Photogrammetric Models using Oblique Aerial Imagery for Construction Site Surveying

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Abstract

Photogrammetry is being used in several industries for creating digital 3-dimensional models of objects. Oblique aerial images are taken from an airplane or spacecraft. The technique involves taking multiple pictures of the same site from several angles, thus allowing interpretations to be made regarding surface elevations. The resulting images can be stitched together to form a topographical map using photogrammetric software. An experiment was conducted in this study to examine the variance between topographic maps created from oblique aerial imagery and traditional land survey methods. In this research, 165 high-resolution oblique aerial images were used to create a topographical surface map for a potential construction site. A land survey using traditional methods was conducted to produce a topographical map of the same area. Comparisons were made between the two topographical surfaces. Results from the experiment showed significant variance between the two topographical surface leading to the conclusion that oblique aerial images cannot be used to replace traditional land surveys to create topographical maps for construction purposes.

Keywords –

Photogrammetry; Oblique Aerial Imagery; Topographical Surface; Site Survey

1 Introduction

Photogrammetry is defined as, “the science and technique of interpreting and evaluating the form, dimension and position of objects by analyzing and measuring images of them” [1]. The photogrammetric process produces a three-dimensional model of an object on a computer screen that is used to make measurements. Photogrammetry is currently used for topographic mapping, geographic information systems, and civil engineering studies. Photogrammetry allows large amounts of data to be recorded, so that it can be accessed at any time to be analyzed for dimensional purposes [2]. Currently, digital terrain models are generated from two-dimensional drawings. These digital terrain models are then used in collaboration with global positioning system enabled earthwork machinery. Photogrammetry technology can save time in the creation of the digital terrain model creation process [3]. The aim of this research is to explore whether aerial photogrammetric modeling can be used for surveying potential construction areas.

Issues with planning and organization are very common occurrences before construction work begins. In order to manage a construction project successfully, accurate information about a potential site is required [4]. At the beginning of the construction process, a contractor needs topographic information for many purposes. These including the implementation of flood prevention measures such as silt fences, to determine the earthwork related quantities, durations of activities, site work costs, etc. Initial surveys of construction sites conducted by surveying engineers cost contracting companies both time and money [5]. If a construction project needed to start immediately, as an alternative, oblique aerial images could potentially be employed to “survey” the site allowing the construction project to begin at a more rapid pace [6]. However, oblique aerial imagery requires further investigation before being used for this purpose.

Oblique aerial imagery and drone imagery can be used to generate a three-dimensional (3D) photogrammetric topography model of a particular area. Such a model provides topographic information that two-dimensional (2D) aerial images cannot. This extra dimension facilitates the creation of custom topographic maps of construction sites. Such maps can be used to identify areas where storm water runoff may occur so that silt fences and other mitigations for erosion control may be placed [7].

For this method to be widely adopted by contracting companies, the accuracy of photogrammetric topography models must be tested [8]. In this research, oblique aerial photographs for a city were used to isolate a potential construction site. Photogrammetry technology was used to create a digital terrain model for the site. The photogrammetric topographical model of the specific area derived from the oblique aerial images was compared to a digital topographical model recorded using traditional land survey techniques of the same area.

2 Literature Review

Photogrammetry was most likely invented in the 1420s during the Italian Renaissance when painters would represent three-dimensional scenes in a two-dimensional medium while creating the sensation of depth. Today the goal of photogrammetry is to take two-dimensional images from different perspectives and create a three-dimensional representation of the same space. The actual term photogrammetry began in 1867 when Albrecht Meydenbauer started the process of measuring photographs to create architectural surveys, which he called “photogrammetrie” [1]. Meydenbauer was a building surveyor for the Prussian government, and his first project was to document a cathedral. While conducting this survey he almost slipped and fell to his death. Because of this accident, he decided to start investigating other ways to record the dimensions of the cathedral. This investigation led him to the idea of taking measurements of the building with pictures. He quickly found that these measurements were very accurate [8]. There are two types of photogrammetry namely, ‘Terrestrial’ and ‘Aerial’. Terrestrial photogrammetry uses images taken from the ground, whereas aerial photogrammetry uses images that are taken from a balloon, plane, or spacecraft. Between 1850 to 1900 plane table, photogrammetry was utilized to take measurements of distances and angles of the elevations of object. A plane table provided a stable surface to create field drawings and maps [1]. In the subsequent sections, a brief discussion of the current uses of photogrammetry technology is included.

