Preliminary comparison between handheld and mobile robotic mapping systems

Eleonora Maset[1], Lorenzo Scalera[2], Alberto Beinat[2], Federico Cazorzi[1], Fabio Crosilla[2], Andrea Fusiello[2], and Alessandro Gasparetto[2]

[1] Department of Agricultural, Food, Environmental and Animal Sciences (DI4A), University of Udine, Italy
{eleonora.maset,federico.cazorzi}@uniud.it

[2] Polytechnic Department of Engineering and Architecture (DPIA), University of Udine, Italy
{lorenzo.scalera,alberto.beinat,fabio.crosilla, andrea.fusiello,alessandro.gasparetto}@uniud.it

Abstract. *Make cities and human settlements inclusive, safe, resilient and sustainable* is one of the Sustainable Development Goals drawn by the United Nations. To support renovation projects, a first essential step is to gain an updated and precise knowledge of indoor and outdoor public spaces and urban areas, which requires accurate and fast mapping systems. In this context, in addition to well-established manual topographic techniques, mobile robotics could play a crucial role in the perspective of acquiring automatic surveys of such environments. In this paper, we present a preliminary comparison between handheld and mobile robotic mapping platforms, using a 3D laser scanner that realizes real-time mapping on the field. Experimental results show that the robotic system could be an efficient alternative to the handheld-mode survey, providing precise point clouds with uniform density.

Keywords: Sustainable Cities and Communities (SDG11) · mobile robotics · laser scanning · mapping systems · Simultaneous Localization and Mapping (SLAM).

1 Introduction

The United Nation 2030 Development Agenda has drawn the importance of making cities and human settlements inclusive, safe, resilient and sustainable [17]. In particular, the Sustainable Development Goal 11 (SDG11) indicates the target to enhance inclusive and sustainable urbanization, as well as to protect and safeguard the world's cultural and natural heritage. At the same time, the SDG11 outlines the aim to substantially increase the number of cities and human settlements adopting and implementing integrated policies and plans towards resource efficiency, adaptation to climate change, and resilience to disasters.

In this context, acquiring and recording updated high-resolution 3D information of internal and external environments is crucial in the study and analysis of both buildings and human settlements [9]. The survey of civil structures, usually performed by means of classical surveying technologies such as Photogrammetry and Terrestrial Laser Scanning (TLS), has been revolutionised in recent years by portable Mobile Mapping Systems (MMSs). These devices can be easily carried by a person who acquires accurate 3D data of the surrounding environments by simply walking through the area of interest, as shown in [13]. Nowadays, several studies have been proposed that examine advantages and disadvantages of portable MMSs in diversified test fields, as demonstrated by a flourishing literature on the topic [16]. For example, in [6] a wearable mobile laser system is evaluated for the indoor 3D mapping of a complex historical site, whereas in [10] the performance of a handheld laser scanner is investigated in different outdoor scenarios, such as the survey of a building facade and a mountain torrent. Mapping systems are used also to inspect constructions or manufactured parts and identify possible discrepancies between the as-built workpieces and their nominal specifications [12]. The data acquired by portable mapping devices are essential to create a Building Information Model (BIM) according to the as-built condition of the structure [11], and recently proved to be fundamental to support functional and occupancy analysis of buildings in challenging situations, such as the COVID-19 pandemic [5].

The acquisition of 3D information on buildings and human settlements could be improved and automated by mounting the mapping devices (e.g., laser scanners or RGB-D cameras) on a robotic platform, which can be steered from remote through the area of interest or can autonomously perform the required survey. Nowadays, mobile robots have been increasingly applied for mapping and surveying in several different fields, such as proximal sensing and precision farming in the agricultural field [14,15], the exploration and inspection in hazardous and challenging environments [4,18], as well as inspections in disaster situations. Mobile robots are also employed for the mapping of archaeological and cultural heritage sites, as shown in [3]. A review on autonomous mobile scanning systems for the digitization of buildings can be found in [1].

In this paper, we present a preliminary comparison and performance evaluation between handheld and robotic mapping systems. In particular, we used a 3D laser scanner, coupled with an Inertial Measurement Unit (IMU), that realizes high-resolution mapping of the surrounding environment and can provide real-time results. Experimental tests are carried out performing the survey of the ground floor of the Rizzi building of University of Udine (Italy) and considering two different scenarios: in the first case, referred to as *handheld*, the device is attached to a telescopic pole and carried manually, while in the second case (*robotic*) it is mounted on a mobile robot. The analysis of the results shows that the robotic mapping platform compares favourably with respect to the handheld modality, and the feasibility of the robotic system for future automatic surveying with the goal of supporting renovation projects for sustainable cities.

