THE HANDS-ON LEARNING OF PRACTICAL PHOTOGRAMMETRY FOR ARCHAEOLOGY

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ABSTRACT

Photogrammetric techniques have been applied in archaeology for over 140 years, but recently, automation in software has significantly increased the popularity of photogrammetry. In 2018, the Master’s Programme in Cultural Heritage at Helsinki University arranged a special intensive hands-on course on geodesy, photogrammetry and laser scanning in Greece in order to provide more in-depth practical skills to students in an inspiring environment. The course was established in co-operation with Aalto University and the Finnish Institute at Athens. In this article, we describe how practical photogrammetry can be learned on an intensive hands-on course. Hands-on experiences and experimental learning enable good practical skills and also a deeper connection and understanding of theory. We believe that the students on the course managed to add photogrammetry to their archaeological toolboxes for the rest of their careers.

1. INTRODUCTION

Terrestrial photogrammetric techniques have been applied in archaeology since the ruins of Persepolis were recorded in 1877 (Stolze and Andreas, 1882; Stolze, 1883). In 1882, Stolze created maps of the ruins of Persepolis by utilising these photographs (Albota, 1976). Since then, photogrammetry has developed a lot, and nowadays, the level of accuracy and automation is at such a stage that photogrammetric methods are also available for non-professionals. The use of photogrammetry in archaeology can be divided into aerial, terrestrial, satellite and underwater applications. Close-range photogrammetry is also suitable for the detailed 3D modelling of individual archaeological objects (e.g. Samaan et al., 2013). In this paper, we are focusing on aerial and terrestrial photogrammetry.

Aerial archaeology has been identified as a useful tool, for example, it is useful for discovering, monitoring, studying and reconstructing archaeological sites. Aerial archaeology started with the balloon measurements of Stonehenge in 1906 (Woolf, 2016). The resulting photographs were published in 1907 (Capper, 1907). In 1919, Roman remains were photographed in the Near East (Beatzeley, 1919). Later, Osbert Crawford utilised military aerial photographs taken from an aircraft in 1921 and detected the missing part of Stonehenge Avenue (Crawford, 1924c). Crawford published several articles and books on aerial archaeology (e.g. Crawford, 1923; Crawford, 1924a; Crawford, 1924b; Crawford, 1924c; Crawford and Keiller, 1928), which are typically considered as the main publications that made aerial archaeology known to the public. In the 1930s, aerial archaeology was already widely in use (Palmer, 1939).
An aerial perspective is usually advantageous for the interpretation of an archaeological site. However, an aircraft or a helicopter is an expensive platform for data collection if the area in focus is relatively small or if photographs are needed daily. Therefore, cheaper alternatives are usually considered. A high mast or a scaffold (see, e.g. Mozas-Calvache et al., 2012) can be sufficient in some cases; however, the use of them requires a suitable terrain and some effort and materials to be established. The use of balloons is one alternative (e.g. Whittlesley, 1970; Altan et al., 2004). The advantage of a balloon is its high capacity to lift payload. The disadvantage of a balloon is its high sensitivity to wind conditions, which makes controlling the balloon difficult. Alternatively, a kite can be used as the platform for a camera (see, e.g. Gavronski and Boyarsky, 1997; Aber et al., 2002). However, a kite requires a certain amount of wind to be operable and requires a skilful operator.

The use of motorised unmanned aerial vehicles (UAVs) for photogrammetric purposes started in the 1970s. One of the earliest implementations of a fixed-wing UAV is described in Przybilla and Wester-Ebbinghaus (1979) and the first article on the rotary-wing implementation was published by Wester-Ebbinghaus (1980). However, such early implementations required manual controlling. The development of precise navigation instruments, such as global navigation satellite systems (GNSSs) and inertial measurements units (IMUs), nowadays enable autonomous image acquisition according to a flight plan. A UAV provides a controllable platform for image acquisition and operates in most weather conditions.

Even if the first archaeological experiment utilised terrestrial photogrammetry, the methods were quite complicated and therefore were rarely utilised in archaeology. The development of stereo cameras and measuring devices even enabled non-professionals to utilise photogrammetric measurements processes (Baeschlin and Zeller, 1934). At the beginning of the twentieth century, the use of terrestrial photogrammetry for archaeological purposes started to increase (see, e.g. Doležal and Baeschlin, 1934).

