Application of photogrammetric techniques for heritage documentation

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Abstract

Photogrammetry is a generally accepted technique for the collection of three-dimensional representations of the environment. For this reason, this technique has also been extensively used to produce high quality 3D models of heritage sites and historical buildings for documentation and presentation purposes. During the last years, the efficiency of traditional image based techniques has been improved considerably due to the availability of systems for digital image acquisition. Additionally, terrestrial laser scanners came on the market, which allow for an accurate area covering geometric data collection by a dense measurement of 3D points. Despite the potential of each single system, in our opinion, a maximum benefit is to be expected by a combination of data from both digital cameras and terrestrial laser scanners. By these means the efficiency of data collection as well as the geometric accuracy and visual quality of the collected textured 3D models can be optimized. Within the paper an overview of photogrammetric collection of virtual 3D models for heritage documentation will be presented and the potential of approaches combining the different techniques will be discussed.

1 Introduction

Photogrammetry has a long history as a tool for the efficient and accurate acquisition of information for topographic and thematic mapping applications. Traditionally, data collection is based on airborne or space-borne images and aims on the provision of products like Digital Surface Models (DSM) and Digital Terrain Models (DTM), i.e. geometric representations of the earth's surface with or without additional objects rising from the terrain; ortho images, i.e. imagery mapped to a ground coordinate system; and 3D representations of topographic objects like streets or buildings. One of the main advantages of photogrammetric techniques is their potential to simultaneously provide both geometry and surface texture for the depicted objects. This is especially important while aiming on the production of 3D virtual models. These virtual models are required for the generation of virtual 3D views and animations, which allow for very realistic presentations of information on the environment. Also triggered by the spread of 3D GIS and the availability of 3D visualization tools for standard hardware, these types of application are becoming more and more important also for the documentation of cultural heritage sites and historical buildings.

In order to allow for photo-realistic presentations of heritage sites, 3D models with good geometric accuracy, large amount of detail, and high resolution texture are required. Additionally, flexible and efficient during data collection can only be achieved by a sufficient degree of automation. Since it is difficult to fulfill these requirements by a single system, in our opinion the integration of different technologies will provide the best solution. One promising approach is the combination of traditional image based techniques with dense point measurement from laser scanning. Both image and laser based sensors can be used from airborne and terrestrial platforms. Terrestrial data collection allows for object measurement with an accuracy in the range of centimeters or even millimeters, which results in highly accurate and detailed models. On the other hand, practical restrictions concerning accessibility and visibility can reduce the efficiency of data collection for larger areas. Thus, the use of airborne sensors can be more economical for area covering data collection. On demand, the resulting 3D models then can be refined by terrestrial techniques. Within the paper first pros and cons of image and LIDAR based data collection for the generation of high quality, textured 3D models will be reviewed in section 2 and 3, respectively. In the last part of the paper, the potential of integrating multiple data sources in the context of cultural heritage applications will be discussed and an outline of our work will be given.

2 Image based data collection

The basic principle of traditional photogrammetric data collection is the application of overlapping imagery for 3D coordinate measurement. If a point is depicted in at least two images, its corresponding 3D object coordinates can be determined. In order to measure 3D point coordinates based on overlapping images, information on position and orientation of the camera at the time of exposure are required. In addition to this 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 more than one image has to be oriented simultaneously, tie points, i.e. corresponding image points are additionally used.