2.1 Mapping and Digital Terrain Modeling

One of the more common applications of photogrammetry is by departments of transportation for mapping purposes. These maps are simply photogrammetrically stitched two-dimensional maps for department of transportations to map out all roads and highways within their state. Commonly a geographic information system (GIS) is created to store and analyze the spatial and geographical data collected throughout the mapping process. In several states in the United States, these GIS databases are often accessible to the public through State Department of Transportation websites.

Digital Terrain Models (DTM) are three-dimensional models that show the changing slope and topography of the surface of a specific area. These DTM’s originate from photogrammetric satellite images taken by departments of transportation, which are then combined to create continuous three-dimensional models with an accuracy of 10 meters. DTM’s can also be created using oblique aerial photographs, Light Detection and Ranging (LIDAR) and direct contour mapping using traditional surveying methods. Highway construction companies utilizing automated global positioning system enabled heavy machinery are using DTMs for grading purposes [3]. These DTMs also provide construction managers with accurate earthwork volumes before the start of a highway project [3]. In the future DTM’s created with photogrammetry may be used for this same exact purpose to cut down on man-hours and improve accuracy of measurements.

2.2 Highway Planning, Design and Maintenance

Photogrammetry is also being employed by departments of transportation for planning and designing future highway corridors and interchanges. Photogrammetry can be used to determine not only the topography of a given area but also can provide useful information for traffic engineering. The user can see urban and suburban areas and how populations are growing in certain areas. This information can show not only where a future highway will not disturb these areas but also where they will be most needed in the future [9].

Departments of transportation employ these photogrammetric maps to determine where road improvements must be made and to track maintenance of state highways. In Budapest, a terrestrial photogrammetric process was explored to examine a road’s roughness, in combination with the International Roughness Index. Digital surface models allow determination of where roads must be resurfaced [10]. Photogrammetry is used by departments of transportation to map out right of ways for highway boundaries [9]. It is also utilized to map out future right of ways in a similar manner to highway planning and design.

2.3 Environmental Planning

The United States Environmental Protection Agency [11] states, “Storm water runoff is rain or snowmelt that flows over land and does not percolate into the soil”. This runoff is prevalent during construction activities as well due to vegetation removal, leaving the soil unprotected from rainfall. If a construction site is not properly protected from soil erosion, it can lose 35–45 tons of sediment per acre per year [11]. Construction activities can cause storm water runoff to have adverse effect to any water system within its vicinity. This sediment is the main storm water pollution coming from construction sites, and the resulting turbidity prevents sunlight from reaching aquatic plants, kills fish, and destroys their spawning areas. Attention to erosion control is critical when: clearing, grading, excavating, working around un-stabilized areas, during paving operations, demolition and debris disposal, dewatering operations, drilling and blasting, material delivery and storage, and landscaping. Longer and steeper slopes on a construction site suffer the most from erosion [11]. The DTM's created using photogrammetric models can be used for identifying potential locations to install abetments to prevent soil erosion [18].

2.4 Oblique Aerial Photography

Aerial photogrammetry is created using photographs of the earths' surface taken from cameras mounted from an aerial object such as an airplane. Traditionally vertical camera configurations are used which provide an overhead view of an area. Oblique aerial imagery is taken from a high altitude at a position that is neither completely horizontal nor vertical but rather at an angle. These oblique aerial images are used in photogrammetry to create three-dimensional (3D) models of object. These images can be used to create three-dimensional images because they capture all sides of an object due to the differing angles captured by the various cameras. This type of imagery is used most commonly for three-dimensional urban mapping [1]. Currently oblique aerial imagery is used in the United States Geographical Information System. The data for provides local authorities and developers better information about an area than can be inferred from a two-dimensional image. This new data was obtained using eight cameras all of which were positioned at a forty-five degree angle facing different directions. The images were used for the purposes of emergency and community planning [13]. These oblique aerial images also can be used to measure distances, coordinates, and elevations within a Digital Terrain Model (DTM). "Measurements and mapping can be done where it is needed, field work can thus be avoided" [19]. The market place for these types of images is transitioning from "aerial mapping" to "aerial surveying."

