# ArcMap as a quality assurance tool in Photogrammetry
Ron Frederiks

Abstract

This paper presents the use of ArcMap, 3-D Analyst, Spatial Analyst and Ianko's ETGeoWizards to perform quality assurance of targeting efforts, positioning of aerial photography and analysis of analytical aerotriangulation at the New York State Department of Transportation Photogrammetry Section. Planned target location data are compared to Global Positioning System (GPS) surveyed target location data. Planned flight line photo centers are compared to airborne GPS derived photo centers to detect possible flightline anomalies. Control selection results are plotted and Aerotriangulation results are overlaid and analyzed to detect potential control and tie point problem areas and to determine the flying height above terrain. The earlier problems are detected using ArcMap the more options are available to solve those problems. The necessary reformatting of point data that is generated from different software packages is discussed.
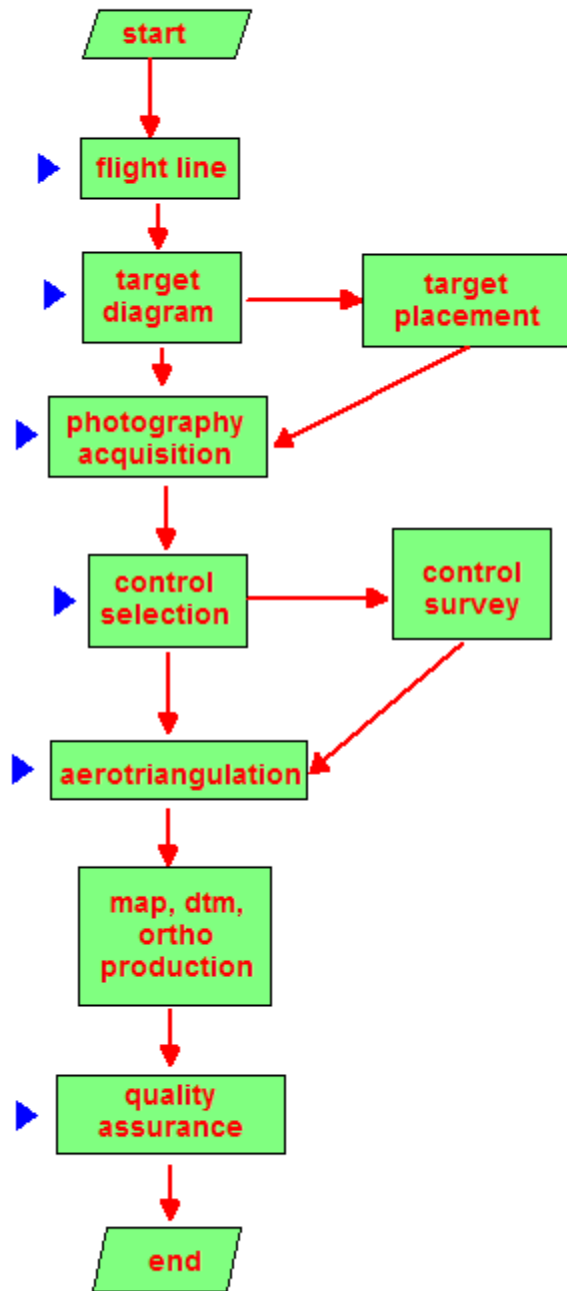
Figure 1. Photogrammetric flowchart

Photogrammetry

In simplified form photogrammetry is defined here as the art and science of obtaining reliable measurements from scanned photography which includes the acquisition of photography. The basic photogrammetric process at the New York State Department of Transportation (NYSDOT) is depicted in figure1.

Flight Line and Targeting

The flight line design process at the NYSDOT is done using Computer Aided Drafting and Design (CADD). The flight lines identify the extent of photo coverage and the proposed beginning and end point of each flight strip and the proposed photo centers. In conjunction to this, target locations requiring survey are added into CADD and overlaid on the flight line information. The CADD file that results is imported into ArcMap with the "add data tool". The target information is checked in ArcMap using the custom built NYSDOT base mapping tools. These customized ArcMap tools allow the users to easily load raster imagery, raster quads, raster contours and orthoimagery for the area of interest through the use of image catalogs and some Visual Basic scripting. The user is able to quickly verify proper positioning of targets using 7.5 minute quadrangle binary raster files (quads), matching contour raster files and orthoimagery files as a backdrop. The orthoimagery usually provides more up-to-date information about a project area than the quadrangle information since the orthoimagery dates to statewide orthoimagery programs from 1995 and 2000-2004. Quads however are still very useful as they provide symbology and text information.

