



Remote Sensing Technologies and Techniques for Parks and Historic Asset Management in Albany, Oregon

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About SCI

The Sustainable Cities Initiative (SCI) is a cross-disciplinary organization at the University of Oregon that promotes education, service, public outreach, and research on the design and development of sustainable cities. We are redefining higher education for the public good and catalyzing community change toward sustainability. Our work addresses sustainability at multiple scales and emerges from the conviction that creating the sustainable city cannot happen within any single discipline. SCI is grounded in cross-disciplinary engagement as the key strategy for improving community sustainability. Our work connects student energy, faculty experience, and community needs to produce innovative, tangible solutions for the creation of a sustainable society.

About SCYP

The Sustainable City Year Program (SCYP) is a year-long partnership between SCI and one city in Oregon, in which students and faculty in courses from across the university collaborate with the partner city on sustainability and livability projects. SCYP faculty and students work in collaboration with staff from the partner city through a variety of studio projects and service-learning courses to provide students with real-world projects to investigate. Students bring energy, enthusiasm, and innovative approaches to difficult, persistent problems. SCYP's primary value derives from collaborations resulting in on-the-ground impact and expanded conversations for a community ready to transition to a more sustainable and livable future.

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About Albany, Oregon

The city now known as Albany has an established history as a central hub in the Willamette valley. Founded in 1848 and incorporated in 1864 the city has served as the Linn County seat since 1851. Albany's unique place in Oregon's history is exemplified in its dedication to historical preservation. Albany is often noted to have the most varied collection of historic buildings in Oregon. Its "four historic districts are listed in the National Register of Historic Places by the United States Department of the Interior." This downtown core has served as the center of revitalization efforts since 2001.

Located on the Willamette and Calapooia rivers Albany spans both Linn and Benton counties. With a population of 51,720 people, Albany is Oregon's 11th largest city and the second largest city in Benton County. Albany is administered under a home rule charter, adopted in 1957 establishing a Council and City Manager model. The city's vision, to be a "vital and diverse community that promotes a high quality of life, great neighborhoods, balanced economic growth and quality public services," is exemplified by its administration and government. Albany has a very active civic community with nearly 100 citizens serving on advisory commissions and committees dedicated to municipal issues.

Historically, Albany's economy has relied on natural resources. As the self-styled "rare metals capital of the world," Albany produces zirconium, hafnium and titanium. Major employment sectors include "wood products, food processing, and manufactured homes." Because of its short, dry temperate growing season Albany farmers excel in producing specialized crops like grass flower and vegetable seeds, "tree fruits, nursery stock, nuts, berries, mint and grains." Albany and the surrounding (Linn and Benton) counties are so agriculturally productive it is often called "The Grass Seed Capital of the World."

Albany's central location and mild climate has made it a popular destination for a variety of outdoor and leisure activities. Located in the heart of Oregon's most populous region with the Pacific coast to the west and the Cascade Range to its east, Albany is connected to the wider state by Interstate 5, Oregon Routes 99E and 34, and US Route 20. The city is also served by Amtrak, a municipal airport, and a local and regional bus network.

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This report represents original student work and recommendations prepared by students in the University of Oregon's Sustainable City Year Program for the City of Albany. Text and images contained in this report may not be used without permission from the University of Oregon.

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Executive Summary

The City of Albany, Oregon has identified three main objectives to assist city staff to manage, analyze, and visualize historic aerial images for the purposes of parks and recreation, as well as manage historic assets. The University of Oregon Remote Sensing class, Geography 486/586, supported these efforts by generating the frameworks for these projects, mostly as descriptions of proof of concept projects.

Sample outputs from these projects, along with detailed descriptions of how to recreate and expand upon them can help the city and its citizens going forward as the technologies and techniques described within become more available and accessible, in both extent and cost. An example of this is LIDAR technology. LIDAR will become more common in the near future, allowing for ongoing change detection and analysis. One of the class's main objectives was to look at the future possibilities and uses for remotely sensed data for park management and planning, for which LIDAR may prove to be critically important.

Another important goal for the class was to examine the possibilities of remote sensing technology in historic asset management. Students worked on data storage and management techniques, including the creation of databases and websites that can store and disseminate information as needed or desired. Another project explored the manipulation of historic aerial imagery using current technologies such as Structure from Motion to create digital orthophotos and three-dimensional software to show what the City of Albany looked like from the air over eighty years ago.

Introduction

The Sustainable City of the Year Program (SCYP) combines efforts of students at the University of Oregon in different disciplines to assist city officials with the planning and implementation towards a more sustainable future. Students in Geography 486/586, Remote Sensing II, explored the use, storage, and manipulation of remotely sensed data, including historical aerial photography and modern methods for collecting data about the surface of the Earth from above using platforms such as airplanes, drones, and satellites.

The class identified three objectives to help Albany manage, analyze, and visualize historic aerial images for the purposes of parks and recreation, as well as manage historic assets. These objectives are:

1. Create a database of geospatially registered images and maps.
2. Provide analysis and visualizations for park and historic asset management and planning.
3. Discuss future needs and possibilities for the use of remote sensing technologies for park and historic asset management and planning.

In order to satisfy these goals, students completed individual final projects that explored specific ways to assist the City of Albany with their objectives. Student projects can be classified into three general categories: Uses of current remote sensing technologies, manipulation of historical imagery with current technologies, and data storage and management.

This write-up outlines procedures and techniques that can be used to reconstruct and expand upon the projects undertaken by Remote Sensing students.

Uses of Current Remote Sensing Technologies

Park Planning and Management

The City of Albany is working to improve their parks and recreation services. There are several ways the field of remote sensing can assist the city in pursuit of these goals.

Remote sensing can be used to measure and monitor vegetation in order to ensure that parks will remain green in the future. Over the past several decades, researchers have recognized the importance of green space to urban residents, and access to green space is correlated with several health metrics (Ekkel and de Vries 2017). Thus, monitoring the health of vegetation that composes urban green space through remote sensing can help identify internal and external threats to the health and vitality of the vegetation.

The Normalized Difference Vegetation Index (NDVI), canopy height, and vegetation density are three metrics derived from remote sensing that are useful for characterizing vegetation within parks. Student applied these metrics for Bryant Park.

Normalized difference vegetation index (NDVI) is a common metric used to assess biomass production and vegetation health. NDVI is calculated by measuring the relative proportions of red and near infrared portions of the electromagnetic spectrum. Healthy vegetation tends to reflect much more near infrared (NIR) incoming solar radiation when compared to visible wavelengths. When vegetation is affected by drought, disease, or dies, it greatly reduces the amount of NIR radiation the vegetation reflects. NDVI is a measure of the difference between red and NIR insolation normalized to total red and NIR insolation. Higher NDVI values tends to indicate healthier vegetation and greater biomass production.

NDVI can be calculated using the image analysis tools within ESRI ArcGIS software. Within ArcGIS, NDVI is a tab within the Image Analysis window. ArcMap will be able to automatically detect the red and near infrared bands of the imagery and calculates NDVI according to the above formula. One should check “Scientific Output” if he or she wants NDVI values between negative one and one. NDVI values less than zero are clouds, water, and snow. Values close to zero soil are bare soil or rock. Values above zero indicates green biomass. Higher values indicate greater biomass production. Grasses and shrubs tend to have values from zero to 0.5 and healthy trees have values between 0.5 and one.

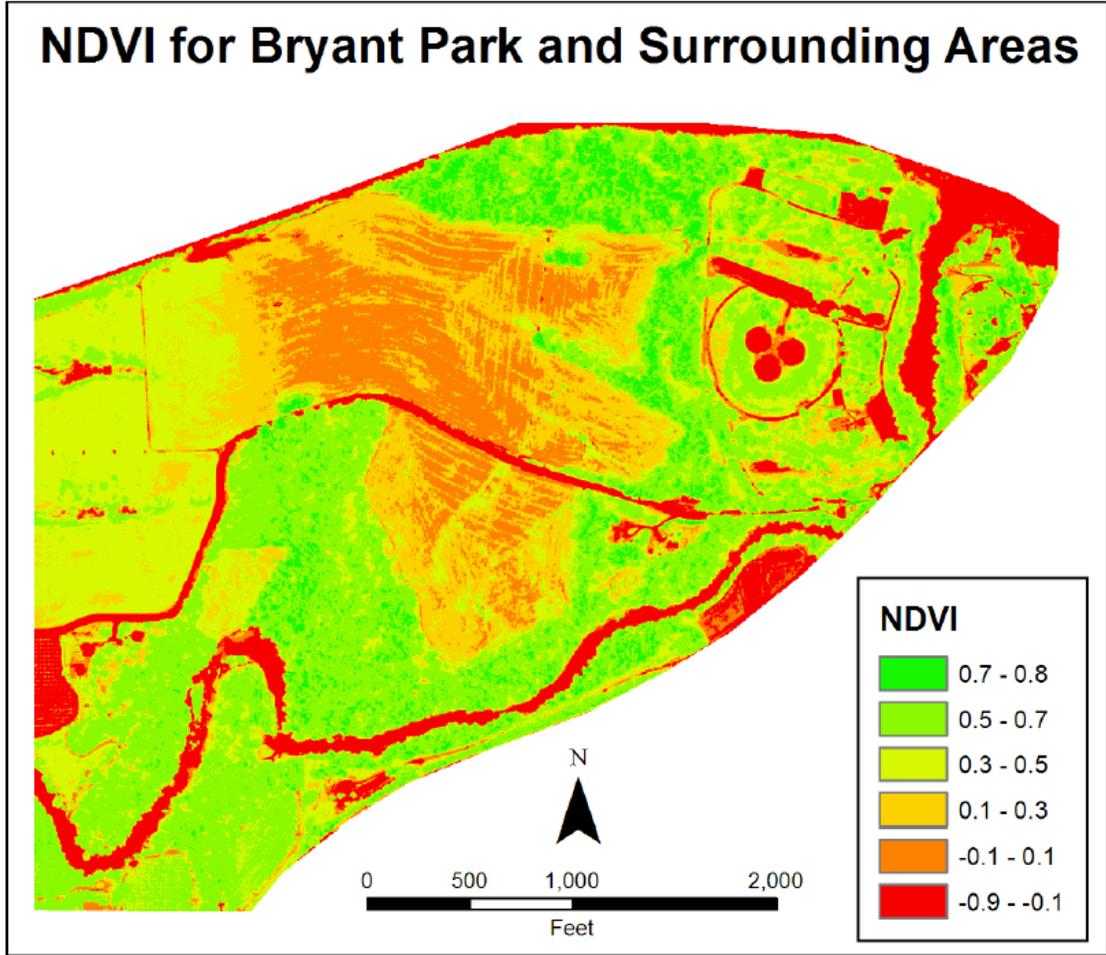


Figure 1: NDVI map of Bryant Park and the surrounding areas. Green areas of the map are trees and ornamental grasses, yellow and orange areas are natural grasses, and red areas are bare earth or water.

Canopy height is an important metric for assessing total biomass in a landscape, and can be calculated by subtracting a bare-earth digital elevation model (DEM) from a digital surface model (DSM). In contrast to a DEM, a DSM is a model of the earth's surface that includes buildings or vegetation. The subtraction of these two rasters results in a height above ground raster. If no buildings are present in the DSM, then the height above ground raster is essentially a canopy height raster. The use of Airborne Light Detection and Ranging (LIDAR) technology assists in the production of these surface models.

LIDAR uses an aircraft-mounted laser to measure the elevation of the earth's surface. A LIDAR point cloud is a visual representation of the LIDAR data, which is generated by shooting laser pulses to the Earth and timing their return. This creates huge datasets of individual elevation points that can be interpolated to generate surfaces. There can be many returns, such as first, second, third, and ground or non-ground, which helps to identify what the pulses are hitting when they are returned. For example,

first returns can identify trees and buildings in areas that have them, because these are the first objects that the pulses hit after they are shot out, and subsequently, the first pulses returned. The LIDAR point cloud is often used for visualization purposes because the LIDAR points include accurate and precise information about the latitude, longitude, and height of an area, which add a third dimension to images. By subtracting the surface of the ground from the surface of the treetops, one can calculate the canopy height.

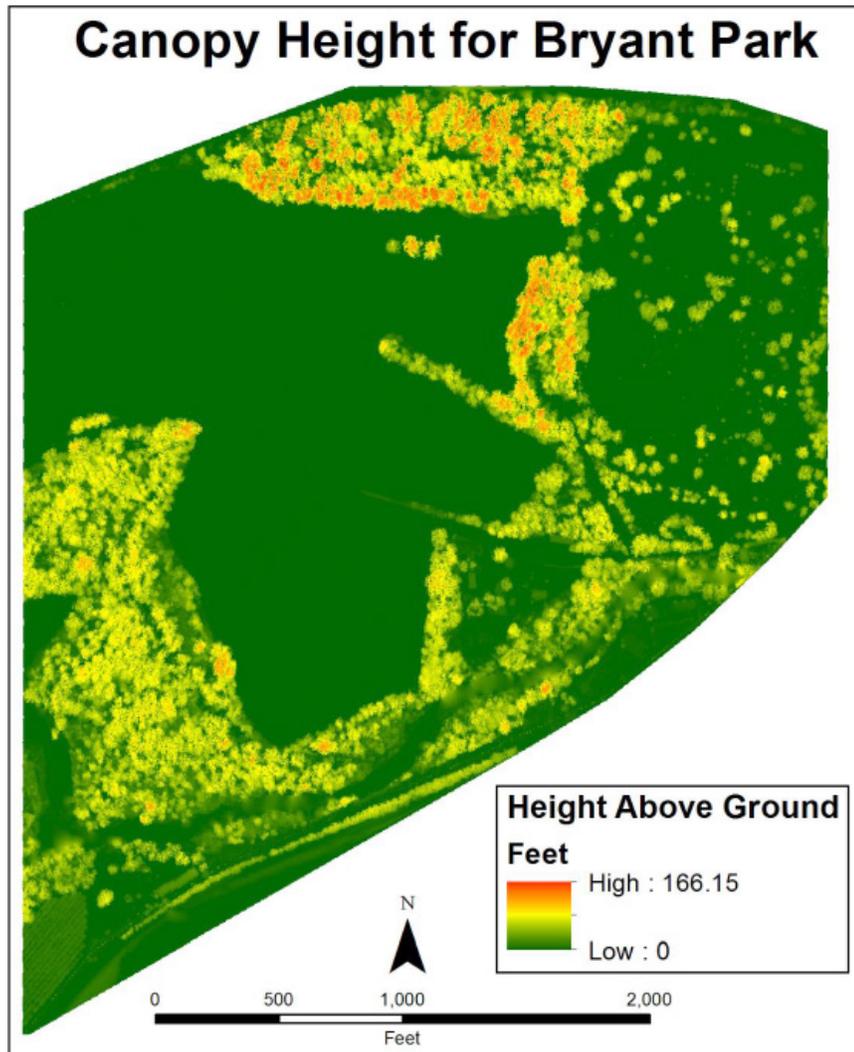


Figure 2: Canopy Heights for Bryant Park and the surrounding areas.

