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DETECTION AND QUANTIFICATION OF MATERIAL DISPLACEMENTS AT HISTORICAL STRUCTURES USING PHOTOGRAMMETRY AND LASER SCANNING TECHNIQUES

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ABSTRACT

This study proposes a new non-contact approach allows detecting, measuring and tracking the change of cracks in the historical structure using photogrammetric techniques and computer methods. The proposed procedure used an accurate generation of true orthophoto of the studied structure using precise 3D surface representations derived from laser scanning and several digital images that entirely cover the object of interest. Cracks are extracted from the generated orthophoto using a series of image processing techniques. The developed algorithm is applied to analyze and monitor the structural damage in Amra Palace, a UNESCO world heritage site, in Jordan desert.

KEYWORDS: Photogrammetry, Laser Scanning, True Orthoimage, Crack Detection, Monitoring

INTRODUCTION

The historical buildings exposed to different environmental conditions and human actions for a long time, which can induce stresses inside the material causing degradation process. The cracks usually appear on the structure as a first visible sign of such problem. In order to help safeguard historic buildings from further damage and to understand future development of the defect, it is necessary to develop effective and adaptable monitoring strategies to assess the state of the damaged object. The results could be used to plan and optimize maintenance and conservation works.

Different methodologies have been traditionally used to quantify and monitor cultural heritage objects using of gypsum strips, geodetic methods, mechanical extensometers and electrical sensors (Glisic et al., 2007; Drdacky, 2005; Inaudi et al., 2001). These procedures have the disadvantage that they required contact tools, which have to be placed manually on the structure like geodetic targets, scaled bar or metric sensors. These devices are accurate but their application depends on the accessibility.

Generally, they are undesirable for both aesthetic and functional reasons since they are needed to be fixed on the surface of the historical buildings for long time interval. Furthermore, these methodologies provide discrete point measurements on damaged area instead of a complete and continuous recording of the extent of the damage in the whole affected area. Thus, they are generally not suited for tasks requiring a large number of measurement points distributed over an object surface (Maas & Hampel, 2006; Arias et al., 2005).

In recent years, researcher's effort has been devoted to find effective non-contact techniques for assessment and monitoring the structures. Computers methods and close-range photogrammetry are proposed as an accurate, economical and flexible approach to detect and assess structural problems. Photogrammetric techniques have been applied to a wide range of objects and tasks in civil engineering material testing and deformation measurement (Fraser & Brizzi, 2003; Whiteman et al., 2002; Woodhose, 1999). (Armesto et al., 2008) and (Arias et al., 2007) use close range digital photogrammetry as a technique for detection and monitoring of damage in historical buildings. Generally, traditional photogrammetry technique presents an accurate system but only a limited and discrete point will be selected on the cracks extent. Those points should be identified in different images manually, which is considered as tedious work. The selected discrete points will produce regular shape crack with sharp edges, which not represent the actual extent and shape of the crack.

Automatic detection and quantification of the cracks in concrete structure using photogrammetry and digital image processing is discussed in different works (Lee et al., 2007, Dare et al., 2002, Ergun & Baz, 2006, Sohn et al., 2005). The final product has an accurate results and continuous recording of the extent of the damage. But in the previous works, the proposed automatic techniques are valid only for quantification of cracks on the concrete surface only.

The proposed algorithms assume the cracks are found on a smooth plan surface in order to establish the geometric relationship between the object surface and image coordinates. Something that is not the case in the archaeological applications. The historical buildings are usually faced with complex object shapes characterized by abrupt changes in depth and breaks on a surface, which cannot be regarded as regular.

Digital true orthophoto is another product of photogrammetry that could be used for accurate surveying and recoding in cultural heritage. Orthophoto 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 (Grussenmeyer et al., 2002). True ortho-photo generation methodologies mainly depend on generation of accurate digital surface models (DSM) of the studied object (Habib et al., 2007; Karras et al., 2007). The production of digital surface models by image based techniques or CAD is not suitable for irregularly curved cultural objects surfaces (Hartley & Zisserman, 2000; Wiedemann, 1996).

Recently, the enormous number of surface points sampled today at very fast rates using the powerful technology of laser scanning represent an alternative fully 3D support for an archaeological orthorectification (Boehler et al., 2001; Georgopoulos et al., 2004).

