A Preliminary Study of the Affect of Dimensional Control on the Accuracy of 3D Photogrammetry Modeling

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Abstract
This research focused on what affects the accuracy of a photogrammetric model using a point by point comparison based on a series of points whose 3-dimensional position has been established with a total station. The motivation for this experiment came from a need for architecture and building professionals to gather 3D spatial information of a structure easily and accurately without the need of traditional measuring devices such as a measuring tape, surveying equipment, and the use of access equipment. To approach this problem, 3D coordinates of individual points along a building façade were gathered using a total station and then compared to a photogrammetric model of the same façade. Then a set of three different photogrammetric models were generated, each given different set of spatial information prior to their generation as control points. The results showed that the more spatial information given to the model prior to its generation, the more accurate the model becomes. However, the accuracy of coordinate data extracted from the photogrammetric models is still limited and may not be suitable for construction activities that require low tolerance.

Keywords
Photogrammetry, Total Station, Building Façade, Point Cloud, Field Measurements

1. Introduction

1.1 Background

There are many ways that an individual could take field measurements. The traditional method is simply using a measuring tape and manually logging the measurements taken. This method often results in inaccurate data due to the limitations of human capabilities. This has led to new technological developments that allow humans to take quick measurements without the loss of accuracy. Laser scanning is one such technology that has the ability to map out an entire room with pin point accuracy. Other new technologies such as drones or total stations have been developed all for the sake of facilitating the survey process. The problem with most of these technologies is that they are often too expensive or too difficult to use for practical purposes. A less expensive method known as digital photogrammetry is being employed in many areas of construction to carry out measurements.

Digital photogrammetry is an emerging technology that uses 2D images captured by a digital camera to acquire dense 3D geometric information for real-world objects. Because it is relatively new, a lot of research is being currently conducted assessing its practical purposes for commercial use. Digital photogrammetry has the potential to provide a contractor spatial information that could be used for many different purposes. Past research concerning the accuracy of digital photogrammetry technology indicates that most errors manifest itself due to the quality of the camera being used, the quality of the photos taken, and the functionality of the software used to generate the 3D model (Dai and Lu, 2010).

The main purpose of this research is to investigate how dimensional control affects the accuracy of a 3D model for a building façade generated using photogrammetric data. For this purposes accuracy was measured relative to a total station. It looked at how one can obtain 3D information using a photogrammetric package complemented by total station control. This information then was analyzed in relation the x, y, z coordinates found using the photogrammetry package. This package included the use of a Leica T camera and the photogrammetry software Agisoft PhotoScan Professional. Photos were taken using the Leica camera and then uploaded to the software to generate a model in which coordinates for certain points would be generated. These coordinates were compared with the coordinates obtained via the total station to see what differences exist.

1.2 Literature Review

1.2.1 Fundamentals of digital photogrammetry

The American Society of Photogrammetry and Remote Sensing (ASPRS) define photogrammetry as "the art, science, and technology of obtaining reliable information about physical objects and the environment through process of recording, measuring and interpreting photographic images and patterns of recorded radiant electromagnetic energy and other phenomena." In other words, the primary application of photogrammetry is to reconstruct an object taken from digital photographs into a 3D format (Liu & Kang, 2014). The actual data acquisition process of photogrammetry includes photographing an object in the field and then uploading those images onto a photogrammetry software which then stiches the images together to form a 3D point-cloud representation of the photographed object. What is essential of this technology is that the photogrammetry software uses mathematical models to describe the relationships between two spaces based on corresponding points of known coordinates in each of them (Mikhail & Weerawong, 1997). So the software recognizes similar points within the photographs and can then logically deduce how the images are related to each other to form a 3D model. The mathematical equations underlying photogrammetry are based on collinearity equations that unify the image coordinate system in the camera with the coordinate system in a global space (Dai & Lu, 2010). Thus, the x,y coordinates of a point within the image will be translated into a x,y,z point in a 3D space (Dai & Lu, 2010). Figure-1 illustrates the basic principles behind photogrammetry and how the camera interprets the global space.

1.2.2 Applications of photogrammetry

The applications of photogrammetry can be categorized into five major categories (Liu & Kang, 2014): 1) architecture and heritage preservation, 2) engineering applications, 3) industrial applications, 4) forensics and accident reconstruction, and 5) medical applications. It is apparent that photogrammetry has the ability to cross over into many different professions and still be used successfully. Photogrammetry has been used to determine vehicle information in car accidents such as Princess Diana's accident in France (Fenton and Ziernicki, 1999). It has been used to determine who lies in fault after traffic accidents by being able to reconstruct accident scenes from photographs and acquire data from these models (Tao & Pei, 2009). Photogrammetry is also used to measure the impact of natural disasters and geological information (Du & Teng, 2009), and to obtain detailed topographic information of large wood restoration projects (Russell, 2015).