Survey crews must place the painted targets before the aerial photography is flown. These targets are then surveyed and used to control the photogrammetric mapping process. Target location coordinates are extracted from the CADD file, in the Universal Transverse Mercator (UTM) or Geographic coordinate system, and supplied to the regional survey groups in a format that is compatible with their handheld GPS receivers. These coordinates are then uploaded and used to position the requested targets. Target locations that are moved get updated handheld GPS coordinates in the field that are then communicated back to Photogrammetry Section. These updated target locations are imported into ArcMap using the "add XY data" tool and assist in the final determination of the control points that are to control each project (figure 2). The "add XY data" tool allows the user to set the projection of the imported coordinate data so that ArcMap can re-project this data on the fly as needed by the software.
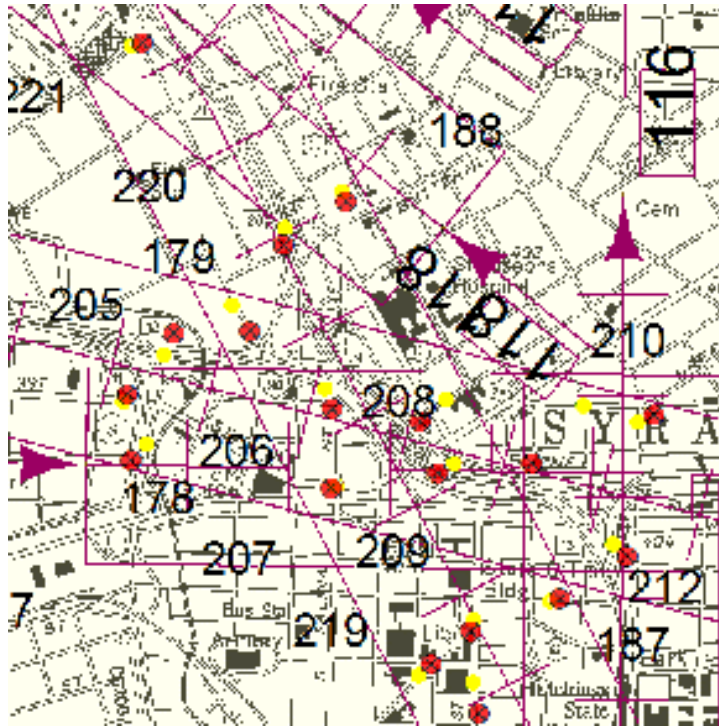
Figure 2. Planned target location shown as yellow circles, actual target location shown as red circles with black crosses overlaid on the flight line coverage. Flight line directions are indicated with arrows.

