

3D Modeling and Reconstruction with Photogrammetry

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Introduction

Photogrammetry is the practice of making measurements from photographs ^[1-5]. Typically this science is used to recover the exact positions of surface points ^[1-3]. The simplest example of this practice is seen in the calculation of the distance between two points on a plane parallel to the photographic image plane from which they were taken ^[3-5]. This was done by simply measuring the distance on the image via a standardized scale. This simple concept is the root of the photogrammetric analysis today ^[1-5].

Photogrammetry is comprised of a number of stages which construct a three-dimensional matrix from a set of overlapping two-dimensional images ^[3,4]. A variety of input formats can be processed via photogrammetric methods to develop three-dimensional render. These include the inner and exterior orientation points, image co-ordinates, three-dimensional coordinates, and the classic input of camera images ^[1,2]. Image coordinates define the location of a subject's points on film. Three-dimensional coordinates, will locate these points in space. The exterior orientation points will then provide the location and space of the camera through which a program analyzes a set of points. Inner orientations points help define the geometric parameters of the imaging process. In our lab, we used photographs as our primarily input of coordinates ^[1-5]. From these points we were able to insert any constructed model into a slicer program for 3D printing^[4].

Photogrammetry has utility in the fields of topographic mapping, architecture, engineering, manufacturing, and geology among others ^[1-5]. The OPN Lab aimed to use this technology to preserve fragile biological models and fossils. Upon producing a three-dimensional render of a specimen, we could import it into a slicer program and 3D print it. In this way, we could not only preserve specimens but share them with larger audiences for a relatively low-cost.

This manual aims to detail our procedure of developing these 3D printed models of our laboratory specimens. For our processing, we used Agisoft© PhotoScan 1.4 Standard Edition. All photographs were taken using a Panasonic© DC-FZ80 LUMIX 18.1-Megapixel 4K Digital Camera. The procedure detailed below is specific to the setting of our laboratory. We used the “P” setting for our photographs. This “programmed automatic” mode allows us We recommend readers adjust settings and set-up procedures such to what works best for them.

Materials for Photogrammetry

- Updated Version of Agisoft© PhotoScan (At the time of writing, version 1.4 was used)
- Panasonic© DC-FZ80 LUMIX 18.1-Megapixel 4K digital camera
- 3D Anti-Glare Scan Spray
- Rotating Tray (Lazy Susan)
- Micro SD Card Reader

Setting Up the Photoshoot

Ideally, the subject of your project should be highly textured. Having objects with texture and multiple distinct faces, will help the software distinguish between planes of the object. This will allow it to create a more complete mesh. If you are hoping to capture an object with smooth sides, the software may have difficulty in overlapping between photographs you take. One way to avoid this is to spray the object with 3D Anti-Glare Scan Spray. This spray will dust your subject in a white spray, leaving your object with a speckled look. This will provide contrast the software needs to construct a mesh.

The shooting location should be evenly lit, with no one side of the object receiving a more light than another ^[3-5]. The best lighting was achieved when the object was placed directly underneath a dimmed fluorescent light at a distance of five feet. The light source itself can be a source of glare, leading to poor processing results. In this situation, we recommend placing a few sheets of paper in front of the light source to lower its intensity.

We highly recommend locating the object of interest in a central location on a raised platform, leaving plenty of space to walk around. We set up our photoshoot such that the object was raised five feet in the air with a minimum of three-feet of walking space around the object. In previous trials, we found that limited space, led to knocking of the object, distorting its orientation between photos. Some objects are best shot on a round-table so that the photographer needs to simply rotate the roundtable a specific number of degrees between shots. This method is ideal for objects with a clear flat base. The method detailed in this manual will present the procedure for objects without a flat base, that have to be walked around to be accurately photographed. It is important to capture object photos against a varied background with many objects and colors. A background that is consistent in color and depth will result in poor processing results as the software can mistake the plain background to be the intended subject.

We used the programmed automatic (P) focus setting on our camera. The camera automatically adjusts shutter speed and aperture for optimal exposure. With this setting, one can still focus on the subject between shots. Photos should have an overlap in the planes of the subject that they capture ^[1-5].

Processing Procedure

STEP 1:

- Open Agisoft© PhotoScan program.
- In the *Workflow* Menu, click the *Add Photos* option. Select the source folder and select the photos you would like to be processed.
- Click *Open*

STEP 2:

- In the *Workflow* menu, click the *Photo View* option.
- In the *Toolbar* Menu, click *Add Selection*.
 - This step asks the software to mask irrelevant elements in the source photos. It will contour the boundary of certain image regions. These regions will be defined by the subject of your photos (the consistent planes between your photos)
 - Outline the subject of interest

STEP 3:

- In the *Workflow* menu, click the *Align Photos* option.
 - Set the parameters with the following settings:
 - *Accuracy* - High
 - *Pair Preselection* - Disabled (*Generic Preselection* - should be used when dealing with a large volume of photos that were not taken with precision)
 - *Constrain features by mask* - Enable
 - *Key Point Limit* - 40000
 - *Tie Point Limit* - 40000
- Click *OK* to start photo alignment (Fig. 1).
 - Depending on the number of photos taken, the overlap between these photos, and the success of the masking step, this step should only take between 1- 5 minutes for most typical data sets (80 photos)

