Using of Laser Scanning and Dense Stereo Matching for 3D Documentation and Virtual Reconstruction of the Ancient Sama Monastery/ Jordan

Article • February 2016
DOI: 10.14355/ijrsa.2016.06.003

CITATIONS
0

READS
28

7 authors, including:

A'Kif Al_Fugara
Al - Albayt University
31 PUBLICATIONS 126 CITATIONS

Rida Al-Adamat
Al - Albayt University
54 PUBLICATIONS 599 CITATIONS

Available from: A'Kif Al_Fugara
Retrieved on: 26 September 2016
Using of Laser Scanning and Dense Stereo Matching for 3D Documentation and Virtual Reconstruction of the Ancient Sama Monastery/ Jordan

A’kif Al-Fugara¹, Rida Al-Adamat², Mwfeg Al Haddad³, Yahya Al-Shawabkeh⁴, Mohammed El-Khalili⁴, Daifallah Obaidat⁵

¹Department of Surveying Engineering, Faculty of Engineering, Al al-Bayt University, Mafraq, Jordan
²Department of GIS and Remote Sensing, Institute of Earth and Environmental Sciences, Al al-Bayt University, Mafraq, Jordan
³Architecture Department, Faculty of Engineering, Al-Balqa’ Applied University, Salt, Jordan
⁴Queen Rania Institutes of Tourism & Heritage, the Hashemite University, Zarqa, Jordan
⁵Department of History, Faculty of Arts and Humanities, Al al-Bayt University, Mafraq, Jordan

Abstract

Sama Monastery is one of the best preserved architecture built in the third century AD at Jordan’s eastern desert. Before the twentieth century, the roofing materials of Monastery, even most of the arch stones, were carried off for the construction of bridges and ferries above the valleys and water channels in the region. Documenting the Monastery which remains in scientific and precise ways is an important goal in order to protect and preserve this important part of the cultural heritage of Jordan. In this study, laser scanner and digital photogrammetry have been used for this purpose. In spite of the potential of each single approach, the integration aims at supporting the visual quality as well as the geometric accuracy of the collected textured 3D models. The purpose of such visual information will serve as a tool for the identification of the nature, extent and severity of the deterioration.

Keywords

Sama Monastery; 3D Laser Scanning; Dense Stereo Matching; 3D Virtual Reconstruction; Combined Approach

Introduction

As an archive gathered over time, the 3D models provide valuable information when restoration is required. Such photorealistic models have to offer geometrical documentation of archaeological monuments means by providing high geometric accuracy measurement and presentation to determine the present state, i.e., the dimension, shape and position, of a historical or a cultural structure in a three-dimensional space as to enable their reconstruction when they fall into ruins or tumbledown by natural phenomena and human activities [1;2;3]. Different methods have been employed by archaeologists to record and model historical buildings based on the level of details and the purpose of documentation. Traditional CAD (Computer Aided Design) is the classic and the most common approach for creating digital 2D and 3D models of buildings. In archaeological applications with complex structures, CAD modeling is generally not considered to be the appropriate modeling method.

Recently, due to the fast development in computer science, different contact-free techniques have been used for generating realistic 3D models of the historical buildings such as digital photogrammetry which introduces non-contact, flexible and accessible surveying tools for 2D–3D archaeological recordation [4;5;6;7]. 3D data collection using laser scanning has become an additional standard tool for the generation of high quality of 3D models of cultural heritage sites and historical buildings [8;9;10]. This technique allows further quick and reliable measurement of millions of 3D points based on the run-time of reflected light pulses, which is then used to effectively generate a dense representation of the respective surface geometry.

Integrating photogrammetry and laser scanning vision presents an effective data collection procedure which generates precise 3D surface representations. The final product allows the creation of detailed and inclusive facade...
plans, which are both graphically superior and geometrically accurate [9]. Although present laser scanners generate intense information along homogeneous surfaces, the resolution of this data can still be inadequate. In contrast, digital photogrammetry is more accurate if such outlines have to be measured. However, image-based modeling alone is difficult or even impractical for surface parts, which contain irregular and unmarked geometric details [8;11]. So it is therefore the combination of both techniques that will be beneficial for accurate and complete description of the object space. The disadvantages of one approach can be compensated for by the advantages of the other technique. By these means, object geometry which is not available in the range data due to occlusions is provided based on photogrammetric measurements [12;13].

