INTEGRATION OF DIGITAL PHOTOGRAMMETRY AND LASER SCANNING FOR HERITAGE DOCUMENTATION

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ABSTRACT:

Within the paper the potential of combining terrestrial laser scanning and close range photogrammetry for the documentation of heritage sites is discussed. Besides improving the geometry of the model, the integration aims on supporting the visual quality of the linear features like edges and cracks in the historical scenes. Although the laser scanner gives very rich surface details, it does not provide sufficient data to construct outlines for all surface features of the scanned object, evene though they are clearly defined in the reality. In our approach, information on edges and linear surface features is based on the analysis of the images. For this purpose an integrated segmentation process based on image data will support the extraction of object geometry information from the laser data. The approach applies image based semi-automated techniques in order to bridge gaps in the laser scanner data and add new details, which are required to build more realistic perception of the scene volume. The investigations and implementation of the experiments are based on data from Al-Khasneh, a well-known monument in Petra, Jordan.

1. INTRODUCTION

The generation of 3D models of historical buildings is frequently required during the documentation of heritage sites i.e. for tourism purposes or to provide education resources for students and researchers. During the generation of these models, requirements such as high geometric accuracy, availability of all details, efficiency in the model size and photo realism have to be met by the different approaches used for data collection [EL-Hakim et al 2002]. One well-accepted technique frequently applied in the context of heritage site documentation is close range photogrammetry [Gruen et al 2002, and Debevec 1996]. In the past decade, these traditional terrestrial approaches have also benefited from the fact that digital image collection is now feasible with of-the-shelf cameras. Thus the efficiency of photogrammetric data collection could be improved considerably by the integration of semi-automatic tools based on digital image processing. Additionally, laser scanning has become a standard tool for 3D data collection for the generation of high quality 3D models of cultural heritage sites and historical buildings [Boehler and Marbs 2002]. These systems allow for the fast and reliable generation of millions of 3D points based on the run-time of reflected light pulses. This results in a very effective and dense measurement of surface geometry. Current limitations regarding the measurement rates, accuracy, or spatial point density will further disappear in the near future, thus laser scanning seems to become the dominating approach for the generation of 3D documentations and presentations of heritage sites.

Despite the considerable progress of these approaches, there are still some limitations, which have an effect on the quality of the final 3D model. Even though current laser scanners can produce large point clouds fast and reliably, the resolution of this data can still be insufficient, especially if edges and linear surface features have to be collected. In the contrary, the digital photogrammetry is more accurate in outline rendition, especially if they are clearly defined in the reality. On the other hand, image based modeling alone is difficult or even impractical for parts of surfaces, which contain irregular and unmarked geometrics details. Additionally, 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 has to be captured.

The complete coverage of spatially complex objects like heritage sites can only be guaranteed, if data collection is realized from different viewpoints. Even though this is possible in most scenarios, problems can result from the fact that setting up and dismounting the complete laser system is relatively time consuming. In contrast to that, the effort to collect additional images with a standard digital camera can almost be neglected. Additionally, compared to laser scanning there are fewer restrictions on the range of measurements during image collection, which simplifies the selection of different viewpoint in order to cover the complete structure of the object. For this reason, it can be advantageous to complete a geometric model, which has been generated from the laser measurement, based on intensity images captured independently from the range data. By these means object geometry, which is not available in the range data due to occlusions is provided based on photogrammetric measurements.

Thus, the highest possible degree in efficiency and flexibility of data collection will be possible, if both techniques are combined during data processing. In our approach this integration helps to improve the geometry and visual quality of the collected 3D model. During data collection the information on edges and

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linear surface features like cracks is based on the analysis of the images, whereas information on object geometry is provided from the laser data. Additionally, areas, which are not accessible in the laser scanner data due to occlusions are added based on semiautomatic evaluation of the imagery. By these means, a complete 3D features for the scene can be generated with sufficient and clear details.

