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Indoor mapping with wearable laser scanner and iPad lidar

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Abstract

Efficiently surveying complex indoor environments remains a challenge due to the accuracy demands of interior geometric data. Laser scanning technology in indoor and outdoor mapping has significantly advanced the field, surpassing conventional measuring devices. Indoor and outdoor mapping processes have typically depended on acquiring terrestrial laser scanner point clouds, a time-consuming and costly technique. Alternatively, we present a novel indoor mapping strategy utilizing simultaneous localization and mapping (SLAM) based on a wearable mobile laser scanner and a laser sensor incorporated into portable iPad tablets. This approach has already been successfully tested in mapping processes, offering a more efficient and economical alternative to conventional terrestrial laser scanning point clouds. Indoor scanning is conducted in this methodology. Initially, the specified region is scanned with a ground-based laser scanner, and the resultant data serves as a reference. Subsequently, this area is scanned with wearable and iPad laser scanners, and a comparative analysis is executed. Based on the case study area findings, the proposed technique could be an alternative to the portable and wearable laser scanning method. This alternative provides notable benefits regarding accuracy and time efficiency for point cloud laser scanning at a local level.

1. Introduction

An interior study involves conducting a building survey or extracting detailed plans and models of an existing interior space. Mapping topics have long included developing and planning interior designs (Sırmacek et al., 2016). The availability of maps and plans is beneficial in evaluating existing building conditions against architectural plans or interpreting them in the context of renovation projects. Accurate and precise measurement of geometric properties of enclosed spaces is crucial for numerous studies today (Güleç Korumaz et al., 2011). In the past, classical metric measuring instruments were used for measurement processes. However, the development of precision measuring devices such as total-station has aided in measuring and mapping architectural structures for similar purposes. Advancements in technology and physics have facilitated the proliferation of laser scanning systems, which use laser signals for measurement purposes. The laser scanning technique allows for the direct, accurate, and automated acquisition of three-dimensional (3D) coordinates of objects (Reshetyuk, 2009; Akar, 2017). Using this technology, it is possible to create exact 3D point clouds that contain intricate details of the target object. These clouds offer high-resolution matching and the potential for change monitoring and presentation, all of which can be measured in any metric (Armesto-González et al., 2009).

Laser scanning techniques can be broadly categorized as modern indoor mapping solutions and fall under terrestrial and mobile laser scanners (Ulvi & Yakar, 2014; Tepeköylü, 2016). The terrestrial laser scanner provides highly accurate direct measurements, regardless of illumination conditions. Digital reconstruction of indoor spaces is possible through the main products derived from 3D point clouds (Masiero et al., 2018). When measuring an area, the TLS system allows quick access to highly precise and densely packed X, Y, and Z information. Nevertheless, this situation presents a Big Data issue when analyzing the data (Zheng et al., 2018). While the ground-based laser scanner yields dense and precise data, it poses limitations due to its high cost and static data collection principle, resulting in limited observation points for capturing polymorphic structures (Ulvi et al., 2015; Özdemir et al., 2021).

In large and intricate indoor mapping projects, obtaining adequate data through terrestrial laser

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scanner systems necessitates many scans, prolonging the data collection period. As cited by Ingman et al. (2020), there is a need to evaluate more efficient and economical scanning systems. For the reasons above, scholars (Sanchez Diaz et al., 2022) conducted a recent study, leading to the development of mobile mapping systems that can achieve similar precision as TLS while using less data and in a shorter timeframe (Yaman & Yılmaz, 2020). The latest MLS systems have solved issues related to measuring, documenting, and mapping complex and inaccessible areas or instances where using laser scanning measurement procedures from the ground is unfeasible (Yılmaz & Yakar, 2016). Compared to fixed instruments, this device streamlines and accelerates the measurement process because measuring from multiple points is unnecessary. Although mobile mapping systems' resolution and density are lower than fixed instruments, the values are adequate for structure analysis. According to Di Filippo et al. (2018), errors in these systems have been minimized due to significant developments in the last few years, particularly in managing various sensors. Additionally, these systems enable solutions for complex outdoor and indoor scenarios, making them practical tools for mapping.

Mobile laser scanning methods use a simultaneous localization and mapping (SLAM) algorithm incorporating a Light Detection and Ranging (LiDAR) sensor, as well as complementary sensors such as RGB cameras or thermographic sensors, to expand the captured data of the environment via Inertial Measurement Unit (IMU) integration. The approach is objective and employs clear and concise language while adhering to grammatical and spelling conventions of British English. These new methods can be classified as lightweight wearable, back, or handheld devices in three setups with capture distances and relative accuracies ranging from 5 to 100 meters. Although initially designed to enhance the navigation capabilities of robots, it has also been utilized for mapping objectives. These systems are based on the SLAM algorithm and do not require Global Navigation Satellite Systems (GNSS) support. They are an alternative to the TLS system in indoor mapping studies. Lidar scanners are another method that has begun to be used in iOS-based mobile smart devices. The use of iPad laser scanners in this field has been particularly cost and time-effective. However, wearable and iPad laser scanners generally have inferior positional accuracy, and numerous studies have disclosed significant inconsistencies between various trajectories. Apple disclosed the latest iPad Pro and iPhone 12 Pro/Pro Max iteration, incorporating a sensor in 2020. Such recent technical progression hints at an increase in cost-effective alternatives becoming available shortly, catering to both professional and consumer markets. It may be simpler to gather 3D data on the environment, but the usefulness of such information is still uncertain.

