Combining 3D Laser-Scanning and Close-Range Photogrammetry - An Approach to Exploit the Strength of Both Methods

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Abstract

The use of 3D laser-scanners in the documentation of archaeological and cultural heritage sites is well established by now. They are becoming more and more popular for a wide range of archeological purposes because of their high performance. The huge datasets produced by a laser-scanner provide considerable possibilities for the modeling and visualization of objects. Although they deliver a point cloud with high density, the accuracy of individual points barely reaches one centimeter. To attain much higher accuracy, photogrammetric methods or optical scanning techniques using structured light can be used. Considering all advantages, each of these methods has its specific limitations.
While photogrammetry carries the potential to measure edges very accurately, the measurement of freely formed and sparsely structured surfaces causes problems. On exactly those surfaces a laser-scanner works properly. However, precise determination of edges is not really possible here.
The paper describes an approach to exploit the strengths of both sensor-types by combining the acquisition and evaluation of datasets. The object of investigation is the Apadana Palace in Persepolis (Iran). Surveyings of reliefs are carried out in a joint project. Participants are the Beuth Hochschule fuer Technik Berlin - University of Applied Sciences, the Iranian Cultural Heritage, Handicraft and Tourism Organisation (ICHHTO) and the Gilan Eng. Surveying Company. The ICHHTO demands detailed mapping of reliefs with all damages, repairs and joints as a base for restoration.
Laser-scans with a resolution of 3 mm are made with a LMS-Z420i from Riegl, Austria. For photogrammetry, a set of 188 images is captured with a calibrated Nikon D200 digital camera. This image block meets the specific requirements of close-range photogrammetry. Both datasets are oriented to the same reference system.
The software package PHIDIAS from PHOCAD, Germany, is applied for simultaneous data processing. During the evaluation process, the edges are determined from the photos and the depth information is taken from the scanner's point cloud. To reach the required accuracy, it is necessary to reduce the noise within the point cloud. This is done by filter techniques that originate from digital image processing.

Key words: *3D laser-scanning, close-range photogrammetry, combining methods*

1 Introduction

For nearly 5 years the Laboratory for Photogrammetry of the Beuth Hochschule fuer Technik Berlin - University of Applied Sciences has been co-operating with Iranian partners in surveying and mapping of ancient Persian buildings and architecture of historic importance. For this purpose geodetic methods, digital photogrammetry and terrestrial laser-scanning are applied.
A part of the recent workings at the cultural heritage site of Persepolis, the surveying of reliefs at the Apadana Palace, includes the combination of photogrammetric methods and scanning techniques. By combining these methods, the advantages of both laser-scanning and close-range photogrammetry are used.

2 Principles and properties of the used methods

Laser-scanning

A laser-scanner generates 3D-coordinates of an object point by measuring the horizontal and vertical angle and the distance between the scanner's center and the object point. This happens with high performance. Depending on the type of scanner and the method of distance measurement used (time of flight or phase difference), it produces from 1,000 points per second (Cyrax 2500) up to over 900,000 points per second (Faro Photon).

The density of points on the object's surface can be predefined by the user and is limited by the minimum angle increment of the system. Depending on the distance from the scanner and the amount of scans, a very high point density can be achieved. But high point density does not coincide with high accuracy. The accuracy of a single point depends primarily on the accuracy of the distance measurement. Depending on different types of scanners and different methods, achievable accuracies of distance measurement vary from sub-millimeters (triangulation) to some centimeters (time of flight)[1]. In addition, some properties of the surface like color or texture, that affect the reflection of the laser beam, can have an effect on the distance measurement.

Beyond that, each type of scanners has its specific limitations in range and measuring volume. The measuring range of scanners employing the time of flight method (200-300m) is longer than the measuring range of scanners employing the phase difference method (70-80m). The range of triangulation scanners is around a few meters[2].

The laser-scanner applied for the workings described in this paper is a LMS-Z 420i from Riegl, Austria. The distance measurement is realized by the time of flight measurement principle with an accuracy of single point measurement of 10 mm.

Close-Range Photogrammetry

Close-range photogrammetry basically uses the principle of triangulation. By mathematically intersecting converging lines in space, the precise location of a point can be determined.

