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A Photogrammetric Workflow to Produce 3D-Models of Geological Samples

Ett fotogrammetriskt arbetssätt för att producera 3D-modeller av geologiska stuffer

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DEPARTMENT OF EARTH SCIENCES
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Abstract

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Photogrammetry and Structure-from-Motion (S-f-M) is a low-cost method of producing digital 3D models of rock samples that can be used for many different research and educational purposes. A 3D model of a delicate rock sample would enable the preservation of the sample and reduce the need of physical manipulation. This thesis presents a systematic workflow to document and study rock samples by using photogrammetry and S-f-M. The manual in this work describes how to use the set up SOOSI (*Spinning Object Optical Scanning Instrumen*t) found at the Department of Earth Sciences at Uppsala University to produce digital 3D models of geological samples. The thesis gives a background to photogrammetry in Earth sciences, and it presents the fundamentals of photogrammetry and the camera. It explains the processing chain of photogrammetry and how computers assist in the photogrammetric process for the reader to understand the importance of the steps in the manual. 3D models produced from following the workflow are presented as well as implications of choices that can be made when following the workflow. The addition of a fixed lens to the camera setup would improve the method's robustness. The models are currently limited due to a lack of absolute scale. A suggestion for developing a method to capture Ground Control Points (GCPs) to solve the scale problem is presented.

Key words: photogrammetry, S-f-M, digital 3D models, geoscience, rock samples, earth sciences

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Sammanfattning

Ett fotogrammetriskt arbetssätt för att producera 3D-modeller av geologiska stuffer
Fanny Bjugger

Fotogrammetri och Structure-from-Motion (S-f-M) är en billig metod för att producera digitala 3D-modeller av stuffer som kan användas i olika forsknings- och undervisningssyften. Modeller av stenstuffer minskar behovet av att fysiskt ta i dem och används därför i syfte att bevara ömtåliga stuffer. Denna uppsats presenterar ett systematiskt arbetsflöde för att dokumentera stuffer genom att använda fotogrammetri och S-f-M. Manualen beskriver hur den fotogrammetriska fotostudion SOOSI (*Spinning Object Optical Scanning Instrumen*t), som finns på institutionen för geovetenskaper vid Uppsala universitet, används för att producera digitala 3D-modeller. Uppsatsen ger en bakgrund till fotogrammetri inom geovetenskapen och den beskriver kamerans och fotogrammetrins grunder. Vidare förklaras fotogrammetrins bearbetningskedja och hur datorer bidrar i den fotogrammetriska processen för att läsaren ska förstå de olika stegen i manualen. 3D-modeller producerade genom att följa arbetsättet presenteras och de olika val som kan tas när en följer manualen och dess implikationer på resultaten diskuteras. Arbetsättet skulle förbättras om ett objektiv med fast brännvidd införskaffades till fotostudion. 3D-modellernas användningsområde begränsas av att de saknar absolut skala därför presenteras ett förslag till att utveckla arbetsmetoden med hjälp av Ground Control Points (GCP:er).

Nyckelord: fotogrammetri, S-f-M, digitala 3D-modeller, geovetenskap, stuffer

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1. Introduction

The purpose of this bachelor thesis is to establish a systematic workflow to document and study rock samples by using photogrammetry and Structure-from-motion (S-f-M). Sending rock samples can be time consuming and 3D-laser scans can be expensive. It can also be hard to fully understand and imagine a rock sample when only seen in 2D or described in words. The end product after following the workflow is to generate a digital 3D model of a rock sample. Photogrammetry and S-f-M is a low-cost method of producing a digital 3D model of a sample that can be used for many different research and educational purposes such as:

- in virtual mineral and geological collections (cf. *Sketchfab.com*, 2023; Apopei, 2021).
- in scientific and learning environments, like in paleontology and geology.
- in mineralogical and petrological studies to extract texture data of minerals and rocks.

The workflow presented in this thesis is meant to be used, as independently as possible, by scientists, in-house or visiting, and students at the Department of Earth Sciences at Uppsala University by using the photogrammetric setup, called SOOSI (*Spinning Object Optical Scanning Instrument*), the camera available at the department and by processing the photos in Agisoft Metashape (https://www.agisoft.com/). In theory, one should only need to be let into the room where SOOSI, the camera, the pad and the computer used for the S-f-M processing are, follow the manual and be able to generate a digital 3D model of the chosen sample.

The first two chapters presents the history and principles of photogrammetry. This is followed by a more technical chapter, 2.3, describing the camera which then continues with a part about the computational development within photogrammetry (chapter 2.4). Chapter 2.5 presents the knowledge needed regarding the photogrammetric processing chain to understand the different steps in the workflow used during this thesis's work. In the method chapter the materials and software being used are presented and how the workflow was tested and fine-tuned. Also, a slimmed down version of the workflow is presented to read the rest of the thesis without having to read the full manual. Results from following the manual are presented which is followed by a discussion and conclusion. The full manual is found in appendix.

2. Background

2.1 Main Principles of Photogrammetry

Photogrammetry is used in order to obtain shapes and position of an object using several pictures and includes methods for measuring and the interpretation of photographs (Kyle et al., 2013). It is often used to three-dimensionally recreate an object in digital form, which means that it is represented in coordinates and geometrical components, or graphically as maps, drawings and pictures (Kyle et al., 2013). Photogrammetry can be considered to be part of remote sensing which is defined by Kääb (2005, p. 14) as "*all methods for non-contact object measurements and their analysis*".

Triangulation is the fundamental principle of photogrammetry. So-called "lines-of-sight" can be extrapolated from each camera to points on the object. By taking photographs from at least two different locations, the lines-of-sight are then mathematically intersected to give the 3-dimensional coordinates of the points of interest. So the process of photogrammetry consists of gathering measurements about an object by analyzing the change in position and perspective of the object, or the camera, from two or several photographs (Collier, 2009).

Maps and aerial photographs appear similar because they represent a planar view of the Earth but aerial photographs will have positional errors. Hence, measurements of distances, areas, or directions can not be derived directly from photos. In order to obtain accurate information from photos and to create a photographic image free from all errors one must correct for distortions and apply photogrammetry (Collier, 2009).

Photogrammetry uses the same physical principle as our eyes to get depth perception by using two different positions to compute 3-dimensional information, which is known as parallax (figure 1). If it is possible to manually or automatically identify an object A (points a1 and a2) from two pictures, Image1 and Image2, taken from two known positions by a camera (CameraPosition1 and CameraPosition2) of which you have the internal characteristics of the camera, and you know the orientation in space of the camera, the 3D position of the object can be computed by calculating the position of the intersection of the lines (a1 - CameraPosition1) and (a2 - CameraPosition2). The more lines you have, i.e. camera position, the more accurate your calculated position of the object will be, just like if you would look at an object and walk around it, you would get a better understanding of the shape and position of it (Girod, 2018). Photos can be obtained in different ways depending on what you want to study and what means you have in order to study it. Satellites, airplanes and drones can capture images of the earth while flying over it and a human can walk around an object while taking pictures of it. In the workflow presented in this paper we let the object rotate while the camera is fixed, at different levels. The net result of this will be the same as for the previous cases where the camera is moving.

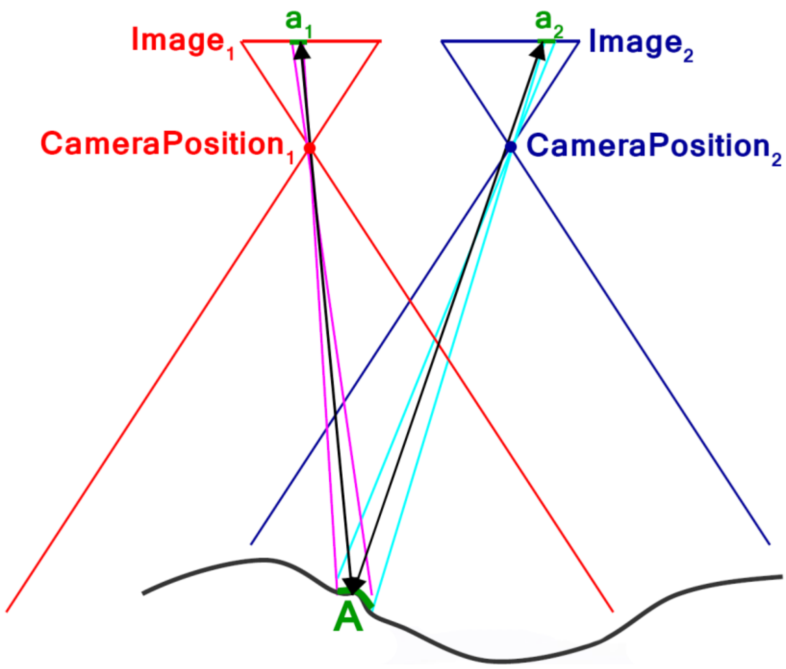

Figure 1. The fundamental concept of photogrammetry. Figure used with permission from Girod, 2023.

2.2 History and Applications

The first working photographic camera was used by Nicéphore Niépce, who took the first permanent picture of the view from his window "*Point vue du Gras*" around the year 1826 (Gemsheim, 1986; Girod, 2016). This first camera was shaped as a box with a pinhole and in the back was a surface coated with light-sensitive chemicals. The amount of light the system could capture, in a relatively short amount of time, increased immensely with the invention of lens cameras and the use of more sensitive chemicals for films (Girod, 2018). Later, the invention of digital sensors further increased the amount of light the cameras could capture. Thanks to these improvements the process of photography became a very practical way of capturing a portion of reality (Girod, 2016).

In the 1840s, Lussedat was the first to propose using photos for surveying and map-making but unfortunately the photographic technology at that time was unfit for the purpose. In the 1880s, photos taken from the ground were used for the first time for geographic applications thus, the original practical photogrammetry was born, the so called terrestrial photogrammetry (Collier, 2009). These early applications of photogrammetry were exercised in mountainous areas where it would be difficult or too dangerous to survey in the terrain, so a camera was used to take pictures of these areas. With the use of photogrammetry the data density attained with theodolites could be enhanced and increased (Girod, 2018).

The first successful attempts at photogrammetry used graphical techniques for measurement, but in the early twentieth century South African and European researchers independently developed instruments which increased the accuracy and speed of measuring. These early instruments only worked well for terrestrial photogrammetry; the first prosperous methods designed for aerial photogrammetry came in the late 1920s (Collier, 2009). This meant that during World War I, the huge expansion in the use of aerial photography for map-making and map revision still relied on simple graphical techniques or the use of optical projection systems. According to Collier (2009) aerial photography became the standard mapping tool by the end of World War I.

Today photogrammetry is used in a multitude of ways and within many different fields. It is not only used in sciences such as geology, biology, and engineering but also in city planning & architecture, cultural heritage projects, archeology and in arts. In remote sensing, photogrammetry is often used to produce digital elevation models (DEMs) which have a plethora of uses. They are used to study landscape and hydrology, engineering, mapping and in the creation of orthoimages (distortion free photographs) and to study surface deformation.

2.3 Photography and the Camera

A camera consists of a few elements: the lens, the diaphragm, the shutter and the sensor or film (figure 2). The fundamental change between modern cameras and cameras decades ago is that photographic film has been replaced by digital sensors. Each element's characteristics affect the camera parameters and thus affects the image (Girod, 2018). I will now go further into explaining some of these parameters in the following section.

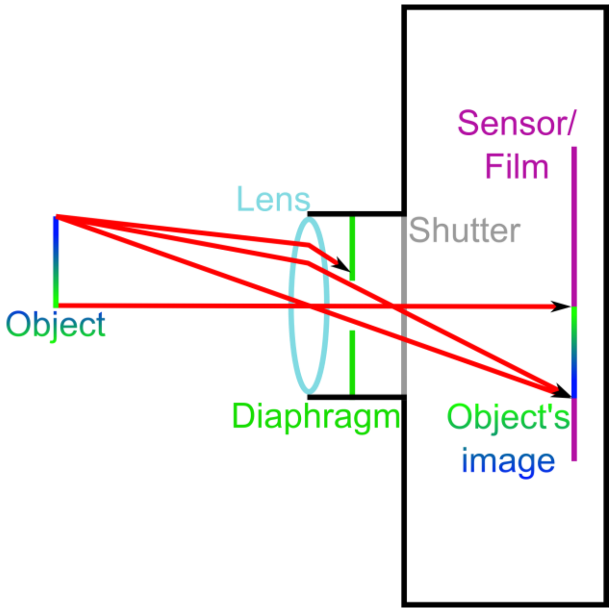

Figure 2. A simple diagram of a camera. Figure used with permission from Girod, 2023.

2.3.1 The Camera Lens and Sensor Parameters

The optical systems of modern cameras are increasingly more complex. By combining several lenses of different types (divergent, convergent, aspherical) and using different glass types and coatings, we can obtain increasingly versatile optics of various kinds and aspects that have lower levels of chromatic and geometric distortions (Girod, 2018). An example of a tool that can be used to obtain a certain type of information in images, and that can be used in the photogrammetric workflow presented in this thesis, is a circular polarizing filter that can be used to minimize reflections and glare from the surface of minerals and rocks.

The cameras four most critical parameters are (Girod, 2018):

- Focal length - *Foc* (in mm). A larger Foc number, meaning a longer focal length will give a more narrow field of view (figure 3).
- Aperture - *f* number. A cameras aperture is like the eye's pupil, it varies in size to let light in. A small f number (meaning the diaphragm, or aperture, is wide open) will let a lot of light through the lens and will result in a short depth of field (figure 4). The vignetting, the fall-off of brightness away from the image center, is also affected by the aperture, or f number. As an example, f/20 is a large f number, and so the aperture is narrow.
- Exposure time. The exposure time is the amount of time (in seconds) during which the light can reach the sensor/film.
- Sensitivity, also called ISO, is a measure of how sensitive the sensor/film is to light. A large ISO number means that less light is needed to get the same brightness in the image but because it is more sensitive there will be more noise in the picture.

