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Combined Photogrammetric Techniques and Computer Vision: 2D–3D Recording of Gharissa, Jordan

Yahya Alshawabkeh, Khaled Douglas, Mohammad Matarya and Bilal Khrisat

Abstract

Traditional techniques for recording and modelling historical buildings using surveying instruments and CAD are tedious and time-consuming procedures, which do not provide detailed descriptions of complex façades. Recent developments in photogrammetry and laser-scanning techniques present non-contact, flexible and accessible surveying tools for 2D–3D recording. This paper discusses the potential for combining photogrammetry, laser scanning and computer vision for the documentation of heritage sites. By these means the efficiency of data collection can be optimized, and accurate true orthophotos of the studied structure can be generated using precise 3D surface representations derived from laser scanning and overlapping digital images. The final product allows the creation of detailed and complete façade plans, which are both graphically superior and accurate. The paper includes a study of the approach applied to historic buildings in Gharissa, one of the best preserved heritage villages in Jordan.

Introduction

CAD modelling

Digital documentation and modelling of historic structures are very important for the conservation of cultural heritage.[1,2] Traditional CAD (Computer Aided Design) is the classic and most common approach

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for creating digital 2D and 3D models of buildings.[3,4] CAD modelling usually produces solid or surface models with a limited amount of curves. In archaeological applications, object shape is often characterized by abrupt changes in depth and irregular breaks on a surface. Hence, CAD modelling is generally not considered to be appropriate for such applications. The models created are also not photo-realistic and are time-consuming and costly to produce for complex heritage sites.[5]

Image-based modelling

As an alternative to the classic building measurement and reconstruction methods, Image-based modelling, also called photometric modelling, has become an efficient and accurate non-contact data acquisition tool in cultural heritage applications.[6] Image-based modelling is a technique for creating 3D models from a set of two-dimensional images of a scene.[7] The geometry is created by identifying sets of common points from two or more source photos and since standard digital cameras can be employed, the required images can be captured at low cost and relatively quickly. Due to the flexibility of the approach it can be used for a wide range of objects and scenes.[8] One example is the photogrammetric reconstruction of the great Buddha of Bamiyan.[9] Realistic 3D models for architecture applications can be created based on a small number of photographs;[10] however, the main advantage of photogrammetry is the potential for simultaneously providing both geometric and surface texture for objects to be depicted. Despite this potential, the photogrammetry technique is highly interactive and requires lengthy and tedious laboratory work, especially for complex sites and objects. Even more importantly, the reconstruction process requires good skills and well-defined features. Difficulties increase when dealing with reliefs and damaged or irregular surfaces, and image shadows are another problem, as some of the corresponding points may be missed.

Laser scanning

Recently, laser scanning has become a standard tool for 3D data collection and the generation of high-quality 3D models of cultural heritage sites and historical buildings.[11] Laser scanners can collect thousands of 3D points every second at high levels of accuracy and precisely digitize complicated objects. Commercially available terrestrial laser scanners apply the so-called time-of-flight measurement principle in which distances to the respective object surface are derived from run-time measurements of reflected light pulses. Point clouds covering the visible object surface are collected by scanning the respective area of interest, resulting in a very effective and dense measurement of the surface's geometry. Even though current laser scanners can produce large point clouds quickly and reliably, the interpretation of the 3D point clouds is still limited. The interpretation of 3D point clouds can be simplified considerably if high-resolution imagery from calibrated digital cameras is available. Additionally, combining the laser scans with digital photo modelling can further enhance the creation of realistic 3D textured models from laser scans.[12,13,14,15] The purpose of texture processing is to integrate the 3D measurements from the laser scanner with 2D information taken with an external or internal camera. This can be found in some commercial 3D systems that provide model-registered colour texture by capturing the RGB values of each LIDAR (Light Detection and Ranging) point using a camera already integrated in the system.[16] However, these images are frequently not sufficient for the high-quality texturing which is necessary for documentation. This is due to the low resolution of the attached camera and also the variation in lighting and the sensed colour for a segment shown in images taken from different positions. Thus it is more useful to acquire geometry and texture by two independent processes.[17]