In this research, an approach combining in situ different surveying techniques were applied in order to provide sufficient and comprehensive data regarding the documentation and evaluation of the status of the west Monastery. The purpose was not only to record the damage, but also to make a first step towards creating a 3D reconstruction and monitoring program of the deterioration rate. Additionally, the 3D digital model can provide reference data as an exact guide to the restoration needed. In order to support the visual presentation of 3D surface details, a hybrid approach combining data from laser scanning and digital imagery was implemented. A complete description of the work carried out is presented, including the acquisition of laser scan and image data, co-registration of point clouds, 3D modeling and texture mapping. The acquisition of the relevant image and laser scanning data besides data pre-processing, which is mainly required for a perfect alignment of laser and image data for high quality mapping as well as texture mapping, is presented.

**Study Area Description**

The west Monastery of Sama is one of the main archaeological sites located in southern edge of the basaltic area of Hora Mount [14], about 12 km to the north east of Mafraq city (Fig. 1). Sama (called now Sama El-Sarhan) can be reached through Amman – Zarqa’s highway that passes through Mafraq towards the Syrian borders in north through the town of Jaber that is located directly on the Jordanian-Syrian borders. Most of archeological remains were built of basaltic stones; the main construction material is possibly only used in architectural residues in all Horan area sites in general [15]. Basalt stones available in the local environment are left by ancient volcanic activities based in Mount of Horan which is covering a wide area, stretching south of Damascus across the northeastern part of Jordan to the northern regions of Saudi Arabia [16;17].

![FIG. 1 SAMA WEST MONASTERY LOCATION](image)

The archeological remains have been exposed to the destruction operations in the past; the building stones were used in other facilities, such as the train railway bridges in the early twentieth century [18], as can be shown in Fig.
Unfortunately, this important part of the world’s cultural heritage is gradually being diminished due to modern houses surrounding archaeological sites, as several of the buildings built up over the archaeological structures residues. In addition, the roads that were constructed recently have caused further destruction of archeological site ruins as can be depicted in Fig.(2.b).

Methodological Work

The process of creating a 3D Virtual Restoration and Visualization of Sama west monastery can be subdivided into the stages of the acquisition of laser scanning and image data, co-registration of point clouds, 3D modeling and texture mapping and 3D buildings reconstructions; the workflow of the data collection is summarized in Fig. (3). Each step of the 3D model generation and restoration will be briefly discussed in the following text.

FIG.3 FLOW CHART OF METHODOLOGICAL FRAMEWORK
3D Digital Modeling Using Laser Scanning Technique

The main steps on 3D modeling by TLS are: data collection using overlapped laser scanning, Point cloud registration, Mesh creation, Texture mapping, 3D virtual model, and identifying Occlusion areas not covered with TLS measurement.

Data Collection Using Overlapped Laser Scanning

3D laser scanning system C10 manufactured by Leica was employed. This scanner features a field of view of 360° in the horizontal direction and 270° in the vertical direction, enabling the collection of full panoramic view. The scanning range of the system allows distance measurements between 0.1 to 300 m, with high scan speed (50k pts/sec). The distance measurement is realized by the time of flight measurement principle based on green laser at 532 nm. The accuracy of single distance measurements is 4 mm. During data collection, a calibrate video snapshot of 1920×1920 pixel resolution was additionally captured, which was automatically mapped to the corresponding point measurement. For the objects with complex shapes, a series of scans must be applied, and scans should have been available in local coordinate system [19]. In this project 22 scans were taken from outside of the Monastery buildings and 10 scans from the inside. With this number of scans, the whole site is supposed to be covered. However, there is a limitation which discourages this result like the wrecked top roof and the gaps between these ruins, and complex motif and sculptures on the high roof.

