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IPHONE 13 PRO VS PROFESSIONAL TLS FOR 3D INDOOR MAPPING

Abstract

In recent years, fast and simple acquisition of geospatial data, fast processing, and distribution is a trend that characterizes geoinformation technologies. The primacy of the acquisition is based on image processing technology and laser scanning. This paper attempts to answer how acceptable these technologies are incorporated into smartphones which can be used for data acquisition. A comparative analysis of the results collected by smartphone and professional laser scanners has been made. The results presented in the paper confirm the usability of the iPhone LiDAR device in the acquisition of point cloud and the development of 3D models of indoor spaces.

Keywords: LiDAR, iPhone 13 pro, Terrestrial Laser Scanning

АЈФОН 13 ПРО И/ИЛИ ПРОФЕСИОНАЛНИ ЛАСЕРСКИ СКЕНЕР ЗА 3Д КАРТИРАЊЕ УНУТРАШЊОСТИ ОБЈЕКАТА

Сажетак

У данашње време брза и једноставна аквизиција геопросторних података, брза обрада и дистрибуција је тренд који карактерише геоинформационе технологије. Примат у аквизицију се базира на технологији обраде слике и ласерском скенирању. Овај рад покушава да да одговор колико су прихватљиве ове технологије инкорпориране у једноставне непрофесионалне уређаје типа мобилног телефона који се могу користити за аквизицију података. Направљена је упоредна анализа аквизиција у резултатима прикупљеним мобилним телефоном и професионалним ласерским скенером. Резултати презентовани у раду потврђују употребни апсект аквизиције мобилних уређаја у изради 3д модела унутрашњег простора.

Кључне ријечи: Лидар, Ајфон 13 про, терестрички ласерски скенер

1. INTRODUCTION

In recent years, demand for detailed and accurate 3D models of indoor spaces has been increased significantly due to their wide application such as construction, indoor navigation, conservation and reconstruction of historical and cultural heritage, promotion of tourist attractions, spatial planning, or development of Building Information Modeling (BIM).

In order to provide a sufficient level of detail, the models need to be based on reliable measurement data. Most often the point clouds represent the raw material for the development of 3D models. Different surveying technologies can be used to collect point clouds from indoor environments such as laser scanning, close-range photogrammetry, depth camera, or simultaneous localization and mapping (SLAM). However, there are several limitations that need to be considered.

The mobile depth camera requires optimization of light conditions and can provide accurate results for smaller room sizes [1].

Close-range photogrammetry uses photographs of the same object taken from different angles to create a 3D point cloud of the object. The geometric representation of the object is created by using a tie point between at least 3 different images. [2] used close-range photogrammetry for 3D modeling of the complex indoor gothic church providing dense point cloud and quality textures. The accuracy of the resulting model is highly influenced by light conditions and camera-resolution which can result in a lack of points and unclear surfaces; therefore, additional lighting is crucial. Although photogrammetric with the nonmetric camera is an inexpensive method it provides less accurate results [3] and demands more careful planning compared to TLS [2].

Laser scanning technology has been widely used for mapping complex environments, resulting in the highly detailed point cloud that can be used for obtaining a 3D model, geometrical analysis, and extraction of characteristic elements such as cross-sections, edges, axes. Two types of laser scanning are widely used for indoor mapping, Terrestrial Laser Scanner (TLS), and Mobile Laser Scanner (MLS). The mobile mapping systems (MMS), based on robot-carried devices have been used to map indoor spaces. SLAM is proposed to solve the problem of robot localization and navigation in an unknown environment. The system is equipped with navigation such as global navigation satellite system (GNSS) and inertial measurement unit (IMU) and imaging sensors such as laser scanning and cameras. The robot uses sensor measurement to build maps incrementally.

Since the application of vehicle-borne MMS in indoor spaces is limited due to size and difficulties in moving the backpack (MMS) has been widely used. [4] applied the 3D laser SLAM algorithm to mobile mapping to acquire geographical information in a complex indoor environment achieving a relative precision of point cloud of 2-4 cm. [5] tested the performance of laser-based and photogrammetric-based backpack system to TLS. The absolute error was 16.3 cm and 50.3 cm; while the relative error was 8.2 cm and 6.1 cm for the laser-based backpack and photogrammetry, respectively. Although SLAM can produce centimeter-level accuracy, it is expensive, the positional accuracy will degrade with an increase of the mapping territory due to cumulative error [6], and registration of point clouds from multiple tasks or robots is challenging [7].