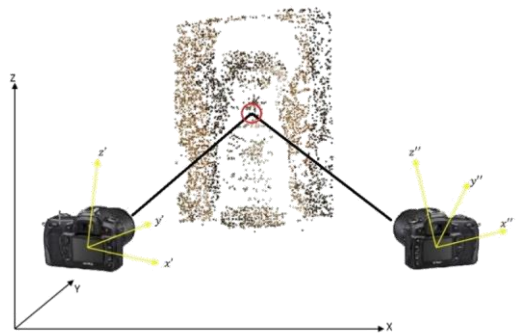


Figure-1: Basic principles behind photogrammetry and how the camera interprets the global space

It is clear that photogrammetry has many uses within many different industries. However, there is one industry that photogrammetry is particularly suited towards: the construction and engineering industry. For example, it has been determined that photogrammetry is a suitable process for measuring structural deformations with a high level of accuracy (Ye, et. al, 2011). Using photogrammetry during the planning stages of construction comes with its own set of benefits such as organized site layouts, optimized site activities and improved construction productivity (Zhu & Brilakis, 2009). In some research laser scanning and photogrammetry are being used in conjunction by using photogrammetry to determine the basic shapes and then using laser scanners to flesh out the fine details (El-Hakim et al., 2004).

1.2.3 Benefits of photogrammetry

Before photogrammetry a site engineer was responsible for manually measuring objects using a traditional measuring tape and then recording the data on the site (Dai & Liu, 2010). The issues associated with this technique are inaccurate reading due to factors such as human error, prolonged time spent in the field, and defective equipment. As an alternative, an engineer can simply take photographs of the object in question and acquire the data later using photogrammetry software. The benefits to using this method are apparent and include:

- Measurements can be taken effortlessly on building products situated in hazardous areas.
- The amount of time acquiring data is significantly reduced.
- The alignment of building products can be monitored by taking pictures at different times.

1.2.4 Accuracy of photogrammetry

Since the late 1990s, there has been a lot of research conducted on the feasibility of photogrammetry within the industry. Accuracy is the most important characteristic as it determines whether data is credible. Most research agrees that using a digital camera to take on-site photos of objects is a promising way to generate measurements at an accurate level (Kim, *et. al*., 2011). The research was also quite clear as to what factors actually cause errors in the measurements generated by image-based models. The most common reasons for data errors are as follows: 1) the quality of the camera used, 2) the quality of the photos taken, and 3) the functionality of the photogrammetry software (Dai & Lu, 2010). Most people tend to agree that close-range photogrammetry is the most effective (Leitch & Coon, 2012). A major issue when taking photos of objects on site is the fact that most construction sites are littered with miscellaneous materials. Often these materials lie in the path of the desired object in question. This can be circumvented by taking a photo from many different angles to provide the software enough information to create an accurate model. In general, most research agrees that photogrammetry is a promising software as long as it is used for the right application.

2 Methodology

In order to gather research data an appropriate site needed to be selected. This site needed to meet a certain criteria so that it could be directly applicable to someone working in the professional world. For example, in the professional world a person most likely will take measurements of objects from corner to corner or from one edge to another of a structure for a certain application. For this reason a building was chosen with features that had very distinct edges. In this case, a façade with a high number of window mullions was chosen due to each mullion having distinct corners and edges.

Figure-2: Building Façade and Point Map

Quantitative data in this experiment was gathered in order to compare the accuracy of a photogrammetric model with the accuracy of a total station. Accuracy was tested by measuring chosen points along the façade. Prior to any data collection each point was manually selected along the surface of the façade. Each point chosen was a section where one window mullion intersected with another. The reason for this was that it made measuring these points more accurate with a distinct corner. A total of 67 points were chosen in this fashion, named as ‘P**’. The next step was to place control points along the surface of the building. These control points (named as ‘CTL**’) were placed in such a way so that they were spread across the surface of the façade evenly. The purpose of these control points was to provide the future model information that it could use to identify the coordinates of the other 67 points. The façade and point map are pictured below in Figure-2.