The acquisition process is completely automated and the DSM generation of any object is an easy and quick procedure. For these reasons the dense DSM generated by a laser scanner device can be considered the optimal solution for a correct and complete 3D description of the shape of a complex object, both from the technical and economical points of view.

The proposed approach is applied for detecting, quantification and monitoring of historical structures using true orthophoto as a monitoring tool to assess the structural health condition.

True photo is generated using precise 3D surface representations derived from laser scanning and portable digital images of damage area. Then cracks are extracted from orthophoto using a series of image processing techniques. The developed algorithms are applied to analyze and monitor the structural damage in Ummayyad Amra Palace.

In the next section, collection of the relevant image and LIDAR data is discussed. Section 3 presents the standard 3D photogrammetry approach for modeling and quantification of the cracks.

Data pre-processing and true orthophoto generation is discussed in section 4; pre-reprocessing is mainly required to achieve perfect co-registration of laser and image data to gain high-quality orthophoto. Image processing analysis for cracks detection and quantification is presented in section 5. The final section gives our conclusion.

DATA COLLECTION AND PROCESSING

Experimental Evaluation (Ummayyads Amra Palace)

The Desert Palaces in east of Jordan demonstrate the best of early Islamic ingenuity. The palaces were built in the seventh and eighth centuries by the Umayyad caliphs. Umayyad is the first great Arab Muslim dynasty of caliphs (religious and secular leaders) founded by Muawiyah I in 661 and lasting until 750.

Built in the early 8th century, Amra palace, depicted in figure 1, is the well-preserved and known desert, a UNESCO World Heritage site. The Umayyad caliph Walid built the palace as a vacation residence or rest stop (Bianchin et al., 2007).

The real attraction to Qusayr Amra is the outstanding frescoes that depict a variety of subjects including hunting scenes, athletic activity, mythological images, and astronomical representations. (Al-Asad & Bisheh, 2000; Creswell, 1989; Ettinghausen & Grabar, 1987). Some of desert palaces, such as Amra palace, witness different environmental conditions that affected their status.

More important, these historical buildings exposed to traffic vibration caused by heavy trucks and Lorries traveling along the close adjacent international highway that connects Jordan to Saudi Arabia and Iraq (Euromed-heritage, 2008).

The vibration can induce stresses inside the material. The effect is clearly visible through the serious cracks in the walls, as can be depicted in figure 1.

Figure 2 shows the progress of the cracks in two images of the main door of the palace taken in different epochs (six months time). Thus, a comprehensive study is needed to assess the current threats and the conservation needs of the palaces to ensure its sustainability. This raises the need to have a permanent monitoring of the palace.

Figure 1. Amra palace, a UNESCO World Heritage site.

Figure 2. Images for the main entrance door of Amra palace taken in different epochs the white arrow in right photo shows a serious crack was created in the upper part of the door.

2D-3D data collection

Data have been collected in the framework of a project aimed at the generation of a 3D documentation system of the desert palaces in Jordan using photogrammetry, laser scanner and a GIS system.

3D laser scanning system GS100, manufactured by Mensi S.A., France was applied. Different high-resolution images have been colleted for the damage areas using portable calibrated camera, Canon 400D, which provides a resolution of 3888x2592 pixels with a focal length of 20 mm, depicted in figure 3.

Figure 3. High resolution images for the studied wall taken using calibrated camera, Canon 400D (3888x2592) pixels.

These images have been taken in the same time of laser scanning collection. For our application 3D model of the Amra palace and the studied wall is depicted in figure 4, the produced model has an average resolution of two cm.

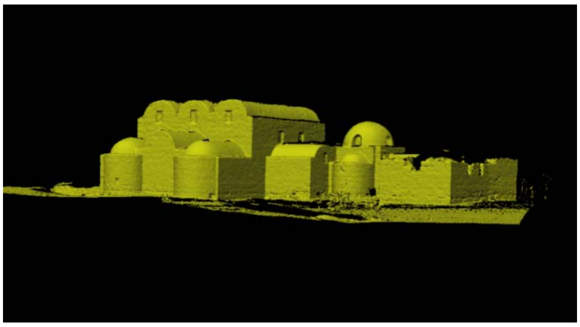

Figure 4: 3D model of Amra palace using laser scanner

Crack modeling using Photogrammetry Approach

Digital Photogrammetry is a technique to measure the 3D geometric position, size and shape of an object obtained from some overlapping imagery instead by direct measure. Photogrammetry has a long history as a tool for the efficient and accurate data acquisition also for cultural heritage applications.

