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3D + Time Reconstruction: Designing Optimal Camera Parameters

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Abstract

Three dimensional plus time reconstructions are an emerging concept in the civil engineering industry. The application possibilities are continuing to develop, resulting in an expansive range of projects. Proper image based modeling should utilize different camera parameters depending on the individual application. Currently, research examining the optimal camera settings for 3D reconstruction quality is limited. Knowing the ideal camera parameters and how each parameter will affect the modeling utilized for image reconstruction settings will improve modeling quality of 3D reconstructions.

This paper examines the effective methods for improving reconstruction features based on picture quality. Camera settings tested include depth of field, shutter speed, ISO light sensitivity, resolution, and the number of pictures taken to be utilized in the 3D reconstruction. The variables also incorporate changes in lighting types, as well as material surface reflections. Distinct trends can be identified within the data set with respect to the mentioned variables.

1 Introduction

The purpose of this study is to determine the optimal parameters associated with the computer modeling of three dimensional figures. A variety of settings and lighting characteristics can affect the quality of the image. All of these factors must be acknowledged, and will lead to the optimal settings and lighting arrangements for the desired image appearance. Formal image based reconstruction protocols will be developed to improve infrastructure testing corresponding to the settings on the Nikon D7100 with a 20 millimeter lens. Objectives also include determining the error associated with Agisoft Photoscan, along with analyzing the performance of the Agisoft Photoscan software.

The modeling associated with this 3D visualization research includes various material surface types applicable to steel and concrete. Acknowledging these conditions, the objects to be utilized in this study will include samples of both of these materials. The samples should be between 3 and 8 cubic inches. The surface reflection of the materials will differ, therefore each will go through the trials as separate entities. The steel will be C-shaped, therefore the settings may be determined under conditions of shadowing.

Other parameters are defined by the camera itself, such as the resolution. Resolution is described as the number of distinct pixels in each dimension (width by height) used to create the image (Nikon Corporation 2014). Lower resolutions will cause the image to be blurry or grainy. Too high of a resolution will overwhelm the computer bandwidth and slow down the image reconstruction due to the high pixel count for each dimension. The resolution possibilities that will be tested in this experiment will include only the common resolution settings found on the Nikon D7100 camera. The possible resolutions for this camera include two initial options for image size, DX(24x16) and 1.3x(18x12). Within the DX format, higher resolutions can be found dictating the picture quality, such as 6000x4000, 4496x3000, and 2992x2000. The 1.3x(18x12) picture format involves resolutions of 4800x3200, 3600x2400, and 1400x1600 megapixels. It is also important to note that if the image is acquired in high resolution, it can be modified to fit a lower resolution. However, for images taken with low resolution quality, the features contained in the image cannot be augmented when the resolution is increased. This experiment will incorporate

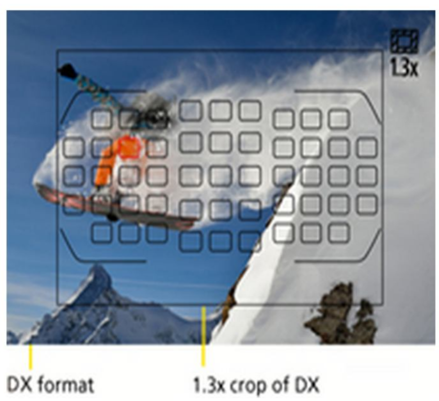


Figure 1: DX vs. 1.3x Format Sample

all of the aforementioned resolution possibilities.

The light sensitivity, includes multiple variables that should be considered for this experiment. These variables include the shutter speed and International Standards Organization (ISO) settings (Comon 2011). A slower shutter speed will allow more light into the picture, while a higher shutter speed reduces the exposure time, capturing less light. DSLR cameras generally give the user the ability to change the shutter speed. A lower ISO number generally reacts best with a slower shutter speed. Light exposure depends on the shutter speed, lens aperture, and scene luminescence. The experiment should include shutter speed ranges from about 2.5 (for bright areas) to 3200 (for fast action), depending on available equipment. The adjusted ISO values will incorporate levels from 100 through 2500. Most DSLR cameras give the user the ability to choose all manual settings, including setting the ISO and shutter speed separately (McMahon 2013). For the purposes of this experiment, both the light sensitivity and shutter speed will be adjusted manually.

Depth of field is the range of distances in which the image appears sharp, and it relates to the pixel size on the sensor (Nikon Corporation 2014). This factor is controlled by the type of camera, aperture, and focus distance. Manual adjustments of camera depth of field rely mostly on the f-stop. Aperture is the opening which allows light to enter the camera. Varying distances can be chosen using mathematical formulas which calculate the required f-stop number along the circle of confusion. The circle of confusion is the small range of camera-to-object distances in which the images are in focus. It can be concluded that the optimal depth of field will be on the edge of the circle of confusion. However, the circle of confusion is dependent on the camera, so the parameter will be based on the Nikon D7100 settings. Mathematical computations may offer further information for determining variables. The appropriate depth of field can also be determined experimentally.