The base for 3-dimensional point measurement by means of close-range photogrammetry is a set of images oriented to a coordinate system. This means that the positions (x, y, z) and the rotation angles (ω, φ, κ) of the images have to be determined prior to the evaluation.

To define a point by photogrammetrical means, the image coordinates (x', y') of this point have to be measured in at least two, better three images. The spatial coordinates are determined by the intersection of rays projected from the image point through the projection center onto the object. The accuracy of both, the orientation and the evaluation, is depending on the pixel size, image scale and distance between two camera positions. Close-range photgrammetry is very versatile and applicable for the acquisition of 3D-data of objects of very different size, from the smallest machine part up to large buildings.

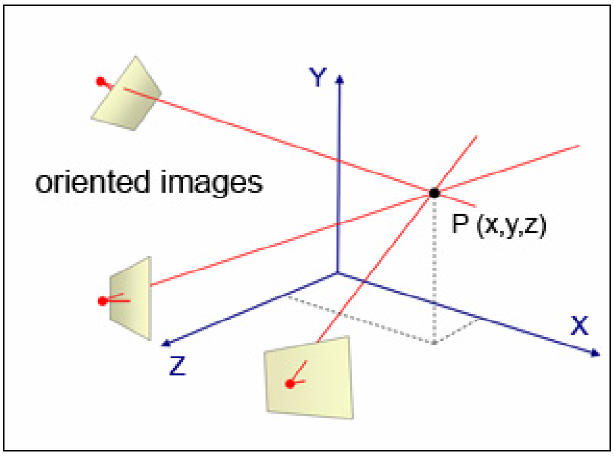


Figure 1. The principle of close-range photogrammetry.

1. Thorsten Schulz and Hilmar Ingensand, „Laserscanning – Genauigkeitsbetrachtungen und Anwendungen," in *Photogrammetrie Laserscanning Optische 3D-Messtechnik, Beitraege der Oldenburger 3D-Tage 2004*,ed. Thomas Luhmann (Heidelberg: Herbert Wichmann Verlag, 2004), 90-97.

2. A. Abdelhafiz, „Integrating Digital Photogrammetry and Terrestrial Laser Scanning" (Dr.-Ing. diss., Technische Universitaet Braunschweig, 2009),20,21.

3 Why to combine these methods?

The specified properties of the used methods show that both the close-range photogrammetry and laser-scanning have their advantages and specific limitations.

A laser-scanner delivers a huge amount of points in a short time. These points describe the object's surface with high density no matter if it is structured or not. But there are difficulties in the determination of edges. The surface is scanned in constant vertical and horizontal steps. So it can not be influenced wether the laser beam hits an edge or a certain point or not. A precise edge determination based on the scanner's point cloud must be done in subsequent evaluation steps by the intersection of planes. For objects with free formed surfaces we deal with in archeology and cultural heritage, e.g. reliefs or other artifacts, this may not lead to the desired results.

Close-range photogrammetry requires little time and little equipment for acquisition of data. Once the images are oriented, the 3D-coordinates of object points can be determined with high accuracy. To identify details of the object, contrasts in the images are needed. So, edges and structures like joints and cracks can be measured very accurately. But we have difficulties on sparsely structured and low-contrast surfaces. Here a clear determination of object points is not possible. In addition to that, the evaluation can be very time-consuming because every point has to be measured in at least two, better three images.

By combining the two methods we want to use the high accuracy potential of close-range photogrammetry in the determination of edges and the high density of points measured on the surface using a laser-scanner.

4 Principle of Combined Application

The combined evaluation of image and laser-scanner data is based on the principle of the so-called monoplotting. In this case, only one oriented image is needed to determine the 3D-coordinates of an object point. On the condition that the image block and the scanners point cloud have the same orientation to the coordinate system, the point cloud replaces the missing third dimension in the images. So a 3D single image measurement is possible[3].

To specify the principle, the image coordinates (x', y') of a certain point are measured in one image. As the position (x, y, z) and the rotation angles (ω, φ, κ) of the image are known, a spatial ray can be defined from the image point through the projection center. Thereby the direction to the object point is fixed. The projected ray is then intersected by the scanners point cloud. The distance from the projection center of the image is determined by an interpolation of the depth values of adjacent scan-points. So, horizontal and vertical direction and distance are defined to calculate the 3D-coordinates of the object point.