Within the paper the presented approaches are demonstrated in the framework of a project aiming at the generation of a 3D virtual model of the Al-Khasneh, a well-known monument in Petra, Jordan. In section 2 the collection and pre-processing of the relevant image and LIDAR data is discussed. This pre-processing is mainly required in order to coregister laser and image data for further processing. Section 3 exemplarily presents our feature extraction approach using the hybrid system for the left door of Al-Khasneh.

2. DATA COLLECTION AND PREPROCESSING

The collection of the data, which has been used for our investigations, was performed in cooperation with the Hashemite University of Jordan. One of the project goals is the generation of a 3D documentation of the Al-Khasneh monument in Petra city, Jordan, which is depicted in Figure 1.

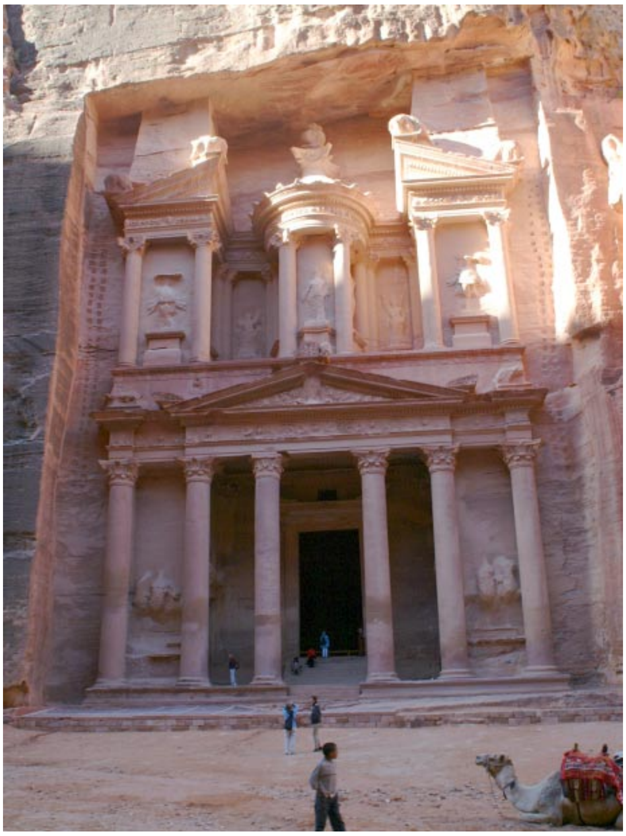

Figure 1. Al-Khasneh facade, Petra

2.1 Al-Khasneh Monument

The ancient Nabataean city of Petra has often been called the eighth wonder of the ancient world. Petra city in southwestern Jordan prospered as the capital of the Nabataean empire from 400 B.C. to A.D. 106. Petra's temples, tombs, theaters and other buildings are scattered over 400 square miles, these architectures are carved into rose-colored sandstone cliffs. After a visitor enters Petra via Al-Siq, a two-kilometer impressive crack in the mountain, the first facade to be seen is Al-Khasneh, which is considered as the best-known monuments in Petra city. The Al-Khasneh facade is 40m high and remarkably well preserved, probably because the confined space in which it was built has protected it from the effects of erosion. The name Al-Khasneh, as the Arabs call it, means treasury or tax house for passing camel caravans, while others have proposed that the Al-Khasneh Monument was a tomb. Behind the impressive facade of Al-Khasneh, large square rooms have been carved out of the rock [Sedlaczek, 2000].

2.2 Sensors Applied

For point collection, the 3D laser scanning system GS100, manufactured by Mensi S.A., France was applied. The scanner features a field of view of 360° in the horizontal and 60° in the vertical direction, enabling the collection of full panoramic views. 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 between 2 and 100 meters. The scanner's spot size is 3 mm at a distance of 50 meters; the standard deviation of the distance measurement is 6 mm for a single shot. The system is able to measure 5000 points per second. During data collection a calibrated video snapshot of 768x576 pixel resolution is additionally captured, which is automatically mapped to the corresponding point measurements.

In addition to the laser data, digital images were captured for photogrammetric processing using a Fuji S1 Pro camera, which provides a resolution of 1536x2034 pixel with a focal length of 20 mm.