Point Cloud Registration and Matching

The first step in generating a 3D model is the registration of the individual scans acquired in the field. The scans need to be brought into a common reference system to create a contiguous point cloud. This involves the transformation of all scans into a single uniform coordinate system. Registration is a fundamental element in the data processing, as the precision achieved in this stage influences all subsequent processing steps [20]. Cyclone-Model was employed for the registration tasks. It is a 3D Point Cloud Processing Software form Leica Geosystems that is widely used for surveying terrestrial applications. Cyclone offers two approaches to combine the individual scans into a single co-ordinate system. One approach relies on target-based registration. This method uses targets as common points for the registration. The other depends on selecting corresponding cloud point features using Iterated Closest Point algorithm. The precision of the resulting transformation depends on the accuracy of scanned targets. In this study, target based registration is used. The final registered point cloud model is shown in Fig.(4).

Cloud Point’s Colure Texture Mapping

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. In this study, the texture was added to the coded subject using the scanner’s integrated camera that provides model-registered colour texture by capturing the RGB values of each cloud point [21]. Figures below show the result for the outer facades and part of a top view to the church with real texture. In addition, the view from the inside of the site is depicted in (Fig.5).
Mesh creation and Surface Modeling

Surfaces can either be formed by directly connecting points which then become parts of the surface [22;23] or by creating a best-fit surface through the points [24]. The first method allows the creation of the model from a complete, unstructured point cloud, but it has the disadvantage of being very susceptible to instrument noise and scan alignment errors. While the best-fit surface generating algorithms perform noise reduction automatically by approximating the surface and as a result remove noise. However, the risk in all smoothing functions is the possible loss of relevant detailed features. In this study, the triangular irregular network (TIN) meshing was used for producing the surfaces of the west Monastery. The final 3D meshed model is depicted in Fig.(6).

Cleaning of Point Clouds

The cleaning of the data, i.e. the removal of objects not relevant to the documentation, is an important step in the 3D modeling. Pre-model cleaning results in smaller models, especially on sites with full of ruins as in the case of west monastery (Fig. 6). Cleaning of scans can be performed on individual scans or on the complete point cloud. However, the cleaning was performed on the complete point clouds to reduce cleaning time as objects appearing in multiple scans which were removed in one operation Figs (7 and 8).
Surface Augmentation (Whole Filling)

Due to the horizontal and vertical limitations range of the laser scanner field of view, holes occur especially when scanning very complex and irregular objects, or wherever a surface is invisible to the scanner. Typical examples are ornamental structure facades or upward facing faces where no scan positions can be found above the surface, such as window ledges, scanner station location and roofs (Fig.9). If no scan data is available, methods for automated hole-filling or surface augmentation have been developed [25]. However, the generated surfaces will not represent the correct geometry of the structure and their using in heritage documentation is questionable. Therefore, different methods for automated hole-filling or surface augmentation have been developed by integrating points cloud generated from laser scanning and close range photogrammetry [8;25]. In this study, the laser scan holes and missing data were filled using Dense Stereo Matching (DSM) Technique. The integration between the two techniques is important in order to have a detailed structure reconstruction and modeling. This work demonstrated the potential and the benefits of integrating laser scanning (TLS) and dense stereo matching (DSM) technique to form a complete and detailed representation of Sama west Monastery.

3D Digital Modeling Using Dense Stereo Matching Technique

Recently, photogrammetric matching algorithms are capable of producing dense 3D point clouds with full automation process in matching the images in wise pixel resolution [26]. There are many tools and softwares available for dense image matching modeling whether web-based or open source with high level of automation [22;27]. In this study, the multi views stereo (MVS) method developed by [26] was used for the generation of precise and dense 3D point clouds. The implementation is based on the Semi-Global matching algorithm developed by Hirschmuller [28]. Different high-resolution images with sufficient overlapping have been collected for the missed data areas using portable calibrated camera, Canon EOS 1100D, which provides a resolution of 4272 x 2848 pixels with a focal length of 18 mm.

