Measurement comparison of city roadway intersection models obtained via laser-scanning and photogrammetry

Marcel Maghiar, Ph.D.,
Georgia Southern University
Statesboro, Georgia

Gustavo Maldonado, Ph.D., P.E. and Dylan Mesta
Georgia Southern University
Statesboro, Georgia

Mariah Peart and Clinton Martin, Ed.D.
Georgia Southern University
Statesboro, Georgia

This project compares and contrasts the suitability of certain measurements for a city roadway intersection of two point-cloud models obtained via a laser scanner and a UAV-borne camera via a photogrammetry workflow. The two methods are employed and a total of 21 measurements are collected and compared from their respective models. The selected site is prone to many accidents and thus city engineers are considering to redesign it for a more efficient traffic flow. Regarding accurate dimensioning, certain features in both models are compared for smaller and larger scale distances, considering a central point location and the benchmarks used for this relatively simple four-way intersection. A basic analysis of discrepancies was also completed and the photogrammetric workflow was found suitable for use in this surveying application and can be used for fast analysis and measuring between closer-range points. Being richer in points and therefore containing more topographic information, the laser-scanning model is referred for larger scale measurements between features which are not in close vicinity.

Key Words: Construction Surveying, Laser Scanning, Photogrammetry, Measurements, Workflow

Introduction and Background Information

Scaled measurements are involved in the majority of daily activities performed by construction personnel, facility management professionals or licensed surveyors in various operations at the construction job site. The focus of this study is to create these measurements and to draw a parallel comparison of measures obtained virtually through distances between common points in two different models obtained via two technological means. From a couple of inches to a couple feet, construction and surveying professionals are in constant need of comparing results of their measurements. Based on the required level of accuracy for specific projects, these measurements may perform in the forms of rough, comparable tolerances and/or high accurate measurements. As an example, measuring dimensions for preparing material takeoffs or site material quantity gaging is an example where accurate measurements may not be needed, therefore they may be less accurate. In this manuscript, the authors are providing an exclusive overview of two different technologies used to generate virtual 3D models for a specific road city intersection in order to compare measurements obtained for the same points and their locations identified within the models, but through dissimilar workflows. These workflows refer to attaining the 3D models by acquiring point-cloud data through photogrammetry and laser scanning of the same city intersection.

Measuring distances and considering dimensions more than 300 feet (almost 100 meters) is not common on a residential construction jobsite and therefore this category may not be a regular daily task for a construction site engineer working on a residential project. However, in some civil engineering projects these distances may appear commonly as they are needed for repetitive construction tasks, as in roadway or city roadway projects. They can also be used for job site layout design, measuring deviations between as-planned and as-built structures or simply for redesigning certain elements within city intersections (as another example). The latter is the actual case presented in this paper. In the following sections, a background information on both workflows will be presented followed by the methodology and results of the identified measurements within models mentioned above, and then the authors will conclude with remarks on the practicality and usability of the reported results.

Laser-based scanners have the ability to acquire a significant amounts of spatial data in a relatively short period of time and it is a category of instruments which can capture surrounding information of an entire site or construction object in just a few scans. The outputs of these devices are usually generated in the form of a rough and dense cloud of three-dimensional points which may be used for certain applications in architecture, engineering, construction or facility management domain. These devices are highly efficient instruments and are currently used in the surveying and construction industry (see Crawford, 2003; Kavanah, 2013). Based on their specific brand and model, some modern scanners are able now to collect spatial coordinates of up to one-million points per second and they are used today for an abundance of practical applications. In an interesting application, Abellán et. al. (2013) used them to study rock slope instabilities; Pesci et. al. (2013) recommends monitoring damaged buildings after an earthquake through a scanning technique that provides rapid and safe measurements in emergency circumstances.

