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Digital Photogrammetry Software Comparison for Rock Mass Characterization

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ABSTRACT: Photogrammetric data collection and analysis techniques are increasingly being used for geotechnical characterization of rock masses, and rock slopes, in particular. There is a growing selection of software packages that can create georeferenced digital 3D models from a photoset and control points. Although each software package is able to create the desired point clouds, different techniques are used to produce them. For a geotechnical investigation, it is important to understand the accuracy of the software being used in order to have confidence in the reliability of the digital 3D models that are created.

In a study similar to one conducted in conjunction with the GoldenRocks ARMA conference in 2006 (and described in Tonon and Kottenstette, 2006), a rock outcrop was selected to be the location for a digital photogrammetry model comparison. Two sets of control points were surveyed on the rock outcrop; one set was provided for the creation of each model, and one set was used to evaluate the accuracy of the model by measuring the difference in the location of the point in the model and in the survey data. An unmanned aerial vehicle (UAV) was used to collect video footage of the site. A set of still frames were extracted from the video that contain overlapping images of the rock outcrop. The set of image files was used to create models with the following photogrammetry software packages: Bentley ContextCapture, Agisoft PhotoScan, and Pix4Dmapper. The accuracy of each of the software packages was compared by quantifying the error in the control points and check points between the model and the field survey. As this comparison is intended to provide guidance for selecting software tools to aid in rock mass characterization, other features were evaluated as well, including user-friendliness. Understanding the accuracy of digital photogrammetry software is critical for justifying the use of such models in a geotechnical investigation. The advantages of these models are numerous but of little value if the data provided by the models do not adequately represent the field conditions.

Bentley ContextCapture was found to have the least error in the control points and Pix4Dmapper was found to have the least error in the check points. The Bentley ContextCapture model also had the highest resolution, closely followed by the Pix4Dmapper model. Based on these qualities and several others including the general usability, Bentley ContextCapture creates the most effective models for potential geotechnical investigations.

1. INTRODUCTION

Utilizing photogrammetric techniques for geotechnical investigations is becoming increasingly common because of the many benefits when compared to more traditional analytical techniques. There are many software packages available on the market that can build georeferenced digital 3D models from a photoset and control points. Each software package is capable of creating a point cloud and mesh; however, the varying techniques used by each software package introduce different sources of error and distortion. When building a point cloud for a geotechnical investigation, it is important to understand the accuracy of the software being used in order to have confidence in the reliability of the digital 3D models that are created.

To compare the accuracy of different photogrammetry software packages, an investigation was conducted similar to one described by Tonon and Kottenstette, 2006, that was conducted in conjunction with the GoldenRocks ARMA conference in 2006. An outcrop was selected on public land along the Burma Road, southeast of Glen, Montana in Madison County. Figure 1 is a map showing the location of the study area. Because of its proximity to the Notchbottom fishing access site, the outcrop is referred to as the "Notchbottom outcrop." The outcrop is approximately 50 feet tall and 200 feet wide and composed of Permian to Mississippian-aged Quartzite (U.S. Geological Survey, 1993). The overlapping joint sets create a blocky rock mass that presents the relief and texture typically preferred for building a successful digital photogrammetry model. The outcrop has adequate 3-dimensional variation to provide an appropriate test site for comparing the different photogrammetry software packages.

A set of nine control points was surveyed on the rock outcrop. Five of these points were used as control points for the creation and georeferencing of the model, and

