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GIGAPAN® PHOTOGRAMMETRY FOR OUTCROP DESCRIPTION, 3D MODELING, AND 3D PRINTING

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ABSTRACT

The collection of 3D information on geological media is fundamental for field geology, however it can be both time consuming and expensive. This report proposes a new method for the collection of 3D information of outcrops using simple to use and inexpensive technology. GigaPan® systems can be used to take high resolution images of outcrops and these images then be either left in 2D for additional description of the outcrop in the lab, or they can be processed in Autodesk 3ds Max® to create realistic 3D models of the outcrops which can then be 3D printed. The collection of this data can allow for maximization of field time and may allow for additional analysis and descriptions in the lab. The ability to visit or revisit an outcrop without physically going there has implications for facilitating collaborative research projects and improving the learning outcomes of students.

KEY WORDS: GigaPan®, Photogrammetry, 3D modeling, 3D printing, Autodesk 3ds Max®

INTRODUCTION

Collecting detailed 3D data from geologic outcrops has been done since the advent of surveying methods and is

one of the most fundamental skills in field geology. This data collection is typically completed using one of the two main data collection techniques: 1)

direct topographic surveying techniques or, 2) remote digital surveying techniques. These methods all have their relative strengths and weaknesses in terms of field time requirements, computer processing requirements, accuracy and precision, and cost (Carrivick, et al., 2016). The products of these different surveying techniques may ultimately be used to create 3D models of landforms or landscapes which then could potentially be 3D printed.

There remains an unexplored field of outcrop scale 3D modeling using GigaPan® photogrammetry and Autodesk 3ds Max® 3D modeling in conjunction with 3D printing to help bring the outcrop back to the lab setting for additional analysis which can be tied to traditional geologic methods; this paper seeks to address this current gap.

BACKGROUND

Direct Topographic Surveying Techniques

Direct topographic surveying techniques require the researcher to be in the field and physically measure features (Carrivick, et al., 2016; Hodgetts, et al., 2004). The two most

common direct topographic surveying techniques require the use of 1) total stations, or 2) differential geographic positioning system (dGPS). Total stations are most effective if the mapping is taking place in a relatively restricted area and doesn't require a large number of points (Carrivick, et al., 2016; Hodgetts, et al., 2004). The advantage of using a total station is its high precision, however it is a costly instrument (Carrivick, et al., 2016; Hodgetts, et al., 2004).

Differential GPS requires the researcher to visit the area of interest and traverse it using a GPS receiver. Using dGPS can be highly precise and accurate and the data generated from this method can be easily added to a geographic information system (GIS) for additional analysis (Carrivick, et al., 2016; Hodgetts, et al., 2004). This technique can be time intensive and dependent on the quality of the satellite signal and precise GPS's, which can have high costs (Carrivick, et al., 2016).

Remote Digital Surveying Techniques

Remote digital surveying techniques allow for denser data

collection quicker than direct surveying techniques and may be done remotely or in the field (Carrivick, et al., 2016). The three most common methods of remote digital survey techniques are 1) photogrammetry, 2) laser scanning, and 3) structure from motion (SfM) (Carrivick, et al., 2016; Cawood, et al., 2017; Fazalli, et al., 2012; Marques, et al., 2020; Remondino and El-Hakim, 2006; Smith, et al., 2016). Traditional photogrammetry has been used since the advent of cameras (Carrivick, et al., 2016). Photogrammetry requires the overlap of two-dimensional images all taken from a fixed location with an ideally metric camera which can allow for the construction of a three-dimensional feature; this technique can be done using airborne or terrestrially based cameras (Bemis, et al., 2014; Carrivick, et al., 2016; Fabuel-Perez, et al., 2010; Tavani, et al., 2014). Photogrammetry is applicable at nearly all scales, from the micro to the macro scale (Carrivick, et al., 2016; Eultiz and Reiss, 2015; Grün, et al., 2004).

Laser scanning can be conducted through both airborne and terrestrially based methods for geologic inventories (Bellian, et al., 2005; Bucklet, et al., 2008; Carrivick, et al., 2016; Hodgetts,

2013; Telling, et al., 2017). Laser scanning can be highly accurate and precise if the GPS connected to it is also accurate and precise (Carrivick, et al., 2016; Rarity, et al., 2014; Telling, et al., 2017). Laser scanning has the advantage over other remote digital survey techniques that it can penetrate through vegetation to get to the true earth surface and can cover a large area (Biber, et al., 2018; Buckley, et al., 2008; Carrivick, et al., 2016; Fabuel-Perez, et al., 2010; Telling, et al., 2017;). However, laser scanning techniques are cost prohibitive and require specialized equipment (Bellian, et al., 2005; Carrivick, et al., 2016).