Target locations are also supplied to a NYSDOT survey ArcIMS ArcMap HTML viewer service application known as the geodetic viewer (figure 3). This application allows the regional survey groups to see the relationship of the targets to surrounding National Geodetic Survey (NGS) control points located in the NGS database, and allows for more efficient planning of ground control surveys.
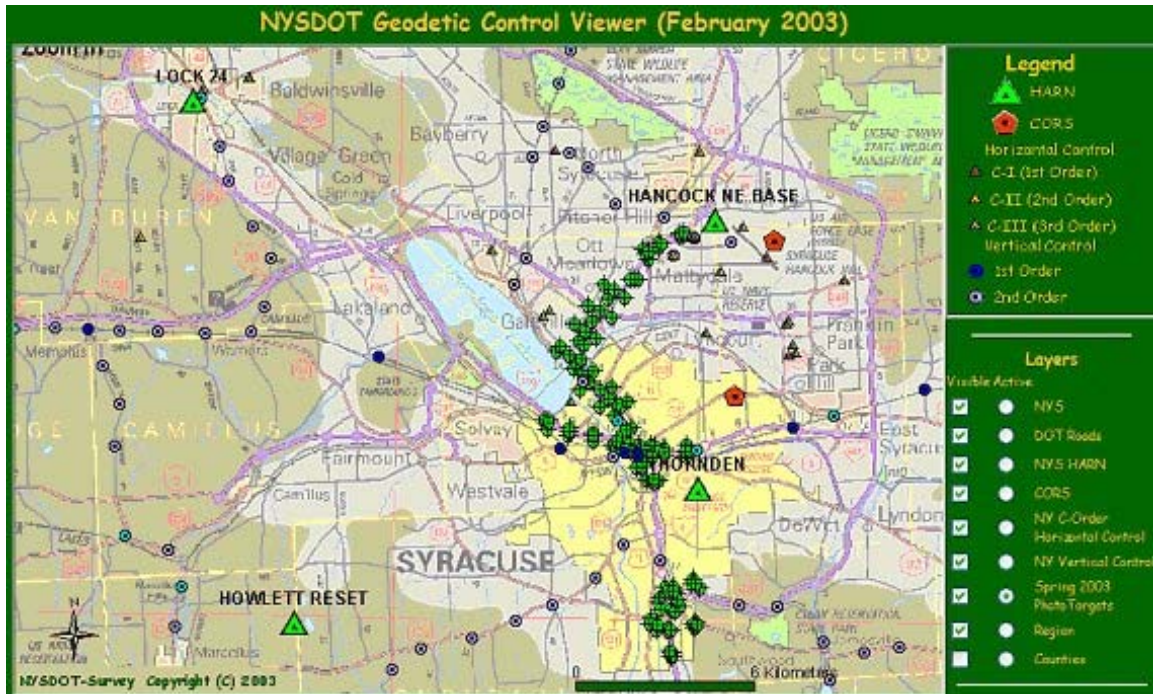
Figure 3. The location of National Geodetic Survey control points (small circles and triangles), High Accuracy Reference Network (HARN) (green triangles) points and Continuously Operating Reference Stations (CORS) (red) is shown with respect to the target locations (green circles with a cross) for the 2 projects shown.

Continuously Operating Reference Stations (CORS)