TLS represents one type of laser scanning which is based on Light Detecting and Ranging (LiDAR). Several studies have applied the TLS in 3D indoor modeling [8], [9], and [10]. TLS has been accepted as the standard technology for 3D data acquisition, enabling high-quality point clouds with high precision and accuracy and a high level of detail [11]. Due to that, it is usually used as the reference data for comparison with other methods or more affordable devices [12]. However, TLS is based on the static data collection principle demanding multiple scanning positions in order to obtain sufficient data. In addition, the overlap between scenes needs to be provided in order to register point clouds. Due to that, it is time-consuming, especially in a large and complex environment. Additional measurements with traditional surveying techniques are needed if the point cloud should be georeferenced [13]. This also increases the time needed for data collection especially when multiple rooms are scanned. Moreover, TLS has some limitations, including weather conditions, dust, object materials, surface reflectivity, and surface roughness. It is hard to measure highly reflective surfaces such as glass or mirrors. Even reflective coating on furniture can create issues requiring multiple scenes to deal with specular reflection.

However, TLS and MMS tend to be expensive due to involved laser scanning device(s) or multiple cameras thus the application for the end-user is typically reduced. Due to technological development more and more sensor systems have become available for 3D indoor mapping in order to address those limitations.

The low-cost RGB-D camera with high frame rates has become a popular method for fast static and dynamic scene reconstruction. However, such a system has limited accuracy of geometrical acquisition due to sensor noise, limited resolution, and misalignments due to movement [14]. The

Microsoft HoloLens representing mobile, head-worn augmented reality (AR) devices have become a popular device for indoor mapping. The quantitative evaluation shows that HoloLens allows fast acquisition of basic single room geometry within a few centimeters [15]. In the case of multiple rooms connected by narrow passages, the larger deviations occur but accuracy is still sufficient for a 3D model of the indoor scene [15], [16].

In recent years, there has been rapid progress in enabling laser scanning technologies in mobile devices such as smartphones and pads. The LiDAR sensor has been included in iPhone 12 pro and iPhone 13 pro. Unlike the expensive solutions based on TLS or MLS, smartphones and tablets were increasingly affordable in everyday practice.

The study aims to evaluate the indoor mapping capacity of the iPhone 13 pro LiDAR sensor with respect to the mapping: room geometry itself i.e. dimensions of rooms and its elements (door, windows), mapping the fine geometrical details of the room, and mapping of flat and curved surfaces.

2. MATERIALS

The performance of the customer-level device and classic TLS was performed on the rectangular shape room whose dimensions are 7.7 m x 3.9 m. Although the room has simple geometry (except one column, two ceiling beams, and several pipes) it is full of furniture and small details on shelves. In addition, on the north wall, there are two large windows.

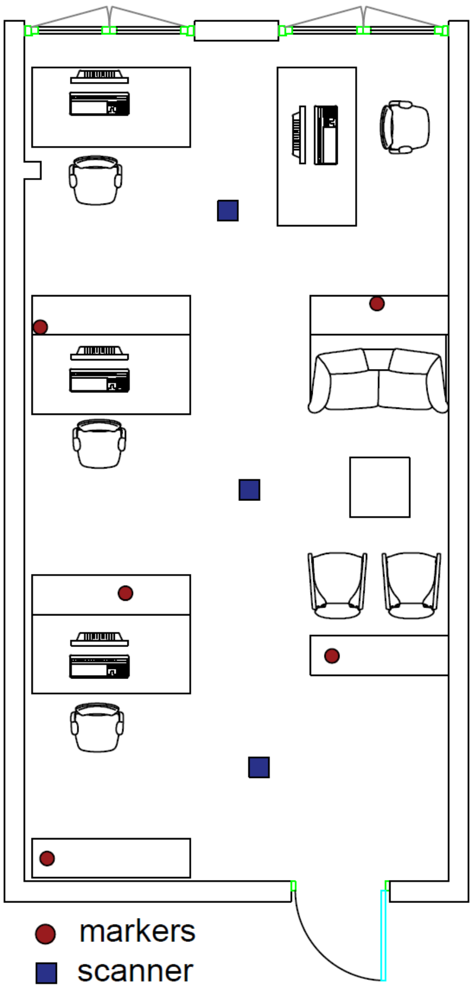


Figure 1. *Study area with markers and TLS positions*

The TLS data used in this study were captured using Faro Focus M 70 laser scanner. Focus M 70 uses phase-based time of flight measurement to estimate distance to object. The scanner covers 360° x 300° field of view. The technical details of scanner are listed in Table 1.