Manufacturers of laser-scanning equipment report the precisions of their equipment, however the final accuracies obtained after completing a full 3D point-cloud model in larger construction sites are generally not known or have to be computed. As described by Boehler (2003) there are several factors affecting those accuracies and some of them relate to the actual mechanical and optical limitations of the instruments and some are associated to the procedures employed to complete the full scanning of a large object/building. For instance, the fact that several scans need to be performed from different stations to fully cover a zone or an area in a city will introduce errors. These errors are produced when data from each scan is transformed into a common system of reference (procedure known as registration). The cloud-to-cloud registration method may introduce even more errors thru attempting to identify several (three or more) common points acquired in two neighboring scans. This particular task is a difficult one because it is improbable to identify a point that was hit twice precisely by the laser beams of two adjoining scans. So selecting quite close, but not necessarily the exact same points, involuntarily will introduce errors. As described below into the methodology section, for this project the number of scans performed in order to generate the point model was relatively low. Also, it worth mentioning that even the use of targets may introduces errors. As reported by Becerik-Gerber et. al. in a 2011 study, they performed research on data acquisition errors caused by target setup, acquisition, and reorientation. These researchers explored how different target types and target layouts are affecting registration accuracy. On a different note, Martin et. al. (2007) conducted a study of a ground-based LiDAR and digital photogrammetry survey of a 55 m (about 170 ft.) high rock slope to compare the accuracy of the three-dimensional digital models derived from both surveys. They have found that the digital elevation models from both surveys were providing very similar results that would be suitable for most rock engineering problems. Nex and Rinaudo (2011) proposed an integration approach of these two procedures in order to overcome their individual weakness. Their approach has been implemented on both terrestrial and aerial applications, showing the reliability and the potentiality of this kind of integration. Another study results by Hugenholtz et.al. (2013) suggest that small drone-acquired imagery may provide a low-cost, quick and flexible alternative to airborne LiDAR for geomorphological mapping.

In this city intersection project, the laser-scanning measurements used for comparison purposes were extracted from the 3-D point cloud model obtained after scanning with a Leica ScanStation C-10 scanner. The main characteristics of the laser-scanning instrument is presented in Table 1.

It may be noted that when determining position coordinates of points with these instruments, the magnitudes of the corresponding position errors are affected not only by the distance from the instrument, but also by the angular accuracy of the device (12 seconds horizontal and vertical, in this case). Therefore, position errors can increase with increasing distances and also increase when angular accuracies decrease. All measurements reported in this study were performed by undergraduate students enrolled in Civil Engineering courses guided and supervised by the faculty members who are co-authoring this article. They have become knowledgeable of the scanning instrument, the related post-processing software from Leica Geosystems (2010), and performed most of the reported measurements voluntarily. They are passionate civil engineering students who desire to master their skills in this area and also in photogrammetry modeling and measuring. Both of them are part of the same College and Department with the co-authoring faculty.

Table 1: Laser scanning instrument parameters and system performance (adapted from Maldonado et. al., 2015)

Item	Laser-Based Scanning Instrument
Type:	Pulse (time of flight)
Range	300 m @ 90%; 134 m @ 18% albedo (minimum range 0.1 m)
Accuracy of single measurement	Within 1-to-50-meter range: Position = 6 mm Distance = 4 mm (Both one sigma)
Angular Accuracies	Horizontal Angle = 12 sec Vertical Angle = 12 sec
Inclination Sensor	Dual-Axis Compensator, with 1.5-sec accuracy.
Scan rate	Up to 50,000 points/sec, maximum instantaneous rate
Dual-axis compensator	Selectable on/off, resolution 1”, dynamic range +/- 5’, accuracy 1.5”

In contrast, a photogrammetric model was used in this study to determine identic measurements between similar features concentrated in the respective topography. This effort was intended to compare the two applications and their workflows for this type of civil engineering projects. An Unmanned Aerial Vehicle (UAV) system as a data acquisition platform was used and as a measurement “instrument” involved in this project virtually was used the post processing software mentioned in the methodology section below. The UAVs are becoming more attractive for many surveying applications in civil engineering. Their performance, however, is not well understood for these particular tasks (Siebert and Teizer, 2014). Nonetheless, due to their relatively low cost and ease of operation, their applications may be suited in analysis and surveying of less complex civil engineering projects.

As Building Information Modeling (BIM) and as-build BIM become popular in the Architecture, Engineering, Construction and Facility Management industry, the as-built information can be captured deploying the technology of 3D laser scanning providing results in a fast way (Tzedaki and Kamara, 2013). Due to the fact that the Scan-to-BIM process requires several users’ input and high skills, these researchers consider aiming to tackle the problem of how to automate that procedure. The photogrammetric workflow presented herein may also be considered to automate the process with relatively fast results and good accuracy. The need of future case studies and the need for the overall approach for project applications taxonomy should emerge soon.