In early examples, the use of photogrammetry produced 2D maps even if the measurements were made in 3D. Topography was illustrated with contour lines. When digital photogrammetry appeared, the use of photogrammetry further increased. The advantage of digitalisation was that 3D models could be stored, edited and visualised. Recently, the development of automated tie point searches (Marmol et al., 2017), structure from motion (Bianco et al., 2018) and dense image matching methods (Remondino et al., 2014) have significantly increased the use of photogrammetry within archaeology. The main products are 3D models that enable other applications, such as the creation of orthophotos (e.g., Alshawabkeh, 2010), the replacement of traditional plan drawings (Kimball, 2016), virtual worlds (e.g. Huvila and Uotila, 2018) and augmented reality (e.g., Barrile et al., 2019), to name just a few of these applications.

At the University of Helsinki, archaeology can be studied in the Bachelor’s Programme in Cultural Studies and the Master’s Programme in Cultural Heritage. Archaeology is the study of the human past via anthropogenic material remains. Among sciences, it is situated somewhere between the humanities, natural sciences and social sciences. Its scope is vast: all aspects of human existence from birth to death and beyond ranging from a few million years ago to the present time-wise and covering everywhere that humans have made their mark (from the tops of mountains to the bottoms of the seas) geographically. Due to this huge scope, there are a plethora of methods that can be applied in archaeological research, and throughout the history of archaeology, archaeologists have been very keen to adopt many of them into their toolkits. On the other hand, this means that during the studies it is not possible to cover many of them in depth. The annual intake of the bachelor’s programme is circa 6–10 students (the
universities of Turku and Oulu have similarly sized programmes), so it does not make sense to make them experts in the same narrow field. Our teaching philosophy has been that we showcase and teach the basics of some of these methods, after which, the students interested in a particular method can expand their know-how by, for example, attending courses from other faculties or universities. To mention a few methods of interest here, our courses cover GIS, total station, RTK-GPS surveying, laser scanning and photogrammetry. The last-mentioned method is on the syllabus of the ‘Archaeological documentation’ course, where we have two lectures on the subject, totalling four teaching hours.

Because archaeological studies include many aspects, there is not enough time to teach photogrammetry in depth. It must also be remembered that other field measurement methods, such as geodetic measurements and laser scanning, are included in teaching. Therefore, in 2018, we arranged a special intensive hands-on course on geodesy, photogrammetry and laser scanning in order to provide more in-depth practical skills to students. Since practical photogrammetry includes many practical details, using a theoretical approach alone does not give enough know-how to successfully apply the method in fieldwork. The course was established in co-operation with Aalto University and the Finnish Institute at Athens. The Finnish Institute at Athens is an academic institution with a mission to carry out and promote Greek archaeology, history, language and culture. The institute organises archaeological fieldwork projects and courses for Finnish students.

The aim of this article is to highlight pedagogical aspects of how practical photogrammetry can be learned on an intensive hands-on course. The focus is on making 3D models. Only UAV-based and terrestrial data acquisition processes are included, and the use of satellite and underwater images for archaeological documentation are not discussed. In addition, this article is only focused on the photogrammetric parts of the course.

2. THE TRAINING AREA AND MATERIALS

The practical training was conducted at nine different archaeological sites near Paramythia in Thesprotia, north-western Greece, a region where the Finnish Institute at Athens has been actively involved in research since 2004 (Forsén, 2009; Forsén and Tikkala, 2011; Forsén et al., 2016; Forsén, 2019). Architectural remains were visible at all the sites studied, offering a range of good objects for photogrammetry and 3D modelling. The types of sites included ranged from Hellenistic fortified acropoleis, through Roman ruins and Byzantine churches, and onto the Ottoman castle of Agios Donatos at Paramythia (Figure 1).

On this intensive course, we used a DJI Phantom 4 (P4) UAV for aerial imaging. The P4’s camera has a 1/2.3” sensor with 12.4 million effective pixels. The lens has the following configuration: a fixed focal length of 20 mm (35 mm format equivalent), a fixed aperture f/2.8, a focus at infinity and a field of view of 94°. It uses a rolling shutter, which can cause distortions in the images if the drone is moving too quickly while shooting. The P4 also has a built-in GPS/GLONASS receiver. The position of the drone for each image is stored in the Exif data and can be used for approximate georeferencing. The automated flight plans were designed with a free mobile application called Pix4Dcapture. This application is generally excellent and easy to use, but sadly it only supports shooting in the JPG format and not in the RAW format. The flight time per battery is about 15–20 minutes, which is the biggest limiting factor for the imaged area. The P4 already came out in 2016 and since then there has been a steady development in camera technology. The price point of similar
new drone model is around €2000, which makes them very viable tools for archaeological use. UAV data was mainly collected by staff, but the data was processed by students.