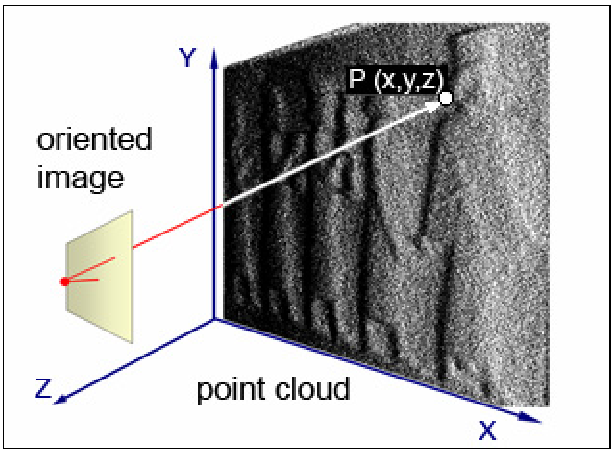


Figure 2. The principle of the combined application (monoplotting).

5 Description of the object and the intent

The Apadana Palace is taking the central position among the ruins of Persepolis. It was the most impressive palace in Persepolis and belonged to the largest buildings in antiquity. The square-shaped main hall alone covered an area of 3600m² and, considering the whole palace with the three verandas, altogether 72 columns of about 20m

3. PHOCAD GmbH, „PHIDIAS – The Photogrammetric Interactive Digital System," Combined evaluation with laserscanner data, www.phocad.de/Produkte/PHIDIAS/English/english

height carried the richly ornamented wooden ceiling. Darius the Great began the construction in 515 BC and his son Xerxes I completed it 30 years later. The palace was used for official audiences and played the central role in the ceremonies of “Noruz”, the Persian New Year’s Day.

Figure 3. The ruins of Persepolis with the Apadana Palace.

The stairways at the entrances are decorated with reliefs showing representatives of all 23 nations of the Persian Empire. Each of them is carrying typical goods as tribute for the Persian King. We want to focus on one of the decorated walls at the eastern entrance, which is about 27 meters long and 4 meters high. The very detailed reliefs are carved out up to 8cm.

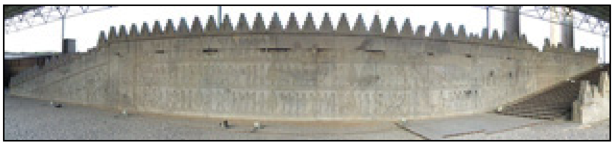


Figure 4. Decorated wall at the stairways of the eastern entrance.

The cultural heritage organization needs detailed mapping of reliefs with all damages, repairs and joints to use it as a base for restoration. Although this map has to be in 2D, we must consider the third dimension to avoid the effects of perspective distortion in the images. So we use two methods working in 3D to produce a 2D-map.

Figure 5. Details of the reliefs at the eastern entrance.

6 Field works

The first step is the definition of a common coordinate system which is represented by reference points. These points are either labeled by retro-reflecting targets for laser-scanning or black and white targets for photogrammetry. Furthermore, “natural” points on the relief are used as reference points. But these “natural” points are solely used for the orientation of the images and not for the registration of laser-scans. The coordinates of the reference points are determined by geodetic means. The measurements were carried out with a Leica TCRM 1201 total station. In an adjustment the coordinates are computed with an accuracy of +/- 1 mm.

The second step is the acquisition of laser-scanner data. Four scans with a resolution of 3 mm were made from different postions. The scans were registered immediately after the last one was captured. That way a constant resolution of points at the object and a complete acquisition without holes at hidden parts of the reliefs can be guaranteed.

The third step is the capture of image data. To meet the requirements of close-range photogrammetry, a number of conditions have to be kept. Every object point should be present in three images captured from different directions. Image scale and distance between two positions as the basic parameters to control the accuracy of orientation and evaluation have to be regarded. So, a set of 188 images is captured using a calibrated Nikon D200 digital camera.