2.3 Measurement Configuration

Because it is not possible to have a complete 3D coverage for the Al-Khasneh facade based on data collected from a single station, three different viewpoints with five scans were done to resolve the occlusions. The problem to choose the viewpoint positions represents an important phase of the survey for such a monument since potential sensor stations are restricted by the mountainous environment surrounding Al-Khasneh. Three positions were selected, from the entrance area of the monument, from the left of the monument, and one scan was collected from an elevated viewpoint. Since the vertical field of view of the laser scanner from these positions could not cover all the facade from one scan, the left and top scanning were done using 2 scans from the same position, taking into consideration sufficient overlapping regions to allow for a subsequent integration. In total, the five scans resulted in almost 5 million collected points.

All the acquired 3D models have been processed using Innovmetric Software, PolyWorks. The model of Al-Khasneh facade resulted from merging the five scans in an independent coordinate system into an absolute coordinate system. After registration of the scans using corresponding points, the software constructs a non-redundant surface representation, where each part of the measured object is only described once. The result of the combination of the five laser scans is given in

Figure 2. The produced model has an average resolution of 2 cm with more than 10 million triangles.

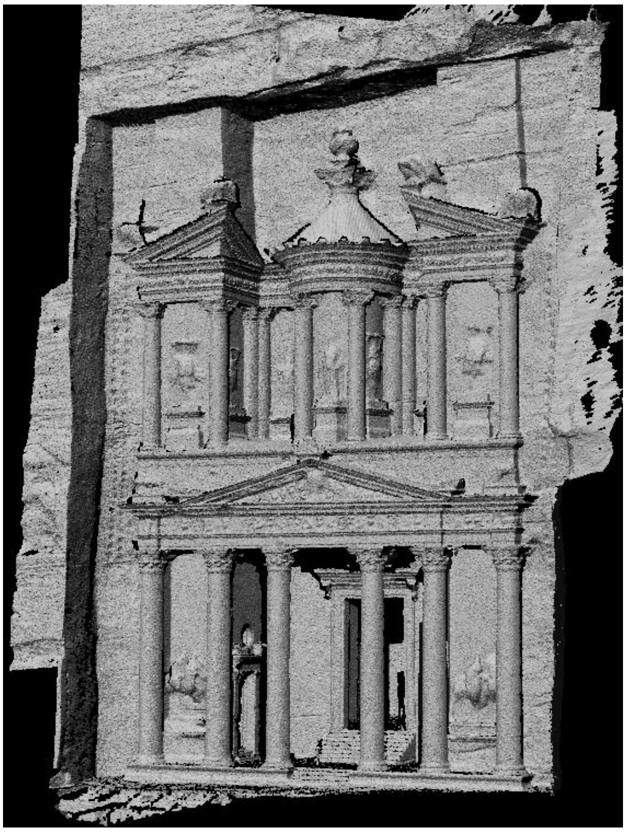

Figure 2. 3D Model of Al-Khasneh created from 5 scans

In additional to the outer survey, a 360-degree scanning from a station in the interior of the Al-Khasneh had been taken, which resulted in 19 million points. Figure 3 shows the point cloud of this scan with colour information overlaid.

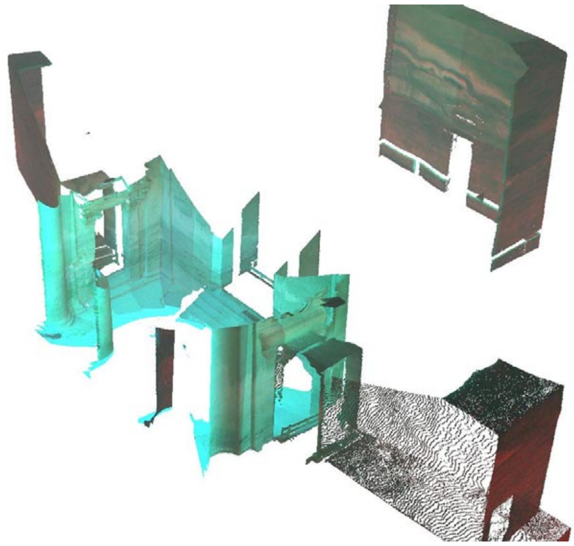

Figure 3. 360 degree scanning for the inner part of Al-Khasneh

3. INTEGRATED DATA PROCESSING

Although the 3D model produced by laser scanner contains a large number of triangles, which are representing the surfaces, it can still difficult to recognize and localize the outlines of the surface features. An example for this type of features, which are clearly visible in an image is depicted in figure 4. This data was collected from the left door of Al-Khasneh. As it can be seen from the corresponding 3D meshed model shown in figure 5, these cracks and the edges outlines are lost beyond the resolution in the available laser data.