Digital orthophoto images

Digital orthophoto images (rectified photography) are another product of photogrammetry that can be used for the accurate surveying and recording of cultural heritage. Orthophotography is the geometric correction in the scale and the position of the distortion of objects in a photograph caused by the perspective projection of the image.[18] Since it has a uniform scale, a true orthophoto has the same properties as a map, and can be used to measure true distances. There are different methods by which the rectification of a photograph can occur; the simplest method is projective rectification, which delivers good results if the object's surface is completely even. If the object has an irregular or complex shape, orthophotography can be used to produce a scale image. Orthophoto generation methodologies mainly depend on the generation of accurate digital surface models (DSM) of the studied object.[19,20,21] The DSMs produced by image-based techniques or a CAD model have a low spatial resolution and cannot represent most cultural objects in detail.[22] The dense DSM generated by a laser scanner device is the optimal solution for a correct and complete 3D description of the shape of a complex object that could be used for a high-resolution true orthophoto of an irregular and complicated surface.

The present paper focuses on the use and integration of photogrammetry, laser scanning and computer vision techniques during recording and documentation of the historical buildings in the ancient village of

Gharissa in Jordan. The aim of integrating these techniques was to derive benefits from the complementary advantages of each in order to provide high-quality 3D surface textures for realistic object visualizations. Additionally, true orthophoto images were generated which allowed accurate measuring and tracking of the changes in the historical structure. In the next section, the collection of the relevant image and LIDAR data for 3D modelling is discussed. A further section discusses data integration and processing for high-quality texture mapping and true orthophoto generation, followed by a final section in which the conclusions of this case study are given.

Data collection and processing

The ancient village of Gharissa

Gharissa (Figure 1) is a small, 4.5 ha, ancient settlement located about 30 km north east of Amman and is considered to be one of the best preserved cultural heritage villages in north central Jordan. The site has witnessed episodes of abandonment and reoccupation in different chronological periods. The earliest architectural remains found on the site go back to the Iron Age II (1000–539 BC) when a watchtower, constructed from very large roughly cut stone blocks, was built on the north western side of the site.

The Classical era in Gharissa is archaeologically well represented. The Roman period (63 BC–AD 324) seems to have been very prosperous as shown by the abundance of the pottery fragments. During the next Byzantine period (AD 324–632) the site continued to be intensively occupied, as the architectural remains and the profusion of pottery finds attest. At the end of the Byzantine period, Gharissa was abandoned, like many other sites in Jordan. It was only reoccupied as an agricultural village during the late Islamic period, the Auyybid–Mamluke period (AD

Figure 1 Ancient Gharissa village. Right: Google Earth Image (2010) Left: one of the historic buildings in the village.

1169–1517), though the great number of pottery fragments from this time indicate an intensive occupation.[23]

At the end of the Auyybid–Mamluke period the site was again abandoned and only partially reoccupied in the Ottoman period. Afterwards the site of Gharissa was abandoned for decades and only reoccupied in the first quarter of the twentieth century by a group of semi-nomadic people who built their village over the remains of the ancient occupational phases. The houses were mainly in the traditional Ottoman style common in that period. The new village was occupied for about four decades before it was abandoned once again.

Although most of the buildings are well preserved, urban expansion and natural factors threaten these buildings. Documentation of the village in scientific and precise ways is an important goal in order to protect and preserve this important but fragile part of the cultural heritage of Jordan.

3D modelling using photogrammetry

The principle of photogrammetry is based on extracting 3D data of an object from overlapping two-dimensional images. If a point is depicted in at least two images, its corresponding 3D object coordinates can be determined theoretically.

The image and object coordinates system are unified using mathematical equations called collinearity equations, shown below. These equations mathematically formulate the fact, that a point in object space (X_A, Y_A, $Z_{A)}$, the projective centre of the optics and the corresponding point in image space x_a, y_a) form one straight line (Figure 2). Thus, any spatial points can be located by the intersection of two rays of light projected from two different camera stations.

