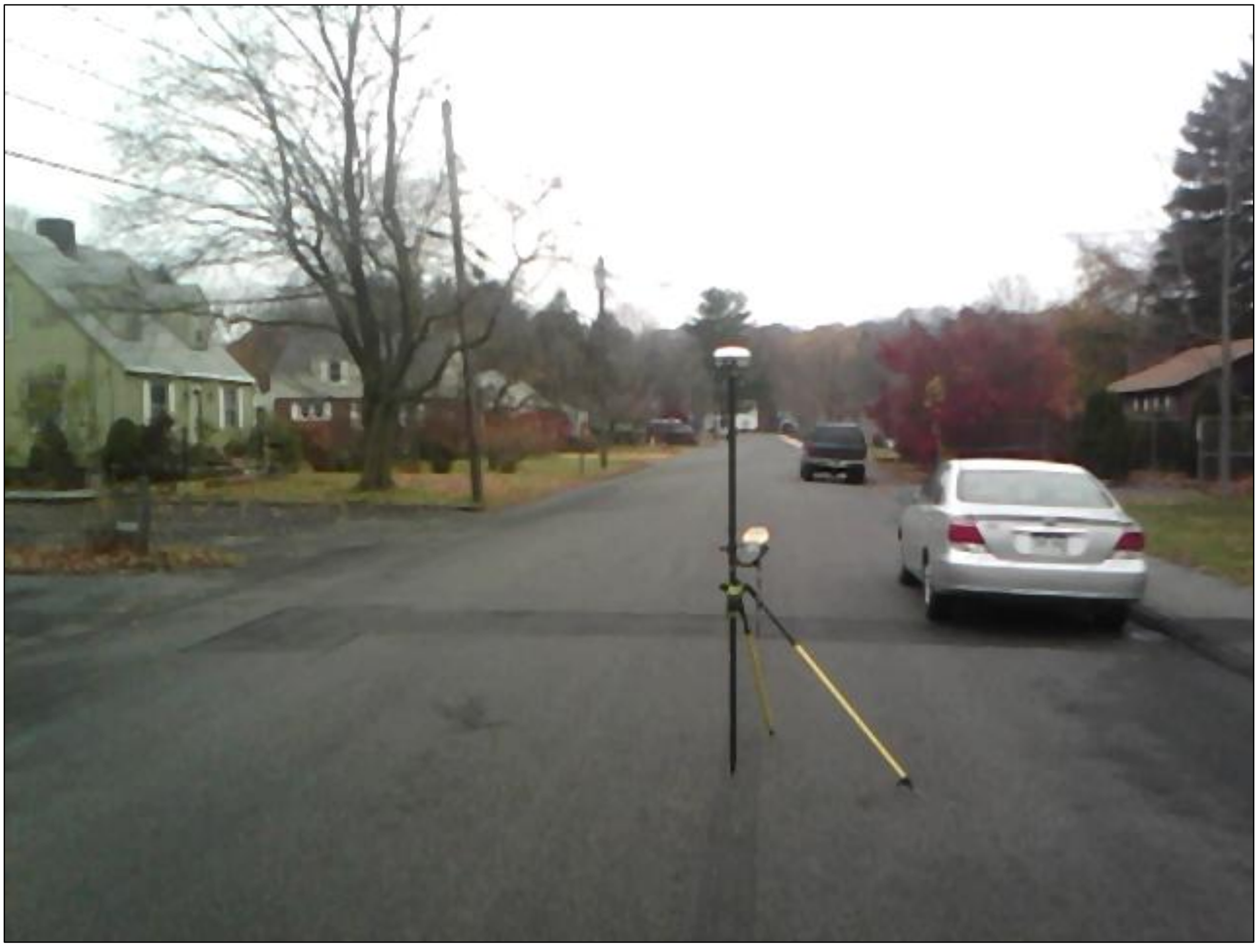

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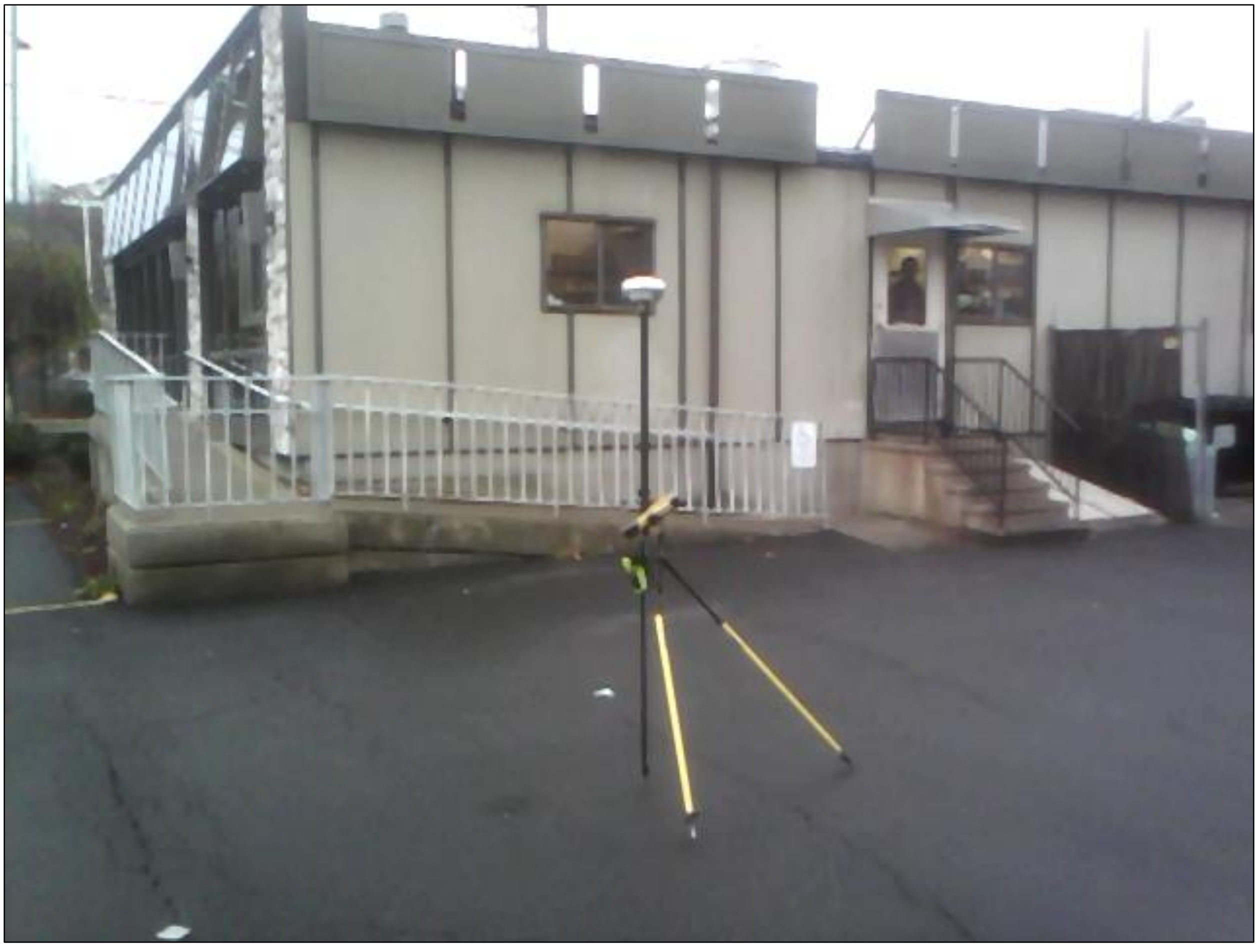

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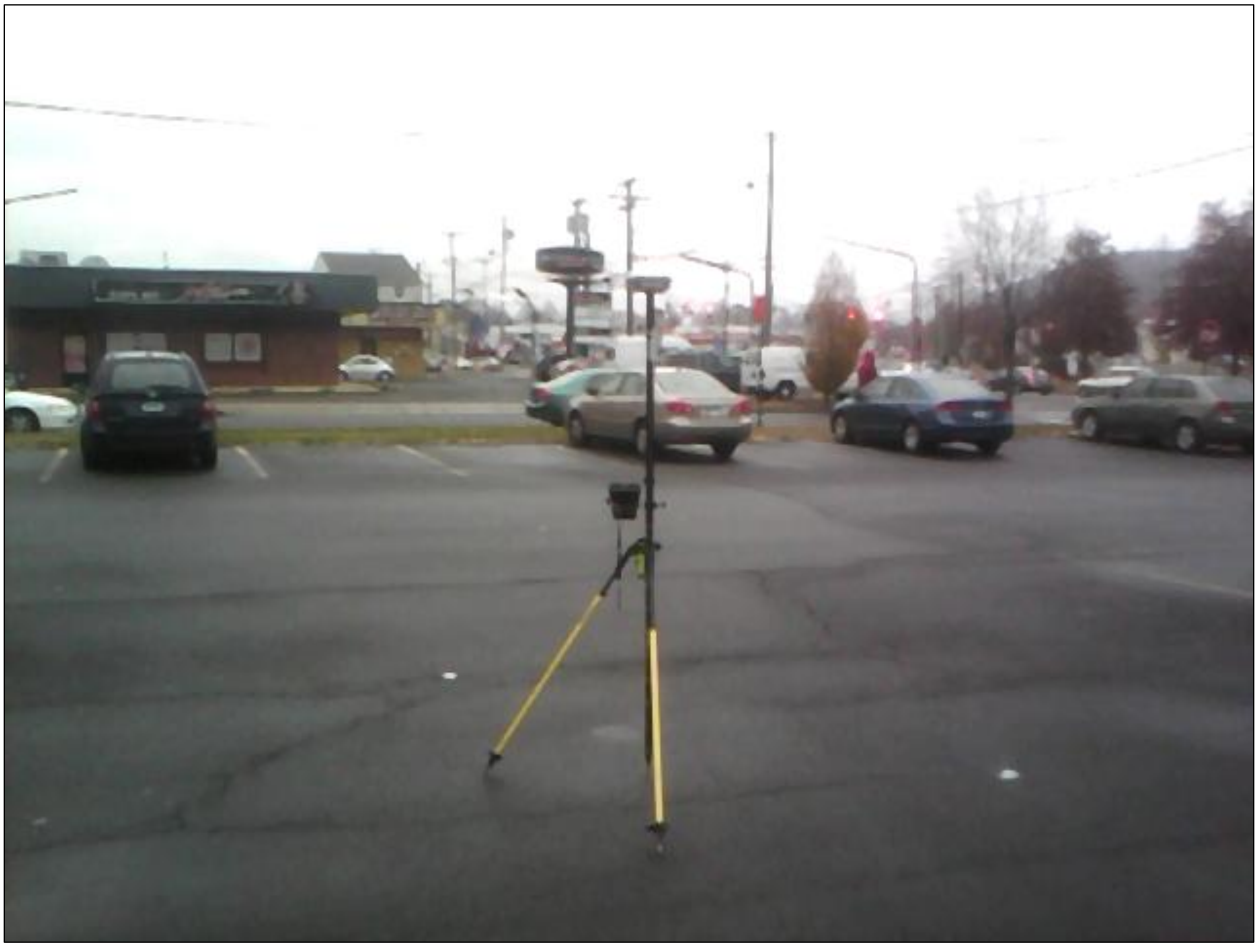
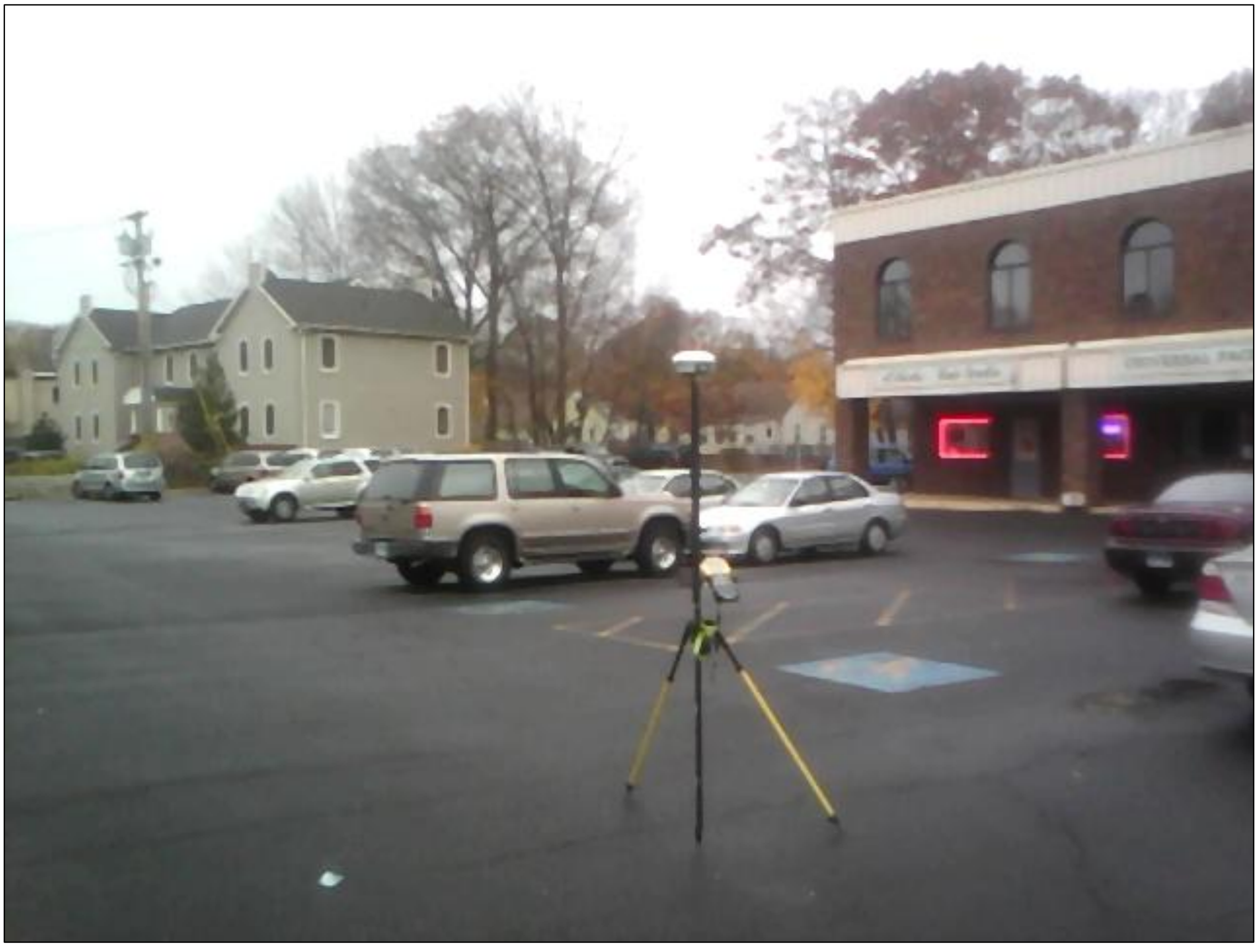


QNP803_S



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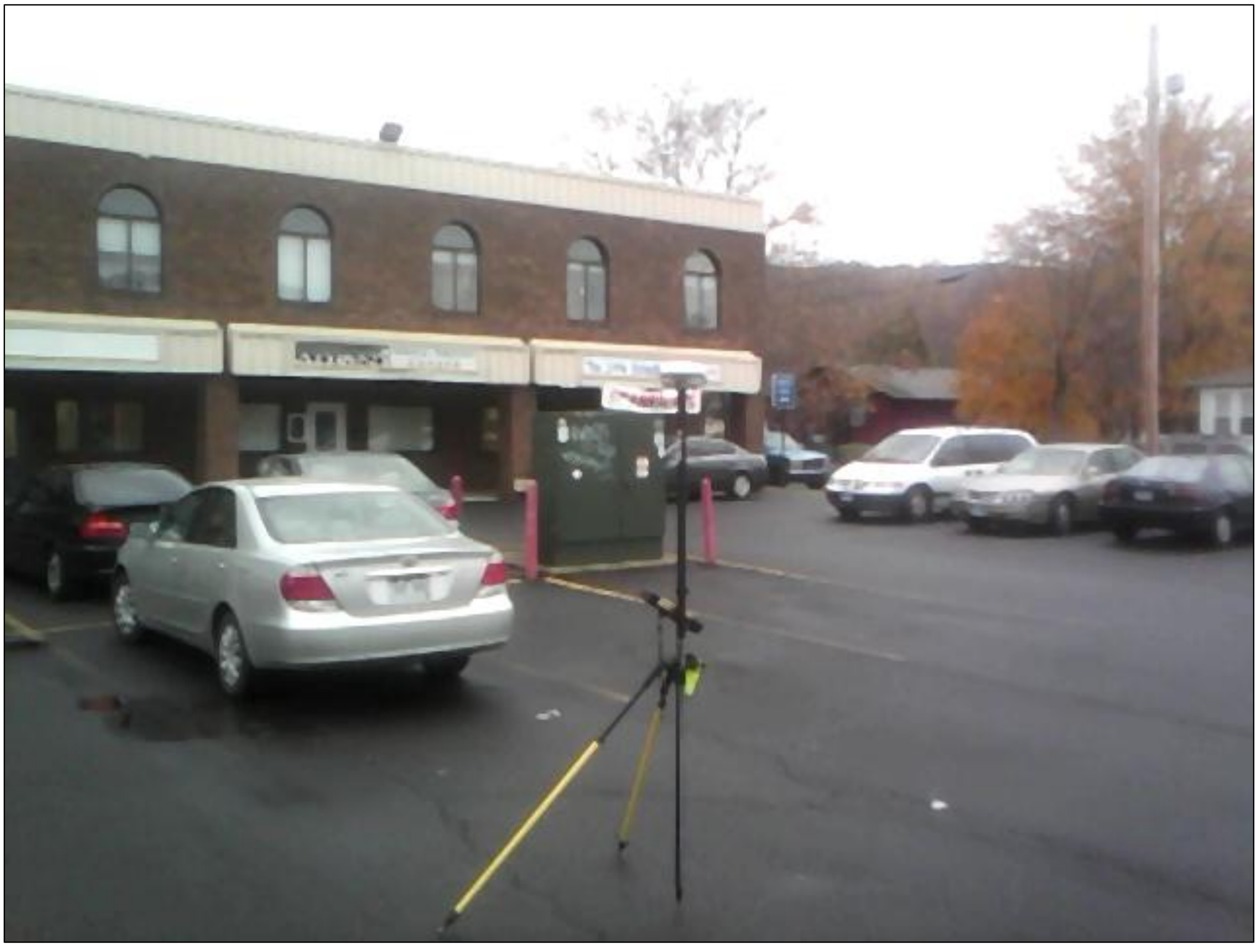

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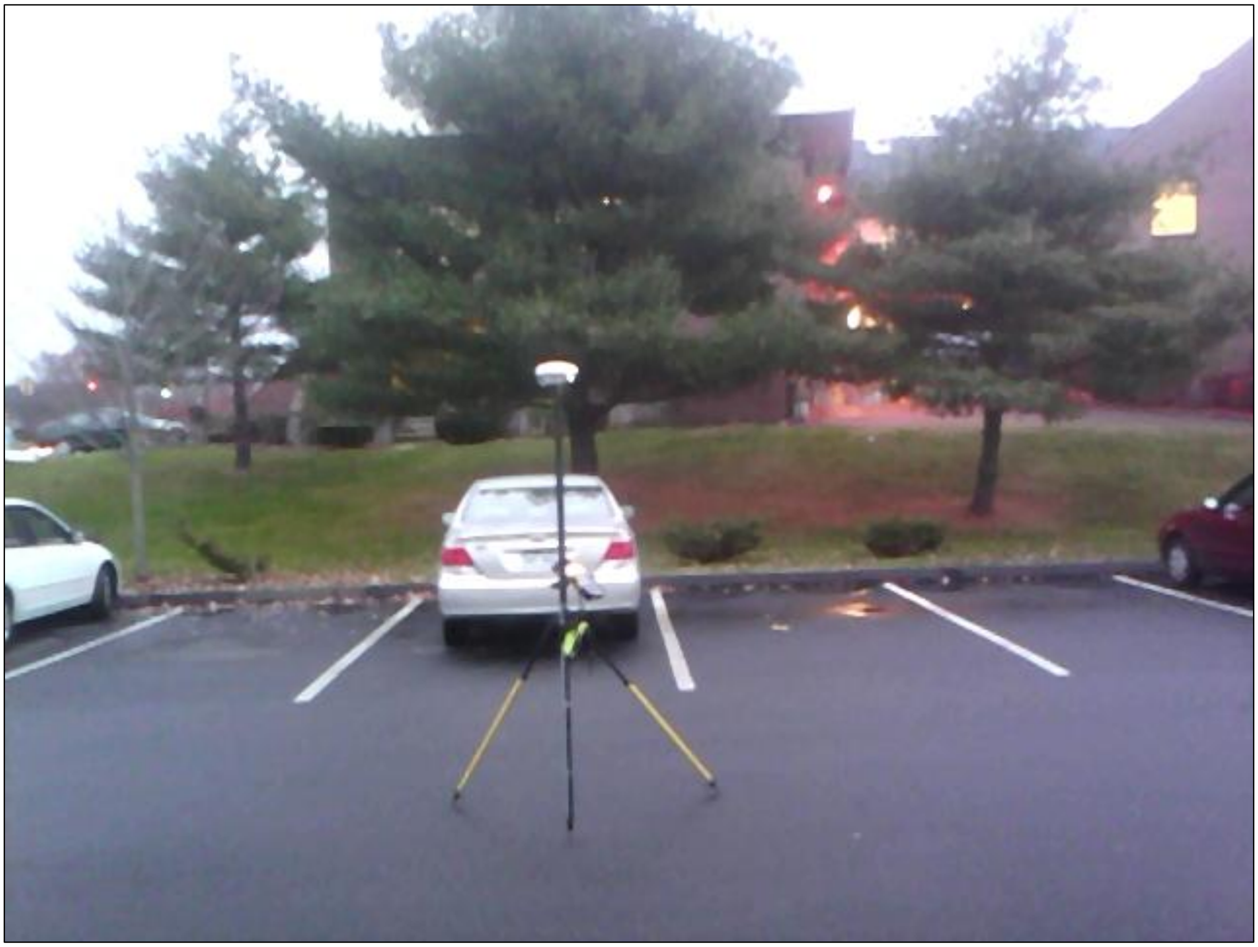

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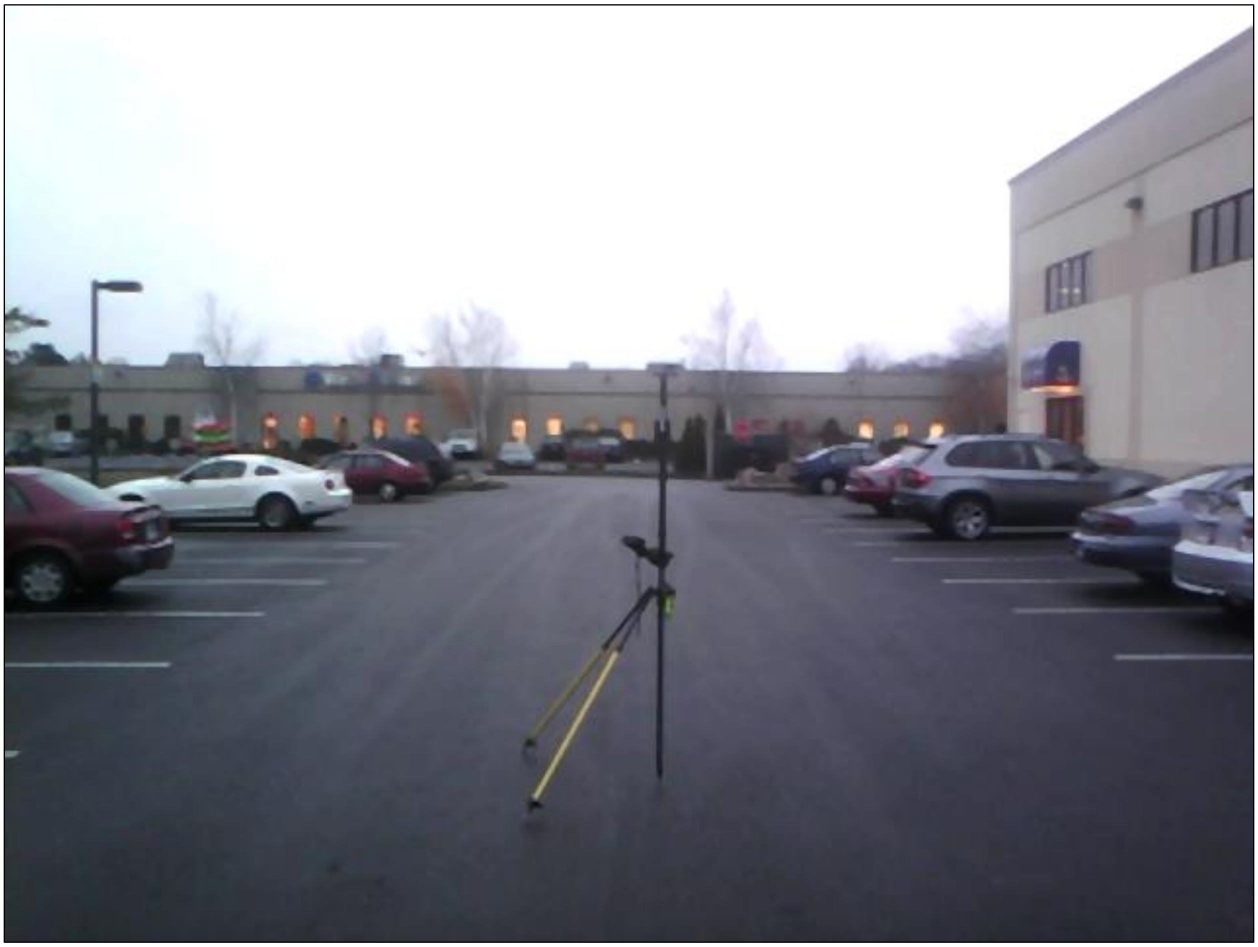

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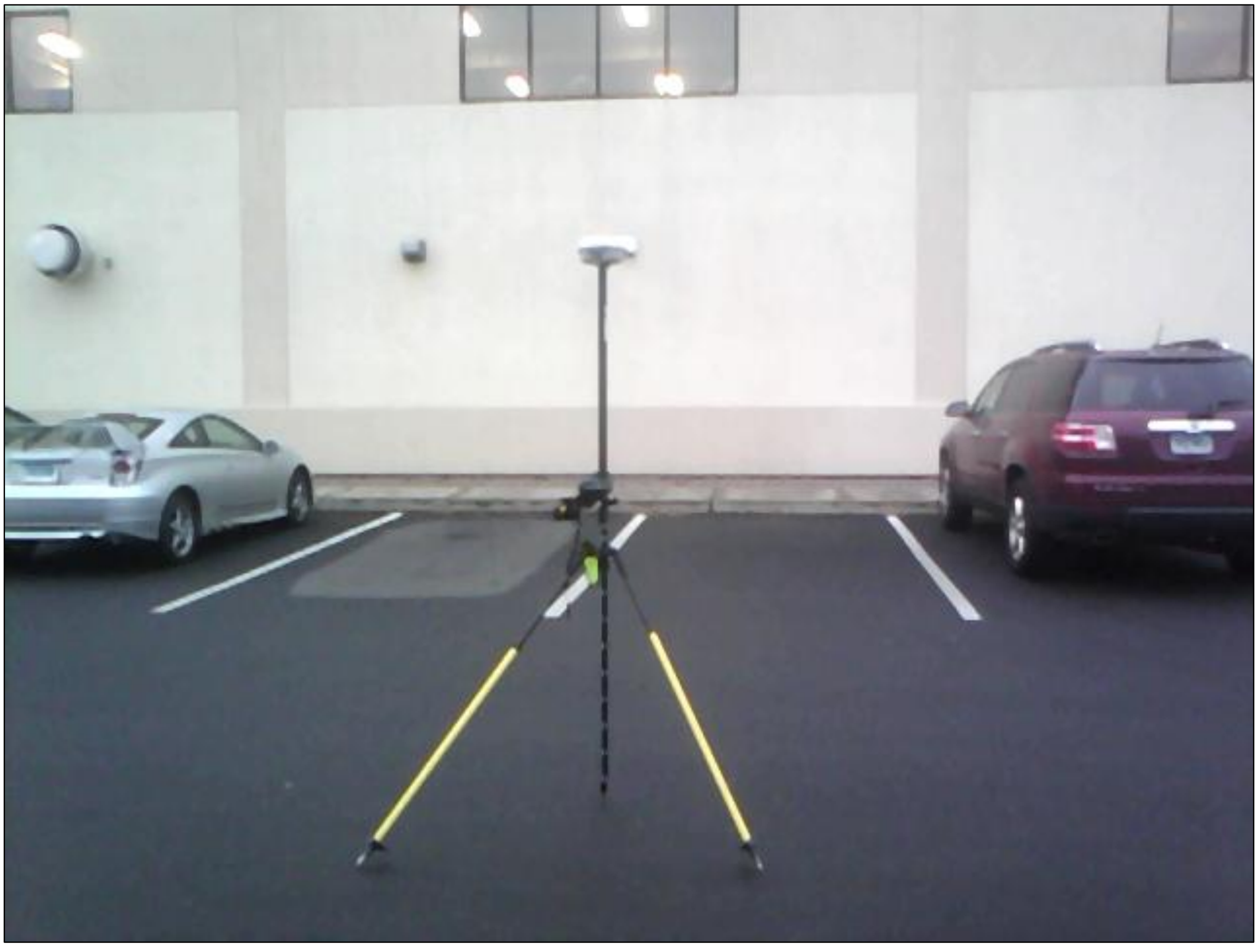

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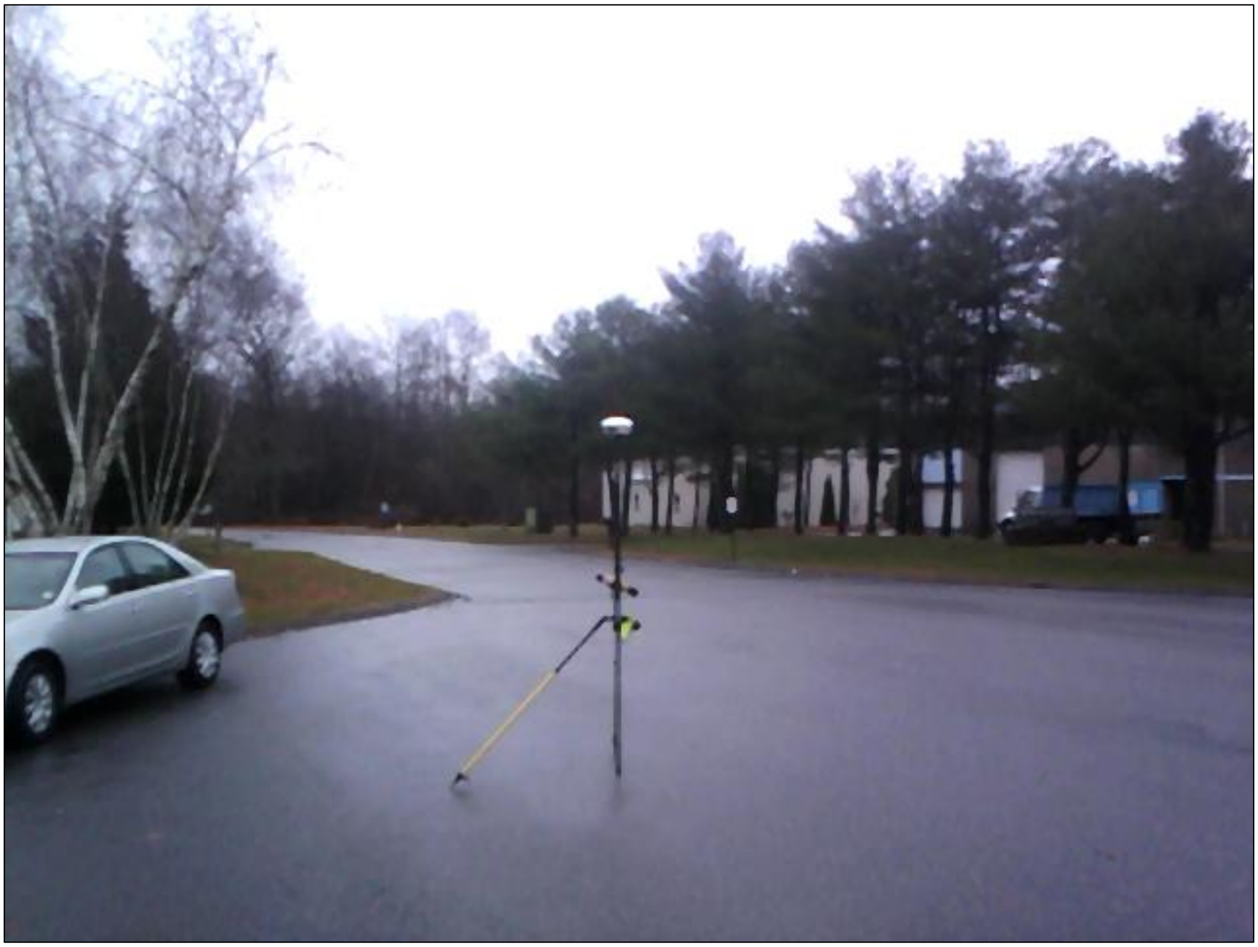

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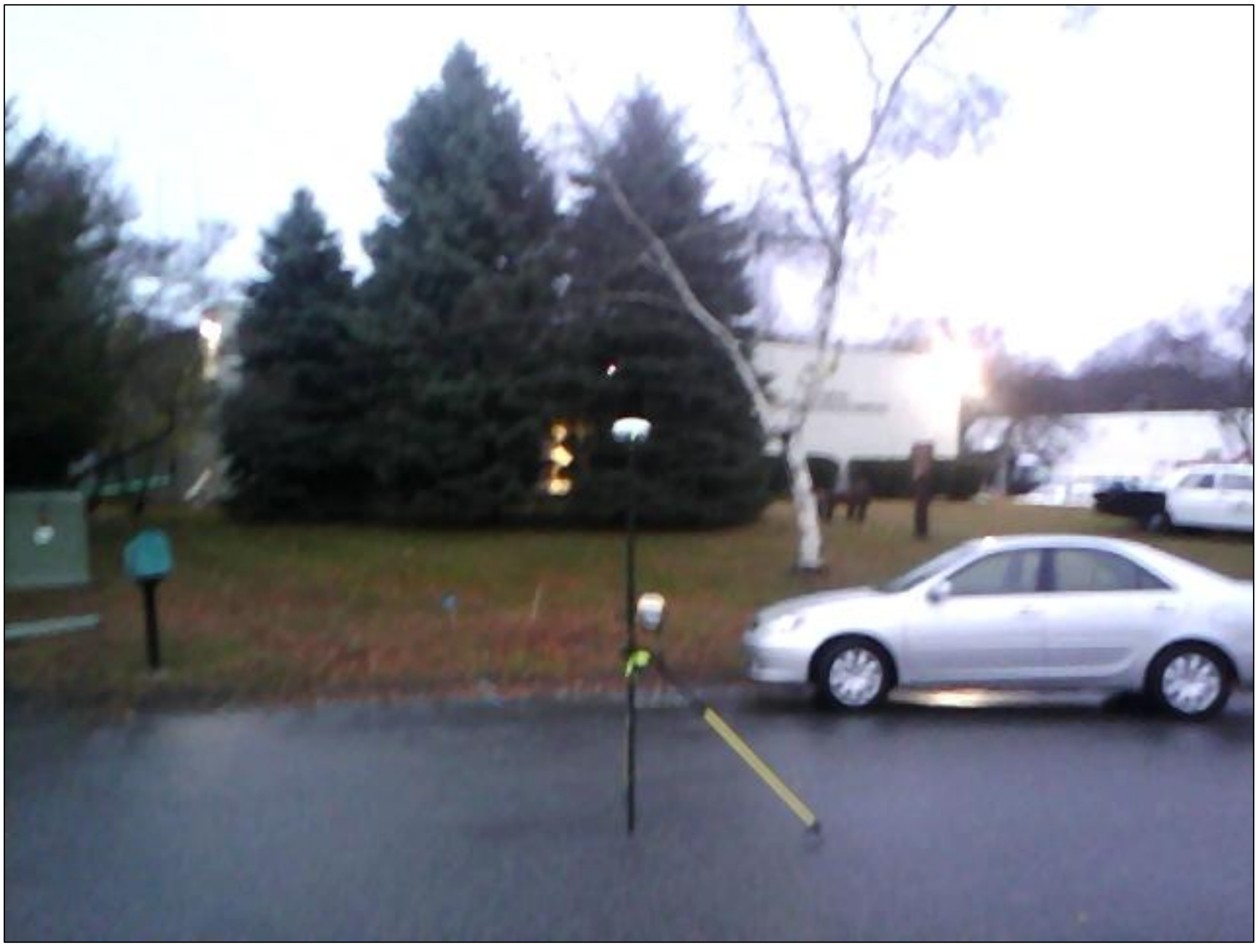