Vegetation density is calculated by laying a grid of cells over the LIDAR elevation points and then counting the number of points within each cell that represent elevations of either vegetation or ground points. Those cells with more vegetation points have more dense vegetation.

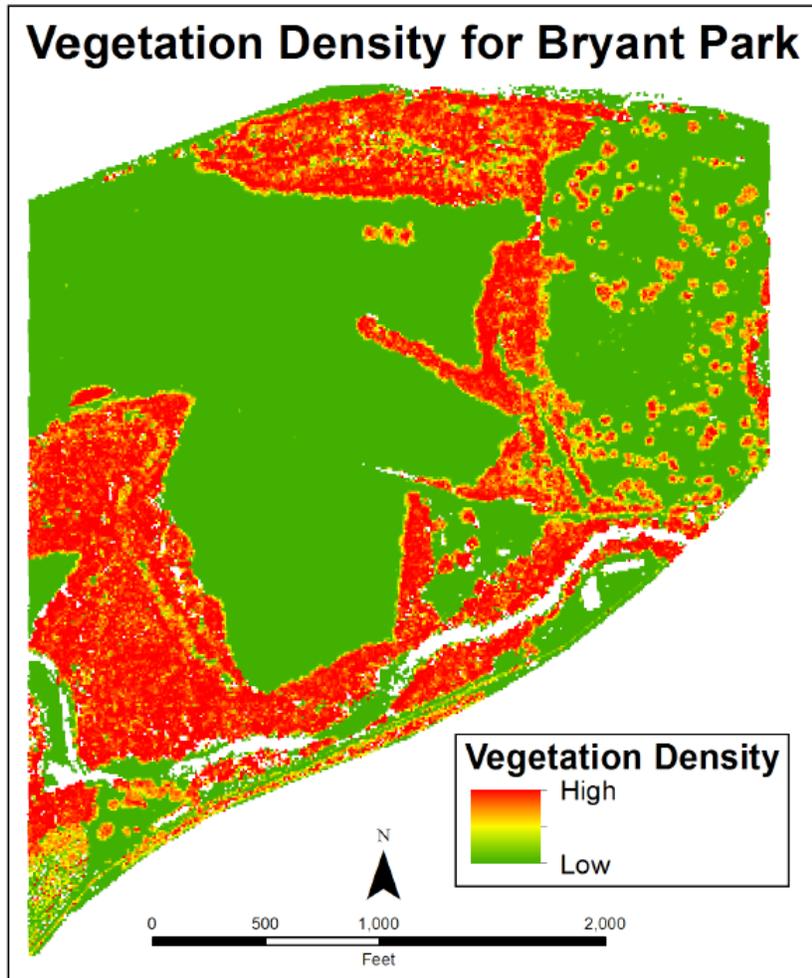
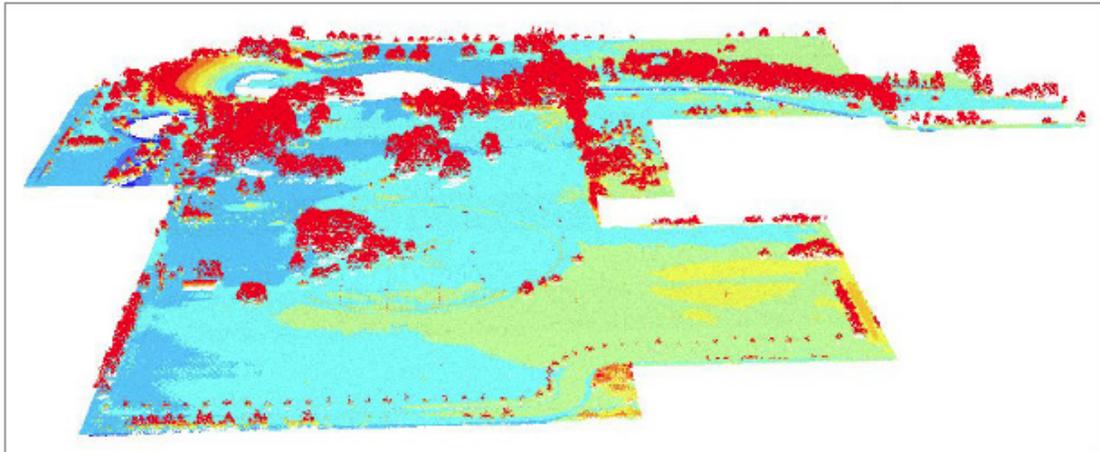


Figure 3: Vegetation Density for Bryant Park and the surrounding areas.

One of the other parks examined in more detail is Timber Linn Memorial Park, which is a community park used for various activities including sports, concerts, and festivals. The park has its own 2006 Master Plan that includes multiple park maps. These include the various options proposed for improvements, existing conditions, soils, land use, opportunities and constraints, as well as a master plan model. A LIDAR point cloud model, with the various products that can be derived from the point cloud, such as classification (vegetation, buildings, and water), elevation, contour, and intensity, could help Timber Linn Park’s future planning and assessment projects.

Lidar Point Cloud for Timber Linn Memorial Park in Albany, Oregon – Oblique View



ArcSceneObliqueView (color by elevation)

Figure 4: Lidar Point Cloud for Timber Linn Memorial Park, oblique view, color by elevation.

Creating the point cloud for Timber Linn Park begins with locating the LIDAR data, and identifying the particular tiles that cover the park. Second, an empty data file is created to load the LIDAR data into, where statistics are calculated and a coordinate system assigned. Third, the LIDAR data is clipped to extract only the data within the park, using another file that outlines the park parameters. Once the LIDAR point cloud is created for Timber Linn Park, it can be viewed in a number of ways using the LAS Dataset toolbar in ArcMap, such as by elevation, class, or return. In addition, various surfaces can be viewed, such as elevation, aspect, slope, and contours. These surfaces can also be seen using various filters that show only the points in a specified return, such as all, ground, non-ground, and first return.

Another application of remotely sensed data deals with path planning and management using aerial photography and LIDAR data. Path management and planning can be a long and arduous process, requiring a great deal of analysis and work not only to suggest and create new pathways and trails, but also to maintain and observe current pathways, how they are used, and if they need renovation. Modern advances in aerial photography and LIDAR can be used to help with the management and creation of paths and trails within Albany. With the use of these remote sensing tools, a larger area of Albany's paths can be analyzed in a shorter amount of time, and locations for site visits can be made more efficient and effective.

Remote sensing can be used in creating and planning new paths and trails. Traditionally pathways are planned using a map, and then designed based on subjective metrics of where a path would be more useful, or most popular. Ranked lists are used to rank how important intended users would find the directness of the path, or if they would prefer a more scenic route. Where are people most likely to be going? Are people happy to take a longer walk if it means not going over

steep topography? These types of questions are not easily answered by looking at a symbolic map alone, and require an understanding of the users and the park space itself, and working through the subjective responses to those questions could be painstaking work. Remote sensing could be used to make path planning much simpler by analyzing how people already use a park, and then performing a cost-benefit analysis to determine if the way a park is being used can be helped by placing official pathways.

Often, a path is clearly identifiable as being worn out of the grass, which goes directly off the intended path. This type of path, a 'desire path', shows where the park users needs have not been satisfied. These paths are self-reinforcing, meaning that if the path is useful to a proportion of path users, then they will continue to use it, continuing to wear down the grass, keeping the path in place. If a project was to be undertaken to create new pathways in public paths, these 'desire paths' could be an ideal place to start in identifying where these paths might go, as an analysis of potential interest in the path is not required, due to the nature of desire paths.



Figure 5: A desire path in North London. (Hulme, 2016)

If a path project was to be undertaken in Albany that used this method of path planning, it would be highly recommended that modern aerial photos and LIDAR data play a role in identifying locations for possible site visits and to ascertain the current use and needs filled by current worn paths. LIDAR data could also be useful in parks with high amount of tree cover; however, a high elevation resolution would be required to resolve paths. From these data sets slope and grade analysis could assess how suitable a pathway may be, and if it would meet federal guidelines. Finally, if a pathway was found to be suitable, the final step in planning would be to conduct local meetings to ascertain the level of need and use cases of the current path, and if local residents would prefer it if their track became an official pathway.

Riparian Zone Vegetation and Structure Monitoring

Vegetation is necessary in riparian areas due to its ability to create a buffer zone and add structure and stability to the area. Without that stability, erosion or deposition can negatively impact areas of a river system.

LIDAR-derived point clouds are able to look at and address various components of these riparian areas. LIDAR data can be combined with GIS data to facilitate “predictive mapping for riparian areas” (Dilts, 2010). LIDAR data can also be combined with hyperspectral imagery to identify vegetation in wetland areas with more accuracy (Klames 2014). This data can also be used to monitor “changes in structure” (Dawson, 2016) in wetland restoration projects.

The LIDAR point cloud returns allow the user to see where vegetation is present and how clustered it is in a particular area.

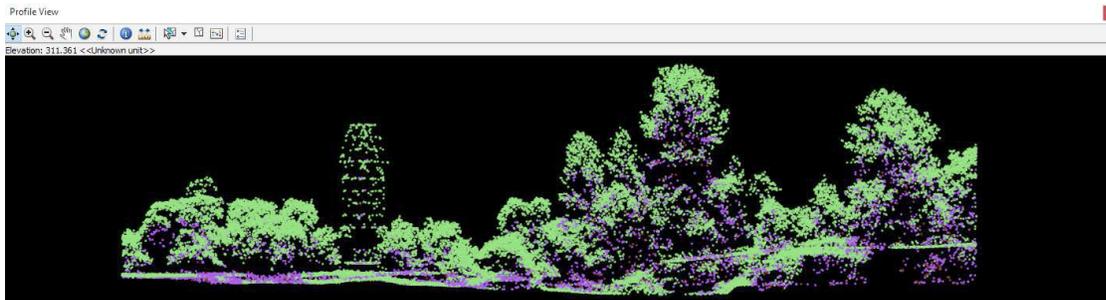


Figure 6: Profile view of a section of the focus area to display potential gaps in vegetation.

Areas can then be pinpointed where vegetation is less prevalent or non-existent. These areas are potential sites where the riparian zone may be degraded and in need of attention.

One riparian buffer of interest for the City of Albany is the confluence of the Calapooia and Willamette Rivers. This confluence area is a very important natural landscape and its conservation is vital for healthy stream flow in this location. By strengthening this riparian ecosystem, a healthier riparian and confluence area can thrive, promoting greater river health in this waterfront area.

Manipulation of Historical Imagery with Current Technologies

Producing Digital Imagery of Albany Using Historical Aerial Photos

Historical aerial photographs from the City of Albany collection can be processed to create a digital orthophoto with many potential uses. Any set of aerial photographs can be used. For example, 25 aerial photographs from the 1936 collection are combined using commercially available software to create a single large orthophoto of Downtown Albany as it appeared in 1936.

An orthophoto is an image that has been corrected for the effects of tilt and topography and therefore is a photographic map that can be treated like any other map, meaning distances can be measured accurately directly from the orthophoto (USGS Digital Orthophoto Website, 2016). Since the image is stored digitally, it can also be used in conjunction with any of the other Geographic Information Systems (GIS) data that is already available from the City of Albany GIS website (www.cityofalbany.net/departments/information-technology-gis) and the class-based Albany GIS geodatabase. The 1936 orthophoto can be used as a base map, with opportunities for other map information to be added on top of it for comparison and analysis (USGS

Digital Orthophoto Website, 2016). Below (1936_Orthophoto and 2015_Orthophoto) is an example showing the Albany parks GIS layer in transparent red in a section of town overlying both the 1936 orthophoto and an existing orthophoto in the city's collection from 2015. Striking changes in both the parks and in the morphology of the river are immediately apparent. The Albany GIS site database has many layers that can be placed on top of the 1936 orthophoto to show how the city has changed over the past eighty years.



Figure 7: 1936 orthophoto with Albany City Parks GIS layer shown in transparent red.



Figure 8: 2015 orthophoto with Albany City Parks GIS layer shown in transparent red.

Agisoft PhotoScan, the commercially available software used to create the orthophoto, utilizes Structure from Motion technology (SfM). SfM is the process of estimating the 3D structure of a scene from a set of 2D images (MathWorks, 2017). Photos can be taken from any position, provided that the object to be reconstructed is visible on at least two photos (Agisoft Manual, 2016). In other words, a set of photos with some overlap can be uploaded into the program to produce a 3D model of the objects captured in the photographs. The 3D models created in the SfM software can then be used to generate new products from the old photos that were input into the program. These products include orthophotos as well as Digital Elevation Models (DEMs). Historic buildings that no longer exist can also be visually represented in a 3D point cloud. This could be useful for historic preservation purposes, or when searching for compatible infill designs for Albany's historic districts.

The orthophoto produced using the SfM software PhotoScan is of similar quality as the original photos with the great advantage of being stored digitally, which means it can be manipulated as well as explored much like the satellite imagery available through the Google Earth viewer. The user can maneuver around the City of Albany examining different sections of the orthophoto in greater detail by zooming in to the image using GIS software like ArcScene.