Point Cloud Generation Using DSM

In order to generate a dense point clouds from the collected images, the camera orientation parameters were calculated using Visual SFM software developed by [29]. The software improves the efficiency of Structure from motion matching algorithm by introducing a preemptive feature matching that provides good balance between the
speed and accuracy. Sparse point clouds for the surface features were extracted as depicted in Fig. (10).

The quality of the point cloud data achieved from Visual SFM software has a large variety. Therefore, the point cloud data resulted from Visual SFM software were filtered from the remaining outliers by using dense image matching software developed at IFP and implemented within a software package called SURE [26]. Fig. (11) shows the result of 3D point cloud for one of the site building facades as shown in SURE software.

Then, meshing process was applied for the purpose of surface generation. The resulted 3D points are presented in Fig. (11).

**Integration of TLS and DSM**

The processing started by registration of the TLS point clouds and DSM point clouds into one coordinate system. The registration was implemented by cloud compare software. For this purpose some corresponding points (at
least 4 points) were selected. Later, the cloud points were linked and were set to a compatible scale; at last the final results were pasted on the 3D model where the missing data exist on the façade of the building. The laser scanning data was selected as a reference points. SFM point cloud was registered using iterative closest point (ICP) to the TLS reference coordinate system with 0.074 mm mean convergence and 8.2 mm standard deviation. Accuracy analysis of point cloud registration for the Sama west monastery dataset is done. Mean convergence and standard deviation values which are calculated by comparing the 3D coordinates of the points were selected manually from point clouds resulted by the SURE after applying the parameters transformation, and the corresponding 3D coordinates of the points from laser scanner data, using the latter as a reference. The meshed result obtained from aligned two data sets from laser scanning and dense image matching techniques as depicted in (Fig. 12).

FIG. 12 INTEGRATED 3D POINT CLOUD SETS FOR TLS AND DSM

3D Reconstruction of Sama Monastery

The virtual 3D model of the west Monastery was reconstructed using the models generated by TSL and DSM. The integrated 3D model was exported to the CAD and 3D Max (Fig. 14). In order to ensure the credibility and the accuracy of the virtual reconstruction, the development of valid virtual 3D model reconstructions of destroyed Sama west monastery is done. The work was done by interdisciplinary team, which consists of specialists in related fields: historians, archaeologists, engineers, and architects. The restoration started by reviewing the documentation of the site, where all the ancient descriptions information is gathered from archives and from the fields investigation. In the next phase the integrated 3D model was exported to 3D max in Computer Aided Design (CAD) environment, where several model creation techniques are available. A knowledge database with parameterized construction elements was created by using integrated 3D model generated (from photogrammetry and laser scanner) which served as the base model that contains all the existing features that Sama west monastery site has (Figure 14).

Later, the base model was modified using the user interface of the database using a detailed plans and hand drawing; this drawing is digitized using a paper scanner for further use in the CAD software, knowing the actual dimensions of these basalt stones from previous archaeological finds. Archaeological wall drawings database were created. A series of engineering analyses were made to guarantee the scientific rigorous and to validate on a
scientific level the virtual reconstruction on the created three dimensional models. Figure illustrates the Virtual reconstruction for destroyed Sama west monastery using CAD software. The final 3D reconstructed model is shown in Fig. (15).

![Virtual reconstruction of Sama west monastery](image1)

**FIGURE 14 INTEGRATED 3D MODEL IN 3D MAX SOFTWARE AS BASE MODEL**

![3D virtual model of Sama west monastery](image2)

**FIGURE 15 3D VIRTUAL MODEL OF SAMA WEST MONASTERY SITE**

**Conclusion and Recommendations**

In this research, the potential of combining laser scanning and dense stereo matching for the conservation and documentation of the Sama west Monastery site is discussed. The purposes to bridge gaps in the laser scanner data resulting from the shadowing affect and add new details, which are not accessible to laser scanner, but they are necessary for building volume perception. The integration aims at supporting the visual quality as well as the geometric accuracy of the collected textured 3D models of the Monastery. The purpose of such visual information may serve as a tool for the identification of the nature, extent and severity of the deterioration.

**References**