There are two different types of oblique imagery: High angle oblique and low angle oblique. The primary difference between the images is that in high angle oblique the horizon is captured in the photograph, whereas in low angle oblique the horizon is not. An advantage of oblique imaging is objects that are unrecognizable in conventional nadir (vertical) aerial photos can be identified in oblique aerial photos, and a much larger area can be captured in each image.

Two important elements to consider in evaluating aerial imaging are distortion and displacement. There are several types of distortion including the curvature of the earth and issues with camera and lens function [14]. While distortion is to be avoided, displacement is good for observing the topography of an area because it allows for stereo viewing, height measurement, and topographic mapping.

The company Pictometry® developed the first system that used a digital five-camera oblique aerial photography system. An example of a five-camera system is illustrated in Figure 1. Four cameras point in different directions (North, South, East, and West) while one camera takes vertical images that are connected to their geographical location via Global Positioning System (GPS) [16]. These cameras are usually gyro-stabilized to ensure photo quality during flight [1].

Figure 1: Five camera oblique aerial system [15].

3 Methodology

Experimental research methodology was chosen in the conduct of this research. The one-tailed null hypothesis for this research is H_A: The oblique imagery photogrammetric model will be accurate enough for surveying potential construction sites. The one-tailed, alternate hypothesis for this research is H_A: The oblique imagery photogrammetric model will not be accurate enough for surveying potential construction sites.

The experiment compared a photogrammetric model of a potential construction site with a digital terrain model created using traditional land survey. The photogrammetric model was created for a potential construction site using oblique aerial imagery obtained from the local authorities. The oblique aerial photographs were obtained from the local planning department, which were donated by Stellacore Corporation. Five 65-Megapixel cameras on the plane captured the oblique aerial photos. Simultaneously, researchers conducted a traditional land survey of the same potential construction site. The traditional land survey was created using contour points and transformed into a digital terrain model. The photogrammetric model was created using Photoscan software. The digital terrain model was created by importing contour points in to Autodesk Revit software.

The analysis involved a comparison of the terrain created by traditional land survey and the photogrammetric model. The boundary for each terrain model was adjusted to ensure that the same area was being compared in both instances. The models were imported into Earthworks, a quantification software for site excavation. The terrain model created from traditional site survey methods was set as the control and the photogrammetric model was compared to the control model. Sections were cut at pre-determined intervals to compare variation in elevation between the terrain models.

4 Results

One hundred and sixty five pictures were isolated from the oblique aerial photographs. These photographs were used to create a model of the general area of the potential construction site, shown in Figure 2.

Figure 2: Photogrammetric model created using Photoscan software

The site was cropped further to a smaller area shown in Figure 3. This area in the photogrammetry model is composed of a 2.6 million point dense cloud, encompassing just over .5 acres. This resulting model was used to put stakes in the ground to signify the area that must be surveyed using traditional methods.

Figure 3: Photogrammetric model of potential construction site

The next set of data collected was the total station survey of the potential construction site, as shown in Figure 4. Leica total station equipment was used to collect elevations at 200 points. The four reference points at the stakes were measured first and were coded as “Bench Mark,” while two hundred additional points were taken at fifteen-foot intervals within the boundaries of the reference points. These additional points were coded as “Topo.”

Figure 4: Traditional topographical land survey of potential construction site

The data from the traditional survey was used to create a topographical map in Autodesk Revit. The data from the photogrammetric model was also imported into Revit to create a separate topographical site map. The data showed some variance between the two maps when it was discovered that a tree on the site was distorting the photogrammetric model. The site from both models was further cropped to eliminate the distortion. A side-by-side view of the two models is shown in Figure 5.