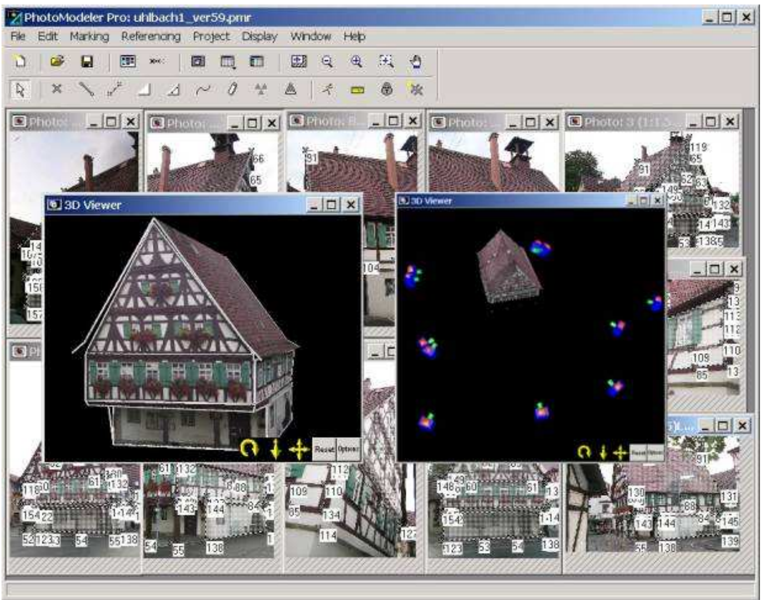


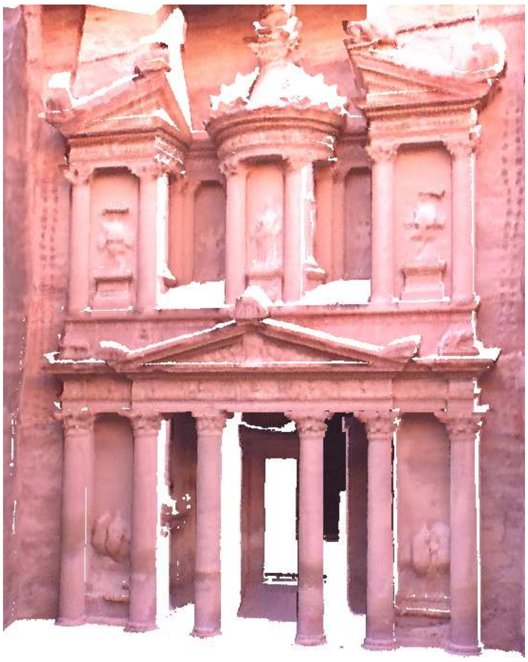
Figure 1: Example collection of 3D virtual model from terrestrial imagery

If the parameters of exterior and interior orientation are available, object and image coordinates are linked by the so-called collinearity equation. 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. Applying this principle, the 3D coordinates of all points can be determined by a spatial intersection of straight lines, if they are observed in at least two images. Thus, for geometric reconstruction of objects like buildings, geometric primitives like points, lines and regions, which are relevant to describe these objects have to be identified in the images. Based on these corresponding image primitives the object can then be reconstructed in the 3D world.

An example for the collection of 3D virtual model from terrestrial images based on a standard software tool is given in Figure 1. For this purpose, corresponding points were manually measured in the different images. During measurement, topological relations between the collected 3D points were additionally defined in order to provide the bounding polygons of the depicted building object. The resulting textured CAD-representation is overlaid to the single images in Figure 1. The second overlay additionally shows the reconstructed camera stations, which were also computed from the measured image points.

3 LIDAR based data collection

Alternatively to the measurement of corresponding image points, laser scanning can be used for collection of 3D point coordinates. This point measurement is realized by the so-called time-of-flight measurement principle for almost all commercially available laser scanners. By these means, distances to the respective object surface are derived from run-time measurements of reflected light pulses. The collection of dense 3D point clouds representing the visible object surface is then realized by scanning the respective area of interest. The main advantage of these systems is their ability to directly provide an enormous number of 3D points. This is especially useful for the 3D reconstruction of objects with a large amount of geometric detail. Additionally, this technique can be used in most environments, since laser scanning is an active system, which provides its own source of illumination. Airborne laser scanning systems can operate at flying heights up to 6000m, whereas typically DTM are collected with a grid spacing of 1 m from flying heights of 1000m.



a) Overview

b) Detailed view of collected point cloud

Figure 2: Building façade recorded by terrestrial laser scanning.

For terrestrial applications several commercial time-of-flight laser scanning systems are available, which can cover distances up to 300 meter. Alternatively, for applications at distances shorter than 5 meters, the use of systems based on active triangulation is possible. These systems provide an even higher resolution and amount of details. An example for a building façade recorded by a time-of-flight terrestrial laser scanner is given in Figure 2. Since this scanner features a true color channel, for each measured 3D point, color information is additionally available. This is especially beneficial for the generation of overview presentations of the object as depicted in Figure 2a. Nevertheless, as it is visible in Figure 2b, the information provided by this type of data is limited to irregularly distributed points. Since scanning results in huge amounts of data, which can reach very easily several million 3D points, additionally intelligent reduction and filtering of the data is required. Thus, for most applications higher-level representations have to be obtained by further data processing. This will for example provide a representation of the façade by simple geometric primitives for the depicted doors, windows and balconies. Despite the fact that laser scanning provides 3D point cloud fully automatically, a number of additional processing steps are required.

