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Multiple Techniques Approach to the 3D Virtual Reconstruction of Cultural Heritage

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Abstract

According to an UNESCO survey, Italy accounts for more than half of the Cultural Heritage of the entire world. Italy's Cultural Heritage therefore represents an enormous wealth not only for the country itself but also for the entire world and this asset should be preserved and documented for future generations and possibly used as source of revenues. Within the relevant methods of the Information Technology which can be applied to Cultural Heritage, that of accurate and realistic 3D "shape capture" of art works has been challenging the scientific community since a long time because an extremely high degree of realism is required. Thereby the virtual reconstruction of cultural heritage sites is becoming a significant field of application in the 3D modeling area. This paper proposes an integrated approach based upon a seamless combination of different 3D measurement techniques for the virtual reconstruction of complex architectures. Depending on the required spatial resolutions, different techniques can be used and at the end all the acquired data have to be integrated into a single 3D model. As example the model of a castle located in Trentino (Italy) was done using surveying, 3D laser scanner, close-range and aerial photogrammetry.

1. Introduction

Many 3D measuring techniques have been developed in the past to satisfy either the requirements for military applications or those for high end applications like the moviemaking industry. Due to the recent advances in microelectronics, optics, computer sciences and computer graphics which have greatly contributed to lowering component's costs, 3D measuring instruments have found applications nearly everywhere. Depending on the performances required, many different instruments based on many physical principles have been developed in the past and continue being researched and developed today. Thus, 3D measuring systems are being employed in sectors like the automotive industry to monitor production processes and the aviation industry in the assembling of parts coming from different producers. They are also employed for fast prototyping purposes, reverse engineering, multimedia productions, fashion etc. Also the application field related to the Cultural Heritage have got benefits from 3D measuring systems. High accuracy and photorealistic 3D measurements and modeling are in fact of paramount importance for the preservation, restoration, documentation and remote fruition of Cultural Heritage. The need of combining multiple techniques, like terrestrial laser scanning, photogrammetry and digital surveying comes from the complexity of some structures and by the lack of a single technique capable of giving satisfactory results in all measuring conditions.

This paper proposes a multiple techniques approach to the 3D virtual reconstruction of cultural heritage. Geometrically accurate and detailed photorealistic models are essential for cultural heritage documentation. It is necessary to combine image-based and range-based modeling in order to have a good trade-off between the level of detail and the size of the model [HD04]. As test bench a medieval castle placed in Trentino A.A. is considered (Figure 1). It is an example of complex architecture with internal complex courtyards and narrow alleys. Images acquired from an helicopter were used to model the whole castle while the detailed inner models were created by means of close-range photogrammetry and 3D laser scanner. In addition to the model of the castle a Dig-

Figure 1: *An aerial view of Valer Castle, located in Tassullo, Trento (Italy).*

ital Surface Model (DSM) of the surroundings was also created in order to visualize the castle within its environment. In the choice of the modeling techniques many factors have to be considered, as for example the required level of detail, occlusions and the place for data acquisitions. At the end of the 3D reconstruction, the models obtained from different sources were unified in the same reference system by means of surveying Total Station and GPS. A walkthrough movie outside and inside the heritage was created as final result.

2. Overview of the techniques

Although in the last few years many investigations were conducted in the field of the 3D modeling of complex objects, there isn't a single technique that can be considered the best for all applications. Techniques also vary in accuracy, reliability, ability to capture details and their level of automation. Therefore, for the modeling of complex architectures it is often very useful to combine data obtained by different technologies. Image-based approaches [RE06] are generally complementary to range-based methods [Bla04]. In [Boe05] and [Ber97] the key features of different laser scanner technologies and photogrammetry-based systems are analyzed. Each method has its advantages at different working environments.

Image-based modeling is suitable for regular geometric surfaces like architectures and monuments [DTM96] [ElH02]. Photogrammetric methods can achieve high geometric accuracy, albeit without capturing all fine geometric details. The same images used to construct the geometry are also used for the texture. Image data can be acquired from ground level or at different altitude and with different sensors. Considering a complex and large architecture, it is hard to take ground images from viewpoints that cover the entire object. Therefore, aerial images from a helicopter are taken to cover the whole object's surface in order to model the overall architecture. Instead, terrestrial close-range images must be used to model some pieces of the structure not visible from the helicopter, or some others that require more details. A good network configuration is often difficult to be achieved, in particular for internal rooms or courtyards. Therefore the image registration step becomes very complex and robust procedures must be used for the orientation phase. As also reported in [VRPG06], in practical 3D modeling cases, it is difficult to work under an optimal image network (good B/D ratio and image distribution), mainly due to constraints in the image acquisition, leading to accuracy degradation of the results. The image-based modeling technique has to be preferred in those cases where occlusions are the major obstacles because it is possible to obtain 3D information from a single image, by recurring to geometric constrains. To achieve optimal and accurate results, the employed camera has to be calibrated. In practical cases, rather than simultaneously calibrate the internal camera parameters and reconstruct the object, it may be better first to pre-calibrate at a given setting using the most appropriate network and then recover the object geometry using those calibration parameters at the same camera setting.

Range-based modeling are capable of capturing most geometric details, but the accuracy varies notably from one scanner to another. One of the reasons that lead up to use terrestrial laser scanner instead of image-based modeling is the impossibility of acquiring images with good angles and good overlaps to create the 3D model; moreover in some situations it's necessary to reach a high level of detail in short time. Both triangulation and time-of-flight systems can be used to acquire data, depending on the distance and on the level of detail demanded. Range scanners based on triangulation work on short distance and with a very high accuracy while range scanners based on time-of-flight work on longer distances (e.g. 300 - 1000 m) but they are usually less accurate than close-range triangulation systems. Details of the acquisition and modeling process can be found in [BR02]. In addition to geometric information, digital images have to be used for the texture mapping [EGP*03].