NYSDOT does a differential correction to the Airborne GPS (ABGPS) derived photo center data to get the best possible position for each photo exposure. NYSDOT uses the National Geodetic Survey (NGS) CORS to accomplish this. All the CORS locations are plotted in ArcMap. One or five-second data collection rate at the CORS is symbolized by color. NYSDOT prefers the use of one second data when processing ABGPS data. Unfortunately the density and locations of the CORS is not optimal for Airborne GPS (ABGPS) projects. Therefore we plot 50 km buffer rings around the CORS. The State Plane Coordinate Zones and the planned flight lines from CADD are also added. This helps us plan what CORS data to download and use when processing specific ABGPS flight data. This also lets us know in which State Plane Coordinate Zone the project will be located.
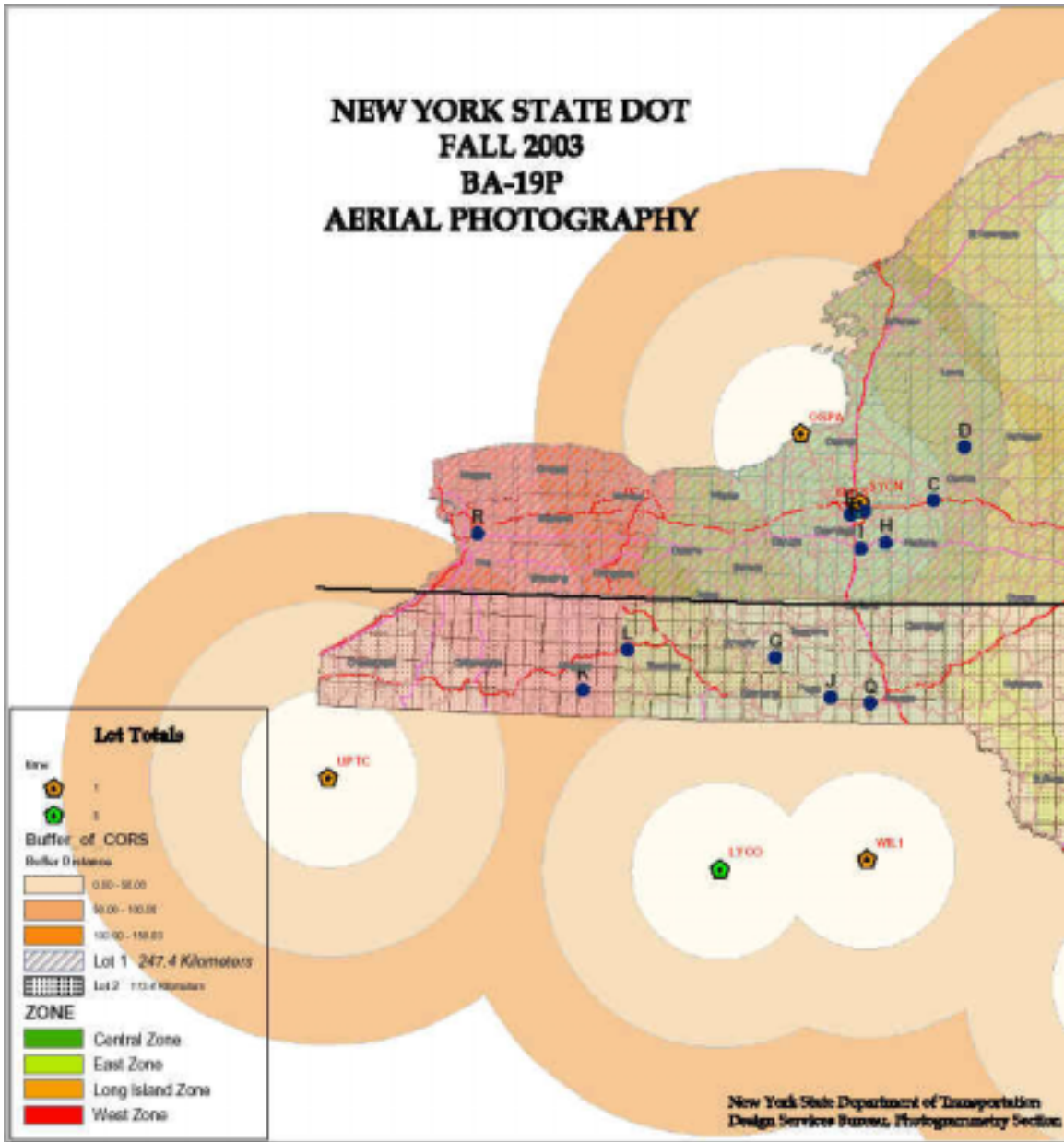
Figure 4. Part of fall 2003 flight map showing the relationship of 50 km buffered Continuously Operating Reference Stations (CORS) with respect to the flight projects (blue circles). Color of the CORS denotes rate of data collection at the CORS.

Airborne GPS

Starting in spring 2004 all NYSDOT photogrammetric flights were flown with Airborne GPS (ABGPS). This in effect provides the XYZ location of each photo center. Each photo center XYZ is processed using Grafnav software and is