Structure from motion is a special type of photogrammetry that removes the limitations of general photogrammetry and reduces the cost. SfM stitches two-dimensional images together, but does not depend on a metric camera nor does it depend on knowing the precise location of the camera (Carrivick, et al., 2016; Westoby, et al., 2012). SfM requires the movement of a camera around the object of interest with overlapping images with known scale markers in the image, from this, algorithms can be used to render a scaled three-

dimensional object (Bistacchi, et al., 2015; Carrivick, et al., 2016; Pitts, et al., 2017; Westoby, et al., 2012). SfM can be done both using airborne and terrestrial methods (Carbonneau and Dietrich, 2017; Caravca, et al., 2020; Carrivick, et al., 2016; Chelsey, et al., 2017; Dering, et al., 2019; Madjid, et al., 2018; Westoby, et al., 2012). SfM is a cost-effective method of remote digital surveying techniques that yields fast, accurate and precise models that can be applied from the micro to macro scales (Caravca, 2020; Carrivick, et al., 2016; Dumitru, et al., 2021; Verma and Bourke, 2019; Westoby, et al., 2012).

GigaPan® Technology

A tool that has been used in the photogrammetry of geologic outcrops is the GigaPan® technology but its full potential hasn't been explored yet (Biber, et al., 2018; Hana, et al., 2019; Lee, et al., 2019; Longson, et al., 2010; Piatek, et al., 2012; Shoen and Stevenson, 2010). GigaPan® is a robotic camera mount system on a tripod that generates high resolution panoramic photos that can cover a large area (Figure 1). This is accomplished by automating the

process of taking many photographs (ten's to thousand's) over a relatively short period of time and stitching them together using the GigaPan® Stitch software. More information about the GigaPan® technology and software can be found at www.gigapan.com (last accessed 8/30/2021).



Figure 1. Image of GigaPan® system in use at Scott Quarry. A digital camera is mounted inside the GigaPan® motorized mount, which itself is attached to an aluminum tripod.

Autodesk 3ds Max® Software

Autodesk 3ds Max® is one of the leading software's used in developing 3D models. This software is free to students and educators and not computer resource intensive which makes it attractive as a tool to use to create models of rocks and outcrops. More information about the Autodesk 3ds Max® software can be found at <https://www.autodesk.com/products/3ds-max/overview> (last accessed 8/30/2021).

3D Printing from Photogrammetry and SfM

Additive printing of 3D models from photogrammetry and SfM has been explored before for archeological materials which have been used primarily for educational and preservation purposes (Balletti, et al., 2017; Bonora, et al., 2021; Howland, et al., 2014). The medical field has also used 3D printing of 3D models from SfM and photogrammetry for both education purposes and prosthetics (Erolin, 2019; Haleem and Javaid, 2019; Ismail, et al., 2020; Petriceks, et al., 2018; Shafiee and Atala, 2016; Turchini, et al., 2018).

Additive printing of 3D models in geology from SfM has not been greatly explored at the outcrop scale. 3D printing in geology has mostly been used for educational purposes using a mixture of photogrammetry and SfM techniques (Hasiuk, 2014; Horowitz and Schultz, 2014; Ishutoz, et al., 2018; Squelch, 2017). It has also been used for modeling rocks for deformation and porosity studies using photogrammetry, SfM, and computed tomographic (CT) techniques (Betlem, et al., 2020; Bishwal, 2019; Ishutov, et al., 2015; Ishutov, et al., 2018; Kong, et al., 2018; Peterson and Krippner, 2019; Xia, et al., 2020).

Field Location and Geologic History

The field study area is within the Hiawatha National Forest in Michigan's Upper Peninsula. This region is primarily underlain by early Silurian dolostones (Engadine and Manistique Groups) which form the Niagara Escarpment in the area (Ehlers, 1973; Sumrall and Larson, 2020).