Lighting in the experiment will be another essential factor of the environment. Light settings will be considered for both indoor and outdoor atmospheres. The type of light source will impact the quality of the photography. If the sun is the primary light source, then the position of the sun in the sky will be a significant detail to record. For indoor lighting settings, the type of artificial lighting will determine a variety of settings and should be placed in such a way as to minimize shadowing. The number of pictures incorporated for each model will also be a parameter. At this time, there is no data on the optimal number of pictures required to accurately model. Current practices incorporate 120 pictures, but additional computer models will be created using 50, 75, 100, 125, and 150 pictures.

Results should indicate optimal camera parameters for modeling in different lighting conditions and using various camera parameters. For the concrete piece, modeling precision will be based on the distance between specified voids in the material. Distance matrices comparing the distances between five voids will be created for the actual model, dense point cloud, and polygon mesh cloud. The dense point clouds and mesh clouds were created using Agisoft Photoscan. To standardize the comparison for increased precision, the standard model set for concrete will be measured. The settings for the standard concrete model include: an ISO of 640, a shutter speed of 25, a depth of field f-stop value of F8, the incorporation of 120 pictures, and a high resolution of DX (6000x4000). A professional lighting kit was utilized with an LED White and Yellow Color Balance at full power. For the steel piece, material dimensions will be measured and gathered for the actual material, dense point cloud, and polygon mesh cloud. Distances and dimensions for the actual samples will be quantified in inches using a dial caliper. In the Agisoft Photoscan models, it may be necessary to scale the model distances to the actual size of the piece. The distances between voids and sample dimensions within the computer models will be measured using the MeshLab software.

2 Metrics

Using the appropriate metrics to meet the stated objectives will be essential. Performance of Agisoft Photoscan will be determined by analysis of the point cloud density, which is based on the number of points recognized by Agisoft Photoscan to be used when generating the 3D models. Performance will also be indicated by the accuracy of model measurements. Trends in point densities compared with the various camera parameters and lighting settings will be discussed. Dimensional error in the real sample versus the standard computer models will be calculated. Statistical data of the measurements will assist with calculating the dimensional error and identifying Agisoft Photoscan accuracy. Conclusions from both the Agisoft Photoscan performance analysis and dimensional error determination will be utilized to form a generic set of optimal camera parameters and lighting settings to assist with future 3D plus time reconstructions.

Overall assessments of the Agisoft Photoscan performance will be dependent upon the software capability to align photographs properly, recognition of points to be used in model generation, and demonstration of the softwares ability to improve model quality based on picture quality and point density. An acceptable performance of Agisoft Photoscan, using the parameters identified for this investigation, will be defined in the following manner:
1. Agisoft Photoscan is able to align 75 percent of all captured photographs. The photograph parameters should designed as the potential optimal settings, and not intended to disrupt photograph alignment.
2. Agisoft Photoscan must recognize more than 40,000 points in over 50 percent of the models using the medium point cloud density setting in the software.
3. The average number of points in each model created by Agisoft Photoscan should be above 50,000 points when the models are created according to a medium point density setting.
4. The total average of the Agisoft Photoscan percent error should be less than five percent.
5. Optimal parameters for improving modeling techniques through Agisoft Photoscan should be provided.

3 Procedure

As indicated, multiple environments with different types of lighting should be utilized in the investigation. For application to outdoor infrastructure, conduct trials outdoors in natural sunlight. Other trials should be performed indoors using generic household lamps to depict a more common laboratory setting. However, a majority of the trials utilize professional LED lighting at a white and yellow color balance. To determine the effects of the color balancing with the professional lighting, separate trials investigated modeling using only yellow or only white light.

3.1 Material Preparation and Set-Up

Acquire small samples of steel and concrete to test. The materials must be situated in such a manner as to reduce shadowing and to allow the greatest majority of the objects surface to be seen. The environment around the camera should be large and open enough to provide ample space to set up camera and lighting equipment and allow free movement around the set-up. In addition, the camera stand surface should avoid disruption of the light settings and prevent reflection from extraneous materials. This may require the stand to be covered in a black cloth or a similar uniform material.

3.2 Changing the Camera Settings

Turn the camera on and remove the lens cap. Please note that the procedure describes the steps specifically for a Nikon D7100. On the left side there is a tab selecting automatic or manual controls. Switch this tab to M, manual. The desired ISO, shutter speed, f-stop, and resolution settings will be set manually.

Change the ISO light sensitivity by pressing the third button down on the back face of the camera where ISO is indicated. Turn the dial in the upper right hand corner of the back face of the camera to increase or decrease the light sensitivity. Alter the f-stop by turning the camera power dial all the way on, or counterclockwise. The screen on top of the camera will light up, allowing the settings to be changed by the dial controls on the front of the camera next to the lens.

Similar to the f-stop, the shutter speed can be changed by pushing the power dial counterclockwise to light the top screen. The dial on the back face of the camera will then increase or decrease the shutter speed to be set to the appropriate exposure.

Change the resolution by modifying the image size and quality. Begin by selecting Menu, the top left button on the back face of the camera. Click down twice using the arrow toggles to the right of the display screen. Scroll down until able to select the image size, then click the desired size. Scroll back up to change the desired image quality.

3.3 Setting up the Professional LED Lighting

The described experimental procedure involves the use of two professional LED lighting equipment sets. Each should have the capability of creating entirely yellow or entirely white light, or be capable of balancing both light types. After setting up the material as discussed above, place the light tripods opposite each other equidistant from the object. Extend the light stands from the ground up turning the knobs tightly to ensure stability. The light should be positioned above and looking down on the material. Position the external lighting as such to reduce shadows and enhance light on the material surface. For C-shape steel this task may prove difficult.