imported into ArcMap using the "add XY data" tool and is overlaid on the planned flight line diagram to determine if the flight exposures are in the correct location (figure 5). The flying height determined by GPS unfortunately is above the Geoid and does not take the orthometric ground elevation into account. Fortunately we can extract data from the National Elevation Dataset (NED) for the project area by going to http://edcnts12.cr.usgs.gov/ned/default.asp using our web browser. We convert the ABGPS data XY coordinates to 3-D feature data using the convert features to 3-D utility in 3-D Analyst designating the NED raster file for the height source. The resulting Point Z (M) elevation point shape will contain the interpolated ground elevation underneath each camera station. Using ETGeoWizard's "convert Point Z (M) to point" utility, we can extract a column that displays the Point Z (M) elevation in text format. The resulting table is edited, adding a column for the computation of the Point Z (M) derived orthometric elevation column subtracted from the ABGPS elevation column to derive values for the height above terrain. A small elevation difference in height indicates higher terrain (smaller distance from the plane to ground) and a larger difference indicates lower terrain (greater distance from the plane to ground). The scale of a photograph is equal to camera focal length divided by the flying height. Looking at the photo scale equation we are now able to calculate the "true" photo scale for each photograph. By exporting this photo information from the 3-D point feature attribute table to a text file and importing this text file into an Excel spreadsheet we can also calculate the endlap (overlap) between any two consecutive photos which is yet another indicator of the achievable photogrammetric mapping accuracy. Currently the only thing missing is the orientation (rotation) angles of each photo since NYSDOT's projects currently are not flown with Inertial Measurement Units (IMU) that record pitch, roll, and yaw (or in Photogrammetry terms omega, phi, kappa). We perceive this to be a possible future enhancement that will allow us to determine crab.
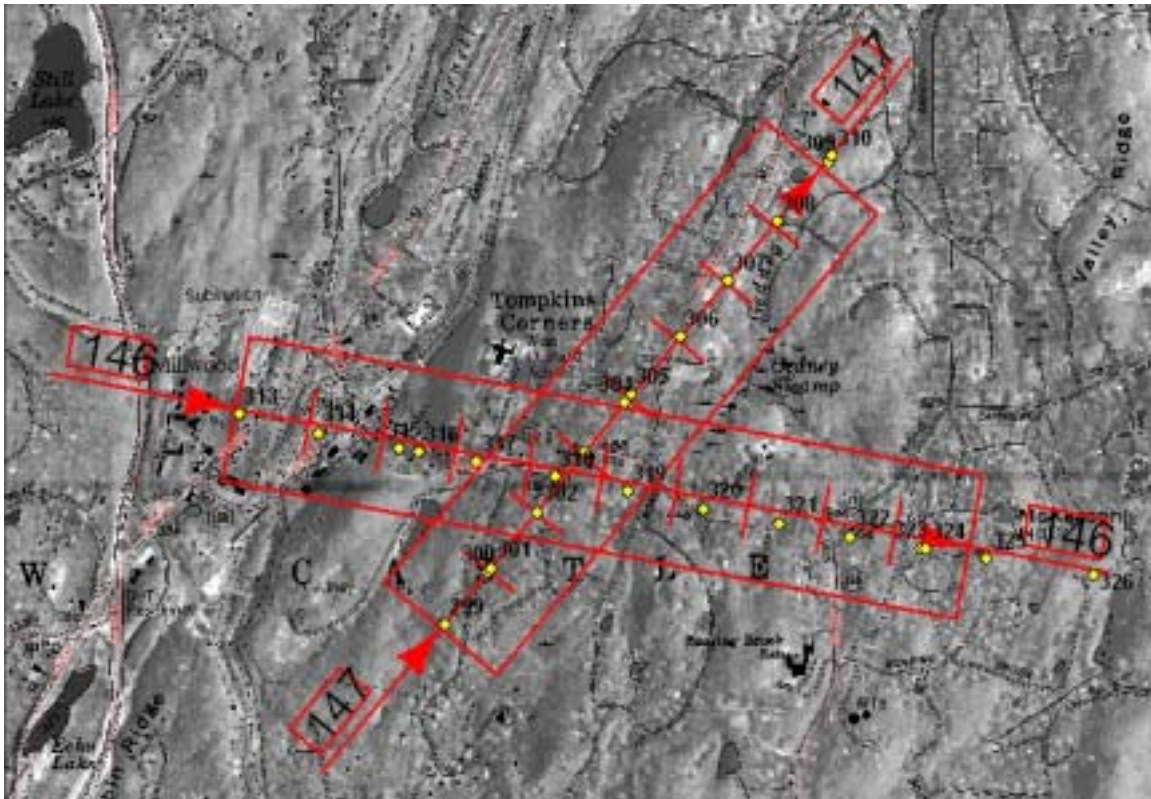
Figure 5. Planned flight information is in red. Actual photo exposures in yellow. Note extra (ghost) events 315 (strip 146) and 304 (strip 147) that are easily identified. The quad and orthoimage backdrop come from the NYSDOT base mapping tools. The actual photo centers line up very well with the planned photo centers of strip 147.