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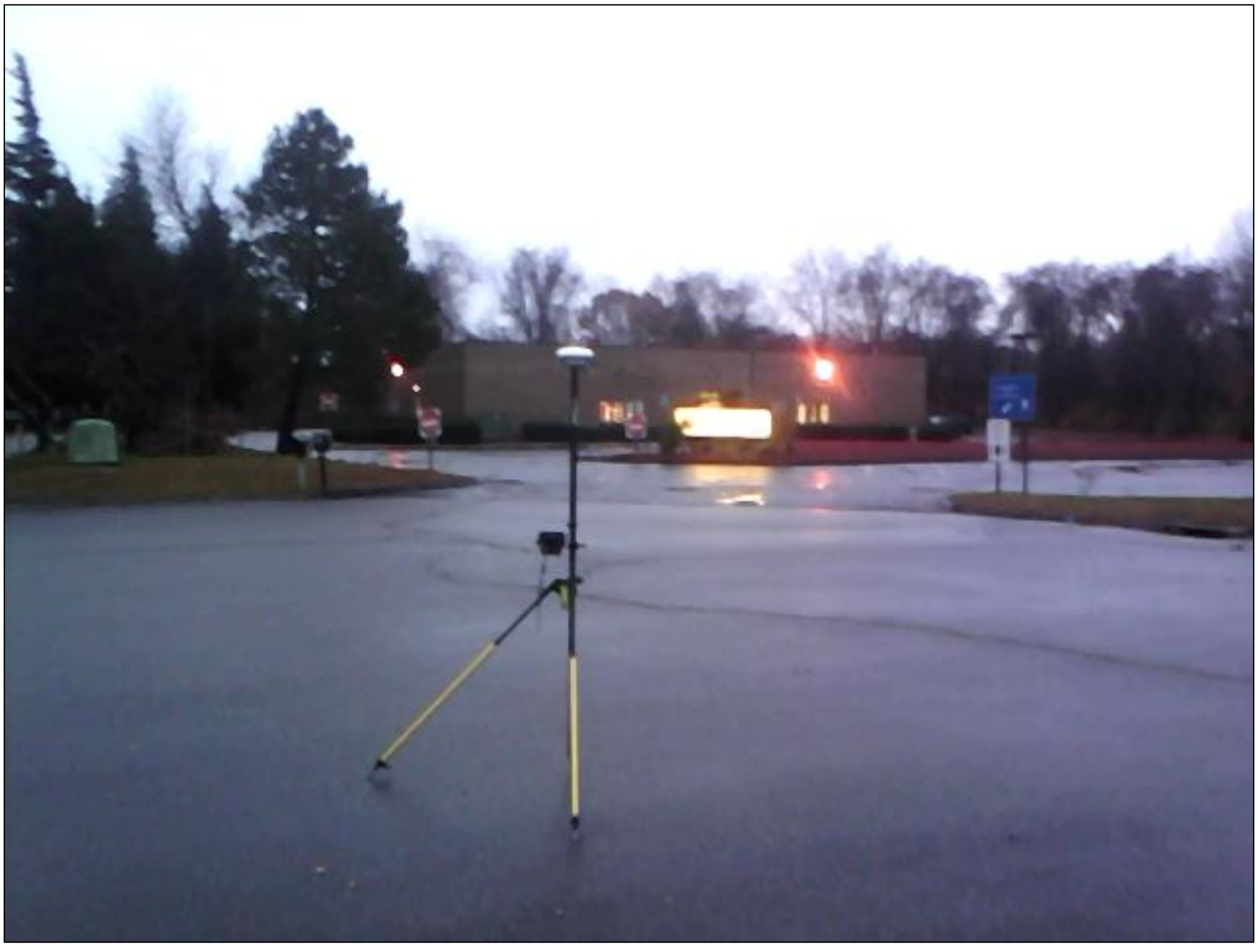

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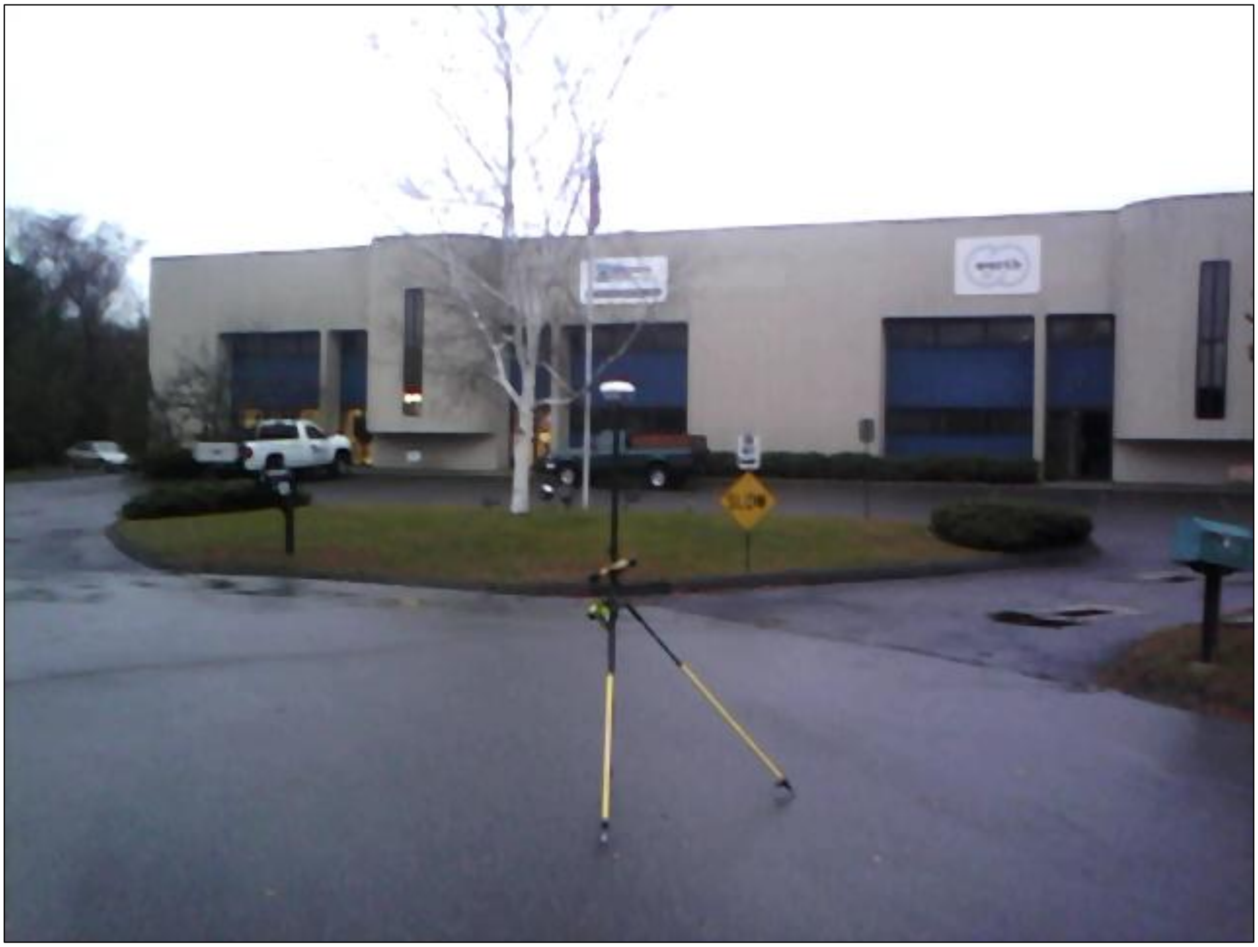
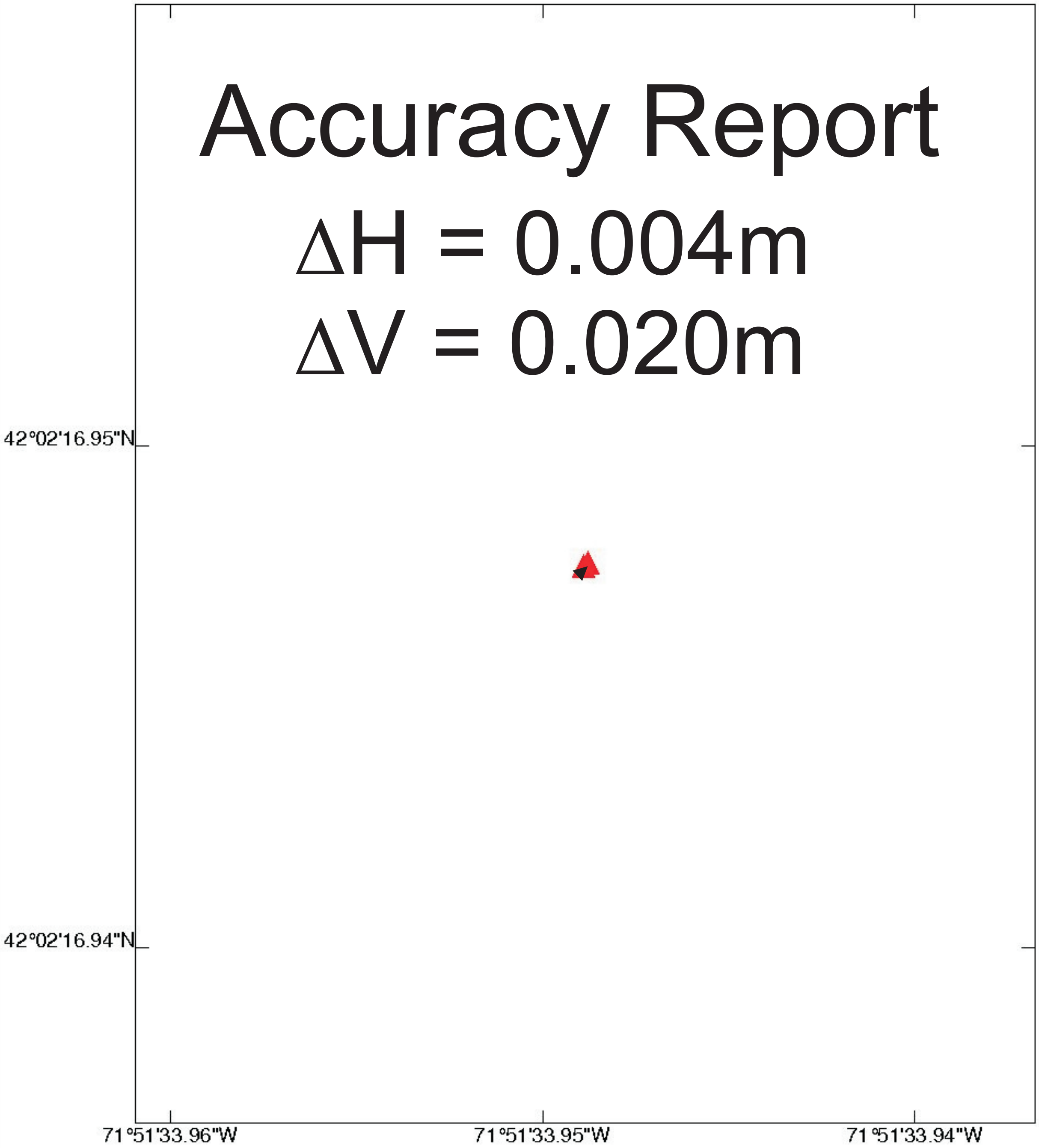


Accuracy Report

$\Delta H = 0.004m$

$\Delta V = 0.020m$



NGS_MY5929 10_19_2010

Lat/Long
WGS 1984

N

Scale 1:4.00

0 0.150

Meters

10/28/2010

GPS Pathfinder™ Office

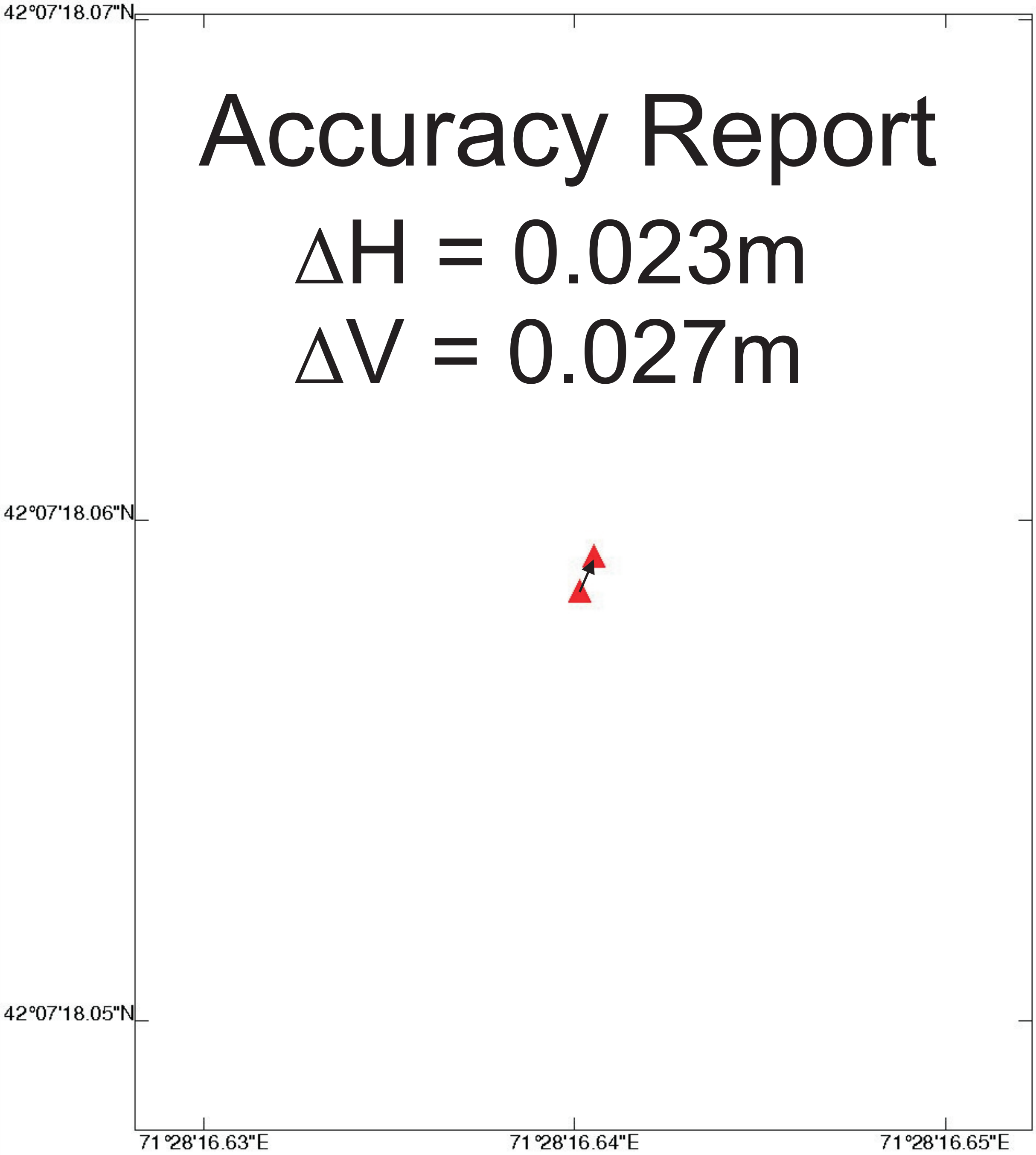
Trimble

CompassData

Accuracy Report

ΔH = 0.023m

ΔV = 0.027m



NGS_AI5590 10_19_2010

Lat/Long
WGS 1984

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0 0.150

Meters

10/28/2010

GPS Pathfinder™ Office

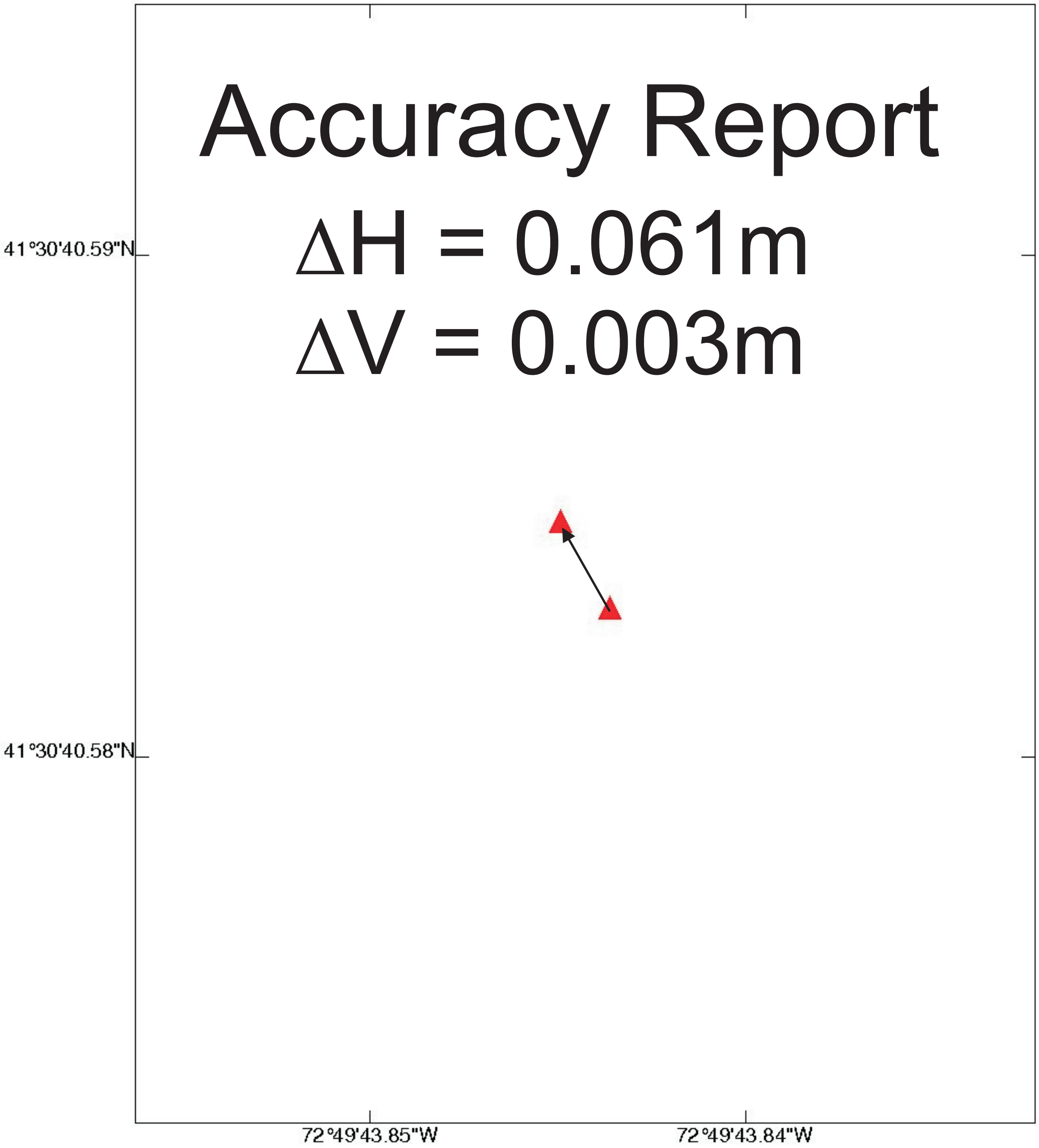
Trimble.

CompassData

Accuracy Report

ΔH = 0.061m

ΔV = 0.003m



NGS_DE7815 10_20_2010

Lat/Long
WGS 1984

N

Scale 1:4.00

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Meters

10/28/2010

GPS Pathfinder® Office

Trimble.

Region 1: Test results for Quinnipiac, CT

Summary

In FEMA-Region 1 the Quinnipiac area encompasses about 443 square miles. A LiDAR data acquisition was ordered for a 2' equivalent contour accuracy, which equals the highest specification level. The area was flown and post-processed by Photo Science. CompassData performed the quality control of the collected and processed LiDAR data with a fundamental vertical accuracy (FVA) and a consolidated vertical accuracy (CVA) assessment, respectively. The planning, data collection, data processing, and data testing were successfully accomplished by the STARR members.

Index

Final Test Results

The vertical accuracy requirements based on flood risk and terrain slope are met with 22.4 cm and 33.1 cm for both FVA and CVA testing. The mandatory requirements for the highest specification for vertical accuracy, 95% confidence level are for FVA < 24.5 cm and CVA < 36.3 cm.

FVA Test

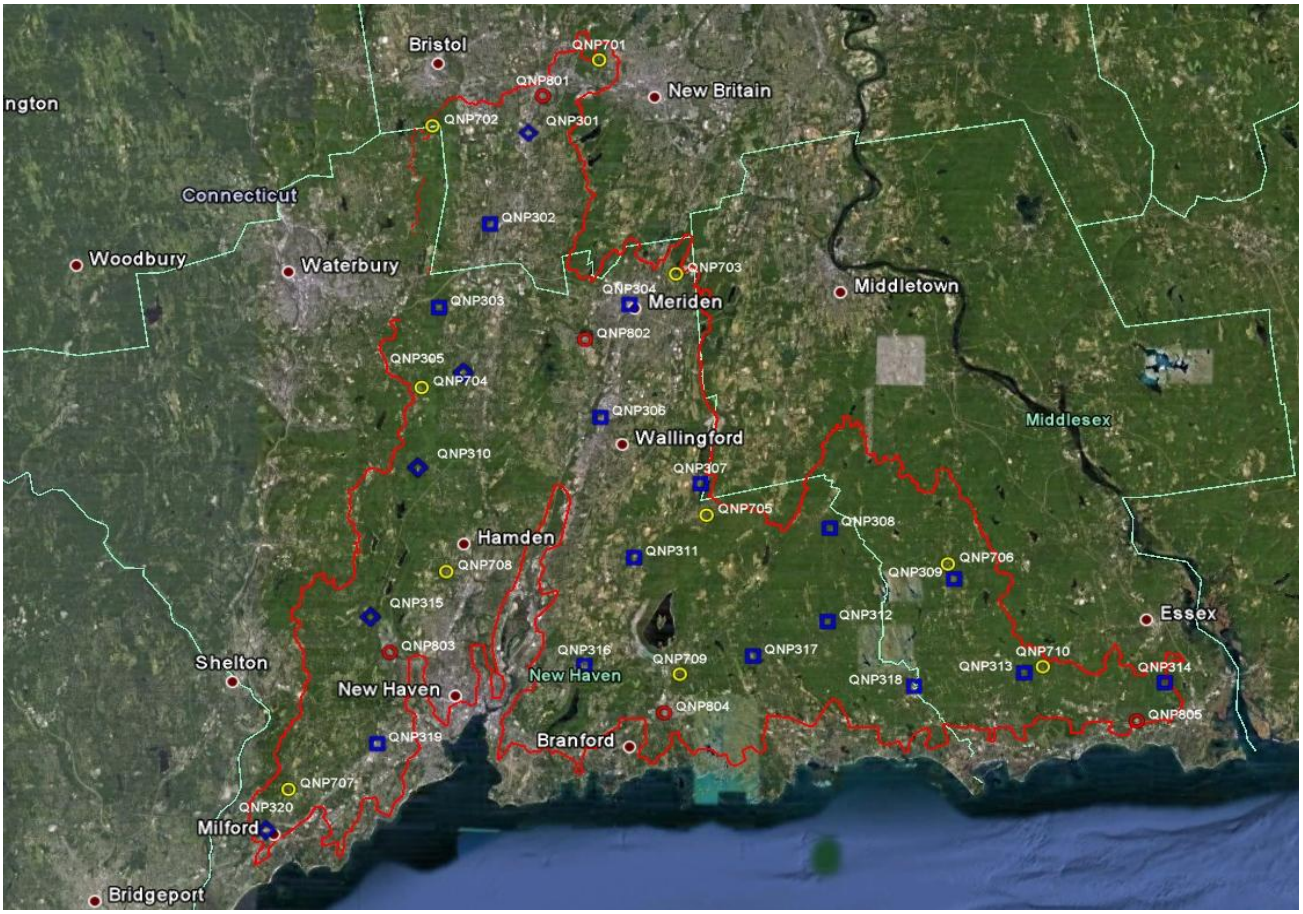
Tested 22.4 cm fundamental vertical accuracy at 95% confidence level in open terrain using $\text{RMSE}_{(z)}$ x 1.9600. The Root Mean Square Error for the elevation differences between GPS control points and LiDAR points is 11.4 cm calculated with 20 FVA points.

CVA Test

Tested 33.1 cm consolidated vertical accuracy at 95th percentile in: open terrain, forest terrain, and urban terrain. The Root Mean Square Error for the elevation differences between GPS control points and LiDAR points is 16.6 cm calculated with 20 supplemental vertical accuracy points (SVA).

Distribution of Testing Points

Region 1, Quinnipiac, CT



Legend:

□	FVA points in open terrain on hard surface
◇	FVA points in open terrain used as well in CVA test
○	SVA points in open terrain
○	SVA points in urban terrain
○	SVA points in forest terrain

According to the area to be tested the 20 FVA points are evenly distributed. Additional 15 SVA points are distributed in respect to the available major land classes.

FVA Test Details

FVA	Date	Northing	Easting	MSL (GPS)	MSL (LiDAR)	Δ Z
QNP301	10/19/2010	4612015.14	677121.44	53.86	53.71	**0.15**
QNP302	10/19/2011	4605980.13	674885.56	59.9	59.86	**0.04**
QNP303	10/20/2010	4600444.12	671853.19	105.69	105.67	**0.02**
QNP304	10/20/2010	4600925.05	683632.58	38.72	38.85	**-0.13**
QNP305	10/20/2010	4596228.74	673468.64	54.22	54.23	**-0.01**
QNP306	10/20/2010	4593491.13	682011.25	16.39	16.52	**-0.13**
QNP307	10/19/2011	4589290.46	688310.81	128.96	128.94	**0.02**
QNP308	10/20/2010	4586570.53	696368.09	114.69	114.67	**0.02**
QNP309	10/20/2010	4583424.74	704147.91	115.57	115.55	**0.02**
QNP310	10/20/2010	4589934.80	670810.54	159.37	159.52	**-0.15**
QNP311	10/19/2011	4584358.41	684296.75	48.56	48.54	**0.02**
QNP312	10/20/2010	4580447.58	696383.90	78.45	78.43	**0.02**
QNP313	10/20/2010	4577364.17	708654.37	34.09	34.07	**0.02**
QNP314	10/20/2010	4576920.53	717396.82	30.18	30.16	**0.02**
QNP315	10/20/2010	4580089.00	668077.96	75.62	75.82	**-0.20**
QNP316	10/20/2010	4577218.76	681388.62	18.63	18.61	**0.02**
QNP317	10/20/2010	4578081.00	691819.58	24.6	24.58	**0.02**
QNP318	10/20/2010	4576322.18	701849.26	6.86	6.84	**0.02**
QNP319	10/20/2010	4571790.43	668664.09	50.16	50.53	**-0.37**
QNP320	10/20/2010	4565957.32	661899.85	24.79	24.77	**0.02**

ΔZ Mean	**0.11**		
ΔZ Min	**-0.37**	**RMSE:**	**0.114**
ΔZ Max	**0.15**	*** 1.96**	**0.224**

Metadata

UTM 18 North, NAD83, NAVD88

All units in meters where applicable.

HAE - GEOID09 = NAVD88

Note:

19 of the 20 FVA points (open terrain) passed. 95% of the points are within the 24.5 cm confidence level. Point QNP319 fails with -37.0 cm. The FVA test is passed.

CVA Test Details

CVA	Date	Northing	Easting	MSL (GPS)	MSL (LiDAR)	Δ Z
QNP301	10/20/2010	4612015.14	677121.44	53.86	53.71	**-0.15**
QNP305	10/20/2010	4596228.74	673468.64	54.22	54.23	**0.01**
QNP310	10/20/2010	4589934.80	670810.54	159.37	159.52	**0.15**
QNP315	10/20/2010	4580089.00	668077.96	75.62	75.82	**0.20**
QNP320	10/20/2010	4565957.32	661899.85	24.79	24.77	**-0.02**
QNP701	10/20/2010	4616860.56	681390.95	105.35	105.60	**0.25**
QNP702	10/20/2010	4612282.38	671198.08	274.05	274.16	**0.11**
QNP703	10/20/2010	4602982.37	686476.09	95.25	95.28	**0.03**
QNP704	10/20/2010	4595168.79	670915.11	190.37	190.51	**0.14**
QNP705	10/20/2010	4587226.27	688730.31	91.61	91.89	**0.28**
QNP706	10/20/2010	4584378.17	703748.41	146.30	146.36	**0.06**
QNP707	10/20/2010	4568648.09	663237.68	27.04	26.71	**-0.33**
QNP708	10/20/2010	4583160.09	672701.92	29.01	29.34	**0.33**
QNP709	10/20/2010	4576768.91	687318.77	34.79	34.87	**0.08**
QNP710	10/20/2010	4577783.66	709801.59	68.73	68.85	**0.12**
QNP801	10/20/2010	4614457.23	677950.88	55.70	55.80	**0.10**
QNP802	10/20/2010	4598548.56	680945.83	30.91	30.91	**0.00**
QNP803	10/20/2010	4577785.05	669317.21	21.90	22.05	**0.15**
QNP804	10/20/2010	4574214.20	686412.39	7.52	7.60	**0.08**
QNP805	10/20/2010	4574344.13	715721.83	8.29	8.34	**0.05**

ΔZ Mean	**0.11**	**RMSE:**	**0.166**
ΔZ Min	**-0.33**	*** 1.96**	**0.324**
ΔZ Max	**0.33**	**95 Percentile**	**0.331**

Land Class Types: O = Open, F = Forest, U = Urban

UTM Zone 18 North, NAD83, NAVD88
MSL = NAVD88/Geoid09
All units in meters

Note:

All 20 of the SVA points (open, forest, and urban terrain) passed. 100% of the points are within the 36.3 cm confidence level. The CVA test is passed.

Appendix E: Post Flight Reports

STARR
Strategic Alliance
for Risk Reduction

Quinnipiac
Post-Flight Aerial Acquisition Report

August 2011

Post-Flight Aerial Acquisition and Calibration Report

FEMA REGION 1
Quinnipiac Watershed, Connecticut

FEDERAL EMERGENCY MANAGEMENT AGENCY
August 2011

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Post-Flight Aerial Acquisition and Calibration Report

1.0

Vendor Contact Information:

GMR Aerial Surveys, Inc. DBA Photo Science
2670 Wilhite Drive
Lexington, KY 40503
(859) 277-8700

Contact: Kurt Allen, PLS
Telephone: 301 -262-9400
Email: kallen@photoscience.com

The purpose of this project is to provide professional surveying and mapping services for the creation of a high-resolution digital elevation model developed from LIDAR data for the Quinnipiac area of interest (AOI). The project area is shown in the graphic below in Figure 1.1

All flights for the project were accomplished with customized single-engine Cessna 206 Aircraft utilizing a Leica sensor. These aircraft provide an ideal, stable aerial base for LiDAR acquisition. This platform has relatively fast cruise speeds that are beneficial for project mobilization / demobilization while maintaining relatively slow stall speeds which can prove ideal for collection of a high-density, consistent data posting.

Photo Science utilized Leica sensors on this project. The systems are capable of collecting data at a maximum frequency of 150 kHz, which affords elevation data collection of up to 150,000 points per second. The system utilizes a Multi-pulse in the Air option (MPIA). This sensor are also equipped with the ability to measure up to 4 returns per outgoing pulse from the laser and these come in the form of 1st, 2nd, 3rd, and last returns. The intensity of the first three returns is also captured during the aerial acquisition.

The project covered 443 square miles and required 1 block or area to cover (block or area is determined by the Base Station Control locations, typically airports with ground control monuments available providing coverage within 18 miles of the base as possible). There were 101 flight lines totaling 1358 flight line miles.