four of these points were used as checkpoints to verify and evaluate the accuracy of the model once it was created. A DJI Phantom 4 Pro UAV was used to collect aerial video footage of the site. A set of overlapping photos was extracted from the footage and was used to create models with the following photogrammetry software packages: Bentley ContextCapture, Agisoft PhotoScan, and Pix4Dmapper. The error in each model was quantified by calculating the difference in the X, Y, and Z coordinates of each checkpoint relative to the survey data and the model. The results presented in this paper are considered preliminary, as the models have yet to be fine-tuned and further analysis is planned.
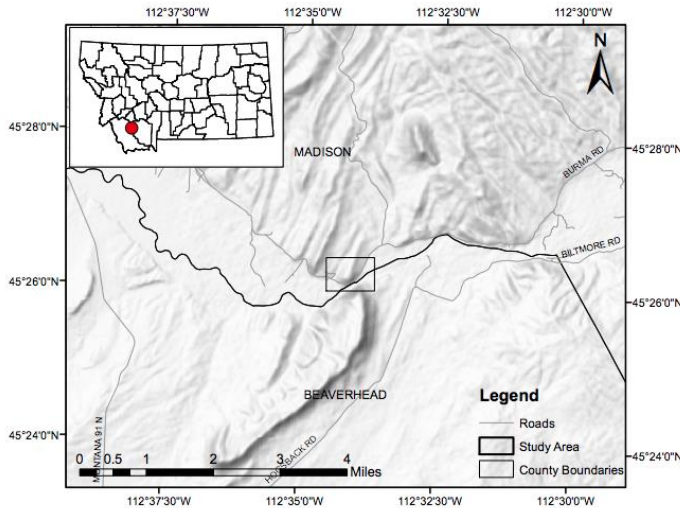

Fig. 1. Location map of the study area located along the Burma Road, southeast of Glen, Montana (produced using ArcGIS)

This software comparison was completed by a user with reasonable skill and understanding of digital photogrammetry modeling, offering a quality of work that is repeatable by anyone familiar with photogrammetry techniques. As this comparison is intended to provide guidance for selecting software tools to aid in geotechnical investigations and rock mass characterization, other features were also evaluated, including ease of use.

2. BACKGROUND

Modern photogrammetry uses a pair or set of overlapping photos taken from different positions to create a three-dimensional digital model of a subject that can be used for further examination and analysis. An advantage of these digital models is that the information can be archived for further investigation and can be used to review the conditions at a site at a specific period of time. Unmanned aerial vehicles (UAVs) have become a simple and accessible way to collect photosets that meet the requirements for building an accurate georeferenced digital 3D model. Combining the use of UAVs with digital photogrammetry allows for easier data collection

in inaccessible sites. For these reasons, photogrammetry is becoming a tool frequently used for geotechnical investigations.

Historically, photogrammetry was created using small sets of photos from optimized camera positions. Aerial photography was collected from airplanes and only large-scale maps were created from the data (Matthews, 2008). With recent technological advances, the method for using photogrammetry has changed to taking larger sets of images from many, not necessarily optimized, positions. UAVs are increasingly being used for imagery collection because of the accessibility of the equipment. This technology can be used by almost anyone because of the decreased cost and processing time for these projects.

Each photogrammetry software package uses different algorithms to create the 3D digital models. It is beyond the scope of this paper to include a description of the differences in these calculations and underlying theory, and many methods are proprietary. The intent of this study is rather to perform a comparison of the software packages by quantifying the error in the 3D digital models, using one study location with conditions typical for a geotechnical investigation.

3. DATA COLLECTION

Nine survey points were marked along the base of the Burma Road outcrop with small targets and spray paint. A Leica TS 11 was used to resection the featured points and determine the locations with respect to two established benchmarks. The resection method was chosen due to the Leica's ability to calculate its own position by measuring the angles between known benchmarks. After the resection was complete, the nine points were surveyed using the TS 11. The benchmark data and the survey data were combined to assign relative coordinates to the survey points.

A DJI Phantom 4 Pro UAV was used to collect video during flight of the outcrop. The UAV was manually flown in horizontal strips perpendicular to and approximately 30-45 feet from the outcrop. Once it reached an end of the region to be imaged, its vertical position was adjusted so the next strip would overlap approximately 50% with the previous strip. The UAV was then flown horizontally back to the opposite end of the outcrop and the process was repeated. The flight lasted approximately 20 minutes and resulted in video footage of the same length. The nine survey points were captured in this imagery.