Objectives of this Study

The main purpose of this study is to perform a preliminary discrepancy analysis comparing measurements obtained by employing two different methods of obtaining a dense point-cloud model through a laser-based instrument and through photos collected via a drone. The referred measurements involve the determination of X-Y-Z coordinates of various points, at different locations selected within the model and the measurement of numerous distances defined by those points. The associated objectives are as follows:

a) Use of a laser-based scanner to obtain a 3D point-cloud model of the selected city intersection, including surrounding areas adjacent to the walkways on both streets
b) Generate the point-cloud model through a photogrammetry workflow and reference the point-cloud model into the same system of reference
c) Compare distance measurements between data points acquired by the laser scanner and the same ones acquired through photogrammetry
d) Conclude on the suitability for both workflows to aim helping city engineers in redesigning this intersection

Overall, the study is comparing the measurements of smaller and larger scale distances, based on a central location and the benchmarks used for this intersection. The distances obtained between data points via the laser scanner workflow and ones acquired through photogrammetry workflow were compared so the authors' goal was to determine the suitability for each type of workflow to aid the city engineers in the conceptual redesign process of this accident-prone intersection.

Methodology

This section presents the workflows used to attain the mentioned objectives. It describes the procedures to scan, to register (or reference) the resulting point clouds into a GPS reference system, then to acquire point coordinates from the final 3D point-cloud model. Also, on the second 3D model, to capture photographs and then to build photogrammetric model; the next steps are to acquire measurements in photogrammetric model and to determine the same point coordinates within both models. Finally, the team was comparing measurements on point coordinates and distances obtained via both methods and draw conclusions on the resulting measurements.

Scanning and Registration of the Point-Cloud Model

Due to the simplicity of the intersection, minimal scans were needed to render the corresponding model. As seen in Fig. 1(b), the four (4) targets, T1-T4, were placed on the side walks away from the main intersection as to not interfere with the scanning procedure, yet still be visible at all scans. The scanner was stationed at the four (4) vertices of the intersection to gain maximum coverage of the intended project and obtain the targets to reference each scan. The scanner then went through the process of acquiring targets, scans the area, and produce pictures at each station. The scanning of this project was conducted before construction and addition of the traffic signs. After all scans were completed, the raw data was extracted and imported to Cyclone 9.0 software, where it was stitched (internal co-registration of points) and the ModelSpace was produced. In the ModelSpace, the user is free to move around, edit, and measure points as needed. Within the model, there are a lot of unnecessary points (generated by traffic of cars, pedestrians, etc.) included in the ModelSpace and they need to be cleaned before the finished (clean) model is produced for any further use. The benchmarks coordinates were obtained by GPS, and the ModelSpace was georeferenced to be in compliance with the East Georgia State Coordinate Plane System. Once complete, the model is able to be exported into a file which is compatible for usage with multiple software including, but not limited, to TruViewer, Autodesk Civil3D, Autodesk AutoCAD, etc.

Capturing Pictures and Building the Photogrammetric Model

The initial phase of photogrammetric workflow is to acquire sufficient photos for the model. The photos need a 60% overlap to effectively work inside the Agisoft PhotoScan (Version 1.3.2) software. Agisoft PhotoScan is a stand-alone software product that performs photogrammetric processing of digital images and generates 3D spatial data to be used in GIS applications, cultural heritage documentation, and visual effects production as well as for indirect measurements of objects of various scales. Wisely implemented digital photogrammetry technique enforced with computer vision methods results in smart automated processing system that, on the one hand, can be managed by a newcomer in the field of photogrammetry, yet, on the other hand, has a lot to offer to a specialist who can adjust the workflow to numerous specific tasks and different types of data (Agisoft, 2017). An unmanned aerial vehicle (UAV) was used to capture all the needed pictures. It flew at roughly 20-25 ft. over the ground and took a total of 658 pictures with a flight layout that covered all four lanes from parallel benchmarks. Some of these pictures (208) were sorted out for clarity and in the same time there was a need to reduce the amount of pictures which Agisoft software algorithm will use to produce the 3D model. It is worth mentioning that capturing of all pictures was done at a different time than that of performing the laser scanning. The drone flight was completed after construction and the traffic signs were added to the street. Once uploaded into PhotoScan, markers are labeled and placed at the benchmarks for individual pictures where they can be seen; this process helps in the alignment of photos. Processing of the model begins with pictures being aligned, then dense clouds are built; after all meshes are built, and textures are added to yield the model as seen in Fig. 1(a). Parameters within each process can be altered with respect to specificity of the project. As seen in Fig. 2(c), the parameters for this project is set relatively around "Medium" for timely results. Increasing any, or all, settings will increase the number of points, clarity, alignment, and others, but it will also make the project very lengthy for processing. The model can be selected for varying settings such as: point cloud, dense cloud, solid model, and wireframe. The dense cloud model is captured in Fig. 1(a) as the model was used later for computing distances and analysis. Once the model is built, the initial markers can be set to specific coordinates to give the model a scale and register the points with the East Georgia State Coordinate Plane System.