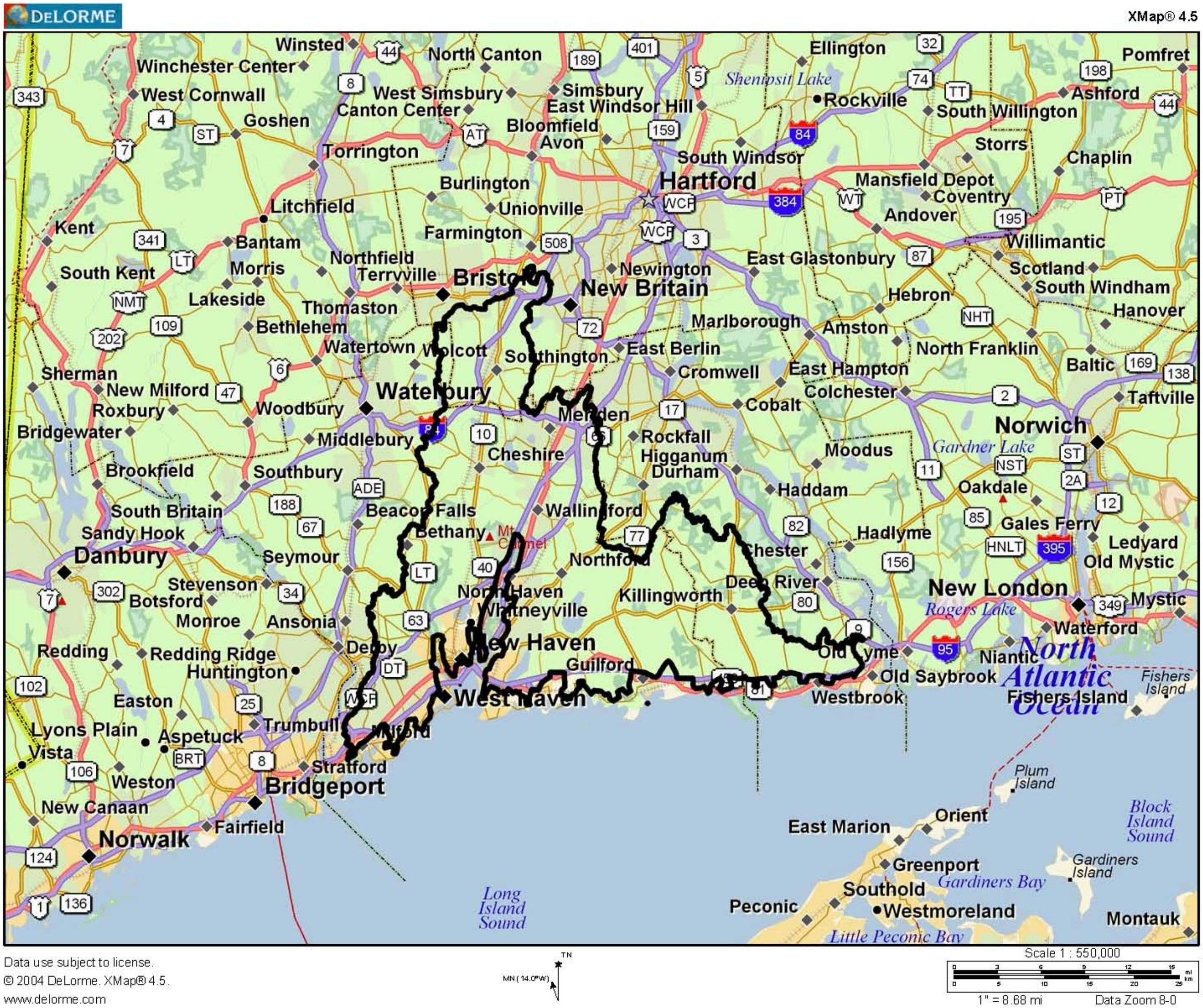


Figure 1.1: Quinnipiac Coverage Area

2.0

Detailed project planning was performed for this project. This planning was based on project specific requirements and the characteristics of the project site. The basis of this planning included the required accuracies, type of development, amount and type of vegetation within the project area, the required data posting, and potential altitude restrictions for flights in the general area. A brief summary of the aerial acquisition parameters for this project are shown in the LiDAR System Specification (Table 2.1) below:

Terrain and Aircraft
Flying Height AGL; 1524 m / 5000 ft
Recommended Ground Speed (GS); 95 kts

Scanner
Field of View (FOV); 34.0 degrees
Maximum Scan Rate; 40.99Hz
Scan Rate Setting used (SR); 41.0 Hz

Laser
Maximum Laser Pulse Rate; 145300Hz
Laser Pulse Rate used; 145300 Hz
Multi Pulse in Air Mode; Enabled
Gain Values (Up/Down); 12; 3
Range Intensity mode; 5
Nominal Maximum Slant Range; 1619.78m
Recommended Range Gate MIN Setting; 1223.63m
Recommended Range Gate MAX Setting; 1632.00m
Equivalent Attenuator Used; 0.59OD
Recommended Laser Current; 37%

Coverage
Full Swath Width; 931.87m
Coverage Rate; 138.52km^2/h
Maximum Line Spacing (No DTM); 787.30m
Minimum Sidelap (No DTM, lower); 15.51%
Minimum Sidelap (upper); 13.30%

Point Spacing and Density
Maximum Point Spacing Across Track; 0.97 m
Maximum Point Spacing Along Track; 1.05 m
Across Track/Along Track Ratio; 0.68
Average Point Density; 3.00 pts / m^2
Average Point Area; 0.31m^2
Average Point Spacing; 0.56m
Nadir Point Density; 2.06pts / m^2

Reflectivity and SNR
Illuminated Footprint Diameter; 0.35m, 1/e^2
Terrain Reflectivity; 0.10
Estimated SNR for diffuse targets Nadir; 14.42 - 13.58
Line/Rail Cross Section; 10.00mm
Line/Rail Reflectivity; 0.30
Estimated SNR for wire targets Nadir; 1.52 - 0.00
Average SNR; 14.00; 14.00;

Accuracy
Estimated Across Track Accuracy; 0.19 - 0.21m
Estimated Along Track Accuracy; 0.19 - 0.20m
Estimated Height Accuracy; 0.13m

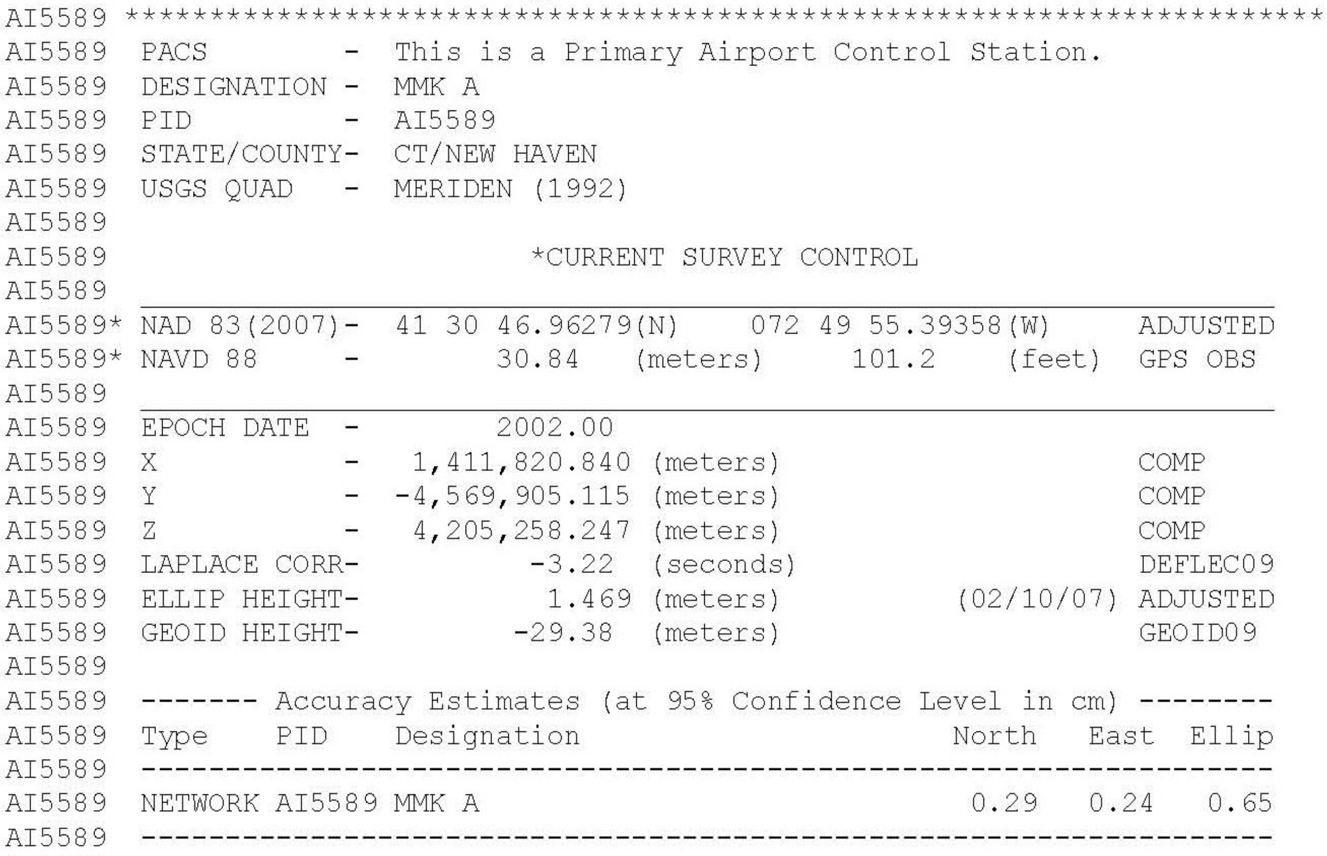
LiDAR System Specification (Table 2.1)

Base Station Information

A base station was utilized at one (1) location during all phases of flight. Typically existing monuments are utilized when available, but on occasion we will set a monument steel pin and utilizes OPUS to determine the exact location.

For this project the following Base Station, outlined in the Table and Map(s) below, was utilized:

“MMK A”– is the designated Primary Airport Control Station



```
AI5589 ***********************************************************************
AI5589  PACS         -  This is a Primary Airport Control Station.
AI5589  DESIGNATION -  MMK A
AI5589  PID          -  AI5589
AI5589  STATE/COUNTY-  CT/NEW HAVEN
AI5589  USGS QUAD    -  MERIDEN (1992)
AI5589
AI5589                         *CURRENT SURVEY CONTROL
AI5589  ___________________________________________________________________
AI5589* NAD 83(2007)-  41 30 46.96279(N)    072 49 55.39358(W)     ADJUSTED
AI5589* NAVD 88      -        30.84   (meters)     101.2    (feet)  GPS OBS
AI5589  ___________________________________________________________________
AI5589  EPOCH DATE   -        2002.00
AI5589  X            -   1,411,820.840 (meters)                     COMP
AI5589  Y            -  -4,569,905.115 (meters)                     COMP
AI5589  Z            -   4,205,258.247 (meters)                     COMP
AI5589  LAPLACE CORR-           -3.22  (seconds)                    DEFLEC09
AI5589  ELLIP HEIGHT-            1.469 (meters)          (02/10/07) ADJUSTED
AI5589  GEOID HEIGHT-          -29.38  (meters)                     GEOID09
AI5589
AI5589  ------- Accuracy Estimates (at 95% Confidence Level in cm) --------
AI5589  Type    PID    Designation                      North   East  Ellip
AI5589  -------------------------------------------------------------------
AI5589  NETWORK AI5589 MMK A                             0.29   0.24   0.65
AI5589  -------------------------------------------------------------------
```

Table 2.2: Base Station Locations

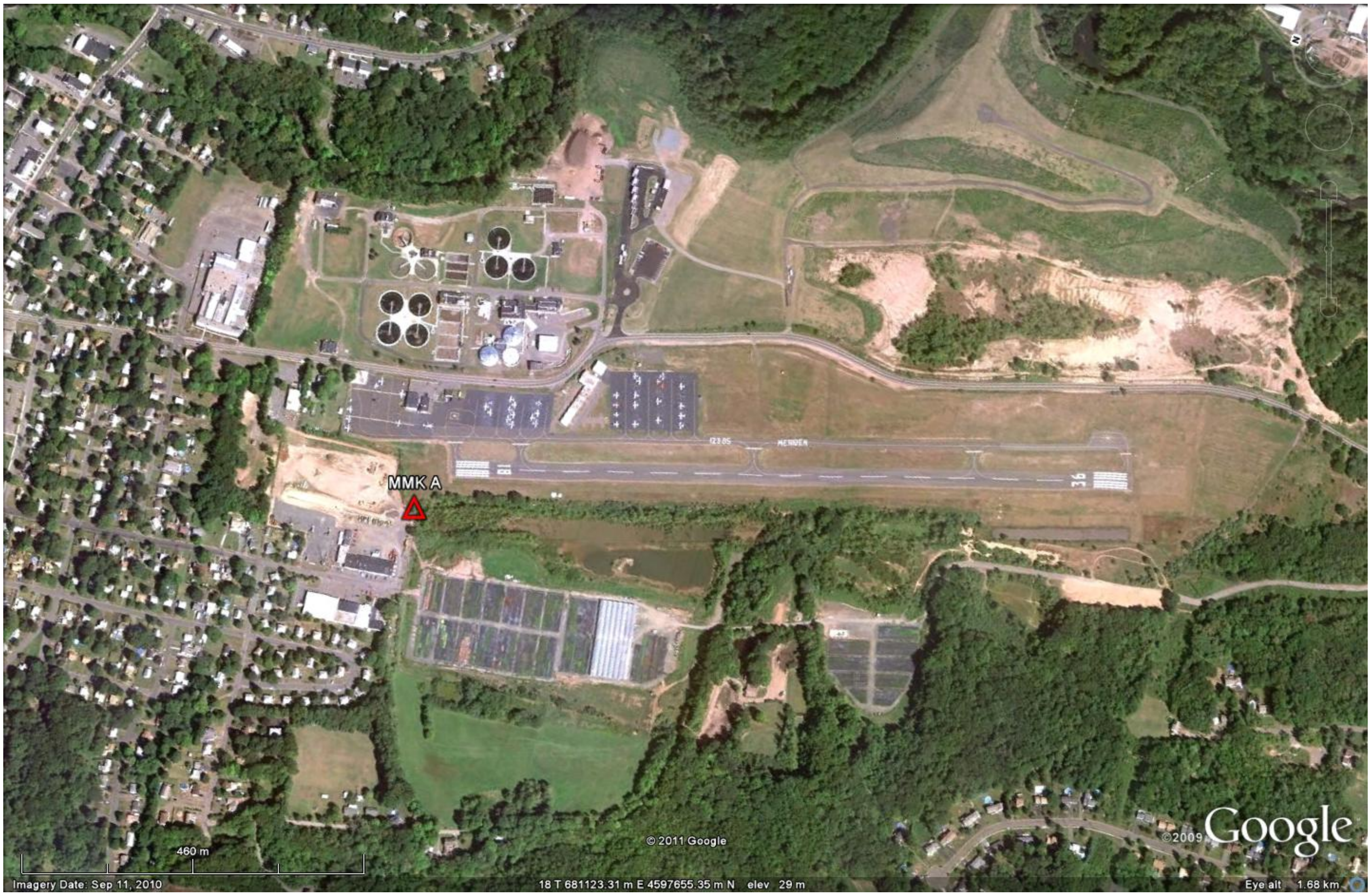

MMK A
460 m
Imagery Date: Sep 11, 2010
© 2011 Google
18 T 681123.31 m E 4597655.35 m N elev 29 m
©2009 Google
Eye alt 1.68 km

Figure 2.1: Base Station Locations

Time Period

Missions were flown between 12/11/2010 and 5/27/2011 totaled ten (10) sorties (or lifts) by two (2) different aircraft. All flights were accomplished by Leica Sensors.

Sensor Number	Project Number	Flight Line Number	Area ID	Date Flown	System Used	Aircraft	Flight_Line Miles
19	7556-005	6	Quinnipiac	5/27/2011	Leica	N6461Z	30.5
59	7556-005	95	Quinnipiac	12/11/2010-3/29/2011	Leica	N7320G	1327.2

Table 2.3: Airborne LiDAR Acquisition Flight Summary

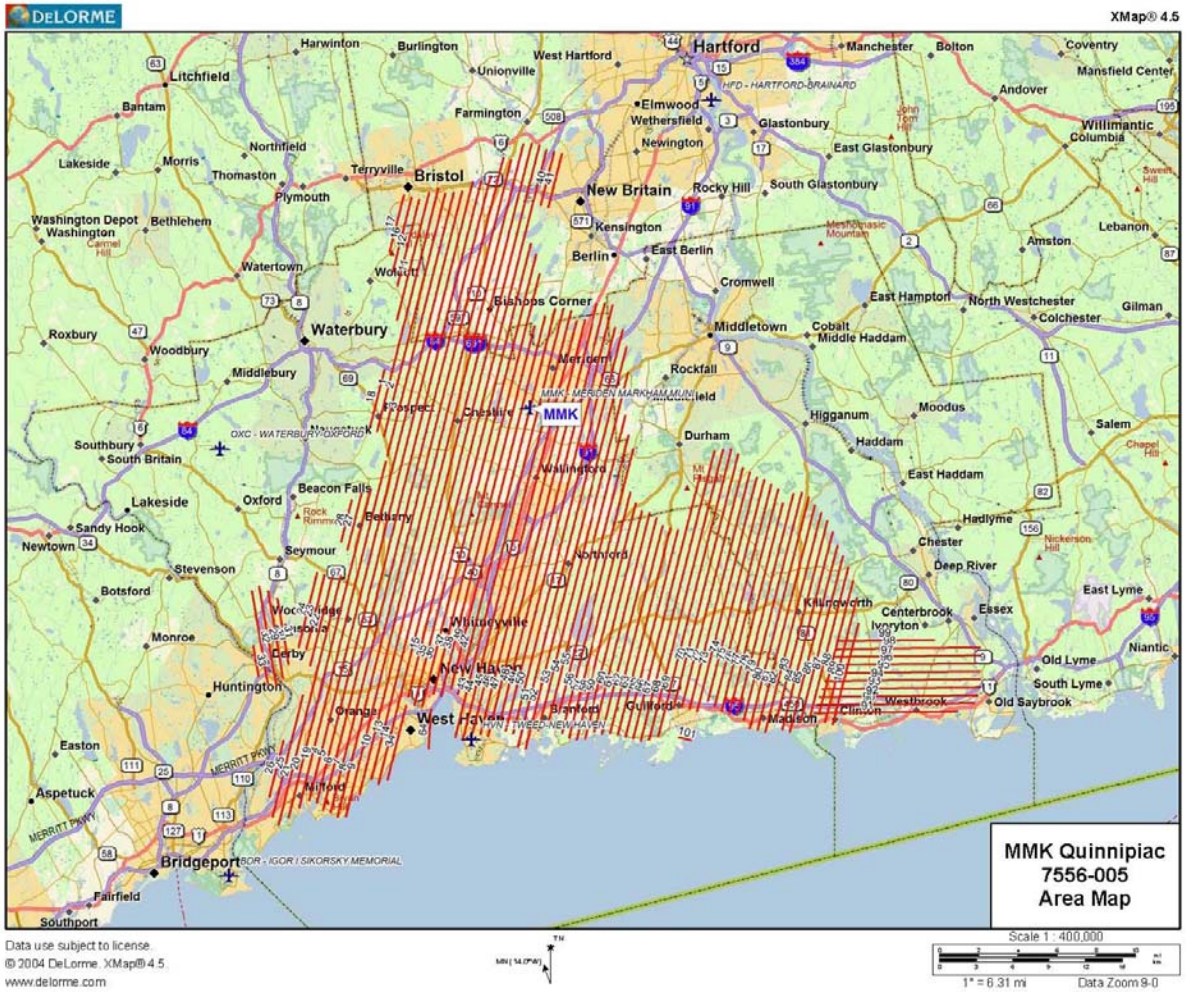


Figure 2.2: LiDAR Flight Layout

3.0
Processing Summary

Leica IPAS and Applanix software was used in the post-processing of the airborne GPS and inertial data that is critical to the positioning of the sensor during all flights. This software suite includes the IPAS from Leica and Applanix POSPac and Waypoint's GrafNav solutions. Both IPAS and POSPac provides the smoothed best estimate of trajectory (SBET) that is necessary for Leica's post processor to develop the point cloud from the LiDAR missions. The point cloud is the mathematical three dimensional collection of all returns from all laser pulses as determined from the aerial mission. At this point this data is ready for analysis, classification, and filtering to generate a bare earth surface model in which the above ground features are removed from the data set.

GeoCue was used in the creation of some of the files needed in downstream processing, as well as in the tiling of the dataset into more manageable file sizes. The TerraScan and TerraModeler software packages are then used for the automated data classification, manual cleanup, and bare earth generation from this data. Project specific macros were used to classify the ground and to remove the side overlap between parallel flight lines. All data was manually reviewed and any remaining artifacts removed using functionality provided by TerraScan and TerraModeler. QT Modeler was used as a final check of the bare earth dataset. GeoCue was then used to create the deliverable LAS 1.2 files for both the All Point Cloud Data and the Bare Earth. In-house software was then used to perform final statistical analysis of the classes in the LAS files.

Flight Log Overview:

- -Post Spacing (Minimum): 0.56 m
- -AGL (Above Ground Level) average flying height: 5000 ft
- -MSL (Mean Sea Level) average flying height: 5266 ft
- -Average Ground Speed: 95 kts
- -Field of View (full): 34 deg
- -Pulse Rate: 145,300
- -Scan Rate: 41.0 Hz
- -Side Lap (Average): 30%

During initial processing (GPS/IMU) certain statistics and tables are generated within the Processing software (either POSPAC or IPAS for Leica), a representative sample are included here and the remaining are located in *Appendix B - Original Flight Logs:*

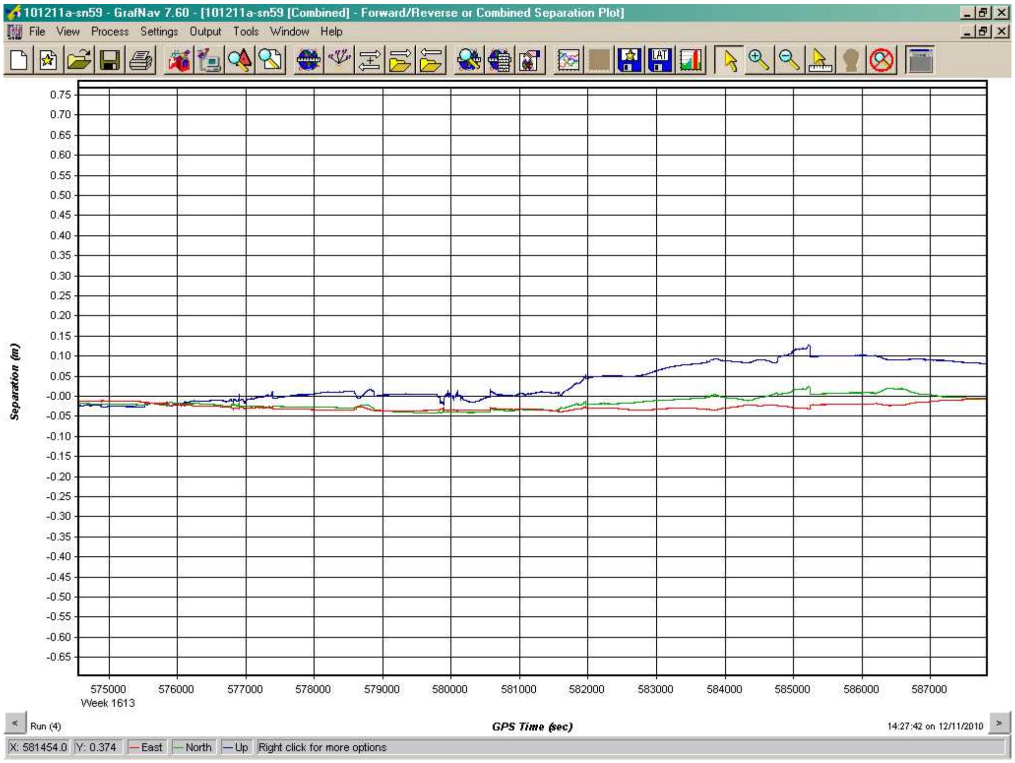


Figure 3.1 – 101211a-sn59 Combined Separation

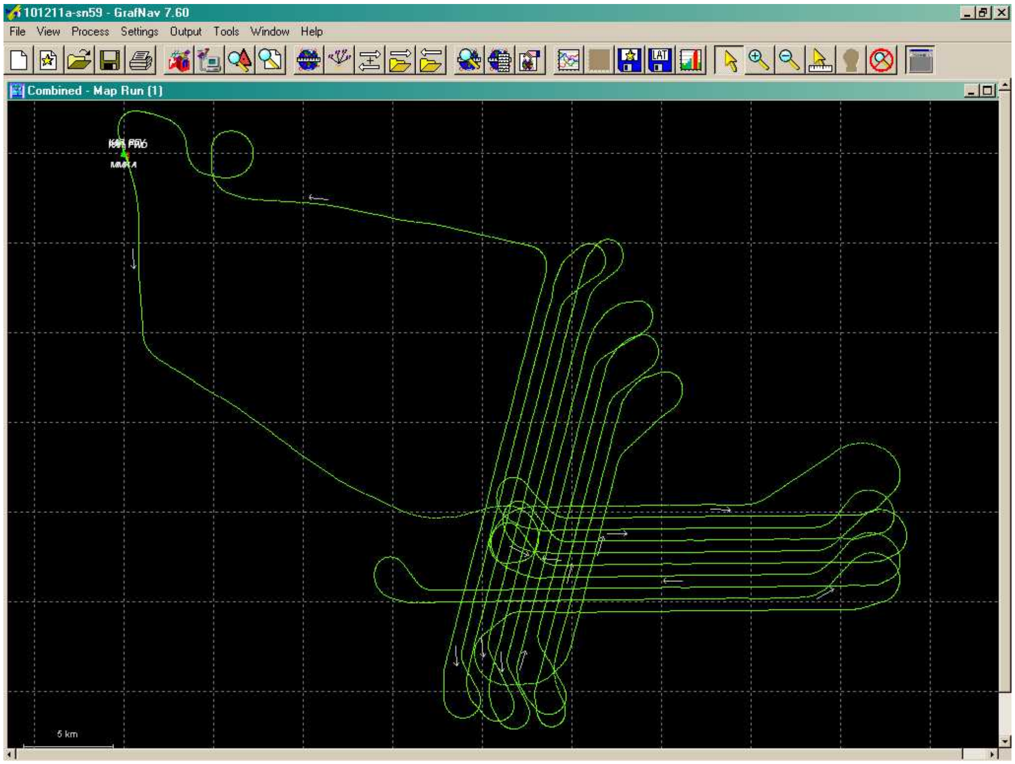

101211a-sn59 - GrafNav 7.60
File View Process Settings Output Tools Window Help
Combined - Map Run (1)
5 km

Figure 3.2 – 101211a-sn59 Map Run of Flight lines

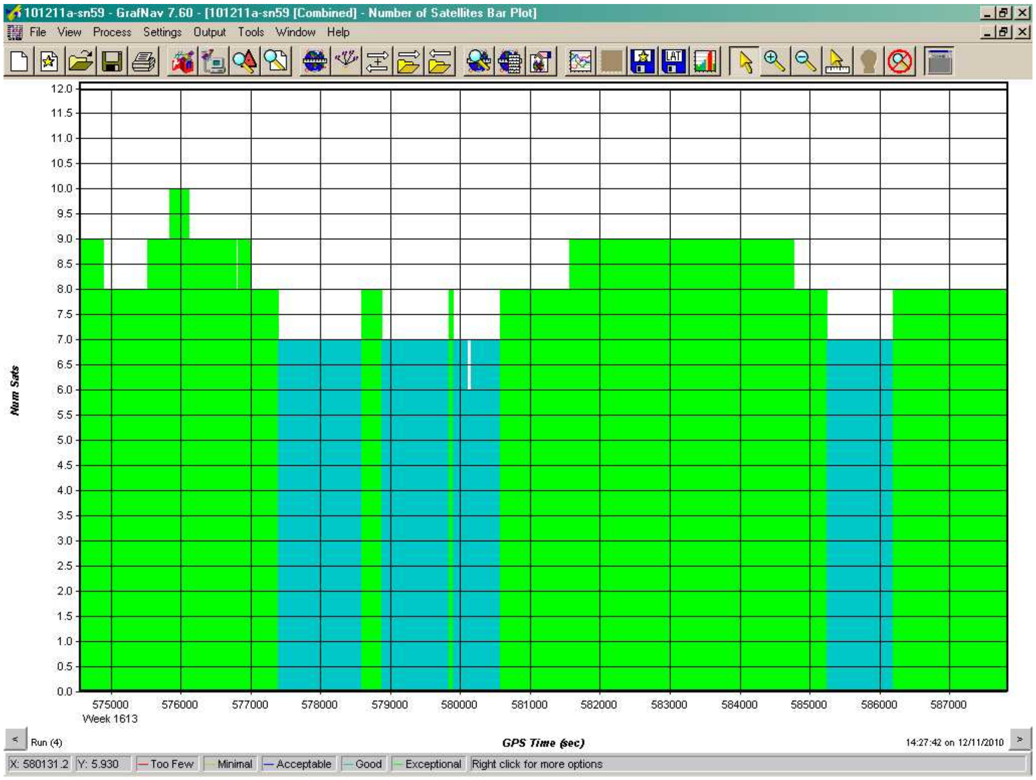


Figure 3.3 – 101211a-sn59 Number of Satellites

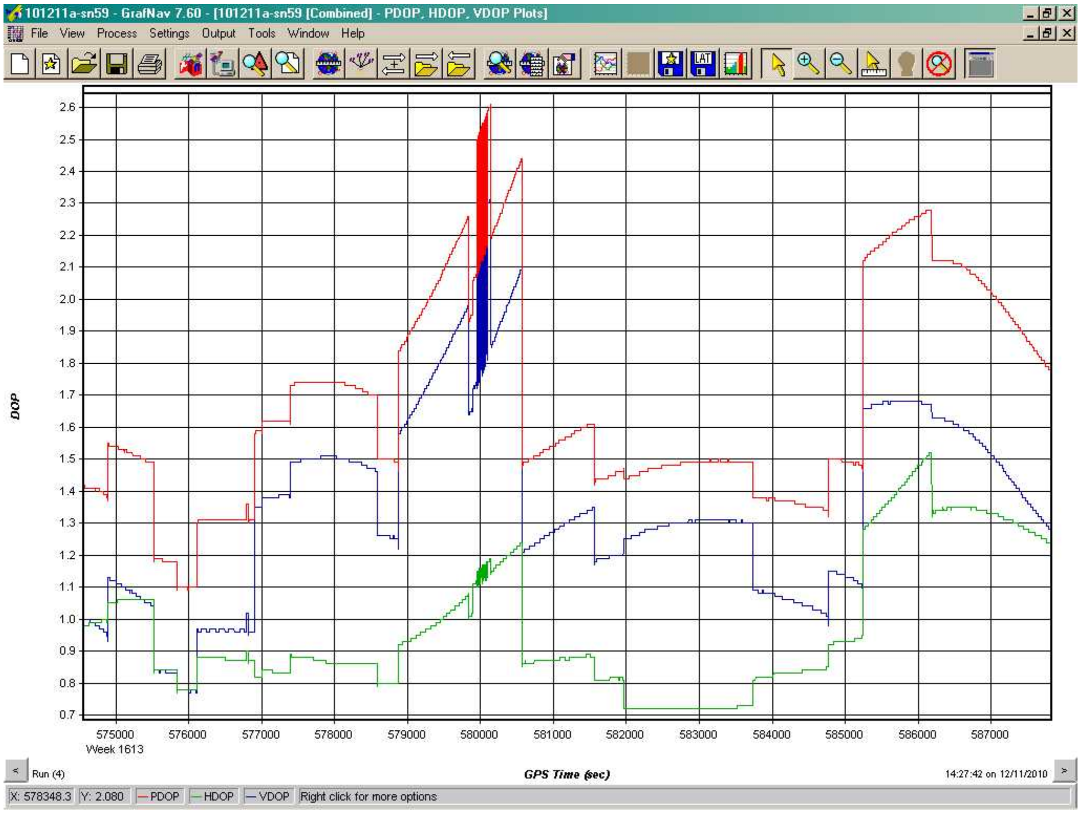
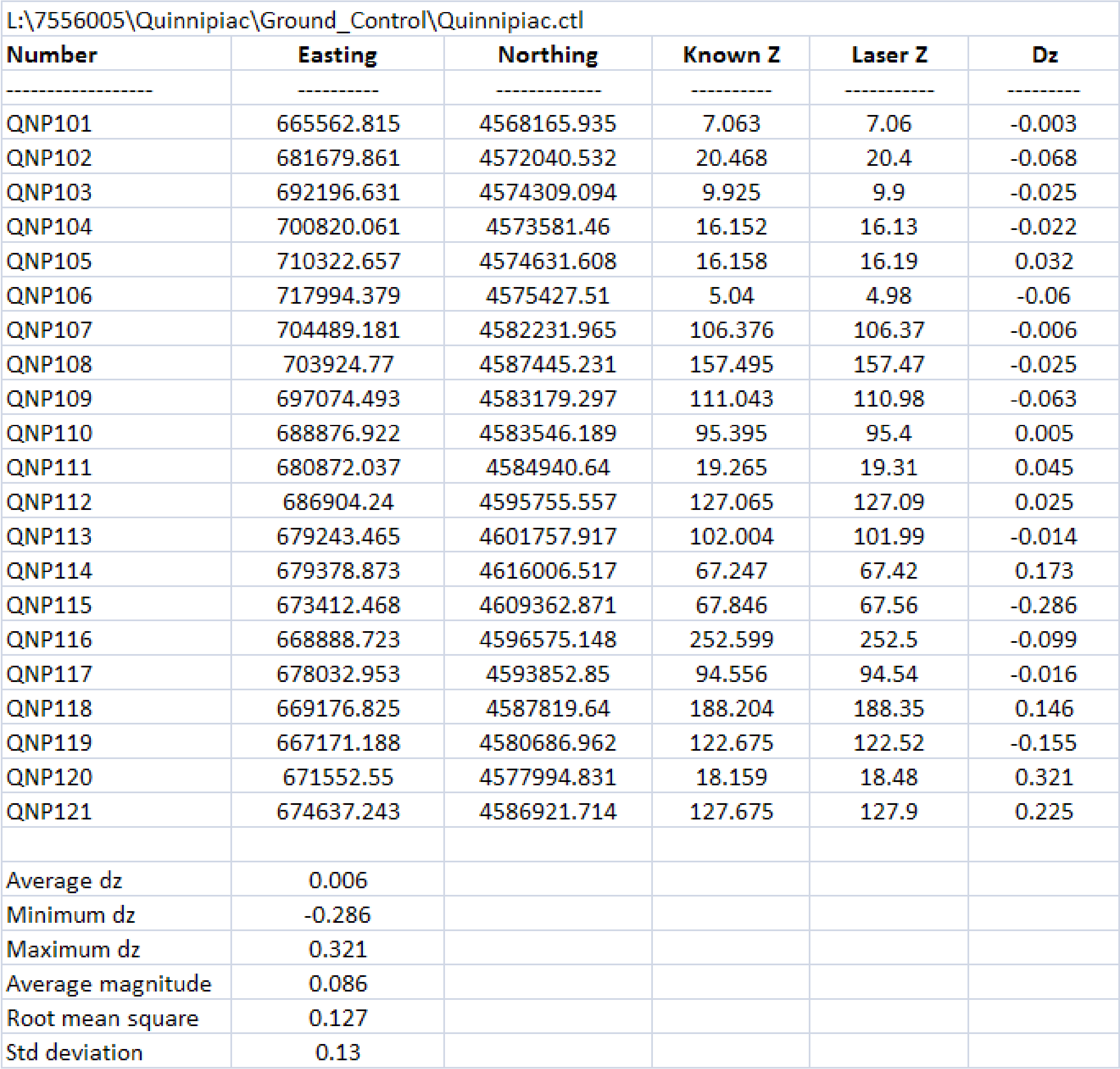


Figure 3.4 – 101211a-sn59 P-DOP Values

4.0

A number of points are provided (or surveyed as part of the project) in order to provide a ground calibration and to help assure the accuracy of the data model. Initially any bias identified between the LiDAR surface and the provided control points are analyzed to average out the difference. The bias is then removed from LiDAR surface to provide a final ground surface. The two sets of data are then compared again and the results indicated below (Meters, UTM18):



L:\7556005\Quinnipiac\Ground_Control\Quinnipiac.ctl

Number	**Easting**	**Northing**	**Known Z**	**Laser Z**	**Dz**
------------------	----------	-------------	----------	-----------	---------
QNP101	665562.815	4568165.935	7.063	7.06	-0.003
QNP102	681679.861	4572040.532	20.468	20.4	-0.068
QNP103	692196.631	4574309.094	9.925	9.9	-0.025
QNP104	700820.061	4573581.46	16.152	16.13	-0.022
QNP105	710322.657	4574631.608	16.158	16.19	0.032
QNP106	717994.379	4575427.51	5.04	4.98	-0.06
QNP107	704489.181	4582231.965	106.376	106.37	-0.006
QNP108	703924.77	4587445.231	157.495	157.47	-0.025
QNP109	697074.493	4583179.297	111.043	110.98	-0.063
QNP110	688876.922	4583546.189	95.395	95.4	0.005
QNP111	680872.037	4584940.64	19.265	19.31	0.045
QNP112	686904.24	4595755.557	127.065	127.09	0.025
QNP113	679243.465	4601757.917	102.004	101.99	-0.014
QNP114	679378.873	4616006.517	67.247	67.42	0.173
QNP115	673412.468	4609362.871	67.846	67.56	-0.286
QNP116	668888.723	4596575.148	252.599	252.5	-0.099
QNP117	678032.953	4593852.85	94.556	94.54	-0.016
QNP118	669176.825	4587819.64	188.204	188.35	0.146
QNP119	667171.188	4580686.962	122.675	122.52	-0.155
QNP120	671552.55	4577994.831	18.159	18.48	0.321
QNP121	674637.243	4586921.714	127.675	127.9	0.225
Average dz	0.006				
Minimum dz	-0.286				
Maximum dz	0.321				
Average magnitude	0.086				
Root mean square	0.127				
Std deviation	0.13				

Table 4.1: Overall Vertical Accuracy Statistics

QA/QC Analysis

A total of 20 points were established in the field for check points assessing the accuracy of the LiDAR surface and met specification.

