3D Reconstruction of Saltanat Gate in Dolmabahce Palace

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Abstract. This paper presents a project on one of the very significant historical landmarks of Ottoman Culture and the most-visited touristic place in Istanbul, Dolmabahce Palace. In this project, a very famous public symbol gate, Saltanat Gate, is chosen with its historical and complex architecture to be reconstructed in 3D digital format by using various scanning techniques and computer graphics. In this paper, the overall process for 3D reconstruction of the gate is described along with a touch-screen based 3D rendering system. Various techniques are used to capture 3D point clouds from many different angles, to generate detailed surface meshes and to handle technical challenges, such as missing points, high resolution data acquisition and vibration at high positions.

Keywords: 3D Reconstruction, Cultural Heritage, Laser Scanners, Complex Architecture, Hole Filling, Large Structures, High-Resolution, Touch Screen.

1 Introduction

Istanbul is described as the city where continents meet; it can also be described as the city where cultures through history meet. As it has been a capital of various empires (Roman, Byzanthyne, Ottoman), Istanbul is the home of many historical structures. There are priceless exhibitions, a sargophacus called Alexandre's Tomb, in the museums; and there are many precious structures, like Palaces and Gates, spread throughout the city. Despite rich cultural and historical information lying in the city, technology usage has not yet reached the desired level for promotion and preservation of cultural data.

Recent advances in 3D modeling and interactive display technologies provided solutions for long-term preservation and enhanced visualization of cultural assets in digital formats. Hence, creating highly detailed 3D models have become very important and challenging subjects. Considering the diverse cultural heritage in Istanbul, along with high risk earthquake layer in the region, 3D reconstruction of cultural assets becomes even more significant. In this sense, this project is a pioneering work in high-resolution 3D reconstruction of cultural heritages in the city.

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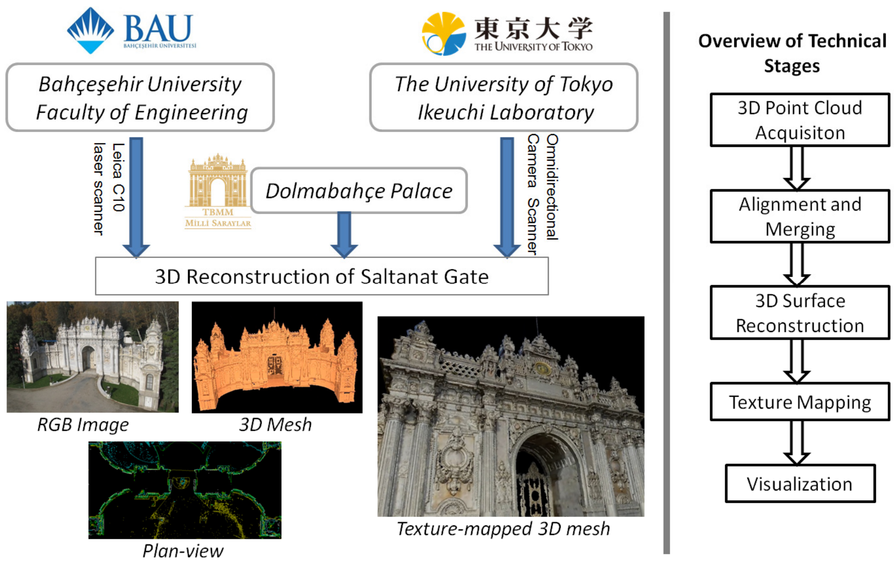

Fig. 1. Project Organization and Overview of the Project

In this project, laser scanners are used to capture 3D point cloud data in the range of 1 cm and several software tools are used to align, merge and create surfaces to reconstruct detailed 3D digital models of Saltanat Gate. Saltanat Gate from Dolmabahce Palace is chosen due to three main reasons. First, Dolmabahce Palace is the only palace where both Ottoman Padisahs (during their last period) and the first President of Turkish Republic lived. Second, Saltanat Gate is very commonly used as a symbol for Istanbul city and Turkish Grand National Assembly Palaces. Third, Dolmabahce Palace has proven to be the mostly visited touristic place in Istanbul.