An examination of the literature linked to the study's topic indicates that the laser system employed in local indoor spaces is adequate regarding resolution and sensitivity. Nevertheless, since the TLS system has the abovementioned drawbacks, mobile and iPad LiDAR systems based on SLAM algorithms offer potential substitutes. Within this study, a practical analysis of mobile systems, which propose a new approach to indoor mapping, has been conducted concerning their sensitivity and resolution. For indoor mapping purposes, scans were conducted using wearable and iPad LiDAR devices to produce point clouds. Subsequently, the same area was scanned using local laser scanning as reference data. After the research, a statistical evaluation was carried out on the functionality of the wearable and iPad LiDAR system, presenting a new alternative to the ground-based laser scanner for indoor production. Additionally, recommendations for future studies were proposed.

2. Method

Terrestrial laser scanners fall under the category of laser scanning and produce a 3D point cloud via Light Detection and Ranging (LiDAR) technology. This enables them to gather many points swiftly, leading to their utilization in different fields like project supervision, structure analysis, development monitoring, progress control, change identification, quality control, and creating piecewise and built-in models. TLS is a commendable option for indoor cartography due to its superior point density and precision. However, 3D mapping in large and complex indoor environments can be costly (Green et al., 2014). Terrestrial laser scanners offer not only 3D geometric information about the measured object but also information about the power of the laser beam that is backscattered by the scanned surface. The local laser scanner detects the intensity, a portion of the energy. This measure of intensity, also known as reflection, indicates the proportion of radiated and reflected power in the laser wave. The digital expression of intensity is typically unitless and varies depending on the sensitivity of the laser scanner detector. Ground-based laser scanner detectors generally have an 8 to 16-bit resolution to capture intensity.

Terrestrial laser scanners are typically grouped into three categories based on length measurement principles: time of flight, triangulation, and phase difference scanners (Karataş et al. 2022). Time-of-flight scanners have an extensive scanning range, while phase difference scanners can measure shorter distances with higher precision and accuracy than time-of-flight scanners (Karataş et al. 2023).

The wearable laser scanning system uses the instantaneous positioning and mapping (SLAM) algorithm. This approach permits the mapping of unfamiliar surroundings by passing range sensors while simultaneously establishing the system's position on the map (Di Filippo et al., 2018). This enables capturing point clouds by traveling to diverse areas and surveying from different positions (Yakar et al., 2008). The SLAM-based device obtains data from the Velodyne Puck LITE LIDAR and IMU sensors to locate itself in the surrounding environment. The SLAM algorithm analyzes this data, detecting geometric object variations such as walls, floors, and columns, to create a map of the local coordinate environment and estimate its location. In WMLS devices, the SLAM algorithm forms the foundation for creating maps and models (Kanun et al., 2021).

The iPad Pro tablet (Apple Inc. San Francisco, USA) is the third device to scan the study areas. This particular generation is fitted with an Apple LiDAR sensor capable of scanning the surrounding environment. The sensor is understood to be a distinctly devised LiDAR scanner with direct time-of-flight, which measures depth in addition to employing a camera and motion sensor. Apple has yet to disclose any official information about the device. The scanner can scan objects up to a distance of 5 meters. We utilized the 3D Scanner App (Laan Labs, New York, USA), which has additional features like coloring and exporting mesh and point clouds.

3. Results

Firstly, laser scanning data were collected. The point cloud data of both WMLS and iPad LiDAR are given in Figure 1. Then, ICP and C2C analyses were performed to compare the point clouds of the proposed methods with the reference data, which are ground-based laser scanning data. Firstly, the proximity analyses of the point clouds of wearable laser scanning to the reference data are given in Figure 2. Then, the proximity analyses of the iPad LiDAR point clouds to the reference data are given in Figure 3.

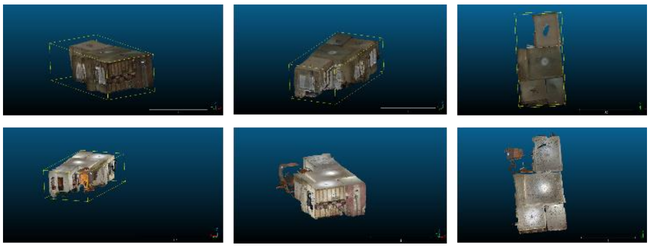

Figure 1. WMLS point cloud (Top), Ipad LiDAR point cloud (Bottom).