Table 1. Characteristics of Faro Focus M 70 laser scanner

Characteristic	M 70	iPhone 13 pro
Range	0.6-70 m	-
Unambiguity interval	614 m for up to 0.5 mil pts/sec	-
Range accuracy	± 3 mm	-
Integrated color camera	Yes	Yes
Sensors	Dual axis compensator, Height Sensor, Compass, Integrated GPS&GLONASS	Built-in GPS, GLONASS, Galileo, QZSS and BeiDou, Digital compass

iPhone 13 pro is equipped with LiDAR scanner primarily to improve the quality of night mode portraits since vertical cavity surface-emitting laser (VCSELs) provide 10-100 times higher brightest than LEDs enabling focused illumination at large distances [17]. However, integrated sensor can also be used the point cloud acquisition. VCSEL technology provide a combination of narrow spectrum, high efficient, fast pulse rise time and minimal spectral shift with temperature. iPhone LiDAR send light using an array of VCSELs. It detects reflected beam using an array of single-photon avalanche diodes. Although, classic laser scanners include one laser beam and moving mirror that deflects the laser beam around environment being scanned, the iPhone LiDAR doesn't include moving parts. Instead, it consists of thousand lasers on chip providing dedicated laser for each point in the LiDAR's field of view.

Distance measurement of VCSELs LiDAR relies on the time of the flight principle i.e. pulsed VCSEL sends a laser pulse to the object of interest and measure a time a photon is traveling from the laser to object and back to detector providing 3D position.

3. METHODOLOGY

3.1. TLS SURVEY

The study is office for 4 people which are organized in "box" system in order to provide the quit and private space for each employee. Due to that the room is divided with three shelves height 1.6 m. Taking into account the size and shape of the room as well as the position of the furniture (Figure 1) the open traverse scanning strategy was used in this case. In order to capture the complete space three scanning position were needed (Figure 1). The scanner positions were determined by two factors: ability to capture the all details and overlap between individual scans. Each scan is saved in internal coordinate system which origin is located in the center of scanner's mirror. Aligning the multiple individual scans onto a single coordinate system i.e. registration were based on targets. The arrangement of the targets in relation to one another and in relation to the scanner position is critical to the registration process. Three-dimensional, white surveying spheres were used as a target. The target is defined by its position, sphere radius and center point used for registration. The targets were arranged in overlapping scan areas. Additionally, distance from scanner and pattern were analyzed. The maximum distance from scanner is mostly affected by resolution and size of the target. The targets were arranged in unique pattern avoiding straight lines, short distance between targets, and same target height (Figure 1).

The resolution and quality are most important scan parameters affecting the level of detail, the scan duration and ability to register the scene properly. Taking into account the size and environmental conditions of study area resolution was set to 1/8 while quality was set for normal indoor conditions (3x). The point distance was 9 mm while scan duration was 4:08 min. In this case scan with color option was used including the acquisition of color photographs of the scan area.

The collected data were post processed in Faro Scene software. The multiple scenes were aligned by using automatic registration and target-based registration mode. The maximum distance error was 0.6 mm. After registration, project point cloud is created and exported in .las format.

3.2. IPHONE SURVEY

Several apps that enable mapping three-dimensional spaces with LiDAR scanner in iPhone is available in App store. In this case, SiteScape [18] was used. It provide fast way to capture and share 3D scans that can be exported as .RCP, .e57 or PLY files. [18] reported that based on conducted small study, including 9 scans of the same space, measurements are accurate to within ± 1 inch on average. The app is available into two modes: Free SiteScape and SiteScape Pro. Free SiteScape is limited to one active scan into the cloud at a time while SiteScape Pro unlock unlimited scans in the cloud. Two scan mode are available. Max Area which allows longer scanning time and Max detail for scans that require higher details. Also, it is possible to adjust the point density and point size (apparat size of points while scanning) Since max number of points is limited to 12 million points per scan due to performance constraints the max detail and increase of point density will significantly reduce the area covered per scene. In this case we used Max area mode with medium point density. The distance between device and objects of interest was between 1-4 meters. The scanning time around 10 minutes.