The brightness of an image depends on 3 of the parameters listed above and their relationship can be seen in this fomula (Girod, 2018):

$$\text{Brightness} \propto (\text{Exposure Time} * \text{ISO}) / \text{Aperture2} \qquad (1)$$

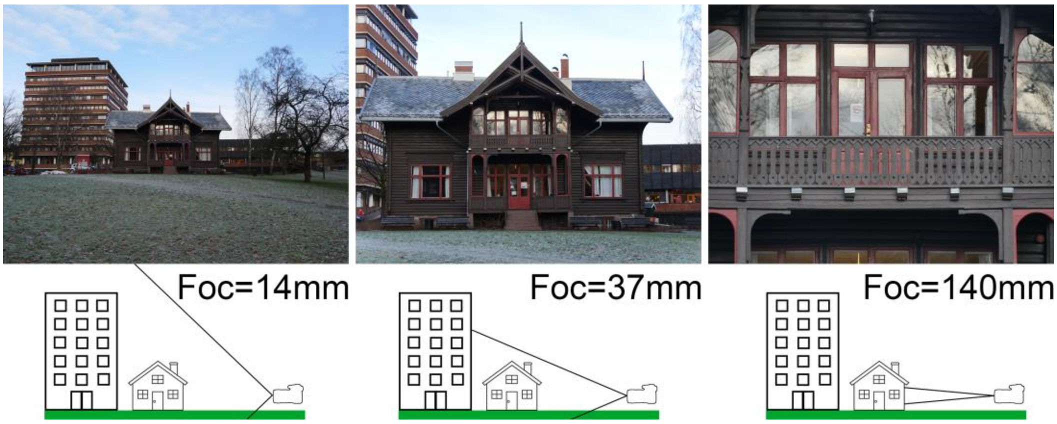

Figure 3. Images taken from the same spot but with increasing focal lengths, *Foc*. Shorter focal lengths show more of the scene but with a lower level of detail. The longest focal length shows only a small part of the scene but with a lot of details. Used with permission from Girod, 2023.

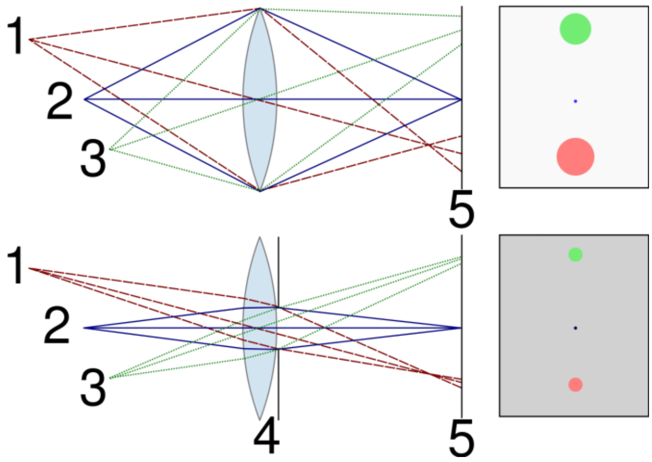

Figure 4. A diagram of how aperture effects the depth of field. Used with permission from Girod, 2023. The top diagram is of an aperture that is wide open, a small f number. The bottom one is of a closed aperture, high f number. 1, 2 and 3 are points farther than focus plane, in focus plane and closer than focus plane, respectively. 4 shows the diaphragm or the aperture. 5 shows the sensor/film and to the right of the film you can see how much the different points are in focus, or not in focus which is seen as a blurry, bigger point. A small f number meaning a wide aperture makes the points that are not in the focus plane appear big and blurry compared to what the bigger f number, narrow aperture gives.

Figure 5. Examples of different apertures and its effect on the depth of field. Used with permission from Girod, 2023. The higher f number, f/20, appears to have a wider depth of field in focus compared to lower f numbers. The lower the f number, the more blur will be seen in the foreground and background. Note that the exposure times are different for the different photographs in order to compensate for the amount of light being let through. The high f number means the aperture is narrow and in order to let enough light in to get a good brightness the exposure time is fairly long, 1/13s. The lowest f number, f/5, means the aperture is very open and in order to not get an over exposed photograph the exposure time is quite short, 1/200s.

2.3.1.2 Distortion

Distortion is the discrepancy between a photograph and the perfection of a theoretical photograph taken by a camera (Girod, 2018). The anomalous curvature of straight lines is the most apparent effect of geometric distortion. This distortion is due to the imperfection of the optical system and the flatness of the sensor (Girod, 2018). Fish-eye lenses give the most extreme geometric distortion, but other zoom lenses (variable focus) also show very visible geometric distortion. Chromatic distortion is another type of distortion and gives divergence in the colours of the photograph and is due to an optical refractive error (Girod, 2018). This happens because the lens fails to focus colours of different wavelengths to the same point (Girod, 2018).

2.3.2 Digital Camera Sensors

In 1975, Eastman Kodak was the first to develop a digital sensor. Before this digital invention, light was captured on film, where the film usually had silver-based solutions. The first digital sensor had a resolution of 100*100 pixels (Lloyd and Sasson, 1978). A sensor consists of a matrix with light sensitive cells, or photo sensors, where the light that hits the cells is converted into electrical current. The current stored in each cell is then converted into digital information. CMOS type sensors and their variants are, according to Girod (2018), the most common sensor technologies in use today due to the rapid readout time, the lower power consumption, and the relatively small production cost. In big sensors we can find the CCD type sensor that used to be the leading type of sensors in all digital cameras historically (Girod, 2018). The array of light sensitive cells in the digital sensor only creates a black and white picture, so supplementary systems are needed to create coloured images. The Bayer matrix (figure 6) is the most common additional system to digital sensors and consists of a layer of colour filters that is laid on top of the sensor and it makes sure that only a certain range of light wavelengths reaches each photosensitive cell (Girod, 2018). Because the human eye can see a lot of green hues, there are twice as many green tiles, or cells, as blue tiles in the layer of colour filters. This will result in a higher accuracy of colours within the green wavelength and the perceived image quality will be better. The colour for each cell, or tile or pixel, is then interpolated from neighbouring pixels (Girod, 2018).

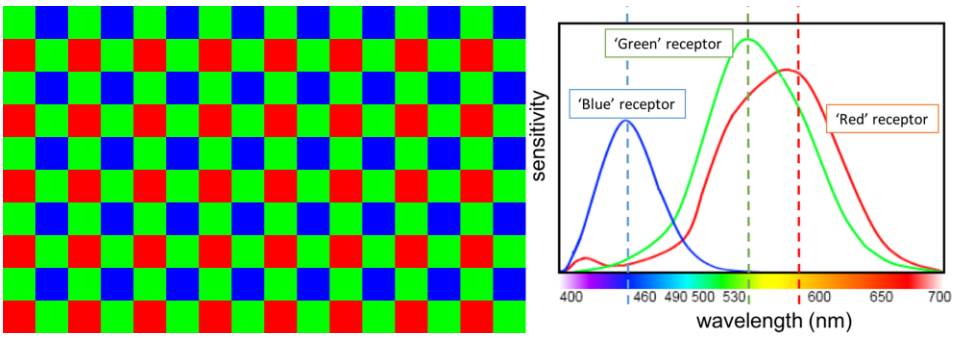

Figure 6. The Bayer matrix seen here on the left with twice as many green tiles than red and blue. On the right: a graph showing the sensitivity of the different receptors of the typical human eye. Figures used with permission from Girod, 2023.

Other patterns than the Bayer matrix exist, such as the Fujifilm X-trans sensors, but also other types of sensors that can use several layers of sensors to capture full resolution images in each of the wavelength's bands as the Foveon X3 sensor for example. Other systems use software to fuse several images together after having images taken through prisms that separate colours to send different wavelengths to different sensors or using different lenses for each colour. (Girod, 2018). Cameras today can capture more than what the human eye can see and help us to get information on both smaller and bigger wavelengths than human biology can do. Near infra-red wavelengths (NIR) for instance is strongly reflected by plants and can therefore be used to identify vegetation (Girod, 2018).

2.4 Computer Assisted Photogrammetry

All aspects of photogrammetry were greatly impacted by the computer revolution. It impacted everything from image acquisition, processing, and storage to achievable data products with the development of gridded Digital Elevation Models, DEMs, and orthorectification. The first thing computers did for photogrammetry was that the data acquired from stereoplotters could more easily be stored and manipulated to make the information gathered more structured and easier to read and use. The second big step was that the images could be scanned and brought into the computer and later could be imported into the computer by digital photography. Having the images on the computer allowed for faster and more streamlined interaction and visualization. As an example, changing the visualized couple of images meant complicated manipulation of stereoplotters but on a computer this only takes a few clicks. By putting in the positions of Tie Points (TPs) and Ground Control Points (GCPs) and solving the systems of equations, relative and absolute orientation data (position and viewing angles of the camera) can be obtained analytically (Girod, 2018). According to Girod (2018), when Global Navigation Satellite Systems (GNSS), like the GPS, developed into being more available, precise, and accurate, it made it easier to gather ground control points. The integration of GNSS systems into the camera and/or on-board the photography acquisition platform led to a decrease in the amount of ground control points needed for georeferencing. Automation of several photogrammetric processes enabled by computers came soon after the development of GNSS, such as tie point detection through algorithms and the computation of elevation data through dense cloud correlation (Girod, 2018). Except for the procurement of the image and orientation data, most professional photogrammetric surveys done today are processed with no human input.

To amateurs, photogrammetry became more accessible and compatible with relatively cheap and non-specialized hardware. The process of Structure-from-Motion (S-f-M) might be one of the biggest inventions to further the advancements of photogrammetry. The S-f-M process was presented by Koenderink and Van Doom (1991) and later implemented in an available open-source code by Snavely et al. (2006) and Snavely (2010). Both the relative external orientations, such as angles of view and positions in a relative space, and the internal orientations, often called camera calibration, such as the information about the cameras' optics and sensors, can be automatically computed using S-f-M (Girod, 2018). These parameters can be automatically calculated from a group of images without knowing in advance when tie points can be identified, which can also be solved automatically (Girod, 2018). Multi-view stereo (MVS) can robustly and automatically compute accurate and dense 3D models given information provided by S-f-M (Furukawa & Ponce, 2010). MVS is the general name for a group of techniques that primarily uses stereo correspondence and more than two images to derive geometry from photographs (Furukawa & Hernández, 2013). The development of faster and better MVS implementations has been made both in commercial software such as Agisoft Photoscan (Agisoft LLC, 2017) and in open-source software such as MicMac (Pierrot-Deseilligny et al., 2017).

2.5 Processing Chain of Photogrammetry

The steps of the modern photogrammetric process enabled by computers and structure-from-motion (S-f-M) can be broken down into steps of different input data, products and processes. Figure 7 from Girod (2023) shows the steps of a S-f-M photogrammetric workflow.

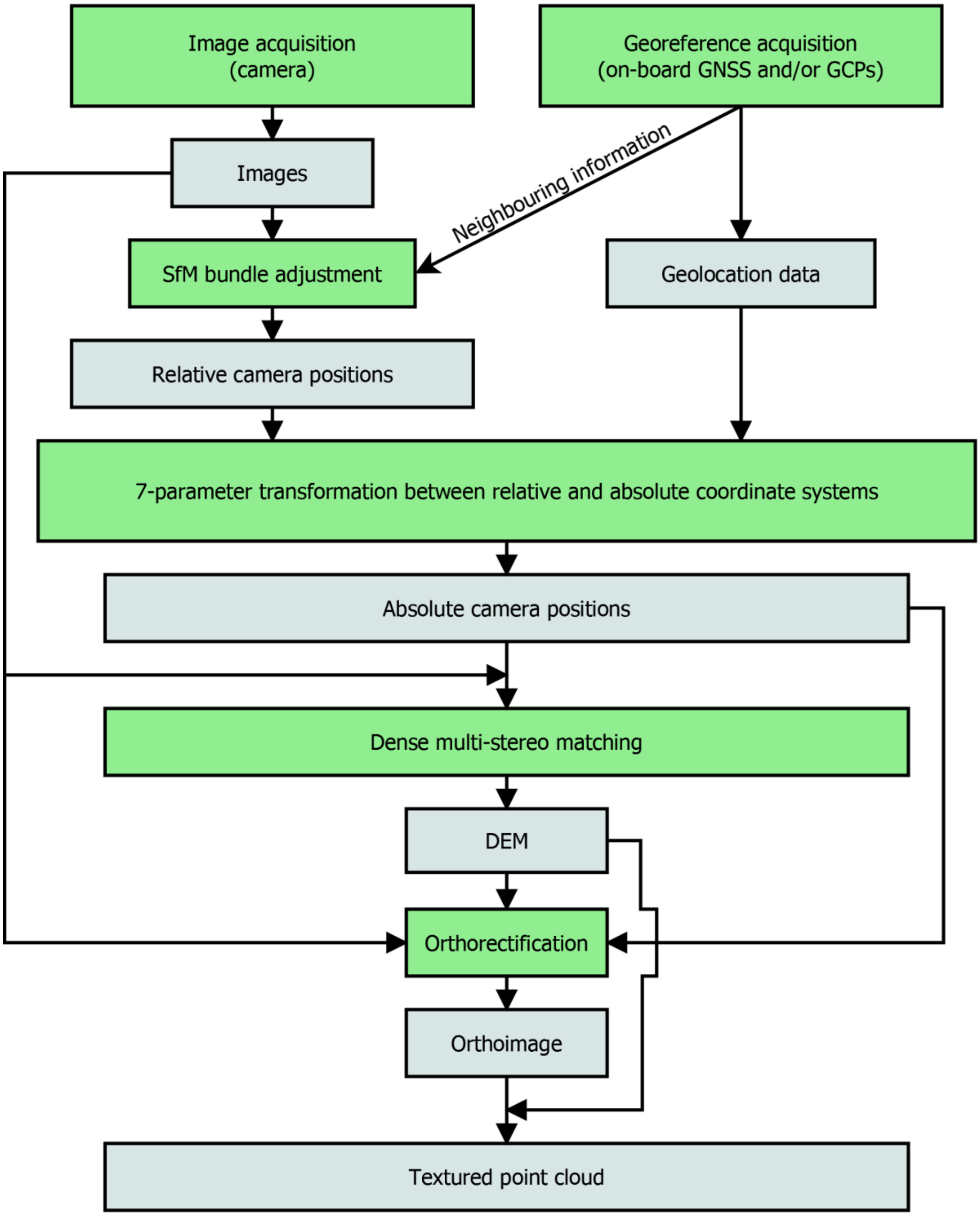

Figure 7. The S-f-M photogrammetric workflow. Processes are shown in green and input data and products are shown in grey. Figure used with permission from Girod, 2023.