The remainder of the paper is organized as follows: in Section 2 the materials and methods used in this work are described, whereas in Section 3 the experimental results are presented. Finally, the paper is concluded in Section 4.

(a) Handheld platform (b) Robotic platform

Fig. 1. Laser scanner attached to a telescopic pole and carried manually (a), and mounted on the mobile robot (b).

2 Materials and Methods

The experimental tests were performed using the HERON Lite system by Gexcel srl [7]. This instrument is composed of a Velodyne Puck LITE laser scanner coupled with a XSens MTI inertial sensor. The laser head is characterized by 16 channels emitting infrared laser beams, allowing to cover a 360° horizontal field of view and a 30° vertical field of view. In its standard configuration, the HERON Lite device is thought to be attached to a telescopic carbon fiber pole, which is manually held during the mapping procedure (Fig. 1(a)). In our tests the HERON Lite system was mounted on a mobile robot, with an angle of approximately 30° between the vertical direction and the laser rotation axis (Fig. 1(b)). In particular, the MP-500 mobile system by Neobotix was adopted, which is equipped with two drive wheels, an undriven castor wheel, and a 2D laser scanner used for safety purposes. The robot has dimensions equal to $814 \times 592 \times 361$ mm and a maximum speed of 1.5 m/s. In this first work, the mobile robot has been steered using a joystick connected by a wi-fi link.

The HERON Lite system provides a map of the scanned environment in real-time, using an on-line Simultaneous Localization and Mapping (SLAM) algorithm. Thanks to this approach, new scans are incrementally added to the current point cloud of the surveyed area as soon as they are available, simultaneously estimating both the system trajectory and the map. More in detail, the procedure is carried out exploiting IMU data to compute a rough estimate of the sensor position and attitude, which is refined through a registration process that aligns each cloud (a single 360° scan) to the previous ones using the well-known Iterative Closest Point (ICP) algorithm [2]. However, this real-time method tends to drift on long paths, downgrading the accuracy of the produced map. So, the final point cloud of the environment is defined via an off-line post-processing, carried out through the HERON Desktop software, that implements a full SLAM approach [8]. In this case, the map is computed simultaneously exploiting all the measurements acquired during the entire survey: a global registration among all the scans is performed, minimizing misalignment errors among the clouds and closing the loops (if any) in the trajectory. These refinements usually lead to a 3D point cloud characterized by a precision of 3 cm and a global accuracy of 5-20 cm, depending on the geometric characteristics of the surveyed area and the presence of closed-loops on the trajectory, which can significantly affect the performance of the SLAM algorithms [7].

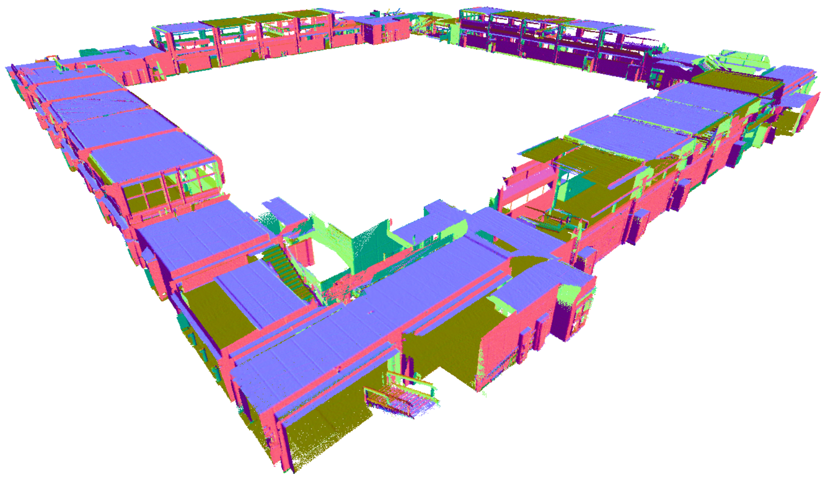
To provide a preliminary comparison between handheld and mobile robotic mapping platforms, we surveyed the ground floor of the west-wing corridor of the Rizzi building of University of Udine (Italy). In both cases the trajectory followed a closed loop around the square-based plant. The main characteristics of the data acquisitions are reported in Table 1. Please note that both surveys were processed assuming the same parameter values for the SLAM algorithms previously described. Figure 2 shows the point cloud obtained with the robotic mapping system, after the manual removal of outliers (points falling outside the area of interest).