Two site visits were made to the Notchbottom outcrop site on February 15, 2018 and March 1, 2018. Each visit lasted approximately 4-5 hours and consisted of surveying, manual geotechnical measurements, and UAV flights to collect imagery of the outcrop.

The video footage collected during this flight was then used to extract a photoset that could be used to construct the models. The photos were extracted from the video footage using Bentley ContextCapture and saved as .jpeg files, so the same photoset could be used to build a model in all three software packages. Photos were extracted from the video approximately every 2 seconds for a total of 236 photos. This process took less than half an hour to complete, and only required the video file as an input. Some photos were removed from the selection because they were taken before the flight, after the flight, or during periods when the flight was paused and the UAV remained in one position for an extended period of time. No other visual editing was applied to the photos.

4. SOFTWARE COMPARISON: 3D MODEL CONSTRUCTION

For this investigation, three digital photogrammetry software packages were tested and analyzed: Bentley ContextCapture, Agisoft PhotoScan, and Pix4dmapper. These software packages were selected for this comparison because they are leading in the field of UAV-based digital photogrammetry modeling for geotechnical investigations.

In each software package, the same photoset of 236 photos was used to create a point cloud and mesh of the outcrop. The control points were marked and were assigned the coordinates that were measured from the field survey. These points were used in the construction and georeferencing of the model. The check points were marked on the photos so that the coordinates could be measured after the construction of the model. Each model was constructed on the same computer and under the same computing conditions. The locations of the control points and check points are shown in Fig. 2.
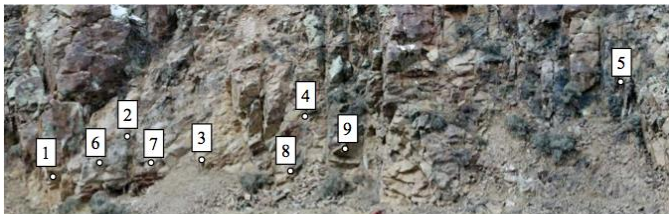

Fig. 2. Control points and check points marked on the Notchbottom outcrop. For scale, the approximate horizontal distance shown in the image is 150 feet.

4.1. Bentley ContextCapture

The first software examined was Bentley ContextCapture (https://www.bentley.com/en/products/brands/contextcapture). The workflow for ContextCapture is generalized as follows. First, import all photos that will be used in the project. Define the sensor size and focal length of the camera used to collect the photos. Next, tag the control points and check points in the photos and enter the coordinates of the points. The

check points are not used to georeference the model but rather are used to verify the accuracy of the model. Next, complete the Aerotriangulation and New Reconstruction. The New Reconstruction allows for Adaptive Tiling, which creates tiles to process individually to preserve RAM space. Finally, run a New Production to create a 3D mesh model. The workflow is clearly laid out, and the software guides the user step-by-step through the process.

Using this method, a 3D digital model (Fig. 3.A.) was created to compare the coordinates of the control points and the check points. It took approximately 8 hours to construct the model from the photoset.

ContextCapture has flexibility with the initial construction of the model. Where photos are not available to import into the software, a video file can be used to extract photos at a defined time interval. These photos are output as .jpeg files, and can be used in other future projects. In addition, a mesh can be created with or without control points, as needed. Georeferencing is required for accurate measurements and coordinates, however the model can still be created without these points. There is not a camera self-calibration in ContextCapture, so the sensor size and focal length of the camera have to be obtained and entered manually. However, these two pieces of information are all that are required for this process.

Included with ContextCapture is the Acute3D Viewer that allows the models to be viewed on any computer. The viewer can be downloaded for free and is an easy and straightforward way to allow someone to view the model that does not have the full software.

4.2. Pix4Dmapper

The second software examined was Pix4Dmapper (https://pix4d.com/product/pix4dmapper-photogrammetry-software/). The workflow for Pix4Dmapper is summarized as follows. First, import all photos that will be used in the project. Tag the control points and check points in the photos and enter the coordinates of the points. Define the coordinate system used for the project. Next, run the Initial Processing step. This will generate a Quality Report with a summary of the number of photos that will be used, the number of tie points matched, the initial error measurements, and more. Next, run the Point Cloud and Mesh step to create the model. Lastly, run the optional DSM, Orthomosaic and Index step if desired.