2.2 Process

The photogrammetry software used for this research was known as Agisoft PhotoScan Professional. This software utilizes photos taken from a digital camera and processes them to generate a 3D point cloud model. The photo taking process was done methodically in order to ensure that the model generated was as accurate as possible. Agisoft PhotoScan recommends that the user take photographs to ensure that there is at least a 60% overlap between consecutive photos. This way the software can more easily identify common points within the photographs and stitch together a model. In the horizontal direction the 60% overlap was achieved by stepping two feet to the side each time a photo was taken until the entire length of the building was covered. To help visualize this 60% overlap a sequence of three photos is shown below in Figure-3. To ensure a 60% overlap in the vertical direction common sense was employed to make sure there were enough like elements within each photo. The photos used for this project were taken from a distance of 15 feet away from the surface of the building and using a 50mm zoom on the camera. The camera was positioned on a tripod for each photograph to prevent any human error that might be generated from holding the camera manually.

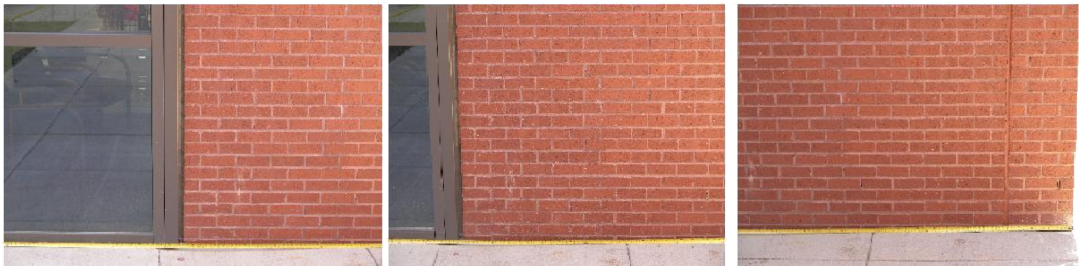


Figure-3: Example of a Set of Photos Taken

A Leica TS06 total station was used to gather the coordinates of each point and control point on the facade. The total station was positioned at an arbitrary distance from the building and was set to NP-Precise which stands for “no prism precise”. Each point and each control point was located through the total station’s scope and measured. This provided an x, y, z coordinate of each point based on the initial location of the station. These coordinates are assumed to be the base-line data that will be used to compare the data collected via the photogrammetric models generated using Agisoft PhotoScan.

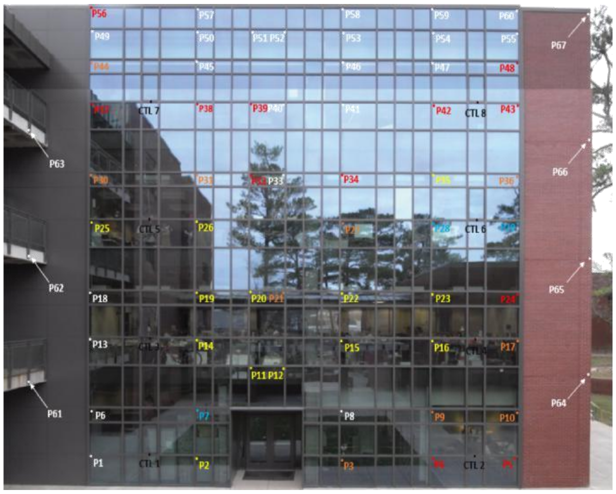
A set of 3 point cloud models was developed using Agisoft PhotoScan to process photos of the façade: the first model was created without giving the software any control points, the second model was created with the coordinates of four control points, and the last model was created with data of all eight control points. The reasoning for generating models with different sets of control points was to observe whether the amount of dimensional control points used affected the accuracy of individual points compared to the total station coordinates.