Carefully screw the light onto the extended light stand. Turn both the yellow and white balance on to full power, or to the desired setting, while keeping the light itself off. Plug in the light, and turn the light power on while looking away from the light.

Upon completion of the experiment, wait about ten minutes before dissembling the equipment to allow the lights to cool. Take the equipment down by reversing the steps in which it was set up. Start dissembling at the top and work downwards.

3.4 Setting Up Indoor Household Lighting

Place the lighting near the equipment in a manner that minimizes shadowing and enhances the amount of light on the object.

3.5 Sunlit Outdoor Environment

Follow the material preparation and set-up, then record the time and day at which the photographs will be taken. Online resources can provide a diagram of sunlight at the exact time and day.

3.6 Determining the Optimal Camera Parameters for the Lighting Environment

Look into the eyepiece of the camera and observe a bar displaying light balance between the internal camera settings and external area lighting. This will be indicated by a zero placed directly above a vertical bar. If there are vertical bars to the left or right of the zero, either the ISO, F-stop, shutter speed, or a combination of these parameters should be modified. Turn the dial for the chosen setting to move the bars until balanced at zero. Figure 2 displays an example of the bar seen through the camera eyepiece.

Figure 2: Light Balance Bar on Nikon D7100

3.7 Object Photography

Pick one location at which to begin and end picture-taking. Circle the object slowly while taking pictures well distributed over the entire circle of the object. Take the pictures in such a manner that each picture is turned no more than 15 degrees from the previous photograph, completely stopping while the camera is capturing the picture. Periodically review the picture using the button on the top left of the back face of the camera. Ensure that the entire visible surface of the object is in the frame of the picture. Avoid changing the camera angle, height, and distance. Consistency is key. Continue in either a clockwise or counterclockwise motion until once again reaching the starting location. Remember to maintain an appropriate rate so as to capture the entire object with the complete set of pictures needed for the specific trial.

3.8 Analysis

Upload the photographs into Agisoft Photoscan, creating a new chunk for each trial. Align the photographs, create a dense point cloud, and create a mesh cloud. The batch processing system within the software can be used to maximize efficiency. Export the models into Meshlab for the measurements. On the concrete models, chose five noticeable voids, mark them, and measure the distances between the specified voids using the ruler tool in Meshlab. In addition, measure the distance between the same indicated voids on the actual piece of concrete, along with one dimension that may be used for scaling the actual concrete size with the computer model. For the steel, measure various dimensions on the specimen model and the actual figure. Scale the measurements taken using the Meshlab software, and compare the measurements. For measuring the real figure, use a dial caliper. It may be helpful to take multiple measurements for each needed distance so that the standard deviations may be determined. This will increase precision of error.

4 Results and Discussion

The variety of parameters utilized to create each model during the investigation are specified in Table 1. The trials are listed in order from the least to the greatest amount of points recognized by Agisoft Photoscan for comparison purposes in Figure 5.

4.1 Agisoft Photoscan Performance

The performance of the Agisoft Photoscan software can be identified by analyzing the quantity of points used to create each model, among other variables. A greater number of points obtained from the pictures corresponds to an increase in the model point cloud density. Generally, higher point cloud densities improve model quality. Therefore, it is essential to understand the parameters that will generate optimal model quality. Distinctive trends were concluded from the point data obtained to create each model. It is important to understand that the subject