Table 1. Characteristics of the surveys performed with the handheld and the robotic mapping platforms.

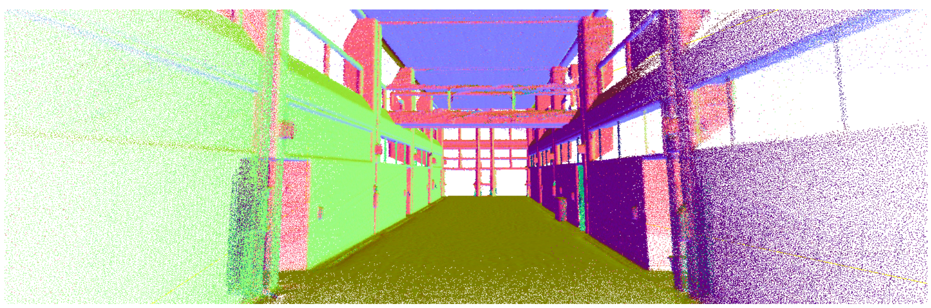
Survey platform	Acquisition time	Trajectory length	Points number
Handheld	5 min 30 s	342 m	35,755,046
Robotic	13 min 40 s	339 m	47,694,577

3 Results and Discussion

To evaluate the results provided by the mobile robotic mapping platform, a comparison with the map produced through the handheld system was performed, investigating at first the possible presence of relative deformations between the two models. In particular, we focused the attention on the south part of the surveyed corridor (Fig. 2(b)) and we preliminary registered the two point clouds via the ICP algorithm. In fact, the coordinates of each model are expressed in an arbitrary reference frame and a relative alignment is therefore needed to subsequently evaluate the differences between the two point clouds. The point-to-point absolute distances between the models were estimated using CloudCompare soft-



(a)



(b)

Fig. 2. Point cloud of the whole corridor of the university building (a), and a detailed view of the south part (b). Points are colored according to the local plane inclination.

ware[3], obtaining a mean distance of 2.2 cm and a standard deviation of 1.5 cm. Figure 3 reports the results for the floor and a wall of the analysed corridor. It can be noticed that higher discrepancies are located on the floor, whereas the wall shows tight correspondence (distances $<$ 2 cm) between the two models. In any case, the computed differences are compatible with the accuracy of the instrument, according to the manufacturer's specifications.

Observing instead the point cloud density that characterizes the two models, it is interesting to highlight that the handheld survey modality provides a bimodal distribution (Fig. 4(a)) with higher density values on the walls (on average, approximately 5000 points/m^2), that decreases to values below 2000 points/m^2 on the floor. On the contrary, the survey performed through the mo-