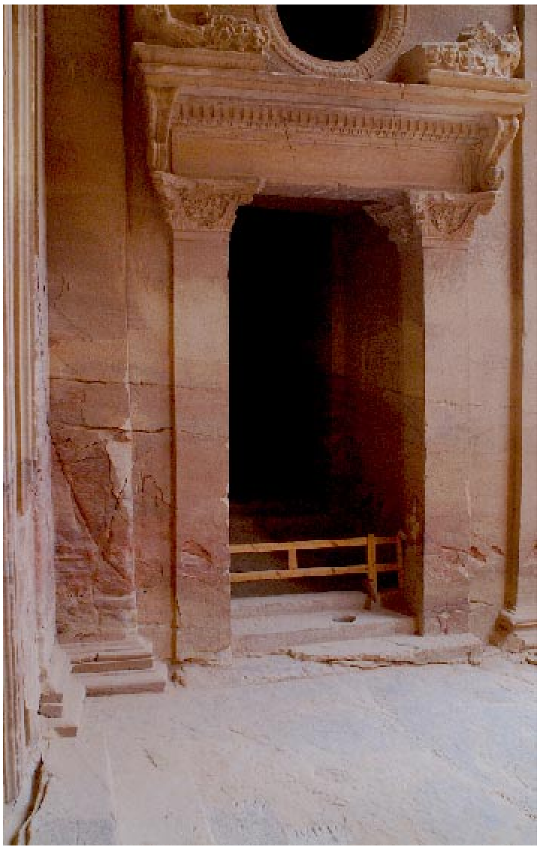

Figure 4. The left door of Al-Khasneh

In order to support the visual quality of such details, a hybrid approach combining data from the laser scanner and the digital imagery was developed. For integration all data sets have to be coregistered in the first processing step. This is realized by aligning the extracted edges from both data sources using an algorithm developed by [Klinec and Fritsch, 2003]. After position and orientation parameters are computed for the sensor stations, distance images are generated from the point cloud in order to provide the missing third dimension in the available images. Finally, an integrated segmentation process based on the image data is be used in order to support the extraction of the details and the surface features outlines from distance images. Additionally, the approach applies a semi-automated feature extraction from images to bridge gaps in the laser scanner data. By these means details can be added that are necessary for generating more realistic perceptions of the scene volume. In the following paragraphs the hybrid approach will be discussed in more details. The left door of the Al-Khasneh depicted in figure 4 and 5 is exemplarily processed.