5.0

List of Deliverables:

- PreFlight Planning Report
- PostFlight Aerial Acquisition and Calibration Report
- LAS v1.2 unclassified point cloud files in tile format.
- LAS v1.2 classified point cloud files in tile format.
- Project metadata in Microsoft Word format.
- The project data was delivered on (Hard Drive/DVD’s).

Flight Line Coverage

FL_Label	FL_NUM	Date_Flown	State	Proj_Name	Area_ID	Mile_label	FL_Miles	Alt_Label	Alt_MSL	Base_Sta	System	Sensor_ Number	AirCraft
Flight Line	1	10-May-11	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	12.7	Alt	5710	MMK A	Leica	59	N7320G
Flight Line	2	10-May-11	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	12.7	Alt	5590	MMK A	Leica	59	N7320G
Flight Line	3	10-May-11	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	13.8	Alt	5470	MMK A	Leica	59	N7320G
Flight Line	4	10-May-11	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	31.9	Alt	5360	MMK A	Leica	59	N7320G
Flight Line	5	08-May-11	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	32.6	Alt	5320	MMK A	Leica	59	N7320G
Flight Line	6	08-May-11	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	33.0	Alt	5280	MMK A	Leica	59	N7320G
Flight Line	7	06-May-11	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	33.4	Alt	5250	MMK A	Leica	59	N7320G
Flight Line	8	06-May-11	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	34.6	Alt	5220	MMK A	Leica	59	N7320G
Flight Line	9	06-May-11	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	34.4	Alt	5200	MMK A	Leica	59	N7320G
Flight Line	10	06-May-11	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	34.1	Alt	5190	MMK A	Leica	59	N7320G
Flight Line	11	10-May-11	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	6.7	Alt	5830	MMK A	Leica	59	N7320G
Flight Line	12	10-May-11	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	4.5	Alt	5890	MMK A	Leica	59	N7320G
Flight Line	13	06-May-11	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	33.4	Alt	5190	MMK A	Leica	59	N7320G
Flight Line	14	06-May-11	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	33.5	Alt	5190	MMK A	Leica	59	N7320G
Flight Line	15	06-May-11	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	28.7	Alt	5230	MMK A	Leica	59	N7320G
Flight Line	16	10-May-11	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	3.9	Alt	5920	MMK A	Leica	59	N7320G
Flight Line	17	10-May-11	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	3.0	Alt	5900	MMK A	Leica	59	N7320G
Flight Line	18	10-May-11	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	3.0	Alt	5820	MMK A	Leica	59	N7320G
Flight Line	19	10-May-11	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	18.2	Alt	5330	MMK A	Leica	59	N7320G
Flight Line	20	10-May-11	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	17.2	Alt	5280	MMK A	Leica	59	N7320G
Flight Line	21	27-May-11	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	13.0	Alt	5190	MMK A	Leica	19	N6461Z
Flight Line	22	27-May-11	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	4.7	Alt	5390	MMK A	Leica	19	N6461Z
Flight Line	23	27-May-11	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	3.8	Alt	5460	MMK A	Leica	19	N6461Z
Flight Line	24	27-May-11	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	3.8	Alt	5450	MMK A	Leica	19	N6461Z
Flight Line	25	08-May-11	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	6.4	Alt	5110	MMK A	Leica	59	N7320G
Flight Line	26	08-May-11	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	3.0	Alt	5140	MMK A	Leica	59	N7320G
Flight Line	27	27-May-11	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	3.0	Alt	5630	MMK A	Leica	19	N6461Z
Flight Line	28	27-May-11	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	2.2	Alt	5590	MMK A	Leica	19	N6461Z
Flight Line	29	18-Dec-10	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	5.1	Alt	5140	MMK A	Leica	59	N7320G
Flight Line	30	18-Dec-10	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	4.5	Alt	5140	MMK A	Leica	59	N7320G
Flight Line	31	18-Dec-10	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	3.4	Alt	5250	MMK A	Leica	59	N7320G
Flight Line	32	18-Dec-10	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	4.8	Alt	5240	MMK A	Leica	59	N7320G
Flight Line	33	18-Dec-10	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	1.6	Alt	5130	MMK A	Leica	59	N7320G

Flight Line	34	06-May-11	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	3.9	Alt	5040	MMK A	Leica	59	N7320G
Flight Line	35	30-Mar-11	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	24.2	Alt	5210	MMK A	Leica	59	N7320G
Flight Line	36	30-Mar-11	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	23.7	Alt	5240	MMK A	Leica	59	N7320G
Flight Line	37	30-Mar-11	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	22.0	Alt	5260	MMK A	Leica	59	N7320G
Flight Line	38	30-Mar-11	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	19.4	Alt	5210	MMK A	Leica	59	N7320G
Flight Line	39	30-Mar-11	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	19.5	Alt	5160	MMK A	Leica	59	N7320G
Flight Line	40	30-Mar-11	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	2.8	Alt	5320	MMK A	Leica	59	N7320G
Flight Line	41	30-Mar-11	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	2.8	Alt	5300	MMK A	Leica	59	N7320G
Flight Line	42	30-Mar-11	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	20.2	Alt	5110	MMK A	Leica	59	N7320G
Flight Line	43	30-Mar-11	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	22.5	Alt	5080	MMK A	Leica	59	N7320G
Flight Line	44	30-Mar-11	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	22.5	Alt	5080	MMK A	Leica	59	N7320G
Flight Line	45	29-Mar-11	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	21.6	Alt	5100	MMK A	Leica	59	N7320G
Flight Line	46	29-Mar-11	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	21.7	Alt	5140	MMK A	Leica	59	N7320G
Flight Line	47	29-Mar-11	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	22.6	Alt	5180	MMK A	Leica	59	N7320G
Flight Line	48	29-Mar-11	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	22.3	Alt	5200	MMK A	Leica	59	N7320G
Flight Line	49	29-Mar-11	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	22.3	Alt	5220	MMK A	Leica	59	N7320G
Flight Line	50	29-Mar-11	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	21.3	Alt	5220	MMK A	Leica	59	N7320G
Flight Line	51	17-Dec-10	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	21.9	Alt	5240	MMK A	Leica	59	N7320G
Flight Line	52	17-Dec-10	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	21.1	Alt	5260	MMK A	Leica	59	N7320G
Flight Line	53	17-Dec-10	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	18.8	Alt	5300	MMK A	Leica	59	N7320G
Flight Line	54	17-Dec-10	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	16.0	Alt	5310	MMK A	Leica	59	N7320G
Flight Line	55	17-Dec-10	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	14.6	Alt	5300	MMK A	Leica	59	N7320G
Flight Line	56	17-Dec-10	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	14.9	Alt	5290	MMK A	Leica	59	N7320G
Flight Line	57	17-Dec-10	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	12.8	Alt	5240	MMK A	Leica	59	N7320G
Flight Line	58	17-Dec-10	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	12.4	Alt	5240	MMK A	Leica	59	N7320G
Flight Line	59	17-Dec-10	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	12.0	Alt	5230	MMK A	Leica	59	N7320G
Flight Line	60	17-Dec-10	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	11.5	Alt	5240	MMK A	Leica	59	N7320G
Flight Line	61	17-Dec-10	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	11.3	Alt	5220	MMK A	Leica	59	N7320G
Flight Line	62	18-Dec-10	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	10.9	Alt	5210	MMK A	Leica	59	N7320G
Flight Line	63	17-Dec-10	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	10.9	Alt	5180	MMK A	Leica	59	N7320G
Flight Line	64	30-Mar-11	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	2.0	Alt	5010	MMK A	Leica	59	N7320G
Flight Line	65	17-Dec-10	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	10.9	Alt	5180	MMK A	Leica	59	N7320G
Flight Line	66	16-Dec-10	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	13.8	Alt	5260	MMK A	Leica	59	N7320G
Flight Line	67	16-Dec-10	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	15.2	Alt	5270	MMK A	Leica	59	N7320G
Flight Line	68	16-Dec-10	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	15.2	Alt	5240	MMK A	Leica	59	N7320G
Flight Line	69	16-Dec-10	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	15.1	Alt	5230	MMK A	Leica	59	N7320G

Flight Line	70	16-Dec-10	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	13.3	Alt	5250	MMK A	Leica	59	N7320G
Flight Line	71	16-Dec-10	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	12.6	Alt	5270	MMK A	Leica	59	N7320G
Flight Line	72	16-Dec-10	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	12.4	Alt	5270	MMK A	Leica	59	N7320G
Flight Line	73	16-Dec-10	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	12.3	Alt	5290	MMK A	Leica	59	N7320G
Flight Line	74	16-Dec-10	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	11.7	Alt	5320	MMK A	Leica	59	N7320G
Flight Line	75	16-Dec-10	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	11.7	Alt	5300	MMK A	Leica	59	N7320G
Flight Line	76	16-Dec-10	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	11.7	Alt	5280	MMK A	Leica	59	N7320G
Flight Line	77	16-Dec-10	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	11.0	Alt	5280	MMK A	Leica	59	N7320G
Flight Line	78	16-Dec-10	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	11.7	Alt	5280	MMK A	Leica	59	N7320G
Flight Line	79	16-Dec-10	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	12.0	Alt	5270	MMK A	Leica	59	N7320G
Flight Line	80	11-Dec-10	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	12.1	Alt	5250	MMK A	Leica	59	N7320G
Flight Line	81	11-Dec-10	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	11.8	Alt	5260	MMK A	Leica	59	N7320G
Flight Line	82	11-Dec-10	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	11.5	Alt	5260	MMK A	Leica	59	N7320G
Flight Line	83	11-Dec-10	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	10.4	Alt	5270	MMK A	Leica	59	N7320G
Flight Line	84	11-Dec-10	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	10.4	Alt	5240	MMK A	Leica	59	N7320G
Flight Line	85	11-Dec-10	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	9.8	Alt	5230	MMK A	Leica	59	N7320G
Flight Line	86	11-Dec-10	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	8.7	Alt	5230	MMK A	Leica	59	N7320G
Flight Line	87	11-Dec-10	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	7.9	Alt	5220	MMK A	Leica	59	N7320G
Flight Line	88	11-Dec-10	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	7.0	Alt	5190	MMK A	Leica	59	N7320G
Flight Line	89	11-Dec-10	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	6.5	Alt	5150	MMK A	Leica	59	N7320G
Flight Line	90	11-Dec-10	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	8.1	Alt	5060	MMK A	Leica	59	N7320G
Flight Line	91	11-Dec-10	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	7.3	Alt	5040	MMK A	Leica	59	N7320G
Flight Line	92	11-Dec-10	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	8.1	Alt	5070	MMK A	Leica	59	N7320G
Flight Line	93	11-Dec-10	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	8.1	Alt	5080	MMK A	Leica	59	N7320G
Flight Line	94	11-Dec-10	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	7.9	Alt	5100	MMK A	Leica	59	N7320G
Flight Line	95	11-Dec-10	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	7.6	Alt	5130	MMK A	Leica	59	N7320G
Flight Line	96	11-Dec-10	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	7.3	Alt	5150	MMK A	Leica	59	N7320G
Flight Line	97	11-Dec-10	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	7.4	Alt	5160	MMK A	Leica	59	N7320G
Flight Line	98	11-Dec-10	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	7.3	Alt	5170	MMK A	Leica	59	N7320G
Flight Line	99	11-Dec-10	Connecticut	7556-005	MMK_Quinnipiac	FL_miles	5.0	Alt	5200	MMK A	Leica	59	N7320G
Flight Line	100	11-Dec-10	Connecticut	7556-005	MMK_Quinnipiac	5.3	5.3	5110	5110	MMK A	Leica	59	N7320G
Flight Line	101	16-Dec-10	Connecticut	7556-005	MMK_Quinnipiac	0.6	0.6	5020	5020	MMK A	Leica	59	N7320G

LIDAR MISSION RECORD SHEET

PHOTO SCIENCE
Geospatial Solutions

2670 Wilhite Drive - Lexington KY - 40503 - 859.277.8700 - www.photoscience.com

Project Name	Quinnipiac
Project Number	
Navigation File	2010 FEMA Allen/MMK_Quinnipiac

Pilot	Tom
Tech	Ryan
Aircraft	N6461Z

Date Flown	May 27, 2011		
Takeoff Time	13:55	(airport)	MMK
Landing Time	15:09	(airport)	MMK

Project's Scanning Requirements

FOV (degrees):	34	Laser Current(%):	37
Scan Rate (Hz):	41		
Pulse Rate (Hz):	145 300	Altitude AGL (ft):	5003
Ground Speed (kts):	95	Range Gate (m):	1223-1632

SPiA ? [✓ MPiA?]

Data Information

POS A/V file name	110527A
From/To	000 → 009
LiDAR Unit #	s/n 019
HD/Card #	3

	Ground	(airport)	Field Elev.	Temp. at Altitude
Begin Temp	29°C	MMK	103'	15°C
Begin Dewpoint	19°C			
Begin Pressure	29.96			
Mid Temp		MMK	103'	15°C
Mid Dewpoint				
Mid Pressure				
End Temp	29°C	MMK	103'	15°C
End Dewpoint	19°C			
End Pressure	29.95			

GPS Base/CORS Used	MMK A
PDOP Avoidance	1330-1345, 1705-1805, 2030-2050, 2145-2230
Static or Flyover Init.?	static
Laser On Time & Off Times	13:56 → 14:56

FILE	FL #	Alt. (AMSL)	Heading	Speed	Returns	Crab	NOTES
110527-180655	27	5630'	N	~95 kts	~99%	8°	scattered above haze, 5m wind, smooth
110527_181323	28	5595'	S	95	99	2°	
110527_181531	22	5395'	S	95	99	5°	
110527_182256	23	5455'	N	95	99	6°	
110527_182948	24	5445'	S	95	99	3°	
110527_184143	21	5195'	N	95	99	8°	
110527_185336	999	5100'	W	100	99	8°	improv the line

MMK A
1.693 m
5.55 f
13:05
15:22

LIDAR MISSION RECORD SHEET

PHOTO SCIENCE
Geospatial Solutions

1410 Indian Trail-Lilburn Rd. - Norcross, GA - 30093 - 770.564.9843 - www.photoscience.com

Project Name	MMK Quinnipiac
Project Number	7556.005
Navigation File	

Pilot	FD
Tech	DH
Aircraft	N7320G

Date Flown	5/10/2011	
Takeoff Time	11:45z	(airport) MMK
Landing Time	13:57z	(airport) MMK

Project's Scanning Requirements			
FOV (degrees):	34	Laser Current(%):	39
Scan Rate (Hz):	49		
Pulse Rate (Hz):	145,300	Altitude AGL (ft):	5000
Ground Speed (kts):	100	Range Gate (m):	1223-1632

SPiA ? [✓ MPiA?]

Data Information	
IPAS File Name	110510a-sn59
From/To	000 ->020
LiDAR Unit #	s/n 059
HD #	1

	Ground	(airport)	Field Elev.	Temp. at Altitude
Begin Temp	14°c	MMK	103ft.	5°c
Begin Dewpoint	1°c			
Begin Pressure	29.99			
Mid Temp	16°c	MMK	103ft.	5°c
Mid Dewpoint	2°c			
Mid Pressure	29.99			
End Temp	16°c	MMK	103ft.	3°c
End Dewpoint	3°c			
End Pressure	29.99			

GPS Base Location(s)	MMK A
PDOP Avoidance	YES
Static or Flyover?	STATIC
Laser On Time & Off Times	11:54-13:48z

BASE- 11:17z 14:12z
start stop
ABGPS- 11:35z 14:05z

FILE	FL #	Alt. (AMSL)	Heading	Speed	Returns	Crab	NOTES
120035	4	5362	29	93	100	4°	40 kt headwind
122210	3	5465	209	110	96	9°	
122210	19	5330	209	111	99	9°	
124222	20	5275	29	92	99	4°	
125355	2	5585	29	92	100		
* 130501	1	5712	209	118	97		low rtns. north end
131606	18	5815	29	91	99		
131922	11	5830	29	91	100		
132621	12	5891	209	111	100		
133326	16	5917	29	94	100		
133834	17	5900	209	113	98		
134513	TIE	5500	100	110	100		

LIDAR MISSION RECORD SHEET

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Project Name	MMK Quinnipiac
Project Number	7556-005
Navigation File	

Pilot	FD
Tech	DH
Aircraft	N7320G

Date Flown	5/8/2011		
Takeoff Time	13:13 Z	(airport)	MMK
Landing Time	14:37 Z	(airport)	MMK

Project's Scanning Requirements			
FOV (degrees):	34	Laser Current(%):	39
Scan Rate (Hz):	49		
Pulse Rate (Hz):	145300	Altitude AGL (ft):	5000
Ground Speed (kts):	100	Range Gate (m):	1223-1632

SPiA ?
[✓ MPiA?]

Data Information	
IPAS File Name	110508a-s59
From/To	000 -> 014
LiDAR Unit #	s/n 059
HD #	1

	Ground	(airport)	Field Elev.	Temp. at Altitude
Begin Temp	17°C			6°C
Begin Dewpoint	6°C			
Begin Pressure	29.89	MMK	103ft.	
Mid Temp	18°C			4°C
Mid Dewpoint	7°C			
Mid Pressure	29.89	MMK	103ft.	
End Temp	18°C			5°C
End Dewpoint	7°C			
End Pressure	29.89	MMK	103ft.	

GPS Base Location(s)	MMK A
PDOP Avoidance	YES
Static or Flyover?	STATIC
Laser On Time & Off Times	13:16 - 14:26z

BASE - 12:45z 14:53z
Start Stop
ABGPS - 13:01z 14:44z

FILE	FL #	Alt. (AMSL)	Heading	Speed	Returns	Crab	NOTES
132736	6	5278	29	98	100		
134828	5	5320	209	105	100		
140939	TIE	5000	330	99	98		
141510	25	5112	209	103	100		
142248	26	5135	29	101	98		

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Project Name	MMK Quinnipiac
Project Number	7556-005
Navigation File	

Pilot	FD
Tech	DH
Aircraft	N7320G

Date Flown	5/6/2011		
Takeoff Time	16:13 z	(airport)	MMK
Landing Time	19:10 z	(airport)	MMK

Project's Scanning Requirements			
FOV (degrees):	34	Laser Current(%):	39
Scan Rate (Hz):	49		
Pulse Rate (Hz):	145,300	Altitude AGL (ft):	5000
Ground Speed (kts):	100	Range Gate (m):	1223-1632

SPiA ? [✓ MPiA?]

Data Information	
IPAS File Name	110506a-sn59
From/To	000 -> 026
LiDAR Unit #	s/n 059
HD #	1

	Ground	**(airport)**	**Field Elev.**	**Temp. at Altitude**
Begin Temp	19°c	MMK	103ft.	4°c
Begin Dewpoint	-3°c			
Begin Pressure	29.93			
Mid Temp	21°c	MMK	103ft.	6°c
Mid Dewpoint	-1°c			
Mid Pressure	29.91			
End Temp	21°c	MMK	103ft.	6°c
End Dewpoint	-1°c			
End Pressure	29.89			

GPS Base Location(s)	MMK A
PDOP Avoidance	YES
Static or Flyover?	STATIC
Laser On Time & Off Times	16:11-18:57z

BASE - 15:30z 19:26z
start stop
ABGPS - 16:03z 19:19z

FILE	FL #	Alt. (AMSL)	Heading	Speed	Returns	Crab	NOTES
162649	15	5225	209	93	98		turbulence
162649	34	5040	209	100	96	7°	"
164700	14	5193	29	123	98		"
170717	13	5186	209	110	100		"
172758	10	5193	29	114	99	10°	"
174903	9	5202	209	98	99		"
180939	8	5224	29	99	99		"
183114	7	5248	209	111	100		"
185518	T/E	5000	90	140	94		"
							need 1-28 & 34

LIDAR MISSION RECORD SHEET

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Project Name	MMK Quinnipiac
Project Number	7556-005
Navigation File	

Pilot	FD
Tech	DH
Aircraft	N7320G

Date Flown	3/30/2011	
Takeoff Time	13:45z	(airport) MMK
Landing Time	16:39 z	(airport) MMK

Project's Scanning Requirements			
FOV (degrees):	34	Laser Current(%):	39
Scan Rate (Hz):	49		
Pulse Rate (Hz):	145,300	Altitude AGL (ft):	5000
Ground Speed (kts):	100	Range Gate (m):	1223-1632

SPiA ?
[✓ MPiA?]

Data Information	
IPAS File Name	110330a-s159
From/To	000 -> 026
LiDAR Unit #	s/n 059
HD #	2

	Ground	(airport)	Field Elev.	Temp. at Altitude
Begin Temp	6°c	MMK	103ft.	-3°c
Begin Dewpoint	-6°c			▨
Begin Pressure	30.16			▨
Mid Temp	10°c	MMK	103ft.	-3°c
Mid Dewpoint	-6°c			▨
Mid Pressure	30.12			▨
End Temp	12°c	MMK	103ft.	-4°c
End Dewpoint	-5°c			▨
End Pressure	30.10			▨

GPS Base Location(s)	MMK A
PDOP Avoidance	YES
Static or Flyover?	STATIC
Laser On Time & Off Times	13:48-16:31 z

BASE - 13:06z 16:59z
start stop
ABGPS - 13:35z 16:48z

FILE	FL #	Alt. (AMSL)	Heading	Speed	Returns	Crab	NOTES
135437	44	5084	209	103	90		
140952	43	5081	29	97	91		
142517	42	5714	209	107	89		
143931	39	5164	29	95	96		
145348	38	5210	209	100	96		
150846	64	5010	18	98	62		
151245	TIE	5000	100	100	28		
151728	37	5256	29	103	98		
153543	41	5300	209	106	96		
153543	36	5240	209	105	98		
* 155435	35	5205	29				*aborted line for traffic*
160624	35	5205	29	105	85		
160624	40	5315	29	96	98		
162820	TIE	5700	128	124	98		
							1-28; 34-44

LIDAR MISSION RECORD SHEET

PHOTO SCIENCE
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1410 Indian Trail-Lilburn Rd. - Norcross, GA - 30093 - 770.564.9843 - www.photoscience.com

Project Name	MMK Quinnipiac
Project Number	7556-005
Navigation File	

Pilot	FD
Tech	DH
Aircraft	N7320G

Date Flown	3/29/2011		
Takeoff Time	13:58 z	(airport)	MMK
Landing Time	15:50 z	(airport)	MMK

Project's Scanning Requirements			
FOV (degrees):	34	Laser Current(%):	39
Scan Rate (Hz):	49		
Pulse Rate (Hz):	145,300	Altitude AGL (ft):	5000
Ground Speed (kts):	100	Range Gate (m):	1223-1632

SPiA ? [✓ MPiA?]

Data Information	
IPAS File Name	110329a-5159
From/To	000 -> 018
LiDAR Unit #	s/n 059
HD #	2

	Ground	(airport)	Field Elev.	Temp. at Altitude
Begin Temp	3°c	MMK	103ft.	-5°c
Begin Dewpoint	-11°c			▨
Begin Pressure	30.06			▨
Mid Temp	6°c	MMK	103ft.	-6°c
Mid Dewpoint	-11°c			▨
Mid Pressure	30.04			▨
End Temp	6°c	MMK	103ft.	-6°c
End Dewpoint	-11°c			▨
End Pressure	30.03			▨

GPS Base Location(s)	MMK A
PDOP Avoidance	YES
Static or Flyover?	STATIC
Laser On Time & Off Times	14:01 - 15:42 z

BASE - 13:29z 16:07z
start stop
ABGPS - 13:46z 15:58z

FILE	FL #	Alt. (AMSL)	Heading	Speed	Returns	Crab	NOTES
140849	50	5223	209	106	96		
142357	49	5216	29	96	96	15°	
143919	48	5201	209	105	98		
145420	47	5175	29	89	92		
151025	46	5137	209	96	97		test video
152544	45	5104	29	103	88		Zip ties 4 tools
154033	TIE	5100	129	123	88		

LIDAR MISSION RECORD SHEET

PHOTO SCIENCE
Geospatial Solutions
1410 Indian Trail-Lilburn Road - Norcross, GA - 30093 - 770.564.9843

Project Name	FEMA CT-MA
Project Number	7556-005
Navigation File	

Pilot	FD
Tech	DH
Aircraft	N7320G

Date Flown	12/18/2010	
Takeoff Time	17:05 z	(apt) MMK
Landing Time	18:15 z	(apt) MMK

Project's Scanning Requirements

FOV (degrees):	34	Laser Current(%):	39
Scan Rate (Hz):	49		
Pulse Rate (Hz):	145,300	Altitude AGL (ft):	5000
Ground Speed (kts):	100	Range Gate (m):	1223-1632

SPiA ?
[✓ MPiA?]

Data Information

IPAS File Name	101218a-s59
From/To	000 -> 012
LiDAR Unit #	s/n 059
HD #	2

	Ground	(airport)	Field Elev.	Temp. at Altitude
Begin Temp	2°c	MMK	103ft.	-6°c
Begin Dewpoint	-7°c			
Begin Pressure	30.08			
Mid Temp	3°c	MMK	103ft.	-6°c
Mid Dewpoint	-8°c			
Mid Pressure	30.05			
End Temp	3°c	MMK	103ft.	-6°c
End Dewpoint	-8°c			
End Pressure	30.05			

GPS Base Location(s)	MMK A
PDOP Avoidance	YES
Static or Flyover?	STATIC
Laser On Time & Off Times	17:07 - 18:07 z

BASE - 16:17z 18:31 z
Start Stop
ABGPS - 16:51z 18:23z

FILE	FL #	Alt. (AMSL)	Heading	Speed	Returns	Crab	NOTES
171242	62	5205	209	96	99		
172128	TIE	5200	315	102	99		
172827	64	5010	198	107	38		
173244	TIE	5100	285	93	38		
173809	31	5246	5	102	98		
174308	30	5139	185	103	88		
174856	29	5139	5	101	95		Small cloud
175512	32	5242	185	101	99		
180141	33	5132	5	99	92		
180555	TIE	5100	93	118	85		

LIDAR MISSION RECORD SHEET

PHOTO SCIENCE *Geospatial Solutions*

1410 Indian Trail-Lilburn Road - Norcross, GA - 30093 - 770.564.9843

Project Name	FEMA CT-MA
Project Number	7556-005
Navigation File	

Pilot	FD
Tech	DH
Aircraft	N7320G

Date Flown	12/17/2010	
Takeoff Time	16:04 z	(apt) MMK
Landing Time	19:00 z	(apt) MMK

Project's Scanning Requirements

FOV (degrees):	34	Laser Current(%):	39
Scan Rate (Hz):	49		
Pulse Rate (Hz):	145300	Altitude AGL (ft):	5000
Ground Speed (kts):	100	Range Gate (m):	1223-1632

SPiA ? [✓ MPiA?]

Data Information

IPAS File Name	101217a-s059
From/To	000 -> 026
LiDAR Unit #	s/n 059
HD #	1

	Ground	(airport)	Field Elev.	Temp. at Altitude
Begin Temp	-1°C	MMK	103ft.	-8°c
Begin Dewpoint	-10°C			
Begin Pressure	29.91			
Mid Temp	1°c	MMK	103ft.	-8°c
Mid Dewpoint	-10°c			
Mid Pressure	29.89			
End Temp	2°C	MMK	103ft.	-7°c
End Dewpoint	-11°c			
End Pressure	29.89			

GPS Base Location(s)	MMK A
PDOP Avoidance	YES
Static or Flyover?	STATIC
Laser On Time & Off Times	16:07 - 18:51 z

BASE - 13:15z 19:43z

start stop

ABGPS - 15:52z 19:07z

FILE	FL #	Alt. (AMSL)	Heading	Speed	Returns	Crab	NOTES
161226	65	5182	209	99	78		
162145	63	5180	29	103	98		
163059	62	5205	209	100	100		Could not process
164011	61	5222	29	102	90		
164929	60	5236	209	98	97		
165847	59	5230	29	99	100		
170820	58	5236	209	102	94		
171813	57	5244	29	95	97		5000ft. for traffic
172932	56	5285	209	101	75		
174024	55	5300	29	99	84		
175105	54	5306	209	105	67		
180221	53	5301	29	97	100		
181621	52	5257	209	110	98		
183031	51	5235	29	95	96		
184647	TIE	5200	160	124	98		

Chester AWOS 118.32

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1410 Indian Trail-Lilburn Road - Norcross, GA - 30093 - 770.564.9843

Project Name	FEMA CT-MA
Project Number	7556-005
Navigation File	

Pilot	FD
Tech	DH
Aircraft	N7320G

Date Flown	12/16/2010	
Takeoff Time	16:52z	(apt) MMK
Landing Time	19:45 z	(apt) MMK

Project's Scanning Requirements				
FOV (degrees):	34	Laser Current(%):	39	SPiA ?
Scan Rate (Hz):	49			[✓ MPiA?]
Pulse Rate (Hz):	145,300	Altitude AGL (ft):	5000	
Ground Speed (kts):	100	Range Gate (m):	1223-1122	

Data Information	
IPAS File Name	101216a-Sn59
From/To	000 -> 025
LiDAR Unit #	s/n 059
HD #	2

	Ground	(airport)	Field Elev.	Temp. at Altitude
Begin Temp	-1°c	SNC	416ft.	-12°c
Begin Dewpoint	-11°c			
Begin Pressure	29.78			
Mid Temp	-1°c	SNC	416ft.	-13°c
Mid Dewpoint	-11°c			
Mid Pressure	29.76			
End Temp	-1°c	SNC	416ft.	-11°c
End Dewpoint	-11°c			
End Pressure	29.76			

GPS Base Location(s)	MMK A
PDOP Avoidance	YES
Static or Flyover?	STATIC
Laser On Time & Off Times	16:55 - 19:33 z

BASE - 16:01z 20:05z
start stop
ABGPS - 16:43z 19:54z

FILE	FL #	Alt. (AMSL)	Heading	Speed	Returns	Crab	NOTES
170305	79	5268	209	103	99		
171233	78	5282	29	102	99		
172213	77	5276	209	97	100		
173115	76	5280	29	101	98		
174039	75	5296	209	95	100		
175009	74	5318	29	105	98		
175945	73	5287	209	98	100		
181047	101	5016	209	90	48		
181457	72	5274	29	105	98		
182508	71	5265	209	100	99		
183554	70	5252	29	97	98		
184614	69	5225	209	97	100		Small cloud
185719	68	5244	29	102	78		
190841	67	5269	209	106	98		
192011	66	5256	29	104	100		
193008	TIE	5300	135	128	100		

320G

516-683-2984 124.075 NY Approach

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1410 Indian Trail-Lilburn Road - Norcross, GA - 30093 - 770.564.9843

11N/C

Project Name	FEMA MA-CT (MMK)
Project Number	75560-005
Navigation File	

Pilot	FD
Tech	DH
Aircraft	N7320G

Date Flown	12/11/2010		
Takeoff Time	15:47 z	(apt)	MMK
Landing Time	19:08 z	(apt)	MMK

Project's Scanning Requirements			
FOV (degrees):	34	Laser Current(%):	39
Scan Rate (Hz):	49		
Pulse Rate (Hz):	145,300	Altitude AGL (ft):	5000
Ground Speed (kts):	100	Range Gate (m):	1223-1832

SPiA ?
[✓ MPiA?]