Figure 1 gives the overview of the project organization. The project is called "Istanbul Preserves Its Cultural Heritage, Istanbul Museums Come Alive with 3D" and it is supported by Istanbul Development Agency 2012-2013 grant program. It is held as a collaborative project between two research groups from Istanbul and Tokyo. XXX (named for blind review process) Laboratory in Istanbul, is a group of young researchers, who are enthusiastic about 3D research and computer graphics. YYY (named for blind review process) group in Tokyo is a world-wide renowned group with deep experience in 3D reconstruction around the world. In this project, experience and enthusiasm meet various technical challenges while creating one-to-one 3D digital model of Saltanat Gate.

1.1 Related Projects in the Literature

3D Reconstruction of historical sites has been a significant research field and there have been several projects [1-7] around the world. One of the leading projects is Bayon Temple 3D Digital Archieve project [1, 12], and it is connected project Virtual Asukakyo[2] project. The group in Ikeuchi Laboratory started the project in 2003 to reconstruct Angkor Thom in Cambodia (160m X 140m X 45m) by using various

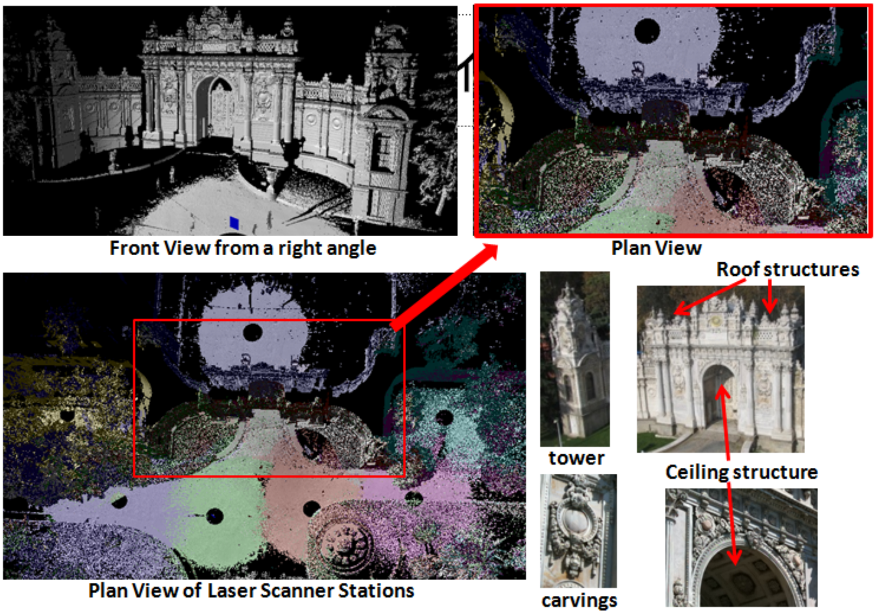

Fig. 2. Architecture of Saltanat Gate

sensors and scanners. During this project various methods were developed and new hardware systems were introduced to meet the needs of challenging geometric structures. They also developed visualization tools, 3D face pattern search tools in the project. 3D Murale [4] project has been supported by IST program of EU. An international team of multimedia content creators and researchers have been led by Brunel University to develop 3D multimedia tools for measurement, reconstruction and visualization of archaeological ruins in Sagalassos, Turkey. They created 360 panoramic views of the archeological excavation sites. Other than above, there have been attempts [6] to create 3D CAD models of various historical and touristic sites all around Turkey. Research group constructed 3D models and developed virtual reality applications.