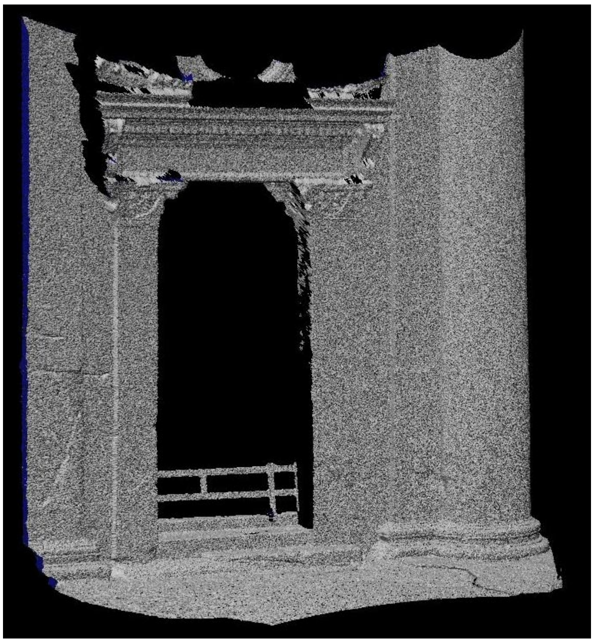

Figure 5. Meshed model for the left door

3.1 Data Coregistration

The quality of the registration process, which aligns the laser scanner data with the imagery, is a crucial factor for the aspired combined processing. This registration can realized if correspondence coordinates are available in both systems. Since the accurate detection and measurement of point correspondences can be difficult especially for the point clouds from laser scanning, straight lines are measured between the image and the laser data as corresponding elements. These lines are then used by a shape matching followed by a modified spatial resection [Klinec and Fritsch, 2003]. The algorithm transforms the 3D straight lines extracted from the laser data and the corresponding 2D image lines, which are given by two points, into a parameterized representation. Then the unknown exterior parameters of the image are determined by spatial resection. In order to solve the spatial resection problem, the least squares algorithm-using Gauss Markov Model with initial values of the exterior orientation parameters is implemented. The extraction of straight edges from laser scanner data is simplified, if the required line is defined by two intersecting planar surfaces as it is demonstrated in figure 6. The corresponding edges in the digital image can be extracted interactively or semi-automatically based on edge segmentation. At least three corresponding straight lines are required to obtain a unique solution for the spatial resection.

3.2 Distance Image Generation

After the camera coordinates and orientation parameters are registered in the laser scanner coordinate system, the collinearity equations are applied to generate a distance image based on the available point clouds. For our exemplary scene, the point cloud was collected from a close viewpoint resulting in 1 cm average resolution. The distance images were generated with the same number of pixels of the corresponding images (1536x2304 pixels).

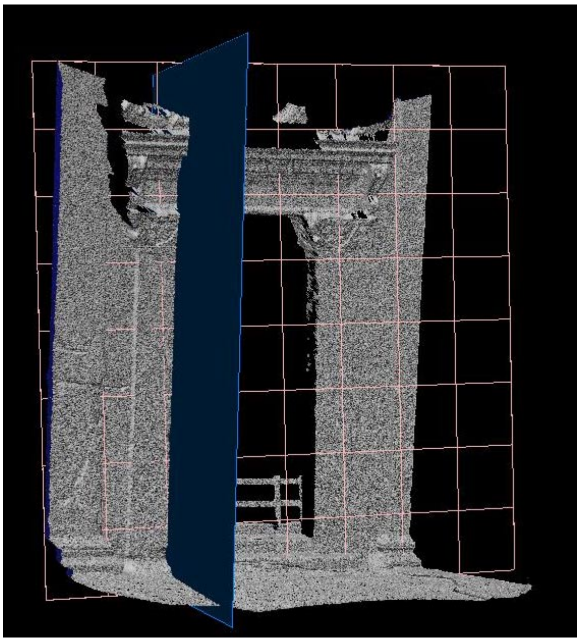

Figure 6. Two intersecting planar surfaces, one of them is represented by grid lines for demonstrating purposes.

Figure 7. The distance image of the left door projected on the corresponding image.

For the left door of Al-Khasneh, three distance images were generated for the three images available from different camera stations. Figure 7 depicts one of these distance images projected on the corresponding image.