For purposes of flight inventory we have started an ArcIMS application that shows the ABGPS flight line for each flight day, the individual camera events, the State Plane Coordinate Zones and the locations of the CORS with 50 km buffer rings. We are planning to add metadata about the GPS antenna on the plane that is needed during the processing of the ABGPS data as well as the antennas at each of the different CORS. We also hope to enhance this application with target and survey information and possible aerotriangulation information in the future.

Control Selection

Once the photography has been received and is scanned, control selection can commence. This process reviews all the targets that have been placed in the field and checks to see whether these targets are visible on the photography. A determination is then made whether additional photo identifiable control points are required for the aerotriangulation process that is needed for the mapping and

orthoimage creation of the project. Any additional control points are described on the digital photography and approximate coordinates are derived from a preliminary aerotriangulation adjustment using the latest handheld GPS coordinates of the targets as control points. The approximate coordinates for these photo identifiable control points are then plotted in ArcMap. An HTML report of these control points is prepared for the surveyor with screen captures from ArcMap to communicate the locations of the selected points.

Survey Control

After all the photo control points have been surveyed they are overlaid on the original coordinates from the control selection process as a Quality Assurance (QA) step. This also helps us detect points that were moved in the field. Large blunders are also easily identified (i.e. improper identification of a control point in the field). The survey control is performed in the State Plane Coordinate System. Since ArcMap is able to automatically re-project coordinates from different coordinate systems, overlaying the different data layers in the photogrammetric process becomes very easy.

Aerotriangulation

Aerotriangulation is a process that determines the exact location and orientation of each photo at the time of exposure. Part of this process involves measuring tie points and control points (targets) on the photos. ArcMap provides an easy way to verify the density and location of the tie points (see Figure 6) and allows us to display residuals for each point. If we really want to get sophisticated we can join the imported photo measurement attribute table to the imported densified control points attribute table. By using queries we can not only find out what photos a point was measured on, but also graphically display where this point is located. An approximate stereomodel or photo footprint can be symbolized in ArcMap. The proper photo orientation for the footprint can be derived from the aerotriangulation process.

NYSDOT uses a Photogrammetry solution by Z(I Imaging. The aerotriangulation software ImageStation AeroTriangulation (ISAT) is used to calculate the Exterior Orientation (EO) parameters (x, y, z, omega, phi, kappa) for each photo. The EO parameters determine location and orientation of each photo in the project. The coordinates from the tie and control points from the aerotriangulation adjustment are extracted in x, y, z, residual x, residual y, residual z and imported into and Excel spreadsheet to be exported to a comma delimited ASCII text file (.csv) that can be added into ArcMap as point events using the "add XY data" tool. The first line in the file is a header row with a column identified as x and a column identified as y that will allow for the correct positioning of each point. By using the z residual as the vertical when creating a digital terrain model one gets a