The applied system cameras were two Nikon D810 bodies with Nikon Nikkor AF-S 16-35mm f/4G ED VR and Nikon Nikkor AF-S 24-120mm f/4G ED VR lenses. Both lenses were fixed to their shortest focal length. In addition, we had the Canon 60D camera body with a Canon EF-S 24 mm f/2.8 STM lens.

![Figure 1. The Ottoman castle of Agios Donatos at Paramythia, constructed on top of a Hellenistic acropolis. This was one training site.](image)

3. LEARNING PHOTOGRAMMETRIC MEASUREMENT PROCESSES

As our learning approach was based on hands-on practices, we aimed for students to start data acquisition as soon as possible. However, before that, some basic principles must be understood. In Section 3.1, we highlight some essential aspects that have a significant influence on photogrammetric processes. In Section 3.2, some details of the post-processing of images and photogrammetric modelling are given. The aim in Sections 3.1 and 3.2 is not to bring out all the details of what was taught but merely to highlight the essential issues that should be understood when learning practical photogrammetric measurements processes.

3.1 Stage 1: Understanding camera and image acquisition

The aim of this stage is to allow students take photographs properly for photogrammetric measurements. At this point, only a minimal amount of theory is given. However, the reasons why something is done are briefly explained. After the instructions of Stage 1, students can start their hands-on experience.

3.1.1 Camera settings

Changing the internal geometry of a camera during image acquisition causes problems for photogrammetric measurements. Therefore, it is advisable to fix all the parameters that can cause
critical changes to the camera. These parameters need to be introduced to students in order to prevent unnecessary problems. Such parameters are focal length, aperture, automatic rotation of images, image stabilisation, image format and image size.

Zooming a camera changes the focal length. Therefore, if a zoom lens is in use, the zoom ring should be jammed in order to prevent unintentional changes. Figure 2 illustrates an easy way to jam a zoom lens by utilising the inner tube of a bicycle and cable ties.

![Figure 2. The zoom ring is jammed with a piece of the inner tube of a bicycle and two cable ties in order to prevent accidental changes of focal length.](image)

The aperture defines how much light penetrates into a camera. Even if we typically want to get as much light as possible, a large aperture (i.e. a small f-number) causes a shorter depth of field. For measurement purposes, a large depth of field is usually needed to keep all parts of targets sharp. Therefore, the f-number usually needs to be F8–F16, depending on the case. On the other hand, a large aperture requires a long exposure time. If a camera is hand held, this easily leads to shaky images. Even if it is tempting to use an image stabiliser, it is not advisable since it randomly creates small changes to the geometry of a camera. In non-optimal light conditions, mounting a camera to, for example, a tripod is a good solution, even if it slows the image acquisition. If hand-held image acquisition is needed, the ISO number can be increased, allowing more sensitivity to the sensor of a camera, which allows shorter exposure times. However, the drawback is the increase of noise in images.

The image size should not be changed during an image acquisition campaign and, to ensure as many details as possible, the maximum resolution is advised. Storing raw images allow more tones in images than, for example, storing JPG images. For example, an 8-bit channel in a JPG image only allows 256 tones when a 12-bit channel of a raw image can have 4096 tones. However, raw images typically need post-processing and conversion to 8-bit images before importing into photogrammetric software.

Many cameras automatically detect if images have been taken in a horizontal or in a vertical orientation and rotate images accordingly. This, however, may confuse some types of photogrammetric software, resulting in handling rotated images as if they have been taken with a different camera. Therefore, automatic image rotation should be switched off in the settings of a camera or the original orientations need to be restored in post-processing.
3.1.2 Signalising, the scale bar and ensuring a good imaging geometry

If the measurements are needed in the known ground coordinate system, it is recommended that ground control points are signalised before image acquisition. The image measurements of signals are significantly more accurate than the use of, for example, natural targets. The coordinates of such ground control points are typically measured with geodetic methods. Many different types of photogrammetric software are able to automatically detect coded signals (see Figure 3). The automatic detection of signals reduces manual work and is thus recommended. In addition, it is important to understand that even if an absolute orientation is not needed, the scale usually needs to be defined. Therefore, at least one reference distance should be measured. In our course, we applied a scale bar (see Figure 4) with a known length to enable defining the scale of the models.