This project is a pioneering project in Turkey in a way that high-resolution 3D reconstruction forms the main objective. The aim is to capture 3D geometrical data of a historically important and architecturally complex large landmark while including the details as much as possible. Texture mapping is also studied in order to analyze patterns and patterns changes on the structure. As a result, this project serves the preservation of cultural heritage, acquisition of high-resolution data for restoration and analysis of geometrical and visual changes in the structure.

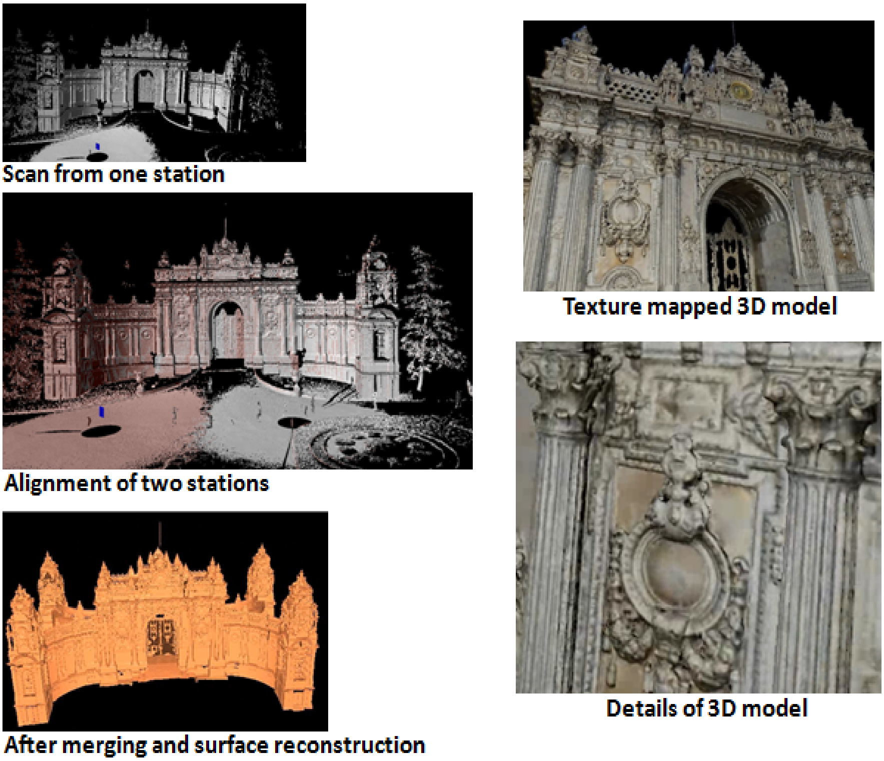

Fig. 3. 3D Reconstruction Stages and Final **3D** model

2 3D Reconstruction with a Laser Scanner

Saltanat Gate was chosen not only for its importance as a cultural and historical landmark, but also for its complex architecture both in large scale and small scale. It has a shape which is composed of two C-like structures when seen from plan-view with very detailed carvings on each surface. Its height is around 31m, width is 50m and depth is 25m. It is composed of four towers, two main gate walls, several columns and inner connecting walls. There are trees around the gate, some of which cause serious occlusions. Figure 2 gives data samples from plan and front views.

In order to capture the entire gate from various angles, e.g. both inside the palace and outside the palace or both roof structures and outside ceiling structures, data acquisition process is divided into two main parts. The first part contains data capture with a laser scanner located on 8 different stations on the ground. The second part contains data capture with a movable camera system fixed on the hook of a crane.

Leica C10 laser scanner is used to capture point cloud data. The scanner is placed in 8 different locations on the ground to capture 3D point cloud data with resolution around 1 cm distance in x and y directions. Figure 3 shows processing steps and sample outcomes from each step. Each data capture station has overlapping regions with the connected stations in order to support robust alignment. Alignment tool [9] of Japanese team is used to store and align big amount of data. After alignment merging process is held. 3D point clouds are cleaned and organized as meshes by merging operation. 3D surfaces are also generated at this step. After merging, optimized 3D surface reconstruction is achieved in two ways. First, for some regions, the method in [10] is used for filling the missing parts. As a second method, Poisson smoothing[8] is applied to some regions generate surfaces and fill holes. Textures mapping is achieved by using RGB data captured along with point cloud data.