Figure 9: 3D ArcScene of 1936 Albany, Oregon and surrounding area.

Furthermore, the orthophoto can be used as a base layer for other GIS layers for easy analysis and comparison of change through time. Any of the data layers available in the City of Albany GIS database offer opportunities to assess the differences, and sameness, of city features as the decades have passed.

Besides the analytical value of the historical orthophoto, there is also cultural value. Many people are drawn to historical imagery, and the 1936 orthophoto is a great window into the past. Owners of historic buildings and property may want to focus in on their property and produce a picture that can be framed and displayed. Public institutions may also want to highlight the history of the city by displaying historic imagery of important places in the city.



Figure 10: Section of the 1936 digital orthophoto showing Bryant Park and a few blocks of Downtown Albany.

These displays can help people connect with the past as they look for places they recognize or see how their neighborhood has changed. Since the orthophoto is stored digitally, the type of imagery that can be pulled from it is unlimited. From a single house to an area-wide view, any image output is easily produced from a single digital orthophoto.

The process to make digital orthophotos from historical imagery can be time-consuming due to photo preparation, finding ground control points that allow the software to identify the position of the imagery and match it to its real world location, and software processing time. Once the process to make a digital orthophoto has been completed once or twice, the methods become routine and the process becomes smoother. To assist with combating this learning curve, a tutorial that guides the user through the process has been included (Appendix A). The tutorial should allow someone who is somewhat familiar with ArcMap, Photoshop, and Excel to successfully use the Agisoft software to make an orthophoto from historical photo sets.

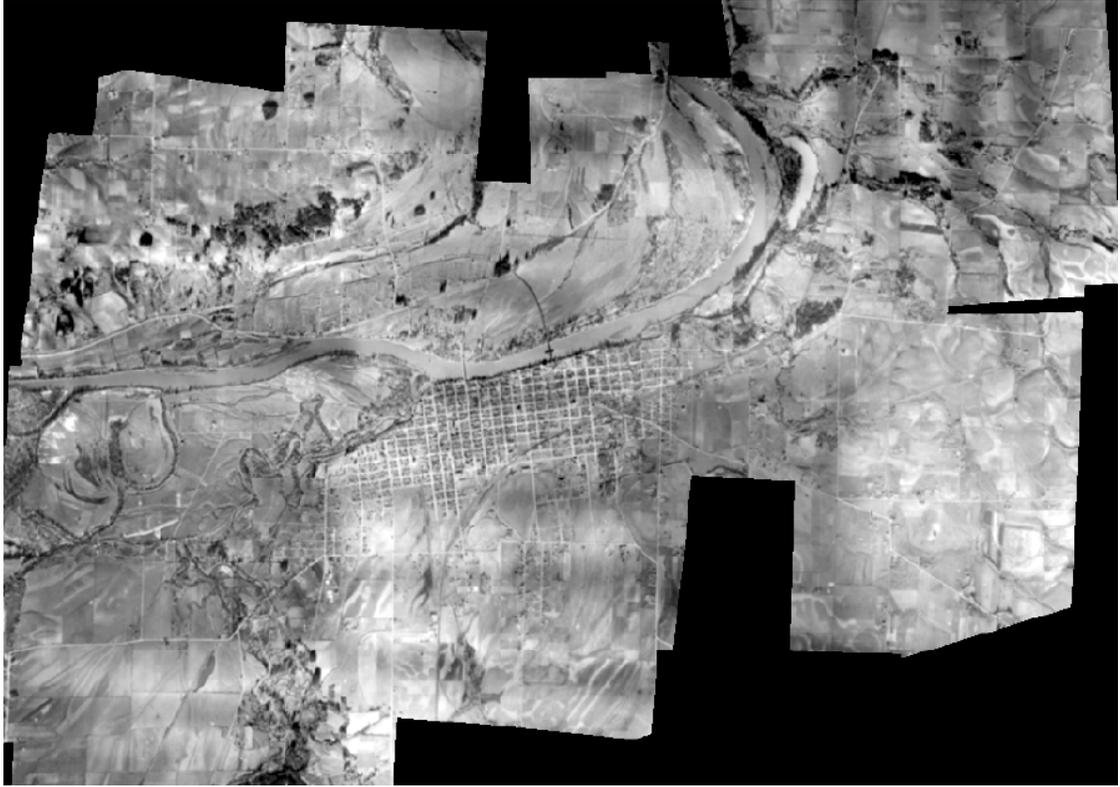


Figure 11: Orthophoto of Albany, Oregon created using historical aerial photos and SfM software.

Users can also produce a 3D model of the city and its environs using ESRI ArcScene. This is accomplished by floating the 1936 orthophoto on the 1936 DEM and rendering the orthophoto with a high quality enhancement for raster images.



Figure 12: 3D ArcScene of 1936 Albany, Oregon and surrounding area.

Data Storage and Management

Mapping & Displaying the Past

Remote sensing can be used for a variety of analyses and products. Many of these methods use both past and present imagery for comparing and mapping changes that have occurred throughout the duration of the city's existence. Several cities have utilized GIS technologies and available historic data to create a visually compelling narrative of their city's unique history to not only provide a window to the past for citizens, but also to help in playing an active role in future city planning and management.

Available historic maps, historic aerial imagery, and on-ground imagery may be used in a way that is beneficial to the City of Albany to highlight historical assets, and to do so in a way that is not just visually appealing and user friendly, but also available on a more technical level for GIS use. By bringing this historic analog information into the digital world and giving it spatial significance, spatial analysis now becomes a possibility. This spatial analysis can then be used to assist planners and managers in decision-making.

The following steps will allow a user to produce an example using already available Albany data:

1. The first step in creating datasets that can be used in GIS is to digitize any analog data that may be available. An example of this is the scanning of historical photographs into digital images.
2. The next step is to bring these datasets into a GIS software platform, such as ArcMap, and assign them coordinates in order to give them spatial information. This can be done by using the 'Georeferencing' tool in ArcMap, which consists of visually assessing the historic photos and map points that align them with an already geographically-referenced orthophoto. By assigning points coordinates, it allows the software to give the historic maps and aerial imagery common units of measurement. With common units and coordinates, the newly digitized datasets can be overlaid on existing imagery for analysis and manipulation. A guide to this process is included in Appendix B.

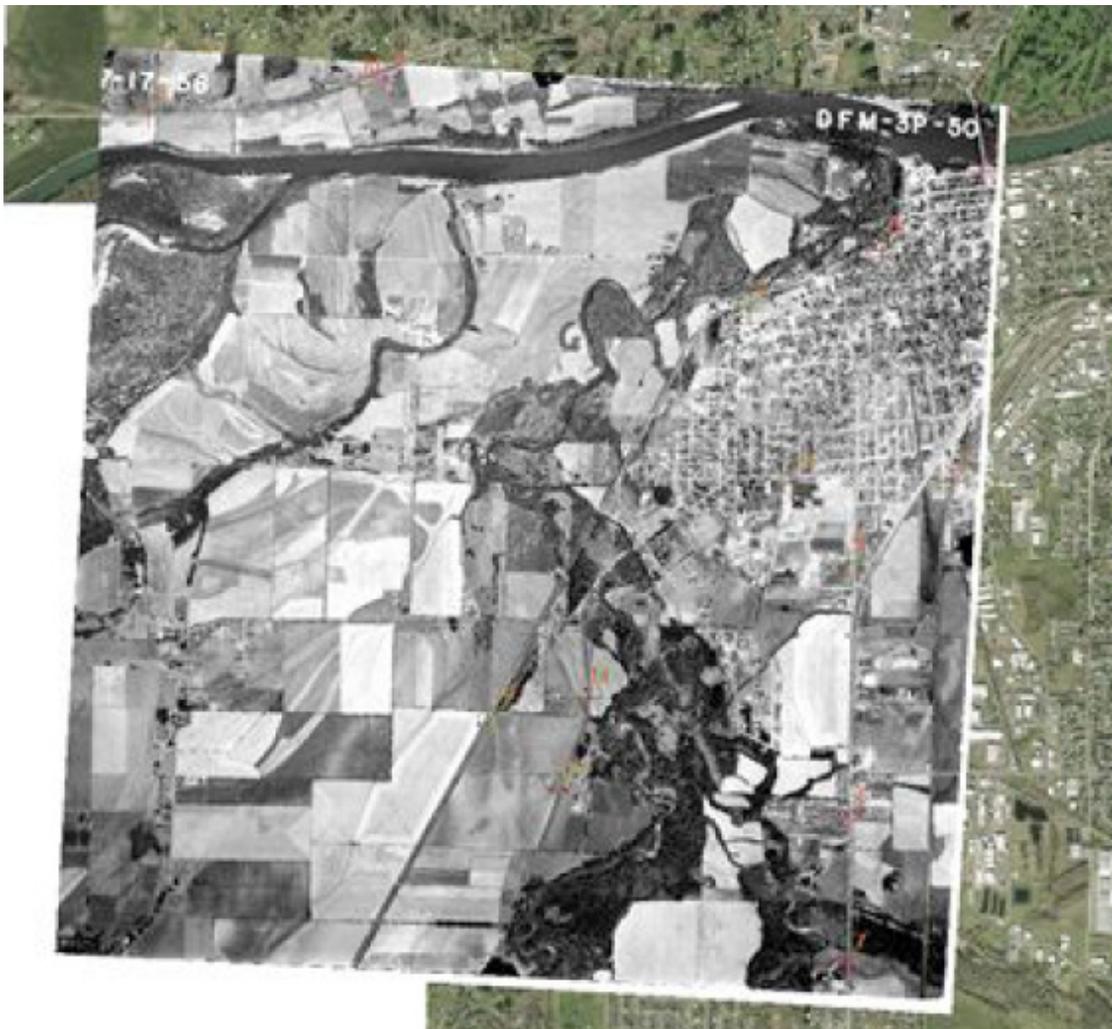


Figure 13: Sample georeferenced historical air photo overlaying a 2015 image.

3. The third step is to create an image mosaic in the ArcMap software of the

georeferenced 1936 imagery. Since each image encompasses only part of the city, it is necessary to bring in multiple images and use a mesh tool to combine them into one large image that spans the greater Albany area. This allows for easier manipulation and analysis over the entire area without having to deal with individual square grids. It also allows for easier display options when integrating the historic imagery into a story map. The process to create a mosaic is included in Appendix C.

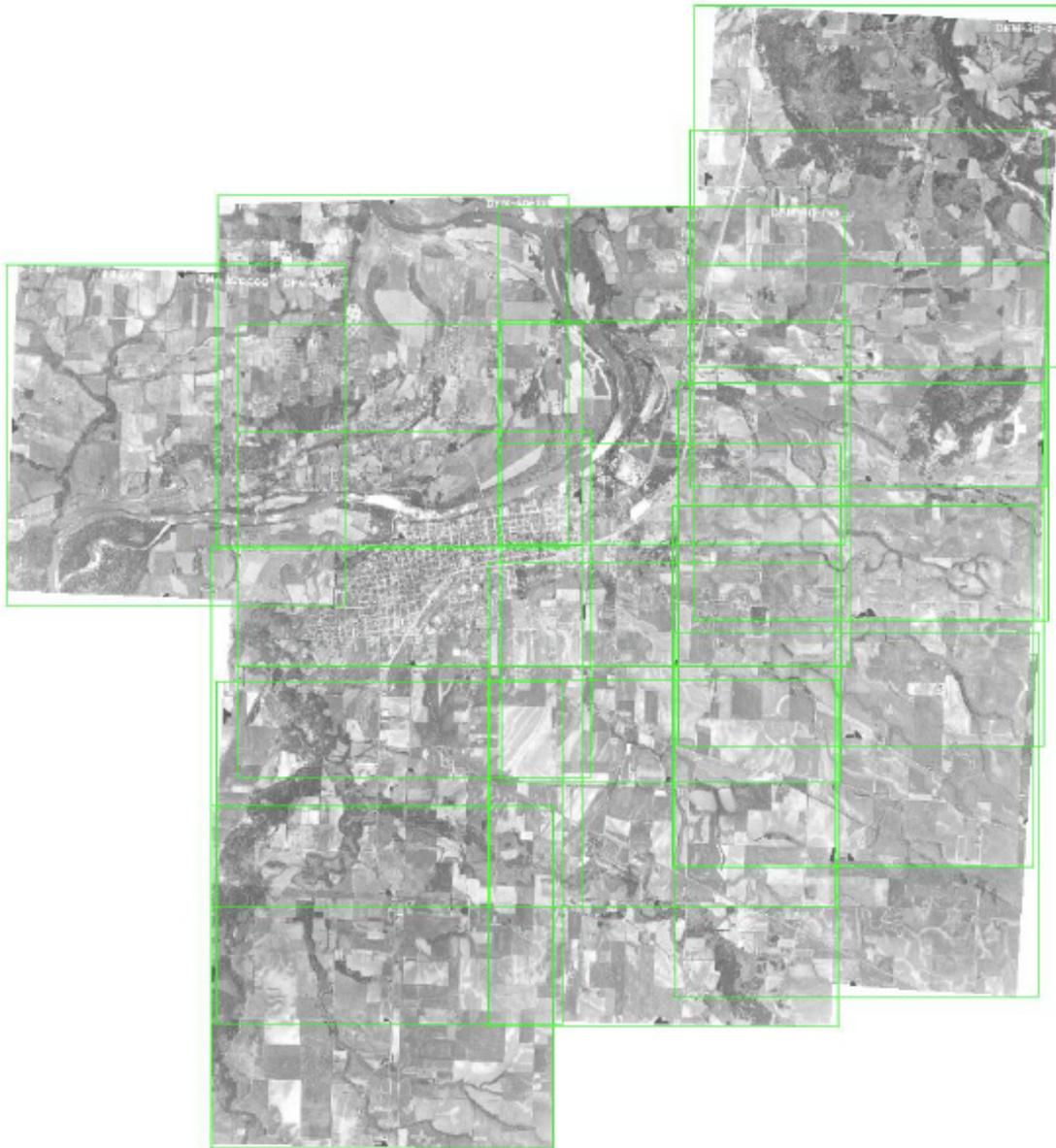


Figure 14: Mosaic of some of the 1948 Albany historical images with footprints showing the boundaries of the original images.