![Figure 3. A coded signal for the automatic recognition of ground control points.](image)

![Figure 4. A scale bar for setting the scale of photogrammetric 3D models.](image)

Photogrammetric measurements are based on the forward intersection of observation rays from the tie points of two or more images taken from different perspectives. Because the accuracy is dependent on the incident angles between these observation rays, it is important to take images from many perspectives with respect to an object that is to be measured. If an object is relatively small, it is natural to take images from all around the object, which leads into a good imaging geometry. However, if the object is a longer object, such as a wall or a fence, one must take special care to establish a good imaging geometry. Traditionally, a regular grid of images is preferred; however, in many cases it is better to take images along overlapping arcs (see Figure 5) to improve the imaging geometry. Especially if a camera is not pre-calibrated and self-calibration is needed, it is also advantageous to sometimes rotate the camera from a horizontal orientation to a vertical orientation because this reduces correlations between camera calibration parameters.

In this phase, it is also important to emphasise that one should ensure that there is enough overlap between images. Otherwise, it might happen that, when photographing large objects, some parts of an image block cannot be connected to other parts. Such a case might lead to separate 3D models that are in different coordinate systems.
In addition, it is advantageous to understand camera calibration alternatives before image acquisition since they have an influence on how images should be taken. It is likely that the same image block that is taken for the 3D modelling of an area or an object is not optimal for the self-calibration of the camera. Since calibration is the main source of errors, it is recommended that the camera should be pre-calibrated or, if this is not possible, a separate image block with especially strong imaging geometry should be taken for better self-calibration. During the course, we practiced both pre-calibration with iWitness software and self-calibration in Agisoft.

3.2 Stage 2: Image processing and photogrammetric modelling

Usually, images benefit from post-processing. Since many camera parameters need to be fixed during photogrammetric image acquisition, the settings are not typically optimal for all situations. Therefore, the visual appearance of the images can change a lot if there are changes in visibility or the angle of the Sun, for example. It is useful to remember that the textures of 3D models come from images, and therefore, image enhancement is usually desired. However, it is typical that there are too many images – they cannot all be manually enhanced, one by one in a feasible time. Therefore, semi-automatic batch processing is recommended. During our hands-on course, we applied Darktable freeware for image enhancement. However, many different but similar types of commercial software exist, such as Adobe Lightroom, Capture One 20 or Skylum Luminar 4, to name just a few.

A typical enhancement process starts with one reference image. For this image, image processing tools are manually applied in order to brighten shadows, darken highlights, adjust the colour balance, sharpen images etc. Usually, similar corrections can be applied to many similar images with batch processing. However, if imaging conditions change too much, a new manual enhancement for a new reference image is required.

Next, the 3D model is created. On our course, we applied Agisoft PhotoScan (nowadays Metashape). If the images have been taken with a good imaging geometry, the standard workflow (including aligning photos, making a dense point cloud, creating a mesh and building textures) gives satisfying 3D models (see Figure 6). In addition, setting the scale and georeferencing require additional steps. Also, we practiced how to integrate results from terrestrial and UAV measurements. In some cases, digital elevation models and orthoimages were also created.
3.3 The daily learning process

We developed a daily routine for our hands-on course. Each day we started data collection and fieldwork at a historical site. The students were divided into smaller groups, each making different tasks. The required tasks included signalising, photo shooting, taking geodetic measurements and laser scanning. Therefore, from the perspective of a student, for example, photo shooting was not an everyday task. Data collection was supervised and assisted by the personnel. In small groups, individual guidance is possible. The students were also encouraged to actively ask questions about the practical work and give peer support to each other. It was ensured that the students got experiences of all the tasks during the course.

Data acquisition was usually completed before noon, and in the afternoons, we headed back to our lodgings. There, we started data processing. Photogrammetric data were processed in two teams. The staff actively followed the progress of both teams. During this phase, practice and theory were connected to enable deeper understanding. When the students were applying new functions in the software, the theory behind them was explained. In addition, the students were encouraged to share their observations and ask questions. Since the groups were not working in the same space, all new observations were shared with another team by the staff. At the end of the working day, the students were asked to reflect on their experiences of the day. Daily feedback was collected verbally in common gatherings. The staff made notes of the conversation. The feedback was then taken into account when the programme for the next day was planned.