The principle of photogrammetry is based on a fact that, if a point is depicted in at least two images, its corresponding 3D object coordinates can be determined. object and image coordinates are linked by the so-called collinearity equation (Kraus 1993).

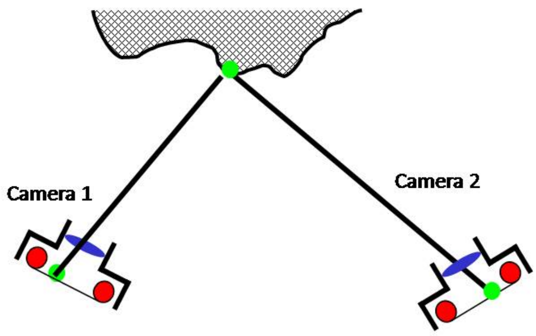

Figure 5. Principle of Photogrammetry for 3D Object Modelling

This equation mathematically formulates the fact, that a point in object space, the projective center of the optics and the corresponding point in image space form one straight line as depicted in figure 5.

In order to measure 3D point co ordinates, information on position and orientation of the camera at the time of exposure are required. In addition to so-called exterior orientation, the parameters of interior orientation have to be provided, which describe the position of the image plane with respect to the center of projection of the camera. Both exterior and interior orientation can be reconstructed, if object coordinates are available for a number so-called control points. If the parameters of exterior and interior orientation are available, object and image coordinates are linked by co linearity equation as follows.

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

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

In these equations:

x_a, y_a : an object A's image coordinates.

XA, YA, ZA : the object's coordinates in object space.

Xo, Yo, Zo : the object space coordinates of the camera position.

r11-r33 : the coefficients of the orthogonal transformation between the image plane orientation and object space orientation, and are functions of the rotation angles

c: camera focal length.

The technique is applied for detection and quantification of a selected serious crack in Amra external wall. Different high-resolution images have been collected from different view. The 3D model of the crack is generated using photometer software as depicted in Figure 6.

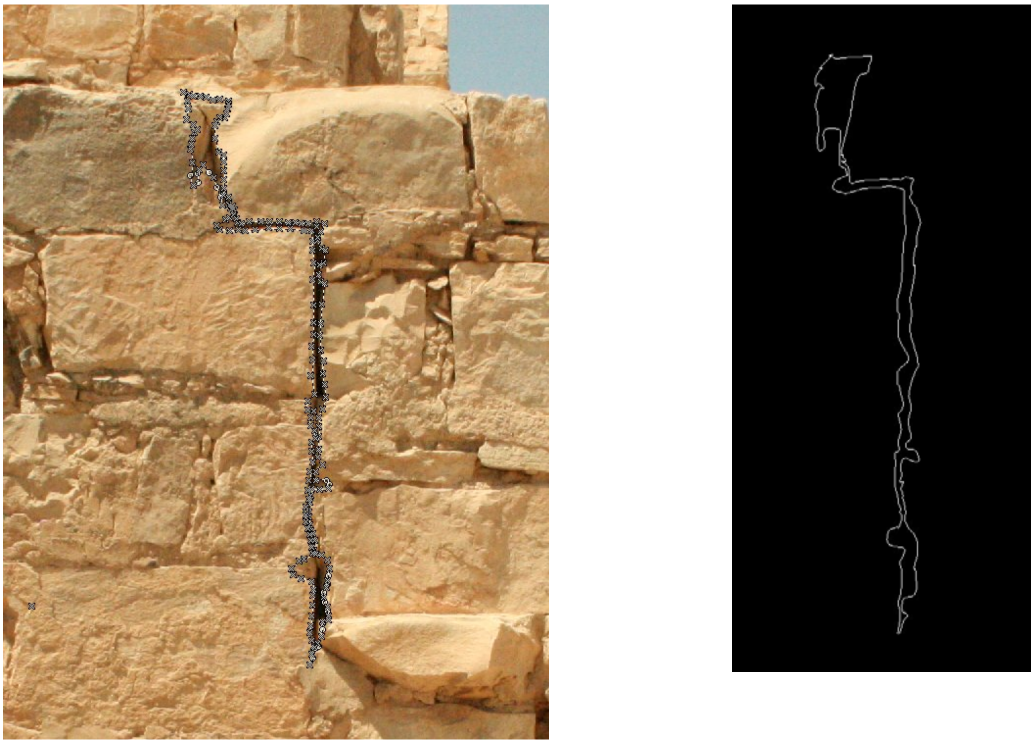

Figure 6. Quantification and 3D modeling of the cracks at the studied wall in Amra palace using photogrammetry approach.