2.5.1 Image Acquisition

The convergent method and the parallel method are the two main methods of photo procurement in photogrammetry.

2.5.1.1 The Convergent Method

The convergent method means taking pictures aiming at the same point in space. The picture in the middle, the primary picture, will use the secondary pictures to get 3D information, or multi-stereoscopy (Girod, 2018). In figure 8A, from Girod (2023), you can see a simple setup of the method. In figure 8B, also from Girod (2023), you can see an example of a setup for taking several sets of images if a single point of view is not enough to see the whole object. In this figure a 360 degrees view in a single plane is shown but the next logical development would be to take pictures in several circles from different altitudes, just like we do in the workflow presented in chapter 3. To make sure a strong geometrical link exists between images of different points of view the images are adjacent to one another, or linking, with significant overlap. The angle between two lines of view is important in order to provide good data. There is a trade-off between having an angle big enough as to be able to get stereoscopy, as very small angles will lead to too much uncertainty and for the computation of tie points and correlation to work where a smaller angle is favoured. 10 to 15 degrees is a good value to ensure we get the computation of tie points and correlation to work and big enough to get stereoscopy (Girod, 2018).

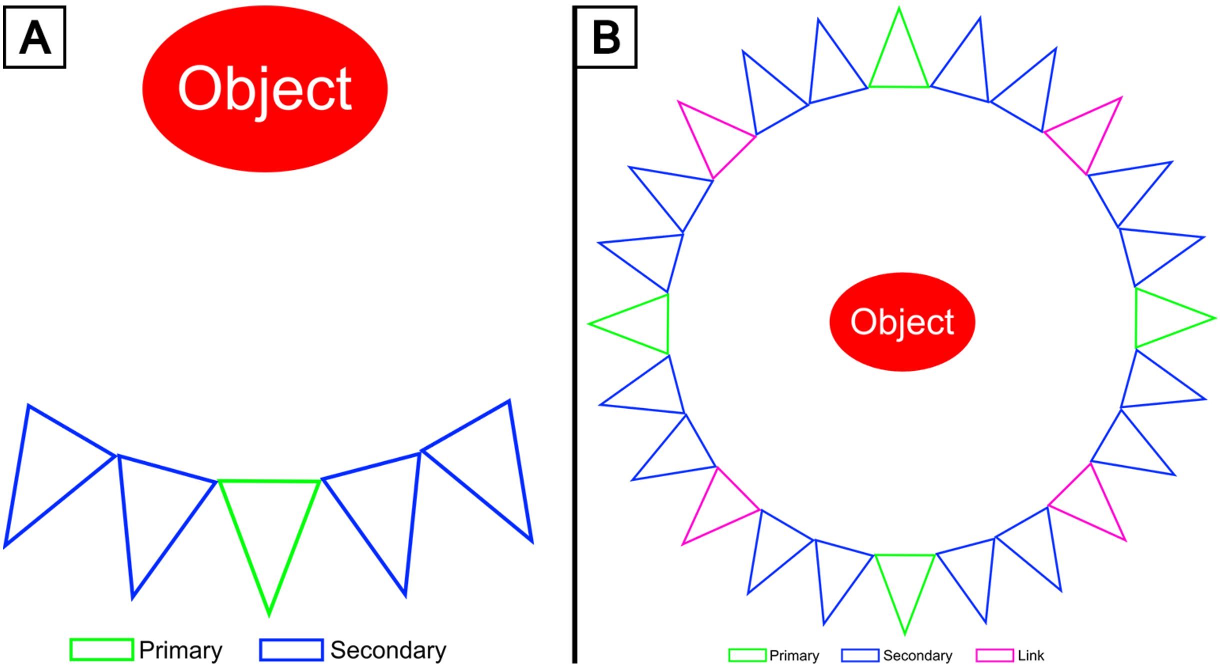

Figure 8. Figure 8A is showing the simple convergent method where the primary image (green) in the middle will use the secondary images (blue) to get multi-stereoscopy. Figure 8B shows the convergence method with multiple points of view where images have been taken in a circle around the object but with the same distance from the center of the object. Figure used with permission from Girod (2023).

2.5.1.2 The Parallel Method

If a scene of interest is somewhat planar, like a part of Earth's surface or a wall or cliff, none of the images taken will represent the whole scene and the parallel method will be the most useful image acquisition method to use. Every point of the scene needs to be seen at least twice so the photographs are taken sequentially and each image needs to cover parts of the other images around it (Girod, 2018). When planning a survey using the parallel method it is important to consider the overlap between images. You can do an along-track overlap, also called the sequential overlap, where you take successive images of the same band or line of images, or you do a cross-track overlap where pictures are taken with an overlap between images of different bands (Girod, 2018). A simple diagram of parameters important in along-track overlap image acquisition can be seen in Figure 9.

According to Girod (2018), the overlap of each photograph on a single line must be at least 67% to make sure that each point is seen at least 3 times. An overlap of 80% is preferred to handle variations of the scene/terrain and for data redundancy. To link images together inter-band overlap is necessary, which can help with hidden parts, like behind buildings as an example, since it provides an additional point of view, but it is not as important as the single band overlap. The inter-band overlap should be 60% to provide an actual overlap of more than 50% (Girod, 2018).

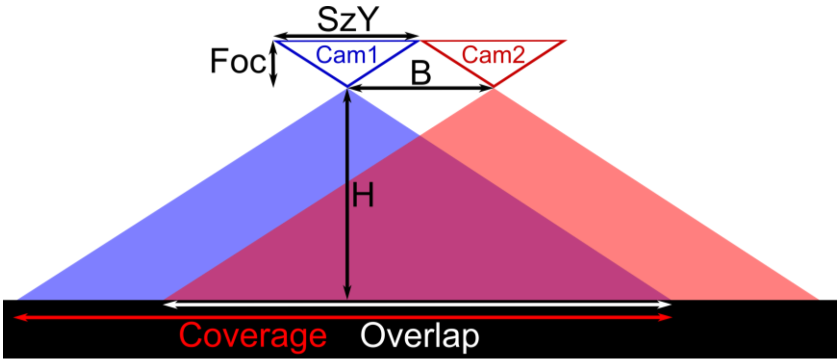

Figure 9. This diagram shows important parameters of an image acquisition of two images (Cam1 & Cam2) along-track. Figure used with permission from Girod (2023).

2.5.1.3 Important Parameters

The Ground Sampling Distance (GSD, in m) or ground resolution is a parameter defined as the size of a pixel projected on the surface of the scene (Girod, 2018). To have an end product with a given GSD is a requirement for most surveys using the parallel method. The ground sampling distance is both dependent on several parameters and it can also affect the settings of these other parameters (Girod, 2018). See the parameters below (and see figure 9 above):

- The pixel matrix spacing of the camera's sensor, $Sz_{Pix,}$ is calculated by dividing the physical width by the pixel's width.
- The focal length of the camera **Foc** (in mm).
- The distance (or flight height) to the scene **H** (in m).

This gives the formula:

$$GSD = \frac{H * Sz_{pix}}{Foc} \tag{2}$$

2.5.2 Tie Points

Tie points (TP) are identified points which correspond to the same location in different images. TPs are necessary to be able to use multiple images in a set and estimate how these images are related to each other. The gathering of tie points can be done manually but it is very time consuming. Automatic search of tie points can be done with the help of computing power by using different automatic tie point detection algorithms such as: SIFT (Lowe, 2004), SURF (Bay et al., 2008) and ASIFT (Morel and Yu, 2009). These and other algorithms can automatically search for tie points in unorganized sets of images. The computing power and the tie point detection algorithms can identify a very large amount of tie points and outliers can then more easily be filtered out. Girod (2018) tells us that the three steps in the automatic tie point collection is as followed:

- Identification of important points. Different algorithms define important points differently.
- The important (remarkable) points are assigned descriptors.
- Descriptors of important points from several images are matched together to determine the tie points.

2.5.3 Orientation and Camera Calibration

The camera(s) need to be calibrated and the collected images need to be oriented, or aerotriangulated, meaning the images are brought together in a unique geometric coordinate system (Girod, 2018). The structure-from-motion (S-f-M) method can do both of these operations, separately or together, by using tie points (Snavely, 2010).

2.5.4 Georeferencing

When the photos are oriented relative to each other in a unique geometric coordinate system, it is usually desired to get an "absolute" reference such as a referencing to a local system for scale or to a cartographic system. Various geodetic information about the scene or object is needed in order to georeference a 3D model, an orthoimage and/or a DEM through absolute orientation (Girod, 2018). Ground Control Points (GCPs) is one way of getting the information needed to be able to georeference. GCPs are points with known coordinates in the desired coordinate system that can be seen in the collected imagery (Girod, 2018). The GCPs can be acquired through different topographic surveying methods such as for example GNSS surveying, or they can be acquired using other products that have been georeferenced such as a map or previously generated DEM or an orthoimage (Girod, 2018).

There are a few mathematical requirements that are needed to achieve georeferencing and they are as follows:

- A minimum of 3 non-co-linear points that can be seen in at least 2 images need to be found (their position in relative space coordinates will be given by optical ray intersection).
- These non-co-linear points must have known positions in the intended "absolute/world" coordinate system.
- The 7 parameters of the transformation between the two systems must be found (1 scale factor, 3 rotations and 3 translations).

For the convergent method the GCPs should surround the scene evenly and be visible in the images (Girod, 2018).

For the parallel method there are several requirements for the reference points according to Girod (2018):

- They need to surround the area of interest (extrapolation is used for zones outside of the reference polygon).
- Some points inside of the area of interest is needed (in order to avert the "dome" or "banana" effect (James and Robson, 2014)).

- To have XYZ for every point is desired but it will still work if some points are Z only or XY only.
- It is always preferable to have more points than strictly necessary, because the precision and accuracy of the data can be evaluated using the unused Ground Control Points.

Camera- or system-integrated GNSS systems, Global Navigation Satellite Systems, are another way to get information on the position of the camera for each picture (Girod, 2018). If the quality of the information given by GNSS is good enough this info can be used on its own to georeference the image or it can be used as complementary data or as a first approximation.

2.5.5 Dense Correlation

The first process of the final reconstruction of the 3D information is called dense correlation or dense multi-view stereopsis (Furukawa and Ponce, 2010). In the workflow being presented later on in this thesis, this process is called "Build dense cloud". Girod (2018) explains that this process can start when the orientation and camera parameters and the position of each image are known and it computes the geometry of the scene using image correlation. Points in the 3D space in a photographed scene can be projected back into the images by using the internal and external orientation of the photographs. By using the internal and external orientation of photographs, a pixel in an image can be projected into an optical ray in the 3D scene. Homologous points can then be searched for in several images (figure 10).

In Girods dissertation (2018) he explains that image correlation is a principle to find common markings in several images and scoring the resemblance between different images. The best score will be identified as a match.

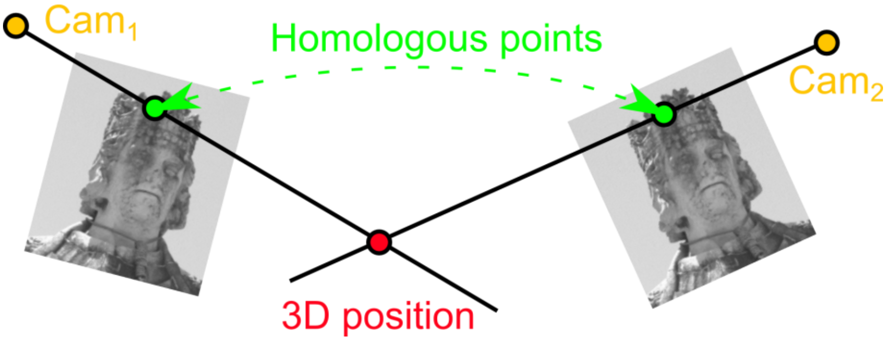

Figure 10. Homologous points seen in two images and the intersecting optical rays of the two homologous points. Figure used with permission from Girod (2023)

In the convergent method (figure 11) a master image must be defined for each subset of images covering the same zone of the scene (Girod, 2018). The master image, or primary image, is defined as the image at the center of a group of images covering the same zone of a scene (Girod, 2018).

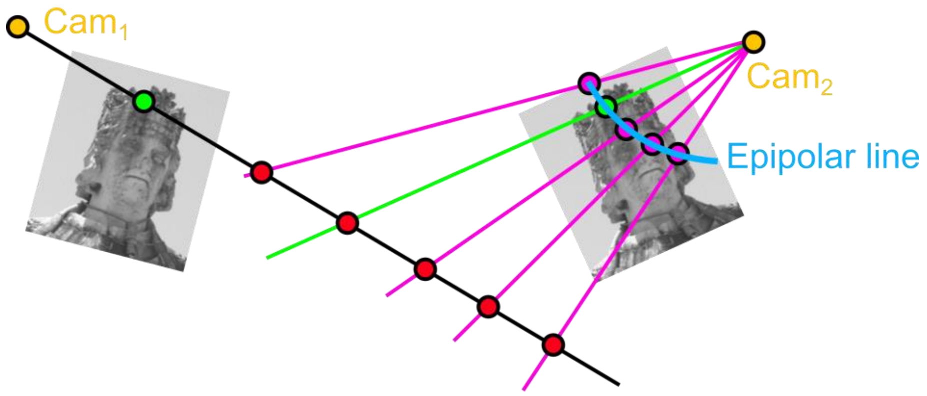

Figure 11. The red points are different 3D solutions along the epipolar line. Figure used with permission from Girod (2023)

Girod (2018) explains that for each pixel of the master image:

- an optical ray is projected into "world coordinates".
- the position of the potential points is computed for different distances on the ray.
- the points are projected into the other images, the points on the images are on the epipolar line.
- the correlation score is computed for each point in each image.
- the position of the point is given by the distance yielding the best compounded score.

