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IFAC-PapersOnLine 48-10 (2015) 105–110

Evaluation of Methods for Robotic Mapping of Cultural Heritage Sites

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Abstract: In archaeological studies the use of new technologies has moved into focus in the past years creating new challenges such as the processing of the massive amounts of data. In this paper we present steps and processes for smart 3D modelling of environments by use of the mobile robot Irma3D. A robot that is equipped with multiple sensors, most importantly a photo camera and a laser scanner, enables the automation of most of the processes, including data acquisition and registration. The robot was tested in the Würzburg Residence. Methods for automatic 3D color reconstructions of cultural heritage sites are evaluated in this paper.

Keywords: laser scanning, 3D modeling, multi-sensors

1. INTRODUCTION

Archaeology is a historical science of high social interest. It studies the human being and its legacy, such as buildings, tools and art. Cultural heritage sites can be found all over the world and they tell us the story of humanity in different areas of the world. Remote sensing has become state of the art in modeling archaeological sites. This way of digitization of entire buildings or areas gives as a unique oportunity to preserve the current state of prehistoric builings and to join forces of experts all over the world. Collecting the data is tedious work. It includes finding the best position for a laser scan, moving the equipment to the position and georeferencing of the scanning position. Letting a robotic system take over this work reduces the time spent in the field by 75 % and decreases the impact to the sites. We present the robot Irma3D, that was designed to create in a tele-operated fashion digital 3D models of environments. This paper describes the setup and the capabilities of the robot and the steps to create these 3D models automatically from multiple sensor sources. The entire process is demonstrated by means of experiments carried out at cultural heritage sites.

In previous work we presented results of tests at Ostia Antica and the Würzburg Residence that showed that the robot can help to automate the process of reconstructing 3D environments. In this paper we focus on the quantitative evaluation of the results. For this purpose we use the data acquired in the Würzburg Residence and evaluate the final model using an additional sensor, the iSpace system from Nikon. The Würzburg Resdience is unique baroque palace in the city center of Würzburg, Germany that was named a UNESCO World Heritage Site in 1981. The Würzburg Residence is ideally suited for the experiments as the large halls allow the setup of the iSpace system so that the entire environment can be observed by this high precision localization system.

In this paper we describe the data collection with the robot Irma3D in this renowned historic sites, the post-processing needed to create a full 3D color model and evaluate the quality of the resulting model comparing different mapping algorithms.

2. EXPERIMENTAL SETUP AND DATA ACQUISITION

Hardware The data was acquired with the mobile robot Irma3D (Intelligent Robot for Mapping Applications in 3D). Irma3D is a small, battery-powered, light weight three wheeled vehicle. It consists of a modified Volksbot RT 3 chassis with two front wheels. Each is actuated by an individual 150 W DC Maxon motor. The motors are powerful enough to move the robot at a maximum velocity of 2.2 m/s The third wheel is in the back of the chassis and is swivel-mounted and thus completely passive as it follows the directions of the front wheels. The high-powered electrical two-wheel drive powered by two 150 W DC Maxon motors is equipped with rotary encoders to measure wheel rotations. This information is used to provide pose estimates of the robot via odometry.

Fig. 1. Irma3D in the Imperial Hall of the Würzburg Residence. Visible in the background is one of the transmitters of the iSpace localization system and a box with two of the reflective targets used for calibration. The handvector bar is used to measure distinctive points in the environment that are used to evaluate the quality of the final model.

Peer review under responsibility of International Federation of Automatic Control.
10.1016/j.ifacol.2015.08.116

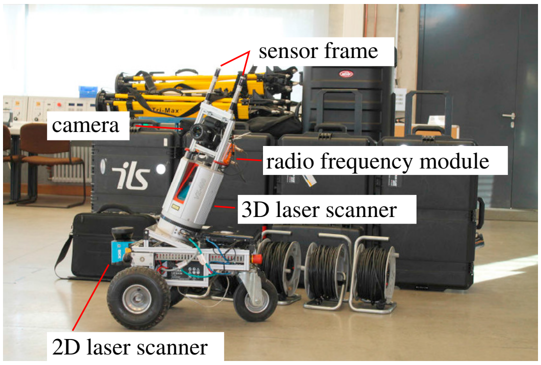

Fig. 2. The Irma3D robot with the setup used in the Residence.