graphical overview of the point residuals for analysis. This technique can also be used to graphically review the x and y residuals. ISAT also allows for the export of the plates coordinate file. This file contains the photo measurements of each point and the photo it was measured on. By editing this file with a text editor like TextPad one can easily reformat this file using macros so that it can be added to ArcMap as point events as described previously. The x and y photo measurement coordinates are used to initially position all the points near the origin. By doing a Join in ArcMap these plate coordinates can be tied to the aerotriangulation EO generated x, y coordinate for each point. This allows for the full analysis of tie points. One can determine how many and what photos a point was measured on. This is very useful for trouble shooting a project or determining whether measurement anomalies exist in the project. Third party aerotriangulation results can also be reviewed this way and QA'd without actually having the aerotriangulation software that was used to generate results.
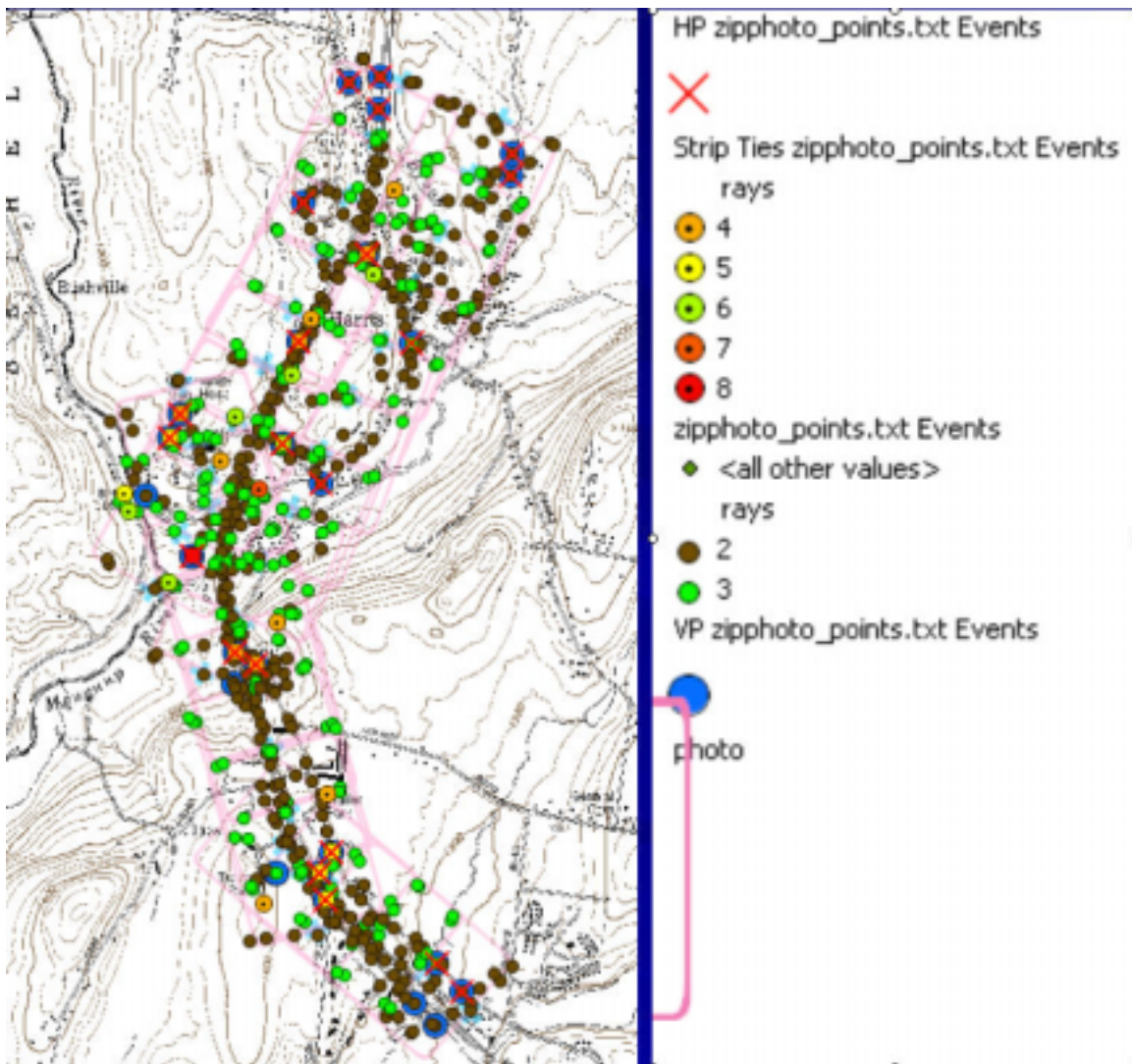
Figure 6. Aerotriangulation results showing horizontal survey control (HP), vertical survey control (VP) and tie points. The number of rays identifies how many photos a tie point was measured on. The approximate stereomodel (photo overlap) footprints are identified in pink.