After completion, singular points or measurements can be obtained, and users can fly around the model in a similar fashion of the Cyclone produced model.

Attainment of Distances for Comparison Purposes

Geo-referencing of the model is essential to assure that the each scale is as close as possible within the respective software. The photogrammetric model had limited range of view due to the span of pictures and because of this, various points for discrepancy had to be obtained within the photogrammetric model's range. A central point, bolt of a water cover near Scan 1 - Fig. 2(a), was set to get radial measurements at varying distances.

Within the Cyclone model, distances are quite easy to obtain because the software allows for the user to pick multiple points and will automatically show the distance. When points were obtained, the Cyclone model was not geo-referenced and the software measurement tool was used to get the distances between the points. Square root of differences (Table 2 below) was used for calculating any distance between selected two points. Model points were selected through use of the "Pick Mode". In order to keep the main central point unaltered, the "Multi-Pick Mode" allows for points to be clicked, and unclicked, for mobility around the model while leaving a singular point (Center). This allows for users to generate the distance between two points, unclick the variable point, and then move to the next position without affecting the center point. Markers are not placed to hold positions, except for the benchmarks, targets. Selecting points are based solely off of visibility and accurate estimation of point placements.

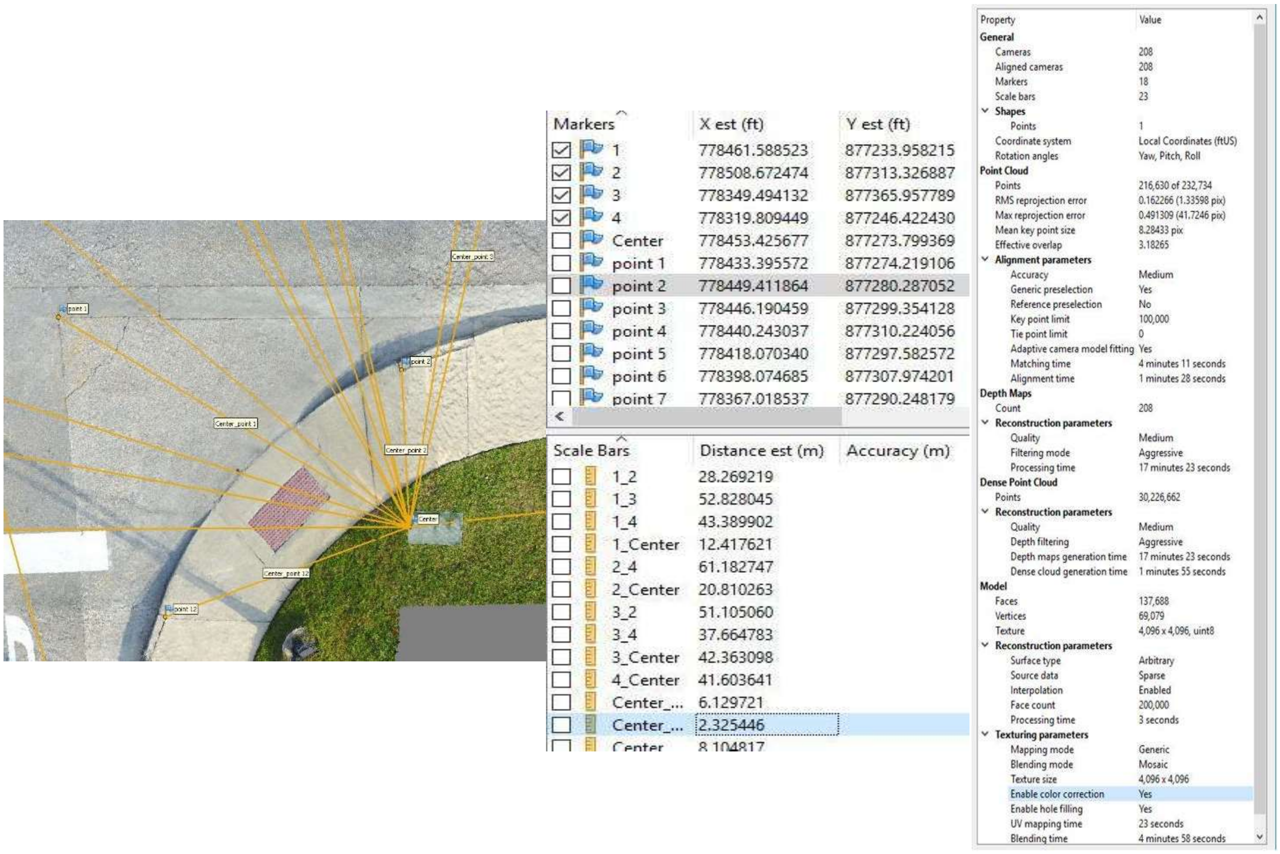
(a) Photogrammetry Model (b) Laser Scanner Model