2.5.6 Orthorectification

Correcting an image of its optical distortion as well as its terrain and pointing angle distortion is a process called orthorectification. In the workflow being presented later on in this thesis, the process is called "Build mesh". According to Girod (2018) the process for this is done backwards by first finding the radiometric information for each point on the map. For each point (X,Y) of the target grid, apply the following algorithm in order to orthorectify an image (figure 12):

- Find the elevation value (Z) associated with (X,Y) by using a DEM (Digital Elevation Model). Use a geometric interpolation if the target grid is not the same as the DEM.
- The 3D point (X,Y,Z) is projected in the image to get image coordinates (i,j) through an orientation function in the S-f-M method.
- The radiometric value for the query point (i,j) in the image is interpolated.
- The value is recorded in the orthoimage (X,Y,Colour).

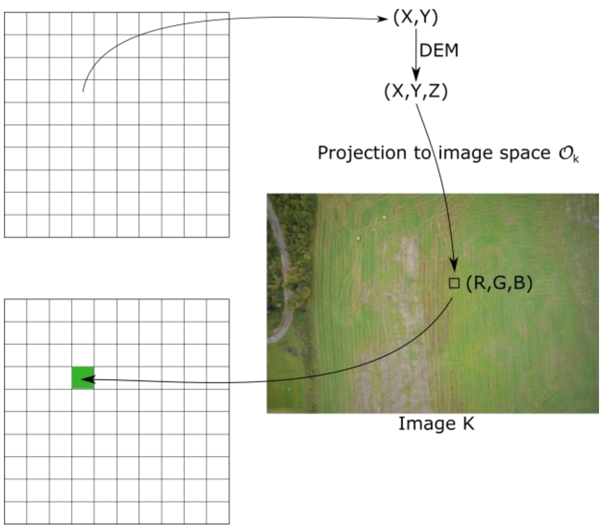

Figure 12. Conception for orthorectification where the image to the right will be used to colour the grid map on the left. Figure used with permission from Girod (2023)

2.5.7 Orthomosaics

When the S-f-M process has computed each individual orthoimage, they can be mosaicked together into a single image of the entire area of interest, such as of a whole model. In the workflow being presented later on, this process is called "Build texture". Because the orthoimages have the same geometry the process of mosaicking is relatively straightforward according to Girod (2018). The values of the images for all query points are averaged as you go through the cartographic space (Girod, 2018). Another method can be used, called the Voronoï diagram (Voronoï,1908; Okabe, 2016; Girod, 2018), where the closest image to the query point is selected to give the colour.

There are however some limitations to these two methods. One limitation is that the same point in the terrain, or in the rock sample, might not have the same colour in all images. Unwanted seams will appear at the boundary between areas covered by individual pictures. To work around or solve these issues, the transition between one picture and another is not defined by each photo's actual border but by boundaries defined by contrasts within the images (Girod, 2018). Another way of solving this problem is to smooth the transitions between images by trying to fit corrections close to the seams (Girod, 2018).

3. Method

I was first introduced to the photogrammetric photo studio and setup, at the department of Earth Sciences at Uppsala University, by Dr. Schmiedel in the spring of 2021. Dr. Schmiedel built the setup and demonstrated its use and explained how to process the images in Agisoft Metashape in order to get digital 3D models of samples being photographed using the setup. A literature study was performed simultaneously as the setup and software were used in order to understand the photogrammetry method and the software.

The manual for the photo session part of the workflow was first composed and then tested by a researcher during which notes were taken of what would need clarifications and of what was redundant in the manual. The manual for the computational part of the workflow, using the software Agisoft Metashape, was composed and another researcher used the full manual, successfully, and came back with some notes on the order of the steps in the manual. The following sections comprise a summary of the manual presented in appendix.

3.1 Set up of SOOSI and Image Acquisition Workflow

SOOSI, *Spinning Object Optical Scanning Instrument*, or the photo studio setup for taking pictures of samples, fits on a rolling cart with compartments for the different materials, such as the lamps and the rotating plate and motor. The material and software for the setup is the 3D photogrammetry bundle from Black Forest Motion (https://blackforestmotion.com/en/applications/3d-photogrammetry-scan/) which consists of the PINE motion controller, slider rail, turntable unit, tilt unit and the necessary cables (figure 13).

Figure 13. SOOSI, the rolling cart with the photogrammetric setup. A. Left: as it looks when not in use. B. Middle and C. right: as it looks when set up and in use (note that the lamps are not turned on).

The Black Forest Motion set-up is controlled through their app, PINE Motion, found on a pad or it can be downloaded to your smartphone. The camera used in the setup is a Sony A77 DSLR with an 18-200mm lens. The lens has lost its locking mechanism so it falls out when tilted down. This was detected while working on making the manual. A solution is to pull the lens out at its maximum to make sure the focal length doesn't change during the photo session. This is not ideal since you want to find a good focal length where most of your sample is within the depth of field and as such a replacement lens should be ordered. One can also try to use tape to fix the lens in a certain position but this solution is less stable than having the lens out in its maximum position. When taking photos of samples with some shiny and reflective surfaces one should use the circular polarizing filter, that can be fitted in front of the lens. The polarizing filter minimize the reflections and glare from the surface of the sample. One can also adjust the amount of lighting and the angle of the lamps.

The background frame with the rotating plate can be seen in figure 13B and 13C. The frame consists of a metal frame with a motor for the rotating plate. The rotating plate and motor can handle samples that weigh up to 40 kilos. The frame can be flipped open to fit the plastic plate that is used to get a uniform background by placing a white or black sheet of paper on it. The frame can be moved in a horizontal direction in order to get the sample at an adequate position from the camera. Choose a background that creates enough contrast to the sample. A white sample might need the black background in order to create a good contrast between the sample and the background as an example.

The sample is placed centered on the rotating plate. The camera needs to be connected by a cable to the PINE Motion controller (unless on is using a camera with wifi that can then be connected through Bluetooth). Make sure the sample is in frame, in focus and that only the background sheet is visible in the background. The sample should be as close to the camera as possible in order to get good photos. The whole sample does not have to be in frame as long as you know all of it will be photographed with enough overlap during the photo session.

The PINE motion app is used to move the camera up and down, to change the tilt of the camera and to decide the settings of the photo shoot. Several sets of images will be taken all around the sample.

The app should be set to make the turntable spin a full 360 degrees. One has to decide the number of rows, how many levels, to take pictures from. The suggested amount is 4 but sometimes 3 rows will suffice, it depends on the size and how complex the geometry of the sample is. The top view and the lowest view on the app need to be set on the app. The number of pictures per rotation is also set on the app. Since Girod (2018) suggests having an angle between 10 and 15 degrees, choose 24, 30 or 36 pictures per rotation meaning you get 15°, 12° or 10° between each frame (360°/24 = 15°, 360°/30 = 12°, 360°/36 = 10°). More than 36 pictures per rotation can be chosen however it will result in a smaller angle, which can lead to errors in triangulation and the photo session and the computational processing will be more time consuming. Setting up and preparing for the photo session shouldn't take more than 30 minutes. The photo session usually takes about 20 minutes but depends on the chosen amount of rows and frames per rotations.

3.2 The Computational Workflow

When the photo session is done move the photos from the camera onto a file on the computer in the room and then open the software Agisoft Metashape. Add pictures to the Agisoft session and disable any bad images. The function for Agisoft Metashape to create a sparse point cloud is called "Align photos". Let the software build a sparse cloud of tie points. The work should be saved after each computational step while following the manual for the Agisoft workflow. Look at the sparse point cloud of the model and delete obvious outliers, such as the turntable which is often detectable (figure 14).

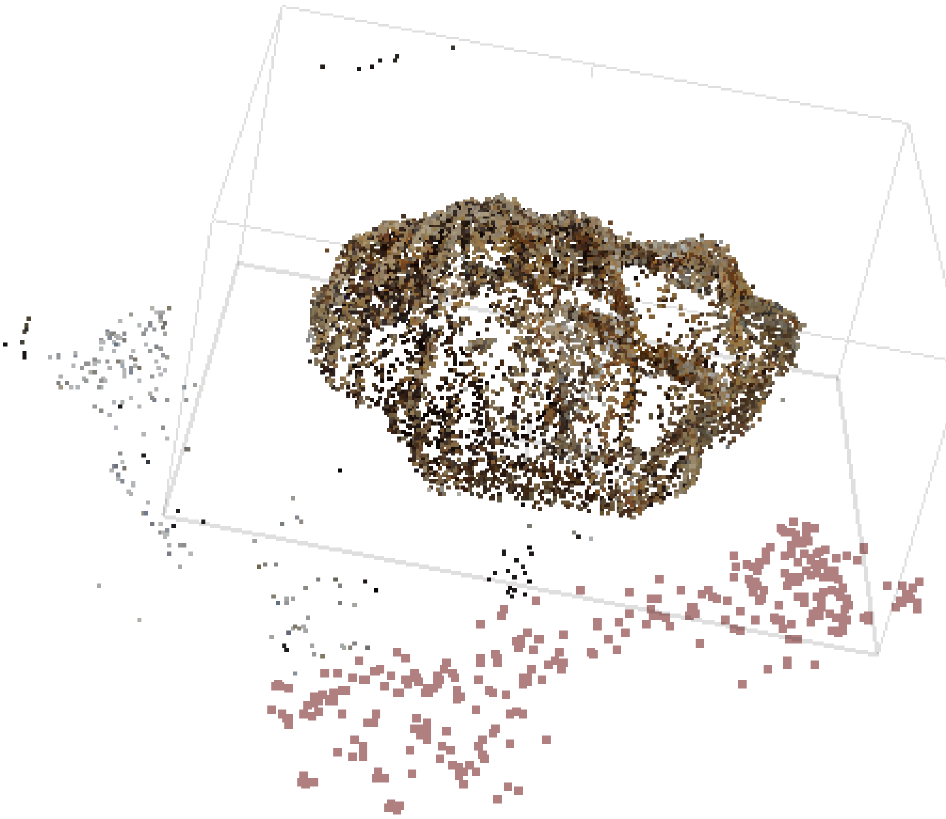

Figure 14. Sparse point cloud of the model with obvious outliers, some outliers marked in dull pink.

Three additional automatic outlier detections are performed:

- Reconstruction uncertainty, level 10.
- Projection accuracy, level 10.
- Reconstruction error value <1.

The next three steps in Agisoft Metashape will take a longer time to process (the time will depend on the amount of photos):

- Build dense cloud.
- Build mesh (figure 15).
- Build texture. When building the texture, the texture count/size should be minimum 4096. This means the program will build a grid with 4096x4096 squares. (A higher number can be chosen but it means the file will be bigger, processing will take more time and the bigger the size the harder it will be to share the model with others.)

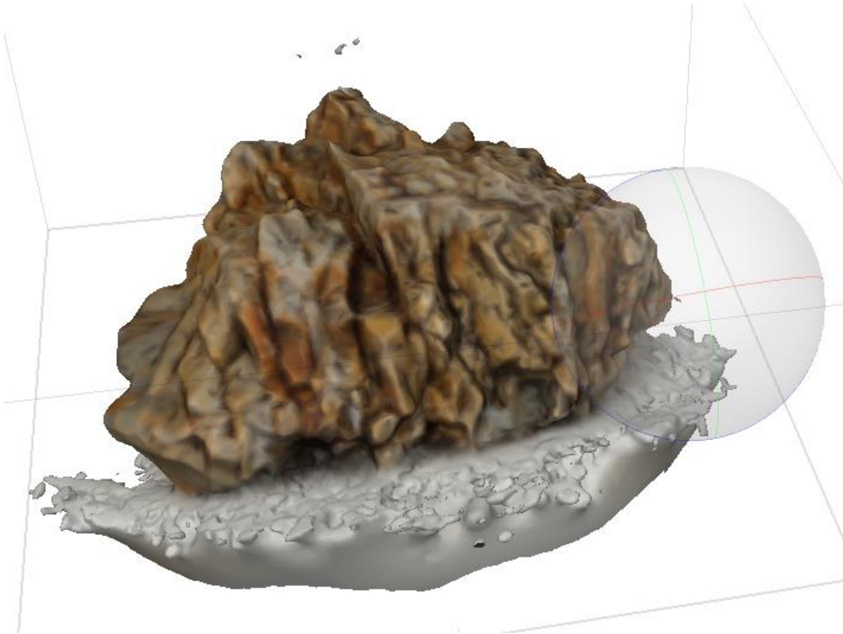

Figure 15. A model of a fractured rhyolite after building a mesh where one can clearly see what part of the model is not of the sample, the light grey parts. These parts can be cropped out using one of the selection tools, such as Free form selection or Rectangle selection.

The end result should be a high-quality 3D model of the rock sample, with one side of the model missing since the base of the sample did not get any pictures taken of it and is therefore "missing" (figure 16). Unless a full model of the sample is desired, it is now time to export the model in the OBJ file format. The texture of the model should be exported to JPEG.

If a complete 3D model is desired the sample must be turned over (180°) on the rotating plate in SOOSI and a new photo session of that side must be performed. The new set of images are then processed in the same Agisoft session by following all the computational steps again until a dense cloud of that side has been built. Merge chunk 1 and 2 in the Agisoft session, then merge dense (point) clouds and thereafter build mesh, followed by build texture. A successful digital 3D model of the sample should now have been produced. The last step is to export the model as OBJ and the texture as JPEG.