Image based photogrammetric data collection allows the efficient production of 3D measurements at high resolution and good geometric accuracy. Since standard digital cameras can be applied, the required images can be captured at low expenses, additionally, the time required for data acquisition at the site is relatively short.

Digital image processing techniques also help to increase the efficiency of photogrammetric data collection by semi-automatic tools.

Despite the potential of close-range photogrammetry for the production of high-resolution 3D measurements of the cracks, the identification of points to be measured, being manual or semi automatic, requires a long and tedious work, especially if a considerable number of points have to be captured.

And the results still discrete points. These increases the needs for an automatic approach provide continuous representation of the crack extent.

Outline of the presented approach

Orthophoto is the standard photogrammetric products for archaeological documentation since it compose a powerful textured representation combining geometric accuracy with a rich detail such as damages and decay. In archaeological application, orthophoto could be used as a monitoring tool to assess the structural health condition to help register and understand future developments.

Orthorectification of historical buildings facades is a very challenging; the challenges are related to the complex surface descriptions. In the proposed methodology the algorithm presented by (Alshawabkeh et al., 2010) is applied for production of true orthophoto.

The algorithm uses precise 3D surface representations derived from laser scanning and digital images that cover the area of interest. Using true ortho images, the extraction of cracks is conducted using the image-processing techniques such as canny edge detection operator. The approach is presented in the following sections.

True orthophoto generation using Photogrammetry and Laser Scanner

The input data are a regular dense grid generated from the irregular DSM acquired using a laser scanner device and a set of high resolution colored images taken for the region of concern in the building surface. The interior parameters of the used images were computed using Australis software.

These parameters were used to eliminate geometric image distortions. Corresponding coordinates between image and laser scanner were then measured using the Photomodeler software, which was also applied to calculate the camera position and orientation in the coordinate system of the geometric model.

Figure 7 shows the 3D model of Amra palace wall textured with the corresponding image. Texture mapping is generated using an algorithm proposed by the author using C++.

Figure 7. Registration of 2D image with corresponding 3D model using interior and exterior parameters of the image shown in the left.

$$i_n = \frac{(X_{ij} - X_{min})}{p} + \frac{1}{2} \quad (1a)$$

$$j_m = \frac{(Y_{max} - Y_{ij})}{p} + \frac{1}{2} \quad (1b)$$

True orthophoto approach, shown in figure 8, requires the pixel size of the new digital image (orthoimage resolution). In our example, the used resolution of the orthophoto is 2 mm at the objects surface. An empty matrix with same dimensions as the orthophoto matrix is created (mxn). Then every triangle of the mesh is ortho-projected onto the area of the ortho-photo using the equations below. Each projected triangle will occupy a number of adjacent grid cells; these cells will have an identity number (ID) of the particular assigned triangle.

In order to project every orthophoto pixel onto the original images with the collinearity equations, the third coordinate (elevation Z) of every orthophoto pixel is needed. Thus every ground pixel, with coordinates X Y of the orthophoto matrix is interpolated in the DSM in order to calculate its elevation Z. The interpolation method used is nearest neighboring sampling, the orthoimage framework production is depicted in figure 8. In our example, the depth image of the studied wall with the same size of the orthophoto is depicted in figure 9. Using the depth image, the texture value for each ground pixel in orthophoto plan is taken backwards from the original images through the exterior orientation and the collinearity equations. Then, an affine transformation is performed in order to find the exact location of the point in the colored image. The positions of the grey-values of the given image have to be transformed to the rectified image. The grey value of the point is calculated by Nearest Neighbor resampling techniques. Figure 10 show the final product of the proposed algorithm, true-orthophotos for the image depicted in figure 3. The performance analysis has been conducted on a standard PC with an Intel 4, 3GHz Processor, and 1GB RAM. In our approach VRML modelling language is used integrated with C++.