3. Results and Discussion

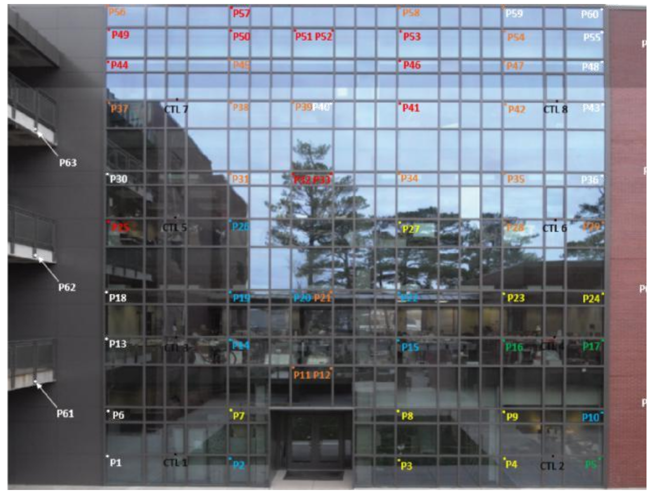
The main results of this experiment are presented in a graphical manner using images of the façade with color coded points placed along it. Each color denotes a different level of accuracy. The coordinates are displayed in feet. The levels of accuracy were measured with six different ranges: less than 1/8”, 1/8” to 1/4”, 1/4” to 1/2”, 1/2” to 3/4”, 3/4” to 1”, and greater than 1”.

Figure-4a shows the point map associated with the coordinates derived from the model that did not used control points. It is evident that the points become less accurate towards the top of the building than at the bottom. The majority of the points located at the top are all off by more than 1”. It is noted that the points around control point 2 are also far more inaccurate than the points located around the other lower control points: control 1, control 3, and control 4. Another interesting note is that the points along the edges of the building are all also over 1” off. Figure-5a is a map of all points with a discrepancy over 1” listed with the difference of the total station coordinates with that of the coordinates generated using Agisoft PhotoScan.

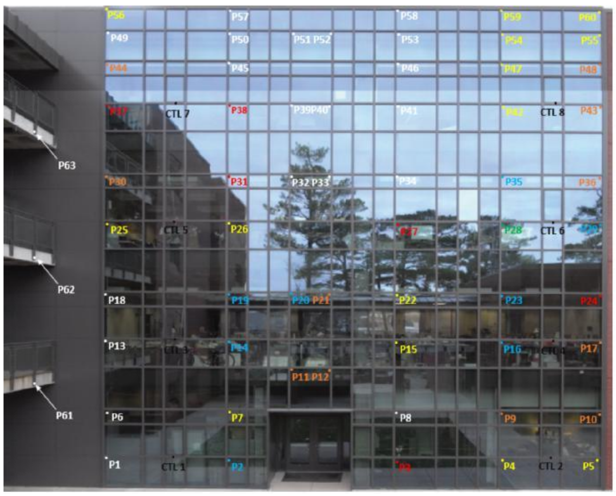
Figure-4b shows the point accuracy map of the photogrammetric model that used the lower four control points. As shown in Figure-5b, it appears as if the points become less accurate towards the top of the façade than at the bottom as well. However, compared to the model that used no control points, the points along the top of this model have increased in accuracy since control points were added. The coordinates around Control Point-2 have increased in accuracy as well as many of the points in the center of the model.



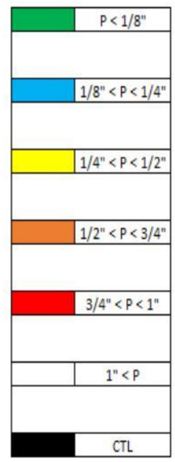
4a: Used No Control Points



4b: Used 4 Control Points



4c: Used All 8 Control Points



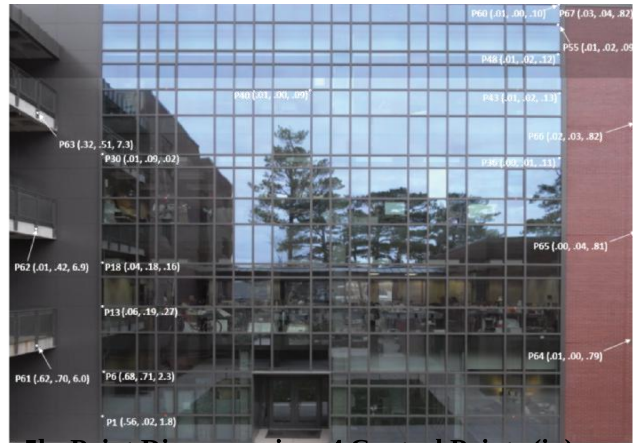
4d: Color Code Legend

Figure-4: Color-Coded Point Cloud Accuracy Maps of Photogrammetric Models with Various Number of Control Points