Once all of the desired data is geographically useful, it can be made available for use in mapping programs and for visual comparisons with current maps. An example of this visualization was created using ArcGIS online, where the historic 1936 data was added to the current imagery pre-installed with the user interfaces provided by the website. This can be done on a more extensive level with the availability of an online server to host different map layers available for Albany. Potentially useful layers include historic imagery from multiple years, or the historic georeferenced maps that can be generated using the methods from the previous section.

It is important to have all of the georeferenced historic photos in one file for each year and have a corresponding Geodatabase for the files, because it allows fast processing in ArcMap and creates an organized and efficient way to use the data that Albany has available.

An additional element that can be added to an organized Geodatabase are the Sanborn Fire Maps. Sanborn Fire Maps are maps drawn by the Sanborn Map Company for the purposes of fire insurance companies. These maps provided detailed information about buildings and their original occupants and purpose. For Albany, several years have been collected: May 1884, September 1888, July 1890, May 1895, May 1908, and May 1925. These came in multiple sheets so that they could be drawn at relatively high scales with specific information. Including these maps allows users to visualize Albany as it stood over 100 years ago, and take stock of the historical assets that still stand today. By georeferencing the Sanborn Fire Maps, one can visualize the historical area over today's imagery. There is also potential to digitize the historic Sanborn Fire Maps to create shapefiles from the historic buildings in Albany.

Sanborn Fire Map sheets can be georeferenced to create a mosaic using the same steps for these processes as used above, covered in more detail in Appendices B and C. Files for each year of the Sanborn Fire Maps can be created so that all years could eventually be georeferenced and put into an Albany Georeferenced Database by year. The Sanborn Fire Map sheets are available in PDF form on the website that hosts them. In order to use them as images in ArcMap, they needed to be converted to a .tif format. This can be done in Photoshop, with all of the converted .tif files made available in each year's file.



Figure 15: May 1884 Sanborn Fire Map georeferenced mosaic overlaying 2015 imagery.

Another product that can be produced using historical imagery and modern technology is to review on-ground photos and assign them locations on a digital map. This could be done in either ArcMap for the desktop or in ArcGIS online. By cross-referencing the historic imagery and maps with current street views (either physically investigating, or using Google Earth), specific buildings can be identified and then historic photos can be assigned a location on the historic map via creating a point with an image link using ArcGIS online. For extensive amounts of images and points, Microsoft Excel data tables may be useful for file management and maintenance and would improve time-efficiency for large amounts of additions and revisions. An example produced by a student in the class showing the type of maps that can be created for Albany using this process is available at <http://arcg.is/1uPHua>.

Conclusion

The use of remote sensing technologies and techniques can be helpful for the future of cities, including Albany. From cataloguing historical imagery in useful and compelling ways to planning future projects for residents and visitors to enjoy, almost any spatially important aspect of planning and management will be positively impacted by considering the contents of this report. The creation of a well-organized database to store the massive amount of data that already exists, along with that which can be produced is crucial in the utilization of that data. The use of LIDAR point clouds significantly expands the number and scale of analytical processes that the city can undertake, especially in park and greenspace management and planning, as this tool can enhance the understanding of vegetation, riparian zones, and path monitoring and planning. These types of analyses are likely to become increasingly important, as new sets of LIDAR data are projected to be obtained with a repetitive frequency that will allow for long-term situational monitoring of many facets of the city. Finally, the creation of orthophotos and other maps using modern techniques and technologies from historically available data can help the city look at the past and plan for the future as new challenges arise.

Appendices

Appendix A:

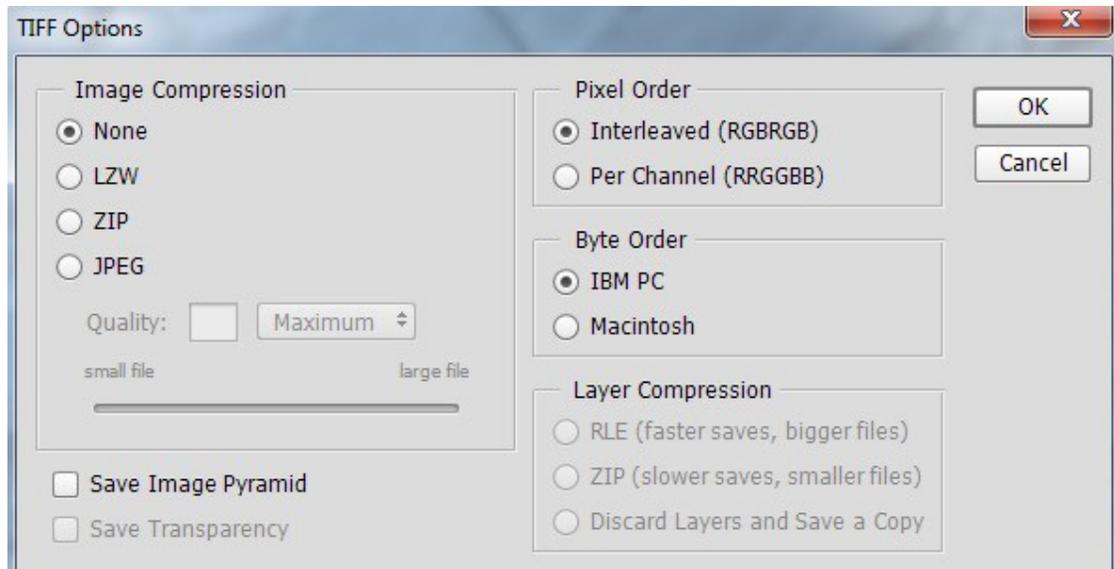
- Producing Digital Orthophotos in PhotoScan using Historical Photos Tutorial

Software used in tutorial:

- Adobe Photoshop
- ESRI ArcMap
- Agisoft PhotoScan
- Microsoft Excel
- Make a new folder either on a network server, or on your C: drive. Working from the C: drive shortens processing time considerably.

Photo Preparation

- The photos need to be prepped for importation into the PhotoScan software.
 1. The historical photos of interest may be scanned and stored digitally already, but if not, they need to be scanned. Image Quality matters for the PhotoScan software, so use the best available scanner.
 2. Crop the photos in Adobe Photoshop, or a similar software package. Each time you open a new photo to crop, use the Save As command to rename the photo. Save as a TIFF file and do not use compression.



Tutorial 1: TIFF options box appears after changing the name, selecting TIFF, and entering save in the Save As options box.

Many old photos have numbers on them already, so if you name them accordingly they should show up in PhotoScan already in order when you load them. You can get rid of writing or other stray marks on the photos at this time if you wish, though PhotoScan does a decent job of eliminating features that are not on the ground. You will want to crop out as little as possible, just enough to make it rectangular and eliminate the borders that are artifacts from the scanning process. The PhotoScan software needs as much overlap from picture to picture as possible, so the cropping should be minimal.

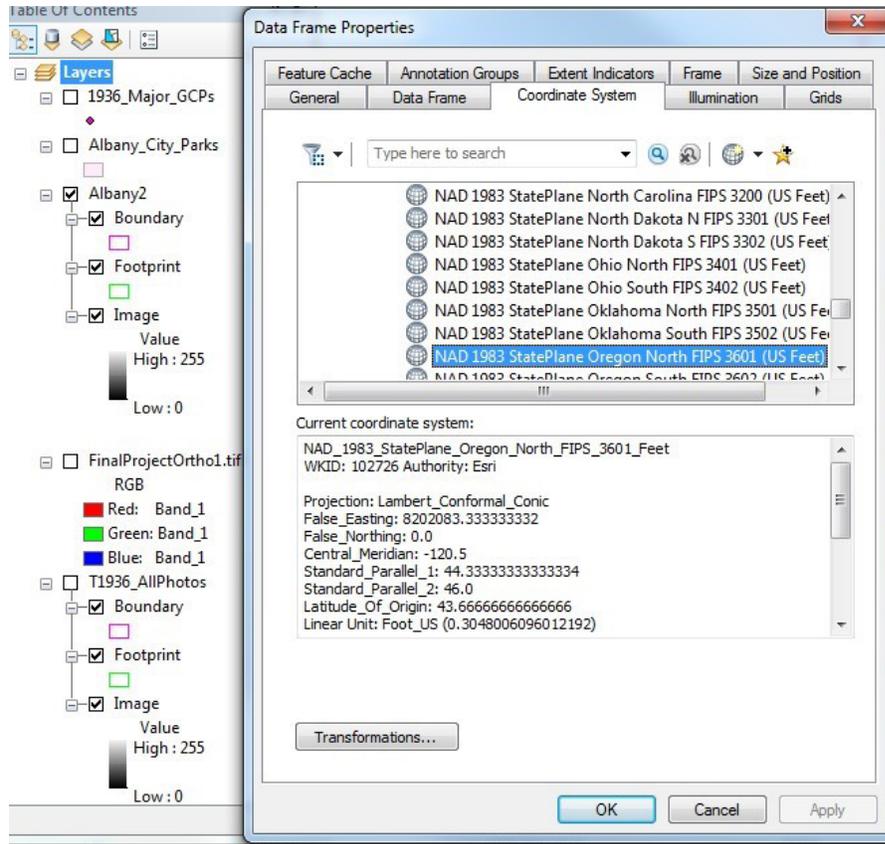


Tutorial 2: Scanned historical image.



Tutorial 3: Cropped and renamed historical image.

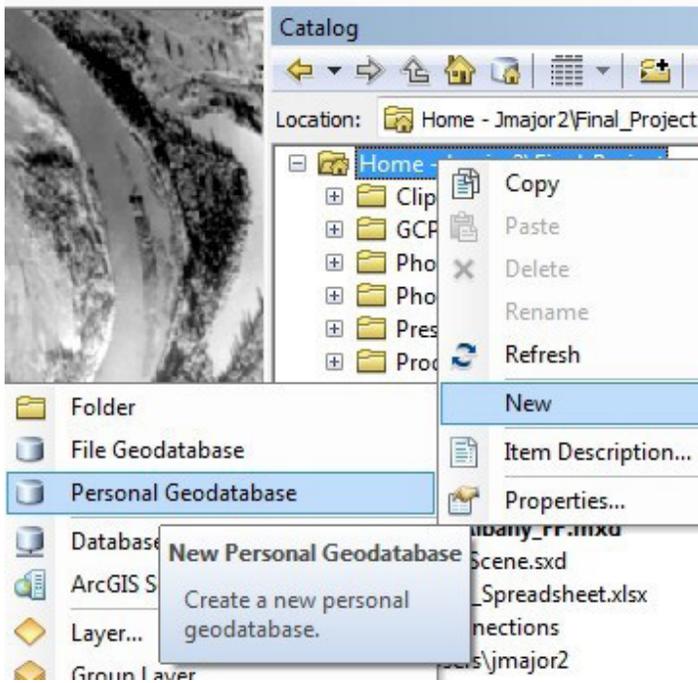
1. Once all the historical photos have been cropped and saved as TIFF files they can be loaded into ArcMap for georeferencing. Set your Layers data frame to the coordinate system you want to use in your project.



Tutorial 4: Set your coordinate system for your data frame.

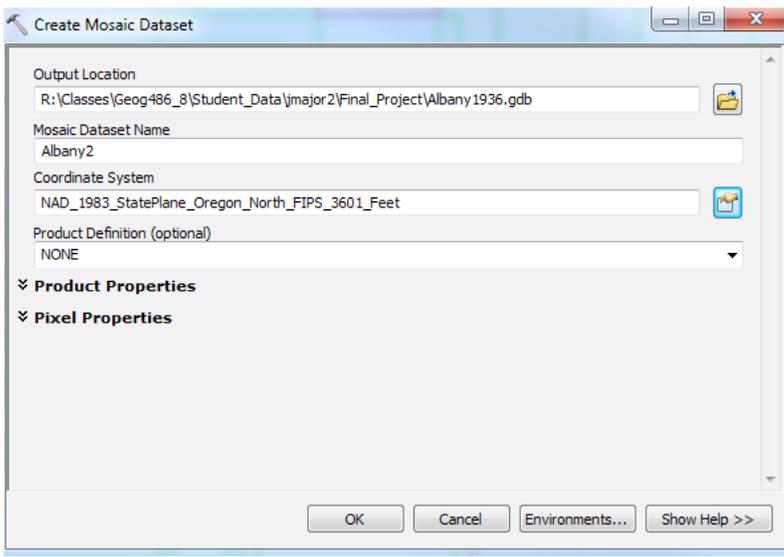
Georeferencing them with a modern orthophoto allows an image mosaic to be made to find image centers, while also allowing us to estimate the height above ground at which the photos were taken.

2. Georeference the photos using the Georeferencing Toolbar in ArcMap; four points must be found in each historical photo that correspond with a location on the modern orthophoto. These do not have to be as precise as the GCPs we will make later. Road intersections often work well and are relatively easy to locate. It just needs to be a road that was in the same location in both the historical photo and the modern photo. The points should be spread out as much as possible around the photo to reduce distortion error.
3. After georeferencing the photos, make a new geodatabase from the catalog in ArcMap in the project folder.



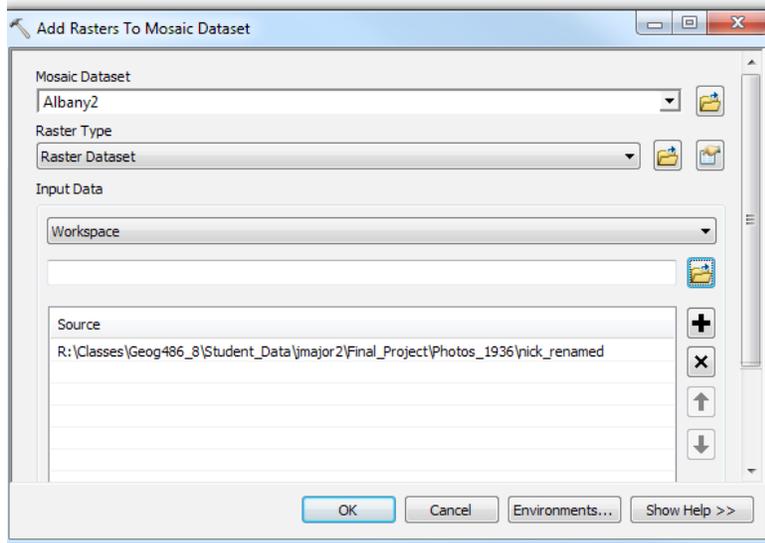
Tutorial 5: Creating a new personal geodatabase in ArcMap.