This workflow was used to build a 3D digital model (Fig. 3.B.) to compare the coordinates of the control points and the check points in the model and in the survey. This model was constructed in approximately 3 hours.

Similarly to the other software packages, Px4Dmapper can build a mesh with or without control points. If control points are provided, the georeferencing of the model allows for accurate measurements and coordinates. Check points can also be tagged in the model so that the model coordinates can be measured, but the survey coordinates are not used in the construction of the model. Pix4Dmapper also has the ability to extract photos from a video file, similarly to Bentley ContextCapture. Pix4Dmapper performs a camera self-calibration, so it is not necessary to enter any information about the camera used to collect the photos for the model.

4.3. Agisoft PhotoScan

The third software examined was Agisoft PhotoScan (http://www.agisoft.com/). The general workflow for Agisoft PhotoScan is as follows. First, import all photos that will be used in the project. Confirm the parameters of the camera that are automatically detected in the camera calibration. Next, run the Align Photos step to estimate the position of the cameras and build a sparse point cloud. Tag the control points and check points as markers in the photos and enter the coordinates of the markers. The check points are not used to georeference the model but rather are used to verify the accuracy of the model. Set the bounding box of the model. Finally, build the dense point cloud and build the mesh. If desired, build a texture, DEM, or orthomosaic.

Using the method described above, a 3D digital model (Fig. 3.C.) was constructed to compare the coordinates of the control points and the check points in the model and in the survey. Agisoft PhotoScan allows a mesh to be constructed with or without control points. If control points are added, the georeferenced model provides accurate measurements and coordinates.

Agisoft PhotoScan was much more computationally intensive than the other two software packages evaluated. The models took much longer to build for correspondingly intensive steps, running for over 20 hours.

Agisoft PhotoScan can be purchased as a stand-alone license, a floating license, or an educational license. These licenses can be purchased as the Standard Edition or the Professional Edition. The Professional Edition comes with the full set of features, and the Standard Edition has a limited subset of these features.

5. SOFTWARE COMPARISON: 3D POINT ACCURACY

The error in the X, Y, and Z coordinates was calculated for each of the point IDs specified in the model, relative to the survey data. Also evaluated is the 3-dimensional distance between the position of each point in the model relative to its true location based on the survey coordinates. The error distance is calculated by taking the square root of the sum of the squares of the coordinate error values. Table 1 shows the error values for Bentley ContextCapture, Agisoft PhotoScan, and Pix4Dmapper, respectively.

6. SOFTWARE COMPARISON: ANALYSIS

Each of the three software packages was used to generate a point cloud and a mesh from the photos of the outcrop. These models are shown in Fig. 3, and a close-up view of one portion of the outcrop is shown in Fig. 4. As shown in Fig. 3, each of the software packages created complete, clear models of the outcrop. There are slight color variations between the different models, but they are fairly true to the imagery of the outcrop. There are also some holes in the models where the UAV imagery did not capture all angles of a feature, however these holes are minimal and do not greatly impact the usability of the model.

There is greater variation in the models when examining them at a closer scale. As shown in Fig. 4., all models are of a high enough quality that they can be used for further analysis. However, the mesh generated of the outcrop in Bentley ContextCapture has the highest resolution. The model retains a great amount of detail even when viewed closely and the features keep the true shape and color. The Pix4Dmapper model has a moderate resolution; the features retain the true shape and color, however some of the detail is lost. The Agisoft PhotoScan model loses much of the detail of the rock when it is examined closely. This limits the usability of the model for further investigation.

