Smartphone Lidar Technology for Low-Cost 3D Building Documentation

Subjects: Others
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Laser scanning technology has long been the preferred method for capturing interior scenes in various industries. With a growing market, smaller and more affordable scanners have emerged, offering end products with sufficient accuracy. While not on par with professional scanners, Apple has made laser scanning technology accessible to users with the introduction of the new iPhone Pro models, democratizing 3D scanning.

Keywords: 3D scanning ; smartphones ; lidar

1. Introduction

Over the past decades, laser scanning has emerged as a cutting-edge technology. Laser scanners generate point clouds that are highly effective in representing objects of varying complexity at different scales [1]. In the 1990s, terrestrial laser scanners (TLS) were introduced to the surveying industry [2], and towards the 2010s, they became more accurate and capable of scanning ranges of hundreds of meters. TLSs are widely used in a variety of applications, including cultural heritage [3][4], change detection [5][6], monitoring and deformation [7][8][9], as-built modelling [10], and forestry [11]. In the late 2000s, mobile mapping systems (MMS), which operate on a vehicle such as a car, were introduced into mapping operations, mainly for data capture on road infrastructure and building facades [12] and extended its use to various applications [13][14][15][16][17][18][19][20].

These systems utilize active or passive sensing to capture the object of interest, along with GNSS and IMU for accurate georeferencing. While the GNSS and IMU combination works well for outdoor applications, in GNSS-denied spaces like indoors, using only inertial sensors leads to an increasing drift rate, one which cannot be corrected due to the unknown function with respect to time [21]. Simultaneous localization and mapping (SLAM) is one of the techniques that offers a solution to this problem. Its fundamental concept is monitoring the sensor's position and orientation (pose) over time in 3 degrees of freedom (DoF) and with relative coordinates, respectively. This is achieved by utilizing overlaps in optical data, such as with previously observed features [21].

Nowadays, numerous low-cost MMS rely on SLAM and can be utilized through various platforms like trolleys, backpacks, and hand-held devices. Although many of these systems have been initialized for entertainment, some have led to research work developments for further applications. In addition to mobile laser scanner solutions, depth cameras represent another commonly employed low-cost alternative in 3D documentation. The integration of RGB and depth cameras generates a 3D representation of the scene by capturing the distance between the object and the camera within their field of view (FOV) and is frequently utilized in computer vision [22]. Two common approaches for depth cameras are time-of-flight (ToF) and structured light. ToF cameras, exemplified by devices like Azure Kinect and HoloLens, emit light pulses and capture the reflected signal to calculate the distance based on the measured time for the light to travel to an object and back. Numerous studies have incorporated both systems in indoor mapping [23][24][25]. Structured light-based cameras project a known light pattern onto the scene and calculate depth information based on the distortion of the pattern on the analyzed object surface. Early generations of Kinect serve as a well-known example of this type of camera and have been utilized in various studies to investigate their capabilities in indoor mapping [22][26][27].

The developments in laser scanning technology and the rapid advancement in low-cost sensor technology have made 3D laser scanning more accessible and cost-effective. Over the years, researchers have investigated comparative evaluation of the lidar-based indoor MSS, such as [28][29][30][31]. Even consumer technology, like some iPhone models, now incorporates laser scanning technology, opening possibilities for the democratization of 3D scanning.

2. Smartphone Lidar Technology for Low-Cost 3D Building Documentation

Using smartphones to obtain spatial information is not a new concept, as smartphones are equipped with inertial sensors that are commonly used in indoor positioning, such as in [32], and cameras that are used in 3D reconstruction based on images or videos [33][34]. Most earlier studies intensively worked with the Google Tango technology, which was launched in 2014 [35] and aimed to evaluate the dependability, influence, and engagement of users in a hardware and software bundle that permits the development of augmented/mixed/virtual reality content exclusively through the use of their smartphones or tablets [36]. The Tango project was only available on a limited number of compatible phones and tablets. In 2018, the project was terminated and replaced with ARCore [37]. Some studies include [38][39], both of which tested the Tango tablet's capability for 3D documentation of indoor spaces. Other examples are [40], which investigated 3D reconstruction using a Tango smartphone in the context of cultural heritage, and [36], which assessed the quality and potential of the system in their study.

Apple introduced lidar sensors into its pro lines of tablets and smartphones, iPad Pro and iPhone 12 Pro, in 2020. This brought a novelty to the 3D scanning subject by incorporating a lidar sensor into user-grade smartphones, leading to the question of whether these devices would be a low-cost alternative with enough accuracy in 3D scanning. Apple's aim was more to improve the camera and enhance the augmented reality experience for its users. Hence, Apple has not released any 3D scanning applications for large spaces or objects after the initial release, apart from the Measure app, which is designed as a measuring tool. However, Apple has provided a software development kit (SDK); since then, many developers have developed 3D scanning apps with ARKit by Apple. As it seems to be compatible with novice users who seek to generate a floor plan to design their houses or to try furniture before buying, more applications that target scanning experts have been released over time. It has also received attention from researchers as a low-cost and over-the-shelf alternative for 3D documentation. Different subjects have been investigated since the release of the first Apple device equipped with the lidar sensor. [41][42] evaluated the iPhone 12 Pro for its use in geoscience applications. The former reports a 10 cm sensor accuracy when demonstrating its use on a coastal cliff, while the latter concludes that the tested iPhone 12 Pro device would be the standard process for capturing rocky slopes and investigating discontinuities, despite limitations in its range. [43][44] assessed the Apple lidar devices for their use in heritage documentation and concluded that this technology holds great promise for the near future. [45] investigated these devices for indoor/outdoor modelling and reported 53 cm for local precision and 10 cm for global correctness. The indoor test space consisted of two adjacent rooms that covered a total of around 200 m^2. [46] evaluated the iPad Pro from the architectural surveying perspective and reported 2 cm precision and 4 cm accuracy for a 1:200 map scale.

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