The first field location used in this study is Scott Quarry, which is a 22m near vertical exposure of the upper Cordell Formation (Manistique Group) and the lower Rockview

Formation (Engadine Group) (Figure 2). The quarry is located approximately 1.5 km south of the community of Dick, MI (Chippewa County) at 0665150m E, 5115470m N, zone 16T. In the quarry the lower section is the Cordell Formation, a chert rich dolostone which contains significant corals, stromatoporoids, brachiopods, crinoids, and minor amounts of bryozoans (Ehlers, 1973; Sumrall and Larson, 2020; Gammer, et al., 2018). The upper part of the quarry is the Rockview Formation, which in the quarry is chert poor and has significant microbiolite laminations (Ehlers, 1973; Sumrall and Larson, 2020; Gammer, et al., 2018). This location was chosen due to it being in a large open space, making it a good case study location to test and use the GigaPan® system to take panoramic images.

The second field location used in this study is a suspected knoll reef (Figure 3) from the McKay Bay Member

of the Bush Bay Formation (Engadine Group) and is located approximately 1.5 km north of the community of Pontchartrain Shores, MI (Mackinac County) at 0686550m E, 5101700m N, zone 16T. The McKay Bay Member is a generally white dolostone which is chert-free and contains numerous fossils and a relatively high porosity (Sumrall and Larson, 2020; Leesburg, et al., 2018). Knoll reefs immediately east of this study area have been described (Johnson, et al., 1979) and this possible knoll reef and its paleontology and petrography has received a preliminary description and was found to contain numerous reef binders (stromatoporoids and stromatolites) and reef builders (mollusks, crinoids, and tabulate coral) (Pearson, et al., 2019). This site was selected due to it providing a relatively small and discrete rock body to test the methods proposed in this paper on.



Figure 2. A photograph of Scott Quarry taken from the lip of the quarry on its west side, looking towards the south-east.



Figure 3. The suspected knoll reef used in this study for 3D modeling and 3D printing.

MATERIALS AND METHODS

GigaPan® Setup

To collect images, a GigaPan® Epic Pro mount with a Canon® 7T camera was used. A Canon 50mm F1.4 lens was used for its ability to operate in poorly lit sites. The GigaPan® and camera were mounted on an aluminum survey tripod with a flat head (Figure 1).

In operation the GigaPan® system breaks up each panorama captured into columns and rows. The columns and rows are defined when calibrating the image boundaries during panoramic setup. Noting row and column numbers for each panorama attempt is extremely important to correctly arrange the photos manually in the GigaPan® Stitch software. Each image was captured in JPEG and CR2 formats. CR2 files are based on the TIFF specification which collects significantly more data per image, which is useful in postediting.

During panorama calibration, multiple test shots with different shutter speeds were taken to find the correct light intake. The camera's light temperature (k) and ISO was manually adjusted for each panorama to best

match the white balance to the outside light at the time and to keep each image consistent for the stitching process. The GigaPan® Stitch software allows for the increase or decrease the number of rows. The images are manually arranged into rows and columns based on the specifications of the panorama boundaries when the image was taken. Once the image is stitched, it is automatically saved as a low-compression TIFF file.

The Scott Quarry panorama was created by stitching 182 images divided into seven rows and twenty-six columns from a central point in the quarry. No additional processing was completed with the Scott Quarry panorama.

The knoll reef was measured using tape measures and meter sticks to ensure the exact size of the outcrop was maintained in the 3D modeling and printing. After measuring the knoll reef, it was photographed by the GigaPan® system from 4 sides to allow for the development of a 3D model. Each side was made of 60 images which were individually stitched together using the GigaPan® Stitching software. The top of the knoll reef was not photographed for this project as there was not a way

to mount to the GigaPan® system over the feature. The different sides of the knoll reef were then additionally processed as described below.

Data Processing and 3D Modeling

While Photoshop® was not used for the panorama stitching process, it was used for editing. Brightness and curve adjustments were used to clean up dim lights and correct the photos hue. The shake reduction filter automatically adjusted blurs with the smart detect and the spot heal tool was used to brush over anything the shake reduction might have missed. The edited panoramas were then converted to a JPEG from their original TIFF format in Photoshop® to lower the risk of crashing within Autodesk 3ds Max®. These JPEG images would later be converted into texture files and placed onto planes in order to accurately model the knoll reefs.

Autodesk 3ds Max® was used because it is a leading program in the 3D modeling / animation industry and it is free to students and educators, it is also not resource intensive on a personal computer. Autodesk 3ds Max®'s create object tool allows users to draw a wide variety of 3D geometric

shapes, lights, and motion controls. A generic cube was initially used as a foundation to work with because of its easy manipulation, and has a large surface area. The GigaPan® panoramas were converted to a texture and placed in this 3D space based on the direction they faced.