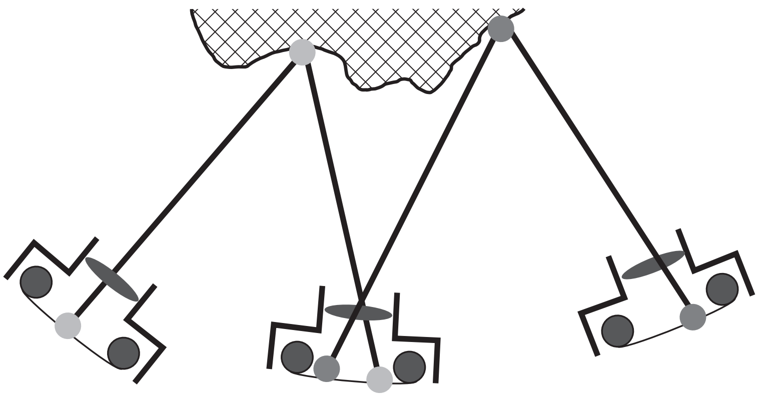

Figure 2 Principle of photogrammetry for 3D object modelling.

$$x_a = \frac{-c\left[r_{11}(X_0 - X_A) + r_{12}(Y_0 - Y_A) + r_{13}(Z_0 - Z_A)\right]}{\left[r_{31}(X_0 - X_A) + r_{32}(Y_0 - Y_A) + r_{33}(Z_0 - Z_A)\right]}$$

$$y_a = \frac{-c\left[r_{21}(X_0 - X_A) + r_{22}(Y_0 - Y_A) + r_{23}(Z_0 - Z_A)\right]}{\left[r_{31}(X_0 - X_A) + r_{32}(Y_0 - Y_A) + r_{33}(Z_0 - Z_A)\right]}$$

The equations involve two aspects of orientation parameters – interior and exterior. The interior orientation parameters describe the internal camera parameters: the position of the image plane with respect to the centre of projection of the camera, including the camera's focal length (c). The exterior orientation parameters describe position and orientation of the camera at the time of exposure (r11–r33). Both exterior and interior orientation can be reconstructed if the object coordinates are available for a number of so-called control points. An example of the collection of a 3D virtual model from terrestrial images, based on a standard software tool (PhotoModeler), is given in Figure 3. For reconstruction of objects geometry in the 3D world, corresponding primitives such as points, lines and regions have to be identified (Figure 4). Figure 5 depicts 3D textured models of some buildings in the historic village. The models are added to Google Earth using Google Sketch Up software (Figure 6).

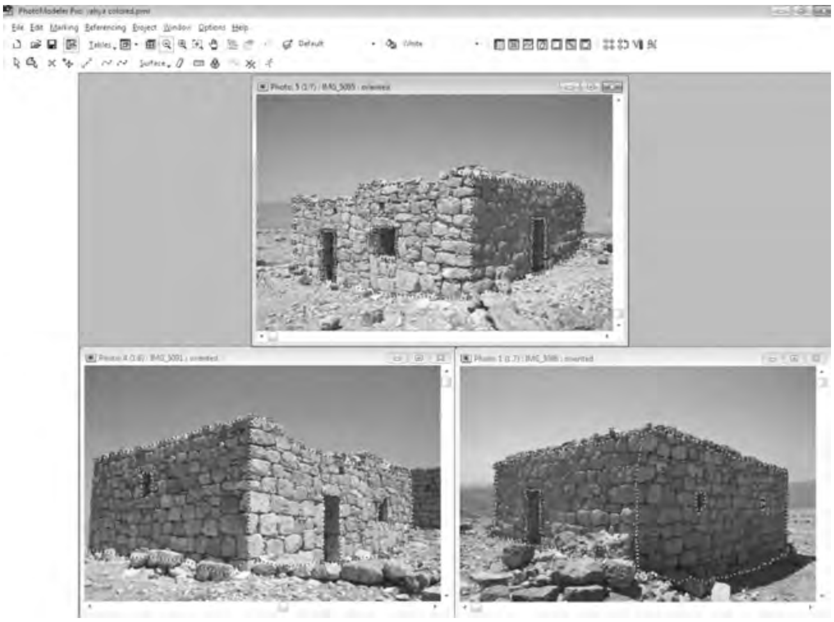

Figure 3 Processing images of one of Gharissa's historical buildings using PhotoModeler software.