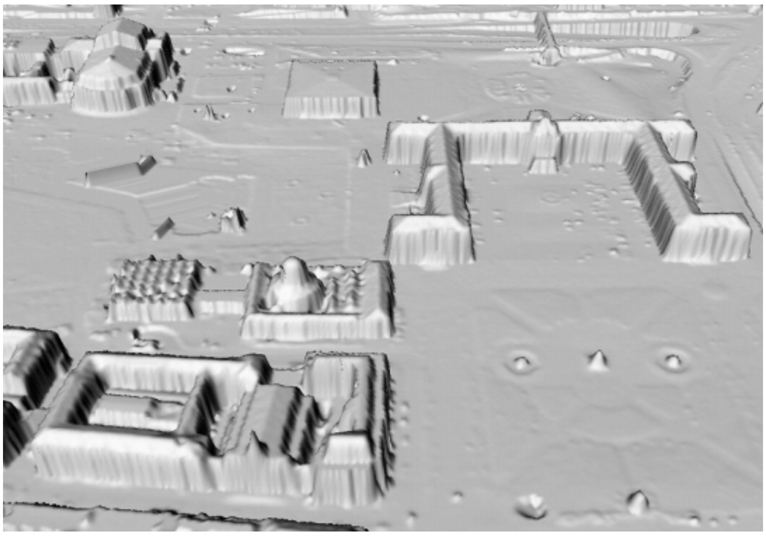


Figure 3: DSM from airborne laser scanning

Figure 4: DSM with texture from aerial image

These processing steps, demonstrated exemplarily for airborne data in Figure 3 to Figure 7 include the fitting of primitives to these point clouds, the creation of complex surface models, and the mapping of imagery to the resulting surfaces to provide texture for realistic visualizations. Figure 3 shows an example of a DSM acquired by airborne laser scanning. In order to generate this surface, the originally measured laser points were interpolated to a regular grid. While this process is relatively simple for airborne data, the generation of connected surfaces can be difficult for terrestrial data due to occlusions, large discontinuities in distance, and errors during point measurement. Additional, terrestrial data collection usually requires the combination of different point clouds collected from different viewpoints. In the visualization of the data has been improved by wrapping an orthorectified image over the DSM surface. This step is more or less equivalent to the collection of corresponding color information as depicted in Figure 2. Although the visualizations in Figure 2a and Figure 4 already look quite appealing, they consist simply of colored 3D points. There are no object entities to which information could be attached, and the amount of data required to represent the model is huge. Also, in Figure 4 building facades are represented poorly and due to inevitable errors in the measured laser points all objects look like they have been wrapped. For this reason complex 3D features have to be extracted from the point clouds and a CAD-like representation of the respective objects has to be provided.

Figure 5: Extracted CAD-models overlaid to LIDAR DSM

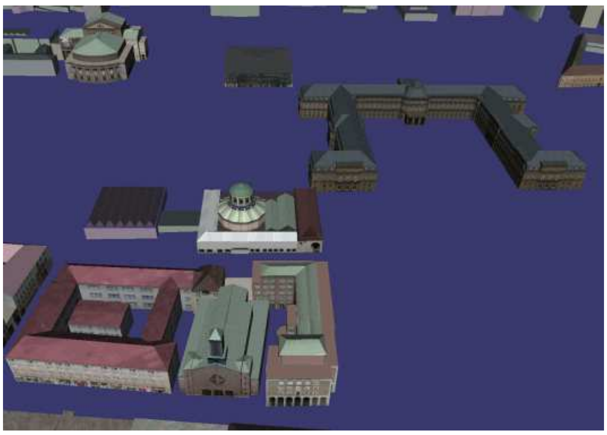


Figure 6: Textured CAD models

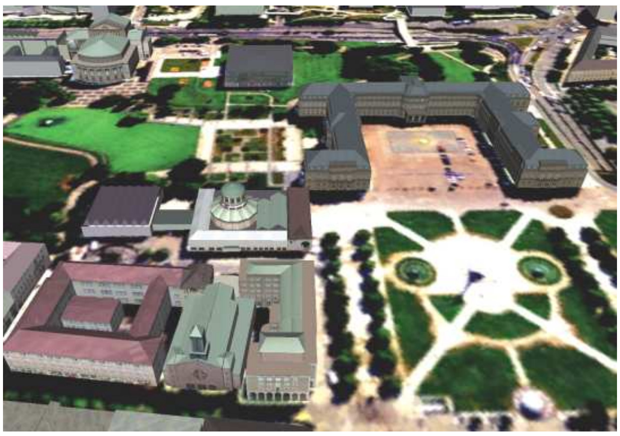


Figure 7: Final model with textured DTM

The results of this step is depicted in Figure 5, where the extracted CAD-models are overlaid to the DSM from airborne laser scanning. For a visualization as it is depicted in

Figure 4, the application of images from airborne sensors can be sufficient. Nevertheless, for high quality visualizations from pedestrian viewpoints, the visual appearance of buildings has to be improved. For this reason, façade texture was additionally collected for a number of buildings and mapped to the corresponding objects. An example of CAD models textured by additional imagery is given in Figure 6, whereas for Figure 7 this textured model is combined with the DTM again. The texture mapping of the facades is based on terrestrial images collected by a standard digital camera. From these images, the façade textures were extracted, rectified and mapped to the corresponding planar segments of the buildings.