Figure 1. Photogrammetric and Laser-scanned Model

The PhotoScan model is more methodical than that of Cyclone. Within PhotoScan software, there is a tool, "Ruler", that can be used to get the measurement between two points such as Cyclone does, but it does not allow the full range of mobility around the model while setting points. The "Ruler" is useful for short points, but PhotoScan has another way of producing measurements that are more beneficial. Just as the benchmarks are laid with markers, points of interest can be plotted with markers and measured within the software. Simply put, a marker is placed as the "Center" and then a point for measuring distance is placed. As seen in Fig. 2(b), points are highlighted within the "Reference" menu, right-clicked, and then "Create Scale Bar" was selected. Automatically a labeled line between the points is created. The estimated distance is given in the "Reference" menu via the scale used by the reference points. This method is recommended because it leaves the points on the model for anyone to reference back to in the future as well as allowing our team to confidently find the corresponding point on the Cyclone model. It also allows for points that have been obtained to be measured, like the established benchmarks. From both of these processes, multiple measurements can be extracted within each model and compared for differences. The measurements are obtained and put into a table where the absolute difference is calculated. This allows for our team to get the averages and variability between distances.

Results and Discussion

Due to time limitations, both models were not tested and compared against an accurate measuring standard like a surveyor's grade total station. Because of this, the authors can only analyze the differences between photogrammetry and laser scanning models obtained. The distances within each model were obtained to the nearest thousandths of a meter. After a total of 21 were collected, the absolute difference is obtained between the two measurements (in photogrammetric and laser scanning models). The research team has decided to convert the differences to US imperial measurements by the conversion factor of 1 ft. = 0.3048 m. Table 3 below was used to calculate the distances of the exact points in the Cyclone Model. The distance between two points is calculated by the square root of summed squared differences of Northing and Easting. The results in Table 2 show that the average absolute difference between photogrammetry and laser scanning is 0.262 ft. (0.08 m). The differences vary from 0.024 ft. at a distance of 68.264 ft. to 0.679 ft. at a distance of 131.211 ft. These numbers demonstrate that at approximately 70 ft. the variance between the two models is quite accurate, and alternately, at farther lengths, such as approximately 130 ft., the models incurred the greatest discrepancy of more than ½ ft. This may be caused by an error of the scale in PhotoScan software due to lower level parameters. Another reason considered in explaining the discrepancy was due to possible misplacement of point selection in each model. The lack of ground control points also decrease the accuracy of the model as a whole. Human error can be prevalent in point selection across two models.



	Markers	X est (ft)	Y est (ft)
☑	1	778461.588523	877233.958215
☑	2	778508.672474	877313.326887
☑	3	778349.494132	877365.957789
☑	4	778319.809449	877246.422430
☐	Center	778453.425677	877273.799369
☐	point 1	778433.395572	877274.219106
☐	point 2	778449.411864	877280.287052
☐	point 3	778446.190459	877299.354128
☐	point 4	778440.243037	877310.224056
☐	point 5	778418.070340	877297.582572
☐	point 6	778398.074685	877307.974201
☐	point 7	778367.018537	877290.248179

	Scale Bars	Distance est (m)	Accuracy (m)
☐	1_2	28.269219	
☐	1_3	52.828045	
☐	1_4	43.389902	
☐	1_Center	12.417621	
☐	2_4	61.182747	
☐	2_Center	20.810263	
☐	3_2	51.105060	
☐	3_4	37.664783	
☐	3_Center	42.363098	
☐	4_Center	41.603641	
☐	Center_...	6.129721	
☐	Center_...	2.325446	
☐	Center	8.104817	