4. Results

The purpose of this work was to make a manual for students and researchers to follow to produce digital 3D models of rock samples using the photogrammetric set up at the department. The full manual can be found in appendix. The manual has been used successfully several times by both students and researchers. Below is an example of a satisfactory 3D model (of a rhyolite) after having implemented the manual (figure 16).

Figure 16. Left: 3D model of a (fractured) rhyolite sample after texture being built, with some grey parts (parts of the rotating plate) not having been cropped out yet. Right: a more zoomed in look at the 3D model where the texture of the sample is showcased.

A good 3D model of a carbonatite was also produced, called the Alnö sample (figure 17). Two sets of photos were taken in order to get photos of all the sides of the sample using 72 rotations (5 degrees). An excess amount of photos were taken to see if that would improve the amount of detailing on the digital 3D model. Each set of photographs were processed independently but within the same Agisoft Metashape session. Dense point clouds were computed separately using the two sets of photos and were subsequently merged. Finally, a mesh was computed of the merged dense point cloud, on which a texture was built. Figure 17 shows the wire frame, or mesh, of the dense cloud of the merged model to the right. To the left in figure 17 you see the wire frame of the same sample but generated from a set of images of 18 frames per rotation. One way to show that the model is of good quality is to look at the model wire frame. The smaller the triangles the better the quality of the model. Another first assessment is to look at how many points you have in the dense point cloud, the more dots the better the model. Figure 18 shows the texture of the two models where one can see a lot of details in the minerals of the rock sample in both models but with a slightly better quality in the model from the 72 frames per rotation set.

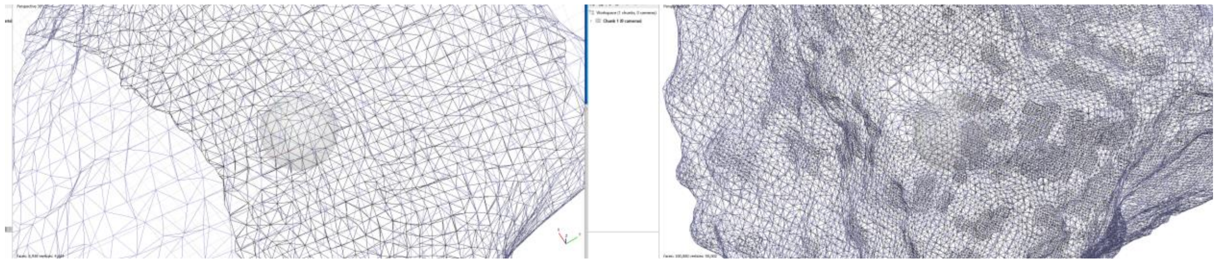

Figure 17. Wire frame of two models of the same sample, looking at approximately the same area, where the size of the triangles are clearly smaller in the model to the right. The left model is processed from a set of images taken with 18 frames per rotation, meaning a 20° angle between each image. To the right a model processed from a set of images with 72 frames per rotation, meaning 5° angle between each image.

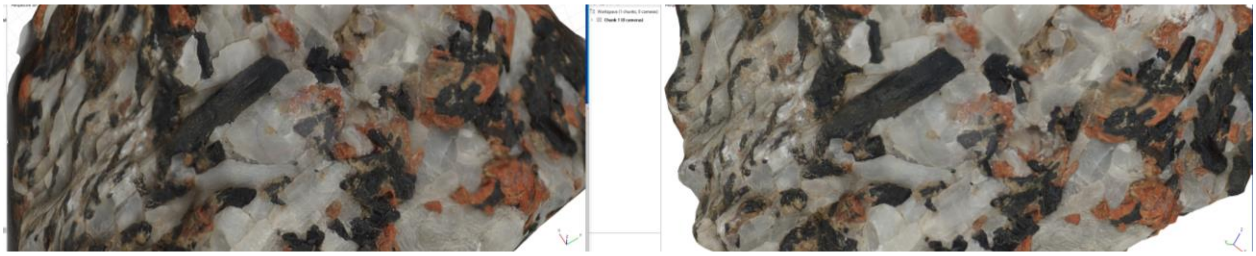

Figure 18. The texture of two models of the same sample, looking at approximately the same area. The left model is processed from a set of images taken with 18 frames per rotation, meaning with a 20° angle between each image. To the right a model processed from a set of images with 72 frames per rotation, meaning 5° angle between each image. The 3D shape of the sample is rendered more accurately in the model to the right. This can most obviously be seen looking to the left side of both of the models. Some surfaces of individual minerals can be equally well rendered in both models.

5. Discussion

5.1 Problems and Limitations

5.1.1 The Camera Lens Problem

The biggest limitation in the workflow to produce 3D models is the problems with the camera and camera lens. The fixed lens, found at the department, have a tendency to not take good pictures, which could be due to the focal length of it not being optimal for the photo studio setup. The adjustable zoom lens has a tendency to fall out which will lead to images with different focal lengths, and having pictures not in focus, within the set of photographs. This leads to low quality of images and low alignment of the photos, which then makes further processing in Agisoft redundant since it doesn't give enough points to work with in the sparse point cloud. The setup today uses a camera which does not have a fixed focal length.

Several sets of pictures were taken of a fairly large gypsum rose but there was always something failing to work such as bad wire connection between the camera and the PINE motion controller, or the lens falling out when tilted down to take pictures from above, thus rendering a set of images with different focal lengths. Other sets of photos, also with camera issues during the photo session, but with a lower number of pictures per rotation was done, 18 frames per rotation which gives an angle of 20 degrees between each frame. These pictures were processed in Agisoft Metashape resulting in a very bad model (figure 19). It is clear from looking at figure 19 that the model is not resembling the gypsum sample, meaning there wasn't enough information to render a representative 3D model (figure 19 and 20). The texture of the model is also poor.

Figure 19. The result of a failed try to do a 3D model of a complex gypsum rose

Figure 20. A photograph of the gypsum rose sample that was not successfully made a 3D model of.

5.1.2 The Reflection Problem

Another optical limitation is the problem with reflections. Following the workflow and using the material at hand in the photo studio SOOSI limits the type of rock samples that can be rendered a 3D model of. A shiny surface, such as certain mineral surfaces on a rock sample, will look different in different lights. The same surface will look different depending on the angle the light hits the surface, thus the same point will look different in each photograph of the photo set. Taking photos of samples with large numbers or large areas of shiny surfaces will yield images that can't be used for processing to produce a 3D model because Tie Points (TPs) will be hard to find and will not be evenly spread out. A set of photos were taken of a piece of obsidian, to test and illustrate this problem. A circular polarizer was used on the lens to reduce reflections and glare. Most photos looked good but the aperture might have been too open (i.e., the f number was too small) because the depth of field was fairly short leading to the area in front and in the back of the picture being fairly blurry. Because the surface of obsidian is shiny one will always get a reflection. In each picture the light is being reflected in a different angle so the same surface of the sample looked different in each photograph (figure 21 and 22). The sample is also almost completely black with large smooth homologous surfaces so there aren't many distinct points to be found in the photographs. The quality of the images was bad and it resulted in a sparse point cloud with very few tie points.

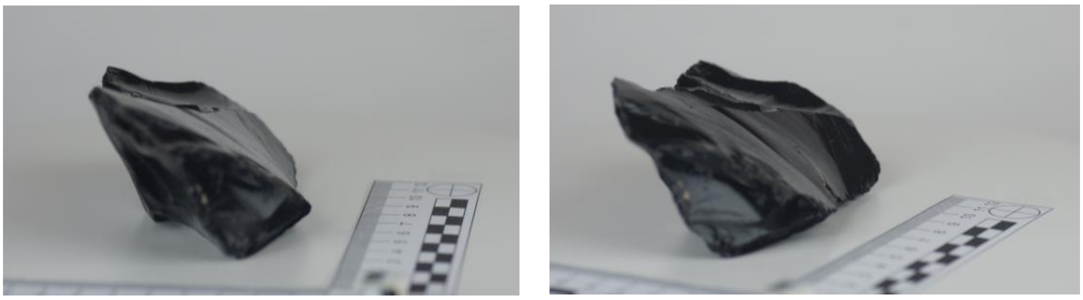

Figure 21. Two images, of obsidian with a white background, separated by an angle of 20 degrees showing how different the same surface looks from the different angles of view.

Another set of photos were taken of the obsidian using a black background to try and get a more diffuse light and minimize the glare and reflections (figure 22). The low contrast between the object and background means you will get more noise in the pictures. The pictures looked good but again the reflection of the light in each image makes it impossible to define enough tie points in order to make a good model. In figure 23 you can see the sparse point cloud and how few and scattered the points are and in figure 24 you see the sparse cloud of the Alnö sample as a comparison.

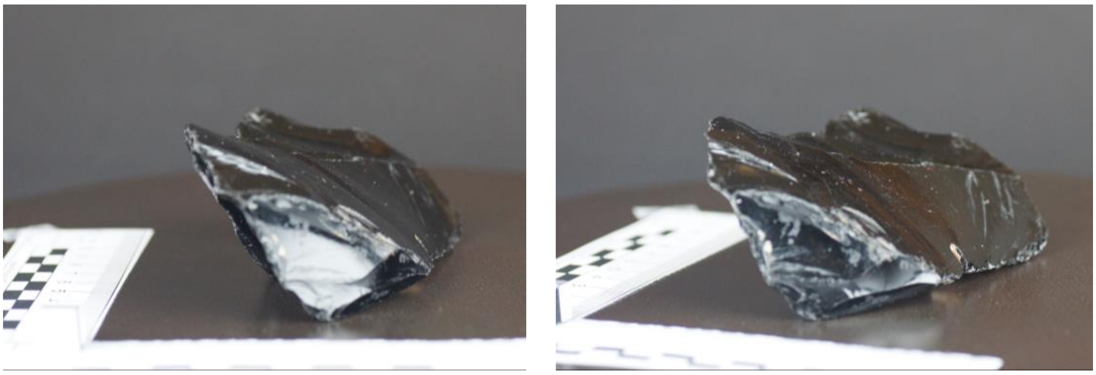

Figure 22. Two images, of obsidian with a black background, separated by an angle of 20 degrees showing how different the same surface looks from the different angles of view

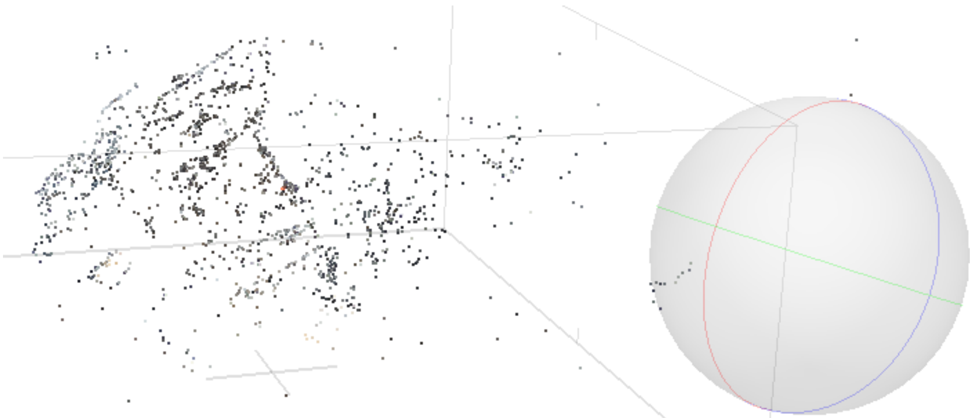

Figure 23. The figure is showing the sparse point cloud, with very few and scattered points, generated from pictures taken of the obsidian sample with a black background and with 18 images per rotation.

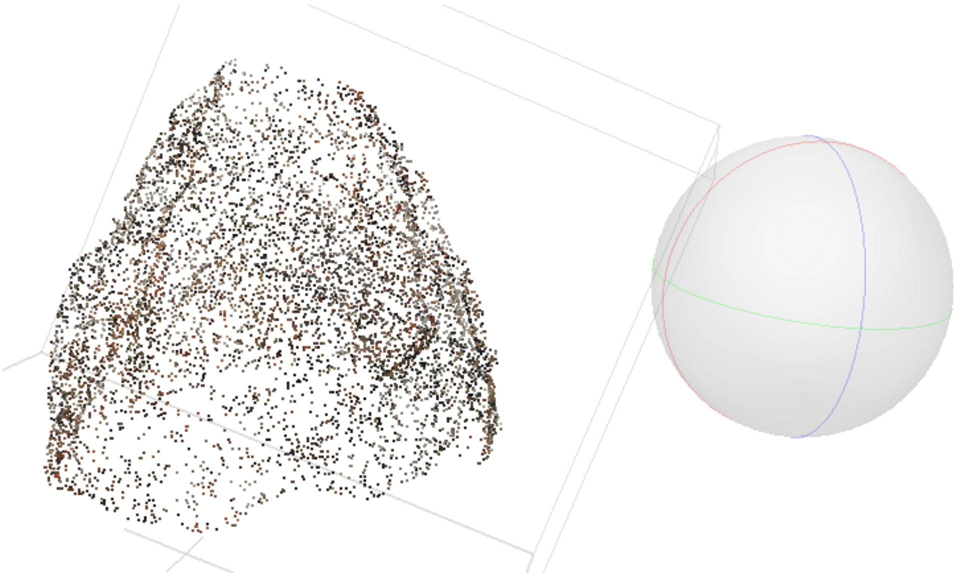

Figure 24. The sparse point cloud of the Alnö sample processed from a photo set of 18 images per rotation.

5.1.3 The problem of unregistered part of samples

A physical limitation with the SOOSI setup is that of not always being able to take photographs from above and underneath a sample. Some samples may only be able to sit with one specific side as the base due to their geometry. Using SOOSI as it is now does not offer a solution to being able to take photos of all the sides of such samples.