4 Combination of multiple data

For this purpose the GUI depicted in Figure 8 was applied. This GUI allows the user an easy selection of corresponding points at the façade and the respective images. Based on this information the effects of perspective distortion are eliminated and the resulting image is snapped to the corresponding part of the building model to be textured. In principle texture mapping is also feasible using a standard tool for photogrammetric data collection as it is discussed in section 2. Compared to this purely image based data collection, the main advantage of the tool depicted in Figure 8 is the possibility to integrate existing CAD models during processing. By these means texture mapping is becoming much more efficient. Since in our application the 3D buildings models were already collected from airborne data, this example demonstrates the advantages of combining different data sources for the collection of 3D virtual models.

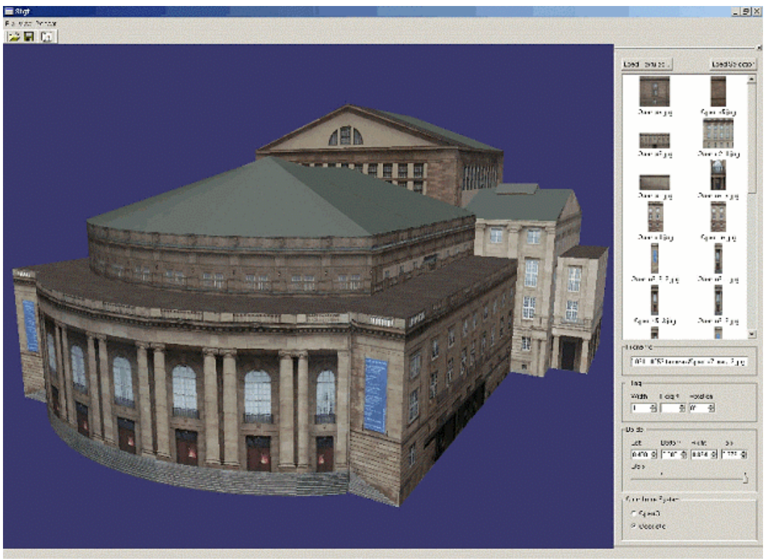


Figure 8: GUI for manual texture mapping of façade imagery.

Similar to this example, there are a number of advantages, if multiple data sources are applied for the collection of 3D virtual models. As it is demonstrated in Figure 2 terrestrial laser scanners can acquire image information for each reflected laser spot. Still, the quality and resolution of these images are limited compared to data collected from standard digital cameras. For this reason, the exclusive use of image texture collected from the laser scanner may not provide the best results. Additionally, the ideal condition for image collection may be not coincide with those of laser scanning. Thus the use of standard cameras for additional and independent image collection will be required. The high resolution of digital images compared to laser scanning data will not only improve texture mapping, but will also help during accurate measurement of object features like break-lines or borders. On the other hand on untargeted surfaces, laser scanning provides a complete 3D map, while image based systems may not be able to perform any measurement without distinguished features. Finally, the combination of terrestrial laser scanning with terrestrial images will allow for geometric control of the collected 3D data.

5 Discussion

As discussed within the paper, a combination of intensity and range sensors will provide the most efficient and flexible solution if the collection of textured 3D models for heritage sites is aspired. Nevertheless, the optimal approach will depend on the type of features to be measured as well as the required accuracy and amount of detail for the final model. In addition to these geometric considerations, the combination of range and image data can support the segmentation and feature extraction process, which is required to provide higher-level representations of the depicted objects.

Similar to the presented applications, the main objective of our future research is to integrate image based approaches and terrestrial laser scanning for cultural heritage documentation. By these means, the collection of accurate and complete high resolution textured 3D model will be feasible. In addition to data collection for the generation of realistic visualizations, one of our main tasks will be the accurate metric survey of objects and structures. Special interest will also be paid on the development of measurement tools, which allow to separate between 3D models of heritage sites before and after the restoration processes.