Ortho imagery

ArcMap can also be used for orthoimagery Quality Assurance (QA). Control points for the orthoimagery projects can be used as checkpoints (figure 7). Checkpoints are used to review the accuracy of the orthoimagery. The verification can be done visually or by measuring the distance from the control point to the displayed image point on the orthoimage. A more rigorous approach consists of testing the orthoimagery against independent survey control or previous mapping based on independent photo control. One can follow the FGDC Geospatial Positioning Accuracy Standards Part 3 specifications for a more rigorous method of quality assessment (http://www.fgdc.gov/standards/documents/standards/accuracy/chapter3.pdf). By storing the distance differences between the surveyed locations and the orthoimage locations of points in an attribute table comprehensive statistics can be derived by exporting this table into a format that software like Excel or Mathcad can import for analysis.
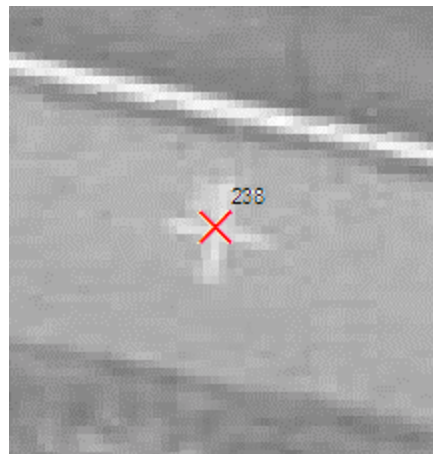

Figure 7. Close up of control point location overlaid on orthoimage. Ortho pixel size is 0.1 m. The imaged target location lines up well with surveyed target location (red cross).

Summary

ArcMap and 3-D Analyst are indispensable tools for planning, trouble shooting and quality assurance during the photogrammetric process at NYSDOT. We are able to use ArcMap during most of the phases of the photogrammetric process allowing us to import and analyze data from different software packages (CADD, Z(I Imaging, Grafnav) and make better informed decisions. As we increasingly start to put photogrammetric application data into ArcIMS we will be able to more effectively communicate and use this project information.

Glossary:

Aerotriangulation the process of determining the locations and orientations (Exterior Orientations) of photography.

Airborne Global Positioning System ABGPS uses a survey grade GPS receiver on an aircraft to help determine the position of the photo center at the moment of exposure

Control points are surveyed points that are measured on the photography and used to help determine the relationship of the photography the survey coordinate system in aerotriangulation.

Crab is when the x axis of the photos are not parallel with the direction of flight.

Exterior Orientation consist of the XYZ position of the exposure center and the orientation angles omega, phi and kappa. Map compilation is possible when the EO's are known for a stereomodel

Inertial measurement unit (IMU) consist of gyros to determine change in acceleration in the 3-axis of movement.

Phi photo rotation about the y axis

Pitch raises ore lowers the nose of an airplane (similar to camera phi)

Densified control consist of passpoint calculated ground coordinate values and survey control points that have updated coordinate values based on an aerotriangulation adjustment. The densified control points in turn are used to calculate the Exterior Orientations for each photo in a project.

Drift is the failure of the pilot to fly along the planned flight line

Kappa photo rotation about the z axis

Map compilation consist of attaching coordinate information to features in a stereomodel.

Omega is photo rotation about the x axis

Orthoimagery is imagery that has been corrected for scale variations due to photo perspective and variations in elevations

Passpoints or tie points are points used to mathematically tie individual stereomodels or strips together. Also see tie points

Photogrammetry the art and science of measuring from remotely sensed data

Proposed flight line consist of planned beginning and end point of a flight strip. Photo coverage and photo centers along a flight path are also shown.

Roll is a rotation around the long axis of the airplane (similar to camera omega)

Quality Assurance is the process of final product verification.

Stereomodel consists of two consecutive photos in a strip of photography. Photography is typically flown with a 60 percent overlap which is also known endlap, which allows for stereoscopic viewing.

Targeting is process of painting crosses in the field before the photography is taken. These points are then surveyed and used as survey control points in aerotriangulation.

Tie points see passpoints

Yaw is a horizontal rotation around the vertical axis of an aircraft (similar to kappa)

References:

Paul Wolf, Elements of Photogrammetry Second Edition, McGraw Hill, Inc 1983

Author Information

Ron Frederiks
New York State Department of Transportation
50 Wolf Road P.O.D. 24
Albany NY 12232
rfrederiks@dot.state.ny.us
phone 518.457.7042