Property	Value
General	
Cameras	208
Aligned cameras	208
Markers	18
Scale bars	23
Shapes	
Points	1
Coordinate system	Local Coordinates (ftUS)
Rotation angles	Yaw, Pitch, Roll
Point Cloud	
Points	216,630 of 232,734
RMS reprojection error	0.162266 (1.33598 pix)
Max reprojection error	0.491309 (41.7246 pix)
Mean key point size	8.28433 pix
Effective overlap	3.18265
Alignment parameters	
Accuracy	Medium
Generic preselection	Yes
Reference preselection	No
Key point limit	100,000
Tie point limit	0
Adaptive camera model fitting	Yes
Matching time	4 minutes 11 seconds
Alignment time	1 minutes 28 seconds
Depth Maps	
Count	208
Reconstruction parameters	
Quality	Medium
Filtering mode	Aggressive
Processing time	17 minutes 23 seconds
Dense Point Cloud	
Points	30,226,662
Reconstruction parameters	
Quality	Medium
Depth filtering	Aggressive
Depth maps generation time	17 minutes 23 seconds
Dense cloud generation time	1 minutes 55 seconds
Model	
Faces	137,688
Vertices	69,079
Texture	4,096 x 4,096, uint8
Reconstruction parameters	
Surface type	Arbitrary
Source data	Sparse
Interpolation	Enabled
Face count	200,000
Processing time	3 seconds
Texturing parameters	
Mapping mode	Generic
Blending mode	Mosaic
Texture size	4,096 x 4,096
Enable color correction	Yes
Enable hole filling	Yes
UV mapping time	23 seconds
Blending time	4 minutes 58 seconds

(a) Radial Measurements (b) Markers and Estimated Distances (c) Parameters

Figure 2. Measurements and Parameters of PhotoScan Model

In 19 of the 21 recorded measurements, the Cyclone measurements were less than the ones obtained in the PhotoScan model. If the precision of accuracy is neglected, both of these models still have functional purposes. Photogrammetry can be used for large scale topographic models for elevation, site layout, area, and volume measurements. Photogrammetry is relatively cheaper than laser scanning, which makes it more cost effective for land surveying for vegetation, site plans, and general topographic maps. However, some of the crowded or more complex topographies may be difficult to obtain through the existing photogrammetry software algorithm as 3D meshed models. Whereas, the laser scanning would be more practical for structures, interiors, and well defined objects. Laser scanning does require a more extensive time of practicing due to the needed knowledge of the instrument and software, while photogrammetry needs only a trained pilot of a UAV. PhotoScan can be taught to someone to build a needed project, but expertise can really carry the software applications a long way. Both procedural workflows can be used in the same project, it just depending on cost and time available to generate the models and perform measurements.

Table 2: Distance Measurements of 21 Points in PhotoScan and Cyclone.

	PhotoScan	*Cyclone*	*PhotoS-Cyclone*	*PhotoS-Cyclone*
Measurement	Distance (m)	Distance (m)	Difference (m)	Difference (ft.)
1	6.130	6.113	0.017	0.056
2	2.325	2.313	0.012	0.039
3	8.105	8.059	0.046	0.151
4	11.821	11.749	0.072	0.236
5	12.988	12.921	0.067	0.220
6	19.828	19.718	0.110	0.361
7	26.813	26.685	0.128	0.420
8	24.320	24.258	0.062	0.203
9	20.965	20.894	0.071	0.233
10	37.054	36.910	0.144	0.472
11	40.096	39.889	0.207	0.679
12	4.109	4.099	0.010	0.033
13	7.558	7.567	0.009	0.030
14	12.418	12.437	0.019	0.062
15	20.810	20.803	0.007	0.024
16	42.363	42.222	0.141	0.461
17	41.604	41.400	0.204	0.669
18	28.269	28.236	0.033	0.108
19	52.828	52.742	0.086	0.283
20	43.390	43.487	0.097	0.318
21	51.105	50.969	0.136	0.445
		Mean=	*0.080*	*0.262*

Table 3: Coordinates of Main Points in Cyclone for Square Difference of Roots

	Laser scan coord. (m)	
Center	-1.628	-0.51
1	-1.639	11.927
2	-20.636	-8.963
3	23.515	-34.43
4	39.763	-1.377