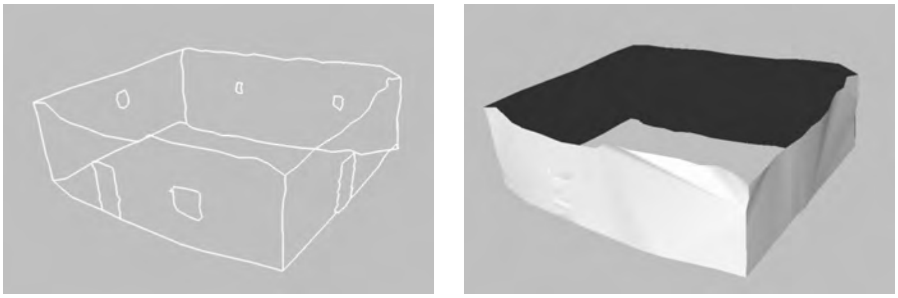

Figure 4 3D line and surface modelling of the historic building.

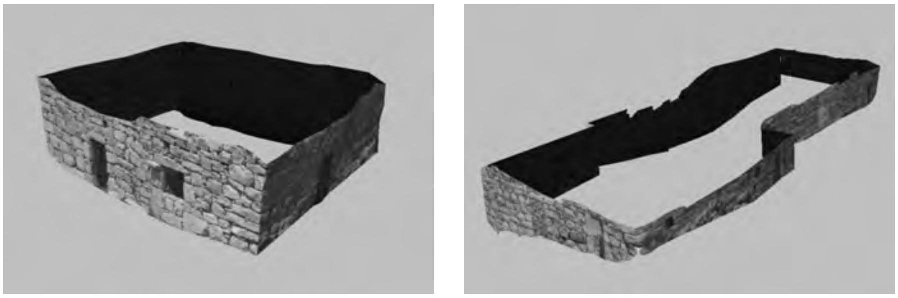

Figure 5 3D textured models of some historic buildings in Gharissa.

Figure 6 Gharissa's historic buildings added as a 3D building layer on Google Earth.

Figure 7 Building façade in Gharissa recorded by terrestrial laser scanning.

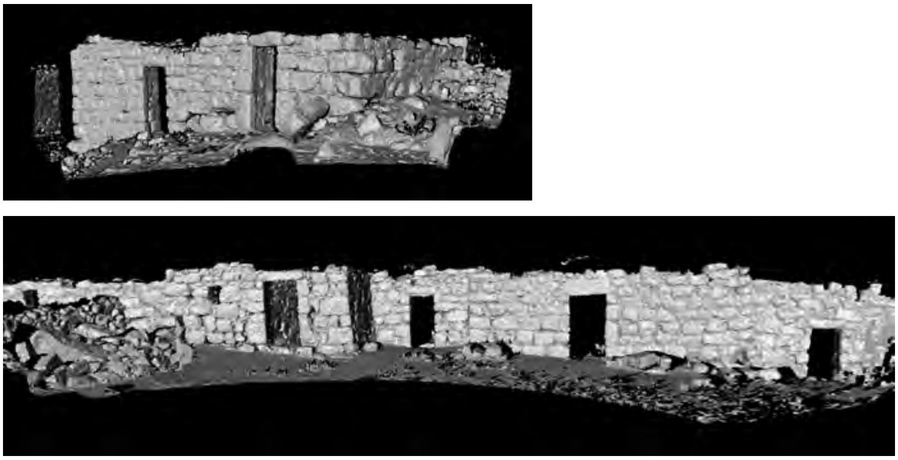

Figure 8 Two different meshed scans of the building.

Terrestrial laser scanning

Instead of using multiple images to reconstruct scene structure, laser scanning can be used for 3D point collection to generate high-quality 3D models of cultural heritage sites and historical buildings. These systems provide an even higher resolution and amount of detail, which can very easily reach several million 3D points. An example of a building facade recorded by a time-of-flight terrestrial laser scanner is given in Figure 7. In the project recorded in this paper, the 3D laser scanning system GS100, manufactured by Mensi S.A., France, was applied. The scanner features a field of view of 360° in a horizontal and 60° in a vertical direction, enabling fully panoramic views to be collected. The distance measurement is realized by the time-of-flight measurement principle based on a green laser at 532 nm. The scanning range of the system allows distance measurements of between 2 and 100 metres. The system is able to measure 5,000 points per second. During data collection a calibrated video snapshot of 768 x 576 pixel resolution is also captured, which is automatically mapped to the corresponding point measurements.