5.1.4 The Scale Problem

Today, the 3D-models produced using this work method possess an arbitrary relative scale. We can get the correct relative geometry and structure of the samples but not its true scale. While developing the work method a cube with known dimensions was put next to the sample when taking photographs but the processing failed to result in getting an absolute scale of the sample. In order to convert an arbitrary scale to an absolute scale, GCPs (Ground Control Points) are required. One way of establishing GCPs is to mark out a few spots on the sample to use as GCPs but it means those would cover a few points of the sample. Exact measurements of the GCPs marked out on the sample are hard to obtain unless the sample has very plane surfaces, which would then limit the range of samples to do 3D-models of with an absolute scale.

5.1.5 Problems with Online Sharing

The digital 3D models produced in this work were only studied by using the software Agisoft Metashape. The manual presented in appendix propose saving the digital 3D model files as OBJ and JPEG but upon testing to upload the model to share it online on sketchfab.com the geometric shape of the sample could be seen but not the texture. One might need to upload more files with the model or use other file formats.

5.2 Solutions and Improvements

5.2.1 The Camera Lens Solution

An improvement to the work method would be to have a camera lens with a fixed focal length appropriate for the distances in SOOSI. This would reduce inaccuracies in the cameras optical parameters and would make the method more robust. Since the image acquisition is the first and most important process in the photogrammetric process it would be wise to invest in a fixed lens in order to ensure getting images of good quality.

In order to get a reliable and decent digital 3D model of the complex gypsum rose the photo sets need to be of an appropriate quality, which would be more likely to obtain by using a fully functional camera lens. As in previous examples, taking two photo sets of the sample with the sample laying on two different sides allows for a better coverage. The sets should be of at least 36 frames per rotation, as to get a 10-degree angle between each image from 4 different levels, i.e., taking pictures from 4 different heights. Using extra lighting from different angles to try and illuminate as many parts as possible of the complex gypsum rose sample would enhance the quality of the images. More pictures of a sample, rather than fewer, gives better 3D models with a more accurate geometry, with less blurry parts and it also gives you the opportunity to zoom in and see more of each crystal in the sample with good image resolution. Simply put, more pictures give more details of the sample but the time needed for taking the pictures will be longer and the processing time in Agisoft will also be longer compared to using a smaller amount of photographs. The digital 3D model made with a large amount of pictures will render a bigger data file which may be harder and more time consuming to share and upload.

5.2.2 Solutions to the Reflection Problem

For very reflective and homogeneous materials, such as obsidian, problems arise with the photogrammetric method like not being able to identify tie-points. Using a polarizer, which only lets light of certain polarizations enter, may alleviate the problem. Obsidian though, as an example, is much too homogeneous and reflective for tie points to be found at all, even if using a polarizer. Other workflows and set-ups are needed in order to make digital 3D models of obsidian or samples with similar properties. A very good paper on such methodology was presented by Apopei et al. in 2021.

5.2.3 Solution to the Problem of Unregistered Part of Samples

To be able to take pictures of all sides of a sample that can only rest on one side one could try to use a material that could be set as a resting block on the rotating plate for the model to rest and balance on. The resting/balancing block would have to be stable because you cannot have the sample wobbling and moving when the pictures are being taken. Poster putty might be a good material to try for this purpose but you would want to make sure it doesn't leave any residue on the sample. Usually, there are a few sides of a rock sample that are of interest and not having a complete digital 3D model showing all sides of the sample will mostly not be an issue, but it does look better to have a full model.

5.2.4 The Scale Problem Solution

Documenting rock samples in the form of digital 3D-models can be a valuable tool. One reason is because when wanting to share information between scientist one may want to avoid physically sending samples by mail, so instead one could send the digital 3D-model of the sample. It also makes it possible to look at the sample after it has been destroyed after making thin sections. The method also lends itself for fragile samples that might easily break and it avoids unnecessary manipulations. You can zoom in and look at structures and minerals without using a loupe or microscope. This could be very useful in educational purposes when speaking and showing the sample in front of a bigger crowd. For teaching, a digital 3D model also allows each individual student to interact with the sample simultaneously. Furthermore, scientists could use 3D models of samples at conferences to make more accessible presentations and they wouldn't have to carry heavy rocks around.

3D models can be published online on, as an example, Sketchfab.com (Perkins et al. 2019 & Apopei et al. 2021). The models produced with the SOOSI setup and method do not have an absolute true scale and no information about the size of the rock samples are given with the models. Therefore, it would be a good idea to add that information to all 3D models of rocks and minerals being published there. The usability of the models would increase immensely if a method were to be developed to yield 3D-models with an absolute scale. Such models could be used more scientifically to obtain properties and textures of the rock samples.

A solution to the problem with obtaining GCPs, and ultimately obtaining the true absolute scale, would be to develop a wire frame in the shape of a cube that could easily be detached and locked securely on the rotating plate. The wire frame would have markings for GCPs which should be accurately measured. The sample would be placed inside of the wire frame for the photo session and the GCPs could then be used in Agisoft to give the absolute scale. One problem though could be that the frame would cover a small part of the sample. This problem would be mitigated by making sure to have enough pictures taken from different levels. The size of the wire frame would, of course, limit the size of the samples that can be photographed but this could be remedied by making several wire frames of different sizes. In order to produce a digital 3D model of a whole sample (all sides of the sample) with an absolute scale, one would take one set of pictures of the sample with the GCP-wire frame. Then flip the sample as to get a set of photos of the underside of the sample but without using the GCP-wire frame in that second photo session. Process both sets of photographs separately in Agisoft and then merge the two models which would render a complete 3D-model of the sample with an absolute scale.

5.2.5 Mitigate Online Sharing

The digital 3D models could be seen and studied in Agisoft Metashape by opening the OBJ file of the model and the JPEG file with the models' texture. Further investigation is needed to find out what files and file formats are necessary to be able to share the 3D models and what other software could be used to study the 3D models. Adding the information of the findings from such an investigation would improve the manual.

6. General Conclusions

This work has resulted in the following main conclusion:

- A systematic workflow for the use of photogrammetry and Structure-from-Motion to study and record rock samples and other objects that fit in the SOOSI studio has been developed.

Moreover, this work has shown that the following changes would further improve the setup, method and usability:

- Investing in a fixed lens which allows for less uncertainty in key photogrammetric parameters. It will also ensure a more repeatable setup.
- Developing a method of measuring GCPs to establish an absolute scale for the 3D models.
- Developing a wire frame cube with established GCPs and dimensions.
- Exploring what software to use to analyze and study the 3D-models.

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Appendix

The Manual for SOOSI

SOOSI, or the photo studio setup for taking pictures of samples fits on a rolling cart with compartments for the different materials, such as the lamps and the rotating plate and motor. The material and software for the setup is the 3D photogrammetry bundle from Black Forest Motion which consists of the PINE motion controller, slider rail, turntable unit, tilt unit and the necessary cables (figure A1).

Figure A1. SOOSIE, the rolling cart with the photogrammetric setup. Left: as it looks when not in use. Middle and right: as it looks when set up and in use.

Everything needed for the set up should be on the trolley except for the camera, camera lens and polarizer which are usually found in the bookshelf next to the door. If the pad is not there it is often in Dr. Borchardt's office. The PINE Motion control unit sits on the handle of the trolley just behind the vertical slider rail. Never remove any cords connected to it, unless another camera is used with a different connection than the in-house camera (the extra connection cord should be found in the same box as the polarizer found on the shelf). The Black Forest Motion set-up, and the PINE Motion control unit, is controlled through their app, PINE Motion, found on the pad or it can be downloaded to a smartphone.

The setup phase for SOOSI

1. Check that there is a SD card in the camera and that the camera battery is charged. Make sure the card is empty, if not delete the photos that are there. (Remember to save your photos. They will be deleted from the SD card if you haven't done it yourself. Please remove all your photos from the SD card before you are done for the day.) Remember to turn off the camera and put on the lens cap when done to save the battery for the photoshoot.

2. Detach the L-bracket (Quickfit plate) from the vertical slider rail. The L-bracket is the only thing on the slider rail you should detach. Don't detach, move or change anything else manually on the slider rail because the tilt of the camera and the vertical level of the camera are moved by motors using the app.

3. Plug in the coiled-up cord, marked with a yellow dot, (already plugged in to the PINE motion controller, marked with a turquoise dot) to the camera, found under the ‘Remote’ hatch on the left side of the camera, and attach the L-bracket with the short side on the outside of the cord (figure A2). Because the jacket is a bit loose, make sure the connection is tight by using the L-bracket to hold the connector in place. (If you are using another camera with a different connection an extra connection cord should be found in the same box as the polarizer found on the shelf.

Figure A2. Left image showing the placement of the “remote” hatch on camera. Right image showing the L-bracket attached to camera in a way that it holds the connector in place.

4. Slide the camera with the L-bracket in place from above on the tilt unit, on slider rail, and secure it by turning the knob. You can choose to have the camera horizontally or vertically.

5. Open the background frame and take out the white plastic plate (background) from its compartment and lay it out on a flat surface. Fit the plastic plate into position on the frame. Easiest to start threading the hole over the motor and fitting the lower part into position and then bend it by pushing the upper part down with one hand while the other hand is pressing the plate down in the bend.

6. Take out a sheet of white paper and cut out a hole by tracing the hole in the plastic plate. Attach the sheet over the plastic plate with tape. At least 3 bits of tape on each side. Make sure the sheet of paper is fastened onto the plastic plate so that you can't accidentally tear it off because it was too loose. The white sheet of paper should be found rolled up under the table and the black sheet in the tube under the table.

7. Find the big box with the rotating plate motor (marked with PINK coloured dot) and the rotating plate. Attach the motor to the holder on the frame and make sure you have it fairly centered on the holder and attach the plate to the motor centered as well (figure A3).

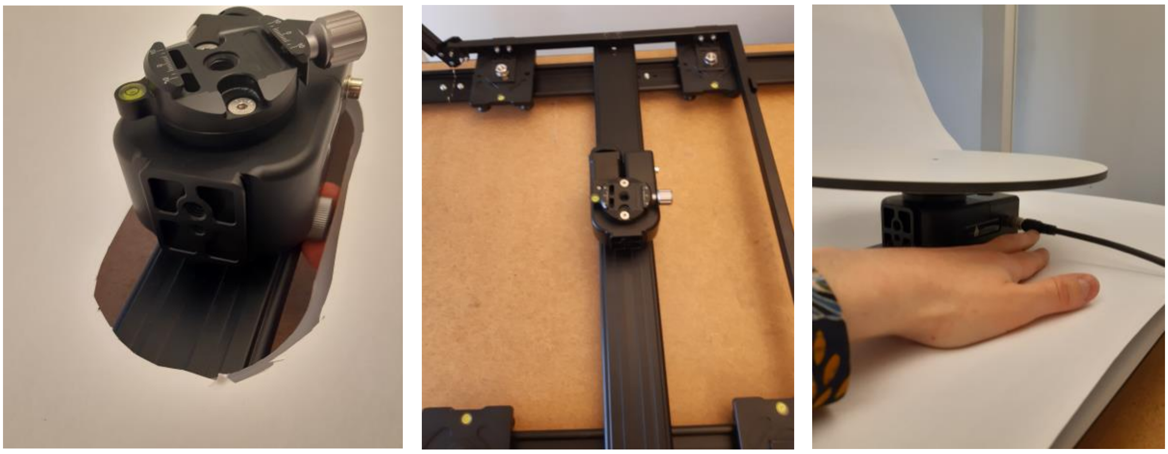

Figure A3. Left: image of rotating plate motor. Image in the middle depicting part of the frame with the rotating plate motor attached to it. Right: image of rotating plate attached to the motor and connected to the pine motion controller through Signal cord 3.

8. Place the sample at the center of the rotating plate and check if it is in frame, if not move the motor a bit and/or move the whole frame back or towards the camera. You want the sample to be as close to the camera as possible in order to get good photos. The whole sample does not have to be in frame as long as you know all of it will be photographed during the photo session. Remember to turn off the camera and put on the lens cap again to minimize risk of getting dust on the lens.

9. Plug in Signal cord 3 (marked with PINK dot and already plugged into the PINE motion controller) to the rotating plate motor by gently inserting and rotating the connector until it fits in the contact. Removing the cord is done by pulling the metal jacket. If the signal cord is not plugged in it should be plugged into the pine motion controller where you see a camera symbol (figure A4, middle) underneath and in between 2 and 3.

Figure A4. Left: Rotating plate motor connected to PINE motion controller. Middle: The cord between rotating plate motor and PINE motion controller should be connected in the hole marked with a camera underneath 2 and 3 on the PINE motion controller. Right: The SOOSI set-up with the background well fitted on the frame.

10. Connect the white power strip found under the table to a power outlet in the room and turn it on by switching the red button on.

11. Assemble the clamp feet for the LED lights (Nanlite Compac 100 Lights, they are of 5600K), marked with a blue-coloured dot, found in the big plastic box (figure A5).

12. Set up the lamps found in the two lowest compartments on the trolley. You can angle the lamps towards the sample to some degree but not more than approximately 20° tilt. If you really need a lamp from above or with a high tilt there are arms in the plastic box that you can try to use as support so the lamp doesn't fall over. You can also play around and use the lamps in the ceiling if you need more light.

13. Connect the lamps to their power cords marked with blue-coloured dots, while holding on to the top of the light with the other hand so you don't accidentally push the light to fall over and onto the sample. Make sure the lights are set on minimum brightness before turning them on and off (figure A5). Turn them on and adjust the brightness and the orientation of the lights in order to get as few shadows as possible.

Figure A5. Left: Clamp feet for the lamps. Middle: Lamps should be off and the effect turned to a minimum to avoid destroying the lamps when connecting them to power. Right: Connecting the lamps to power.

The Control Phase

14. Turn on the camera and remove the lens cap and check that the lights are not in the way of the sample in the frame. Make sure the sample is in frame with only the white (or black) background in frame. If you are using the camera and the camera lens at the department, make sure the lens is all the way out because the lens can't lock itself to one focal length. If it is not all the way out there is a risk it will fall out during the photo session which will give you different focal lengths which is something you do not want.