Data Information	
IPAS File Name	101211a-3159
From/To	000 -> 029
LiDAR Unit #	s/n 059
HD #	1

	Ground	(airport)	Field Elev.	Temp. at Altitude
Begin Temp	4°c	MMK	103 ft.	1°c
Begin Dewpoint	-4°c			
Begin Pressure	30.26			
Mid Temp	6°c	SNC	416 ft.	2°c
Mid Dewpoint	-4°c			
Mid Pressure	30.24			
End Temp	7°c	MMK	103 ft.	2°c
End Dewpoint	-4°c			
End Pressure	30.21			

GPS Base Location(s)	MMK A
PDOP Avoidance	YES
Static or Flyover?	STATIC
Laser On Time & Off Times	15:52 - 18:56 z

BASE - 14:48 z 19:29 z
start stop
ABGPS - 15:36 z 19:17 z

FILE	FL #	Alt. (AMSL)	Heading	Speed	Returns	Crab	NOTES
160040	99	5203	104	112	99		
160848	98	5166	284	94	98		
161629	97	5162	104	104	100		
162433	96	5145	284	97	100		
163157	95	5125	104	106	99		
164025	94	5101	284	102	98		
164809	93	5078	104	105	95		
165643	92	5068	284	104	99		
"	90	5058	104	97	98		
171706	91	5040	284	103	97		
172459	100	5108	29	103	98		
173200	89	5150	209	99	100		
173935	88	5190	29	101	97		
174645	87	5218	209	101	99		
175449	86	5227	29	100	99		
180315	85	5226	209	100	96		
181208	84	5240	29	104	100		
182152	83	5266	209	100	98		
183103	82	5262	29	102	99		
184008	81	5264	209	95	99		
184939	80	5250	29	101	99		

Conn Area: **MMK Quinnipiac** Project No **7556-005**

Contact: Photo Science; F Godby at
859 277-8700 or Cell: 859 421-5258

Flight Logs

FLIGHT LINE	*FL MILES*	*ALTITUDE*	*BASE STATION*	*FLIGHT FILES*	*DATE FLOWN*	*S/N*	*FIELD QC*	*Comments*
1	12.7	5710	MMK A	MMK_Quinnipi MMK_QUINNI	5/10/2011	59	Y	
2	12.7	5590	MMK A	MMK_Quinnipi MMK_QUINNI	5/10/2011	59	Y	
3	13.8	5470	MMK A	MMK_Quinnipi MMK_QUINNI	5/10/2011	59	Y	
4	31.9	5360	MMK A	MMK_Quinnipi MMK_QUINNI	5/10/2011	59	Y	
5	32.6	5320	MMK A	MMK_Quinnipi MMK_QUINNI	5/8/2011	59	Y	
6	33.0	5280	MMK A	MMK_Quinnipi MMK_QUINNI	5/8/2011	59	Y	
7	33.4	5250	MMK A	MMK_Quinnipi MMK_QUINNI	5/6/2011	59	Y	
8	34.6	5220	MMK A	MMK_Quinnipi MMK_QUINNI	5/6/2011	59	Y	
9	34.4	5200	MMK A	MMK_Quinnipi MMK_QUINNI	5/6/2011	59	Y	
10	34.1	5190	MMK A	MMK_Quinnipi MMK_QUINNI	5/6/2011	59	Y	
11	6.7	5830	MMK A	MMK_Quinnipi MMK_QUINNI	5/10/2011	59	Y	
12	4.5	5890	MMK A	MMK_Quinnipi MMK_QUINNI	5/10/2011	59	Y	
13	33.4	5190	MMK A	MMK_Quinnipi MMK_QUINNI	5/6/2011	59	Y	

Flight Logs should be FAXED to 859-277-8901 immediately after each days flights with lines and other details noted

Operator: D. Holt
Pilot: F. Davis

AIRCRAFT Tail Number: N7320G
Sensor Serial Number: Sn59

Date: 5/6/2011

FLIGHT LINE	FL MILES	ALTITUDE	BASE STATION	FLIGHT FILES	DATE FLOWN	S/N	FIELD QC	Comments
14	33.5	5190	MMK A	MMK_Quinnipi MMK_QUINNI	5/6/2011	59	Y	
15	28.7	5230	MMK A	MMK_Quinnipi MMK_QUINNI	5/6/2011	59	Y	
16	3.9	5920	MMK A	MMK_Quinnipi MMK_QUINNI	5/10/2011	59	Y	
17	3.0	5900	MMK A	MMK_Quinnipi MMK_QUINNI	5/10/2011	59	Y	
18	3.0	5820	MMK A	MMK_Quinnipi MMK_QUINNI	5/10/2011	59	Y	
19	18.2	5330	MMK A	MMK_Quinnipi MMK_QUINNI	5/10/2011	59	Y	
20	17.2	5280	MMK A	MMK_Quinnipi MMK_QUINNI	5/10/2011	59	Y	
21	13.0	5190	MMK A	MMK_Quinnipi MMK_QUINNI	5/27/11	19		
22	4.7	5390	MMK A	MMK_Quinnipi MMK_QUINNI	5/27/11	19		
23	3.8	5460	MMK A	MMK_Quinnipi MMK_QUINNI	5/27/11	19		
24	3.8	5450	MMK A	MMK_Quinnipi MMK_QUINNI	5/27/11	19		
25	6.4	5110	MMK A	MMK_Quinnipi MMK_QUINNI	5/8/2011	59	Y	
26	3.0	5140	MMK A	MMK_Quinnipi MMK_QUINNI	5/8/2011	59	Y	
27	3.0	5630	MMK A	MMK_Quinnipi MMK_QUINNI	5/27/11	19		

Flight Logs should be FAXED to 859-277-8901 immediately after each days flights with lines and other details noted

Operator: D. Holt

Pilot: F. Davis

AIRCRAFT Tail Number: N7320G

Sensor Serial Number: Sn59

Date: 5/6/2011

FLIGHT LINE	FL MILES	ALTITUDE	BASE STATION	FLIGHT FILES	DATE FLOWN	S/N	FIELD QC	Comments
28	2.2	5590	MMK A	MMK_Quinnipi MMK_QUINNI	5/27/11	19		
29	5.1	5140	MMK A	MMK_Quinnipi MMK_QUINNI	12/18	59	Y	
30	4.5	5140	MMK A	MMK_Quinnipi MMK_QUINNI	12/18	59	Y	
31	3.4	5250	MMK A	MMK_Quinnipi MMK_QUINNI	12/18	59	Y	
32	4.8	5240	MMK A	MMK_Quinnipi MMK_QUINNI	12/18	59	Y	
33	1.6	5130	MMK A	MMK_Quinnipi MMK_QUINNI	12/18	59	Y	
34	3.9	5040	MMK A	MMK_Quinnipi MMK_QUINNI	5/6/2011	59	Y	
35	24.2	5210	MMK A	MMK_Quinnipi MMK_QUINNI	3/30/2011	59	Y	
36	23.7	5240	MMK A	MMK_Quinnipi MMK_QUINNI	3/30/2011	59	Y	
37	22.0	5260	MMK A	MMK_Quinnipi MMK_QUINNI	3/30/2011	59	Y	
38	19.4	5210	MMK A	MMK_Quinnipi MMK_QUINNI	3/30/2011	59	Y	
39	19.5	5160	MMK A	MMK_Quinnipi MMK_QUINNI	3/30/2011	59	Y	
40	2.8	5320	MMK A	MMK_Quinnipi MMK_QUINNI	3/30/2011	59	Y	
41	2.8	5300	MMK A	MMK_Quinnipi MMK_QUINNI	3/30/2011	59	Y	

Flight Logs should be FAXED to 859-277-8901 immediately after each days flights with lines and other details noted

Operator: D. Holt

Pilot: F. Davis

AIRCRAFT Tail Number: N7320G

Sensor Serial Number: Sn-59

Date: 12/18/2010

FLIGHT LINE	FL MILES	ALTITUDE	BASE STATION	FLIGHT FILES	DATE FLOWN	S/N	FIELD QC	Comments
42	20.2	5110	MMK A	MMK_Quinnipi MMK_QUINNI	3/30/2011	59	Y	
43	22.5	5080	MMK A	MMK_Quinnipi MMK_QUINNI	3/30/2011	59	Y	
44	22.5	5080	MMK A	MMK_Quinnipi MMK_QUINNI	3/30/2011	59	Y	
45	21.6	5100	MMK A	MMK_Quinnipi MMK_QUINNI	3/29/2011	59	Y	
46	21.7	5140	MMK A	MMK_Quinnipi MMK_QUINNI	3/29/2011	59	Y	
47	22.6	5180	MMK A	MMK_Quinnipi MMK_QUINNI	3/29/2011	59	Y	
48	22.3	5200	MMK A	MMK_Quinnipi MMK_QUINNI	3/29/2011	59	Y	
49	22.3	5220	MMK A	MMK_Quinnipi MMK_QUINNI	3/29/2011	59	Y	
50	21.3	5220	MMK A	MMK_Quinnipi MMK_QUINNI	3/29/2011	59	Y	
51	21.9	5240	MMK A	MMK_Quinnipi MMK_QUINNI	12/17	59	Y	
52	21.1	5260	MMK A	MMK_Quinnipi MMK_QUINNI	12/17	59	Y	
53	18.8	5300	MMK A	MMK_Quinnipi MMK_QUINNI	12/17	59	Y	
54	16.0	5310	MMK A	MMK_Quinnipi MMK_QUINNI	12/17	59	Y	
55	14.6	5300	MMK A	MMK_Quinnipi MMK_QUINNI	12/17	59	Y	

Flight Logs should be FAXED to 859-277-8901 immediately after each days flights with lines and other details noted

Operator: D. Holt

Pilot: F. Davis

AIRCRAFT Tail Number: N7320G

Sensor Serial Number: Sn-59

Date: 12/17/2010

FLIGHT LINE	FL MILES	ALTITUDE	BASE STATION	FLIGHT FILES	DATE FLOWN	S/N	FIELD QC	Comments
56	14.9	5290	MMK A	MMK_Quinnipi MMK_QUINNI	12/17	59	Y	
57	12.8	5240	MMK A	MMK_Quinnipi MMK_QUINNI	12/17	59	Y	
58	12.4	5240	MMK A	MMK_Quinnipi MMK_QUINNI	12/17	59	Y	
59	12.0	5230	MMK A	MMK_Quinnipi MMK_QUINNI	12/17	59	Y	
60	11.5	5240	MMK A	MMK_Quinnipi MMK_QUINNI	12/17	59	Y	
61	11.3	5220	MMK A	MMK_Quinnipi MMK_QUINNI	12/17	59	Y	
62	10.9	5210	MMK A	MMK_Quinnipi MMK_QUINNI	12/17	59	Y	Could not process ? Re-shot on 12/18
63	10.9	5180	MMK A	MMK_Quinnipi MMK_QUINNI	12/17	59	Y	
64	2.0	5010	MMK A	MMK_Quinnipi MMK_QUINNI	12/18	59	Y	
65	10.9	5180	MMK A	MMK_Quinnipi MMK_QUINNI	12/17	59	Y	
66	13.8	5260	MMK A	MMK_Quinnipi MMK_QUINNI	12/16	59	Y	
67	15.2	5270	MMK A	MMK_Quinnipi MMK_QUINNI	12/16	59	Y	
68	15.2	5240	MMK A	MMK_Quinnipi MMK_QUINNI	12/16	59	Y	
69	15.1	5230	MMK A	MMK_Quinnipi MMK_QUINNI	12/16	59	Y	

Flight Logs should be FAXED to 859-277-8901 immediately after each days flights with lines and other details noted

Operator: D. Holt
Pilot: F. Davis

AIRCRAFT Tail Number: N7320G
Sensor Serial Number: Sn 59

Date: 12/16/2010

FLIGHT LINE	FL MILES	ALTITUDE	BASE STATION	FLIGHT FILES	DATE FLOWN	S/N	FIELD QC	Comments
70	13.3	5250	MMK A	MMK_Quinnipi MMK_QUINNI	12/16	59	Y	
71	12.6	5270	MMK A	MMK_Quinnipi MMK_QUINNI	12/16	59	Y	
72	12.4	5270	MMK A	MMK_Quinnipi MMK_QUINNI	12/16	59	Y	
73	12.3	5290	MMK A	MMK_Quinnipi MMK_QUINNI	12/16	59	Y	
74	11.7	5320	MMK A	MMK_Quinnipi MMK_QUINNI	12/16	59	Y	
75	11.7	5300	MMK A	MMK_Quinnipi MMK_QUINNI	12/16	59	Y	
76	11.7	5280	MMK A	MMK_Quinnipi MMK_QUINNI	12/16	59	Y	
77	11.0	5280	MMK A	MMK_Quinnipi MMK_QUINNI	12/16	59	Y	
78	11.7	5280	MMK A	MMK_Quinnipi MMK_QUINNI	12/16	59	Y	
79	12.0	5270	MMK A	MMK_Quinnipi MMK_QUINNI	12/16	59	Y	
80	12.1	5250	MMK A	MMK_Quinnipi MMK_QUINNI	12/11	59	Y	
81	11.8	5260	MMK A	MMK_Quinnipi MMK_QUINNI	12/11	59	Y	
82	11.5	5260	MMK A	MMK_Quinnipi MMK_QUINNI	12/11	59	Y	
83	10.4	5270	MMK A	MMK_Quinnipi MMK_QUINNI	12/11	59	Y	

Flight Logs should be FAXED to 859-277-8901 immediately after each days flights with lines and other details noted

Operator: D. Holt

Pilot: F. Davis

AIRCRAFT Tail Number: N7320G

Sensor Serial Number: Sn 59

Date: 12/11/2010

FLIGHT LINE	FL MILES	ALTITUDE	BASE STATION	FLIGHT FILES	DATE FLOWN	S/N	FIELD QC	Comments
84	10.4	5240	MMK A	MMK_Quinnipi MMK_QUINNI	12/11	59	Y	
85	9.8	5230	MMK A	MMK_Quinnipi MMK_QUINNI	12/11	59	Y	
86	8.7	5230	MMK A	MMK_Quinnipi MMK_QUINNI	12/11	59	Y	
87	7.9	5220	MMK A	MMK_Quinnipi MMK_QUINNI	12/11	59	Y	
88	7.0	5190	MMK A	MMK_Quinnipi MMK_QUINNI	12/11	59	Y	
89	6.5	5150	MMK A	MMK_Quinnipi MMK_QUINNI	12/11	59	Y	
90	8.1	5060	MMK A	MMK_Quinnipi MMK_QUINNI	12/11	59	Y	
91	7.3	5040	MMK A	MMK_Quinnipi MMK_QUINNI	12/11	59	Y	
92	8.1	5070	MMK A	MMK_Quinnipi MMK_QUINNI	12/11	59	Y	
93	8.1	5080	MMK A	MMK_Quinnipi MMK_QUINNI	12/11	59	Y	
94	7.9	5100	MMK A	MMK_Quinnipi MMK_QUINNI	12/11	59	Y	
95	7.6	5130	MMK A	MMK_Quinnipi MMK_QUINNI	12/11	59	Y	
96	7.3	5150	MMK A	MMK_Quinnipi MMK_QUINNI	12/11	59	Y	
97	7.4	5160	MMK A	MMK_Quinnipi MMK_QUINNI	12/11	59	Y	

Flight Logs should be FAXED to 859-277-8901 immediately after each days flights with lines and other details noted

Operator: D. Holt

Pilot: F. Davis

AIRCRAFT Tail Number: N7320G

Sensor Serial Number: Sn 59

Date: 12/11/2010

FLIGHT LINE	FL MILES	ALTITUDE	BASE STATION	FLIGHT FILES	DATE FLOWN	S/N	FIELD QC	Comments
98	7.3	5170	MMK A	MMK_Quinnipi MMK_QUINNI	12/11	59	Y	
99	5.0	5200	MMK A	MMK_Quinnipi MMK_QUINNI	12/11	59	Y	
100	5.3	5110	MMK A	MMK_Quinnipi MMK_QUINNI	12/11	59	Y	
101	0.6	5020	MMK A	MMK_Quinnipi MMK_QUINNI	12/16	59	Y	

Flight Logs should be FAXED to 859-277-8901 immediately after each days flights with lines and other details noted

Operator: D. Holt

Pilot: F. Davis

AIRCRAFT Tail Number: N7320G

Sensor Serial Number: Sn 59

Date: 12/11/2010

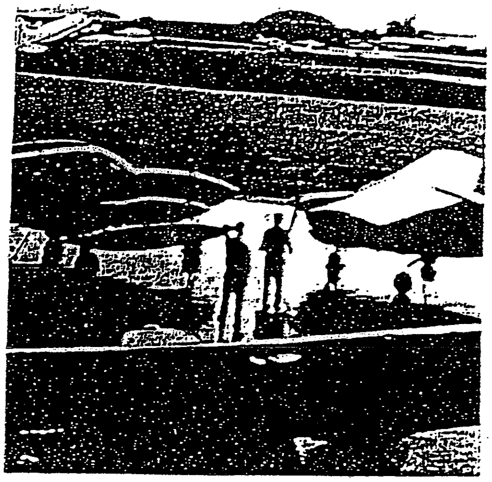
PHOTO SCIENCE
Geospatial Solutions

Station Occupation Report For Airborne GPS

Project: FEMA Quinnipiac MMK

Location: KMMK
Project Number: 7556-005
Completed by: D. Holt
Date: 5/10/2011

Receiver: 5700
Receiver Type: Trimble
Antenna Type: Zephyr Geodetic (P/N41249-00)
Station ID: AI5589 (MMK A)
Start -- H.I. (m): 2.053
End -- H.I. (m): 2.053
H.I. (ft):
Start Time: 11:17z
End Time: 14:12z
Time Zone: EDT
Operator: D. Holt



Comments: Use for 110510a-sn59

PHOTO SCIENCE
Geospatial Solutions

Station Occupation Report For Airborne GPS

Project:	FEMA Quinnipiac MMK
Location:	KMMK
Completed by:	D. Holt
Project Number:	7556-005
Date:	5/8/2011

Receiver:	5700
Receiver Type:	Trimble
Antenna Type:	Zephyr Geodetic (P/N41249-00)
Station ID:	AI5589 (MMK A)
Start -- H.I. (m):	2.053
End -- H.I. (m):	2.053
H.I. (ft):	
Start Time:	12:45z
End Time:	14:53z
Time Zone:	EDT
Operator:	D. Holt

Comments: Use for 110508a-sn59

PHOTO SCIENCE
Geospatial Solutions

Station Occupation Report
For Airborne GPS

Project: FEMA Quinnipiac MMK

Location: KMMK

Project Number: 7556-005

Completed by: D. Holt

Date: 5/6/2011

Receiver: 5700

Receiver Type: Trimble

Antenna Type: Zephyr Geodetic (P/N 41249-00)

Station ID: AI5589 (MMKA)

Start -- H.I. (m): 2.053

End -- H.I. (m): 2.053

H.I. (ft):

Start Time: 15:30z

End Time: 19:26z

Time Zone: EDT

Operator: D. Holt

Comments: Use for 110506a-sn59

PHOTO SCIENCE
Geospatial Solutions

Station Occupation Report
For Airborne GPS

Project: MMK Quinnipiac

Location: Meriden, CT
Project Number: 7556-005
Completed by: D. Holt
Date: 3/30/2011

Receiver: SR9500
Receiver Type: Leica
Antenna Type: AT302
Station ID: AI5589 (MMK A)
Start -- H.I. (m): 2.06
End -- H.I. (m): 2.06
H.I. (ft):
Start Time: 13:06z
End Time: 16:59z
Time Zone: EDT
Operator: D. Holt

Comments: Use for 110330a-sn59

PHOTO SCIENCE
Geospatial Solutions

Station Occupation Report
For Airborne GPS

Project: MMK Quinnipiak

Location: Meriden, CT

Project Number: 7556-005

Completed by: D. Holt

Date: 3/29/2011

Receiver: SR9500

Receiver Type: Leica

Antenna Type: AT302

Station ID: AI5589 (MMK A)

Start -- H.I. (m): 2.06

End -- H.I. (m): 2.06

H.I. (ft):

Start Time: 13:29z

End Time: 16:07z

Time Zone: EDT

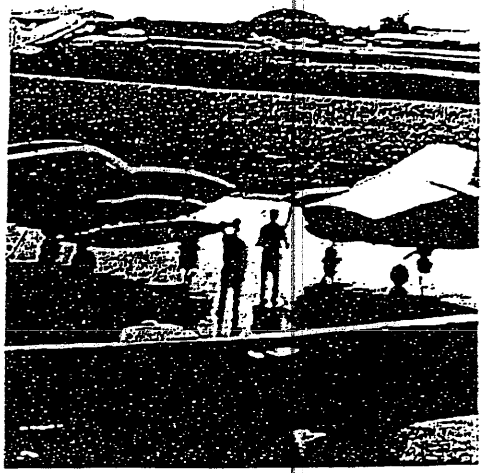
Operator: D. Holt

Comments Use for 110329a-sn59

PHOTO SCIENCE
Geospatial Solutions

Station Occupation Report
For Airborne GPS

Project:	FEMA CT-MA (Quinnipiac)		
Location:	KMMK	Project Number:	7556-005
Completed by:	D. Holt	Date:	12/18/2010



Receiver:	SR 9500
Receiver Type:	Leica
Antenna Type:	AT 302
Station ID:	MMK A
Start -- H.I. (m):	2.06
End -- H.I. (m):	2.06
H.I. (ft):	
Start Time:	16:17z
End Time:	18:31z
Time Zone:	EST
Operator:	D. Holt

Comments: Use for 101218a-sn59

PHOTO SCIENCE
Geospatial Solutions

Station Occupation Report
For Airborne GPS

Project: FEMA CT-MA

Location: Quinnipiac- KMMK

Project Number: 7556-005

Completed by: D. Holt

Date: 12/17/2010

Receiver: SR9500

Receiver Type: Leica

Antenna Type: AT302

Station ID: AI5589

Start -- H.I. (m): 2.06

End -- H.I. (m): 2.06

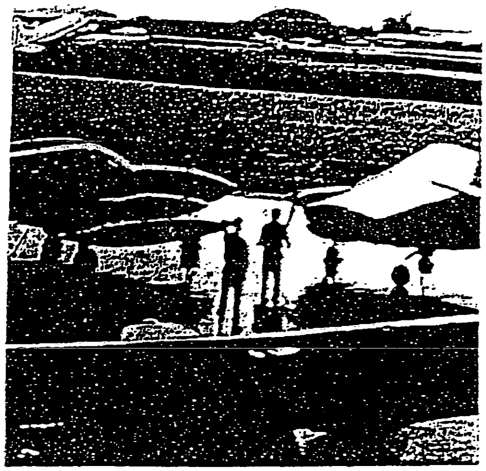
H.I. (ft):

Start Time: 13:15z

End Time: 19:43z

Time Zone: EST

Operator: D. Holt



Comments use for 101217a-SN59

PHOTO SCIENCE
Geospatial Solutions

Station Occupation Report For Airborne GPS

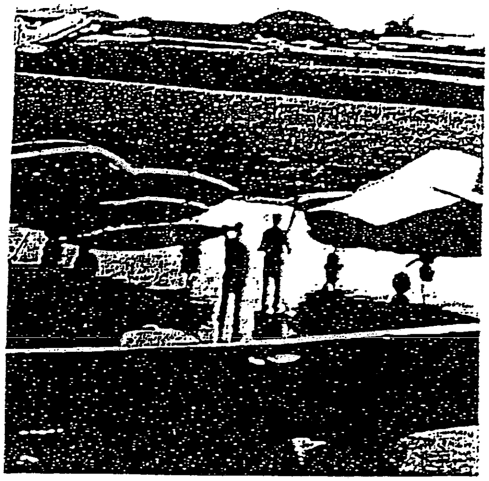
Project: FEMA CT-MA

Location: KMMK

Project Number: 7556-005

Completed by: D. Holt

Date: 12/16/2010



Receiver: SR 9500

Receiver Type: Leica

Antenna Type: AT 302

Station ID: MMK A

Start -- H.I. (m): 2.06

End -- H.I. (m): 2.06

H.I. (ft):

Start Time: 16:01 z

End Time: 20:05z

Time Zone: EST

Operator: D. Holt

Comments: Use for 101216a-sn59

PHOTO SCIENCE
Geospatial Solutions

Station Occupation Report For Airborne GPS

Project: FEMA LiDAR CT-MA (Quinnipiac)

Location: KMMK

Project Number: 7556-005

Completed by: D. Holt

Date: 12/11/2010

Receiver: Leica

Receiver Type: SR 9500

Antenna Type: AT 302

Station ID: AI5589

Start -- H.I. (m): 2.06

End -- H.I. (m): 2.06

H.I. (ft):

Start Time: 14:48z

End Time: 19:29z

Time Zone: EST

Operator: D. Holt

Comments Use for 101211a-sn59

LASER Calibration USING SURFACE PROFILES

Introduction

Laser bore site calibration is the process whereby the angular misalignment between the IMU and the laser is determined. The components determined are **roll, pitch and heading.** These are rotations around the X, Y and Z-axis respectively.

In addition the above there are mechanical values that need to be resolved. These include pitch at the edge of the swath, and torsion. There may be a change in pitch from nadir to the edge of the swath, depending upon the alignment of the rotating mirror with respect to the mirror shaft. Torsion defines the elasticity of the shaft of the rotating mirror and is apparent under acceleration when the mirror oscillates.

The bore site calibration process to determine these values is undertaken in a relative mode only as there is no comparison with ground data. Subsequently, it should adhere to the basic survey principle of working from the whole to the part, i.e. daily operation of the equipment should always be at a lower flying height and smaller Field Of View (FOV) than used in calibration, so that the residuals of calibration are reduced rather than multiplied. It is critical to undertake the bore site process in such a way that any errors will be exaggerated so that any remaining residuals can be minimized.

The final value to be determined to ensure data conforms to ground truth is the **range correction.** Data may be higher or lower than ground truth, which is supplied from ground survey. In this instance a constant amount is added to the laser range to achieve the correct ground height.

Roll. Roll is a rotation around the X-axis and is evident as an error in position across track and an error in height with data on one edge high and on the other edge low. Roll is resolved by flying a single flight line over a flat surface in opposite directions. Any error will be exaggerated by having as wide a swath width as possible. This requires a maximum flying height and the maximum FOV.

Pitch. Pitch is a rotation around the Y-axis and is evident as an error in position along track. Using laser point data only, a pitch error cannot be determined over a flat surface. Pitch error is only evident when viewed over a sloping surface. The surface being viewed must be a large regular shape and chosen so as to eliminate any errors introduced when interpolating between individual laser points. The sloped surface being viewed must be at least 6 times larger than the maximum point spacing.

Pitch error is checked in the nadir position and also at the edge of the swath. Nadir pitch is resolved by flying a single flight line in opposite directions with a small along track spacing. Any error will be exaggerated by having a maximum flying height. The viewing surface should fall in the nadir position.

Pitch at the edge of the swath is resolved by flying a single flight line in opposite directions with a swath width as wide as possible. This requires a maximum flying height and the maximum FOV. The viewing surface should fall on the edge of the swath.

Heading. Heading is a rotation around the Z-axis and is evident as an error in position with data on one edge of the swath moved forward and on the other edge of the swath moved back. Using laser point data only, a heading error cannot be determined over a flat surface. Heading error is only evident when viewed over a sloping surface. The surface being viewed must be a large regular shape and chosen so as to eliminate any errors introduced when interpolating between individual laser points. The sloped surface being viewed must be at least 6 times larger than the maximum point spacing.

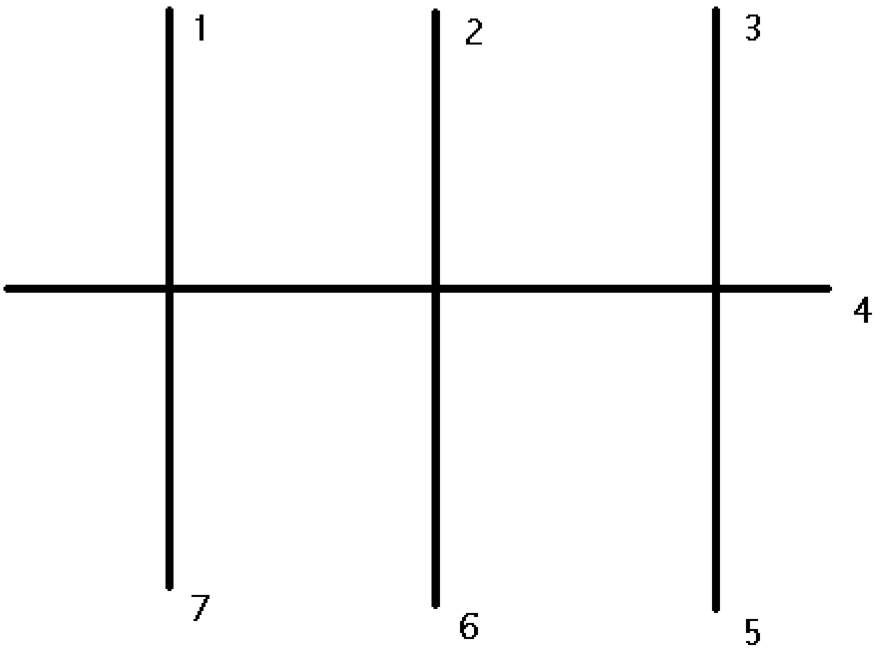
Heading is resolved by flying two slightly overlapping flight lines in the same direction. Any error will be exaggerated by having as wide a swath width as possible. This requires a maximum flying height and the maximum FOV. The viewing surface should fall in the overlap area.

Torsion. Determination of torsion should not be undertaken until Roll has been resolved. Torsion is apparent at times when the mirror shaft is under maximum acceleration. This occurs at the edge of the swath when the mirror changes direction. There is no torsion effect in the middle of the swath as the mirror has maximum velocity but no acceleration.

Range. The intensity of the laser return can bias the range correction required for each laser point. The measured intensity of any laser point can vary due to the reflectivity of the surface and also as a function of range to the ground. Surfaces with higher reflectivity produce a shorter time interval and shorter range for the laser shot and are therefore higher than ground survey. Surfaces with lower reflectivity produce a longer time interval and longer range for the laser shot and is therefore lower than ground survey.

Flight Plans

Roll, Pitch, Heading and Torsion. Bore site flights should be completed within 5km of the airfield and GPS base station. A suggested flight plan configuration to determine Roll, Pitch (both nadir and swath edge), Heading and Torsion includes one long flight line and three crossing lines of approximately equal length. All lines are flown in opposite directions several times at different altitudes. A sample is as follows is as follows:



Flight line 2-6 is designed to determine nadir pitch and should be centered over the target building and oriented perpendicular to the ridge of the building. Flight lines 1-7 and 3-5 should be 40% of the swath width either side of flight line 2-6. Flight lines 1 and 3 or 5 and 7 are used to determine heading. Flight lines 1 and 7 or 3 and 5 are used to determine pitch at the edge of the swath. Flight lines 1 and 7, 2 and 6 or 3 and 5 are used to determine roll. Flight line 4 plus either 1, 2, 3, 5, 6 or 7 is used to determine torsion.

Flight parameters to determine Roll, Pitch (both nadir and swath edge), Heading and Torsion are as follows:

Flying Height: 3,500m AGL or 11500ft AGL
Aircraft Speed: As Slow as Possible

Flight Line	FOV	SR	Mode	Pulse	Remarks
1	70	25	1	25000	2000m or 6000ft parallel to flight line 2
2	70	12.5	1	25000	
3	70	25	1	25000	2000m or 6000ft parallel to flight line 2
4	20	12.5	1	25000	Perpendicular to flight line 2
5	70	25	1	25000	Opposite direction to flight line 3
6	70	12.5	1	25000	Opposite direction to flight line 2
7	70	25	1	25000	Opposite direction to flight line 1

Range

A minimum of three-ground truth survey points should be established which are situated in open level areas and have surrounding surfaces, which are dark, medium and light respectively. Data is collected over these control points at different flying heights and with different laser attenuator settings. Flights should be completed within 5km of the airfield and GPS base station. A suggested flight plan configuration to determine Range is as follows:

Flight parameters to determine Range are as follows:

Flying Height: 3,500m AGL or 11500ft AGL
Aircraft Speed: As Slow as Possible

Flight Line	FOV	SR	Mode	Pulse	Attenuator	Flying Height
1	20	40	1	55000	1	500m/1600ft
2	20	40	1	55000	1	637m/2100ft
1	20	40	1	55000	0.5	637m/2100ft
2	20	40	1	55000	0.5	880m/2900ft
1	20	40	1	55000	0.5	1123m/3700ft
2	20	40	1	55000	0	1123m/3700ft
1	20	35	1	45000	0	1717m/5600ft
2	20	30	1	38000	0	2312m/7600ft
1	20	25	1	33000	0	2906m/9500ft
2	20	20	1	29000	0	3500m/11500ft

Adjusting Bore site Values

Roll. Roll is determined by taking a profile across track. If there is no roll error the surfaces will coincide. If there is a roll error the surfaces will cross. Measurements are taken at the separation at each edge of the swath. Take the average separation and divide by the swath width. This is the amount (in radians) of adjustment required for the initial roll value. To move data clockwise (right side of swath down) add roll. To move data counter-clockwise (right side of swath up) subtract roll. Always reprocess and verify data once any adjustment has been made.

Nadir Pitch. Nadir Pitch is determined by taking a profile along track through the target building. If there is no pitch error the surfaces will coincide. If there is pitch error the surfaces will be offset in position. Measure the separation between the two surfaces (sloped roof of building), divide by two and divide by the aircraft flying height above ground. This is the amount (in radians) of adjustment required for the initial pitch value. To move data forward add pitch. To move data back subtract pitch. Always reprocess and verify data once any adjustment has been made.

Edge Pitch. The pitch at the edge of the swath will be different to the nadir pitch if the rotating mirror is not mounted exactly perpendicular to the mirror shaft. It is calculated the same as nadir pitch.

Heading. Heading is determined by taking a profile along track through the target building. If there is no heading error the surfaces will coincide. If there is heading error the surfaces will be offset in position. Measure the separation between the two surfaces (sloped roof of building) and divide by the swath width. This is the amount (in radians) of adjustment required for the initial heading value. To move data clockwise, i.e. left side of swath forward, add heading. To move data counter-clockwise, i.e. left side of swath back, subtract heading. Always reprocess and verify data once any adjustment has been made.

Torsion. Determination of torsion should not be undertaken until Roll has been resolved. Torsion is determined by taking a profile along track through the center of flight line 4. No torsion is apparent in this location and this data is used as truth. If there is no torsion error the perpendicular flight line surface will coincide. If there is torsion error the perpendicular flight line surface will coincide in the center but be displaced at the edge of the swath. To move the edges of the surface up, add torsion. To move the edges of the surface down, subtract torsion. The amount of adjustment cannot be measured by a linear method and is determined by an iterative estimated adjustment method. Always reprocess and verify data once any adjustment has been made.

Range. Initial processing should be completed with a range correction set at 0.0. A table should then be recorded for the laser point nearest each control point showing the height error and intensity for all control points on each flight line. From this table the range correction at intensity 0.0 is to be calculated. This is added to the post processor as the range correction. A final intensity range correction table should be then be calculated showing increments in range correction with respect to increments in intensity. Data should be reprocessed and verified once the range correction and intensity range correction table have been determined.

Settings. Once adjustments have been made, the settings are saved in the Post Processor and the registry file is updated.

Photo Science Calibration Site

Photo Science has “built” a calibration site at Capitol City Airport in Frankfort, KY (KFFT). This site has several large buildings, which are used in the process, and we have numerous control points that we have established throughout the area used for testing the data. The flight lines, shown in image below, are similar to those outlined above. The flights start at the highest elevation of 12,200 feet MSL and drop progressively, with the lowest being 2,400 feet MSL. The steps above, along with the data from flyovers for this site are integrated into our calibration routine.

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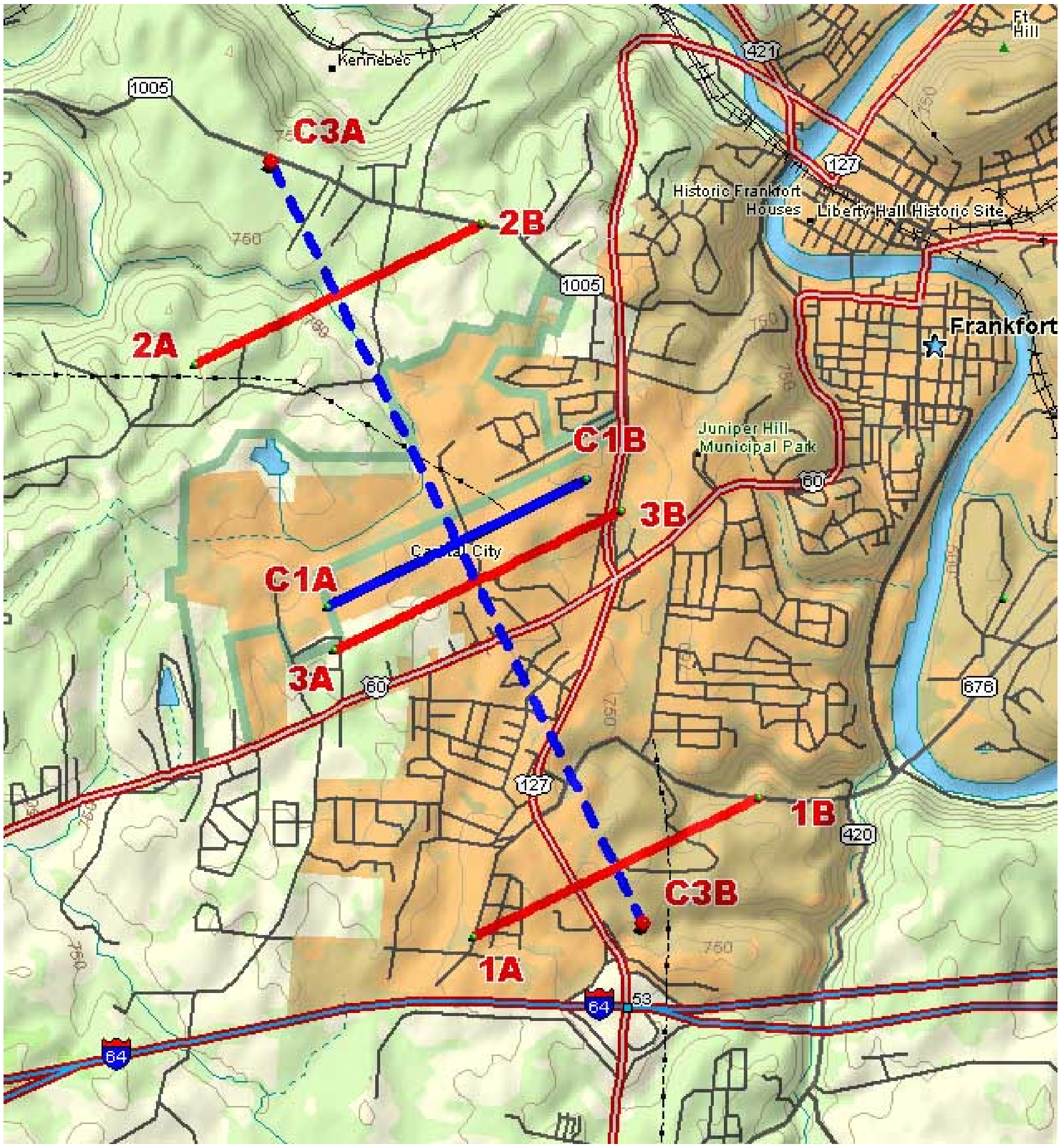

The calibration is undertaken anytime there are hardware changes to the system, reason to believe that the current calibration may have changed, or approximately every three months.