3.4 Course feedback

Motivation is one of the major factors supporting learning. According to the student feedback, the following factors positively affected intrinsic motivation. The course was voluntary, which naturally attracts students who have some initial interest towards the subject. For archaeological documentation, 3D modelling was understood to be highly useful. Hands-on learning was found to be interesting, and varying historical places increased motivation. The background of each site was provided by the staff to further increase motivation. During the two weeks, new aspects of
photogrammetry were revealed and some routines were learned. The students found it interesting to understand what was behind some of the automatic routines of the software. In addition, the students found photogrammetric 3D modelling rewarding because the outcome is visually attractive, including coloured 3D point clouds, textured 3D mesh models, digital elevation models and orthoimages. Some of the students considered that the contents of the course gave them good knowledge that they will be able to apply in their forthcoming master’s thesis and in post-graduate studies.

Factors that decreased motivation were the occasional times when only some of the students could do something and the rest just needed to wait. In addition, making models with laptops leads to long computing times. In particular, making a dense point cloud and textures for 3D models are time consuming. This factor also prevented students from using the highest resolutions.

4. DISCUSSION

The structure of the course was designed in such a way that students started hands-on work from the very beginning. At first, only the minimum number of instructions were given. Because models were only used for teaching purposes, possible failures were not critical. On the contrary, problems in achieving the desired outcome raised questions and allowed students to discover themselves improvements to practices. Leaving space for student discoveries we could say that, at those moments, we enabled experimental learning. In experimental learning, when a student discovers new knowledge, it has a significant meaning or changes the student’s behaviour, which usually leads to deeper learning (Ligado et al., 2022). Since there were many opportunities to repeat the photogrammetric process, the groups were constantly able to improve their performance. However, the teachers needed to ensure that there were more successful cases than failures in order to maintain interest in the method. In practice, this was done during data collection and data processing by observing the students’ actions. If it seemed obvious that something was wrong or incomplete, the staff members intervened by giving more guidance or reminded the students about the previously given instructions. For example, there were cases when a scale bar was not placed in the scene or when the imaging geometry was not going to be sufficient for photogrammetric 3D modelling. If one group failed to get results, data from another group was shared.

The cycle of learning seemed to work efficiently. The photogrammetric workflow started fluently when a staff member instructed the student on how to generally prepare the scene and take images. Each site had its own characteristics, which typically slightly changed the data acquisition design. The data processing phase allowed group discussions, and possible problems and the students’ observations gave the staff many opportunities to give explanations, tips and explain the theoretical background. Sharing observations and the solutions to problems among all the groups brought new aspects into discussions. Asking the students to reflect on each day allowed the students to express how they felt about the day. This also enabled the students to analytically think about how they had acted during the learning process. More than once these reflections revealed that some part of the process needed adjustment. This gave an excellent opportunity for the students to think about a possible solution themselves instead of a staff member immediately revealing the solution. Such an approach improves problem-solving skills. Based on feedback, we also added small information sessions and tutorials in order to make unclear topics more understandable. Quickly, when the photogrammetric process was repeated in new sites, peer support became apparent beside the staff’s support. Based on the staff members’ daily observations of the students’ work, the groups’ confidence and individuals’ photogrammetric skills increased significantly during the course. This was apparent since the photographing efficiency was constantly improving, the students were soon
able to place targets and the scale bar optimally without the staff members’ help; the questions turned from practical, basic problems to being more related to understanding nuances; the imaging geometries of collected image blocks improved, making photogrammetric modelling more robust; and using photogrammetric software became more fluent.

5. CONCLUSIONS

In this article, we have described how archaeological students can learn practical photogrammetry on an intensive hands-on course. The students were instructed on the photogrammetric processes so they were able to start getting hands-on experience quickly, though we also left some space for experimental learning. This allowed the students to make their own observations and findings about photogrammetric image acquisition, image enhancement and 3D modelling. The process was iteratively adjusted according to the students’ observations and experiences. If some important aspects were not detected by the students, the staff revealed them one by one. In addition, we utilised mistakes and inefficiencies in order to deepen learning since such occasions gave an opportunity to improve the students’ problem-solving skills. At the same time, such cases allowed the staff to share theory and photogrammetric knowledge precisely on the focal subject that concerned the students at that given moment.

The inspiring environment, vivid background stories about the historical sites and the discovery of new aspects of photogrammetry ensured high motivation throughout the course. We believe that the participants experienced a memorable course and that they managed to add photogrammetry to their archaeological toolboxes for the rest of their careers.

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7. REFERENCES


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