In order to create the models with the correct scale and have a check on the final accuracy of the results, some control and check points are generally acquired with a Total Station. For wide and complex structures, these points can also be used to register all the individual models in the same reference system since it is not always possible to find common points between these models. Considering as final aim the combination of the whole terrestrial model with a digital terrain model of the surroundings, some surveying stations can acquire GPS data to place the structure in the global coordinate system.

A key step in the 3D modeling process is the integration of the different models generated with different source data and techniques. In this phase, all the models must be transformed into the same reference system. First the models created by image-based modeling have to be assembled together and then registered with those generated using range sensors. The registration is done either with common points or with control points, or both. The registration of the terrain model with the overall object model is done with some control points and the GPS data.

3. Practical 3D modeling project

In this section an example of 3d modeling of a medieval castle is reported. The medieval castle considered is a complex architecture with internal complex courtyards and narrow alleys. Both laser scanner and image-based modeling have been used to create the 3D model of the complex architecture which is approximately 35 m high (the tower) and has a base of ca 40 x 70 m. As the castle is located on a small hill, it was hard to find an adequate number of places where to capture images. Therefore 16 aerial photographs acquired from a helicopter were used to model external walls and roofs. The used camera is a Kodak DCS SLR/n pre-calibrated in our laboratories at a focal length setting of 66 mm. The camera positions were recovered with a bundle-adjustment. In Figure 2 the overall 3D model of the castle is shown.

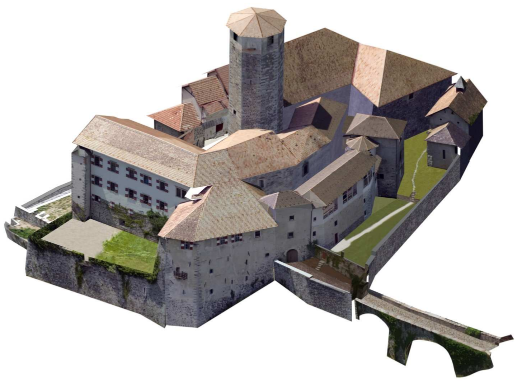

Figure 2: *Overall 3D model of the castle.*

For the internal courtyards and paths, terrestrial images (acquired with the same camera but with a focal length set at 18 mm) were used. As man-made objects generally contains planes, right angles and parallel lines, these cues and geometric constraints (perpendicularity or orthogonality) together with image invariants should be used to retrieve 3D information of occluded objects. Some examples of internal courtyards modeled by means of image-based modeling are displayed in Figure 3.

Figure 4 shows some views of the 3D model of a 3-levels virtually reconstructed courtyard full of arches and columns.

For other areas of the castle, a time-of-flight laser scanner was used to recover the required 3D model. In particular, the internal chapel of the castle was scanned with a Leica HDS3000 and a resolution of 1 cm. Furthermore, for the texturing of the model, images acquired with a Kodak DCS Pro SLR/n and a focal length of 18 mm, were used. Figure 5 shows the results of the modeling and Figure 6 shows an internal view of the 3d model of the chapel.

Figure 3: *3D models of some internal courtyards.*

Figure 4: *Some renderings of the generated virtual courtyard.*

Figure 5: *3D model of the internal chapel.*

In order to put the heritage building in its correct environment a digital terrain model of the surroundings was realized. Two aerial images were used to generate the DSM of the landscape around the castle. The images have a scale of 1:40,000, a pixel size of 21 μm and a foot-print of approximately 1 m. The stereo images were oriented using some control points acquired with a GPS and placed in the UTM-WGS84 reference system. Afterwards a DSM with a resolution of 3 m was automatically created by means of an "in house" software (at ETH) developed for the automated 3D modeling from terrestrial, aerial and satellite images.

Finally all the recovered 3D data were merged together (Figure 7) and unified in the same reference system.

Figure 6: *Different visualizations of the 3D model of the internal chapel.*

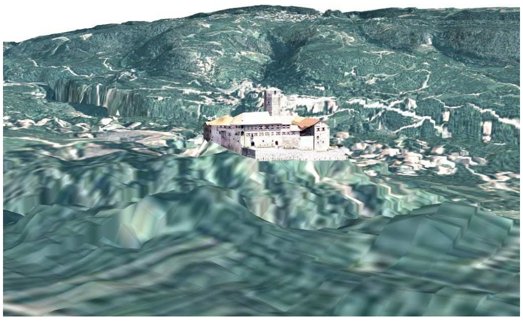

Figure 7: *: The castle integrated into the DSM.*

4. Conclusions

The multiple techniques approach suggested in this paper proved to be effective for the 3d modeling of complex cultural heritage sites. In the example reported more than one technique has to be used to achieve a photorealistic model of the castle. Some considerations about 3D modeling of complex architectures have been done and a methodology that can be applied in the reconstruction of various heritage architectures has been explained. The image-based modeling allows to perform 3D models at low cost but with generally high manual interaction while the laser scanner allows to perform detailed 3D models with fast acquisition but often with a lot of editing time. The right way, according to our experiences, is the merging of the two techniques. The demanded level of detail, time and effort to invest in the modeling, occlusions and the surrounding spaces to take images have to be considered in the choice of the reconstruction technique.
As final result the exterior walls of the castle, some internal courtyards and a Digital Surface Model of the surroundings were modelled realizing a photorealistic 3D model of the castle. A flying through movie which shows all the complex parts of this architecture and its surrounding landscape was realized. In this way the 3D model can be visualized from all the viewpoints.

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