3D Data Acquisition by Terrestrial Laser Scanning for Protection of Historical Buildings

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Abstract—**With the development of information techniques and the need of digital earth and cyber city, the three dimensional (3D) information play much more important role in presentation and illustration of historical buildings. 3D modeling and virtual reality techniques have demonstrated the ability of visualizing the real world in three dimension space which provides a platform for better communication and understanding of historical buildings. This paper focuses on the acquisition of three dimensional data by using terrestrial laser scanners. Firstly, we review different approaches for acquiring 3D data and their advantages and disadvantages. Secondly we focus on a newly developed technology – terrestrial laser scanning. Thirdly, we present the practical use of a 3D laser scanning system: Riegl LMS-Z420i in a historical cultural heritage site, San Fan Qi Xiang, Fuzhou city, China. Finally, the testing results and the conclusions are provided.**

Keywords-3D data acquirsition; Terrestrial laser scanning; Historical heritage

I. Introduction

Digital city provides a framework to accommodate spatial and non-spatial information and provide powerful tools for 3D modeling and visualizing virtual 3D scenes of a cyber-city. It is required to have a fully understanding of a historical heritage before protecting or rebuilding it. In particular, 3D visualization and simulation play essential role in historical buildings. Due to its high historical value, it is important to measure and model a historical site including many ancient buildings with relatively high accuracy. Thus we aim at efficient approach for precision 3D data acquisition toward the establishment of measurable 3D models of the historical site, San Fan Qi Xiang (SFQX). In section 2, we give a review on available approaches for 3D data acquisition for 3D modeling. The testing site, instrument and the testing processes are introduced in section 3. The testing results and discussions are also presented in the same section. The conclusions and suggestions are provided in the last section.

II. A review of the approaches of 3D data acquisition

A. *Map-based approach*

Since the buildings are the dominating features of cities, reconstruction of 3D buildings is the main task in construction of a digital city. The map-based 3D data acquisition is a widely used conventional approach due to availability of the existing maps. The two dimensional data (X, Y) can be acquired from large scale topographic maps either in paper or in digital form. The height (Z) of building can be obtained based on the number of floors. By integrating these two, the 3D data can be collected. For the digital terrain model (DTM), contour lines are digitized from topographic maps for building DEM. This approach is usually applied by integrating 2D and 3D software packages such as AutoCAD and 3D max to build the 3 D models and other objects. With the development of geographic information system (GIS) and the enhancement of its 3D capability, this approach can be implemented relatively easily in a GIS environment and with a moderate accuracy in the Z dimension. However, it is done manually in most cases, thus it is labor-consuming. Additional work is required too to obtain the texture of buildings, which is essential in reconstruction of a realistic 3D model.

B. *Image-based approach*

The image-based 3D data acquisition is usually performed by using stereo image pairs. Both aerial-photogrammetry and close-rang photogrammetry are based on a block of overlapped images [8]. It has been proved to be a primary approach for 3D data acquisition and object reconstruction. Photogrammetry has been considered to be a classic and dominant approach for mapping of a large area. It is proven to be stable and accurate approach for 3D mapping in a moderate scale (1:5,000 to 1:50,000). With the development of digital imaging technology and the high-resolution space-borne sensors such as IKONOS, QuickBird, the image-based 3D data acquisition and modeling has been regarded as a cost effective approach in terms of large area mapping in a moderate scale. However, the obtained accuracy (decimeter) and the actual image resolution may not

1-4244-1312-5/07/$25.00 ©2007 IEEE

meet the requirement of precise modeling of historical buildings (millimeter to centimeter). In addition, photogrammetry has long been regarded as a sophisticated technology since operators need to be trained with professional skills and know how. Only those well trained operators can apply this approach.

C. Point cloud- based approach

Point clouds – the term is applied to the mass of 3 dimensional points recorded by a laser scanner. They are often used in collecting surface data to provide high accuracy measurements of visible objects.

Laser scanners usually made up of a laser, that has been optimized for high speed surveying, and of a set of mechanisms that allows the laser beam to be directed in space in a range that during a scanning session, more than 1,000 points are surveyed per second. Modeled objects will typically have an accuracy of 2-5 mm, dependent on the structure of the object and the accuracy of the single scanned points.

Terrestrial laser scanning technology was introduced at end of the 20th century. It has been widely used in many areas. The commercial application of the technology has proven to be a fast and accurate method for objects measurement and extraction.

D. Integrated approach

Laser scanners offer the fascinating possibility of measuring millions of points within short time periods. Thus, it is possible to record complete 3D objects efficiently [5]. Some of them have been integrated with a digital camera to capture images at the same time.

The integrated approach utilizes the point cloud and image-based approaches in which point cloud and color imagery are acquired simultaneously by the laser scanner and a digital camera attached to the scanner. The 3D information captured by the laser scanner is complemented with digital imagery where point cloud can be used to reconstruct the geometry of objects and image data can be used for coloring the structures obtained by point data and for texturing the extracted patches. By combining with photogrammetry techniques, an ortho-image can be produced that can be used in representing the surroundings.