Despite the fact that laser scanning provides 3D point cloud automatically, additional processing steps such as meshing are required to convert the point-based data into a visually more intuitive representation. The meshing process could be used to convert the set of collected raw 3D points into a triangulated surface (Figure 8).

Combined photogrammetry, 3D scanning and computer vision

Texture mapping

Texture mapping is a powerful tool in computer graphics used to apply an image over a 3D model. Some commercial 3D systems provide model-registered colour texture by capturing the RGB values of each LIDAR point using a camera already integrated in the system. However, the images collected using this camera have a low resolution (768 x 576 pixels). Additionally, the ideal conditions for taking the images may not coincide with those for laser scanning. Thus, these images are frequently insufficient for high-quality texturing, which is required for documentation (Figure 9). These images are mainly used for scan registrations and not for texture mapping. It is therefore more useful to acquire geometry and texture by two independent processes and allow for an

Figure 9 Top: 3D textured model of the facade using scanner integrated camera Bottom: the image used for texture mapping (768 x 576 pixels).

image collection at the optimal position and time for texturing. This is especially true for the realistic documentation requirements of heritage sites.

In this paper, the approach presented by Alshawabkeh and Haala is employed for texture mapping the 3D laser scanning models and using an independent Canon 400D camera (3,888 x 2,592 pixels).[24] The approach used the interior orientation parameters of the calibrated camera in order to create zero distortion images. Then a registration process, which aligns the laser scanner data with the imagery, is achieved using corresponding coordinates in both systems. In this approach, the corresponding coordinates between image and laser scanner were measured using PhotoModeler software, which was applied to calculate the camera position and orientation in the coordinate system of the geometric model. Then the warping of RGB values is defined by the standard co-linearity equations. Figure 10 depicts a 3D textured model using this approach. The performance analysis has been conducted on a standard PC using C++ and VRML languages.

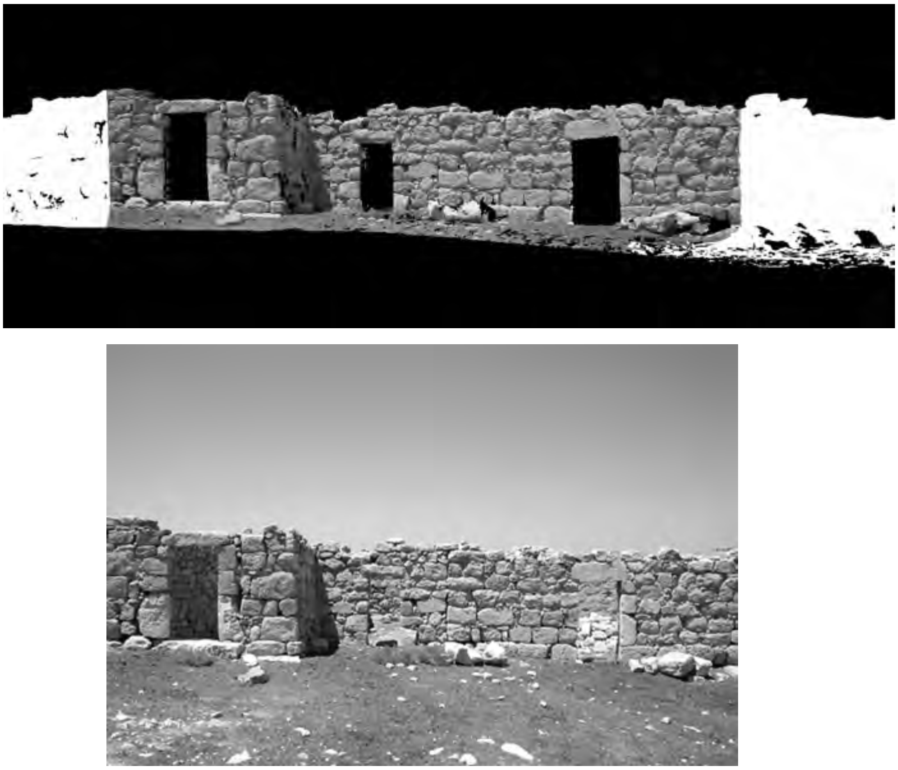

Figure 10 Top: High quality 3D textured model of the building using a Canon calibrated camera. Bottom: the image used for texture mapping (3,888 x 2,592 pixels).