There is the smallest error in the control points for Bentley ContextCapture, however there is the smallest error in the check points for Pix4Dmapper. The distance between the survey point and model point, maximum error, and minimum error for the control points and the check points is provided in Table 2. There is an average distance of 0.0089 feet from the survey point to the model point for the control points in Bentley ContextCapture. This is an order of magnitude less than the error in the model with next highest average distance, Pix4D. There is an average distance of 0.0506 feet from the survey point to the model point for the check points in Pix4Dmapper.

Because the control points are used to construct and georeference the model, it would be expected that there is less error in the control points than the check points. This is true for each of the software packages except for Agisoft PhotoScan. There is an average distance of 0.1056 feet in the control points and an average distance of 0.0703 feet in the check points.

Fig. 3. View of model mesh of outcrop in Bentley ContextCapture (A), Pix4Dmapper (B), and Agisoft PhotoScan (C)

Table 1. Error of Control and Check Points Compared to Field Survey Calculated using Bentley ContextCapture (top), Agisoft PhotoScan (middle) and Pix4Dmapper (bottom).

Bentley Context Capture	Point ID	Error X (feet)	Error Y (feet)	Error Z (feet)	3D Error Distance (feet)
Control Points	1	0.002	0.001	0.006	0.0064
	2	0.006	0.003	0.004	0.0078
	3	0.013	0.008	0.007	0.0168
	4	0.003	0.005	0.007	0.0091
	5	0.002	0.001	0.004	0.0046
	Avg				0.0089
Check Points	6	0.01	0.098	0.036	0.1049
	7	0.035	0.131	0.01	0.1360
	8	0.076	0.039	0.069	0.1098
	9	0.033	0.133	0.004	0.1371
	Avg				0.1219
Agisoft Photo Scan	Point ID	Error X (feet)	Error Y (feet)	Error Z (feet)	3D Error Distance (feet)
Control Points	1	0.054	0.011	0.025	0.0605
	2	0.022	0.043	0.17	0.1767
	3	0.03	0.01	0.018	0.0364
	4	0.003	0.051	0.186	0.1929
	5	0.005	0.013	0.06	0.0616
	Avg				0.1056
Check Points	6	0.006	0.002	0.029	0.0297
	7	0.026	0.017	0	0.0311
	8	0.077	0.063	0.081	0.1283
	9	0.031	0.022	0.084	0.0922
	Avg				0.0703
Pix4D Mapper	Point ID	Error X (feet)	Error Y (feet)	Error Z (feet)	3D Error Distance (feet)
Control Points	1	0.024	0.021	0.009	0.0331
	2	0	0.001	0.01	0.0100
	3	0.025	0.021	0.004	0.0329
	4	0.009	0.006	0.004	0.0115
	5	0.011	0.011	0	0.0156
	Avg				0.0206
Check Points	6	0.009	0.011	0.044	0.0462
	7	0.028	0.025	0.009	0.0386
	8	0.074	0.012	0.063	0.0979
	9	0.016	0.001	0.011	0.0194
	Avg				0.0506