Table 1. Trial Parameters

Trial	Material	ISO	Shutter Speed	F-Stop	Number of Pictures	Lighting	Resolution
1	Steel	4000	30	F11	50	Indoor LED Balance	DX 6000x4000
2	Steel	4000	25	F11	120	Indoor LED Yellow	DX 6000x4000
3	Steel	4000	50	F11	120	Indoor LED Balance	1.3x(2400x1600)
4	Steel	4000	30	F6.3	120	Indoor Household	DX 6000x4000
5	Steel	4000	30	F11	75	Indoor LED Balance	DX 6000x4000
6	Concrete	640	6	F8	120	Indoor LED Balance	DX 6000x4000
7	Steel	4000	40	F11	120	Indoor LED White	DX 6000x4000
8	Steel	4000	50	F11	120	Indoor LED Balance	1.3x(3600x2400)
9	Concrete	640	25	F8	50	Indoor LED Balance	DX 6000x4000
10	Steel	4000	30	F11	120	Indoor LED Balance	1.3x(4800x3200)
11	Concrete	640	25	F8	120	Indoor LED Balance	DX 6000x4000
12	Steel	6400	25	F11	120	Indoor LED Balance	DX 6000x4000
13	Concrete	640	13	F8	120	Indoor LED Balance	DX 6000x4000
14	Steel	4000	30	F11	100	Indoor LED Balance	DX 6000x4000
15	Steel	100	20	F2.8	120	Indoor LED Balance	DX 6000x4000
16	Steel	4000	50	F11	120	Indoor LED Balance	DX 4496x3000
17	Steel	4000	30	F11	120	Indoor LED Balance	DX 2992x2000
18	Steel	2500	250	F3.2	120	Indoor LED Balance	DX 6000x4000
19	Concrete	640	100	F2.8	120	Indoor LED Balance	DX 6000x4000
20	Concrete	1250	25	F8	120	Indoor Household	DX 6000x4000
21	Concrete	640	25	F8	75	Indoor LED Balance	DX 6000x4000
22	Concrete	640	25	F8	100	Indoor LED Balance	DX 6000x4000
23	Concrete	640	25	F8	120	Indoor LED Yellow	DX 6000x4000
24	Steel	4000	30	F11	120	Indoor LED Balance	DX 6000x4000
25	Steel	4000	30	F11	125	Indoor LED Balance	DX 6000x4000
26	Steel	640	15	F8	120	Indoor LED Balance	DX 6000x4000
27	Steel	4000	30	F11	150	Indoor LED Balance	DX 6000x4000
28	Steel	640	100	F2.8	120	Indoor LED Balance	DX 6000x4000
29	Concrete	640	25	F8	120	Indoor LED Balance	DX 6000x4000
30	Concrete	640	25	F8	125	Indoor LED Balance	DX 6000x4000
31	Concrete	640	25	F8	120	Indoor LED White	DX 6000x4000
32	Steel	640	1600	F8	120	Outdoor	DX 6000x4000
33	Concrete	100	13	F2.8	120	Indoor LED Balance	DX 6000x4000
34	Concrete	640	25	F8	150	Indoor LED Balance	DX 6000x4000
35	Concrete	640	25	F8	120	Indoor LED Balance	DX 4496x3000
36	Concrete	640	1600	F8	120	Outdoor	DX 6000x4000
37	Concrete	640	25	F8	120	Indoor LED Balance	DX 2992x2000
38	Concrete	640	25	F8	120	Indoor LED Balance	1.3x(4800x3200)
39	Concrete	640	25	F8	120	Indoor LED Balance	1.3x(2400x1600)
40	Concrete	640	25	F8	120	Indoor LED Balance	1.3x(3600x2400)
41	Concrete	100	100	F13	120	Outdoor	DX 6000x4000
42	Steel	100	100	F11	120	Outdoor	DX 6000x4000

material changes the optimal parameters. Experiment results indicate that concrete and steel had different point cloud density peaks in relation to the variables tested. Therefore, the optimal camera and light settings will vary depending on material surface reflection. However, some parameters also displayed similar trends for both steel and concrete models, indicating there will be variability in Agisoft performance and modeling techniques.

The greatest difference between surface reflection modeling is displayed in resolution testing. Steel models indicated a clear preference for DX resolution formatting while concrete point densities improved using the more focused 1.3x resolution formatting. As made evident in the first subplot of Figure 3, the largest resolution quality within the DX formatting, DX(6000x4000), created the highest model point density for the steel figure. Switching from small to medium resolution qualities had little impact on the model. Furthermore, the medium resolution quality of 1.3x(3600x2400) significantly improved Agisoft Photoscan performance for concrete modeling.

During the investigation, it was observed that there were key variables relating to the cameras light balance parameters of ISO, f-stop, and shutter speed. However, the most influential of these three variables changed depending on the material. The shutter speed impacted the concrete picture quality most noticeably. Examination of how the exposure time impacts the point cloud density displays an almost linear negative correlation between the shutter speed and the number of points in the concrete models. According to the data, slower shutter speeds result in improved Agisoft Photoscan performance. Meanwhile, the ISO had the greatest effect on the steel modeling quality. However, no correlation was found between the light sensitivity of the camera and the software performance.