Models that are reconstructed based on high accuracy point cloud and textured by images that obtained at the same site are regarded as measurable realistic 3D models which are considered as a useful tool for documentation and protection of historic buildings and ancient neighborhood.

III. CASE STUDY - 3D DATA ACQUISITION FOR DOCUMENTATION OF A HISTORICAL HERITAGE - SAN FANG QI XIANG, FUZHOU

A. Site description

The study area, called San Fang Qi Xiang (SFQX) in Chinese, is a well-known traditional residential neighborhood that consists of three lanes and seven alleys in the downtown area of Fuzhou city. There are many typical Chinese residential houses that had been built in the Ming and the Qing Dynasties with a total area of 45 hectares. Some 14,000 inhabitants are still living in this area. More than 60 buildings have been classified as protection architecture by the national and provincial authorities. Due to the historical reasons, the current living condition of this area is very bad. On the one hand, the living condition needs to be improved urgently. On the other hand, the historical buildings these people live in have to be well protected. Therefore, the proper planning and protection of this site becomes a very important task of the local government.

The aim of this research is to record the historical site and to establish 3D models with high accuracy (millimeter accuracy for the interior models and centimeter accuracy for the building models). Therefore, the overall procedure for data acquisition has been subdivided into three categories: scanning of the whole area from the roofs of high-rise buildings in the surrounding areas, scanning of individual buildings from the ground, and scanning of the interiors of buildings. All acquired data and 3D models will be served as a firm base for documentation of the cultural heritage and to support planning, historical building maintenance, and urban renewal projects as well as for building digital city of Fuzhou.

B. Terrestrial laser scanner: RIEGL *LMS-Z420i*

The 3D laser scanning system Riegl LMS-Z420i (see figure on the left side) made by RIEGL, Horn, Austria is considered as a high accuracy and long range terrestrial laser scanning system. The system consists of a high performance long-range 3D laser scanner, associated operating and processing software RiSCAN PRO, and a calibrated and definitely orientated high-resolution digital camera. It provides non-contact object recording. By using a vertical deflection and polygonal mirror, the system allows to acquire a scene with a large field of view (FOV=360 H x 80 V). The scan rate is from 1,000 to 25,000 point per second with the accurate less then 10 mm. The minimum measurement range is 2 m and maximum range can reach up to 1000 m. The scanned data are transmitted to a laptop via TCP/IP Ethernet Interface and the camera data are fed into the same laptop via USB/firewire interface.

The RiSCAN PRO software that runs on platforms Windows XP and 2000 SP2 that allows the operator to perform a large number of tasks including sensor configuration, 3D data acquisition, data visualization, data manipulation, and data archiving.

C. Data acquisition

In the case study, Riegl LMS-Z420i terrestrial laser scanner is selected to carry out this research. Other related equipment are described as follows: (i) Dell Latitude D800 laptop is used in the field, in which the RiSCAN PRO software is installed; (ii) Nikon D100 (f=14 mm) digital camera that is mounded on the top of the scanner is used in acquisition of calibrated color image data; (iii) Riegl Cylinder and SOKKIA reflectors are used as control points for registration and merging scanned data obtained by different scans and merging point cloud data and image data; (iv) Several UPSs are needed for the power supply in the field.

1) Scanning of large area

In general, the airborne photogrammetry or satellite remote sensing is needed to acquire the background images. Due to the fact that airborne laser scanning is too expensive to scan an area less than 1 square kilometer and the density of the acquired point data is lower than the terrestrial one, therefore we decided to use the high-rise buildings around the study area as platforms to perform oblique scanning.

For geo-referencing of different scans and the merging with the large scale base maps, the local coordinate system was chosen for the surveying of the required control points for each determined scanning site. Totally 16 scanner stations on top of eight high-rise buildings around the test site were selected. The coordinates of all stations were measured by the total station and the differential GPS at the same period of time. Thus, all the point clouds were registered into local coordinate system. It was done in three working days after scanning. Some 2.1Gigabytes of 3D data have been recorded at the test site with the ground resolution rang from 5 cm to 30 cm, vary depends on the distance between scanning station to the objects (the scan resolution was set up as 0.04 degree). The scanning time varies from 11 minutes to about 1 hour depends on the scanning range and visibility of the interested areas. Figure 1 shows the small part of 3D model of the SFQX based on the scanning data.