An edit poly modifier was the main modifier to manipulate and distort the cube into the reef shape. This was done by adding and manipulating vertices around the object. Lowering the distance between these vertices 0" by 0" will crash Autodesk 3ds Max®, making frequent saves required. Measurements of the outcrop were taken on site which was used to reconstruct the reef structure with Autodesk 3ds Max®. The push / pull paint deformation modifier was the last big modifier to cut down on sharp edges and smooth out rigid areas. Finally, the turbosmooth modifier was applied to make it look more natural.

For the final render in Autodesk 3ds Max® a blue hue was added to the camera to make the background blur and a displacement map was added to the reef as a texture. A cream grey dolomite rock texture was applied. The ground was formed with a basic green

color and a small hill shape. Next a high dynamic range imaging map designed the background lighting, trees were grown using a basic tree material. Leaves and grass were created using bitmap images and their alphas, and were placed on the planes.

3D Printing

A stereolithography STL file was created in Autodesk 3ds Max® of the knoll reef which was readable by the 3D

printer. A Mono Maker Select Plus® 3D printer with 1.75mm recyclable filament was used for this printing. The freeware Cura was used to import the STL file and allowed for scaling of the knoll reef model to fit within the bed of the printer. Painters tape was applied to the bed of the printer to help prevent warping. Before printing, the printer bed was levelled and heated. The knoll reef that was 3D printed was at a scale of 60:1 and took 6.5 hours to print.



Figure 4. A panorama of the eastern half of Scott Quarry constructed from the GigaPan® imagery – the original panoramic image is larger than 1GB in size.

RESULTS

Scott Quarry

The development of a panorama for Scott Quarry was created from the GigaPan® Stitch Software (Figure 4). This was treated as a first step to ensure that a panorama could be

constructed before developing the 3D knoll reef models. The panorama created using the GigaPan® left in 2D space can allow for possible detailed description of the outcrop later in the lab, allowing for maximization of time in the field (Figure 5).



Figure 5. A zoomed in section of the right part of Figure 4 in Scott Quarry showing possible detail to supplement stratigraphic interpretations. For this project the area as a whole was the focus of the imaging, however future work could result in more fine-scaled photography allowing for very high-resolution imagery.



Figure 6. The four sides of the knoll reef after being processed in the GigaPan® Stitch software. These four images were used to reconstruct a 3D model of the reef (Figure 7).

Knoll Reef

The knoll reef was photographed from 4 sides using the GigaPan® system, with the individual sides stitched together with the GigaPan® Stitch software (Figure 6). Each individual side was mounted on its own plane and rendered into a 3D model using Autodesk 3ds Max® (Figure 7). The knoll reef was then 3D printed as a demonstration of proof of concept for this entire process (Figure 8).

DISCUSSION

Strengths of this Method

In the field this method excels in that it is low cost and rugged. The cost of the GigaPan® mount, camera and lens, and tripod is relatively low compared to other remote digital surveying techniques (Carrivick, et al., 2016). These instruments are also rugged and can hold up well to field use. Finally, given the nature of the GigaPan® system to produce high resolution images allows this method to be used at a variety of scales. These reconstructed panoramas can be used as 2D surfaces or may be stitched together using Autodesk 3ds Max® to allow for additional and supplemental

analysis and description of the outcrops after the field work is complete.

The computer processing of the images into a 3D model using Autodesk 3ds Max® is not resource taxing and can be completed with freely available software. The method also allows for the 3D printing of geologic outcrops which means that additional analysis of the rock body may be completed after the field work is completed.

Weaknesses of this Method

The field limitations of using a GigaPan® is the battery life of the camera and mount. The length of time required for the GigaPan® to complete its photography can also be difficult in the field setting due to changes in light and shadows as this process may take a long time to complete; though this can be somewhat addressed through subsequent photo editing.

In the lab the 3D printing of the model is restricted to the resolution and scale of the printer. In an ideal situation a larger printer with higher precision could be used to reconstruct a more precise model and additional features could be integrated better into the model with scaling (e.g. paleontological resources).