Challenges and Lessons Learnt: The Saltanat gate has a very complex architecture, which contains detailed carvings. Capturing all the points on the carving surfaces located at very high places is the most challenging part. Due to restricted viewpoints, intelligent algorithms are required to learn geometric structure in 3D and to be able to estimate the data in missing parts. Since, reconstruction quality of missing parts affects the resolution of 3D model, this problem is still open to further studies.

Another challenge in this project is the trees around the structure. Especially, four towers are closely surrounded by trees resulting in severe occlusions, where at some viewpoints it is impossible to capture the data. To deal with this issue, captured data from four main towers are used to construct one full 3D model of a tower and used as a reference to fill the missing parts of each tower.

While applying texture mapping, RGB images from various viewpoints are used jointly. However, depending on the capture time in a day, sun lighting effects on each image result in irregular shadows. During the display of the entire 3D model, one general front view image is used for texture mapping. But, in detailed viewing mode, defected shadows appear at some parts as a result of merging multiple RGB images.

Dealing with big amount of data is a general problem for 3D reconstruction process. The total amount of 3D model of the gate, which consists of only point clouds is around 8GB. To process, store and visualize this data, very powerful devices are needed. On a DELL Precision T3610 workstation (Intel Xeon E5-1650 v2 (3.5GHz), 8GB DDR3 1866MHz ECC RAM, 2GB nVidia Quadro K2000, 1TB (7.200rpm) SATA3 HDD), still it takes weeks to process 3D reconstruction steps, however it is not possible to visualize and edit the entire data in real-time. In this project, data acquisition and processing steps took 6 months. It was a one year project, the first half year passed with preparations, planning and trial data captures to arrange appropriate parameters. The latter half of the year, data acquisition and processing was repeatedly held at periods. In each period, the data was improved and completed one level up. A group from YYY visited Turkey twice, first one for the preliminary study for 8 days, second one for capturing high places by using a hanging camera system for 10 days. XXX team held field works by using laser scanner on the ground from multiple viewpoints. Weather conditions, accessibility of the place for field work and hardware requirements slowed down the process. Another time consuming issue is the education of personnel who are assigned to the project in Dolmabahce Palace.

Fig. 4. 3D Reconstruction with a Hanging Camera System

Considering the project team from various backgrounds, in order to achieve fruitful collaboration and effective working environment, a general technical and social orientation is very important for everybody to organize the work and avoid unexpected problems.

One of the important issues is the equipments' specification, which mainly depends on the amount of research grant. Besides, since high-valued devices are purchased and used in the project, security problems may arise during field works. Laser scanners with high-resolution data capture capacity are very expensive and big devices reducing the mobility of the device. On the other hand, to reach details at various parts of large structures, the mobility and weight of equipments become critical concerns. This motivates research for mobile, light-weight, high-resolution outdoor scanners.

3 3D Reconstruction with Hanging Camera System

In order to capture the details in higher parts of the gate, a 3D data capture system working at high altitudes is required. In this project, we design a sensor fusion system which is mounted to a hook of a crane. However, this capture system faces the challenge of the physical vibrations, since during the scanning process sensor motion can significantly affect the data distortion. Figure 4 shows the hanging sensor fusion system mount to a crane in close view and on air.

3.1 Sensor Synchronization and Calibration

The system is mainly composed of a Z+F Imager 5010C scanner to capture 3D point clouds and a Ladybug3 camera to capture omni-directional RGB images. We adopt an u-blox GPS to send pulse per second (PPS) signals to both devices to synchronize the sensors. The extrinsic calibration between 3D scanner and omni-directional camera has been down using method [13] which first manually selects correspondences on both 3D data and a spherical image and then minimizes the distance of the correspondences w.r.t. extrinsic camera parameters, i.e. rotation and translation

3.2 System Setup and Data Acquisition

Both devices are rigidly fixed on a metal stick next to each other and the stick is hung tightly under the floor of a crane's hook. The stick is tied with ropes from two ends. During data capture, these ropes are adjusted by humans on the ground to keep the motion of the stick as stable as possible, hence the sensor motion is stabilized to some extent.