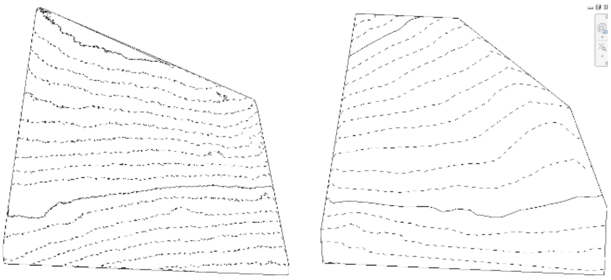


Figure 5: Photogrammetric model contour map (left) and traditional land survey contour map of potential construction site

Two different techniques for comparing the differences between the topo surfaces were used to analyze the data. First, both models were compared in Earthwork software to find how they differ in a cut and fill amount and three-dimensional visual inspection. Second, the models were overlaid and section cuts were made to measure variance in elevation. The overlaid models in Earthworks is shown in Figure 6.

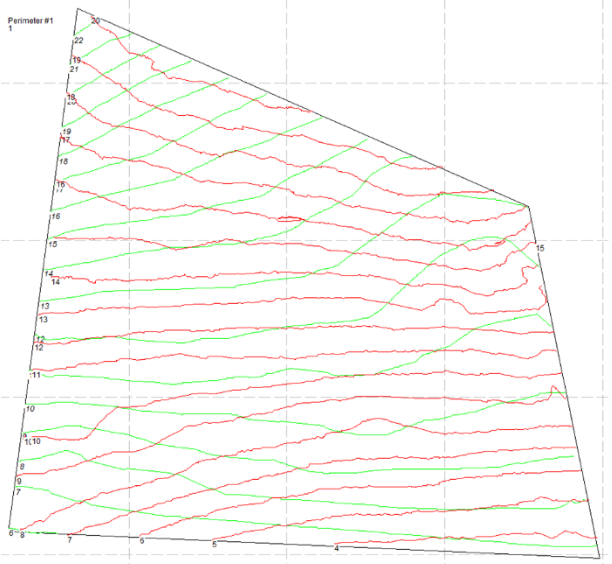
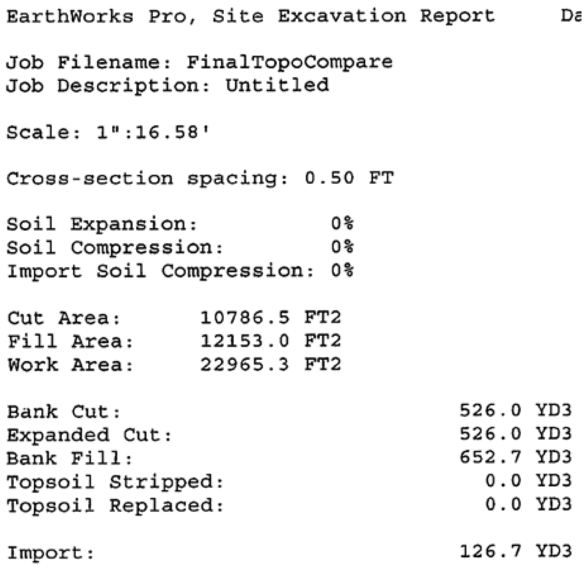


Figure 6: Overlay of contour maps in earthworks software

The total station contour lines are depicted in green while the photogrammetry contour lines are shown in red in Figure 6. For this research, the total station survey was used as the control and given the distinction of the "existing" surface in the software. The photogrammetry surface model was classified as the proposed surface. The software measured the amount of cut and fill necessary to make the total station topographical surface have the exact same as the proposed surface.



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EarthWorks Pro, Site Excavation Report      Da

Job Filename: FinalTopoCompare
Job Description: Untitled

Scale: 1":16.58'

Cross-section spacing: 0.50 FT

Soil Expansion:            0%
Soil Compression:          0%
Import Soil Compression: 0%

Cut Area:       10786.5 FT2
Fill Area:      12153.0 FT2
Work Area:      22965.3 FT2

Bank Cut:                              526.0 YD3
Expanded Cut:                          526.0 YD3
Bank Fill:                             652.7 YD3
Topsoil Stripped:                        0.0 YD3
Topsoil Replaced:                        0.0 YD3

Import:                                126.7 YD3
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Figure 7: Earthworks data output

The three most notable numbers shown in Figure 7 are on the 'Bank Cut', 'Bank Fill', and 'Import' numbers. The Bank Cut of 526.0 cubic yards reveals the amount of cubic yards that will need to be removed from certain areas of the surface. In contrast, the Bank Fill of 652.7 cubic yards shows the amount of dirt that is needed in other areas. The 'Import' line of 126.7 cubic yards denotes that a larger amount of earth will need to be added than will be removed to make the existing surface have the same contours as the proposed surface. In order to make the existing surface take on the same terrain as the existing shape, the area would need to have 126.7 cubic yards of dirt imported to the site. This amount of dirt would be the equivalent of about twelve to thirteen truckloads of earth.