4. After the geodatabase is made, create an empty mosaic dataset using the Create Mosaic Dataset Tool. Remember to set the proper coordinate system for the project.



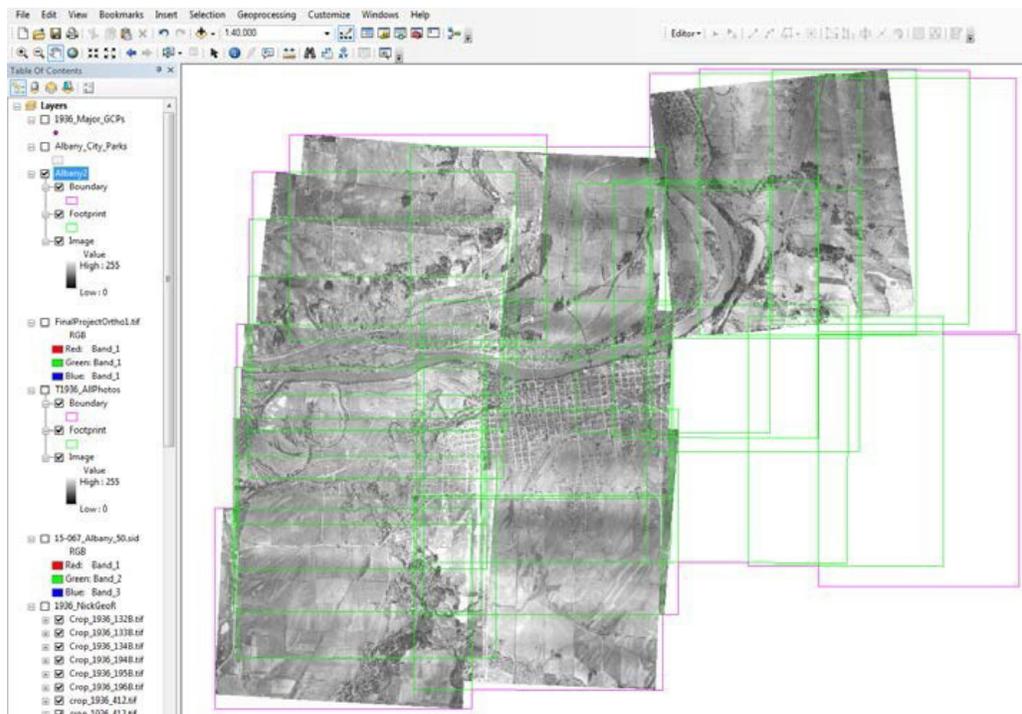
Tutorial 6: Create Mosaic Raster Tool options box.

5. Add rasters (cropped TIFF files) to the empty mosaic using the Add Rasters to Mosaic Dataset Tool.



Tutorial 7: Add Rasters to Mosaic Dataset Tool options box.

When the tool has run successfully, it will look something like this. The machine used for the tutorial had difficulty drawing the imagery properly, but it works fine when zoomed in. Do not worry about this too much if it happens; this is all part of the process of making a much better image— the orthophoto.



Tutorial 8: Mosaic with Boundary, Footprint, and Image.

- Finally, the attribute table of the Footprints can be opened in the mosaic layer to find the image centers that will assist in alignment in PhotoScan. Export the footprint attribute table to excel using the Table to Excel Tool, estimate the altitude where the photos were taken, and eliminate all columns except the name, x, y, and z columns, and save it as a comma separated value file (.csv). It can also be saved as a text file, as the PhotoScan software will import either.

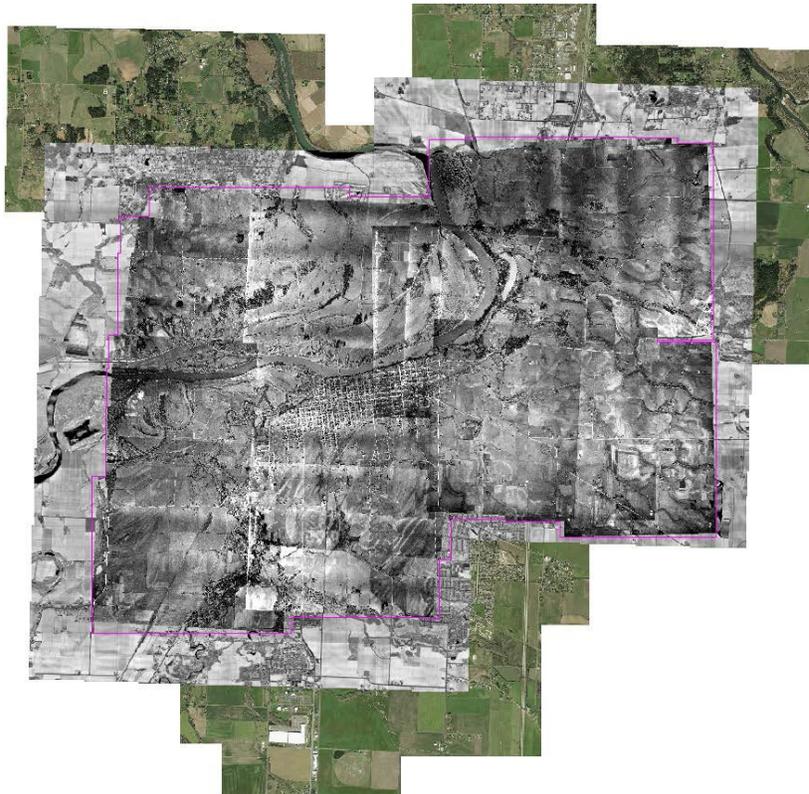
| | A | B | C | D | E |
|----|----------------------|-------------|-------------|------------|---|
| 1 | #Label | X/East | Y/North | Z/Altitude | |
| 2 | 132_1936_crop_um.tif | 7533637.811 | 362671.5925 | 6088 | |
| 3 | 133_1936_crop_um.tif | 7538197.408 | 362354.2571 | 6088 | |
| 4 | 134_1936_crop_um.tif | 7541585.646 | 361465.034 | 6088 | |
| 5 | 194_1936_crop_um.tif | 7534035.895 | 367908.2322 | 6088 | |
| 6 | 195_1936_crop_um.tif | 7532190.396 | 368459.8496 | 6088 | |
| 7 | 196_1936_crop_um.tif | 7530221.498 | 368498.8287 | 6088 | |
| 8 | 412_1936_crop_um.tif | 7541518.518 | 373271.5198 | 6088 | |
| 9 | 413_1936_crop_um.tif | 7539349.867 | 373604.6443 | 6088 | |
| 10 | 414_1936_crop_um.tif | 7536443.081 | 373392.8402 | 6088 | |
| 11 | 415_1936_crop_um.tif | 7534019.78 | 373206.3606 | 6088 | |
| 12 | 470_1936_crop_um.tif | 7523974.151 | 371305.9913 | 6088 | |
| 13 | 471_1936_crop_um.tif | 7523913.887 | 366827.6123 | 6088 | |
| 14 | 472_1936_crop_um.tif | 7524442.071 | 364254.517 | 6088 | |
| 15 | 473_1936_crop_um.tif | 7524206.159 | 361451.1676 | 6088 | |
| 16 | 474_1936_crop_um.tif | 7524575.153 | 359062.6135 | 6088 | |
| 17 | 475_1936_crop_um.tif | 7523975.719 | 355323.6336 | 6088 | |
| 18 | 505_1936_crop_um.tif | 7514975.176 | 354608.9709 | 6088 | |
| 19 | 506_1936_crop_um.tif | 7516063.555 | 356969.6502 | 6088 | |
| 20 | 507_1936_crop_um.tif | 7515609.182 | 358929.8707 | 6088 | |
| 21 | 508_1936_crop_um.tif | 7515772.1 | 361099.8021 | 6088 | |
| 22 | 509_1936_crop_um.tif | 7515768.624 | 363100.9903 | 6088 | |
| 23 | 510_1936_crop_um.tif | 7516455.154 | 365290.7861 | 6088 | |
| 24 | 511_1936_crop_um.tif | 7516572.251 | 367710.7591 | 6088 | |
| 25 | 512_1936_crop_um.tif | 7516869.19 | 369632.5472 | 6088 | |
| 26 | 513_1936_crop_um.tif | 7518419.953 | 371762.717 | 6088 | |

Tutorial 9: .csv file ready for import into PhotoScan.

Ground Control Points and Validation Points

At this point, the photos as well as the image centers and altitude .csv file are ready to be uploaded into PhotoScan. There is still one more bit of preprocessing that needs to be done to produce the third important piece of data that must be imported into PhotoScan to start a project— that is finding GCPs to make into Marker Points in PhotoScan. To georeference the point cloud in PhotoScan there need to be points found from high accuracy data, such as LIDAR, that correspond to points on the historic photos. The program takes a relatively small number of points and computes the location values for the rest of the point cloud from them.

1. In ArcMap, add LIDAR Intensity data, ideally just for the immediate area you are interested in; intensity rasters in areas you are not using slows down the processing and resampling. It is sometimes best to turn off the Image and Footprint portions of the mosaic and use the Boundary as a guide. Wait to add the HighestHit and BareEarth LIDAR datasets for now in the interest of improving processing speed.
2. Add a modern orthophoto to the data frame to help identify points that are in both the historic and modern imagery. One can now toggle between the individual historic photos, the LIDAR Intensity imagery, and the modern orthophoto to find common points.



Tutorial 10: Layers in ArcMap from bottom to top: modern orthophoto, LIDAR Intensity, historical photos, and mosaic boundary. These layers can now be toggled between to find common points.

- Start identifying common points using any resources you can find to positively identify a point that was in existence and clearly visible in at least two (2) historical photos and the LIDAR intensity imagery. It may be easiest to use Google Earth and internet searches of addresses, especially using real estate websites, to find when a particular feature or structure was built. Sometimes a city or town will have a database of historic structures as well and those can be excellent resources.
- Create a new point shapefile in ArcMap for the GCPs and add fields to its attribute table. For completeness, add fields for marker location, marker, address, and columns for three pictures, though PhotoScan only needs two (sometimes the common GCPs show up better in one picture than others and if the location is blurry or obscured on one photo, just leave it out).

| FID | Shap | OBJEC | Image1 | Image2 | Image3 | MarkerLoc | Marker | Address |
|-----|-------|-------|--------|--------|--------|---|--|--|
| 0 | Point | 23 | 412 | 413 | 0 | Ground, SW corner of house | House (1920) | 37818 Shady Bend Rd NE |
| 1 | Point | 15 | 413 | 414 | 412 | Ground, SW corner of structure | House (1920) | 33659 Murder Creek NE |
| 2 | Point | 9 | 512 | 511 | 0 | Ground, SE corner of structure | Old Barn NW of Albany | Just west of Oak Grove Elem. on NW oak grove rd. |
| 3 | Point | 20 | 412 | 413 | 0 | Ground, center of N side of house | house (1890) | 1875 Clover Ridge Road NE |
| 4 | Point | 14 | 512 | 513 | 0 | Ground, SE corner of house | House (1928) | 1610 NW Laurel Way |
| 5 | Point | 18 | 196 | 470 | 0 | Ground, NE corner of house | house (1890) | 608 NE Nebergall Loop |
| 6 | Point | 4 | 511 | 512 | 513 | Ground, center east side of house | House (1903) | 1070 NW Scenic Drive |
| 7 | Point | 16 | 413 | 414 | 415 | Sidewalk, where the walk meets the carriage pull | House | 1330 Old Salem Rd NE |
| 8 | Point | 3 | 472 | 513 | 510 | Ground, SW corner of structure | Fairmount Grange (1930) | 835 NW Albany Rd |
| 9 | Point | 22 | 509 | 510 | 0 | Ground, SE corner of structure | House (1910) | 4829 NW Hwy 20 |
| 10 | Point | 11 | 472 | 473 | 0 | Ground, inside corner of sidewalk at SW corner of | Munn House (1880) | 1105 Water Ave NE |
| 11 | Point | 21 | 132 | 194 | 0 | Ground, SW corner of structure | House (1924) | 2601 Salem Ave SE |
| 12 | Point | 25 | 132 | 472 | 473 | Ground, SE corner of house | House (1905) | 406 Geary Street |
| 13 | Point | 7 | 472 | 473 | 0 | Ground, Center of west side of structure | Cumberland Presbyterian Church (1892) | 401 SE Main Street |
| 14 | Point | 12 | 472 | 473 | 510 | Sidewalk, ctr of sm path where it joins lg path | Riverside Cemetery (est 1847) | West end of 7th Ave |
| 15 | Point | 1 | 472 | 473 | 474 | Ground, SE corner of structure | Central Elementary (1915) | 338 SW 9th Ave. |
| 16 | Point | 19 | 133 | 134 | 0 | Ground, NW corner of shop | old commercial structure | 5923 Santiam Hwy |
| 17 | Point | 13 | 506 | 507 | 508 | Ground, SE corner of structure | old barn on the Lone Oak Livestock Ranch | 3117 Lone Oak Ln |
| 18 | Point | 2 | 474 | 507 | 509 | Ground, East Entrance | Grey Hall, Albany College (1925) | Queen and Broadway |
| 19 | Point | 5 | 473 | 474 | 475 | Ground, center front entrance | John A. Millard House (1880) | 2115 Ferry St. SW |
| 20 | Point | 24 | 132 | 474 | 0 | Ground, SE corner of house | House (1925) | 2120 Geary St SE |
| 21 | Point | 10 | 506 | 507 | 508 | Ground, SW corner of structure | Old barn associated with house (1911) | 36068 Riverside Dr. SW |
| 22 | Point | 6 | 474 | 475 | 473 | Ground, SW corner of structure | Smith House (1909) | 2455 Marion St. SW |
| 23 | Point | 17 | 132 | 133 | 0 | Ground, SW corner of structure | House (1900) | 2607 Three Lakes Rd SE |
| 24 | Point | 8 | 505 | 506 | 0 | Ground, NE of fence junction | field near Riverside, SW of Albany | Riverside Drive |

Tutorial 11: GCP shapefile attribute table. Populated with GCPs (notice how the attributes are entered for later).