True orthophoto generation

A digital orthophoto is a uniform-scale photograph. Thus, distances can be calculated with it, as with a map. In order to generate true orthophoto rectification it is necessary to remove the effects of relief displacement and camera tilt. True orthophoto methodologies mainly depend on the generation of accurate DSMs of the studied object. The production of DSMs by image-based techniques (photogrammetry) or CAD is not suitable for irregularly curved cultural objects. For these reasons the dense DSM generated by a laser scanner device can be considered as the optimal solution for a correct and complete 3D description of the shape of a complex object, from both technical and economic points of view.

In the application presented in this paper the mathematical model presented by Alshawabkeh et al. has been used.[25] The framework of this model is shown in Figure 11. The input data is the surface model of the object collected using a laser scanner (Figure 8), in addition to colour images that cover the area of interest with their exterior and interior parameters. Images are then used for true orthophoto generation (Figure 12). The quality registration process, which aligns the laser scanner data with the imagery, can be achieved if corresponding coordinates are available in both systems. The corresponding coordinates between the image and the laser scanner were measured using the PhotoModeler software, which was used to calculate the camera position and orientation in the coordinate system of the geometric model.

Choosing the pixel size of the new digital image (ortho-image resolution), every orthophoto pixel is projected to the original images with the collinearity equations. In this paper's application the pixel size for the true orthophoto was 4 mm at object scale. In order to apply the collinearity principle, the third coordinate (elevation Z) of every

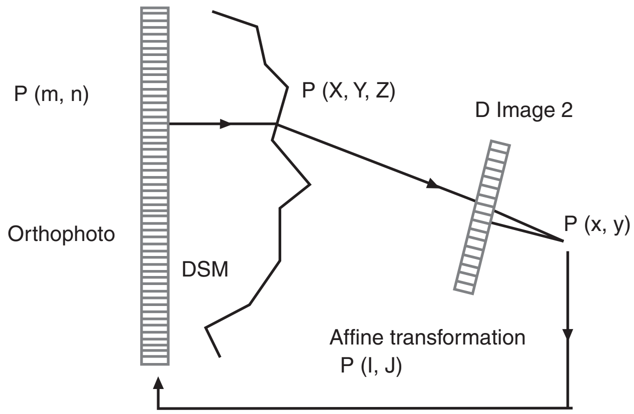

Figure 11 Framework for the orthophoto generation algorithm.

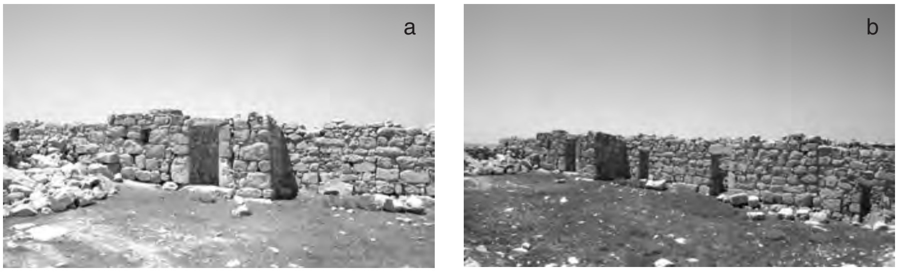

Figure 12 Two images of the studied wall taken from different positions used for true orthophoto generation.

Figure 13 The depth map of the studied wall has the same size as the required orthophoto (953 x 6,608 pixels).

Figure 14 True orthophoto for the image depicted in Figure 12a. Grey pixels represent areas out of the view of the image; in the white areas no DSM data was available.

Figure 15 True orthophoto for the image depicted in Figure 12b. Grey pixels represent areas out of the view of the image; in the white areas no DSM data was available.

orthophoto pixel was needed. The Z value was taken from a depth image generated using the DSM (Figure 13). Using the depth image, the texture value for each ground pixel in the orthophoto plan is taken backwards from the original images through the collinearity equations. Then, an affine transformation is performed in order to find the exact location of the point in the coloured image. The positions of the grey-values of the given image have to be transformed to the rectified image. Figures 14 and 15 show the final product of the proposed algorithm.