Additionally, when we are working on a project where we will be on-site for two to three days we perform a "mini" calibration consisting of three flight lines, similar to the above laid out over a local airport, at two altitudes. This is performed for the data to be available in case we have a problem with the current calibration.

For each project we establish, with GPS surveys, several points for ground truthing. These are generally points in a flat area, where we get an average elevation to test the vertical accuracy. Each of the points is selected with different types of reflective surfaces for comparisons as well. These points are compared against a Digital Elevation Model generated from the LiDAR data and this serves as our accuracy assessment.

avR49 - avR100

0.007199
0.018791
0.01961
0.020059
0.020654
0.020264
0.019381
0.01913
0.019259
0.018311
0.018101
0.019101
0.019444
0.019745
0.020485
0.021226
0.021747
0.02102
0.021819
0.021102
0.021416
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0.021654
0.021192
0.021216
0.020988
0.020525
0.020345
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0.020608
0.020185
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0.019508
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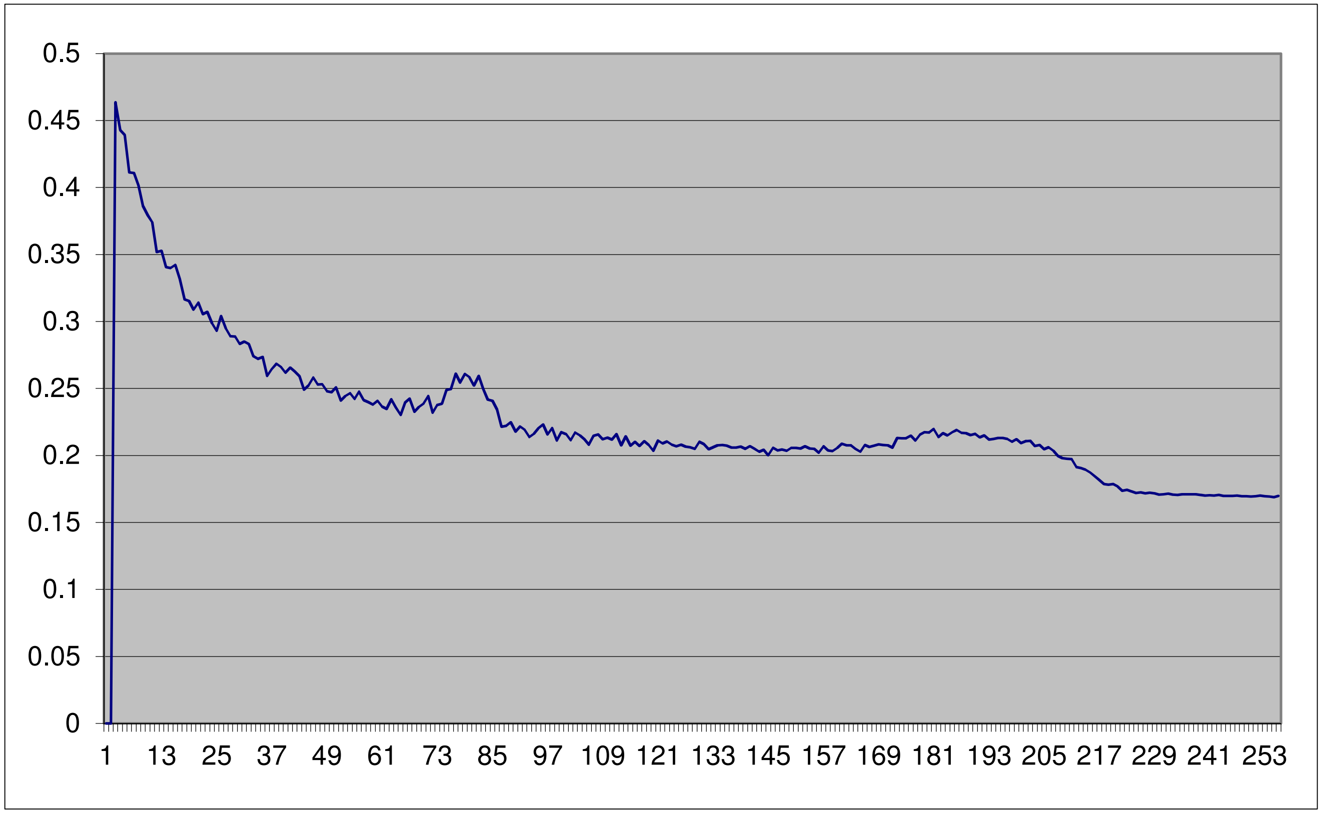
0.021866

Sum Intensity 30…Intensity 225
4.534747

TPR Range offset
0.023



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0.023024
0.022628
0.021528
0.020403
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0.019329
0.019079
0.018694
0.018997
0.01966
0.020115
0.020971
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0.021491
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0.021803	

Appendix F: Quality Assurance

Project Information	
Project Name:	**Quinnipiac**
Project Description:	Region1 LiDAR Acquisition
State:	CT
HUC-8:	11000004
Provider Name:	Photo Science, Inc.
Collection Area:	443 Square Miles (Includes all overlapping tiles and all no data voids at edges.)
Specification Level:	HIGH
Contour Accuracy:	2ft
Point Cloud	
NPS	0.21m
Date Delivered:	8/11/2011
Date QC:	8/15/2011
Media:	Hard Drive
Contents of Media:	666 version 1.2 las files
Tiles Reviewed	33
QC tiles with NPS > Spec Level	Pass-only at edges where including no data voids
Voids or Gaps	Pass-Voids only over open water
Reviewed By:	Dan Hoff
Bare Earth	
NPS	0.21m
Date Delivered:	8/11/2011
Date QC:	8/15/2011
Media:	Hard Drive
Contents of Media:	666 version 1.2 las files
Tiles Reviewed	66
QC tiles with NPS > Spec Level	Pass-only at edges where including no data voids
Voids or Gaps	Pass-Voids only over open water
Artifact QA	Pass
Reviewed By:	Dan Hoff

	Included	Comments
Pre-Flight Report		
Planned flight lines (sufficient coverage, spacing, length)	Pass	
if attachment list attachment name	Pass	
Planned GPS stations	Pass	
Planned Control (sufficient to control and boresight)	Pass	
Planned airport locations	Pass	
Calibration plans	Pass	
Quality procedures for flight crew	Pass	
Planned scanset (planned for proper scan angle, sidelap, design pulse)	Pass	
Type of aircraft	Pass	
Aircraft utilizes ABGPS	Pass	
Re-flight procedure (tracking, documenting, processing)	Pass	
project design supports accuracy requirements of project	Pass	
Project design accounts for land cover and terrain types	Pass	

Non-Classified Point Cloud		
Macro Review		
LAS Point Cloud Files	Pass/Fail	Comments
Projection	Pass	
Datum	Pass	
Units	Pass	
Area covered 100m buffer	Pass	
Data Voids	Pass	only over water
Correct Header	Pass	
Correct NPS	Pass	
Returns Contain		
GPS time stamp	Pass	
GPS second in microsec	Pass	
Easting	Pass	
Northing	Pass	
Elevation	Pass	
Intensity	Pass	
Return #	Pass	
Classification	Pass	
Classification is correct	Pass	
Cloud file structure conforms to layout	Pass	
Cloud file naming conforms to project	Pass	
Tiles checked for gaps and voids	Pass	voids only over water
Micro Review		
Total Number of Tiles:	666	
Number of tiles to be reviewed:	33	
	Pass/Fail	
Excessive Noise	Pass	
Elevation Steps	Pass	
LP360 Scan and profile	Pass	

	Included	Comments	
Post Flight Report			
GPS Base Station INFO			
GPS base station - names	Pass		
GPS base station - lat/longs	Pass		
GPS base station - heights	Pass		
GPS base station - Maximum PDOP	Pass		
GPS base station - map	Pass		
GPS base station - spatial data	Pass		
GPS/IMU			
GPS quality - Max horizontal variance (cm).	Pass		
GPS quality - Max vertical variance (cm).	Pass		
GPS quality - Notes on GPS quality	Pass		
GPS quality - GPS separation plot	Pass		
GPS quality - GPS altitude plot	Pass		
GPS quality - PDOP plot	Pass		
GPS quality - Plot of GPS distance from base stations	Pass		
Coverage			
Coverage - Verification of AOI coverage	Pass		
Coverage - Spatial data	Pass		
Flights			
Flights - Calibration lines	Pass		
Flights - As-flown trajectories	Pass		
Flights - Spatial data	Pass		
Control			
Control - Ground control and base station layout	Pass	Base Station Only	
Control - Spatial data	N/A	Included as map	
Data verification/QC			
Data verification process documented	Pass		
Flight logs			
Incorporated as appendix			
Job # / name	Pass		
Lift #	Pass		
Block or AOI designator	Pass		
Date	Pass		
Aircraft tail number, type	Pass		
Pilot name	Pass		
Operator name	Pass		
Airport of operations	Pass		
GPS base station names	Pass		
Flight lines			
Flight line	Pass		
Line #	Pass		
Direction	Pass		
Start/stop	Pass		

Altitude	Pass		
Scan angle/rate	Pass		
Speed	Pass		
Conditions	Pass		
Comments	Pass		
Settings			
AGC switch setting	N/A		
Laser pulse rate	Pass		
Mirror rate	N/A		
Field of view	Pass		
Comments	Pass		

Classified Point Cloud

Macro Review

LAS Bare Earth	**Pass/Fail**	**Comments**
Projection	Pass	
Datum	Pass	
Units	Pass	
Area covered 100m buffer	Pass	
Data Voids	Pass	
Correct Header	Pass	
Correct NPS	Pass	
Returns Contain		
GPS time stamp	Pass	
GPS second in microsec	Pass	
Easting	Pass	
Northing	Pass	
Elevation	Pass	
Intensity	Pass	
Return #	Pass	
Classification	Pass	Some spots over water classfied as ground
Classification is correct	Pass	
Cloud file structure conforms to layout	Pass	
Cloud file naming conforms to project	Pass	
Tiles checked for gaps and voids	Pass	

Micro Review

Total Number of Tiles:	666	
Number of tiles to be reviewed:	66	
Excessive Noise	Pass	
Elevation Steps	Pass	
2% Artifacts	Pass	
LP360 Scan and profile	Pass	

Appendix G: Deliverables

Quinnipiac River USGS HYDROLOGIC UNIT CODE 11000004

Ground Control
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J:\FEMA\R01\CONNECTICUT_09\NEW_HAVEN_09009\NEW_HAVEN_009C\11-01-0721S\SubmissionUpload\Terrain\2142894

Acquisition
J:\FEMA\R01\CONNECTICUT_09\MIDDLESEX_09007\MIDDLESEX_007C\11-01-0721S\SubmissionUpload\Terrain\2142895
J:\FEMA\R01\CONNECTICUT_09\NEW_HAVEN_09009\NEW_HAVEN_009C\11-01-0721S\SubmissionUpload\Terrain\2142895