Subplots.pdf

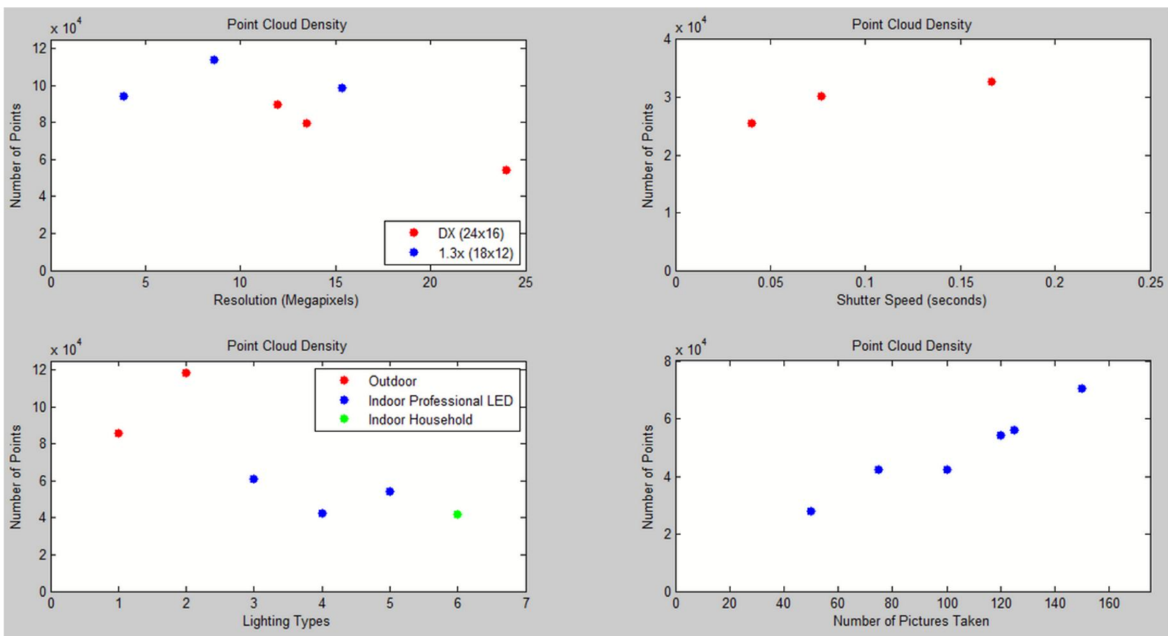


Figure 3: Concrete Model Points vs. Parameter Setting Changed

Concrete and steel models demonstrated similar trends for Agisoft Photoscan performance corresponding with the lighting types and number of photographs captured. Both materials displayed greater model qualities from pictures taken in an outdoor environment, rather than being surrounded by either professional lighting or household lighting as the primary light source. As seen in subplot three of Figure 2 and Figure 3, outdoor lighting at midday had a significant impact on the point cloud densities. Notice two different values were recorded for outdoor lighting in each scenario. The peak values in both graphs can be attributed to shutter speed. For each material, one trial was conducted utilizing a shutter speed of 1/100 seconds while the other trial used a shutter speed of 1/640 seconds. The impact of shutter speed was greatly emphasized by the comparison of these two trials. Another objective for the experiment was to determine a change in modeling behavior when different quantities of photographs were incorporated into modeling. The fourth subplots presented in Figure 2 and Figure 3 demonstrate a clear positive correlation between the number of pictures taken and the point cloud densities. With no significant changes made to the standard parameters of the trials, both materials showed overwhelming evidence of Agisoft Photoscans improved modeling performance based on the picture quantity. Interestingly, the trend also identifies that the relationship is nonlinear, so performance cannot be solely based on the utilized number of pictures.

Having discussed the influence of individual parameters on the point cloud density, it is important to understand

Subplots.pdf

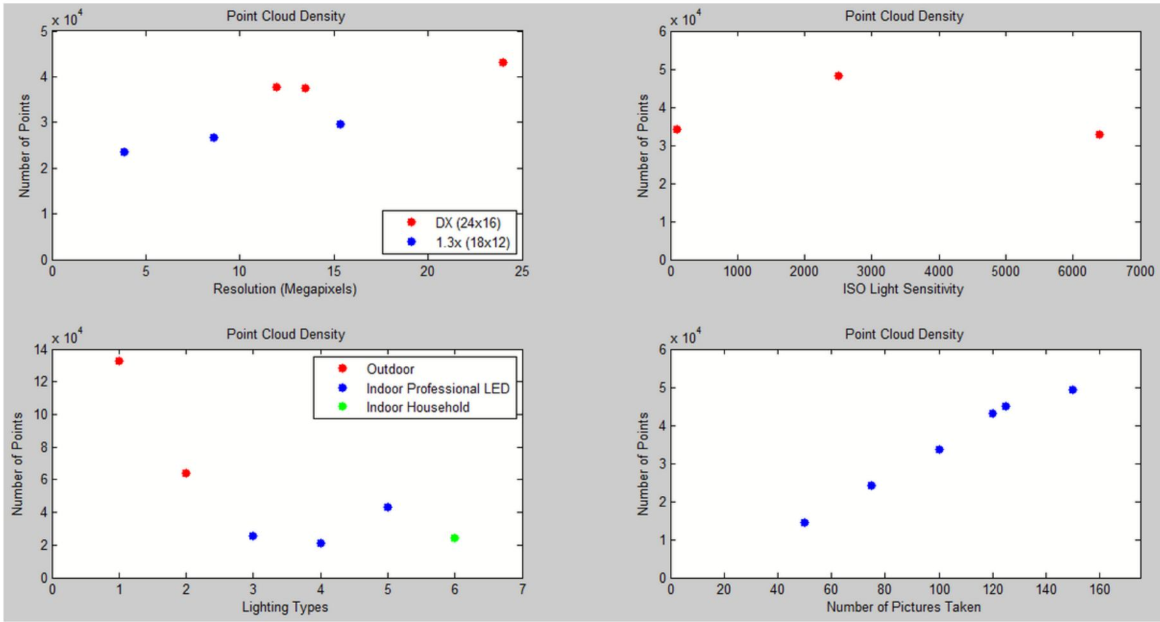


Figure 4: Steel Model Points vs. Parameter Setting Changed

the overall model statistics relating the number of points recognized by the software. Over half of the models returned between 24,000 and 44,000 points from the captured photographs to be used for modeling. However, the impact of the outdoor lighting environment heavily skewed the data average, as the point cloud density for outdoor lighting tripled the density for the professional LED lighting. The entire range of point densities used to create a 3D model was about 14,300 to 132,700 points.

The point density distribution associated with both concrete and steel models are displayed in Figure 5. The graphs relate the independent variable and its subset to the number of points recognized to create the 3D model. The number of points utilized for the model generation is portrayed on the y-axis, and the independent variable for each trial is identified by the colors as displayed in the graph legends. In addition, the subset identifier within each variable is indicated by the marker size. For example, two colors on the graphs describe image size: magenta represents DX resolution formatting, and black designates 1.3x resolution formatting. Resolution quality of the image is demonstrated by the size of the point on the graph. The 1.3x(4800x3200), or the resolution for that image size, is described by the largest marker size shown in black. The number of pictures, shutter speed, light sensitivity, and resolutions all are marked intuitively relative to their respective number values for each trial. Lighting, as it is not as intuitive, can be found in marker sizes from smallest to largest in the following order: household lighting, Professional LED Yellow, Professional LED White and Yellow Balance, Professional LED White, and Outdoors.