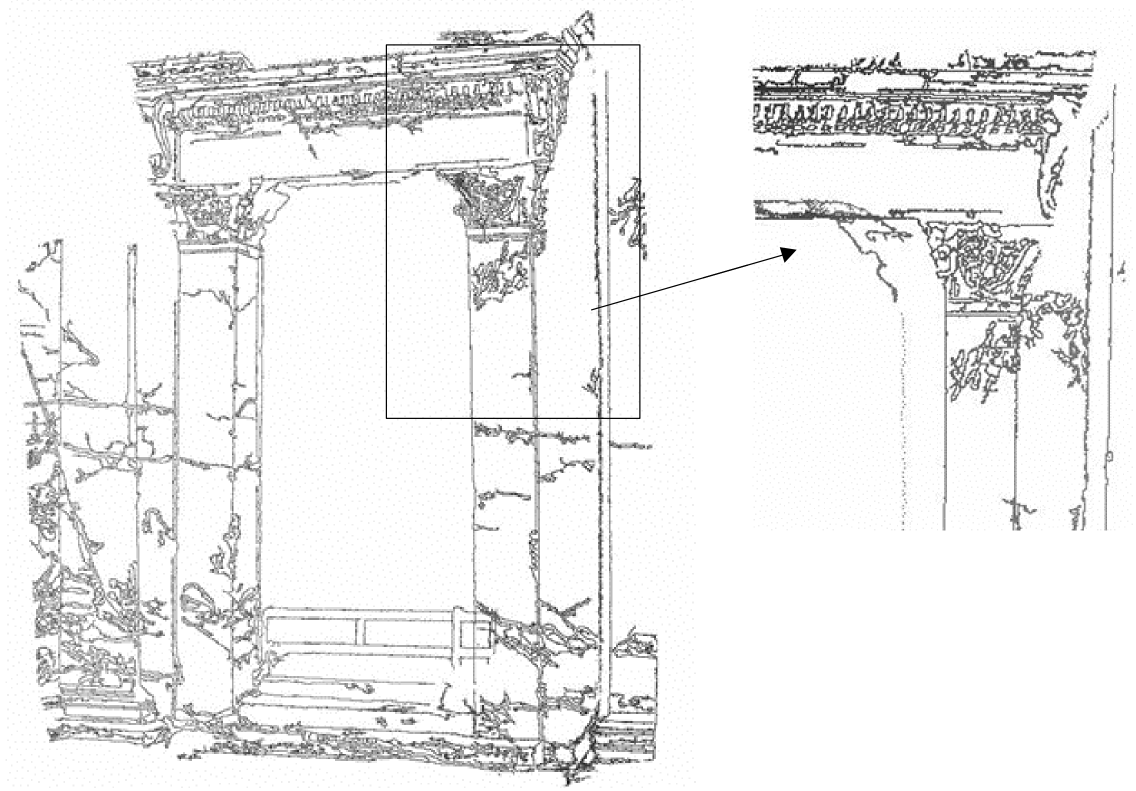

Figure 8. 3D features extracted for the left door of Al-Khasneh, the inner edge of the column is added from image based measurements.

3.3 Image Segmentation

The segmentation process is used to automatically extract the 2D coordinates of the linear features from three different digital images. For this purpose, an edge detection based on the Lanser filter has been applied on the 3 imagery images. The third dimension of the segmented outlines is provided from the distance images. Figure 8, depicts the final 3D features extracted for the left door of Al-Khasneh. It can be seen that the data contains all of the edges and linear surface features in a clearly outlines. In total the feature-based representation contains 143.6 thousand points, whereas the original point cloud of the same portion has 1.1 million points.

3.4 Occluded Features from Image Based Measurement

It can be seen from the 3D features presented in figure 5 that due to the position of the laser scanner, the inner edge of the right column of the door has no data. The occluded edge can be added based on semiautomatic evaluation of digital imagery to have a complete data set for the scene. In our approach, the 3D coordinates of initial points were extracted manually. Then an automatic stereo matching has been applied for closely spaced images to add more points on the edge. For matching within the segmented parts of the edge epipolar constraint is used. The occluded edge is added to the 3D features as it can be shown in right part of figure 8.

4. SUMMARY AND CONCLUSION

The work described in this paper was developed as a part of an ongoing project, which aims to underline the necessity to integrate image based measurements and laser scanner techniques in order to optimize the geometric accuracy and the visual quality of 3D data capture for historical scenes. In our approach, the segmentation process is used as an intermediate step to extract information on edges and linear surface features, whereas the 3D information of theses details is provided from the laser scanner data. By the combination of both data sources, the shape of 3D features can be determined accurately, since the interpretation of point clouds and meshed models is improved using the available images. Finally, the approach applies semi-automated image based feature extraction. These features can be added to data from laser scanning in order to generate a more realistic perception of the complete scene.

5. ACKNOWLEDGEMENTS

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