Table 2: Average, Maximum, and Minimum Error

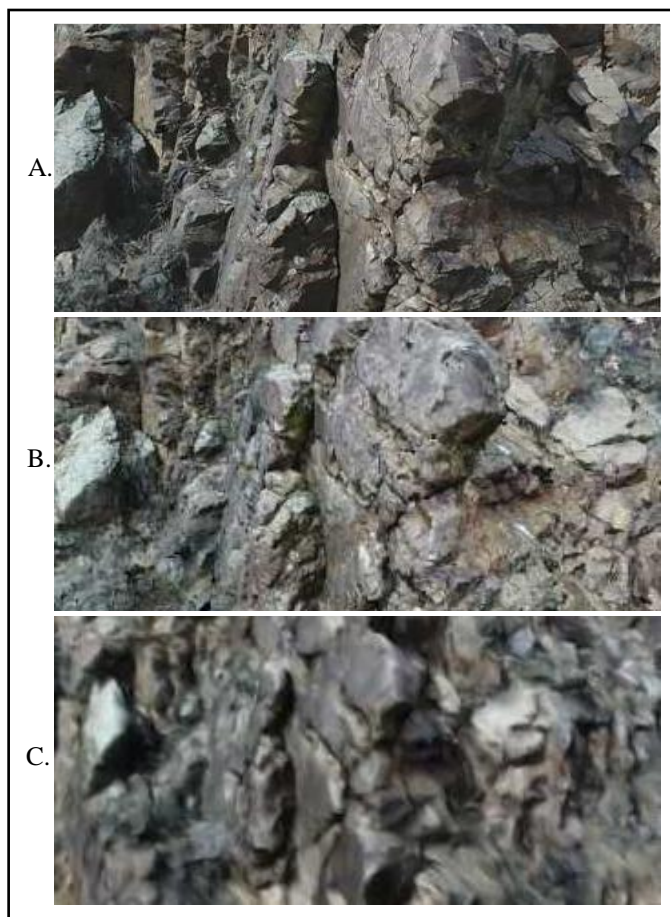|	Software	3D Distance (feet)	Max. Error (feet)	Min. Error (feet)
Control Points	Bentley CC	0.0089	0.0130	0.0010
	Pix4D	0.0206	0.0250	0.0000
	Agisoft	0.1056	0.1860	0.0030
Check Points	Bentley CC	0.1219	0.1330	0.0040
	Pix4D	0.0506	0.0740	0.0010
	Agisoft	0.0703	0.0840	0.0000

Fig. 4. Close-up view of model mesh of outcrop in Bentley ContextCapture (A), Pix4Dmapper (B), and Agisoft PhotoScan (C)

The Bentley ContextCapture model took approximately the same amount of time to build as the Pix4Dmapper model; however, the Agisoft PhotoScan model took significantly longer than the other software packages. All models were run on the same computer one at a time in similar conditions. Model runtimes were limited by the operating power of that computer, but all models would have been affected similarly.

7. CONCLUSIONS AND FUTURE WORK

Bentley ContextCapture, Pix4Dmapper, and Agisoft PhotoScan were used in this investigation to create digital 3D photogrammetric models of an outcrop along Burma Road, southeast of Glen, Montana. A survey was completed to measure the coordinates of nine points along the outcrop. The coordinates for five of these points were input into the model as control points to georeference the model. Four of these points were used as check points to verify the coordinates of the points in the model to the coordinates of the survey.

From this investigation, Bentley ContextCapture has the least error in the control points and Pix4Dmapper has the least error in the check points. The Bentley ContextCapture model also had the highest resolution,

closely followed by the Pix4Dmapper model. Based on these qualities and several others including the general usability, Bentley ContextCapture creates the most effective models for potential geotechnical investigations.

This investigation examined the accuracy of three photogrammetry software packages currently available for building accurate 3D digital models from UAV-based imagery. The results found from this investigation are considered preliminary, as the models have yet to be fine-tuned and further analysis is planned incorporating a larger number of surveyed points in a wider variety of locations. In addition to accuracy of position of points within the model, discontinuity measurements provided by the models will be compared to those measured during a field investigation. Additional photogrammetry software packages will also be evaluated in future investigations. This investigation is part of a larger study to evaluate available UAV-based imagery and software for rock mass characterization. The accuracy and reliability of these tools is instrumental if they are to be used for professional geotechnical investigations.

REFERENCES

Matthews, N.A. 2008. Aerial and Close-Range Photogrammetric Technology: Providing Resource Documentation, Interpretation, and Preservation. Technical Note 428. U.S. Department of the Interior, Bureau of Land Management, National Operations Center, Denver, Colorado. 42 pp.

Tonon, F., J.T. Kottenstette. 2006. *Laser and Photogrammetric Methods for Rock Face Characterization*. American Rock Mechanics Association.5-12.

United States Geological Survey, 1993. Geologic map of the Dillon 1 degree x 2 degrees quadrangle, Idaho and Montana. Map. Miscellaneous Investigations Series Map I-1803-H. Reston, Va: U.S. Department of the Interior.