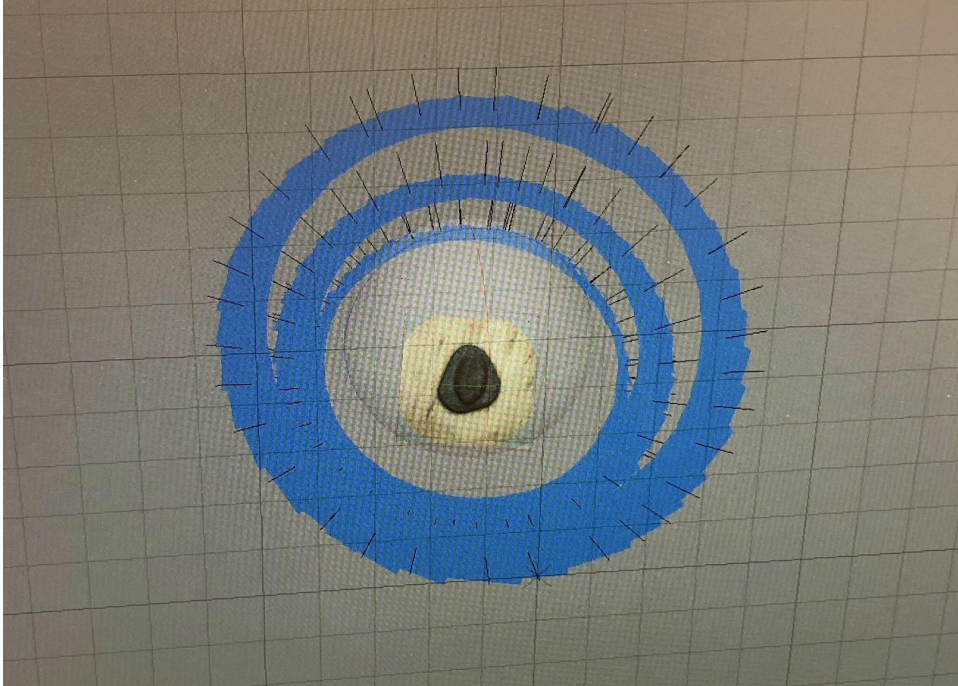


Figure 1: This image shows a successful photo alignment. Each blue face represents one three-dimensional locations of the camera during object capture.

STEP 4:

- In the *Workflow* menu, click the *Build Dense Cloud* option.
 - Set the parameters with the following settings:
 - *Quality* - High (The higher the value selected for this parameter, the more processing time required)
 - *Depth Filtering* - Aggressive (This makes the program focus on small details and curves of the object in question. Lower settings will make the program gloss over the details and extrapolate a smooth plane between small uneven points, leading to less accurate results)
- Click *OK*
 - Unwanted points in the dense cloud produced can be removed with the help of the *Crop* selection tool.

STEP 5:

- In the *Workspace* menu, click the *Build Mesh* option.
 - Set the parameters with the following settings:

- *Surface Type* - Arbitrary
- *Source Data* - Dense Cloud
- *Polygon Count* - High
- *Interpolation* - Enabled
- Click *OK*

STEP 6:

- In the *Workflow* menu, select the *Build Texture* option.
 - Set the parameters with the following settings:
 - *Mapping Mode* - Generic
 - *Blending Mode* - Mosaic
 - *Texture Size/Count* - 4096 x 1 (Width & height of the texture atlas in pixels. This determines the number of files for texture to be exported to)
 - *Enable Color Correction* - Disabled (Unless the photos have extreme brightness variation)
- Click *OK*

STEP 7:

- In the *File* menu, select the *Export* option.
- Select *Export Model*.
 - This will produce the file as an STL file that can be scaled and 3D Printed.

Troubleshooting

Fractured Dense Cloud:

After the dense cloud, you may find that the produced dense cloud is fractured and only segments of your object were captured. The most common reasons and solutions for this are listed below:

- Glare - Uneven and overly bright lighting is the most common culprit of fractured dense clouds.
 - Make sure that your lighting setup delivers an even uniform amount of light to every plane of the object.
 - We recommend positioning your light source at least five feet from the object.
 - If the light is too close or bright, it can mask planes of an object. As a result, during photo alignment and dense cloud creation, the program may not be able to distinguish between photos.
 - If your lighting itself cannot be adjusted, placing a few sheets of white printer paper in front of the source can serve as a handy dimmer and light filter.
 - Our lab also worked with 3D Printing Spray. This spray coats the object in a speckled dull white powder that allows the software to distinguish between photos. The spray also removes a lot of glare from resin-coated and shiny objects.

Semi-Circle Photo Alignment:

- Incomplete Photograph Capture - Failing to capture the entirety of an object can lead to a photo alignment that does not cover every face of an object.
 - Make sure that you capture your subject from as many angles as you can, making a complete circle around it (Fig. 2)
 - Repeat this circle at various heights so as to get the overhangs and shelves on the object.
 - Be sure that every photo is focused. Blurry images slow down processing and often result in failed renders.