7 Evaluation

The software PHIDIAS from PHOCAD, Germany, was applied for simultaneous data processing. PHIDIAS is a photogrammetric application integrated in Bentley Microstation. Besides the photogrammetrical functions, it provides the combined evaluation with laser-scanner data.
The evaluation procedure starts with an image block orientation. In each of the 188 photos the image coordinates of the control points and additional tie points are measured. Based on these

measurements, every camera position and rotation can be calculated in a bundle block adjustment.
The results of the adjustment are shown in the illustrations below.

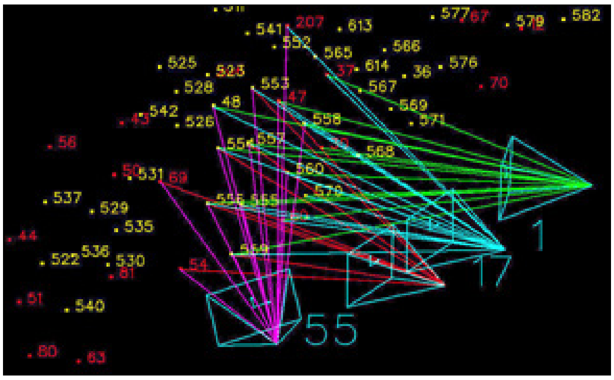


Figure 6. Results of the bundle block adjustment (4 images).

For the sake of clarity the results for only four images are shown in figure 6. It shows the cameras at their calculated positions and the bundles of rays intersecting at the tie points and control points. Figure 7 shows the results of the bundle block adjustment considering all point measurements in all images of the block.

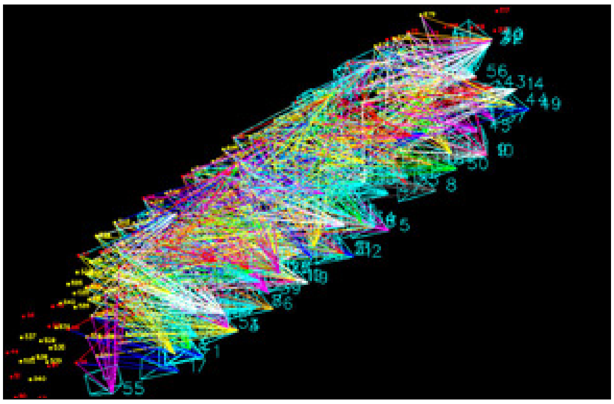


Figure 7. Results of the bundle block adjustment (188 images).

The orientation process attained an accuracy of +/- 1 mm. Effects of radial distortion are corrected in all image measurements. As the next step, the geometrical evaluation of the relief can be started.
The geometry of contours and edges are determined by straight photogrammetrical means. To define the outline of a detail, e.g. a particular person within the relief, a plane is created by measuring at least three points in the immediate vicinity. This plane now represents the depth value for the single image measurements of the contour line. Additional 3D-edges describing details beyond the plane are measured using multi-image photogrammetry technique. The points defining these edges are measured in three images to determine the coordinates by ray intersection.
Then the laser-scanner data are loaded directly into PHIDIAS. The lines on the convex parts of the reliefs are determined by means of mono-image evaluation (see figure 8).

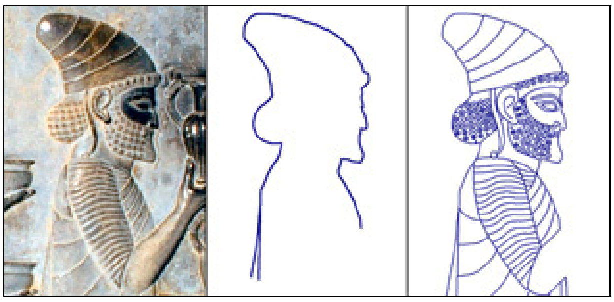


Figure 8. Image and the two steps of evaluation.

A point is measured in one image, the depth value is interpolated from the point cloud. At this point differences between the lines resulting from the monoplotting and the expected positions of lines are visible. The reason that causes this problem is the variance within the laser-scanner data. The variance affects the interpolation of the depth value and this results in geometrical errors (see figure 9).