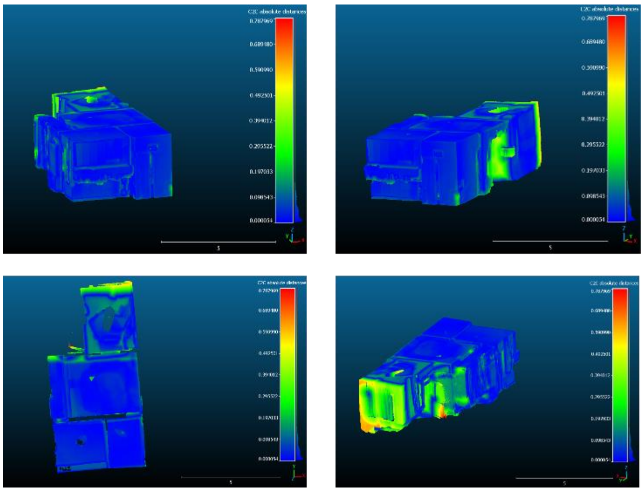

Figure 2. Comparison of WMLS data with reference data

4. Conclusion

Our research indicates that it is feasible to use WMLS and iPad LiDAR point clouds, with SLAM assistance, as an alternative to TLS point clouds in the test region, with an acceptable level of precision. As TLS measurements are costly and time-consuming, mainly when collecting data in corridors between rooms, our study shows that SLAM-based WMLS measurements can reduce data collection time. Additionally, we have found the accuracy of TLS room locations reasonable. Therefore, this study demonstrates that WMLS presents a favorable option, particularly about time, for generating a thorough point cloud that meets the required precision for indoor mapping applications. This method is more efficient than constructing TLS stations for point cloud-based investigations, requiring less labor. The SLAM point cloud is accurately aligned with the reference, with an accuracy of 2.1 cm, while the iPad LiDAR exhibits comparable alignment, with a value of 11.5 cm. Based on the C2C analysis, the TLS measurements show a discrepancy of 3.1 cm compared to the WMLS data. In contrast, the iPad LiDAR exhibits a difference of 11.8 cm, which is deemed acceptable given the intricacies of indoor mapping.

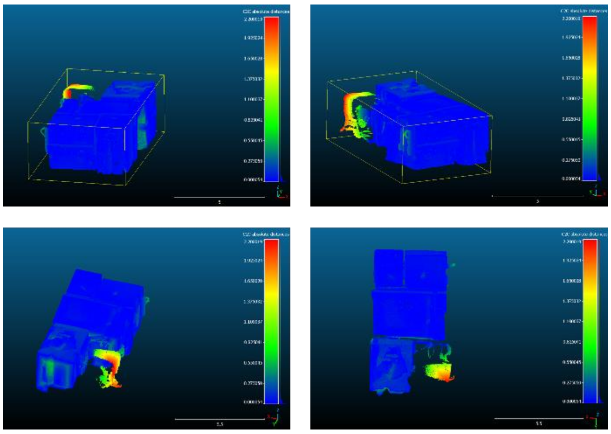

Figure 3. Comparison of Ipad LiDAR data with reference data

However, SLAM-based WMLS and iPad LiDAR incur drawbacks, mainly when operating in long, narrow, or huge environments, in areas with no substantial features such as furniture or other suitable geometric targets for robust mapping, or even in open space. In order to enhance the internal geometric integrity, it is necessary to have features at close intervals, and measurements should be taken through closed-loop paths. Most indoor environments possess adequate geometric features present at short intervals/distances. Meanwhile, the environments that lack adequate geometric features are few. In such situations, it is possible to rectify the deficiencies of WMLS and iPad LiDAR in narrow corridors by incorporating additional features in hindering regions. These features may include furniture or other objects that can enhance perceptible surfaces or even opening doors to draw in supplementary surfaces.

Nevertheless, it is vital to perform operations with well-thought-out planning before mapping the environment due to the abovementioned limitations. Additionally, planning for TLS scanning is more complex than mapping with alternative methods. The collection of point clouds using wearable and mobile LiDARs is a quicker process. The density of mobile LiDAR point clouds relies on the distances between the scanner and the features being measured and the speed at which mapping is conducted. Noisy data is shared, particularly in instances where walking speed is slower. This noise can make recognizing small objects measuring less than

3 cm or displaying window placements complex. However, the research indicates that the noise in the point clouds gathered by the proposed methods has a negligible impact on the accuracy of both registration and 3D mapping compared to TLS point clouds. SLAM-assisted WMLS and iPad LiDAR outperform the TLS method in terms of speed. It takes approximately 1 hour to collect data using WMLS for the studied area compared to 8 hours using individual TLS. Moreover, the WMLS and iPad LiDAR approach can be applied to indoor and outdoor mapping and provide a viable alternative to the TLS system.

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