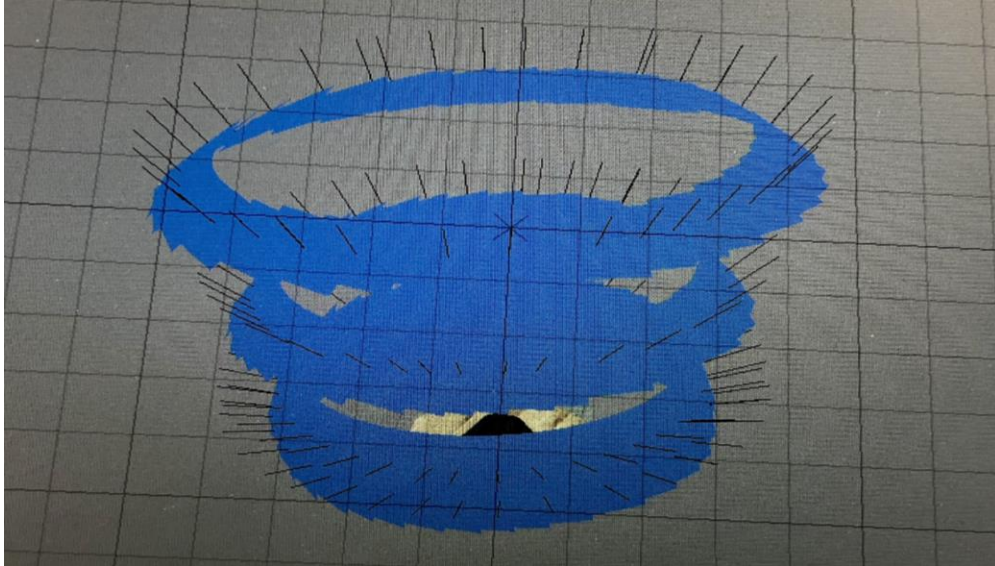


Figure 2: This image shows the ideal three ring orientation of the cameras required for accurate and detailed processing.

Low Quality Textures:

- Blurry Photos - Failing to focus the camera before each photo can result in blurry photos that the program will not align correctly.
 - A poor photo alignment will result in a poor dense cloud, mesh, and ultimately textures as the program will extrapolate on what little data is usable in the dataset.
- Distant Photos - Taking images from too great a distance will result in the loss of detail in the dataset.
 - Aggressive depth filtering will rectify some of this but it is easier and faster to take photos correctly at the offset.
 - When trying to capture small details on a subject, bring the camera closer (within a foot) to the object. Maintain the three circle standard of coverage but focus on the fine detail in each shot.
 - Be sure to maintain a $\frac{1}{3}$ coverage of faces between each photo. If your photos are so close that one photo does not overlap with the other, the software will not be able to construct an accurate mesh.

OPN Lab Projects

We experimented with photogrammetry to preserve and recreate some of the models in our institution as a way to test the utility and efficacy of the technology (Fig. 1-7).



Trilobite Fossil

Figure 3: This image compares the results of the photogrammetry process used on a trilobite fossil.



Figure 4: This image shows the level of detail and texture that photogrammetry is capable of capturing in replica production.

Skull



Figure 4: This image compares the results of the photogrammetry process used a mammal skull.



Figure 5: This image highlights the ability of photogrammetry to capture small cavities and gaps in a model.

Crinoid Fossil



Figure 6: This image displays the ability of photogrammetry to capture minute details in a model that would not be picked up by a standard scanning method.

Left Femur



Figure 7: This image shows the preserved level of detail between scaled photogrammetry meshes and prints.

Applications

Currently photogrammetry is widely used in the fields of archaeology, entertainment technology, and product design. It is also a promising tool in the natural sciences. We have demonstrated that it has utility in the preservation and distribution of biological models. It has potential for use in the modeling of increasingly complex biological subjects including but not limited to organ models and microbial species. In this way, this tool has the potential to spread science education to learners who might not have access to real biological models.

Hazards

There are a number of safety hazards associated with 3D printing. In particular, the 3D printing bed can become very hot when in use. Readers should exercise caution when removing any prints from the printer bed. Also, the 3D printing process can release harmful nanoparticles into the air, which can cause several serious health issues, including asthma attacks, respiratory arrest, strokes, and even cardiac arrest. Readers should keep their 3D printer in a well ventilated area and wear proper protective equipment when operating the printer (e.g., masks or respirators and goggles or safety glasses to protect their respiratory systems and eyes from these nanoparticles). We encourage readers to review the safety information pertaining to their 3D printer, and research to learn more about 3D printing safety.

Disclosures

I declare that I have no conflicts of interest related to any product, brand, company, website, or other item discussed in this manual. As well as with other open-source instruments and equipment developed by this lab, we encourage readers to improve upon the designs and methods set forth in this manual by using other materials and equipment. We urge them to bring their own insights and inspirations to the project.

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