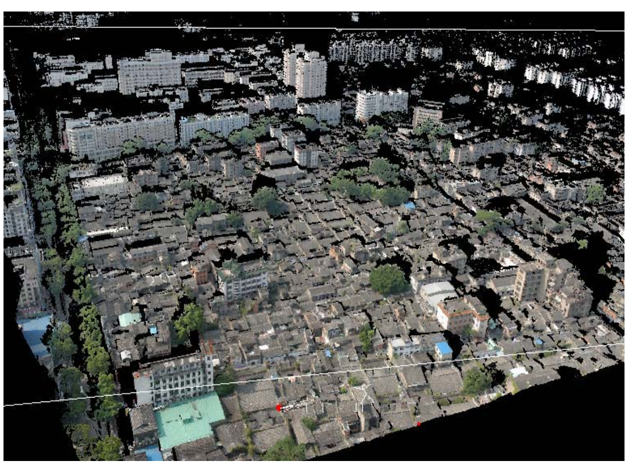

Figure 1. The overview of a part of 3D model of SFQX

2) Scanning of individual buildings

For scanning of individual buildings, only the internal control points needed for the registration of the scanned point clouds obtained in different stations. The reflectors used as control points have to be well-distributed around the building to ensure that the adjacent scanning stations have at least 5 control points overlapped. The scanning process has been divided into 3 steps: (i) recording the position of reflectors; (ii) acquiring the object's 3D points; (iii) capturing the object's color image. The ground resolution ranges from 7 mm to 35 mm in this testing. Figure 2 illustrates an example of a merged 3D model obtained based on the scanning of individual buildings.

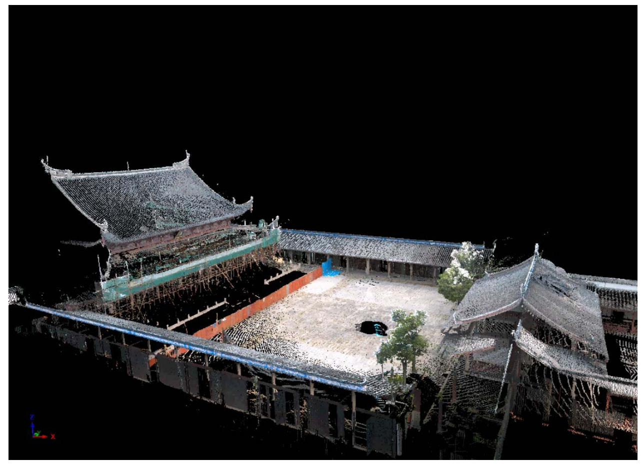

Figure 2. A combined 3D model based on scanning of individual building

3) Scanning of the interior of buildings

The objective of this testing is to record the details of the historical buildings and serves as architectural surveying and documentation historical buildings for a late use in ancient building maintenance. A short-distance (less then 5 m) scanning with high resolution (0.04 degree) setting is applied in the testing. Thus the ground resolution of the obtained point clouds is less then 4 mm. The scanned data is then used to produce the ortho-images of walls, ceilings, windows and other protected items. An example of the produced ortho-images is presented in Figure 3. Other applications include 3D modeling and building of 3D measurable realistic models for interiors of the protected buildings.

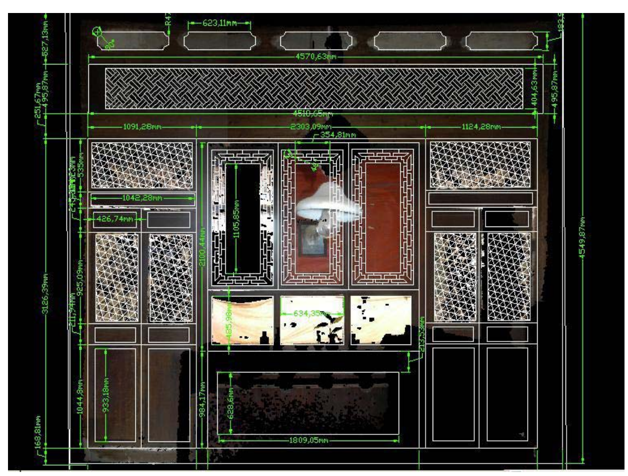

Figure 3. 2D measurement on the top of ortho-image

D. *Data processing and 3D modeling*

The data processing can be subdivided into two steps: pre-processing and post-processing. The data pre-processing includes data re-sampling, camera calibration and image rectification, coloring (RGB) the point clouds, registration and merging of different scans etc. This step is implemented mainly by using the RiSCAN PRO software. The post data processing includes 3D modeling, objects reconstruction and visualization of buildings as well as producing of ortho-images of the buildings interiors such as walls, ceilings, windows, doors, etc. for documentation and maintenance.

The 3D-mesh models (figure 1 and figure 2) are produced by creating triangulation and interpolation of the measured points, which are then draped with the digital images. Figure 3 shows the architecture measurements and documentation based on the ortho-image. This is produced in the CAD software package such as AutoCAD.

IV. CONCLUSION

The use of terrestrial laser scanners for architectural surveying is a promising technique in order to produce 3D measurable models for documentation and research use. The high speed operation provides an efficient approach for 3D spatial data acquisition. Therefore it is considered as a significant development for efficient documentation of historical heritage.

The terrestrial laser scanning can also be applied in acquiring 3D data of a large area in certain circumstances such as the performed oblique scanning from a building roof.

The 3D laser scanning should not be suggested to replace the existing techniques, but they should be coexisting and cooperating as different players in the field. The testing results show that the technology has many potential uses in other areas too.

ACKNOWLEDGMENT

This research is supported by the Hi-Tec Research and Development Project (863 project, No. 2006AA12Z151) and the research founding of State Key Laboratory of Information Engineering in Surveying, Mapping and Remote Sensing, Wuhan University (No. (04) 0101).

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