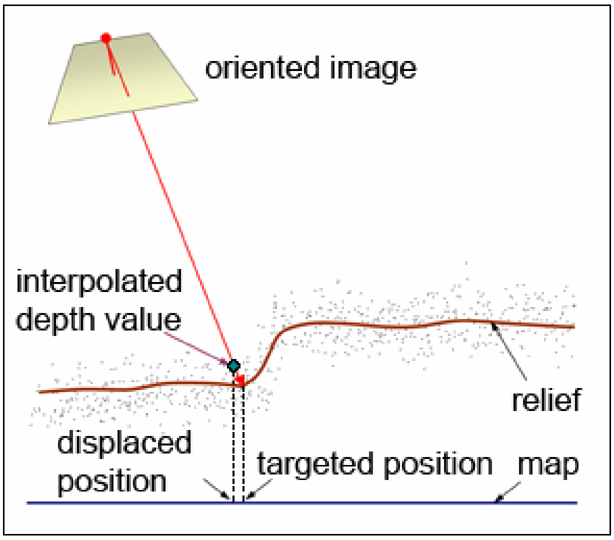
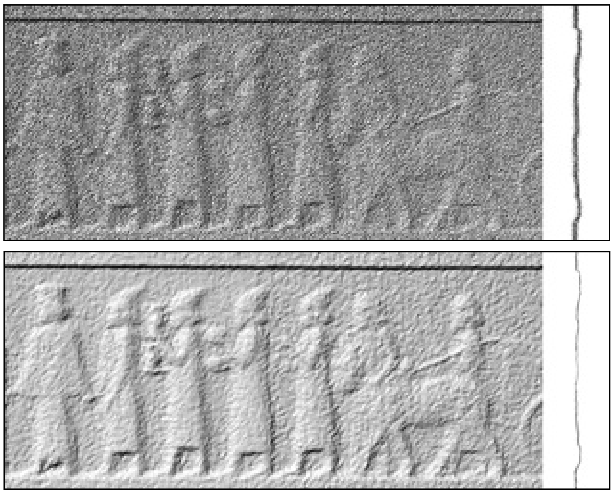


Figure 9. Differences resulting from incorrect depth interpolation.

So the variance must be reduced. This can be achieved by applying a filter to the laser-scanner data.
The process of filtering is done in ERDAS Imagine, an image processing software for satellite and aerial imagery. At first the whole point dataset of the relief has to be subdivided into overlapping tiles of manageable size. These tiles are converted from xyz coordinate files into grayscale images. For this purpose, the points are "resampled" to a raster. The z-coordinate is translated into a gray scale value. Then a median filter with a kernel size of 5 by 5 pixel is applied to the gray scale images. This filter type and size was chosen because of the best results shown in a test series. After the filtering, the image files are reconverted into xyz coordinate files with their original range of values. Figures 10 and 11 show the difference between the unfiltered and filtered point clouds.



Figures 10 and 11. Shaded view of the unfiltered and filtered point cloud with their corresponding cross sections.

The optimized datasets can be loaded into PHIDIAS and used for the combined evaluation.

As shown in figure 13 and 14, a very detailed map of the extensive reliefs has been created. Examinations at different areas of the reliefs result in deviations of max +/- 3 mm for details evaluated by monoplotting. The accuracy of drawing of a particular point depends on the position this point is located in the image. Details evaluated in the center of an image reach a higher accuracy (+/- 1 mm) than details located on the margins (+/- 3 mm).

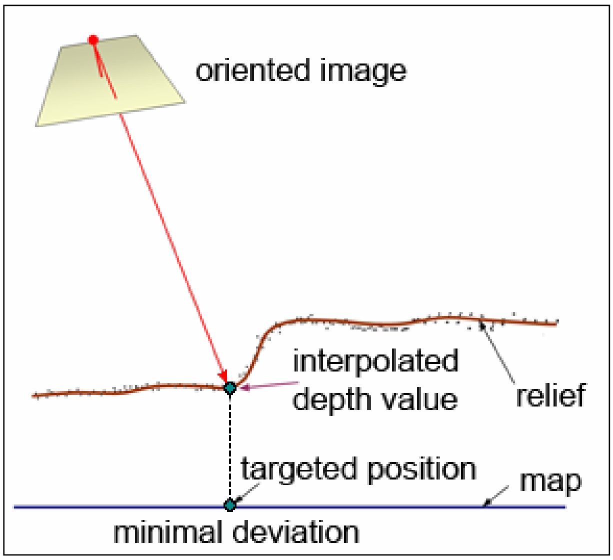


Figure 12. Minimized differences.