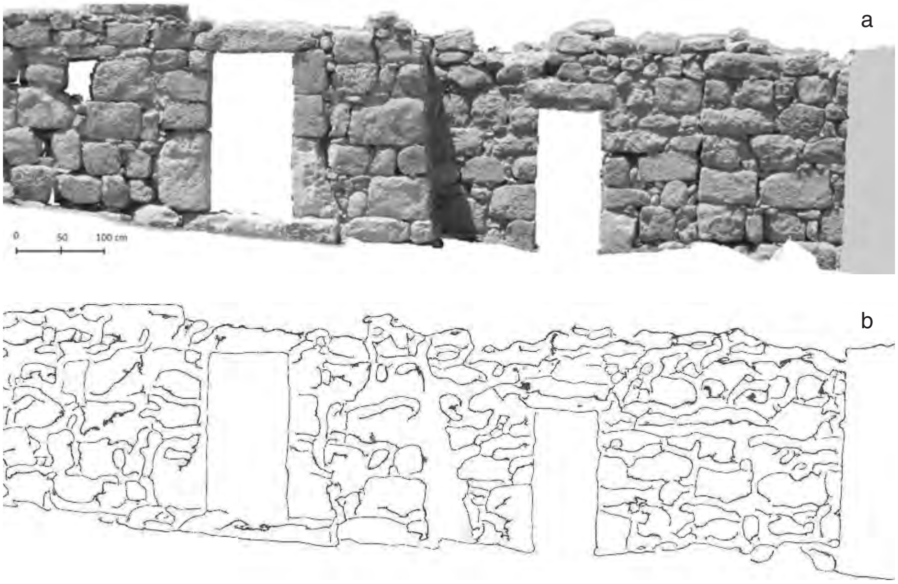

Figure 16 a) The true orthophoto of the image depicted in Figure 12a, b) the outlines of the edges and cracks generated from the true orthophoto.

Once an image has been orthorectified, spatial data can be accurately measured in terms of distances and area. In order to optimize the measurement process, extraction of stone and crack edges is conducted using segmentation. In our application a Canny filter has been applied on the true orthophoto for feature extraction. The results are shown in Figure 16 b.

Conclusion

Photogrammetry, laser scanning and computer vision techniques present flexible and accessible metric surveying tools for the 2D and 3D recording and modelling of heritage sites. The integration of these techniques aims to optimize the surveying results by using the complementary advantages of each. For example, the high-quality 3D texturing of scanned data to assure reliable interpretation, and the digital orthophoto to present an accurate scaled map for metric measurement and assessment of the structure. The work introduced in this paper presents the initial phases of the application of these tools in documenting Gharissa, Jordan. The approach was used for the detection and quantification of the cracks and the gaps in the Gharissa walls where it demonstrated the promising ability of the technology to accurately detect and quantify the continuous extent of material displacements without the need to come into physical contact with the structure. The results determined the displacements both in terms of quantification and movement direction. The technique will be developed in future in order to have a non-contact monitoring approach to historical structures using true orthophoto as a tool to assess the structural condition.

Biography

Yahya Alshawabkeh, PhD (Architectural Photogrammetry)
Dr Yahya Alshawabkeh is Assistant Professor at the Department of Conservation Science of Queen Rania Institute of Tourism and Heritage, The Hashemite University. He is particularly interested in work on integration of digital photogrammetry and laser scanning for heritage documentation.

Khaled Douglas, PhD (Archaeology)
Dr Douglas is Assistant Professor at the Department of Sustainable Tourism at Queen Rania Institute of Tourism and Heritage, The Hashemite University. He is the director of the archaeological project at Gharissa, and the director of the archaeological excavations at Jneneh, an Early Bronze and Iron Age site, Zarqa-Jordan.

Mohammad Matarya, BA (Conservation Science)
Mohammad Matarya is a research assistant and master's student at Queen Rania Institute of Tourism and Heritage. His field of interest is the application of photogrammetry and computer vision in archaeological applications.

Bilal Khrisat, PhD (Geoarchaeology)
Dr Bilal R. Khrisat is Assistant Professor at the Department of Conservation Science of Queen Rania Institute of Tourism and Heritage. His field of interest is the application of scientific methods in archaeology, stone weathering and conservation documentation and management of archaeological sites and cultural heritage management.

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