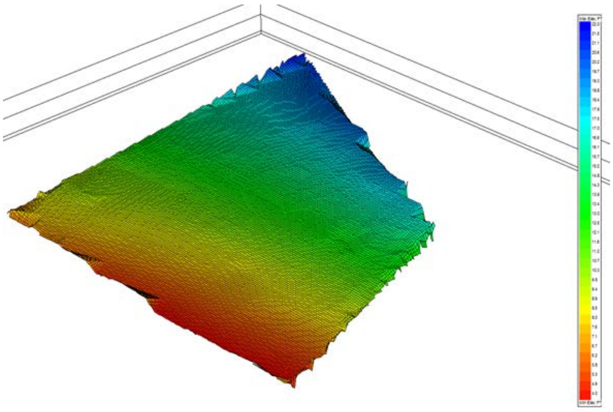

Figure 8: 3D Digital terrain model from photogrammetric model of test site

A visual inspection of the two topographical surveys indicates similarities and differences in the topographical surfaces shown in Figure 8 and 9. The green in the figures represents flat surface, orange represents high elevation and blue represents low elevation. The color maps support the evidence from the cut-fill report.

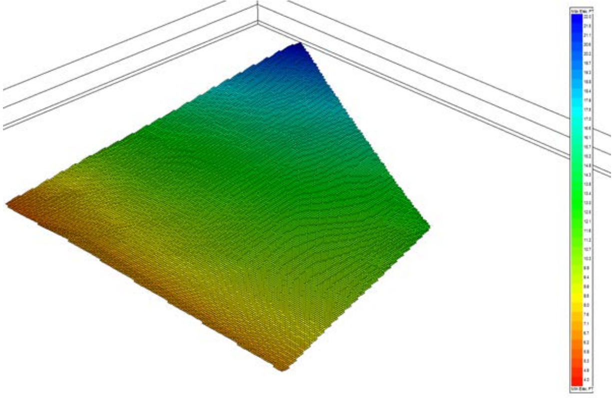

Figure 9: 3D Digital terrain model from traditional land survey of test Site

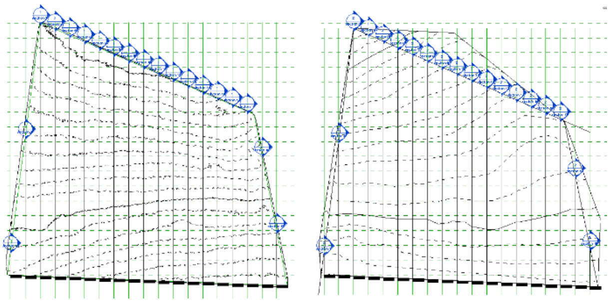

Figure 10:Cross section analysis of topographical surfaces

The second method used for comparing the variations between the two site surveys is a cross section analysis. Both surveys were placed on a ten-foot-by-ten-foot grid as shown in Figure 10. This was done to check if small areas of the site were giving distorted results in the cut-fill analysis. Figures 11 and 12 show an overlay of two topographical surface. Figure 11 represents the two surfaces overlaid with minimal variance whereas Figure 12 represents an overlay showing significant variance.

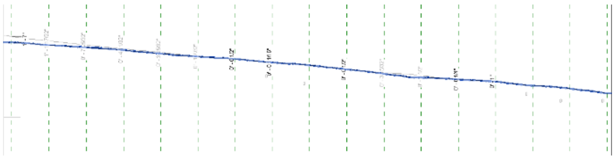

Figure 11: Representative cross-section with minimal variance between the two topographical surfaces