The pose estimates are improved using data from the Xsens MTi IMU device that is also attached to the robotic platform. For obstacle avoidance when moving autonomously a Sick LMS 100 2D laser scanner is added to the front of the robot. This sensor can also be used to improve the localization of the robot. The central sensor of Irma3D is the 3D laser scanner VZ-400 by RIEGL Measurement GmbH. The scanner is mounted on top of the Volksbot RT 3 chassis. Attached to the top of the scanner is a Canon 1000D DSLR camera. After a 3D scan has been acquired the camera is used to acquire color information for the point cloud. Also mounted on top of the laser scanner is an iSpace sensor frame.

iSpace is a high-precision position and tracking system from Nikon Metrology Nikon Metrology (2014). The optical laser based system consists of several transmitters. These are mounted on a wall or on tripods to cover the experimental area both indoors and outdoors. The rotating head of each transmitter emits two perpendicular fan-shaped laser beams at a unique distinguishable frequency near 40 Hz. The vertical openng angle of the laser beams is limited to 40 degrees and the detectable range lies between 2 to 55 meters. Several sensor frames can be located within the system. A sensor frame consists of at least one detector, a photo diode with a horizontal opening angle of 360 degrees and a vertical opening angle of 90 degrees. A small radio frequency module transmits the sensor data wirelessly to the base station of the iSpace system, a PC running the iSpace control software. A sensor frame with one detector is sufficient to acquire 3D position information. To measure also the rotation and to increase the accuracy of the position data the sensor frame used on the robot has a total of four detectors. A sensor frame with two detectors, the handvector bar, is used to measure points in the environment to evaluate the quality of the resulting model. The iSpace system differs from other position and tracking systems as the transmitters do not actively observe the position of the sensor frames. Instead, each sensor frame receives the laser data from the transmitters and sends the information on to the control PC. The control PC calculates the elevation and azimuth angles between all detectors for a sensor frame and each visible transmitter based on the received data defining a straight line between transmitter and detector. Given the relative transformation between the transmitters the length of the lines is calculated using triangulation. To determine the position of the transmitters a calibration procedure using a few hundred points from a special sensor frame is applied. An optimization process calculates the position of all transmitters in a self-defined coordinate system. Three points, the origin, a point on the x-axis and a point on the y-axis allow the user to define its own coordinate system. In typical environments the iSpace system is able to perform measurements at a sampling rate of 40 Hz with a maximum error of [$\pm$0.25]mm. In practice environmental factors such as size, reflection of the surface and occlusions of the transmitters have to be taken into consideration.

Experimental environments The robot was tested in two halls in the Würzburg Residence, namely the White Hall and the Imperial Hall. The Residence Palace in Würzburg Germany was labeled a UNESCO World Cultural Heritage site in 1981. Being built from 1720 to 1744 with the interior finished in 1780 it is now one of Europe's most renowned baroque castles Bayerische Verwaltung der staatl. Schlösser, Gärten und Seen (2014). It was laboriously reconstructed after being heavily damaged during World War II. Not destroyed during the war remained the large unsupported trough vault above the main stair-case designed by architect Balthasar Neumann, the Garden hall with ceiling paintings by Johann Zick, the white hall with the impressive stucco work by Antonio Bossi and the Imperial hall with frescos by Giovanni Battista Tiepolo. With its large colorful paintings by the Venetian painter Giovanni Battista Tiepolo and fine stucco work by stuccoist Antonio Giuseppe Bossi in many of the almost 400 rooms the Würzburg Residence is a unique example of baroque style.

Experiments were carried out in both the White hall and the Imperial hall, two large halls with impressive 3D structure. Together with the colorful paintings in the Imperial hall the environment can only be captured by the combination of two technologies, e.g., laser scanning and photography.

Data collection To capture the entire environment, data has to be collected at several locations. This is especially crucial due to the restricted field of view of the camera. Accordingly the robot is moved to a scanning location and stops there for data collection. The Riegl VZ-400 laser scanner works in a way that it emits a beam of light into a specific direction. After the light is reflected from a distant object and returns to the scanner, the time between sending and receiving is used to calculate the distance to this object. The sensor is able to capture 125.000 points per second with an opening angle of $360° \times 100°$. Thus, a typical laser scan with a resolution of 0.04° to 0.03° takes between 3 and 5 minutes. To achieve the full 360° horizontal field of view, the scanner head is rotated around its vertical axis. This feature is used to capture the full 360° degrees with the camera. After the scan is taken, the scanner head is rotated in discrete steps to take 12 pictures with a resolution of 3888×2592 at each scanning location. Assuming that the transformation between the camera and the laser scanner is known the point cloud from the laser scanner can then be enhanced with the information from the camera. The calibration procedure used to determine this transformation between camera and the laser scanner is described in detail in Borrmann et al. (2014).