8 Conclusion

By combining the acquisition and evaluation of laser-scanner data and image data, results with a high richness of detail and accuracy are produced. This would not be possible if laser-scanning or close-range photogrammetry were applied separately. Small details visible and measurable in an image can not be identified in the noisy point cloud. Also, such small details would not be noticeable in the scans even with an additional filtering process. However, by means of close-range photogrammetry sparsely structured surfaces can hardly be measured with an adequate point density. Here, the combination of methods is the key to get best results with a reasonable amount of time, work and equipment.

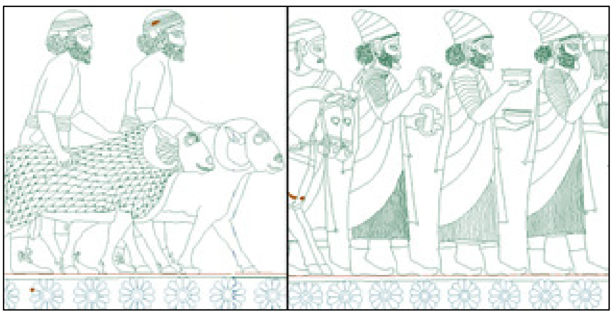
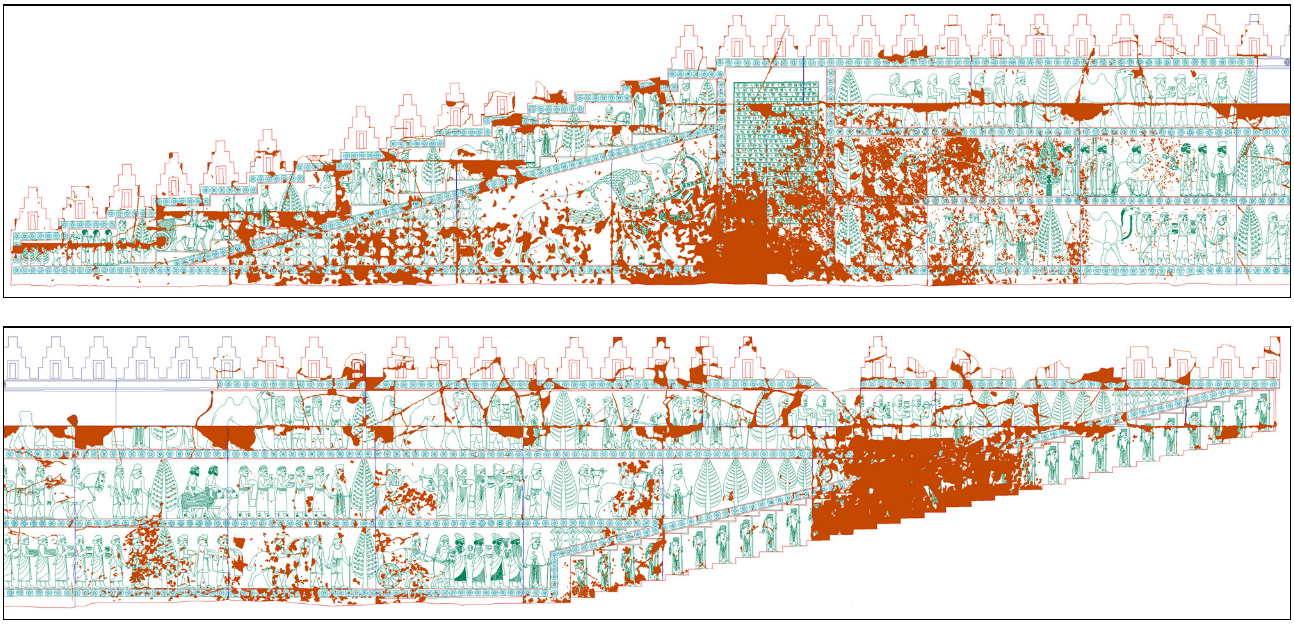


Figure 13. Details of the resulting 2D map.



Figures 14a and 14b. The complete 2D map (left and right part).

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