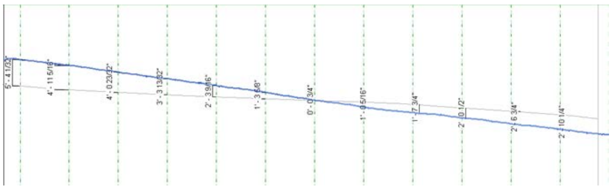

Figure 12: Representative cross-section with significant variance between the two topographical surfaces

Nineteen cross sections were placed vertically ten feet apart across both survey areas, and seventeen similar reference planes were placed horizontally at ten feet apart. These cross sections and reference planes intersected within the survey area at 229 points. At these points, measurements were taken of the elevation difference between the two topographical surfaces. Once all variations were measured at each intersection the distances were compiled in a spreadsheet and analyzed. The results of the average variance between the two topographical surfaces at each of the vertical nineteen sections is shown in Figure 13.

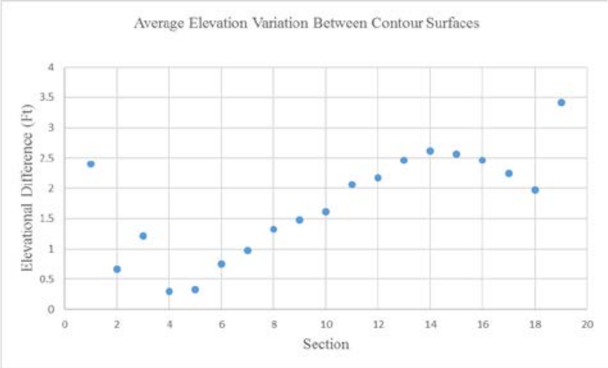

Figure 13: Average variance between the two topographical surfaces

The lowest average variance at a given section was 0.33ft and the highest variance was 2.56ft, as shown in Figure 13. The average variance in topographical surface between all points was 1.54ft.

5 Conclusions

A key question for this research was to answer, “How does the accuracy of a photogrammetric topography model created from oblique aerial images compare with topography data from traditional land surveys?” This question was answered by creating the total station and photogrammetric elevation models and then assessing the variations between the two models. The models were compared by calculating the amount of cut and fill necessary to make the total station topo-surface equal the photogrammetric surface. Although the Import value of 126.7 cubic yards would be a minimal amount of earth to bring into a site just over a half acre (13 truckloads) one must take a step back and observe this quantity with a broader perspective. The cut quantity for this area would be 526.0 cubic yards of earth and the fill would be 652.7 cubic yards. Although the overall import would be a relatively small amount of earth, the cut & fill quantities are both about 5 to 6 times as much. This research is not concerned with the actual earthwork estimate for making one topo surface similar to the other; the focus is on the variation between the two planes. For this reason, it is more important to focus on the cut and fill values as a sum. Instead of subtracting the two values from one another, they should be added together. This would result in a total amount of earth to be moved: 1178.6 cubic yards. This amount of earth would be the equivalent of about 118 truckloads of earth. Compared to the earlier 13 truckloads of earth, these 118 loads is a very large amount of earth to have to move in order to make the two-topo surfaces equal to one another.

The other way in which Key Question 1 was analyzed was by taking 19 similar section cuts of both topo-surfaces and quantitatively comparing their variations. After comparing the surfaces at 229 points it was found that the two models varied on average about 1.54ft at any point in the model. The average variation of 1.54ft between the models would be a large discrepancy to use for any application pertaining to the construction industry.

While observing the cut and fill map and the 3D elevation color maps, visual observations can be made about the variations between the two topography models. In the cut and fill map, it appears as if the models are most accurate in the middle of the survey area while the corners require the most cut and fill and therefore are the least accurate areas. This correlation might be because the middle of the area has less change in elevation than the corners of the same area. In the 3D elevation color maps, the colored areas appear to be similar but not the same. In addition, the total station maps seems to be smoother on the surface while the photogrammetric map is jagged and more uneven. The photogrammetric map shows a slightly broader range of elevation change than the total station surface.

In conclusion, the total station map and the photogrammetry surface are very similar in nature and share many characteristics; however, the two maps are not the same. The results indicate that a photogrammetric topographical surface map cannot be used to create a realistic topographical surface map for construction purposes. The alternative hypothesis for the experiment was proved true in that “*The oblique imagery photogrammetric model will not be accurate enough for the purpose of surveying potential construction sites*”.

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