During early stages of the project, it was predicted that Agisoft Photoscan would not be able to align every photo for each picture set into the 3D reconstruction. Therefore, results were intended to include an analysis of software performance additionally based on the number of pictures used to create each model. After completing data collection, only one of the 4,840 pictures was not aligned correctly by the software. This one error was later determined to have been caused by poor photograph quality. An operator error, movement during photograph capture, likely instigated the misalignment and does not reflect on the performance of Agisoft Photoscan. Using photograph alignment as a parameter, Agisoft Photoscan has a high performance level and can obtain points from all photographs of good quality.

The final performance indicator for Agisoft Photoscan evaluated in this project is the distribution of the number of points used to create each model. The average number of points used to generate each model was about 51,400 points. The distribution of the number of points recognized for each trial is displayed in Figure 6. The graph demonstrates the number of points in each trial in the form of a histograph with a binomial distribution and a right data skew. Figure 6 indicates that a median of 30,000 points were used to create each 3D model. In addition, Agisoft Photoscan recognized over 40,000 points for 24 of the 42 trials. The parameters utilized for each trial are listed in Table 1. By the defined metrics, this is an acceptable performance level.

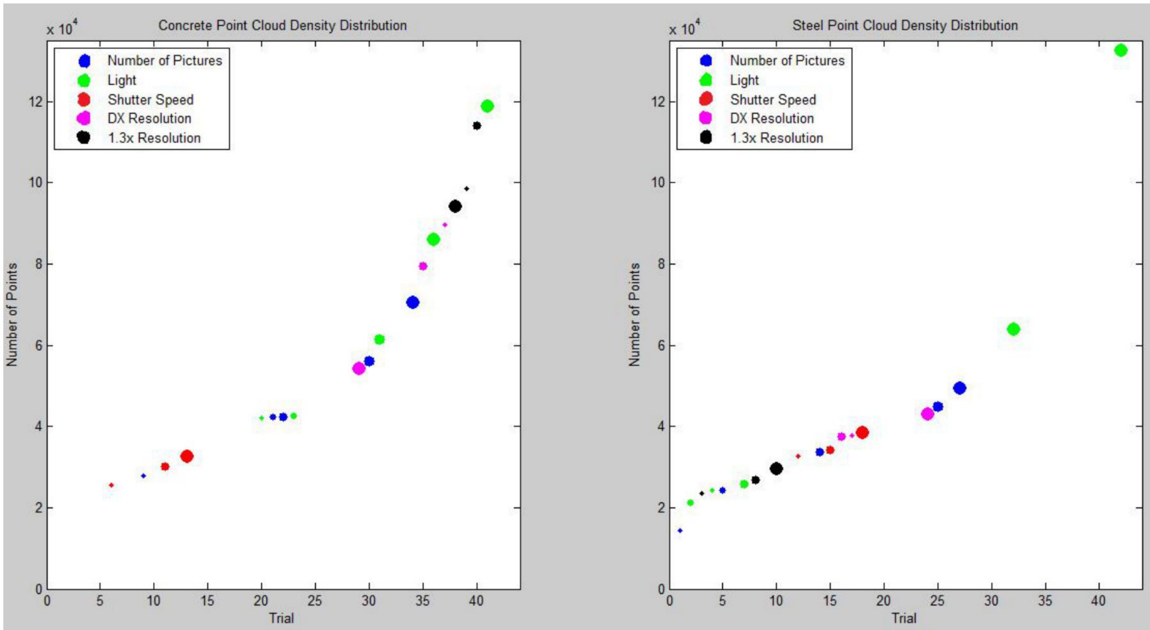


Figure 5: Point Cloud Density Distributions Relating Number of Points, Trial Independent Variable, and Variable Subset

4.2 Analyzing Dimensional Errors

Dimensional errors discovered during the experiment are a quantitative measure between a real object and its Agisoft Photoscan models. These models included both a dense point cloud and mesh cloud reconstruction of the standard parameters and settings for the concrete and steel objects. The concrete sample used during the investigation had a smooth, finished surface on one side and a rough surface on the opposite side of the piece. The incorporation of rough and smooth surfaces enhanced understanding of the software capabilities for different surface textures. The steel sample was C-shaped, which generated more shadows in the photographs, allowing for future study on the impact of shadows in 3D modeling.

Expanding on the dimensional errors with the software on concrete, the smooth and rough textures differed in software error results. As previously mentioned, the dimensional error for concrete materials was based on the difference in measured void distances. The model distances were measured on MeshLab software. The dense point cloud model for finished concrete returned void distances habitually higher than the distances recorded from the actual object. The average percentage of error between the dense point cloud and actual measured void distances was less than one percent, with an average standard deviation of 0.016 inches. On rough surface textures of concrete, the average percentage of error and average standard deviation are slightly higher at 2.47 percent and 0.024 inches, respectively. However, the rough texture model presented void distances generally smaller than the actual measured values. The reason for this difference between the surface texture modeling accuracies most likely results from the angles in the material that cannot be determined from the computer model. The points within the cloud model were not dense enough to accurately measure the dimensions from the effects of the rough surface texture. The results indicate that the dense point cloud is an accurate model for the original sample when dealing with smooth and rough surface textures of low surface reflection.