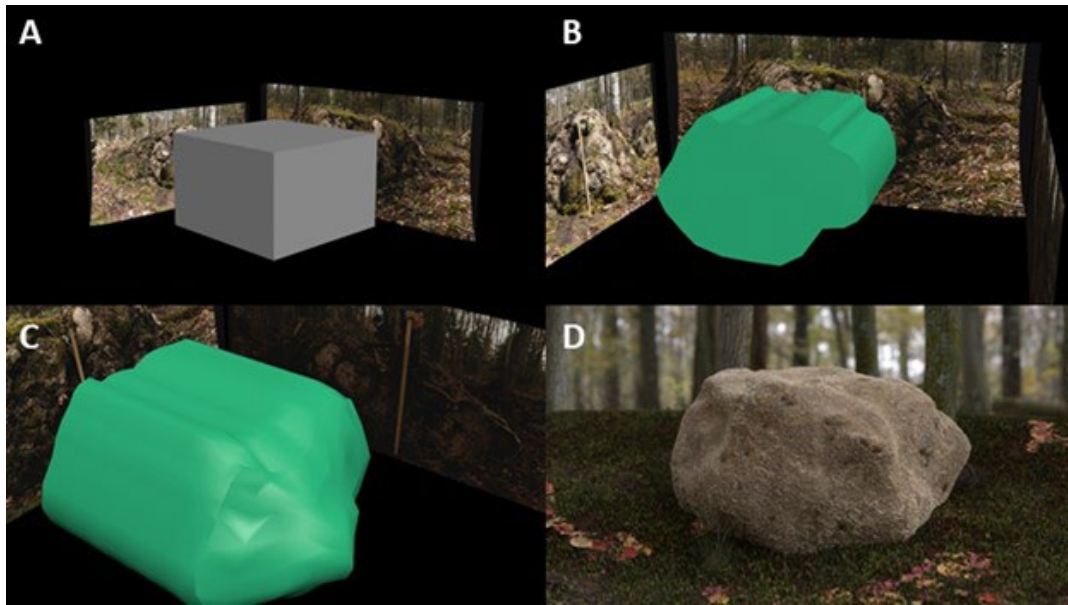


Figure 7. Construction of the 3D model of the knoll reef using Autodesk 3ds Max®. A) The images of the four faces of the reef were superimposed on a blank cube in Autodesk 3ds Max®. B and C) Sculpting of the cube based on the images allowed for its construction in 3D space. D) The final rendering of the reef based on sculpting from four GigaPan® images.



Figure 8. The four sides of the knoll reef 3D print at a scale of 60:1.

Future Implications

The methods described in this paper have implications for allowing the user to maximize the time spent in the field describing rocks. With high-resolution images stratigraphic columns may be constructed based on the imagery resulting in less data collection in the field. It may also allow for greater collaborations as possible collaborators may not have to go to the field together and can instead view and describe an outcrop together digitally. While these methods will not replace the need for field-based research they may facilitate greater collaborations along with deeper and subsequent analysis of outcrops without necessarily requiring additional field work (McCaffrey, et al., 2005; Whitmeyer, et al., 2010).

These methods also have implications for the future of geoscience education. The collection of high resolution 2D and 3D models of outcrops could be used for lab instruction for students with mobility challenges or allow for students to interact with outcrops that are far removed from where they are (De Paor, 2016; Dolphin, et al., 2019; Horowitz and Schultz; 2014; Ishutov,

et al., 2018; Piatek, et al., 2012; Pringle, et al., 2004; Riquelme, et al., 2019; Squelch, 2017; Whitmeyer and Dordevic, 2020). Neither this method nor ones similar to it will replace the need for field-based instruction, but it may be able to meaningfully supplement it.

Future Considerations

In the future this project and method should be expanded to additionally include imagery from the top of the structure of interest to allow a complete reconstruction of it. This will likely be best accomplished using an unmanned aerial vehicle. This project may also be expanded upon using a larger 3D printer which would allow for more detailed rendering of the outcrop when printed and possible integration of notable paleontological resources. Finally, future considerations may see the evaluation of different file types used across the software to evaluate further ways to make this process more efficient or increase the precision of the intermediary and final products.

CONCLUSIONS

Moving from a geological site to a 3D printed model that fits in your

hand is a lengthy process but not laborious one. This paper reports on a way to complete this using inexpensive and rugged field instruments with minimal computing power required for data processing. Outcrops can be photographed using a GigaPan® system and the images then used immediately in 2D space for additional description of the rock / outcrop in the lab setting thereby maximizing field time or the images can be processed in Autodesk 3ds Max® to render an accurate 3D model of the outcrop which can then be 3D printed to allow for additional analysis and description.

The use of this method and others like it has implications for the future of geologic research and education. This method allows for the possibility of researchers to maximize

their field time and to 'revisit' the outcrop without leaving their lab. It also potentially allows for the improvement of student outcomes as they now may be able to interact with far-flung outcrops which consist of rocks different from where they are studying.

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