- Once a good GCP has been found, select the start editing command from the Editing Toolbar in ArcMap and select the new point shapefile. Select the create features tool from the Editor Toolbar.
- Make sure to place the point on the LIDAR Imagery! The measurements that need to be taken are from the LIDAR data, and though roughly georeferenced the historical photos and mosaic image, they are not exactly lined up in the correct geospatial location.
- Place the GCP and edit the attributes. Keeping detailed records of the points will help later, both in finding them in PhotoScan and having details about important points in the project for later.



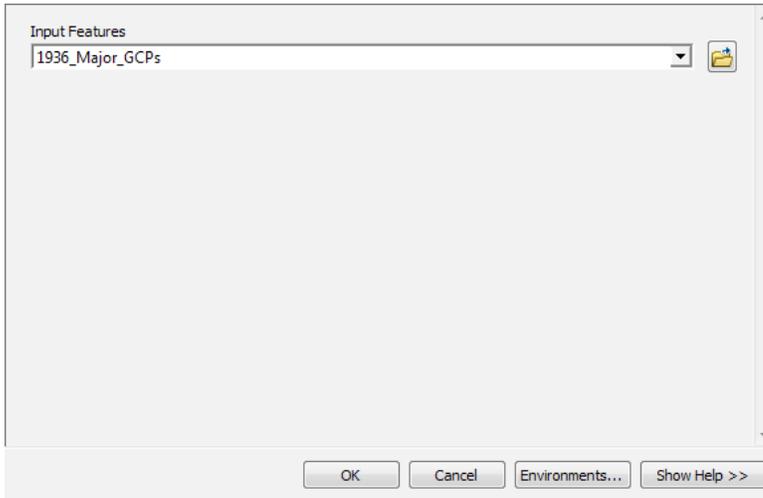
Tutorial 12: Ground Control Point added to LIDAR Imagery.

8. Find more points spread around the area of interest for the project. The PhotoScan software does not need a great deal of Marker Points (what it calls GCPs), but it is nice to have more absolutely necessary so some can be used as validation points and others can be discarded if they turn out not to be optimal when looking at the photos and placing markers in PhotoScan. If the study area is small, there can be fewer GCPs, but for larger study areas try to find more.



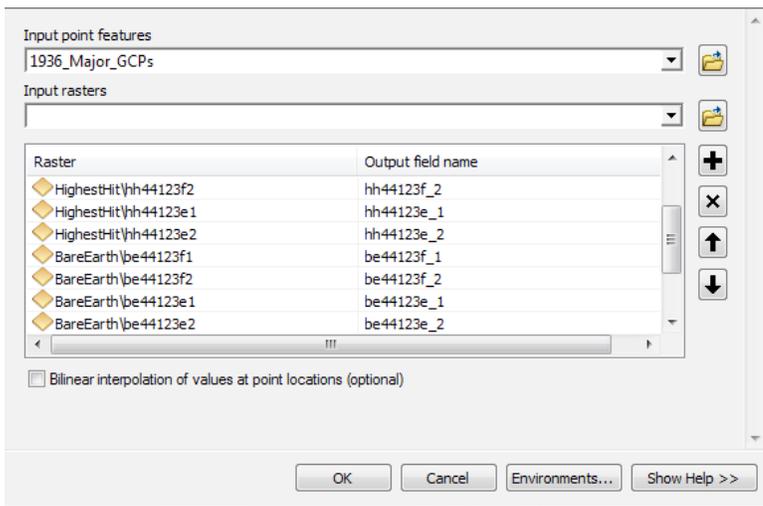
Tutorial 13: GCP spread around the LIDAR Intensity image that can now be used as Markers in PhotoScan or Validation Points for error assessment.

9. Now it is time to add the LIDAR DEM data so the x, y, and z coordinates can be extracted from the GCPs. Add the LIDAR BareEarth and HighestHit datasets to the ArcMap project.
10. Add x and y coordinates to your GCP attribute table by running the Add XY Coordinates Tool.



Tutorial 14: Add XY Coordinates Tool.

11. Add the elevation of the GCPs by running the Extract Multi Values to Points Tool.



Tutorial 15: Extract Multi Values to Points Tool.

- Each of the input rasters that went into the Extract Multi Values to Points Tool is now represented in the attribute table of the GCPs. Each point has a value in one HighestHit column and one BareEarth column. All other columns show the no value present default, usually -9999 in ArcMap. This will be narrowed down to one z value for each GCP in Excel a little later.
- Extract the attribute table to Excel using the Table to Excel Tool. Each GCP has a column for each BareEarth and HighestHit, but there are only values in two of them: one for each, BE and HH. Make a new column for the Point_Z and determine where points were placed in the LIDAR Intensity imagery. If the GCP is on top of a building choose the HH value and copy and paste it into the corresponding Point_Z column and row. If the GCP was located on the ground use the BE value and insert it into the proper cell.

| ECTID | POINT_X | POINT_Y | hh44123f1 | hh44123f2 | hh44123e1 | hh44123e2 | be44123f1 | be44123f2 | be44123e1 | be44123e2 | Point_Z |
|-------|-------------|-------------|-------------|-------------|-----------|-----------|-------------|-------------|-----------|-----------|-------------|
| 23 | 7540742.961 | 377752.2852 | 262.9169851 | -9999 | -9999 | -9999 | 262.3519897 | -9999 | -9999 | -9999 | 262.3519897 |
| 15 | 7538321.047 | 375348.1315 | 292.1440125 | -9999 | -9999 | -9999 | 291.4530029 | -9999 | -9999 | -9999 | 291.4530029 |
| 9 | 7512166.793 | 372538.0752 | -9999 | 259.5400085 | -9999 | -9999 | -9999 | 259.0539856 | -9999 | -9999 | 259.0539856 |
| 20 | 7541274.922 | 372511.6402 | 251.8359985 | -9999 | -9999 | -9999 | 233.0930023 | -9999 | -9999 | -9999 | 233.0930023 |
| 14 | 7521319.105 | 372107.439 | 311.6730042 | -9999 | -9999 | -9999 | 291.0660095 | -9999 | -9999 | -9999 | 291.0660095 |
| 18 | 7526579.109 | 372020.6491 | 203.2949982 | -9999 | -9999 | -9999 | 202.6900024 | -9999 | -9999 | -9999 | 202.6900024 |
| 4 | 7514433.573 | 370130.7157 | -9999 | 347 | -9999 | -9999 | -9999 | 347.7059977 | -9999 | -9999 | 347.7059977 |
| 16 | 7535410.301 | 370117.9677 | 219.8289948 | -9999 | -9999 | -9999 | 219.5809937 | -9999 | -9999 | -9999 | 219.5809937 |
| 3 | 7521834.251 | 368218.7078 | 208.9409943 | -9999 | -9999 | -9999 | 207.8190002 | -9999 | -9999 | -9999 | 207.8190002 |
| 22 | 7511092.559 | 368272.668 | -9999 | 248.397995 | -9999 | -9999 | -9999 | 239.3739929 | -9999 | -9999 | 239.3739929 |
| 11 | 7527469.797 | 365581.2149 | 211.3639984 | -9999 | -9999 | -9999 | 211.1170044 | -9999 | -9999 | -9999 | 211.1170044 |
| 21 | 7532089.925 | 365504.4663 | 223.8869934 | -9999 | -9999 | -9999 | 222.7230072 | -9999 | -9999 | -9999 | 222.7230072 |
| 25 | 7529678.349 | 364630.7546 | 220.5510046 | -9999 | -9999 | -9999 | 219.5330015 | -9999 | -9999 | -9999 | 219.5330015 |
| 7 | 7527619.011 | 364385.3166 | 231.3609924 | -9999 | -9999 | -9999 | 215.9100037 | -9999 | -9999 | -9999 | 215.9100037 |
| 12 | 7520750.761 | 362890.8307 | 220.5789948 | -9999 | -9999 | -9999 | 220.1519928 | -9999 | -9999 | -9999 | 220.1519928 |
| 1 | 7523677.348 | 362242.1032 | 225.427002 | -9999 | -9999 | -9999 | 217.2279968 | -9999 | -9999 | -9999 | 217.2279968 |

Tutorial 16: Copying an elevation value from the BareEarth LIDAR data from a GCP placed on the ground and moving into the Point_Z column.

- Make a new spreadsheet for the Marker Points and only copy over the Name, x, y, and z columns. Change the names of the GCPs to something that helps to find them later in PhotoScan.
- Add Easting to the POINT_X title and Northing to the POINT_Y title to prevent any confusion when the file is uploaded to PhotoScan. Save this as a .csv file. It is now ready for importation into PhotoScan.

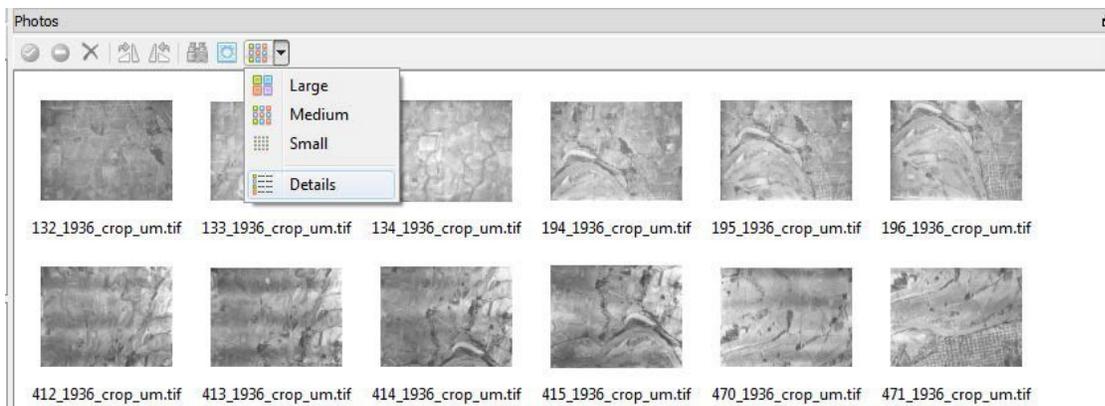
| Name | POINT_X (Easting) | POINT_Y (Northing) | Point_Z |
|--------------------------------|-------------------|--------------------|-------------|
| Grey Hall | 7519814.713 | 359698.3685 | 233.0709991 |
| Fairmont Grange | 7521834.251 | 368218.7078 | 207.8190002 |
| Cumberland Presbyterian Church | 7527619.011 | 364385.3166 | 215.9100037 |
| Riverside Cemetery | 7520750.761 | 362890.8307 | 220.1519928 |
| House | 7535410.301 | 370117.9677 | 219.5809937 |

Tutorial 17: .csv file ready for importation into PhotoScan.

PhotoScan

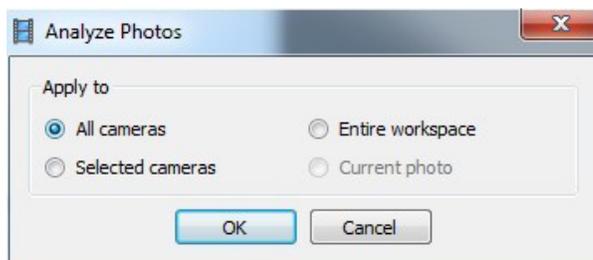
It is now time to input the photos, image centers and altitude, and the Markers into PhotoScan. For a click-by-click tutorial of the PhotoScan process for picture sets, see James Dietrich's blog at <http://adv-geo-research.blogspot.com/2015/06/photoscan-crash-course-v1-1.html#georef>. The Agisoft PhotoScan User Manual is also helpful.

1. Open PhotoScan and save the Project in a folder in your workspace. Even if using a network drive for the rest of the project, it is highly recommended to move the project and all the files it needs to the C: drive. It will save hours of processing time. Save a version of the PhotoScan Project after each major step along the workflow. These will be named the same as that part of the workflow, so the first save can be ProjectName_Input, and so on.
2. In the Workspace window click on the add photos button (or select it from the Workflow drop down menu at the top of the user interface) and navigate to the photos. Select them all and click open.
3. In the Photos window click the change view button and choose Details.



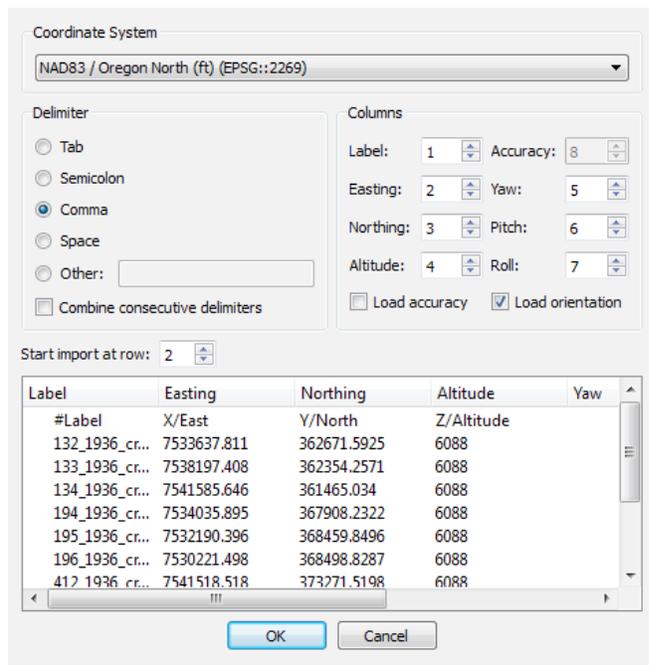
Tutorial 18: Change to details view for the photos.