As previously mentioned, the steel and concrete materials provide an interesting comparison for the effect of surface reflection on 3D modeling. The dense point cloud model for steel resulted in greater percentages of error and standard deviations than those of the concrete dense point cloud. Average error was 7.11 percent, while standard deviation averaged 0.038 inches. In addition, the distances between the voids as measured in the dense point cloud model on MeshLab returned smaller values than the void distance measurements of the actual model. The mesh cloud dimensional error compared with the actual objects measurements were also analyzed. A majority of the distances between voids measured on the smooth side of the concrete were smaller than the actual measurements of the void distances. Similarly, all measurements for the rough surface texture of concrete in the mesh cloud were smaller than the actual void distances measured on the concrete sample. For both the dense point cloud and mesh cloud models, only one actual steel sample dimension was smaller than the computer generated model dimensions.

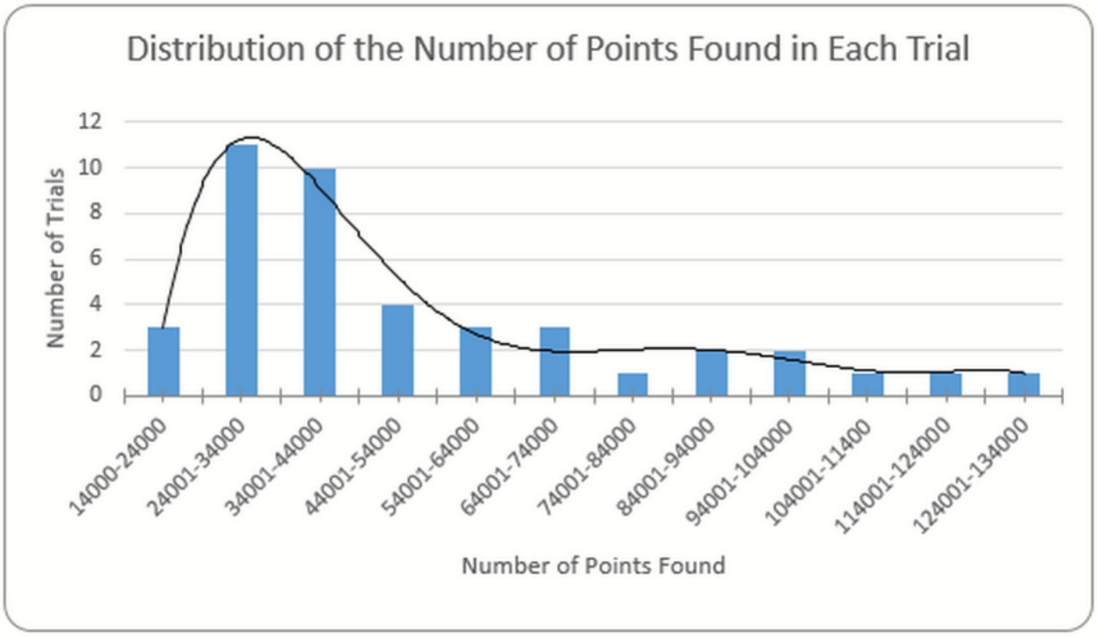


Figure 6: Concrete Point Cloud Density Determined by Parameters

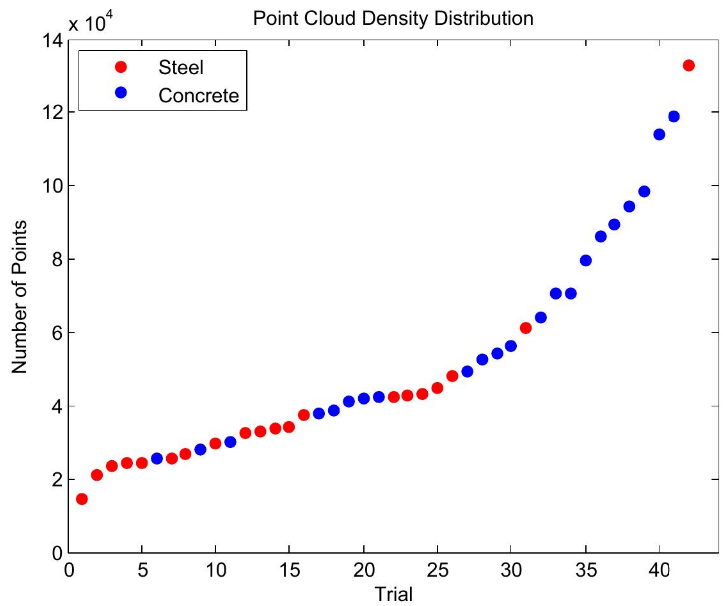
In other words, the dimensions measured based on the Agisoft Photoscan software models were smaller than the actual sample dimensions. When comparing the dense point cloud and mesh cloud measurements to each other, it was determined that the dense point cloud measurements for concrete were all greater than those for the mesh cloud. However, steel demonstrated an opposite trend the polygon mesh cloud dimension values were greater than those gathered from the dense point cloud. This was most likely due to approximations within the model because of the number of faces used to create the polygon mesh model.