The setup is first placed at the highest place and data acquisition process is held with 360 rotations of the camera and scanner. Next, it is moved a level downwards and data acquisition is repeated. This process continues at a fix number of vertical poses, then the crane is moved horizontally to a new location to capture next region. Finally, all data from various stations of this setup is merged with data acquired from ground stations. Figure 4 depicts the team working on a data capture process with palace personnel.

3.3 3D Data Rectification

The data distortion must exist since the sensor motion (vibration) cannot be completely canceled. To rectify the data distortion, we use the method proposed by Banno et. al [14] which initially calculates sensor motions from RGB cameras by structure from motion (SfM) technique and then globally minimizes the 3D distortion constrained by 3 terms: 1) 3D projection error, 2) motion smoothness and bundle adjustment.

3.4 Alignment, Merging and Texture Mapping

After data rectification, the 3D scans are first registered to the world coordinate system using a fast alignment algorithm proposed by Oishi et. al [15] and then the mesh merging process is carried out with [16]. Two devices simultaneously capture 3D geometric data and color data from a very close position to the target. Since the relative pose and position of the two devices do not change, the texture mapping problem can be automatically solved using the previous calibration parameters. That is, each spherical image captured by omni-directional camera can be automatically located and oriented in the coordinate system and then projected to 3D point cloud.

4 Display of 3D Model on a Touch Screen

After reconstructing Saltanat Gate in 3D digital format, next step in the project is presenting outcomes to public. In this project, a touch screen based visualization tool is implemented to display 3D model of the gate with two options: with or without textures. The tool is composed of two parts: first part is 3D rendering and second part is user input management. The total amount of data (excluding textures) after alignment, merging, cleaning processes yields in 8 GB data. In order to display this big data, customized openGL based software has been implemented. OpenGL Shading Language [11] is used to achieve fast rendering. The data is stored in multiple levels of resolutions and the corresponding resolution has been displayed depending on the zoom level of the view.

For visualization and interactive user experience, 40" Vestel Full HD Panel is utilized in the setup. After a welcome screen, users start viewing 3D model from a front view. Then, they can interact with the model via touch screen to rotate, zoom in, zoom out 3D model. The system works in real-time and users can play with the model in real-time. First, a lower resolution of the model is visualized to display the entire gate in the screen, higher-resolution model parts are displayed when zoom in is applied. The difficulty in building such as system comes at two points. First point is how to hierarchically organize multi-level resolution data to achieve maximum user satisfaction. Second point is to construct a compatible hardware system of screen and processing unit (PU). Usually, processing power of PU inside the screen will not be enough for 3D rendering and big size data. So, rendering software runs on a separate machine, while user inputs come from screen PU. It is challenging to synchronize and combine both processors to achieve effective results.

5 Conclusions

In this paper, 3D reconstruction project of a significant landmark, Saltanat Gate in Dolmabahce Palace, has been introduced. The project is important as a pioneering work in Istanbul and also in the country in terms of technical challenges and achievements. It is organized by local researchers in collaboration with research group from the University of Tokyo. Hardware systems and software methods have been presented to create a complete 3D digital model of a large complex architecture within the ranges of 1cm. Furthermore, technical and organizational challenges faced throughout the project have been discussed (data size and complexity, equipment, personnel) along with the applied solutions to realize the project. A complete 3D digital model is generated for heritage preservation, architectural restoration and data analysis purposes. And, generated 3D model is visualized on a touch screen device for visitors to provide an interactive virtual tour of the gate.

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