4. Highlight the top photo, right click, and choose Estimate Image Quality. Select All cameras.



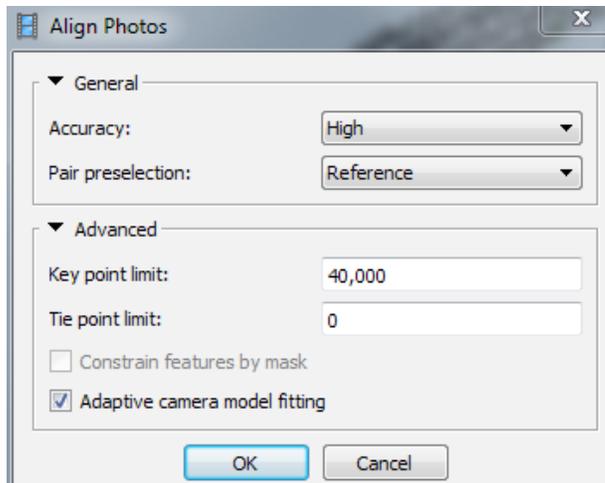
Tutorial 19: Select all cameras.

- If the image quality is poor ($< .5$), try reloading the photos into Photoshop and sharpening the images using the Unsharpen Mask Tool. Save the photos as a new set in case it does not work, and if necessary reload the images and return to this point. Remember to change the names of the image centers and estimated altitude if this becomes necessary. The names have to match for PhotoScan to recognize they go together.
- When the photos quality is acceptable, add the .csv file that contains the image centers and altitude information. Click on the Import button in the Reference window. Open the .csv file.
- Set the coordinate system to the project coordinate system.
- Make sure the delimiter is the correct (comma for .csv), and make sure the columns match. Start import using the first row with image data.



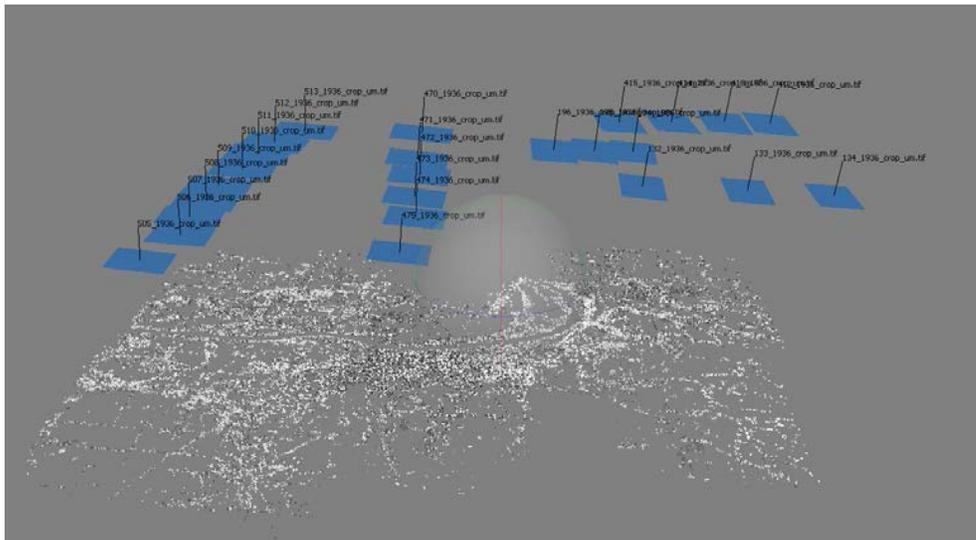
Tutorial 20: Import .csv of image centers and estimated altitude of camera.

- Click on the Align Photos button on the Workflow pull-down menu. These settings are used for historical photos (below). Only use the reference Pair Selection if there are georeferenced photos (this is the case in this tutorial). The default for tie point limit rarely works well for old photos. It is not necessary to take it down all the way to zero. Like all settings in the software, play with it until you find a setting that works.



Tutorial 21: Align Photos option window.

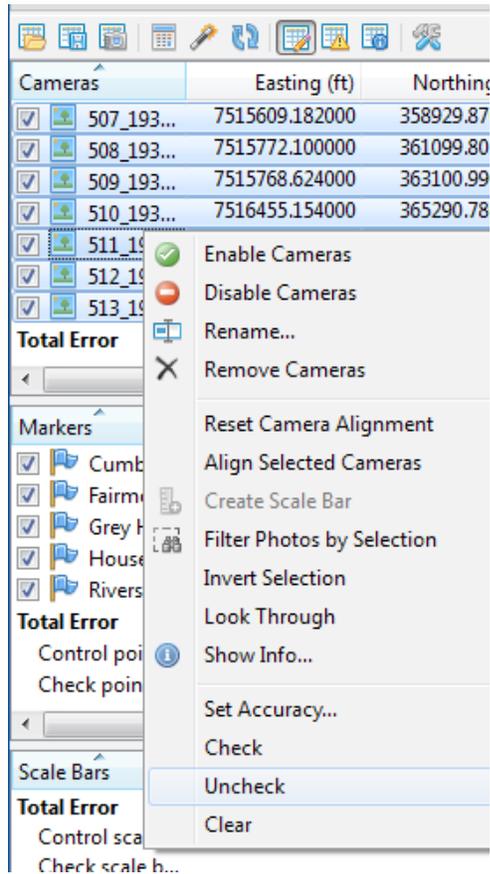
10. Save the project as ProjectName_PhotosAligned. The result should be a Sparse Point cloud.



Tutorial 22: Photos Aligned and Sparse Point Cloud.

11. Upload the Marker Point .csv file the same way as the image centers .csv file. Since the Markers are not directly tied to anything like the image centers were tied to the photos (same name), PhotoScan will try to find a match and will not, resulting in a pop-up box asking if you want to create a new marker. Select yes to all.
12. Select all the cameras in the Reference window, right click and click uncheck. This

must be done so the program does not use the image centers any longer. They were just there to help with alignment, so they are no longer necessary.



Tutorial 23: Uncheck the boxes next to the Cameras.

13. Use the Excel spreadsheet for the Markers that show their locations and have what images the markers are included in to help place the markers.

| A | B | C | D | E | F | G |
|----------|--------|--------|--------|---------------------------------------|----------------------|--|
| OBJECTID | Image1 | Image2 | Image3 | Marker | Address | MarkerLoc |
| 2 | 474 | 507 | 509 | Grey Hall, Albany College (1925) | Queen and Broadway | Ground, East Entrance |
| 3 | 472 | 513 | 510 | Fairmount Grange (1930) | 835 NW Albany Rd | Ground, SW corner of structure |
| 7 | 472 | 473 | 0 | Cumberland Presbyterian Church (1892) | 401 SE Main Street | Ground, Center of west side of structure |
| 12 | 472 | 473 | 510 | Riverside Cemetery (est 1847) | West end of 7th Ave | Sidewalk, ctr of sm path where it joins lg path |
| 16 | 413 | 414 | 415 | House | 1330 Old Salem Rd NE | Sidewalk, where the walk meets the carriage pull |

Tutorial 24: Marker spreadsheet.

14. Go to the first picture with a Marker location and place the Marker at the Location indicated by right clicking on the spot where you want to place the Marker and choosing the correct marker.
15. Go to the next photo and do the same thing. It should be easier to find this time; PhotoScan tries to guess where it should be. After placing the second marker highlight the marker in the reference tab, right click and select Filter Photos by Marker.
16. Now the Photos window should show the rest of the photos with the Marker in them. Place the markers in these photos and then hit the reset filter button in the Photo toolbar.



Tutorial 25: Filtered Photos with the Grey Hall marker placed in each. Little binoculars icon with a red x is the Reset Filter button.

17. Repeat this for three markers and then hit the update button on the Reference Toolbar and the rest of the Markers will be placed at their estimated locations.
18. Now just right click on the remaining Markers in the Reference window and Filter Photos by Marker to place the remaining flags.
19. Once all the Markers are placed, update again and notice the error in the Markers section of the Reference window. If anything is way off check that the Markers are all placed in the proper location. It is very easy to misplace a Marker, especially the early ones that are manually located.

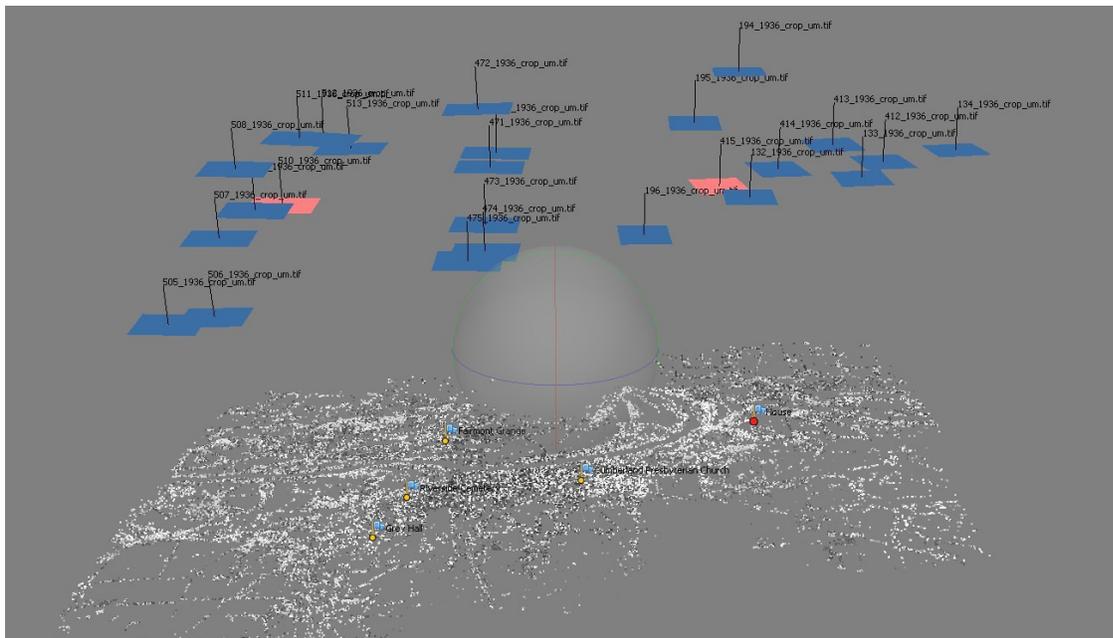
| Reference | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|--|----------------|---------------|---------------|--------------|-------------|--|---------|--------------|---------------|---------------|--------------|-----------|--|---|----------------|---------------|------------|----------|-----------|--|--|----------------|---------------|------------|----------|-----------|--|---|----------------|---------------|------------|----------|----------|--|---|----------------|---------------|------------|----------|----------|--|---|----------------|---------------|------------|----------|----------|--|--------------------|--|--|--|--|--|--|----------------|--|--|--|--|-----------|--|--------------|--|--|--|--|--|--|
| Cameras | Easting (ft) | Northing (ft) | Altitude (ft) | Accuracy (m) | Error (m) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| <input type="checkbox"/> 507_193... | 7515609.182000 | 358929.870700 | 6088.000000 | 10.000000 | 1431.824974 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| <input type="checkbox"/> 508_193... | 7515772.100000 | 361099.802100 | 6088.000000 | 10.000000 | 1413.808995 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| <input type="checkbox"/> 509_193... | 7515768.624000 | 363100.990300 | 6088.000000 | 10.000000 | 1374.057783 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| <input type="checkbox"/> 510_193... | 7516455.154000 | 365290.786100 | 6088.000000 | 10.000000 | 1378.633175 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| <input type="checkbox"/> 511_193... | 7516572.251000 | 367710.759100 | 6088.000000 | 10.000000 | 1357.669755 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| <input type="checkbox"/> 512_193... | 7516869.190000 | 369632.547200 | 6088.000000 | 10.000000 | 1347.627152 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| <input type="checkbox"/> 513_193... | 7518419.953000 | 371762.717000 | 6088.000000 | 10.000000 | 1346.822660 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Total Error | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| <table border="1"> <thead> <tr> <th>Markers</th> <th>Easting (ft)</th> <th>Northing (ft)</th> <th>Altitude (ft)</th> <th>Accuracy (m)</th> <th>Error (m)</th> <th></th> </tr> </thead> <tbody> <tr> <td><input checked="" type="checkbox"/> Cumber...</td> <td>7527619.011000</td> <td>364385.316600</td> <td>215.910004</td> <td>0.005000</td> <td>28.220773</td> <td></td> </tr> <tr> <td><input checked="" type="checkbox"/> Fairmon...</td> <td>7521834.251000</td> <td>368218.707800</td> <td>207.819000</td> <td>0.005000</td> <td>11.528551</td> <td></td> </tr> <tr> <td><input checked="" type="checkbox"/> Grey Hall</td> <td>7519814.713000</td> <td>359698.368500</td> <td>233.070999</td> <td>0.005000</td> <td>8.064132</td> <td></td> </tr> <tr> <td><input checked="" type="checkbox"/> House</td> <td>7535410.301000</td> <td>370117.967700</td> <td>219.580994</td> <td>0.005000</td> <td>8.103913</td> <td></td> </tr> <tr> <td><input checked="" type="checkbox"/> Riversid...</td> <td>7520750.761000</td> <td>362890.830700</td> <td>220.151993</td> <td>0.005000</td> <td>4.802039</td> <td></td> </tr> <tr> <td colspan="6">Total Error</td> <td></td> </tr> <tr> <td>Control points</td> <td colspan="4"></td> <td>14.717899</td> <td></td> </tr> <tr> <td>Check points</td> <td colspan="4"></td> <td></td> <td></td> </tr> </tbody> </table> | | | | | | | Markers | Easting (ft) | Northing (ft) | Altitude (ft) | Accuracy (m) | Error (m) | | <input checked="" type="checkbox"/> Cumber... | 7527619.011000 | 364385.316600 | 215.910004 | 0.005000 | 28.220773 | | <input checked="" type="checkbox"/> Fairmon... | 7521834.251000 | 368218.707800 | 207.819000 | 0.005000 | 11.528551 | | <input checked="" type="checkbox"/> Grey Hall | 7519814.713000 | 359698.368500 | 233.070999 | 0.005000 | 8.064132 | | <input checked="" type="checkbox"/> House | 7535410.301000 | 370117.967700 | 219.580994 | 0.005000 | 8.103913 | | <input checked="" type="checkbox"/> Riversid... | 7520750.761000 | 362890.830700 | 220.151993 | 0.005000 | 4.802039 | | Total Error | | | | | | | Control points | | | | | 14.717899 | | Check points | | | | | | |
| Markers | Easting (ft) | Northing (ft) | Altitude (ft) | Accuracy (m) | Error (m) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| <input checked="" type="checkbox"/> Cumber... | 7527619.011000 | 364385.316600 | 215.910004 | 0.005000 | 28.220773 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| <input checked="" type="checkbox"/> Fairmon... | 7521834.251000 | 368218.707800 | 207.819000 | 0.005000 | 11.528551 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| <input checked="" type="checkbox"/> Grey Hall | 7519814.713000 | 359698.368500 | 233.070999 | 0.005000 | 8.064132 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| <input checked="" type="checkbox"/> House | 7535410.301000 | 370117.967700 | 219.580994 | 0.005000 | 8.103913 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| <input checked="" type="checkbox"/> Riversid... | 7520750.761000 | 362890.830700 | 220.151993 | 0.005000 | 4.802039 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Total Error | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Control points | | | | | 14.717899 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Check points | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |

Tutorial 26: Reference Window with all markers placed and the Updated.