15. You want the sample to be as close to the camera as possible in order to get good photos. The whole sample does not have to be in frame as long as you know all of it will be photographed during the photo session. You do not want to have anything else in the frame than the sample,

the turntable and the background frame. You can move the background frame by loosening the red knobs, two on each side. You can also flip the camera on its side.

16. Turn on the tablet by pressing the side button on the top of the left short side. open the black forest motion app, PINE Motion (figure A6).

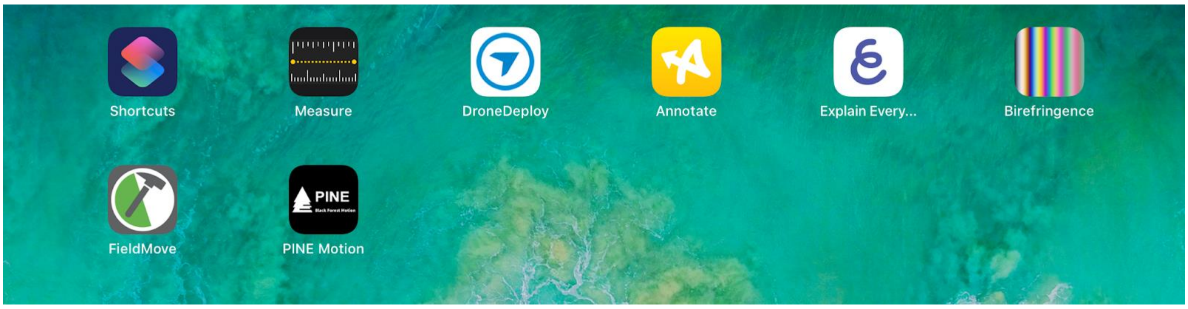

Figure A6. The PINE motion app found on pad, seen on the second row to the left.

17. Check on the PINE motion controller, the black box behind the slider rail with cords connected to it and marked with a turquoise dot, that the power is on, a green light should be blinking on the side, and check that it is connected through Bluetooth to the pad, blue light blinking on the side. If there’s no Bluetooth connection go into settings on the pad and turn it on and choose to connect to ‘PINE R’.

18. ‘Motor Quick Setup’ might pop up when you open the app (Figure A7). Choose for:
    Motor 1.1: BFM slider 19:1
    Motor 1.2: BFM NT Head
    Motor 1.3: BFM 3D-Turntable.

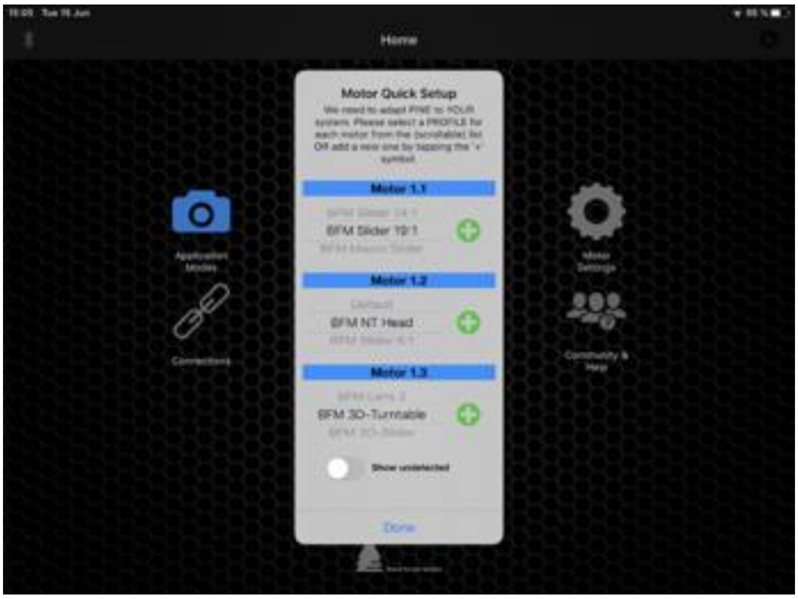

Figure A7. The motor quick setup as seen on the PINE motion app.

19. If the connection isn't working, e.g. can't find motor 3, unplug motor 3 on the pine motion controller found behind the rod and plug it in again. If it still is not working, turn the power off and on again and try again, also, try closing the app and open it up again.

20. Press 'Application Modes' and then 3D-Scan. '3D-Mode Motor Selection' will pop up, for Turntable choose motor 1.3 and none for focus since our focus is manual (figure A8).

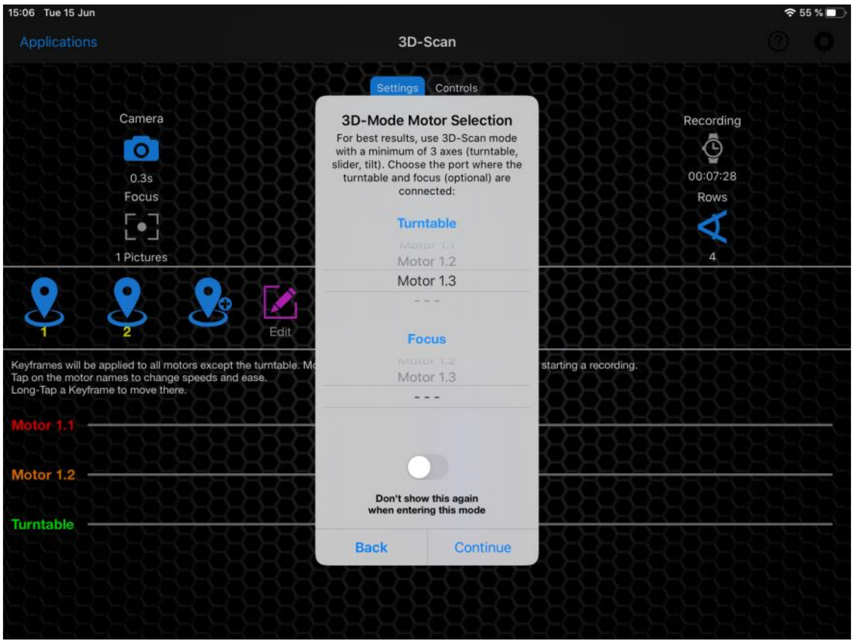

Figure A8. The 3D-Mode Motor Selection as seen on the PINE motion app.

21. Turn on the camera and set it on autofocus (if you are in Automode, then it is always under autofocus. If you are using manual mode, please set it to autofocus instead of manual focus).

22. Move the camera up to the level you want to set your top view by using the app, motor 1.1, and angle the camera, motor 1.2 (figure A9). You move the motors by sliding your fingers over the bar on the app. Press 'Set View Above' on the app when you have decided on the level and angle of the camera (figure A10). There should be a green 'check' sign over the blue figure on the app when it is set. You can override and set a new top level by pressing the figure and choose 'override'.

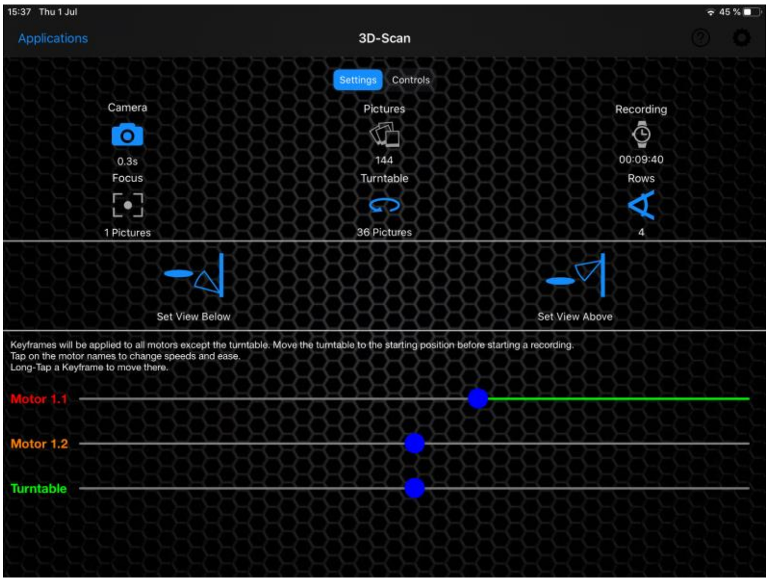

Figure A9. Sliding the finger over the motor 1.1 bar to get the camera on the rod to move up or down (it is quite slow moving). Same procedure to get motor 1.2 to change the angle of the camera or to get the turntable to rotate.

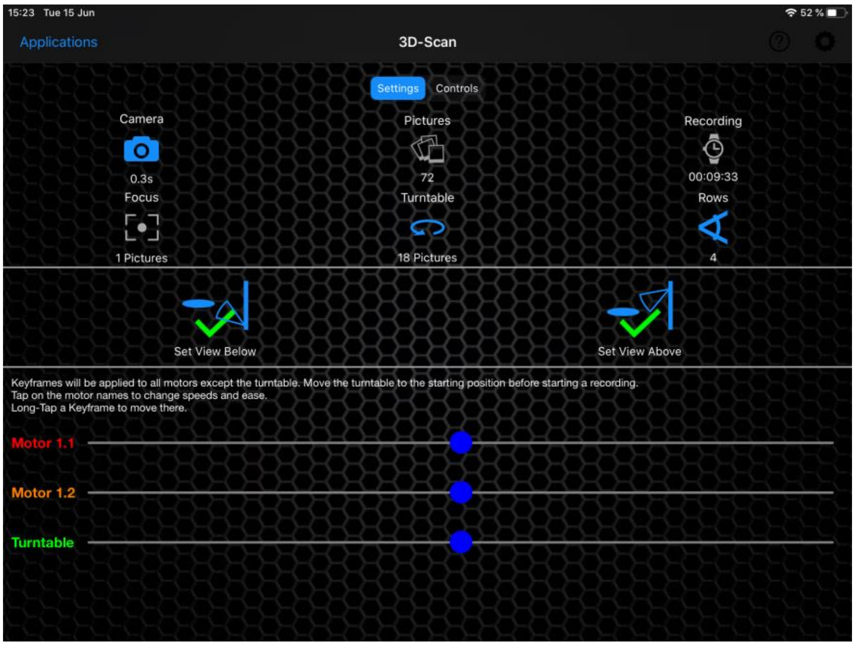

Figure A10: The green check mark for having set view from above and from below.

23. Move the camera down, and angle it, to set the view from below. Press ‘Set View Below’ on the app.

24. Focus the camera with the setting on the knob next to the lens set to MF, when focused turn the knob to any other setting so the focus is fixed.

25. Decide how many levels you want to take pictures from (usually 4) and change it, if necessary, by pressing on ‘Rows’ on the app (figure A11).

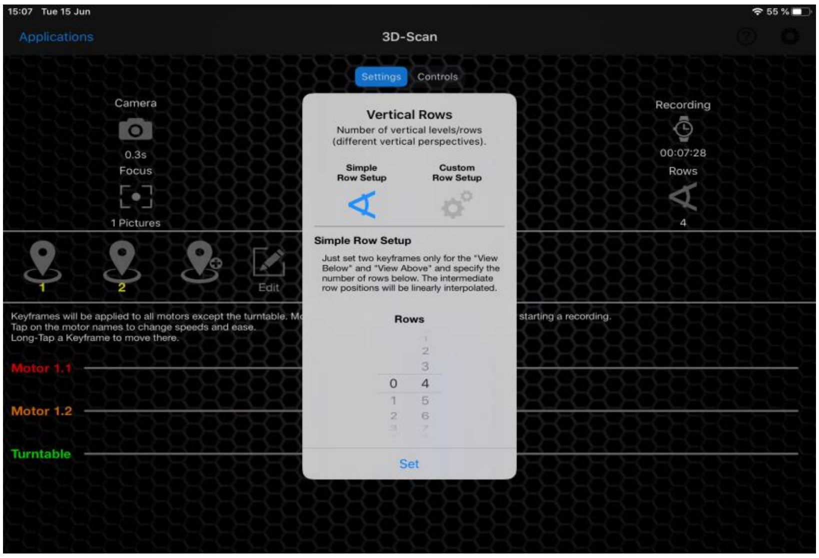

Figure A11. Choose the number of vertical rows in the PINE motion app.

26. Decide how many pictures per rotation you want and change it on the app, if necessary, by pressing 'Turntable'. You want to have enough rotations so that you have an angle between each picture not bigger than 20° (18 pictures per rotation means 20° between each frame, 360°/18 = 20°) in order to get enough overlap for the photogrammetry. I suggest starting with 30 or 36 rotations meaning you get 12° or 10° between each frame. A thumb rule is that you want as few pictures as possible to still be able to give good data and a good 3D-model. The more pictures you have the more time the data processing will take and a model with a lot of data will be much harder to share then a good model with a smaller amount of data points.

27. Make sure to write down what settings you've decided to use: how many levels, how many frames per rotation (and what angle between frames) and the total number of pictures you will have after the photo session. Also, write down: how much light you are using, maybe take a picture of the setup so you see the angle of the lights, if you are using the polarizer, what sample you are working with and the date so that it is easy for you to go back and see what you have done at a later stage.

28. Take a picture manually of your hand in the photo so that you can easily find the start of the first photo of photo session when looking at the images on the computer later (but make sure the focus doesn't shift to your hand instead of the sample when taking that picture).