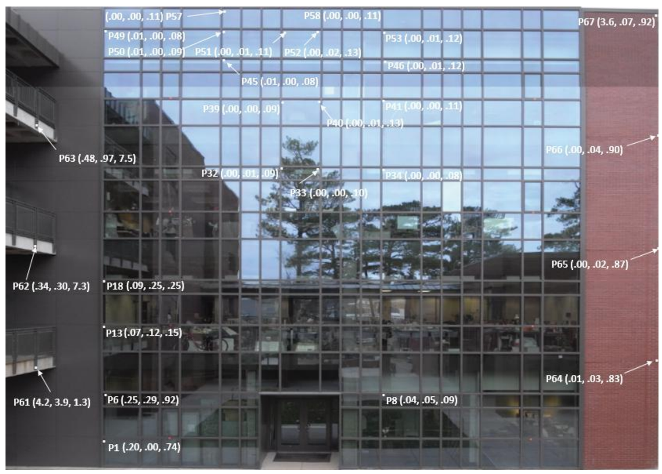
The point cloud accuracy map of the third photogrammetric model that used all 8 control points is shown in Figure-4c. An interesting development occurred: it seems as if the points at the top of the model all have a discrepancy over 1" from the total station coordinates. This is contradictory of the coordinates generated from the model using only 4 control points. Control Point-2 has even become less accurate from the previous graphic (Figure-4b). However, one thing has remained constant throughout all of the sets of data which is the points located along the side of the building remain inaccurate with a discrepancy over 1". Figure-6c is a map of all points of the model with a discrepancy over 1" listed with the difference of the total station coordinates.

Table-1 shows the average error in X, Y and Z direction (absolute values) for all three photogrammetric models compared to the total station coordinates. When considering this data it is clear that the model generated using four control points is the most accurate on the plane of the curtain wall storefront.

5a: Point Discrepancies - No Control Point (in)



5b: Point Discrepancies - 4 Control Points (in)



5c: Point Discrepancies - 8 Control Points (inches) Figure-

5: Point Discrepancies of Photogrammetric Models Table-

1: Average Error of the Models

Photogrammetric Model	Avg. Δx (in)	Avg. Δy (in)	Avg. Δz (in)
Used No Control Point	0.02	0.07	0.21
Used 4 Control Points	0.03	0.01	0.17
Used 8 Control Points	0.05	0.03	0.13

Most of the points at the top of the façade had an error greater than 1" before any control points were used. Points surrounding control point 2 also had a very low level of accuracy. Once the software was given the coordinates of the lower four control points both the points located at the top of the building and the points surrounding control point 2 became far more accurate, as shown in figure. Most of the top points all became accurate within 1" and the points surrounding control point 2 all became accurate within ½". There is a similarity between the first model and the second in that the points along the edge of the building suffered the most. In both models these points had an error greater than 1". Interestingly, once the model had been given 8 control point coordinates the total accuracy decreased - it is apparent that the top most points have decreased in accuracy with an error greater than 1" and the points surrounding control point 2 also decreased in accuracy to an error between ¼" and ½".

One of the most apparent reasons for inaccurate data is the distance a person is from the point being photographed. In every photogrammetric model generated the points located at the top of the building had more inaccurate readings than the points at the bottom. One theory is that the resolution of the photos is far greater when a picture is taken from a closer position. Since the photographs were taken from the ground level, the images of the top section of the building came out with a far lower resolution. This makes it difficult to place a marker accurately because the point is much harder to find. The second reason for inaccurate data on the top of the building was due to the angle of the images taken. Since all the photos were taken from the ground level which provided some very angled shots of the top part of the facade. Another factor affecting the accuracy was the façade chosen for this research. This particular façade featured a high number of windows. These windows created a surface which was reflective, transparent, and shiny in multiple photographs. Photos of such surface may confuse the software severely as it can not identify the true surface of the structure.

4. Conclusion

After analyzing the data and compiling the research results it is determined that the methodology used in this study does provide some 3D spatial information that can be used by architects or constructors for certain activities. However, the accuracy of the data can be significantly affected by many factors, including type of the building surface, method and camera used to take the photos, capability of the photogrammetry software, etc. If the information and recommendations set forth by this research are followed in future applications it is very possible that the accuracy of acquiring 3D spatial information from photogrammetric models will improve.

One of the main issues and challenges during the course of this experiment was adhering to the guidelines set forth by the photogrammetry software used in this research. These guidelines suggest certain building types, method of taking photographs, quality of photographs taken, and outdoor conditions while taking photographs. However, adhering to these standards can be quite difficult and it severely limits ones options when trying to use this technology for practical purposes on a construction site. This experiment ventured outside of these guidelines and it severely affected the accuracy of the results.

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