[3] https://www.danielgm.net/cc/

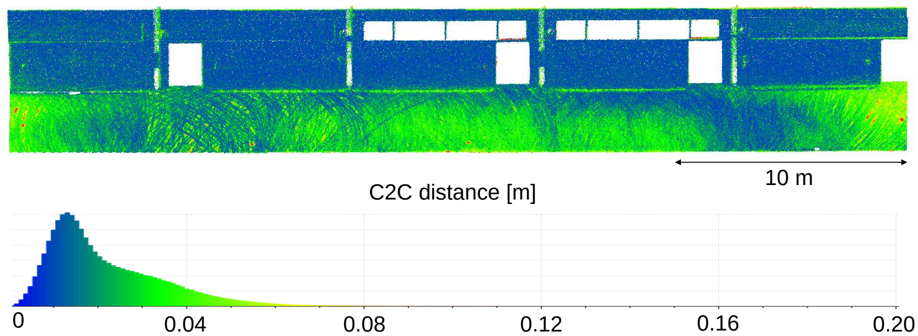
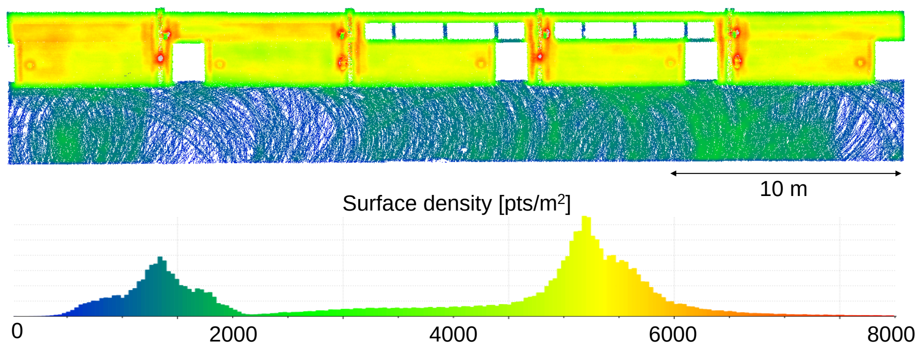
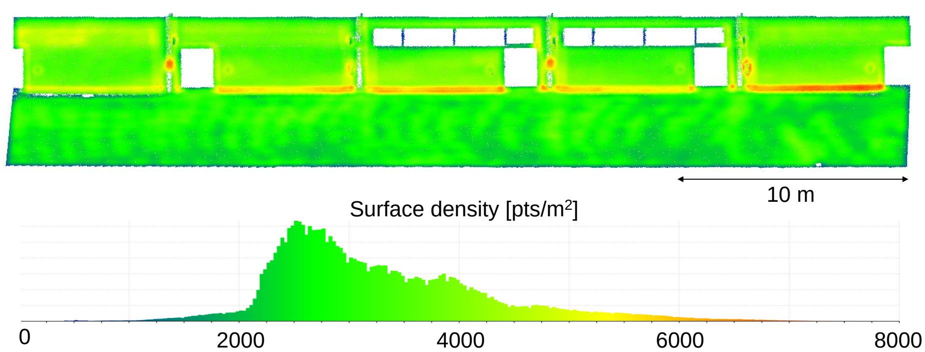


Fig. 3. Cloud-to-cloud absolute distances computed between the point clouds obtained by the handheld and the robotic mapping platforms.



(a) Handheld mapping platform



(b) Robotic mapping platform

Fig. 4. Surface density characterizing the point cloud obtained from the handheld-mode survey (a) and the robotic mapping system (b).

Table 2. Results of the plane fitting procedure. The RMS of the distances between the points and the corresponding estimated plane are reported for each considered patch.

Plane	Handheld mapping	Robotic mapping
Wall #1	2.5 cm	1.6 cm
Wall #2	3.0 cm	1.6 cm
Wall #3	2.6 cm	2.9 cm
Wall #4	2.2 cm	2.0 cm
Floor #1	1.4 cm	1.4 cm
Floor #2	1.2 cm	1.3 cm

bile robotic platform guarantees a more uniform point distribution, with an average density of 3300 points/m^2 that characterizes all the surveyed surfaces.

In addition to a more consistent point density, the point cloud acquired with the robotic system shows also a slightly lower level of noise. This feature was quantitatively verified extracting six patches of points from the walls and floor and fitting a plane to each subset. Table 2 reports the Root Mean Square of the distances of the points from the corresponding fitted plane, showing on average a RMS of 2.2 cm for the model obtained from the handheld-mode survey and 1.8 cm for the robotic mapping case. A possible explanation of this behavior may lie in the fact that the robot performs the survey at lower speed and, above all, avoids the oscillations and sudden movements to which the laser scanner can be subjected when it is mounted on a pole and carried by a walking person.

4 Conclusion

Acquiring updated and detailed 3D models of buildings is an essential preliminary step in any renovation project that can lead to more sustainable and resilient cities, which is the aim of the Sustainable Development Goal 11. In this context, robotic mapping systems could represent a fundamental aid to reduce and automate the time-consuming manual work usually required for the surveying operations. In this paper, we presented preliminary results relating to indoor surveys carried out by mounting a 3D laser scanner on a remote-controlled robot. Quantitative evaluations demonstrate a tight correspondence between the point cloud obtained from the robotic mapping and the one retrieved via the handheld platform, with the former showing a more uniform point distribution and lower noise level: robotic mapping could be therefore a viable alternative to the well-established surveying mode.

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