29. You are now ready to start the photoshoot. Change the view from Settings to Controls → press start (figure A12).

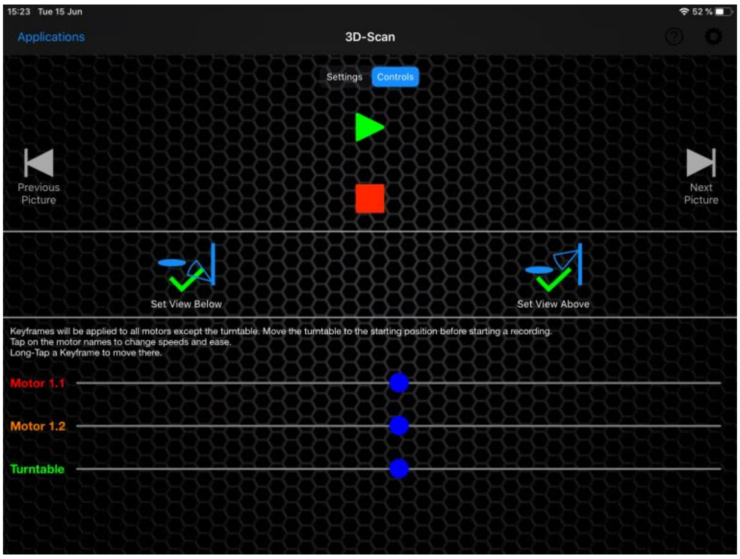

Figure A12. Change the view from Settings to Controls.

30. Check that the photos being taken are in focus. You see the photo on the screen on the camera. If not in focus, press the pause button on the app and change the focus on the camera by switching the knob next to the lens to MF, refocus, switch the knob and press start on the app. Due to the lens and/or the camera you might have to do this on each level and maybe even during each rotation so keep an eye on the photos being taken on the camera and be ready to pause and change the focus. (If the pictures being taken are suddenly out of focus you can try to pause the session in the app on the pad, and reset the focus. If the session does not pause, it happens sometimes, just try to reset the focus while in session.

31. When the photo session is over, put on the lens cap and turn down the lights and turn them off.

The Computer Session

32. The computer should always be on so if the screen is black turn the screen(s) on and log in by using your username and password.

33. Make a folder with your name in This PC → Erika (D:). Make a new folder within your folder named something like “photos of sample x”.

34. To plug in the camera to the computer: take out the USB cord, marked with a yellow dot, that is found in the small plastic box (often found in the bookshelf close to the door) and plug it in the camera and in the fast (blue) USB port on the computer. Make sure the camera is on to see the files on the computer.

35. Move the photos from the camera to your photo file. Make sure to empty the SD-card on the camera before you turn it off. Remember to turn off the camera after you’ve moved your photos from the camera to your file on the computer.

36. Open Agisoft Metashape.

37. Click on: Workflow → add pictures. Open your folder with pictures and choose 'jpeg only' on the bar down to the right. Choose all the pictures.

38. Make sure you are in workspace and not in reference which you can see in the lower left-hand corner of your Agisoft window.

39. View → photos. You should see the photos in a window that you can move to the other screen.

40. In the photo window you can look at the photos and disable the ones you don't want to use, like if you have photos of your hand or photos taken before you started the session and photos completely out of focus.

41. Disable photos by right click → disable.

42. Choose all the photos, you haven't disabled, in the list with info then right click and choose 'Estimate image quality', a window will open, choose 'selected cameras'.

43. Look at the list with info about the photos and disable all the photos with image quality under 0.6. You can change the view in the photo window to information instead of seeing each photo as a thumbnail (figure A13).

Photos

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DSC04954	6000x4000	✓	0.640897	2021:05:21 17:08...	SONY	SLT-A77V	90	F/4.5	100	1/250	135			90	D:/TobiasS_Work/IcelandDykeTip/DSC04954.JPG
DSC04955	6000x4000		0.560945	2021:05:21 17:09...	SONY	SLT-A77V	90	F/5.6	100	1/250	135			90	D:/TobiasS_Work/IcelandDykeTip/DSC04955.JPG
DSC04956	6000x4000	✓	0.650913	2021:05:21 17:09...	SONY	SLT-A77V	90	F/5.6	100	1/250	135			90	D:/TobiasS_Work/IcelandDykeTip/DSC04956.JPG

Figure A13. The window with the photo information. In this window you can see what images are disabled because of low image quality, you also see which frames have been aligned and other data about the optical parameters of each image.

44. Workflow → click 'Align photos'. A window will open with settings. Choose: General: accuracy low and generic preselection; Advanced: key point limit 40.000; Tie point limit 4.000 and adaptive camera model fitting (figure A14).

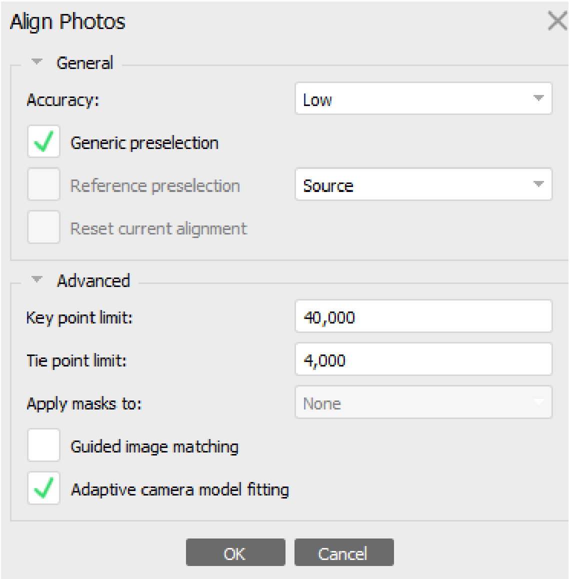

Figure A14. Align photos settings.

45. Save your work.

46. Look in the list if you have some pictures that didn't align. You can manually choose a photo before and after the one that didn't align and right click and choose 'Align selected cameras'.

47. Look at the model. You should now see a sparse point cloud of the model (figure A15) and you can start deleting obvious outliers, such as the turntable which is often detectable.

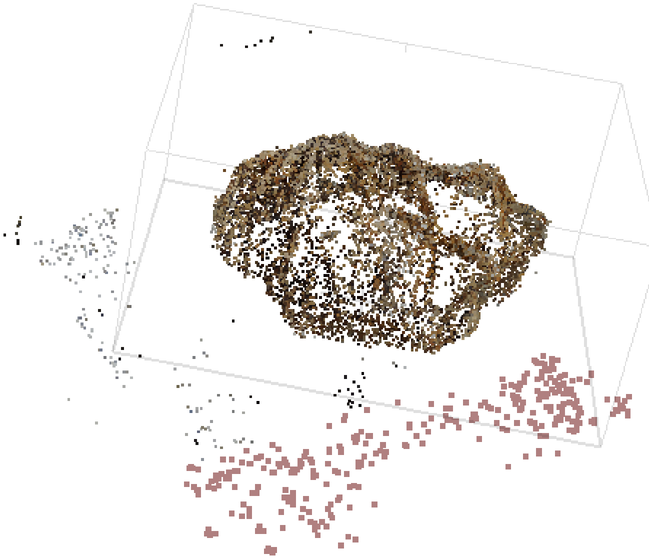

Figure A15. Sparse point cloud of the model with obvious outliers, some outliers marked in dull pink.

48. The whole model can be moved around by moving the mouse while pressing down the scroll wheel on the mouse. You zoom in and out with the scroll wheel on the mouse.

49. If you can already see what is the sample and what are obvious outliers, like the rotating plate, you can manually select those outliers like this: Model → Free form selection, mark the outliers by hand and delete. The selected points and/or area are shown in a dull pink colour (figure A15). You can crop out stuff you know isn't part of the sample at any time when you work with the 3D model in Agisoft Metashape.

50. Remember to click on the arrow on the toolbar to get out of free form selection and back into navigation.

51. Click on Model → Gradual selection and start with reconstruction uncertainty, level 10. The chosen points will become dull pink when selected, press delete.

52. Click on Model → Gradual selection and choose projection accuracy, level 10. Press delete.

53. Click on Model → Gradual selection and choose reconstruction error value <1, press delete.

54. Now look at the model and delete outliers again, if there are obvious outliers on the model and things like the rotating plate that are not part of the actual sample, and manually select those like this: Model → Free form selection, mark the outliers by hand and delete. The selected points and/or area are shown in a dull pink colour. You can crop out stuff you know isn't part of the sample at any time when you work with the 3D model in Agisoft Metashape.

55. Remember to click on the arrow on the toolbar to get out of free form selection and back into navigation.

56. Save your work.

57. Workflow → Build dense cloud, choose Quality: low and Depth filtering: aggressive (figure A16).

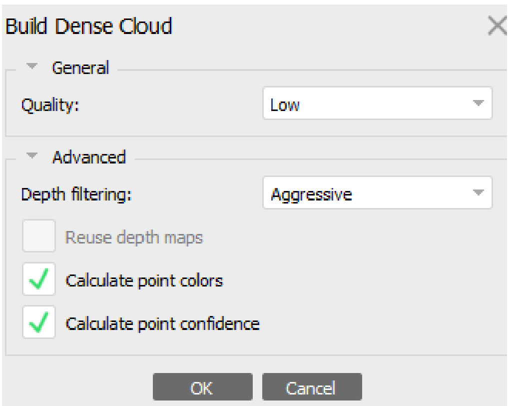

Figure A16. Build dense cloud settings.

58. Save your work.

59. Workflow → Build mesh (figure A18). Settings should be as seen in figure A17:

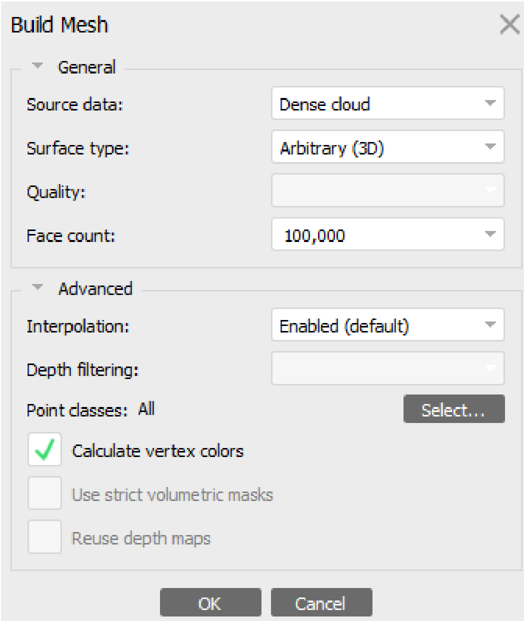

Figure A17. Build mesh settings.

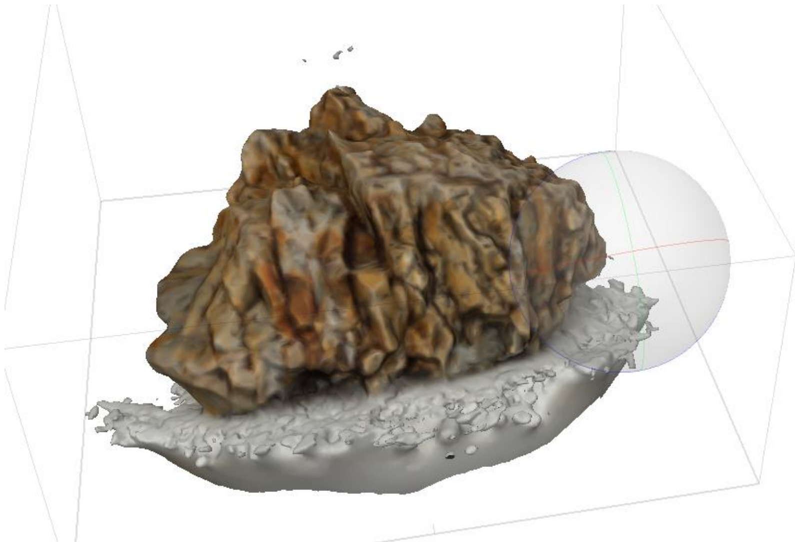

Figure A18. A model (of a fractured rhyolite) after building a mesh where you can clearly see what part of the model is not of the sample, the light grey parts. These parts can be cropped out using one of the selection tools, such as Free form selection or Rectangle selection.

60. Save your work.

61. Workflow → Build texture. Texture count/size should be minimum 4096. This means the program will build a grid with 4096x4096 squares. You can use a higher number but it means the file will be bigger, processing will take more time and the bigger the size the harder it will be to share your model with others (figure A19).

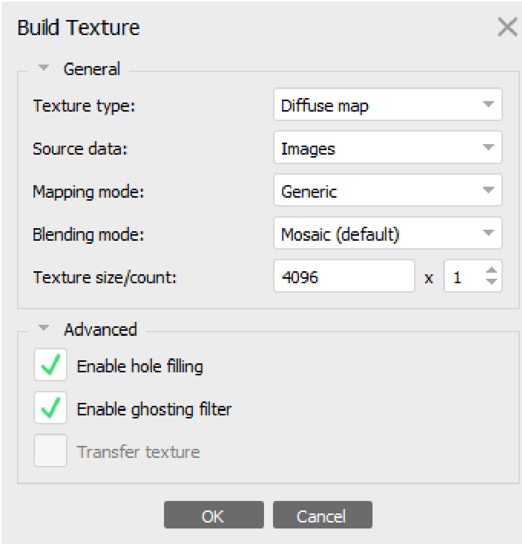

Figure A19. Build texture (lowest) settings.

62. Save your work.

63. Now click on File → export → export model in file format: OBJ. Choose a file name with no spaces and avoid special characters such as å,ä,ö etc.

64. Export texture to JPEG (include comma + file specific name).

65. When you have finished using SOOSI make sure to take everything down and store each item in the right spot.

Merging Models

If you want to produce a full 3D-model of the sample you need to take an additional set of photographs while the sample lays on another side as to get images of all sides of the sample. You can then merge the two models by following these steps:

66. Follow step "add pictures" to "build dense cloud" (step nr 37-58) for the photos from the second photo session. This should be done in the same Agisoft session so that the two chunks can be chosen for the next step.
67. Workflow → merge chunks 1 & 2
68. Save
69. Workflow → merge dense clouds (same settings as in step 57)
70. Save
71. Workflow → build mesh (same settings as in step 59)
72. Save
73. Workflow → build texture (same settings as in step 61)
74. Save
75. Export model as OBJ
76. Export texture as JPEG


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