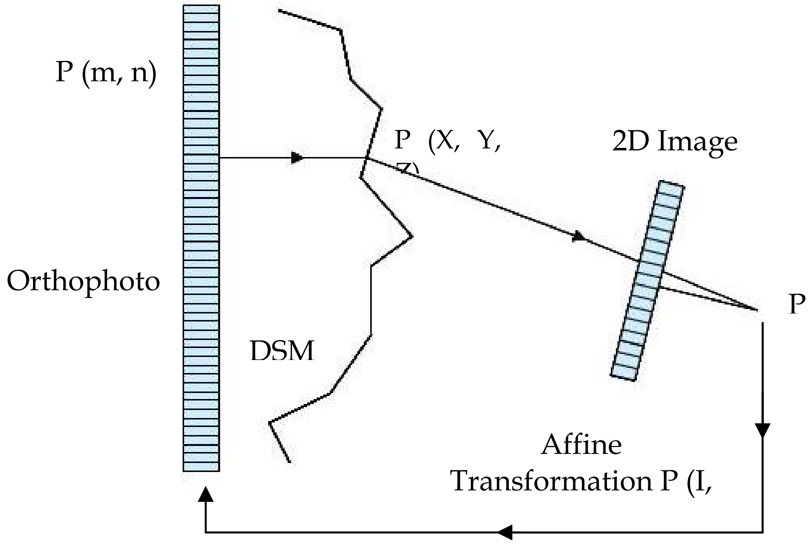

Figure 8. The true orthoimage framework production (After Alshawabkeh et al. 2010)

Figure 9. Generating depth map of the wall surface with the same size of the required orthophoto

Figure 10. True orthophoto for the image with pixel size 2 mm at object space.

Crack Detection and Quantification using true orthophoto and Image processing (Segmentation)

Extraction of cracks from the image is conducted using segmentation. The segmentation algorithms developed for image have been discussed extensively in the literatures (Palmer, 1996). The algorithms now can apply a real time segmentation of the intensity images; a widely used example is canny operator (Canny, 1986). The algorithms rely on differences in gray values of digital images. Cracks would be darker than the surrounding surface and could be easily extracted. Using an efficient operator for detecting cracks in the scaled orthophoto offers efficient approach for direct quantification of the cracks. In our application Canny filter has been applied on the generated trueorthophotos for edge extraction. To generate a binary image of cracks, a thresholding method is used. The results for the studied image are depicted in figure 11.

The results provide a continuous record of the extent of damage in the whole affected area. It is probable that small cracks exist around crack extracted from thresholding could be undetected. In this case, the region of concern in the building surface is cropped from the true orthoimages, and further thresholding is performed locally in existing crack regions with a higher threshold value as depicted in figure 12. For further routine monitoring activities, the results of the image processing, are archived.

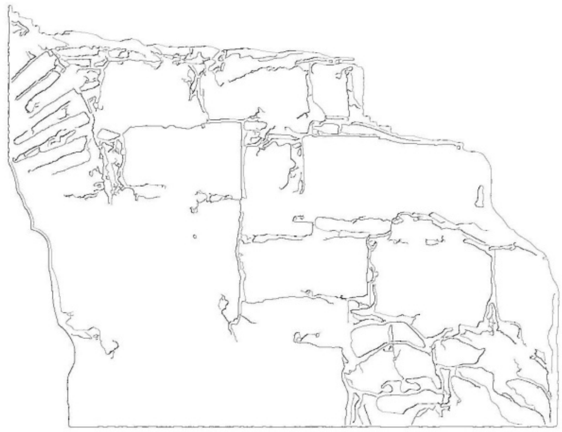

Figure 11. Binary edge map for the cracks extracted from true-orthopho using canny operator.

Figure 12. The binary edge map for the concern region using high threshold values, and measurement of the crack width

CONCLUSION

The management and the sustainability of the historical structures require periodic monitoring. Therefore, it is be necessary to develop an effective and adaptable monitoring strategy. Traditionally techniques used in measurement of material displacements in a structure involve contact tools only provide measurements at punctual places. The research presents a new methodology for monitoring of historical structures based on close-range photogrammetry and computer methods. The promising approach has the ability to accurately detect and quantify the continuous extent of material displacements without coming into physical contact with the structure. The results allow to determine the displacements both in terms of quantification and movement direction. The proposed procedure used an accurate generation of true orth-ophoto of the studied structure using precise 3D surface representations derived from laser scanning and digital images. Cracks are extracted directly from the generated orthophoto using real time segmentation operator. The results could be used for monitoring purposes. Further work in accuracy of this methodology will be investigated in further researches.

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