In effort to demonstrate precision within the experiment, the average coefficient of variation for the finished and rough concrete dense point clouds were 1.18 percent and 1.74 percent, respectively. After outlier eliminations for the steel dimension measurements, the coefficient of variation for the dense point cloud averaged 2.37 percent. Notice that the coefficient of variation values are only representative of a single operator. Variations between operators was not measured. Equation 1 represents quantitative data percentages of error strictly for the Agisoft Photoscan software.

$$E(Agisoft) = E(calculated) - E(operator) \tag{1}$$

Where E(Agisoft) is the error attributed only to the Agisoft Photoscan software. E(calculated) indicates the percentage of error identified between the actual object measurements and either the dense point cloud model measurements or mesh cloud measurements. Meanwhile, E(operator) defines the precision of the measurements and is a reflection on the operator techniques. The operator error will vary between individuals. Based on this equation, the error which can be attributed to the Agisoft Photoscan software is displayed in Equation 1.

As seen in Figure 7, the steel models generally had smaller point densities than the concrete models. This development is likely a result of the surface reflection properties and object coloring. The steel was naturally darker in color and included shadowing due to its shape. Therefore, the material requires enhanced lighting settings, even more so than the concrete requires. Evidence for this conclusion is displayed by the peak outdoor steel point density, which is greater than the concrete peak point density determined in the outdoor lighting environment. The smooth texture of the steel causes less unique features to identified and built into the model.



Cloud Density Distribution.pdf

Figure 7: Point Cloud Density Distribution

Table 2. Agisoft Error

Model Information	Average E(calculated)	Average E(operator)	Average E(Agisoft)
Dense Point Cloud Concrete, Smooth	0.59	1.18	0.59
Dense Point Cloud Concrete, Rough	2.47	1.74	0.73
Dense Point Cloud Steel	7.11	2.37	4.74
Dense Point Cloud Average			2.02
Mesh Cloud Concrete, Smooth	1.22	0.48	0.74
Mesh Cloud Concrete, Rough	6.28	0.62	5.66
Mesh Cloud Steel	6.15	2.37	3.78
Mesh Cloud Average			3.39
Total Average			2.71

5 Conclusion

Multiple conclusions were identified during the experiment which may prove helpful in future 3D modeling. Considering the presented evidence on Agisoft Photoscan performance, it can be concluded that the software can effectively create 3D plus time reconstructions for materials of varying surface properties. For concrete materials, utilizing the dense point cloud modeling method is more accurate than and almost as precise as the mesh cloud method. The mesh cloud models are more precise, but are not as accurate as the dense point cloud figures. For steel materials, the mesh cloud model was more accurate. However, both dense point clouds and mesh clouds are within acceptable ranges of accuracy and precision. After considering all of the error data, it is concluded that the Agisoft Photoscan generated models will result in about 2.71 percent error, after accounting for operator error.

Interestingly, the decreased point densities in the steel models appeared evident when determining final Agisoft Photoscan dimensional error in Table 1. The decreased number of data points collected from the image set created a less accurate sample depiction. This resulted in greater percentages of error and higher standard deviations than those calculated for the concrete sample models.

As mentioned in the results, one outlier in the steel measurements data was removed from consideration. For reasons unknown, the c-shaped thickness dimension distorted the averages by about five percent. It is speculated that the measured value is so small that it could not be accurately determined using the scale associated with the computer measured value, especially when combined with operator errors. The error incurred relates to the accuracy of the MeshLab software, which was only determined to be skewed for this particular dimension. The dimensional error of Agisoft Photoscan is not represented in this outlying figure. Therefore, values determined for the c-shaped thickness dimension were not included with the reported statistics.

Key observations were discovered during the process of the investigation which will also be essential for modeling quality. As suggested by the parameter name and definition, the depth of field, or F-stop, should be higher when photographing larger objects. In contrast, smaller objects should have a lower depth of field. Using a high depth of field can increase the noise within the modeling image. If modeling one particular object, keep that object a specified distance from its surrounding objects, as this may also increase image noise. There must be a balance between the noise and quality, which is impacted by changing lighting parameters. Additionally, decreasing the shutter speed will increase the possibility for human error in the experiment. The camera will more easily detect movement in the frame, even while the camera is held still, and it will produce a blurry image. Another factor to consider during photogrammetry is that the shutter speed has a much greater impact on the light balance than either the depth of field or light sensitivity parameters. To maintain the balance of light between the parameters, multiple parameters often had to change correspondingly.

Based on the number of points recognized by the Agisoft Photoscan software, suggestion for setting optimal modeling parameters can be determined. For concrete, a resolution of 1.3x(3600x2400) should be used in outdoor natural sunlight during midday. Use a shutter speed around 1/100 seconds and no less than 1/20 seconds to minimize human error. Photograph quality also generally increases with a greater depth of field. Change the light sensitivity accordingly to receive a zero reading on the light balance bar. It is recommended that between 120 and 175 images are captured to receive sufficient data for modeling but prevent excessive noise. For steel, the optimal camera parameters will include natural sunlight outdoors during midday at a resolution of DX (6000x4000). Increase the depth of field, use a shutter speed around 1/100 seconds and no less than 1/20 seconds, and adjust the light sensitivity once again until the light balance bar reads zero.

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7 References

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