Post Processing
J:\FEMA\R01\CONNECTICUT_09\MIDDLESEX_09007\MIDDLESEX_007C\11-01-0721S\SubmissionUpload\Terrain\2142896
J:\FEMA\R01\CONNECTICUT_09\NEW_HAVEN_09009\NEW_HAVEN_009C\11-01-0721S\SubmissionUpload\Terrain\2142896

```
Folder PATH listing for volume Region_I
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    |   \---11000004
    |       +---General
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    |       |   |   
    |       |   +---09007C_Middlesex_County_CT_Metadata
    |       |   |       09007C_Quinnipiac_Ground_Control_Metadata.txt
    |       |   |       09007C_Terrain_metadata.xml
    |       |   |       
    |       |   \---09009C_New_Haven_County_CT_Metadata
    |       |           09009C_Quinnipiac_Ground_Control_Metadata.txt
    |       |           09009C_Terrain_metadata.xml
    |       |           
    |       \---Supplemental
    |           +---FVA_CVA Quinnipiac
    |           |   +---01_Final_Statistics
    |           |   |       TheAccuracyReport_10_19_2010.pdf
    |           |   |       TheAccuracyReport_10_20_2010.pdf
    |           |   |       TheAccuracyReport_con10192010.pdf
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|       |           09009C_Quinnipiac_Acquisition_Metadata.txt
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|           |   Quinnipiac_PointCloud_HeaderAnalysis.xls
|           |   Quinnipiac_PreFlightReport_STARR.pdf
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\---2142896 - Processing
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    |   |   |       101218_LogFile.txt
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    |   |   |       110329_LogFile.txt
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    |   |           192.168.1.29110527_LogFile.txt
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    |   |   |   Project Flight Line Logs.pdf
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    |   |   |   Station Occupation Report.pdf
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    |   |   |       101211a-sn59 DOP Values.jpg
    |   |   |       101211a-sn59 Estimated Position Accuracy.jpg
    |   |   |       101211a-sn59 Map Run.jpg
    |   |   |       101211a-sn59 Number of Satellites.jpg
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    |   |   +---101216a-sn59
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    |   |   |       101216a-sn59 DOP Values.jpg
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|   |               fwdproc_110527a-sn019.log
|   |               idx_110527a-sn019.txt
|   |               revproc_110527a-sn019.log
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|   |           |       Quinnipiac_GCPs_NAD83.prj
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|   |           |       Quinnipiac_GCPs_NAD83.sbx
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|   |           |       QNP121.gif
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|   |           +---07_Final_Coordinates
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|   |       QUINNIPIAC_Flight_lines Excel file.xls
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|   |       QUINNIPIAC_Flight_lines.prj
|   |       QUINNIPIAC_Flight_lines.shp
|   |       QUINNIPIAC_Flight_lines.shx
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|           ALS_SN19_091601.xml
|           LASER Calibration USING SURFACE PROFILES.doc
|           SN019IBRC_Table091601.txt
|           SN019_Rivit_091601.xls
|           sn059_081122_MH.reg
|           SN059_IBRC.txt
|           tproffset_sn19_011609.txt
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Quinnipiac_11000004_Directory_Contents.txt
   Quinnipac_FVA_Passed.xlsx
   Quinnipiac_CVA_passed.xlsx
   Region 1 Quinnipiac Testing Results FVA CVA.pdf
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From: trackingupdates@fedex.com
Sent: Wednesday, August 31, 2011 4:24 PM
To: HUFFINES, James
Subject: FedEx Shipment Notification

This tracking update has been requested by:
Company Name:
GREENHORNE & O'MARA
Name:
Kelly Aldrich
E-mail:
kaldrich@g-and-o.com

Kelly Aldrich of GREENHORNE & O'MARA sent Marie Sparrow of FEMA Engr Library % Zimmerman
Assoc 1 FedEx Standard Overnight package(s).
This shipment is scheduled to be sent on 09/01/2011.
Reference information includes:
Reference:
110558.009.QA12.EXP
Special handling/Services:
Deliver Weekday

Status:
Shipment information sent to FedEx

Tracking number:
797471443168

To track the latest status of your shipment, click on the tracking number above, or visit us at fedex.com.
To learn more about FedEx Express, please visit our website at fedex.com.
This tracking update has been sent to you by FedEx on the behalf of the Requestor noted above. FedEx does not validate the authenticity of the requestor and does not validate, guarantee or warrant the authenticity of the request, the requestor's message, or the accuracy of this tracking update. For tracking results and fedex.com's terms of use, go to fedex.com.
Thank you for your business.

From: TrackingUpdates@fedex.com
Sent: Wednesday, August 31, 2011 4:15 PM
To: HUFFINES, James
Subject: FedEx Shipment Notification

This tracking update has been requested by:
Company Name:
GREENHORNE & O'MARA
Name:
Kelly Aldrich
E-mail:
kaldrich@g-and-o.com

Kelly Aldrich of GREENHORNE & O'MARA sent Dan Walters, Geo Liason ME,MA,RI of USGSNSDI Partnership Office 1 FedEx Standard Overnight package(s).
This shipment is scheduled to be sent on 09/01/2011.
Reference information includes:
Reference:
110558.009.QA12.EXP
Special handling/Services:
Deliver Weekday

Status:
Shipment information sent to FedEx

Tracking number:
797471473528

To track the latest status of your shipment, click on the tracking number above, or visit us at fedex.com.
To learn more about FedEx Express, please visit our website at fedex.com.
This tracking update has been sent to you by FedEx on the behalf of the Requestor noted above. FedEx does not validate the authenticity of the requestor and does not validate, guarantee or warrant the authenticity of the request, the requestor's message, or the accuracy of this tracking update. For tracking results and fedex.com's terms of use, go to fedex.com.
Thank you for your business.

STARR

Date:
August 31, 2011

Contract #
HSFEHQ-090D-0370

Task Order #
HSFEHQ -10-J-0005

Subject:
STARR Elevation Data (LiDAR)

Transmittal:

To: **Marie Sparrow**
FEMA Engineering Library
%Zimmerman Associates, Inc
847 South Pickett Street
Alexandria, VA 22304

From: James Huffines
Greenhorne & O'Mara, Inc
5565 Centerview Drive
Ste 107
Raleigh, NC 27606

Transmitted:

☐ For Your Use
☐ For Your Approval/Signature
☐ For Your Information
☐ For Your Review
☐ As Requested
☒ For Storage

The following:

COPIES	DATE	DESCRIPTION
1	8/31/11	Hard Drive Containing: Concord HUC8, Nashua HUC8, and Quinnipiac HUC8 terrain data See readme.txt included on hard drive for directory structure information.
		Includes: Ground Control data, QC Checkpoint (FVA/CVA) data, PreFlight Report, PostFlight Report, Tile Index shapefile, Collection Area shapefile, Point Cloud (All Returns) LAS files, QC Testing Results, QA Review spreadsheet, Compliance Certificates for Survey, Point Cloud (Bare Earth LAS files and LiDAR, Metadata for Survey and Point Cloud Data, and TSDN

Remarks:

If you have any questions or require additional information please feel free to contact me at 919-532-2332.
Please sign this transmittal upon receipt and mail to address shown above or fax to 919-851-8393.

Printed Name and Date: JAMES LEE HUFFINES 8/31/2011

Signature:

STARR

Date:
August 31, 2011

Contract #
HSFEHQ-090D-0370

Task Order #
HSFEHQ -10-J-0005

Subject:
STARR Elevation Data (LiDAR)

Transmittal:

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The following:

COPIES	DATE	DESCRIPTION
1	8/31/11	Hard Drive Containing: Concord HUC8, Nashua HUC8, and Quinnipiac HUC8 terrain data See readme.txt included on hard drive for directory structure information.
		Includes: Ground Control data, QC Checkpoint (FVA/CVA) data, PreFlight Report, PostFlight Report, Tile Index shapefile, Collection Area shapefile, Point Cloud (All Returns) LAS files, QC Testing Results, QA Review spreadsheet, Compliance Certificates for Survey, Point Cloud (Bare Earth LAS files and LiDAR, Metadata for Survey and Point Cloud Data, and TSDN

Remarks:

If you have any questions or require additional information please feel free to contact me at 919-532-2332.
Please sign this transmittal upon receipt and mail to address shown above or fax to 919-851-8393.

Printed Name and Date: JAMES LEE HUFFINES 8/31/2011

Signature:

Appendix H: Guidance Documents

U.S. Department of Homeland Security
500 C Street, SW
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FEMA

DATE

MEMORANDUM FOR: Mitigation Division Directors Regions I-X, CTPs, Mapping Partners

FROM: Doug Bellomo, Director
Risk Analysis Division

SUBJECT: Procedure Memorandum No. XX—Standards for Lidar and Other High Quality Digital Topography

EFFECTIVE DATES: August 1, 2010

Background: Beginning in Fiscal Year (FY) 2010, Federal Emergency Management Agency (FEMA) initiated a five-year program for Risk Mapping, Assessment, and Planning (Risk MAP). FEMA's vision for the Risk MAP program is to deliver quality data that increases public awareness and leads to mitigation actions that reduce risk to life and property. To achieve this vision, FEMA will transform its traditional flood identification and mapping efforts into a more integrated process of accurately identifying, assessing, communicating, planning for, and mitigating flood risks.

Under Risk MAP, FEMA seeks to:

- Deliver new data and products that expand risk awareness and promote mitigation planning that leads to risk reduction actions.
- Increase production efficiencies for Flood Insurance Rate Maps (FIRMs) and Flood Insurance Studies (FISs).

Issue: To implement FEMA's Risk MAP vision and provide the high quality topographic data necessary to meet Risk MAP's goals, FEMA Regions and Mapping Partners need upgraded guidance concerning the accuracy, and processing of high quality topographic data including Light Detection and Ranging (lidar) data. To that end, this Procedure Memorandum will supersede Appendix A: Guidance for Aerial Mapping and Surveying of the *Guidelines and Specifications for Flood Hazard Mapping Partners* (Guidelines) in key areas (defined in the Procedure Memorandum Attachments), and must be implemented beginning with all topographic data collected by FEMA beginning in FY 2010.

Actions Taken: When procuring topographic data under the Risk MAP Program the Mapping Partner assigned to obtain topographic data or perform independent QA of topographic data must meet the specifications detailed in this Procedure Memorandum's attachments. The attachments align FEMA's high quality topographic specifications, found in Appendix A of the Guidelines, with the United States Geological Survey (USGS) *Lidar Guidelines and Base Specifications* v13 so that data procured and used by the Federal government is consistent across agencies and is updated to industry standards. Further, adherence to these specifications will support the Risk MAP Program by closing gaps in existing flood hazard data; supporting risk assessments; and better communicating risks to community officials and the public.

Existing elevation data, not acquired by FEMA, but planned for use on a new flood hazard analysis must comply with the accuracy, density and the final product metadata requirements detailed in the attachments and, but is not required to comply with the other specifications included and referenced below.

Consistent with FEMA's overall approach to flood hazard identification, this Procedure Memorandum aligns FEMA topographic data specifications to level of risk, and accounts for different slopes in the terrain that can affect the accuracy of base flood elevations and the delineation of mapped floodplains. These specifications represent the minimum requirements. Where funding partners are involved or where the engineering requirements dictate, projects may use higher specification levels or include additional processing. Quality assurance requirements for high quality topographic data are also provided.

Attachments:
Attachment 1 – Definitions
Attachment 2 – Alignment of FEMA Appendix A to USGS *Lidar Guidelines and Base Specification* v13
Attachment 3 – Topographic Breakline and Hydro-Enforcement Specifications
Attachment 4 – Topographic Data Quality Review Process

Distribution List:

Attachment 1 – Definitions

Digital Elevation Data – Includes all of the following terms: mass points, point clouds, breaklines, contours, TINs, DEMs, DTMs or DSMs.

- **Breakline –** A linear feature demarking a change in the smoothness or continuity of a surface such as abrupt elevation changes or a stream line. The two most common forms of breaklines are as follows:
  - A **soft breakline** ensures that known elevations, or z-values, along a linear feature are maintained (e.g., elevations along a pipeline, road centerline or drainage ditch), and ensures the boundary of natural and man-made features on the Earth's surface are appropriately represented in the digital terrain data by use of linear features and polygon edges They are generally synonymous with 3-D breaklines because they are depicted with series of x/y/z coordinates.
  - A **hard breakline** defines interruptions in surface smoothness, e.g., to define streams, shorelines, dams, ridges, building footprints, and other locations with abrupt surface changes. Although some hard breaklines are three dimensional (3-D) breaklines, they are often depicted as two dimensional (2-D) breaklines because features such as shorelines and building footprints are normally depicted with a series of horizontal coordinates only which are often digitized from digital orthophotographs that include no elevation data.
- **Contours –** Lines of equal elevation on a surface. An imaginary line on the ground, all points of which are at the same elevation above or below a specified vertical datum.
- **Digital Elevation Model (DEM) –** An elevation model created for use in computer software where bare-earth elevation values have regularly spaced intervals in latitude and longitude (x and y). The Δx and Δy values are normally measured in feet or meters to even units; however, the National Elevation Dataset (NED) defines the spacing interval in terms of arc-seconds of latitude and longitude, e.g., 1/3rd arc-second.
- **Digital Surface Model (DSM) –** An elevation model created for use in computer software that is similar to DEMs or DTMs except that DSMs depict the elevations of the top surfaces of buildings, trees, towers, and other features elevated above the bare earth.
- **Digital Terrain Model (DTM) –** An elevation model created for use in computer software of bare-earth mass points and breaklines. DTMs are technically superior to a gridded DEM for many applications because distinctive terrain features are more clearly defined and precisely located, and contours generated from DTMs more closely approximate the real shape of the terrain.
- **Mass Points –** Irregularly spaced points, each with latitude and longitude location coordinates and elevation values typically used to form a TIN.
- **Metadata –** Project descriptive information about the elevation dataset.
- **Point Cloud –** Often referred to as the "raw point cloud", this is the first data product of a lidar instrument. In its crudest form, a lidar raw point cloud is a collection of range measurements and sensor orientation parameters. After initial processing, the range and orientation of each laser value is converted to a position in a three dimensional frame of reference and this spatially coherent cloud of points is the base for further processing and analysis. The raw point cloud typically includes first, last, and intermediate returns for each laser pulse. In addition to spatial information, lidar intensity returns provide texture or color information. The combination of three dimensional spatial information and spectral information contained

in the lidar dataset allows great flexibility for data manipulation and extraction. As used in this procedure memorandum, two additional lidar data processing terms are defined as follows:

- **Lidar Preliminary Processing –** The initial processing and analysis of laser data (GPS/IMU/laser ranges) to fully "calibrated point clouds" in some specified tile format. All lidar data will be set to ASPRS LAS Class 1 (unclassified) and must include testing for Fundamental Vertical Accuracy (FVA). The tile format can change later, if necessary.
- **Lidar Post-Processing –** The final processing and classification of lidar data to the required ASPRS LAS classes, per project specifications. This must include testing for Consolidated Vertical Accuracy (CVA). At this point, the datasets are referred to as the "classified point cloud."

- **Triangulated Irregular Network (TIN) –** A set of adjacent, non-overlapping triangles computed from irregularly-spaced points with lattitude, longitude, and elevation values. The TIN data structure is based on irregularly-spaced point, line, and polygon data interpreted as mass points and breaklines and stores the topological relationship between triangles and their adjacent neighbors. The TIN model may be preferable to a DEM when it is critical to preserve the precise location of narrow or small features, such as levees, ditch or stream centerlines, isolated peaks or pits in the data model.
- **Z-Values –** The elevations of the 3-D surface above the vertical datum at designated x/y locations.

Geospatial Accuracy Standard – A common accuracy testing and reporting methodology that facilitates sharing and interoperability of geospatial data. Published in 1998, the National Standard for Spatial Data Accuracy (NSSDA) is the Federal Geographic Data Committee (FGDC) standard relevant to digital elevation data when assuming that errors follow a normal error distribution. However, after it was learned that lidar datasets do not necessarily follow a normal distribution in vegetated terrain, the National Digital Elevation Program (NDEP) published its "Guidelines for Digital Elevation Data" and the American Society for Photogrammetry and Remote Sensing (ASPRS) published the "ASPRS Guidelines: Vertical Accuracy Reporting for Lidar Data," both of which were published in 2004 and use newer terms defined below as Fundamental Vertical Accuracy (FVA), Supplemental Vertical Accuracy (SVA) and Consolidated Vertical Accuracy (CVA). All of these standards, designed for digital elevation data, replace the National Map Accuracy Standard (NMAS) that is applicable only to graphic maps defined by map scale and contour interval.

Accuracy – The closeness of an estimated value (e.g., measured or computed) to a standard or accepted (true) value of a particular quantity. Note: With the exception of GPS Continuously Operating Reference Stations (CORS), assumed to be known with zero errors relative to established datums, the true locations of 3-D spatial coordinates or other points are not known, but only estimated. Therefore, the accuracy of other coordinate information is unknown and can only be estimated. Other accuracy definitions are as follows.

- **Absolute Accuracy –** A measure that accounts for all systematic and random errors in a data set. Absolute accuracy is stated with respect to a defied datum or reference system.
- **Accuracy$_{\mathbf{r}}$ –** The NSSDA reporting standard in the horizontal component that equals the radius of a circle of uncertainty, such that the true or theoretical horizontal location of the

point falls within that circle 95-percent of the time. Accuracy$_r$ = 1.7308 x RMSE$_r$. Horizontal accuracy is defined as the positional accuracy of a dataset with respect to a horizontal datum.

- **Accuracy$_z$ —** The NSSDA reporting standard in the vertical component that equals the linear uncertainty value, such that the true or theoretical vertical location of the point falls within that linear uncertainty value 95-percent of the time. Accuracy$_z$ = 1.9600 x RMSE$_z$. Vertical accuracy is defined as the positional accuracy of a dataset with respect to a vertical datum.
- **Consolidated Vertical Accuracy (CVA) –** The result of a test of the accuracy of vertical checkpoints (z-values) consolidated for two or more of the major land cover categories, representing both open terrain and other land cover categories. Computed by using the 95th percentile, CVA is always accompanied by Fundamental Vertical Accuracy (FVA).
- **Fundamental Vertical Accuracy (FVA) –** The value by which vertical accuracy can be equitably assessed and compared among datasets. The FVA is determined with vertical checkpoints located only in open terrain, where there is a very high probability that the sensor will have detected the ground surface. FVA is calculated at the 95% confidence level in open terrain only, using RMSE$_z$ x 1.9600,
- **Local Accuracy –** A value that represents the uncertainty in the coordinates of a control point relative to the coordinates of other directly-connected, adjacent control points at the 95-percent confidence level. The reported local accuracy is an approximate average of the individual local accuracy values between this control point and other observed control points used to establish the coordinates of the control point.
- **Network Accuracy –** A value that represents the uncertainty in the coordinates of a control point with respect to the geodetic datum at the 95-percent confidence level. For National Spatial Reference System (NSRS) network accuracy classification in the U.S., the datum is considered to be best expressed by the geodetic values at the CORS supported by the National Geodetic Survey (NGS). By this definition, the local and network accuracy values at CORS sites are considered to be infinitesimal, i.e., to approach zero.
- **Percentile –** Any of the values in a dataset of errors dividing the distribution of the individual errors in the dataset into one hundred groups of equal frequency. Any of those groups can specify a specific percentile, e.g., the 95th percentile as defined below.
- **Precision –** A statistical measure of the tendency of a set of random numbers to cluster about a number determined by the dataset. *Precision* relates to the quality of the method by which the measurements were made and is distinguished from *accuracy* which relates to the quality of the result. The term "precision" not only applies to the fidelity with which required operations are performed, but, by custom, has been applied to methods and instruments employed in obtaining results of a high order of precision. Precision is exemplified by the number of decimal places to which a computation is carried and a result stated.
- **Positional Accuracy** – The accuracy of the position of features, including horizontal and/or vertical positions.
- **Relative Accuracy** – A measure that accounts for random errors in a data set. Relative accuracy may also be referred to as point-to-point accuracy. The general measure of relative accuracy is an evaluation of the random errors (systematic errors and blunders removed) in determining the positional orientation (e.g., distance, azimuth) of one point or feature with respect to another.
- **Root Mean Square Error (RMSE) –** The square root of the average of the set of squared differences between dataset coordinate values and coordinate values from an independent

source of higher accuracy for identical points. The vertical RMSE ($RMSE_z$), for example, is calculated as the square root of $\sum(Z_n - Z'_n)^2/N$, where:

  - Z_n is the set of N z-values (elevations) being evaluated, normally interpolated (for TINs and DEMs) from dataset elevations of points surrounding the x/y coordinates of checkpoints
  - Z'_n is the corresponding set of checkpoint elevations for the points being evaluated
  - N is the number of checkpoints
  - n is the identification number of each of the checkpoints from 1 through N.
- **Supplemental Vertical Accuracy (SVA) –** The result of a test of the accuracy of z-values over areas with ground cover categories or combination of categories other than open terrain. Computed by using the 95th percentile, SVA is always accompanied by Fundamental Vertical Accuracy (FVA). SVA values are computed individually for different land cover categories. Each land cover type representing 10% of more of the total project area is typically tested and reported as an SVA. SVA specifications are normally target values that may be exceeded so long as overall CVA requirements are satisfied.
- **95% Confidence Level** – Accuracy reported at the 95% confidence level means that 95% of the positions in the dataset will have an error with respect to true ground position that is equal to or smaller than the reported accuracy value. The reported accuracy value reflects all uncertainties, including those introduced by geodetic control coordinates, compilation, and final computation of ground coordinate values in the product. Where errors follow a normal error distribution, $Accuracy_z$ defines vertical accuracy at the 95% confidence level (computed as $RMSE_z$ x 1.9600), and $Accuracy_r$ defines horizontal (radial) accuracy at the 95% confidence level (computed as $RMSE_r$ x 1.7308).
- **95th Percentile –** Accuracy reported at the 95th percentile indicates that 95% of the errors will be of equal or lesser value and 5% of the errors will be of larger value. This term is used when errors may not follow a normal error distribution, e.g., in forested areas where the classification of bare-earth elevations may have a positive bias. Vertical accuracy at the 95% confidence level and 95th percentile may be compared to evaluate the degree to which actual errors approach a normal error distribution.

Resolution – In the context of elevation data, resolution is synonymous with the horizontal density of elevation data points for which two similar terms are used:

- **Nominal Pulse Spacing (NPS)** – The estimated average spacing of irregularly-spaced lidar points in both the along-track and cross-track directions resulting from: the laser pulse repetition frequency (e.g., 100,000 pulses of laser energy emitted in one second from a 100 kHz sensor); scan rate (sometimes viewed as the number of zigzags per second for this common scanning pattern); field-of-view; and flight airspeed. Lidar system developers currently provide "design NPS" as part of the design pulse density, although the American Society for Photogrammetry and Remote Sensing (ASPRS) is currently developing standard procedures to compute the "empirical NPS" which should be approximately the same as the "design NPS" when accepting statistically insignificant loss of returns and disregarding void areas, from water for example. The NPS assessment is made against single swath first return data located within the geometrically usable center portion (typically ~90%) of each swath. Average along-track and cross-track pulse spacing should be comparable. When point density is increased by relying on overlap or double-coverage it should be documented in metadata and not by changing the project's reported NPS. The NPS should be equal to or less than the Digital Elevation Model (DEM) post spacing when gridded DEMs are required as part of project specifications. This same definition for NPS could similarly apply to irregularly-spaced mass points from photogrammetry or Interferometric Synthetic Aperture Radar (IFSAR) data. NPS pertains to lidar only and is not intended to pertain to photogrammetry or IFSAR.

- **DEM Post Spacing –** Sometimes confused with Nominal Pulse Spacing, the DEM Post Spacing is defined as the constant sampling interval in x- and y-directions of a DEM lattice or grid. This is also called the horizontal resolution of a gridded DEM or the DEM grid spacing. It is standard industry practice to have:
  - 1-meter DEM post spacing for elevation data with 1-foot equivalent contour accuracy;
  - 2-meter DEM post spacing for elevation data with 2-foot equivalent contour accuracy;
  - 5-meter DEM post spacing for elevation data with 5-foot equivalent contour accuracy.

Attachment 2 – Alignment of FEMA Appendix A to USGS Lidar Specification v13

FEMA is aligning Appendix A of the *Guidelines and Specifications for Flood Hazard Mapping Partners* (Guidelines) to the USGS *Lidar Guidelines and Base Specification* v13 to modernize the FEMA specifications to current industry practice, leverage the expertise of the USGS Geography discipline, maintain Federal standards across agencies, and support the use of elevation products acquired as part of Risk MAP by other agencies for other purposes thus maximizing the Government's investment.

Overall, new elevation data purchased by FEMA must comply with the USGS *Lidar Guidelines and Base Specification* v13, except where specifically noted in this Procedure Memorandum.

Because FEMA's needs for elevation are specific to floodplain mapping, FEMA has some unique requirements that differ from the USGS specifications. To supplement the existing USGS specifications, FEMA-specific items such as cross section surveys, bridges, and other features in Appendix A of the Guidelines remain valid except where superseded by more current information provided in this attachment. Table 1 summarizes the sections in Appendix A that are fully superseded, partially superseded or not superseded by this Procedure Memorandum.

Table 2.1 Currency of Major Sections within FEMA's Appendix A: Guidance for Aerial Mapping and Surveying

Section	Name	Status
A.1	Introduction	Is not superseded and remains valid.
A.2	Industry Geospatial Standards	Remains valid but is appended by additional standards which use newer standards from the National Digital Elevation Program (NDEP) and American Society for Photogrammetry and Remote Sensing (ASPRS) to test elevation data for Fundamental Vertical Accuracy (FVA), Supplemental Vertical Accuracy (SVA), and Consolidated Vertical Accuracy (CVA).
A.3	Accuracy Guidelines	Partly superseded, especially Table 2, below, that specifies variable vertical accuracy standards and nominal pulse spacing (NPS), depending on the risk level and terrain slope within the floodplain being mapped.
A.4	Data Requirements	Major portions are superseded. Subsection A.4.2.3 pertaining to breaklines, subsection A.4.3 pertaining to elevation data vertical accuracy, and subsection A.4.5 pertaining to mapping area, are superseded. Subsection A.4.11 pertaining to other digital topographic data requirements, including Table A-3, Digital Topographic Data Requirements Checklist, is now superseded by other FEMA procurement guidelines. Subsection A.4.9 on data formats is partially superseded by the addition of lidar LAS formatted datasets. Subsections pertaining to cross sections (A.4.6) and hydraulic structures (A.4.7) remain valid.
A.5	Ground Control	Is not superseded and remains valid.
A.6	Ground Surveys	Is not superseded and remains valid.

Section	Name	Status
A.7	Photogrammetric Surveys	Remains valid but is appended by additional standards which require low confidence areas to be delineated for photogrammetry as well as lidar and interferometric synthetic aperture radar (IFSAR). The vast majority of section A.7 remains valid and unchanged.
A.8	Airborne LiDAR	Superseded with references the USGS *Lidar Guidelines and Base Specification* v13; and by NDEP and ASPRS guidelines for accuracy testing and reporting of lidar data.

2.1Elevation Specifications Based on Risk Levels

FEMA maintains a national dataset that estimates flood risk. The basic data is calculated at the Census Block Group level, and is also aggregated to the sub-watershed, watershed and county levels. These data assign a risk value and a risk rank to each area. The areas are grouped into 10 classes with an equal number of members based on risk rank. These 10 classes are called risk deciles.

The table below provides the minimum elevation standards for new engineering analyses produced by FEMA. The highest and high specifications are suitable for either basic or enhanced engineering analyses. The medium and low specifications are suitable for basic engineering analyses. Where more than 20% of the project area covered by the new elevation will have enhanced engineering analyses, the next higher elevation specification level may be appropriate. When the scope of the enhanced engineering analyses is not sufficient to justify increasing the overall project specification level, the bulk elevation data collection may be enhanced by field survey in areas of enhanced engineering analyses if necessary.

Table 2.2. Vertical Accuracy Requirements based on Flood Risk and Terrain Slope within the Floodplain being mapped

Level of Flood Risk	Typical Slopes	Specification Level	Vertical Accuracy, 95% Confidence Level FVA/CVA	Lidar Nominal Pulse Spacing (NPS)
High (Deciles 1,2,3)	Flattest	Highest	24.5 cm/36.3 cm	≤1 meter
High (Deciles 1,2,3)	Rolling or Hilly	High	49.0 cm/72.6 cm	≤2 meters
High (Deciles 2,3,4,5)	Hilly	Medium	98.0 cm/145 cm	≤3.5 meters
Medium (Deciles 3,4,5,6,7)	Flattest	High	49.0 cm/72.6 cm	≤2 meters
Medium (Deciles 3,4,5,6,7)	Rolling	Medium	98.0 cm/145 cm	≤3.5 meters

Medium (Deciles 4,5,6,7)	Hilly	Low	147 cm/218 cm	≤5 meters
Low (Deciles 7,8,9,10)	All	Low	147 cm/218 cm	≤5 meters

Whereas contour lines are for visual interpretation and are unnecessary for FEMA's automated H&H analyses, the term "equivalent contour accuracy" is used to show the accuracy of contour lines that could be produced from a DEM if needed for manual analysis; this is also for the benefit of those who do not understand NSSDA terminology that defines vertical accuracy at the 95% confidence level. Table 3 explains "equivalent contour accuracy" for various standard contour intervals, referenced also in terms of vertical root mean square error ($RMSE_z$), National Standard for Spatial Data Accuracy (NSSDA) $Accuracy_z$, SVA and CVA.

Table 2.3. Accuracy Terms that Equal "Equivalent Contour Accuracy"

Equivalent Contour Accuracy	FEMA Specification Level	$RMSE_z$	NSSDA $Accuracy_z$ 95% confidence level	SVA (target)	CVA (mandatory)
1 ft		0.30 ft or 9.25 cm	0.60 ft or18.2 cm	0.60 ft or18.2 cm	0.60 ft or18.2 cm
2 ft	Highest	0.61 ft or 18.5 cm	1.19 ft or 36.3 cm	1.19 ft or 36.3 cm	1.19 ft or 36.3 cm
4 ft	High	1.22 ft or 37.1 cm	2.38 ft or 72.6 cm	2.38 ft or 72.6 cm	2.38 ft or 72.6 cm
5 ft		1.52 ft or 46.3 cm	2.98 ft or 90.8 cm	2.98 ft or 90.8 cm	2.98 ft or 90.8 cm
8 ft	Medium	2.43 ft or 73.9 cm	4.77 ft or 1.45 m	4.77 ft or 1.45 m	4.77 ft or 1.45 m
10 ft		3.04 ft or 92.7 cm	5.96 ft or1.82 m	5.96 ft or1.82 m	5.96 ft or1.82 m
12 ft	Low	3.65 ft or 1.11m	7.15 ft or 2.18 m	7.15 ft or 2.18 m	7.15 ft or 2.18 m

FEMA's requirements for elevation data are specific to flood risk analysis. As a result, FEMA's requirements diverge from the USGS specification which is intended to serve a different purpose. Two of the key differences with the FEMA specifications are the requirements for vertical accuracy and nominal pulse spacing. The FEMA requirements in these areas are only similar to the USGS requirements in the highest specification level, but otherwise differ for the lower accuracy levels.

All data collected must go through lidar preliminary processing and the unclassified point cloud must be tested as specified in the USGS specification. Where the Mapping Activity Statement (MAS) requires bare earth post-processing of the floodplain area of interest (AOI), the elevation data must be tested and comply with both the FVA and CVA requirements. Where no bare earth post-processing is specified, only the FVA requirements apply for lidar preliminary processing.

Many other organizations require higher-accuracy lidar data for diverse applications and combine their resources to solve multiple needs with lidar. FEMA prefers to acquire elevation data through partnerships so that the resulting data will meet a broader variety of end user needs and be more consistent with the overall USGS specification. These partnership elevation collection activities will frequently utilize specifications that exceed the minimums described above in Table 2. Before committing funds to a new elevation mapping project, FEMA Regional staff should first determine whether funds could be spent more effectively by cooperating with other agencies to more cost-effectively acquire elevation data. FEMA is a member of the National Digital Elevation Program (NDEP) which was formed, in part, to avoid duplication of effort among state and federal government agencies acquiring digital elevation data. USGS maintains state geospatial liaisons that are a good source of information regarding the status of existing and/or planned mapping activities in their states.

2.2 Light Detection and Ranging (lidar)

Lidar is capable of delivering 1- foot equivalent contour accuracy with sub-meter NPS used to produce DEMs with 1-meter DEM gridded post spacing. Therefore, lidar could satisfy FEMA's requirements for elevation data in high risk, moderate risk, and low risk areas. Lidar is often the best technology for mapping the elevations of the bare earth terrain in dense vegetation.

If this technology is selected for high risk areas, lidar will be collected in accordance with the USGS *Lidar Guidelines and Base Specification*, v13, for the National Geospatial Program except as noted. FEMA does not require the data to be hydro-flattened, as specified in v13. Also, FEMA does not require all data to be processed to the bare earth terrain, but instead limits the area to be processed to areas in the vicinity of floodplains that will require hydraulic modeling. See FEMA's Procurement Guidelines for specifics on this topic.

The following USGS specifications are most relevant to FEMA and are consistent with FEMA requirements:

- Fundamental Vertical Accuracy (FVA) pertains only to open, non-vegetated terrain. The FVA is specified at a higher level of accuracy than other land cover categories. The FVA is a mandatory specification that must be satisfied in order to be usable by FEMA for flood risk mapping within the specified level of flood risk.
- Supplemental Vertical Accuracy (SVA) pertains to other major land cover categories representative of the floodplain being mapped. SVA values are target values, where one SVA category can test higher and another lower than the target SVA value so long as the overall CVA is satisfied for the consolidated equivalent contour accuracy.
- Consolidated Vertical Accuracy (CVA) pertains to all land cover categories combined. Compliance with the CVA specification is mandatory in order for an elevation dataset to qualify for satisfaction of a specified equivalent contour accuracy.
- For the highest specification level equivalent to 2 foot contour accuracy, the relative accuracy should be ≤ 7 cm $RMSE_z$ within individual swaths; ≤ 10 cm $RMSE_z$ within swath overlap (between adjacent swaths). These relative accuracy specifications double to 14 and 20 cm, respectively, for risk areas that utilize the high elevation specification with 4 foot equivalent contour accuracy. This specification is not applicable to lower risk areas.
- Consistent with USGS *Lidar Guidelines and Base Specification*, v13, a regular grid, with cell size equal to the design NPS*2 will be laid over the first return data within the geometrically usable center portion of each swath. At least 90% of the cells in the grid shall contain at least one lidar point.
- All data collected will be delivered consistent with the USGS Raw Point Cloud deliverable requirements.

- Where lidar post-processing is performed, the deliverables must also include the classified point cloud deliverable. The data will be delivered in full compliance with LAS classes 1 (processed, but unclassified), 2 (bare-earth ground), 7 (noise), 9 (water), 10 (ignored), and 11 (withheld). All points not identified as "withheld" are to be classified. "Overlap" classification (Class 12) shall not be used.
- The horizontal datum shall be referenced to the latest adjustment of the North American Datum of 1983 (NAD83 [NSRS2007]).
- The vertical datum shall be referenced to the North American Vertical Datum of 1988 (NAVD88) whenever available. Areas outside of the continental U.S. where NAVD88 is not available should be referenced to a reproducible local datum that can be used to support floodplain management.
- The most recent approved Geoid model from the National Geodetic Survey (NGS) shall be used to perform conversions from ellipsoidal heights to orthometric heights.
- The standard coordinate reference system and units shall be Universal Transverse Mercator (UTM), meters. Considerations for other standard coordinate systems such as State Plane can be made for projects which are contributed to by mapping partners.
- The single non-overlapped tiling scheme shall be established and agreed upon by the data producer and FEMA prior to collection, consistent with the USGS *Lidar Guidelines and Base Specifications,* v13.
- Specifications for breaklines and hydro-enforcement are addressed in Attachment B.
- Specifications for lidar accuracy testing by land cover categories within the floodplain being mapped are addressed in Attachment C.

Lidar dataset deliverables shall include the following:

1. Metadata should comply with the requirements in the USGS *Lidar Guidelines and Base Specification*, v13. In addition, the finished elevation product for hydraulic modeling should be documented by a FGDC-compliant metadata file that complies with the FEMA Elevation Metadata Profile. Project documentation must also include a Pre-flight Operations Plan and Post-flight Aerial Survey and Calibration Report as described in Attachment 4.
2. Raw point cloud data shall comply with the requirements in the USGS Lidar Guidelines and Base Specification, v13.
3. Classified point cloud data shall comply with requirements in the USGS Lidar Guidelines and Base Specification, v13.
4. Optional breaklines, when produced, shall be delivered in compliance with guidance in Attachment 3
5. Optional digital bare earth elevation data product(s) (e.g., DEM, DTM, contours) in file formats specified in the Statement of Work.

2.3 Photogrammetry

Photogrammetry is also capable of delivering 1-foot equivalent contour accuracy and a DEM with 1-meter post spacing. Therefore, photogrammetry could also satisfy FEMA's requirements for elevation data in high risk, moderate risk, and low risk areas. Except for the new requirement to delineate areas of low confidence, existing guidance published in section A.7, Photogrammetric Surveys, in Appendix A of FEMA's Guidelines, remain current for new aerial image acquisition with either film or digital cameras.

The USGS annually contracts for leaf-off orthoimagery of selected areas under the National Geospatial Program, typically producing digital orthophotographs with pixel resolution of 30 cm (~1 foot) or 15 cm (~6 inches), as do many states and local governments; and the USDA contracts for leaf-on orthoimagery of major areas of the U.S. annually under the National Agricultural Imagery Program (NAIP) with pixel resolution of 1 meter. Although intended for production of digital orthophotos, those same images could be reused for production of digital elevation data because the aerotriangulation (AT) solution for production of orthophotos can be reused for establishing stereo models from which DEMs can be produced by photogrammetric auto-correlation and/or manual compilation. Elevation accuracies typically achievable by reuse of digital imagery and AT metrics are as follows:

- Typically acquired at an elevation of approximately 4,800 feet above mean terrain, imagery and AT solutions used to produce digital orthophotos with 6-inch pixel resolution should be acceptable for elevation data with 2.5-foot equivalent contour accuracy
- Typically acquired at an elevation of approximately 9,600 feet above mean terrain, imagery and AT solutions used to produce digital orthophotos with 1-foot pixel resolution should be acceptable for elevation data with 5-foot equivalent contour accuracy
- Typically acquired at an elevation of approximately 30,000 feet above mean terrain, imagery and AT solutions used to produce digital orthophotos with 1-meter pixel resolution should be acceptable for elevation data with 15-foot equivalent contour accuracy.

Photogrammetric dataset deliverables shall include the following:

1. Metadata shall include:
    - Collection Report detailing mission planning and flight logs, flying heights, camera parameters, forward overlap and sidelap.
    - Survey Report detailing the collection of control and reference points used for calibration and QA/QC.
    - Aerial triangulation (AT) report detailing compliance with relevant accuracy statistics.
    - Processing Report detailing photogrammetric processed used to manually compile elevation data or to semi-automatically compile elevation data with automated image correlation or other techniques.
    - QA/QC reports.
    - Geo-referenced extents of each delivered dataset.
2. Digital bare earth elevation data product (DEM, DTM, mass points, breaklines, contours) specified in the Statement of Work.
3. Optional breaklines, when produced, shall be delivered in compliance with guidance in Attachment 3

2.4 Ground Surveys

All ground surveys must be performed in accordance with procedures in Section A.5, Ground Control, and Section A.6, Ground Surveys, in Appendix A of FEMA's Guidelines. Cross-section surveys and hydraulic structure surveys shall also be performed in accordance with sections A.4.6 and A.4.7, respectively, of Appendix A.

2.5 Low Confidence Areas

Regardless of technology used, FEMA requires that low confidence areas be delineated by the data provider to indicate areas where the vertical data may not meet the data accuracy requirements due to heavy vegetation even though the specified nominal pulse spacing was met or exceeded in those areas. The metadata must explain steps taken to minimize the areas delineated as low confidence areas. Accuracy test points are normally retained within such areas and are not discarded. The data provider must take reasonable steps to minimize areas delineated as low confidence areas, taking into consideration the density of the vegetation in the floodplain being mapped and other factors.

These low confidence areas must be delivered as polygons in accordance with a database schema. The database schema for polygons defining low confidence areas is as follows.

Feature Dataset: TOPOGRAPHIC **Feature Class:** CONFIDENCE
Feature Type: Polygon
Contains M Values: No **Contains Z Values:** No
Annotation Subclass: None
XY Resolution: Accept Default Setting **Z Resolution:** Accept Default Setting
XY Tolerance: 0.003 **Z Tolerance:** N/A

2.5.1 Description

This polygon feature class will depict areas where the ground is obscured by dense vegetation, meaning that the resultant bare-earth digital terrain model (DTM) may not meet the required accuracy specifications in these obscured areas. Low confidence areas can pertain to lidar, photogrammetry or IFSAR.

2.5.2 Table Definition

Field Name	Data Type	Allow Null Values	Default Value	Domain	Precision	Scale	Length	Responsibility
OBJECTID	Object ID							Assigned by Software
SHAPE	Geometry							Assigned by Software
DATESTAMP_DT	Date	Yes			0	0	8	Assigned by Contractor
SHAPE_LENGTH	Double	Yes			0	0		Calculated by Contractor
SHAPE_AREA	Double	Yes			0	0		Calculated by

								Contractor
TYPE	Long Integer	No	1	Obscure	0	0		Assigned by Contractor

2.5.3 Feature Definition

Code	Description	Definition	Capture Rules
1	Low Confidence Area	“Low confidence areas” are defined by the data provider to indicate areas where the vertical data may not meet the data accuracy requirements due to heavy vegetation even though the nominal pulse spacing was met or exceeded in those areas.	Capture as closed polygon. Compiler does not need t z-values of vertices; feature class will be 2-D only.

Attachment 3 – Topographic Breakline and Hydro-Enforcement Specifications

FEMA has no minimum breakline requirements; breaklines are optional and depend upon the procedures used to perform hydrologic and hydraulic modeling. The FEMA Project Manager should specify the breaklines requirements if desired based on the planned approach for hydraulic analysis or the mapping partner may propose breakline requirements based on the anticipated hydraulic modeling approach.

When optional breaklines are produced, the following breakline topology rules must be followed for the applicable feature classes. The topology must be validated by each contractor prior to delivery to FEMA.

Name: BREAKLINES_Topology			Cluster Tolerance: 0.003 Maximum Generated Error Count: Undefined State: Analyzed without errors	
Feature Class	**Weight**	**XY Rank**	**Z Rank**	**Event Notification**
COASTALSHORELINE	5	1	1	No
HYDROGRAPHICFEATURE	5	1	1	No
PONDS_AND_LAKES	5	1	1	No
HYDRAULICSTRUCTURE	5	1	1	No
ISLAND	5	1	1	No

Topology Rules

Name	Rule Type	Trigger Event	Orgin (FeatureClass::Subtype)	Destination (FeatureClass::Subtype)
Must not intersect	The rule is a line-no intersection rule	No	HYDRAULICSTRUCTURE::All	HYDRAULICSTRUCTURE::All
Must not intersect	The rule is a line-no intersection rule	No	HYDROGRAPHICFEATURE::All	HYDROGRAPHICFEATURE::All
Must not intersect	The rule is a line-no intersection rule	No	COASTALSHORELINE::All	COASTALSHORELINE::All
Must not intersect	The rule is a line-no intersection rule	No	PONDS_AND_LAKES::All	PONDS_AND_LAKES::All
Must not intersect	The rule is a line-no intersection rule	No	ISLAND::All	ISLAND::All
Must not overlap	The rule is a line-no overlap line rule	No	HYDROGRAPHICFEATURE::All	COASTALSHORELINE::All
Must not self-intersect	The rule is a line-no self intersect rule	No	HYDRAULICSTRUCTURE::All	HYDRAULICSTRUCTURE::All
Must not self-intersect	The rule is a line-no self intersect rule	No	HYDROGRAPHICFEATURE::All	HYDROGRAPHICFEATURE::All
Must not self-intersect	The rule is a line-no self intersect rule	No	COASTALSHORELINE::All	COASTALSHORELINE::All

Name	Rule Type	Trigger Event	Orgin (FeatureClass::Subtype)	Destination (FeatureClass::Subtype)
Must not self-intersect	The rule is a line-no self intersect rule	No	PONDS_AND_LAKES::All	PONDS_AND_LAKES::All
Must not self-intersect	The rule is a line-no self intersect rule	No	ISLAND::All	ISLAND::All

Attachment 4 – Topographic Data Quality Review and Reporting Process

To complement the topographic data specifications in this procedure memorandum, this attachment describes data quality review processes and reporting obligations to be performed on new topographic data procured by FEMA as part of a flood hazard study or Risk MAP project. The mapping partner responsible for producing the elevation data is responsible for the quality of the product. In addition, FEMA may assign another mapping partner to perform Independent QA/QC of Topographic Data

Existing topographic data leveraged by FEMA should be certified to meet or tested for the vertical accuracy requirements specified in this procedure memo. In addition, the quality reviews described here are best practices that may be applied to existing topographic data. However, some of the documentation needed to perform some of these reviews may not be readily available for existing data..

4.1 Quality Reviews and Reporting Performed by Data Provider

The mapping partner responsible for producing new elevation data must submit copies of QA reports as specified in USGS Lidar Guidelines and Base Specification version 13. Unless the responsibility for checkpoint surveys and vertical accuracy testing is specifically assigned to a different mapping partner performing Independent QA/QC, the mapping partner responsible for producing the elevation data must test the unclassified point cloud data for Fundamental Vertical Accuracy (FVA) and, when lidar post-processing is performed must also test the bare earth product for Supplemental Vertical Accuracy (SVA) and Consolidated Vertical Accuracy (CVA).

4.1.1 Ground Survey of Quality Review Checkpoints

Quality review checkpoint surveys shall be performed in accordance with procedures in Section A.6.4, Checkpoint Surveys and A.6.5 Survey Records, in Appendix A of FEMA's Guidelines.

Checkpoints surveyed for accuracy reporting shall not be used by the data provider in the calibration or adjustment of the topographic data.

4.1.2 Assessment of Initial Vertical Accuracy

Assessment of the fully calibrated, raw point cloud initial vertical accuracy is required to ensure data has successfully completed preliminary processing. The absolute and relative accuracy of the data, relative to known control, shall be verified prior to classification and subsequent product development , by calculating FVA, measured in open, non-vegetated terrain. The spatial distribution of checkpoints for FVA testing should be based on the entire project collection area, distributed to avoid clustering, and support vertical accuracy reporting that is representative of the whole project.

If the project area exceeds 2,000 square miles it must be divided into smaller blocks of 2,000 square miles or less and tested as individual areas. In addition, the division of large project areas should apply the following rules if applicable:

- Divide areas by vendor used
- Divide areas by sensor type (manufacturer)
- Divide areas by flight dates if significant temporal difference is present
- Other logical project divisions based factors that might have a systematic relationships to data quality.

Reporting of positional accuracy shall be in accordance with ASPRS/NDEP standards as well as the USGS *Lidar Guidelines and Base Specification*, v13, Section II.13 and shall use the following statement:

Tested ____ (meters) fundamental vertical accuracy at 95% confidence level

Reporting on the assessment of the point cloud initial vertical accuracy shall include the following at a minimum:

- ***A description of the process used to test the points***
- A graphic depicting the spatial distribution of the ground survey checkpoints
- Descriptive statistics and RMSEz in FVA calculations

4.1.3 Assessment of Bare Earth Vertical Accuracy

When bare earth post-processing is included in the project, assessment of the vertical accuracy for the delivered bare earth elevation product is required to ensure data has successfully completed post processing. Reporting of positional accuracy shall be in accordance with ASPRS/NDEP standards for FVA and CVA. Testing should be performed on the bare earth deliverable as specified in the mapping activity statement, along with the following guidance:

- If an assessment of initial vertical accuracy (FVA) was conducted prior to the processing of the data (section 4.1.2), the FVA checkpoints can again be used in the CVA computations if located within the area to be processed
- The SVA for up to three significant land cover categories, in terms of percentage of the project area covered, shall be tested in addition to the open/bare ground areas already tested for FVA Land cover categories making up 10% or more of the project area should be included in the SVA testing
- For smaller projects less than 1,000 square miles, fewer check points for SVA testing is acceptable. The number of checkpoints shall be reduced to control the QA cost to about 10% of the acquisition and processing cost. The checkpoints should be distributed evenly across the SVA land cover types.
- Processing areas greater than 2,000 square miles must be divided into smaller blocks of 2,000 square miles or less and tested as individual areas. In addition,

the division of large processing areas should apply the following rules if applicable:

- Divide areas by vendor used
- Divide areas by sensor type (manufacturer)
- Divide areas by flight dates if significant temporal difference is present
- Other logical project divisions based factors that might have a systematic relationships to data quality.

1.

- Each block of 2,000 square miles or less shall be tested for FVA, SVA, and CVA