20. If they look reasonable, hit the Optimize Cameras Button, leaving all the defaults as they are, and click OK. This will re-estimate the actual location of the cameras that took the photos more precisely and adjust the point cloud accordingly. Markers are now tied to individual points in the Sparse Point Cloud and all other points will be estimated using them. Notice the error is now very small. This only applies to the points that have been placed, not the total error of the model. That will have to be assessed later, outside the program.

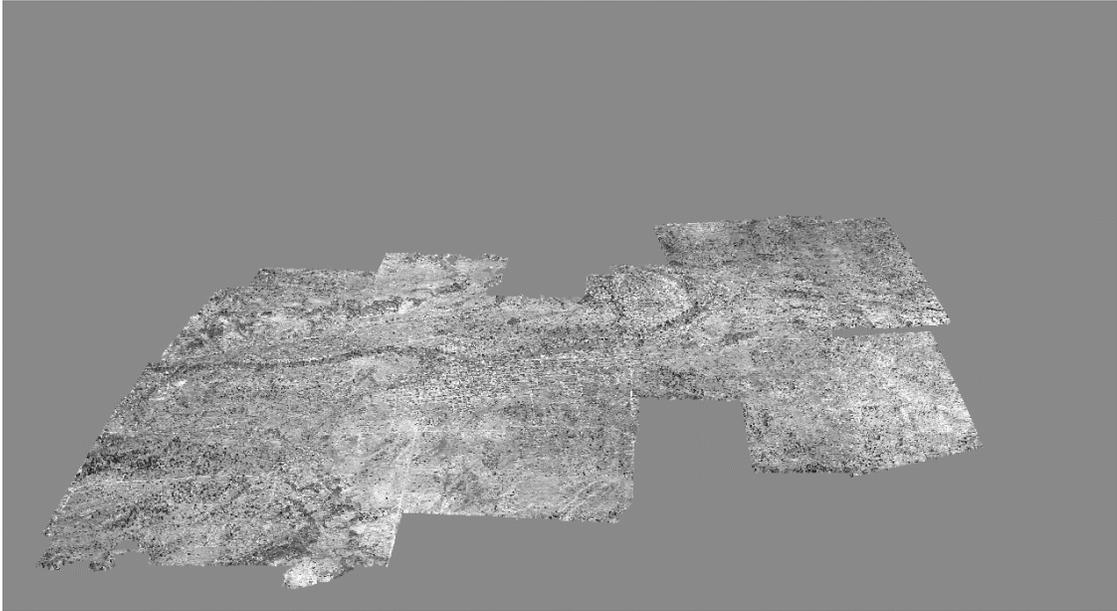
| Cameras | Easting (ft) | Northing (ft) | Altitude (ft) | Accuracy (m) | Error (m) | |
|---|----------------|---------------|---------------|--------------|-------------|------|
| 507_193... | 7515609.182000 | 358929.870700 | 6088.000000 | 10.000000 | 2259.610494 | |
| 508_193... | 7515772.100000 | 361099.802100 | 6088.000000 | 10.000000 | 2878.664956 | |
| 509_193... | 7515768.624000 | 363100.990300 | 6088.000000 | 10.000000 | 2270.045346 | |
| 510_193... | 7516455.154000 | 365290.786100 | 6088.000000 | 10.000000 | 2165.878416 | |
| 511_193... | 7516572.251000 | 367710.759100 | 6088.000000 | 10.000000 | 2802.809724 | |
| 512_193... | 7516869.190000 | 369632.547200 | 6088.000000 | 10.000000 | 2678.787224 | |
| 513_193... | 7518419.953000 | 371762.717000 | 6088.000000 | 10.000000 | 2420.687536 | |
| Total Error | | | | | | |
| | | | | | | |
| Markers | Easting (ft) | Northing (ft) | Altitude (ft) | Accuracy (m) | Error (m) | Proj |
| <input checked="" type="checkbox"/> Cumber... | 7527619.011000 | 364385.316600 | 215.910004 | 0.005000 | 0.000785 | |
| <input checked="" type="checkbox"/> Fairmon... | 7521834.251000 | 368218.707800 | 207.819000 | 0.005000 | 0.001664 | |
| <input checked="" type="checkbox"/> Grey Hall | 7519814.713000 | 359698.368500 | 233.070999 | 0.005000 | 0.001791 | |
| <input checked="" type="checkbox"/> House | 7535410.301000 | 370117.967700 | 219.580994 | 0.005000 | 0.000553 | |
| <input checked="" type="checkbox"/> Riversid... | 7520750.761000 | 362890.830700 | 220.151993 | 0.005000 | 0.003110 | |
| Total Error | | | | | | |
| Control points | | | | | 0.001820 | |
| Check points | | | | | | |

Tutorial 27: Error after using the Optimize Photos Tool.



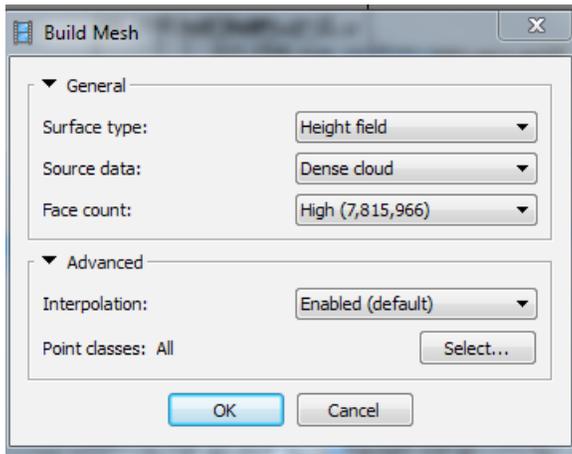
Tutorial 28: The Model with Markers Placed and Cameras Optimized.

21. Following the Workflow, build a Dense Point Cloud. If the machine has enough memory, try the high quality with moderate depth filtering. If a message saying “error: not enough memory” appears, try relaxing the depth filtering first. If that does not work, reduce the quality to medium.
22. Click on the Dense Cloud Button on the top toolbar to see the dense cloud when it has been built. Hide/show elements in the program like the trackball, cameras, bounding box and other things under the View drop-down menu.



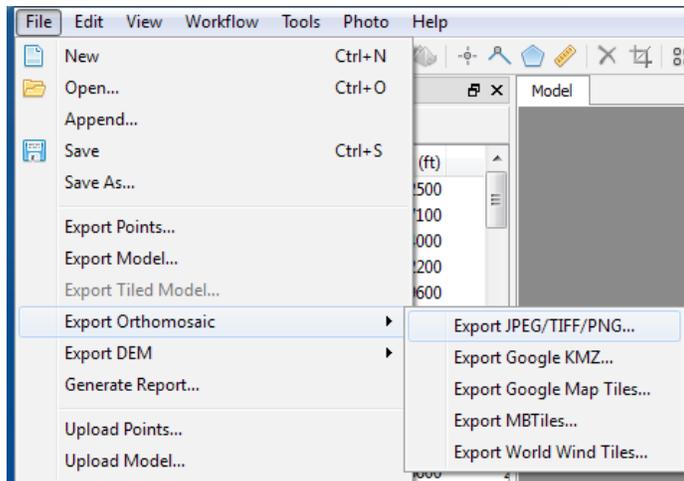
Tutorial 29: Dense Point Cloud with the Hide All Selected from the view drop-down menu.

23. Save as ProjectName_DenseCloud.
24. Build the Mesh under the Workflow drop-down menu. Use the Height Field surface type. The Arbitrary setting has not worked well in testing.



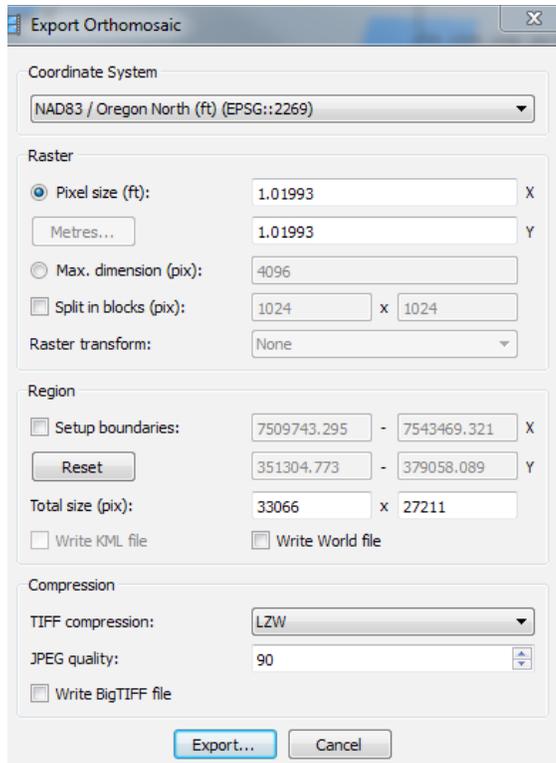
Tutorial 30: Settings I use to build a Mesh for historical photos.

25. Save as ProjectName_Mesh.
26. Build the Orthophoto. Select Build Orthomosaic from the Workflow pull-down menu.
27. Set the Projection, it is best to leave the rest of the Build Orthomosaic window with the defaults.
28. Export the orthophoto.



Tutorial 31: Export the Orthophoto.

29. Check the pop-up Export Orthomosaic window to make sure all the settings are correct.

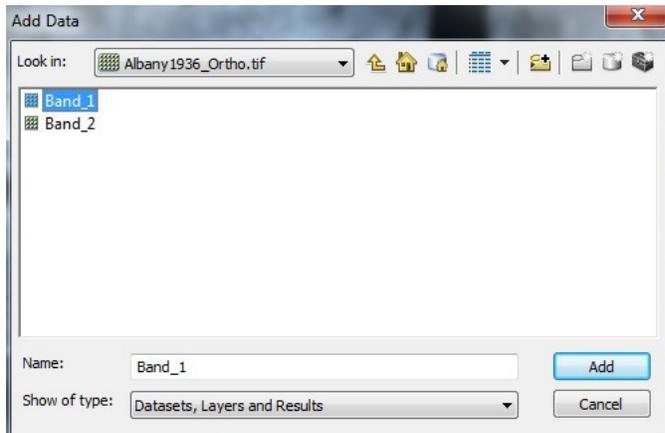


Tutorial 32: Export Orthomosaic Window.

30. Save the orthophoto to a location in your project folder. It is now ready to be opened in ArcMap to be inspected.

Opening the Orthophoto in ArcMap

1. Select the add data button in a new ArcMap Project.
2. Navigate to the folder where you saved the orthophoto and double click on the shapefile. Select Band_1 so it shows up in greyscale. Otherwise, it will pop up as an aquamarine color, and have to be fixed in the properties/symbology tab of the orthophoto layer by selecting Band_1 for all the channels.



Tutorial 33: Add orthophoto Band_1 to an ArcMap Project.

Congratulations! You have created an orthophoto out of historical air photos using Structure from Motion software!

Appendix B:

Georeferencing Steps using ArcMap

1. Open an ArcMap document and add all of the historical photos from one year to the document. Along with the photos, add a current reference image, such as an orthophoto.
2. Open the “Georeferencing” toolbar in ArcMap.
3. For each image, identify roughly 10 ground control points on the image; use the “Add ground control points” tool in the “Georeferencing” toolbar.
4. Ground control points should be points on the historical image that are also identifiable on the present day imagery.
5. View the Link table in the “Georeferencing” toolbar to ensure that the error for each point is somewhat low.
6. Once the ground control points are added to the image, save the link table, with the image name for easy identification.
7. Use the “Georeferencing” tool bar to “Update Georeferencing”.
8. Save and repeat these steps for each image for the year. Once all the images for one year are georeferenced, move on to mosaicking these georeferenced images.

Appendix C:

Mosaic Steps using ArcMap

1. Add all georeferenced photos, from one year, to ArcMap.
2. Within ArcMap, navigate to the ArcCatalog pop up window.
 - Create a geodatabase for the desired year.
 - Within the geodatabase, create an empty mosaic dataset by right clicking the Geodatabase, clicking on “New” and then on “Mosaic Dataset”.
3. Navigate to the “Geoprocessing” toolbar, then to “Data Management” tools.
 - Use the “Add Raster to Mosaic Dataset” tool to add all the georeferenced raster images to the Mosaic.
4. Once the Mosaic is created, right click the layer properties, then click on “coordinate system”, and change the coordinate system to the desired coordinate system.
5. Repeat these steps for each year of imagery, each in its own ArcMap document.

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