Conclusions and Recommendations for Further Research

Tables 2 and 3 show that the average absolute difference between photogrammetry and laser scanning is 0.262 ft. (0.08 m). There is not an overall constant difference and therefore it is observed that some measures vary from 0.024 ft. at a distance of 68.264 ft. to 0.679 ft. at a distance of 131.211 ft. The numbers illustrate that, at approximately 70 ft., the variance between the two models is quite close and therefore both models will be appropriate to use for city engineers or surveyors when these type of related small distance measurements are needed. Alternately, for longer distance measurements or greater lengths needed to be known in the redesigning process (of up to approximately 130 ft.), the models incurred the greatest discrepancy of more than 0.5 ft. As the laser scanning model has a greater point density than the photogrammetric model, it will be probably preferred as a choice in further measurements needed to a wider scope of work. The cause for potential introduced errors were discussed in the previous results section and subsequently the team concluded empirically about the lack of ground control points also decreasing the accuracy of the model along with introduction of the human errors for generating both models. However, conventional existing surveying techniques can be time consuming and most of the time unsafe to personnel. Unmanned Aerial Vehicle (UAV) systems provide a novel platform for introducing photogrammetric measurements for various purposes. Major benefits in using photogrammetry in this case are autonomous/fast data acquisition, relatively low errors (which may be further verified) and a sizeable point cloud. The UAVs may further be tested for larger infrastructure projects in the region to potentially aid in project decision making.

As stated previously, one of the limitations of this study was the lack of standard and very accurate measurements of the same selected points within both models with a surveyor's grade total station or similar instrument. Because of this limitation, the authors can only analyze and conclude on the usability of the models for the purpose of needed intersection redesign and, therefore, differences between photogrammetry and laser scanning model measurements were analyzed with this focus in mind. Due to the UAVs relatively low cost, simplicity of operation and a short period of time for collection of photos, the photogrammetric workflow was found suitable for use in this surveying application and it may be used in analysis and for measuring needed distances between certain features pertaining to the intersection, but more closely situated. As the laser scanning model is richer in point density, it may be referred for larger measurements between features situated not in close vicinity. Certainly, the advantage of using the scanners is the large amount of spatial data that can be captured.

This research team plans as future work to further geo-reference the laser scanning 3D point cloud obtained and to take accurate measurements with an accurate (classical) survey-grade instrument (a precise total station). Another discrepancy analysis between measurements attained within the 3D models and those collected with classical survey-grade instruments will be employed for a new comparison on the obtained accuracies. The final models and results will be discussed with the local city engineers to help in the process of redesigning this intersection. The selected location involves two intersecting streets currently regulated by signage, but unfortunately with multiple accidents per year. The discrepancies in measurements will provide an estimate of the accuracies achieved by the laser-based, point-cloud model and by the photogrammetric model. Analyzing this type of models to properly represent spatial areas will assist researchers to realize the tolerances required in similar civil and construction engineering projects. The explored procedures and newly generated protocols will assist in producing future models for further analysis of deteriorating bridges, possible forensic studies of collapsed structures or modeling of other sensitive components and structures (i.e. nuclear power plants, mechanical rooms of large commercial buildings, etc.)

In addition to the study of discrepancies and the parallel comparison, this work will add educational value to many undergraduate students in the Construction and Civil Engineering programs. During at least two semesters, various groups of undergraduate students have the chance to practice proper techniques to work with total stations, learned the use of modern laser-based scanners and use photogrammetric software to process pictures acquired via drones, all these while performing research beneficial to their future careers. The educational value of these projects is also acknowledged by these students acquiring new cutting-edge technology skills in the implemented Senior-Capstone Project courses or in the existing elective courses (like Introduction to Laser Scanning or Close-Range Photogrammetry) offered in the current curricula for both Civil Engineering and Construction programs.

Acknowledgements

The authors of this manuscript would like to express appreciation and be thankful to the Undergraduate Research Committee of the Allen E. Paulson College of Engineering and Computing of Georgia Southern University for funding past undergraduate research proposals on similar topics and, in the same, time aiding in acquiring materials or consumables needed for instruments or devices used in this project. More recently, a student group lead by one of the co-author of this paper has obtained a new undergraduate research grant (right after submission of this paper) and the funds will assist the project to continue and perform accuracy measurements in order to compare both data sets obtained so far with the ground survey data. The findings of this follow-up study will be reported in a future manuscript.

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