Checkpoints used for testing SVA of the bare earth elevation product must be located in the areas where bare earth post-processing was performed, distributed to avoid clustering, and support vertical accuracy reporting that is representative of the post processed areas. The SVA results will then be combined with the FVA results to compute CVA for the entire project area.

Reporting on the assessment of the vertical accuracy of the post-processed, delivered elevation data shall include the following at a minimum:

- ***A description of the process used to test the points***
- A graphic depicting the spatial distribution of the ground survey checkpoints
- An analysis of checkpoints that have errors exceeding the 95th percentile in SVA and CVA calculations
- Descriptive statistics and RMSEz in FVA calculations

4.1.4 Aerial Data Acquisition and Calibration

The mapping partner responsible for producing new elevation data must also submit a pre-flight Operations Plan and a post-flight Aerial Acquisition and Calibration Report will be provided to FEMA and/or their representatives by the data acquisition provider and uploaded to the MIP by the data provider. This information will aid future quality review efforts. The required reporting includes the following, outlined in Tables 4.1 and 4.2.

Table 4.1. Pre-flight Operations Plan

Item	Contents	Format
Flight Operations	• Planned flight lines	MS Word or

Plan	- Planned GPS stations - Planned control - Planned airport locations - Calibration plans - Quality procedures for flight crew (project-related for pilot and operator) - Planned scanset (sensor settings and altitude) - Type of aircraft - Procedure for tracking, executing, and checking reflights - Considerations for terrain, cover, and weather in project	PDF

Table 4.2. Post-flight Aerial Acquisition and Calibration Report

Item	Contents	Format
GPS Base station info	- Base station name - Latitude/Longitude (ddd-mm-ss.sss) - Base height (Ellipsoidal meters) - Maximum Position Dilution of Precision PDOP - Map of locations	Excel, TXT, MS Word, or PDF for data; ESRI shape file for map of locations (data and info may be in attribute table)
GPS/IMU processing summary	- Max Horizontal GPS Variance (cm) - Max Vertical GPS Variance (cm) - Notes on GPS quality (High, Good, etc.) - GPS separation plot - GPS altitude plot - PDOP plot - Plot of GPS distance from base station/s	MS Word or PDF with screenshots
Coverage	- Verification of project coverage	ESRI shape files reflecting the actual coverage area and not the applicable tiles.
Flights	- As-flown trajectories - Calibration lines	ESRI shape files

Item	Contents	Format
Flight logs	• Incorporated as appendix Should include: • Job # / name • Lift # • Block or AOI designator • Date • Aircraft tail number, type • Flight line, line #, direction, start/stop, altitude, scan angle/rate, speed, conditions, comments • Pilot name • Operator name • AGC switch setting • Laser pulse rate • Mirror rate • Field of view • Airport of operations • GPS base station names or numbers Comments	
Control	• Ground control and base station layouts	ESRI shape files
Data verification/QC	• Description of data verification/QC process • Results of verification and QC steps	MS Word, Excel or PDF

4.2 Quality Reviews and Reporting Performed by Independent QA/QC

When a mapping partner is assigned to perform *Independent QA of Topographic Data* macro and micro reviews of the submitted reports and data shall be performed. Macro reviews are automated processes or are checks required to establish overall data quality and shall be applied to the entire project area. Micro reviews are typically manual in nature and shall be used to check no less than 3 project tiles or 5% of the total number of project tiles, whichever is the greater amount.

Tables 4.3 and 4.4 outline macro and micro reviews to be conducted on the raw point cloud and for data that is post-processed. Some reviews are duplicated between the raw point cloud and post-processing phases due to the potential for errors to be introduced into the data during post-processing.

Table 4.3. Review of fully calibrated raw point cloud

Macro Reviews	
Product	**Reviewed for**
Pre-flight Operations Plan	• Compliance with section 4.1.4 and checklists in 4.2.1 • Compliance with the specifications outlined in the Mapping Activity Statement
Post-flight Aerial Acquisition and Calibration Report	• Compliance with section 4.1.4 and checklists in 4.2.1 • Compliance with the specifications outlined in the Mapping Activity Statement

Macro Reviews	
Product	**Reviewed for**
LAS Point Cloud Files	• Project area coverage – buffered by a minimum of 100 meters • Data voids • Inclusion of GPS time stamp • Correct projection, datum and units • Multiple Discrete Returns (at least 3 returns per pulse) • Correct header information • Other LAS attributes required by Mapping Activity Statement such as intensity values • Correct nominal pulse spacing as required by specific risk and/or level of study and buy-up options.
Metadata	• Compliance with the FEMA Terrain Metadata Profile
Micro Reviews	
Product	**Reviewed for**
LAS Point Cloud Files	• Excessive noise • Elevation steps • Other anomalies present in the point cloud

Table 4.4. Review of post-processed data

Macro Reviews	
Product	**Reviewed for**
LAS Point Cloud Files	• Compliance with checklists in section 4.2.1 • Project area coverage – buffered by a minimum of 100 meters • Data voids • Inclusion of GPS time stamp • Correct projection, datum and units • Multiple Discrete Returns (at least 3 returns per pulse) • Correct header information • Other LAS attributes required by Mapping Activity Statement such as intensity values • Correct nominal pulse spacing as required by specific risk and/or level of study and buy-up options. • Easting, northing and elevation reported to nearest 0.01m or 0.01 ft • Correct file-naming convention
Metadata	• Compliance with the FEMA Terrain Metadata Profile

Macro Reviews	
Product	**Reviewed for**
Micro Reviews	
Product	**Reviewed for**
LAS Point Cloud Files	• Excessive noise • Elevation steps • Other anomalies present in the point cloud • Correct classification and cleanliness: no more than 2% of the project area classified to bare ground shall contain artifacts such as buildings, trees, overpasses or other above-ground features in the ground point classification (Class 2). In addition, no more than 2% of the project area shall contain incorrect classifications of points. (USGS *Lidar Guidelines and Base Specification*, v13, Section IV.14. •
Optional - Breaklines	• Correct topology • Horizontal placement • Completeness • Continuity *See Attachment 3 for breakline topology rules to be checked against*

If the mapping partner responsible *Independent QA of Topographic Data* is tasked to perform assessment of vertical accuracy of the elevation data as described above in sections 4.1.2 and 4.1.3:

- Assessment of FVA only for pre-processed data to be stored and FVA, SVA, and CVA for post-processed data
- Review of data provider vertical accuracy assessment reports

4.2.1 Recommended Checklists

The following checklists are recommended for use during Independent QA/QC review to facilitate the process.

Pre-flight review checklist

Checklist	Pass / Fail	Comments
Planned lines – sufficient coverage, spacing, and length		
Planned GPS stations		
Planned ground control – sufficient to control and boresight		
Calibration plans		
Vendor quality procedures		
Lidar sensor scan set – planned for proper scan angle, sidelap, design pulse.		
Aircraft utilizes ABGPS		

Sensor supports project design pulse density		
Type of aircraft – supports project design parameters		
Reflight procedure – tracking, documenting, processing		
Project design supports accuracy requirements of project		
Project design accounts for land cover and terrain types		

Post-flight review checklists

Checklist for QA of Flight Logs

Checklist	Included Yes/No	Comments
Flight logs – job #/name		
Flight logs – block or AOI		
Flight logs – date		
Flight logs – aircraft tail #		
Flight logs – lines - #		
Flight logs – lines - direction		
Flight logs – lines – start/stop		
Flight logs – lines – altitude		
Flight logs – lines – scan angle		
Flight logs – lines – speed		
Flight logs – conditions		
Flight logs – comments		
Flight logs - pilot name		
Flight logs - operator name		
Flight logs - AGC switch		
Flight logs – GPS base stations		

Checklist for Aerial Acquisition Report

Checklist	Included? Yes/No	Comments
GPS base station – names		
GPS base station – lat/longs		
GPS base station – heights		
GPS base station – map		
GPS quality – separation plot		
GPS quality – PDOP plot		

GPS quality - horizontal Acc.		
GPS quality - vertical Acc.		
Sensor calibration process		
Verification of AOI coverage		
As-flown trajectories		
Ground control layout		
Data verification process documented		

Final terrain product review checklists

Checklist for QA of Terrain Products		
Checklist	**Pass/Fail**	**Comments**
Vertical datum correct		
Horizontal datum correct		
Projection correct		
Vertical units correct		
Horizontal units correct		
Each return contains – GPS week, GPS second, easting, northing, elevation, intensity, return # and classification		
No duplicate entries		
GPS second reported to nearest microsecond		
Easting, northing, and elevation reported to nearest 0.01 m or 0.01 ft		
Classifications correct – 1. Unclassified; 2. Bare-earth ground; 7. Noise; 9. Water; 10. Ignored ground; 11. Withheld		
Cloud file structure conforms to project tile layout		
Naming conforms project requirements		
Deliverable tiles checked for significant gaps not covered by aerial acquisition checks and/or caused by data post-processing/filtering		

M.4 Terrain Submittal Standards

M.4.1 Overview

This section describes the format and type of terrain data required to be submitted to FEMA for FISs. All data must be submitted in digital format. The Mapping Partner performing "Develop Topographic Data" is required to submit the data in this section.

The Mapping Partner should refer to Appendix A of these Guidelines for guidance on terrain data production. This section is not intended to detail the specifications and procedures for coastal hydrographic surveys. The reader is referred to the following additional sources for details on coastal surveys:

- National Oceanic and Atmospheric Administration (NOAA) NOS Hydrographic Survey Specifications and Deliverables (April 2007);
- NOAA Office of Coast Survey Hydrographic Surveys Division Field Procedures Manual (March 2007); and
- U.S. Army Corps of Engineers (USACE) National Coastal Mapping Program Joint LiDAR Bathymetry Technical Center for Expertise.
- Appendix D of the *Guidelines and Specifications for Flood Hazard Mapping Partners* (February 2007).

The submitting Mapping Partner must retain copies of all Project-related data for a period of 3 years. The submitting Mapping Partner will need these data for responding to the following:

- Questions from FEMA or the receiving Mapping Partner during the review of the final draft materials;
- Comments and appeals submitted to FEMA during the 90-day appeal period following the issuance of preliminary maps; and
- Other concerns and issues that may develop during the processing of the new or revised FIS report and FIRM.

M.4.2 Requirements

M.4.2.1 Data Files

The minimum data required for the terrain data submission are the source terrain and topographic maps from the terrain data used in the study. These data can be contained in a single file or in tiled files. When tiled files are submitted, they must be accompanied by a tiling index file. If any processing has been performed, the original and final files must be submitted as well. For instance, if terrain data were blended from three different sources to create the final terrain data, the original of the three sources and the final terrain file that results from the blending process must be submitted. This information is required to be a georeferenced, digital submittal. The following information must be submitted when it is used to perform a study:

- LiDAR data (bare earth and all returns);
- Tiling index for data files;
- Breaklines and Mass Points;
- Contours;
- Bathymetry;
- Digital Elevation Models (DEMs);
- Hydro-corrected DEMs;
- Triangulated Irregular Networks (TINs);
- Hydro-corrected TINs;
- USGS topographic data;
- All other terrain data; and
- LiDAR data generated as part of the project must be submitted as two separate files: one for bare earth only, and one for all returns if bare earth processing was performed as part of this project. For existing LiDAR data not processed as part of the project, the bare earth data must be submitted, and the submittal of the all returns data (if available) is optional.

A project narrative describing the SOW, direction from FEMA, issues, information for next Mapping Partner, etc. (see DCS User Guide for additional details).

M.4.2.2 General Correspondence

A file that compiles general correspondence must be submitted by the Mapping Partner assigned to "Develop Topographic Data." General correspondence is the written correspondence generated or received by the Mapping Partner to fulfill the requirements of developing topographic data. Correspondence includes any documentation generated during this task such as letters; transmittals; memoranda; general status reports and queries; SPRs; technical issues that need to be documented; and direction given by FEMA.. Contractual documents, such as a signed SOW or MAS, are not to be submitted as a part of this appendix.

M.4.2.3 Certification of Work

FEMA-funded (including CTP-funded projects if they are a part of FEMA's flood mapping program) terrain data development must be certified using the Certification of Compliance Form provided in Figure M-11 in section M.10. Submittal of this certification at "Develop Topographic Data" workflow step is required if this is the only task performed by the Mapping Partner. Mapping Partners that are contracted to perform multiple mapping tasks can submit one certification form to certify all the work performed. A PDF file of this form with the original signature, data, and seal affixed to the form must be submitted digitally in the general directory identified in section M.4.2.8. This form must be signed by a registered or certified professional from the firm contracted to perform the work, or by the responsible official of a government agency. A digital version of this form is available at www.fema.gov.

M.4.2.4 Acceptable File Formats

Terrain data used to perform the study must be submitted in a georeferenced, digital format as listed below. These data can be contained in a single file or in a tiled set of files. Any tiled data must have an accompanying index spatial file.

- Contours, Masspoints, and breaklines – Personal geodatabase, DXF, or shapefile
- DEMs – ESRI grid, GeoTIFF, or ASCII grid
- LiDAR – LAS file, ASCII x, y, z file
- Terrain – ESRI ArcGIS
- Word – project narrative
- PDF – correspondence and certification

PDF files must be created using the source file (e.g., Word file), if the source file is created by the Mapping Partner, rather than raster scans of hard copy text documents. PDF files created must allow copying of text and pasting to another document. In addition, ESRI shapefiles must include .PRJ files.

M.4.2.5 Metadata

A metadata file in XML format that complies with the NFIP Terrain Metadata Profiles (provided in Section M.14) must be included with the submittal. The profiles follow the FGDC Content Standard for metadata and define additional domains and business rules for some elements that are mandatory for FEMA, based on the specific submittal type. For each spatial data source in the metadata file, the Mapping Partner must assign a Source Citation Abbreviation.

If metadata is available from an agency or organization that provided data for use in the study, it should be included in the metadata submittal in addition to the NFIP Terrain Metadata Profiles. Reference the data providers' original metadata record in the Lineage section of the NFIP metadata profile. If there is a Web-accessible metadata record for the original data set, the URL to the metadata may be provided in the optional Source Citation - Online Linkage element. Otherwise, the Source Contribution [free text] element may include information on how to access the metadata record for the data sets obtained.

M.4.2.6 Transfer Media

Mapping Partners must submit files via the internet by uploading to the MIP (http://www.hazards.fema.gov) or by mailing the files to FEMA on one or more of the following electronic media:

- CD-ROM;
- DVD; or
- External Hard Drive (for very large data submissions with a return label for shipment back to the partner).

In special situations or as technology changes, other media may be acceptable if coordinated with FEMA.

When data is mailed to FEMA, all submitted digital media must be labeled with at least the following information:

- Mapping Partner's name;
- Community name and State for which the FIS was prepared;
- Terrain Data;
- Date of submission (formatted mm/dd/yyyy); and
- Disk [*sequential number*] of [*number of disks*]. The media must be numbered sequentially, starting at Disk 1. [Number of disks] represents the total number of disks in the submission.

M.4.2.7 Transfer Methodology

Terrain artifacts can be uploaded to the MIP by following the guidelines for Data Submission and Validation located on the MIP (https://hazards.fema.gov) under "User Guidance" in the "Guides & Documentation" tab of "MIP User Care".

M.4.2.8 Directory Structure and Folder Naming Conventions

The files presented in section M.4.2 Requirements must be submitted to the MIP or mailed to FEMA within the following directory structure. Data files must be organized under an applicable 8-digit Hydrologic Unit Code (HUC-8). The following folders can be created either on a local work space (i.e., a personal computer) or within the work space for the community on the MIP. If the following folders are generated locally, these newly created folders and their contents must be uploaded to the MIP. Terrain files are arranged into appropriate directories based on data type.

- \HUC-8\General
  - Project narrative
  - Certification
- \HUC-8\Correspondence
  - Letters; transmittals; memoranda; general status reports and queries; SPRs; technical issues; direction by FEMA; and internal communications, routing slips, and notes.
- \HUC-8\All_Returns
  - LIDAR data – All Returns
  - LIDAR Tile Index spatial file (if used)
- \HUC-8\Bare_Earth
  - LIDAR data – Bare Earth Points
  - LIDAR Tile Index spatial file (if used)
- \HUC-8\Breaklines
  - 3D breakline spatial files
  - 3D breakline Tile Index spatial file (if used)

  - 2D breakline spatial files
  - 2D breakline Tile Index spatial file (if used)
  - Mass Points
- \HUC-8\Contours
  - Contour spatial files
  - Contour Tile Index spatial file (if used)
  - Bathymetric files
  - Bathymetric Tile Index spatial file (if used)
- \HUC-8\DEM
  - Uncorrected DEM files
  - Tile Index spatial file (if used)
- \HUC-8\HDEM
  - Hydrologically correct DEM files
  - Tile Index spatial file (if used)
- \HUC-8\TIN
  - Uncorrected TIN files
  - Terrain (ESRI ArcGIS format)
  - Tile index spatial file (if used)
- \HUC-8\HTIN
  - Hydrologically corrected TIN files
  - Terrain (ESRI ArcGIS format)
  - Tile Index spatial file (if used)
- \HUC-8\Supplemental Data
  - As-built drawings
  - GIS representation of structures

U.S. Geological Survey
National Geospatial Program
Lidar Guidelines and Base Specification

Version 13 – ILMF 2010

The U.S. Geological Survey National Geospatial Program (NGP) has cooperated in the collection of numerous lidar datasets across the nation for a wide array of applications. These collections have used a variety of specifications and required a diverse set of products, resulting in many incompatible datasets and making cross-project analysis extremely difficult. The need for a single base specification, defining minimum collection parameters and a consistent set of deliverables, is apparent.

Beginning in late 2009, an increase in the rate of lidar data collection due to American Reinvestment and Recovery Act (ARRA) funding for The National Map makes it imperative that a single data specification be implemented to ensure consistency and improve data utility. Although the development of this specification was prompted by the ARRA stimulus funding, the specification is intended to remain durable beyond ARRA funded NGP projects.

The primary intent of this specification is to create consistency across all NGP funded lidar collections, in particular those undertaken in support of the National Elevation Dataset (NED). Unlike most other “lidar specs” which focus on the derived bare-earth DEM product, this specification places unprecedented emphasis on the handling of the source lidar point cloud data. This is to assure that the complete source dataset collected remains intact and viable to support the wide variety of non-DEM science and mapping applications that benefit from lidar technology. In the absence of other comprehensive specifications or standards, it is hoped that this specification will, to the highest degree practical, be adopted by other USGS programs and disciplines, and by other Federal agencies.

Adherence to these minimum specifications ensures that bare-earth Digital Elevation Models (DEMs) derived from lidar data is suitable for ingestion into the NED (National Elevation Dataset) at the 1/9 arc-second resolution, and can be resampled for use in the 1/3 and 1 arc-second NED resolutions. It also ensures that the point cloud source data are handled in a consistent manner by all data providers and delivered to the USGS in clearly defined formats. This allows straight-forward ingest into CLICK (Center for Lidar Information, Coordination, and Knowledge) and simplifies subsequent use of the source data by the broader scientific community, particularly with regard to cross-collection analysis.

It must be stressed that this is a **base specification,** defining <u>minimum parameters</u>. It is expected that local conditions in any given project area, specialized applications for the data, or the preferences of cooperators, may mandate more stringent requirements. The

USGS encourages the collection of more detailed, accurate, or value-added data. A list of common upgrades to the minimum requirements defined here is provided in Appendix 1.

In addition, it is recognized that the USGS NGP also employs lidar technology for specialized scientific research and other projects whose requirements are incompatible with the provisions of this Specification. In such cases, and with properly documented justification supporting the need for the variance, waivers of any part or all of this Specification may be granted.

It is conceivable that in some cases, based on specific topography, land cover, intended application, or other factors, the USGS-NGP may require specifications more rigorous than those defined in this document. It is expected that this would be highly uncommon.

Lidar is still a relatively new technology; adolescent but not fully matured.. Advancements and improvements in instrumentation, software, processes, applications, and understanding are constantly being made. It would not be possible to develop a set of guidelines and specifications that address all of these advances. The current document is based on our understanding of and experience with the industry and technology at the present time. Furthermore, we acknowledge that there is a lack of commonly accepted "best practices" for numerous processes and technical assessments (i.e., measurement of NPS, point clustering, classification accuracy, etc.). The USGS encourages the development of such best practices through the appropriate industry and professional governance organizations, and we eagerly await the opportunity to include them in future revisions to this and other similar documents.

It is not the intention of the USGS to stifle the development of the lidar industry, nor to discourage innovation within the technology. Technical alternatives to any part of this document may be submitted with any proposal and will be given due professional consideration.

I. COLLECTION

1. Multiple Discrete Return, capable of at least 3 returns per pulse

   Note: Full waveform collection is both acceptable and welcomed; however, waveform data is regarded as supplemental information. The requirement for deriving and delivering multiple discrete returns remains in force in all cases.

2. Intensity values for each return.

3. Nominal **Pulse** Spacing (NPS) of 1-2 meters, dependent on the local terrain and landcover conditions. Assessment to be made against single swath, first return data located within the geometrically usable center portion (typically ~90%) of each swath. Average along-track and cross-track point spacings should be comparable.

4. Collections designed to achieve the NPS through swath overlap or multiple passes are generally discouraged. Such collections may be permitted with prior approval.

5. Data Voids [areas => $(4*NPS)^2$, measured using 1st-returns only] within a single swath are not acceptable, except:

   - where caused by water bodies
   - where caused by areas of low near infra-red (NIR) reflectivity such as asphalt or composition roofing.
   - where appropriately filled-in by another swath

6. The spatial distribution of geometrically usable points is expected to be uniform and free from clustering. In order to ensure uniform densities throughout the data set:

   - A regular grid, with cell size equal to the design NPS*2 will be laid over the data.
   - At least 90% of the cells in the grid shall contain at least 1 lidar point.
   - Assessment to be made against single swath, first return data located within the geometrically usable center portion (typically ~90%) of each swath.
   - Acceptable data voids identified previously in this specification are excluded.

   Note: This requirement may be relaxed in areas of significant relief where it is impractical to maintain a consistent NPS.

7. Scan Angle: Total FOV should not exceed 40° (+/-20° from nadir) USGS quality assurance on collections performed using scan angles wider than 34° will be particularly rigorous in the edge-of-swath areas. Horizontal and vertical accuracy shall remain within the requirements as specified below.

   Note: This requirement is primarily applicable to oscillating mirror lidar systems. Other instrument technologies may be exempt from this requirement.

8. Vertical Accuracy of the lidar data will be assessed and reported in accordance with the guidelines developed by the NDEP and subsequently adopted by the ASPRS. The complete guidelines may be found in Section 1.5 of the Guidelines document. See:

   http://www.ndep.gov/NDEP_Elevation_Guidelines_Ver1_10May2004.pdf

   Vertical accuracy requirements using the NDEP/ASPRS methodology are:

   FVA <= 24.5cm ACCz, 95% (12.5cm RMSEz)
   CVA <= 36.3cm, 95th Percentile
   SVA <= 36.3cm, 95th Percentile

   - Accuracy for the lidar point cloud data is to be reported independently from accuracies of derivative products (i.e., DEMs). Point cloud data accuracy is to be tested against a TIN constructed from bare-earth lidar points.
   - Each landcover type representing 10% or more of the total project area must be tested and reported as an SVA.
   - For SVAs, the value is provided as a target. It is understood that in areas of dense vegetation, swamps, or extremely difficult terrain, this value may be exceeded. Overall CVA requirements must be met in spite of "busts" in individual SVAs.

   Note: These requirements may be relaxed in cases:

   - *where there exists a demonstrable and substantial increase in cost to obtain this accuracy.*
   - *where an alternate specification is needed to conform to previously contracted phases of a single larger overall collection effort, i.e., multi-year statewide collections, etc.*
   - *where the USGS agrees that it is reasonable and in the best interest of all stakeholders to use an alternate specification.*

9. Relative accuracy <=7cm $RMSE_Z$ within individual swaths; <=10cm RMSEz within swath overlap (between adjacent swaths).
10. Flightline overlap 10% or greater, as required to ensure there are no data gaps between the usable portions of the swaths. Collections in high relief terrain are expected to require greater overlap. Any data with gaps between the geometrically usable portions of the swaths will be rejected.
11. Collection Area: Defined Project Area, buffered by a minimum of 100 meters.
12. Collection Conditions:
   - Atmospheric: Cloud and fog-free between the aircraft and ground
   - Ground:
     - Snow free. Very light, undrifted snow may be acceptable in special cases, with prior approval.

    - No unusual flooding or inundation, except in cases where the goal of the collection is to map the inundation.
- Vegetation: Leaf-off is preferred, however:
    - As numerous factors will affect vegetative condition at the time of any collection, the USGS NGP only requires that penetration to the ground must be adequate to produce an accurate and reliable bare-earth surface suitable for incorporation into the 1/9 (3-meter) NED.
    - Collections for specific scientific research projects may be exempted from this requirement, with prior approval.

II. DATA PROCESSING and HANDLING

1. All processing should be carried out with the understanding that all point deliverables are required to be in fully compliant LAS format, v1.2 or v1.3. Data producers are encouraged to review the LAS specification in detail.
2. If full waveform data is collected, delivery of the waveform packets is required. LAS v1.3 deliverables with waveform data are to use external “auxiliary” files with the extension “.wdp” for the storage of waveform packet data. See the LAS v1.3 Specification for additional information.
3. GPS times are to be recorded as Adjusted GPS Time, at a precision sufficient to allow unique timestamps for each pulse. Adjusted GPS Time is defined to be Standard (or satellite) GPS time minus $1*10^9$. See the LAS Specification for more detail.
4. Horizontal datum shall be referenced to the North American Datum of 1983/HARN adjustment. Vertical datum shall be referenced to the North American Vertical Datum of 1988 (NAVD 88). The most recent NGS-approved Geoid model shall be used to perform conversions from ellipsoidal heights to orthometric heights.
5. The USGS preferred Coordinate Reference System for the Conterminous United States (CONUS) is: UTM, NAD83, Meters. Each discrete project is to be processed using the predominant UTM zone for the overall collection area.

   State Plane Coordinate Reference Systems that have been accepted by the European Petroleum Survey Group (EPSG) and that are recognized by ESRI GIS software may be used by prior agreement with the USGS.

   Alternative projected coordinate systems for collections in Alaska, Hawaii, and other areas Outside the Conterminous United States (OCONUS) must be approved by the USGS prior to collection.
6. All references to the Unit of Measure “Feet” or “Foot” must specify either “International” or “U.S. Survey”
7. Long swaths (those which result in a LAS file larger than 2GB) should be split into segments no greater than 2GB each. Each segment will thenceforth be

regarded as a unique swath and shall be assigned a unique File Source ID. Other swath segmentation approaches may be acceptable, with prior approval. Renaming schemes for split swaths are at the discretion of the data producer. The Processing Report shall include detailed information on swath segmentation sufficient to allow reconstruction of the original swaths if needed.

8. Each swath shall be assigned a unique File Source ID. The Point Source ID field for each point within each LAS swath file shall be set equal to the File Source ID prior to any processing of the data. See the LAS Specification.
9. Point Families (multiple return "children" of a single "parent" pulse) shall be maintained intact through all processing prior to tiling. Multiple returns from a given pulse shall be stored in sequential (collected) order.
10. All collected swaths are to be delivered as part of the "Raw Data Deliverable". This includes calibration swaths and cross-ties. All collected points are to be delivered. No points are to be deleted from the swath LAS files. <u>This in no way requires or implies that calibration swath data are to be included in product generation</u>. Excepted from this are extraneous data outside of the buffered project area (aircraft turns, transit between the collection area and airport, transit between fill-in areas, etc.). These points may be permanently removed.
11. Outliers, blunders, noise points, geometrically unreliable points near the extreme edge of the swath, and other points deemed unusable are to be identified using the "Withheld" flag, as defined in the LAS specification.
    - This applies primarily to points which are identified during pre-processing or through automated post-processing routines.
    - If processing software is not capable of populating the "Withheld" bit, these points may be identified using Class=11.
    - "Noise points" subsequently identified during manual Classification and Quality Assurance/Quality Control (QA/QC) may be assigned the standard LAS classification value for "Noise" (Class=7), regardless of whether the noise is "low" or "high" relative to the ground surface.
12. The ASPRS/LAS "Overlap" classification (Class=12) shall not be used. ALL points not identified as "Withheld" are to be classified.
    - If overlap points are required to be differentiated by the data producer or cooperating partner, they must be identified using a method that does not interfere with their classification, such as:
        - Overlap points are tagged using Bit:0 of the User Data byte, as defined in the LAS specification. (SET=Overlap).
        - Overlap points are classified using the Standard Class values + 16.
        - Other techniques as agreed upon in advance
    - The technique utilized must be clearly described in the project metadata files.

Note: A standard bit setting for identification of overlap points has been planned for a future version of LAS.

13. Positional Accuracy Validation: The absolute and relative accuracy of the data, both horizontal and vertical, and relative to known control, shall be verified prior to classification and subsequent product development. This validation is obviously limited to the Fundamental Vertical Accuracy, measured in clear, open areas. A detailed report of this validation is a required deliverable.

14. Classification Accuracy: It is expected that due diligence in the classification process will produce data that meets the following test:

    > Within any 1km x 1km area, no more than 2% of non-withheld points will possess a demonstrably erroneous classification value.
    >
    > This includes points in Classes 0 and 1 that should correctly be included in a different Class as required by the contract.

    Note: This requirement may be relaxed to accommodate collections in areas where the USGS agrees classification to be particularly difficult.

15. Classification Consistency: Point classification is to be consistent across the entire project. Noticeable variations in the character, texture, or quality of the classification between tiles, swaths, lifts, or other non-natural divisions will be cause for rejection of the entire deliverable.

16. Tiles:

    Note: This section assumes a projected coordinate reference system.

    - A single non-overlapped tiling scheme will be established and agreed upon by the data producer and the USGS prior to collection. This scheme will be used for **all** tiled deliverables.
    - Tile size must be an integer multiple of the cell size of raster deliverables.
    - Tiles must be sized using the same units as the coordinate system of the data.
    - Tiled deliverables shall conform to the tiling scheme, without added overlap.
    - Tiled deliverables shall edge-match seamlessly and without gaps in both the horizontal and vertical.

III. HYDRO-FLATTENING REQUIREMENTS

Note: Please refer to Appendix 2 for reference information on hydro-flattening.

Hydro-flattening pertains only to the creation of derived DEMs. No manipulation of or changes to originally computed lidar point elevations are to be made. Breaklines may be used to help classify the point data.

1. Inland Ponds and Lakes:
    - ~2-acre or greater surface area (~350' diameter for a round pond) at the time of collection.
    - Flat and level water bodies (single elevation for every bank vertex defining a given water body).
    - The entire water surface edge must be at or below the immediately surrounding terrain.
    - Long impoundments such as reservoirs, inlets, and fjords, whose water surface elevations drop when moving downstream, should be treated as rivers.
2. Inland Streams and Rivers:
    - 100' **nominal** width: This should not unnecessarily break a stream or river into multiple segments. At times it may squeeze slightly below 100' for short segments. Data producers should use their best professional judgment.
    - Flat and level bank-to-bank (perpendicular to the apparent flow centerline); gradient to follow the immediately surrounding terrain.
    - The entire water surface edge must be at or below the immediately surrounding terrain.
    - Streams channels should break at road crossings (culvert locations). These road fills should not be removed from DEM. However, streams and rivers should **not** break at elevated bridges. Bridges should be removed from DEM. When the identification of a feature as a bridge or culvert cannot be made reliably, the feature should be regarded as a culvert.
3. Non-Tidal Boundary Waters:
    - Represented only as an edge or edges within the project area; collection does not include the opposing shore.
    - The entire water surface edge must be at or below the immediately surrounding terrain.
    - The elevation along the edge or edges should behave consistently throughout the project. May be a single elevation (i.e., lake) or gradient (i.e., river), as appropriate.

4. Tidal Waters:
    - Water bodies such as oceans, seas, gulfs, bays, inlets, salt marshes, very large lakes, etc. Includes any water body that is affected by tidal variations.
    - Tidal variations over the course of a collection or between different collections, will result in discontinuities along shorelines. This is considered normal and these “anomalies” should be retained. The final DEM should represent as much ground as the collected data permits.
    - Variations in water surface elevation resulting in tidal variations during a collection should NOT be removed or adjusted, as this would require either the removal of valid, measured ground points or the introduction of unmeasured ground into the DEM. The USGS NGP priority is on the ground surface, and accepts there may be occasional, unavoidable irregularities in water surface.
    - Scientific research projects in coastal areas often have very specific requirements with regard to how tidal land-water boundaries are to be handled. For such projects, the requirements of the research will take precedence.

Cooperating partners may require collection and integration of single-line streams within their lidar projects. While the USGS does not require these breaklines be collected or integrated, it does require that if used and incorporated into the DEMs, the following guidelines are met:

1. All vertices along single-line stream breaklines are at or below the immediately surrounding terrain.
2. Single-line stream breaklines are not to be used to introduce cuts into the DEM at road crossings (culverts), dams, or other such features. This is hydro-enforcement and as discussed in Section VI, creates a non-traditional DEM that is not suitable for integration into the NED.
3. All breaklines used to modify the surface are to be delivered to the USGS with the DEMs.

The USGS does not require any particular process or methodology be used for breakline collection, extraction, or integration. However, the following general guidelines must be adhered to:

1. Bare-earth lidar points that are in close proximity breaklines should be excluded from the DEM generation process. This is analogous to the removal of masspoints for the same reason in a traditional photogrammetrically compiled DTM.

   The proximity threshold for reclassification as “Ignored Ground” is at the discretion of the data producer, but in general should be approximately equal to the NPS.

2. These points are to be retained in the delivered lidar point dataset and shall be reclassified as “Ignored Ground” (class value = 10) so that they may be subsequently identified.
3. Delivered data must be sufficient for the USGS to effectively recreate the delivered DEMs using the lidar points and breaklines without significant further editing.

IV. DELIVERABLES

The USGS shall have unrestricted rights to all delivered data and reports, which will be placed in the public domain. This specification places no restrictions on the data provider's rights to resell data or derivative products as they see fit.

1. Metadata

Note: “Metadata” refers to all descriptive information about the project. This includes textual reports, graphics, supporting shapefiles, and FGDC-compliant metadata files.

- Collection Report detailing mission planning and flight logs.
- Survey Report detailing the collection of control and reference points used for calibration and QA/QC.
- Processing Report detailing calibration, classification, and product generation procedures including methodology used for breakline collection and hydro-flattening *(see Sections III and Appendix 1 for more information on hydro-flattening)*.
- QA/QC Reports (detailing the analysis, accuracy assessment and validation of:
    - The point data (absolute, within swath, and between swath)
    - The bare-earth surface (absolute)
    - Other optional deliverables as appropriate
- Control and Calibration points: All control and reference points used to calibrate, control, process, and validate the lidar point data or any derivative products are to be delivered.
- Geo-referenced, digital spatial representation of the precise extents of each delivered dataset. This should reflect the extents of the actual lidar source or derived product data, exclusive of Triangular Irregular Network (TIN) artifacts or raster NODATA areas. A union of tile boundaries or minimum bounding rectangle is not acceptable. ESRI Polygon shapefile or geodatabase is preferred.
- Product metadata (FGDC compliant, XML format metadata). One file for each:

  - Project
  - Lift
  - Tiled deliverable product group (classified point data, bare-earth DEMs, breaklines, etc.). Metadata files for individual tiles are not required.
- FGDC compliant metadata must pass the USGS metadata parser (“mp”) with no errors or warnings.

2. Raw Point Cloud

- All returns, all collected points, fully calibrated and adjusted to ground, by swath.
- Fully compliant LAS v1.2 or v1.3, Point Record Format 1, 3, 4, or 5
- LAS v1.3 deliverables with waveform data are to use external “auxiliary” files with the extension “.wdp” for the storage of waveform packet data. See the LAS v1.3 Specification for additional information.
- Georeference information included in all LAS file headers
- GPS times are to be recorded as Adjusted GPS Time, at a precision sufficient to allow unique timestamps for each pulse.
- Intensity values (native radiometric resolution)
- 1 file per swath, 1 swath per file, file size not to exceed 2GB, as described in Section II, Paragraph 7.

3. Classified Point Cloud

Note: Delivery of a classified point cloud is a standard requirement for USGS NGP lidar projects. Specific scientific research projects may be exempted from this requirement.

- Fully compliant LAS v1.2 or v1.3, Point Record Format 1, 3, 4, or 5
- LAS v1.3 deliverables with waveform data are to use external “auxiliary” files with the extension “.wdp” for the storage of waveform packet data. See the LAS v1.3 Specification for additional information.
- Georeference information included in LAS header
- GPS times are to be recorded as Adjusted GPS Time, at a precision sufficient to allow unique timestamps for each pulse.
- Intensity values (native radiometric resolution)
- Tiled delivery, without overlap (tiling scheme TBD)

- Classification Scheme (minimum):

Code	Description
1	Processed, but unclassified
2	Bare-earth ground
7	Noise (low or high, manually identified, if needed)
9	Water
10	Ignored Ground (Breakline Proximity)
11	Withheld (if the "Withheld" bit is not implemented in processing software)

Note: Class 7, Noise, is included as an adjunct to the "Withheld" bit. All "noise points" are to be identified using one of these to methods.

Note: Class 10, Ignored Ground, is for points previously classified as bare-earth but whose proximity to a subsequently added breakline requires that it be excluded during Digital Elevation Model (DEM) generation.

4. **Bare Earth Surface (Raster DEM)**

Note: Delivery of a bare-earth DEM is a standard requirement for USGS NGP lidar projects. Specific scientific research projects may be exempted from this requirement.

- Cell Size no greater than 3 meters or 10 feet, and no less than the design Nominal Pulse Spacing (NPS).
- Delivery in an industry-standard, GIS-compatible, 32-bit floating point raster format (ERDAS .IMG preferred)
- Georeference information shall be included in each raster file
- Tiled delivery, without overlap
- DEM tiles will show no edge artifacts or mismatch. A quilted appearance in the overall project DEM surface, whether caused by differences in processing quality or character between tiles, swaths, lifts, or other non-natural divisions, will be cause for rejection of the entire DEM deliverable.
- Void areas (i.e., areas outside the project boundary but within the tiling scheme) shall be coded using a unique "NODATA" value. This value shall be identified in the appropriate location within the file header.
- Vertical Accuracy of the bare earth surface will be assessed and reported in accordance with the guidelines developed by the NDEP and subsequently adopted by the ASPRS. The complete guidelines may be found in Section 1.5 of the Guidelines document. See:

http://www.ndep.gov/NDEP_Elevation_Guidelines_Ver1_10May2004.pdf

Vertical accuracy requirements using the NDEP/ASPRS methodology are:
FVA <= 24.5cm ACCz, 95% (12.5cm RMSEz)
CVA <= 36.3cm, 95th Percentile
SVA <= 36.3cm, 95th Percentile

All QA/QC analysis materials and results are to be delivered to the USGS.

- Depressions (sinks), natural or man-made, are **not** to be filled (as in hydro-conditioning and hydro-enforcement).
- Water Bodies (ponds and lakes), wide streams and rivers ("double-line"), and other non-tidal water bodies as defined in Section III are to be hydro-flattened within the DEM. Hydro-flattening shall be applied to all water impoundments, natural or man-made, that are larger than ~2 acre in area (equivalent to a round pond ~350' in diameter), to all streams that are nominally wider than 100', and to all non-tidal boundary waters bordering the project area regardless of size. The methodology used for hydro-flattening is at the discretion of the data producer.

  Note: Please refer to the Sections III and VI for detailed discussions of hydro-flattening.

5. **Breaklines**

Note: Delivery of the breaklines used in hydro-flattening is a standard requirement for USGS NGP lidar projects. Specific scientific research projects may be exempted from this requirement. If hydro-flattening is achieved through other means, this section may not apply.

- All breaklines developed for use in hydro-flattening shall be delivered as an ESRI feature class (PolylineZ or PolygonZ format, as appropriate to the type of feature represented and the methodology used by the data producer). Shapefile or geodatabase is preferred.
- Each feature class or shapefile will include properly formatted and accurate georeference information in the standard location. All shapefiles must include the companion .prj file.
- Breaklines must use the same coordinate reference system (horizontal and vertical) and units as the lidar point delivery.
- Breakline delivery may be as a continuous layer or in tiles, at the discretion of the data producer. Tiled deliveries must edge-match seamlessly in both the horizontal and vertical.

APPENDIX 1

COMMON DATA UPGRADES

1. Independent 3rd-Party QA/QC by another AE Contractor (encouraged)
2. Higher Nominal Pulse Spacing (point density)
3. Increased Vertical Accuracy
4. Full Waveform collection and delivery
5. Additional Environmental Constraints
    - Tidal coordination, flood stages, crop/plant growth cycles, etc.
    - Shorelines corrected for tidal variations within a collection
6. Top-of Canopy (First-Return) Raster Surface (tiled). Raster representing the highest return within each cell is preferred.
7. Intensity Images (8-bit gray scale, tiled)
8. Detailed Classification (additional classes):

Code	Description
3	Low vegetation
4	Medium vegetation (use for single vegetation class)
5	High vegetation
6	Buildings, bridges, other man-made structures
n	additional Class(es) as agreed upon in advance

9. Hydro-Enforced and/or Hydro-Conditioned DEMs
10. Breaklines (PolylineZ and PolygonZ) for single-line hydrographic features (narrow streams not collected as double-line, culverts, etc.), including appropriate integration into delivered DEMs
11. Breaklines (PolylineZ and PolygonZ) for other features (TBD), including appropriate integration into delivered DEMs
12. Extracted Buildings (PolygonZ): Footprints with maximum elevation and/or height above ground as an attribute.
13. Other products as defined by requirements and agreed upon in advance of funding commitment.

APPENDIX 2

HYDRO-FLATTENING REFERENCE

The subject of modifications to lidar-based DEMs is somewhat new, and although authoritative references are available, there remains significant variation in the understanding of the topic across the industry. The following material was developed to provide a definitive reference on the subject only as it relates to the creation of DEMs intended to be integrated into the USGS NED. The information presented here is not meant to supplant other reference materials and it should not be considered authoritative beyond its intended scope.

The term "**hydro-flattening**" is also new, coined for this document and to convey our specific needs. It is not, at this time, a known or accepted term across the industry. It is our hope that its use and acceptance will expand beyond the USGS with the assistance of other industry leaders.

Hydro-flattening of DEMs is predominantly accomplished through the use of breaklines, and this method is considered standard. Although other techniques may exist to achieve similar results, this section assumes the use of breaklines. The USGS does not require the use of any specific technique.

The Digital Elevation Model Technologies and Applications: The DEM Users Manual, 2nd Edition (Maune *et al.*, 2007) provides the following definitions related to the adjustment of DEM surfaces for hydrologic analyses:

1. **Hydrologically-Conditioned (Hydro-Conditioned)** – Processing of a DEM or TIN so that the flow of water is continuous across the entire terrain surface, including the removal of all spurious sinks or pits. The only sinks that are retained are the real ones on the landscape. Whereas "hydrologically-enforced" is relevant to drainage features that are generally mapped, "hydrologically-conditioned" is relevant to the entire land surface and is done so that water flow is continuous across the surface, whether that flow is in a stream channel or not. The purpose for continuous flow is so that relationships/links among basins/catchments can be known for large areas. This term is specifically used when describing EDNA (see Chapter 4), the dataset of NED derivatives made specifically for hydrologic modeling purposes.
2. **Hydrologically-Enforced (Hydro-Enforced)** – Processing of mapped water bodies so that lakes and reservoirs are level and so that streams flow downhill. For example, a DEM, TIN or topographic contour dataset with elevations removed from the tops of selected drainage structures (bridges and culverts) so as to depict the terrain under those structures. Hydro-enforcement enables hydrologic and hydraulic models to depict water flowing under these structures, rather than appearing in the computer model to be dammed by them because of road deck elevations higher than the water levels. Hydro-enforced TINs also utilize breaklines along shorelines and stream centerlines, for example, where these breaklines form the edges of TIN triangles along the alignment of drainage features. Shore breaklines for streams would be 3-D breaklines

> with elevations that decrease as the stream flows downstream; however, shore breaklines for lakes or reservoirs would have the same elevation for the entire shoreline if the water surface is known or assumed to be level throughout. See figures 1.21 through 1.24. See also the definition for “hydrologically-conditioned” which has a slightly different meaning.

While these are important and useful modifications, they both result in surfaces that differ significantly from a traditional DEM. A “hydro-conditioned” surface has had its sinks filled and may have had its water bodies flattened. This is necessary for correct flow modeling within and across large drainage basins. “Hydro-enforcement” extends this conditioning by requiring water bodies be leveled and streams flattened with the appropriate downhill gradient, and also by cutting through road crossings over streams (culvert locations) to allow a continuous flow path for water within the drainage. Both treatments result in a surface on which water behaves as it physically does in the real world, and both are invaluable for specific types of hydraulic and hydrologic (H&H) modeling activities. Neither of these treatments is typical of a traditional DEM surface.

A traditional DEM such as the NED, on the other hand, attempts to represent the ground surface more the way a bird, or person in an airplane, sees it. On this surface, natural depressions exist, and road fills create apparent sinks because the road fill and surface is depicted without regard to the culvert beneath. Bridges, it should be noted, are removed in most all types of DEMs because they are man-made, above-ground structures that have been added to the landscape.

Note: DEMs developed solely for orthophoto production may include bridges, as their presence can prevent the “smearing” of structures and reduce the amount of post-production correction of the final orthophoto. These are “special use DEMs” and are not relevant to this discussion.

For years, raster Digital Elevation Models (DEMs), have been created from a Digital Surface Model (DSM) of masspoints and breaklines, which in turn were created through photogrammetric compilation from stereo imagery. Photogrammetric DSMs inherently contain breaklines defining the edges of water bodies, coastlines, single-line streams, and double-line streams and rivers, as well as numerous other surface features.

Lidar technology, however, does not inherently collect the breaklines necessary to produce traditional DEMs. Breaklines have to be developed separately through a variety of techniques, and either used with the lidar points in the generation of the DEM, or applied as a correction to DEMs generated without breaklines.

In order to maintain the consistent character of the NED as a traditional DEM, the USGS NGP requires that all DEMs delivered have their inland water bodies flattened. This does not imply that a complete network of topologically correct hydrologic breaklines be developed for every dataset; only those breaklines necessary to ensure that the conditions defined in Section III exist in the final DEM.

APPENDIX 3

SAMPLE METADATA TEMPLATE

[to be added]

APPENDIX 4

REFERENCES

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