3.3. ACCURACY ASSESSMENT

In order to enable an accurate comparison, both surveys were conducted at same day, one after another providing static scenes without movement of any object. The accuracy of point clouds are firstly tested by measuring object dimension from point cloud in order to test the point cloud scale. For more robust measure of the difference between two surveys the CloudCompare [19] software was used. To test devices capability to determine the area and volume of the room Conure extractor tool was used.

Cloud-to-Cloud tool computes distance between two clouds i.e. for each point within compared point cloud the distance to the reference point cloud wis computed. Different algorithms can be used for quantification of distance between point clouds. Those algorithms can be categorized as global matching algorithms (nearest neighbor distance, nearest neighbor with local modeling) and local-searching algorithm (integrative closest point) [19].

To prepare the point clouds for comparison, it is necessary to check the co-registration of each cloud. This is due to fact that point clouds are available in different coordinate system. The cloud matching technique was used to reduce registration error. Point clouds were firstly co-register using Fine registration tool. The estimated value of RMSE was 12 cm therefore Align tool is used for precise point cloud alignment based on at least three manually identified points which were distributed over study area. The final RMSE was 2.2 cm. Cloud-to-cloud difference were calculated using the C2C implemented in CloudCompare software. TLS point cloud was used as reference.

4. RESULTS AND DISSCUSION

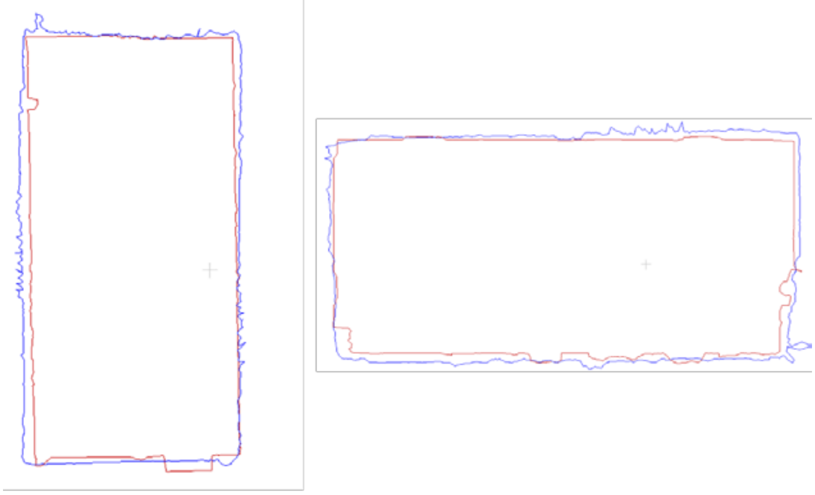
In order to compere the performance of devices the registered Focus M 70 point cloud and iPhone point cloud exported directly from SiteScape were compared.

First, a preliminary data check was performed and the values of the lengths in the points cloud were checked in order to preliminarily verify data and the ability of the device to measure the exact dimensions of well-defined standard objects. In this case, we used five tables which are distributed across the study area (Figure 1.). The true dimensions of tables were checked by using measurement tape. The result of accuracy assessment is presented at Table 2. As results suggest, the Faro Focus M 70 obtained highly accurate results with maximum error of 4 mm, while the accuracy of the iPhone 13 pro is within ± 5 cm. Based on the results it can be conclude that error don’t increase with increase of length rather it has random character. Therefore, it can be concluded that scale isn’t causing problems and that are most likely coursed by operator ability to define exact boundaries of object. This is expected due to lower density of iPhone point cloud.

Table 2. Compression of object size manually measured from point cloud

True [m]	Faro [m]	iPhone 13 pro [m]	True [m]	Faro [m]	iPhone 13 pro [m]
0.60	0.598	0.583	0.80	0.796	0.789
0.60	0.597	0,579	1.60	1.596	1.648
1.40	1.497	1.385	0.80	0.798	0.807
0.80	0.798	0.776	1.60	1.599	1.584
1.60	1.598	1.646	0.80	0.799	0.790

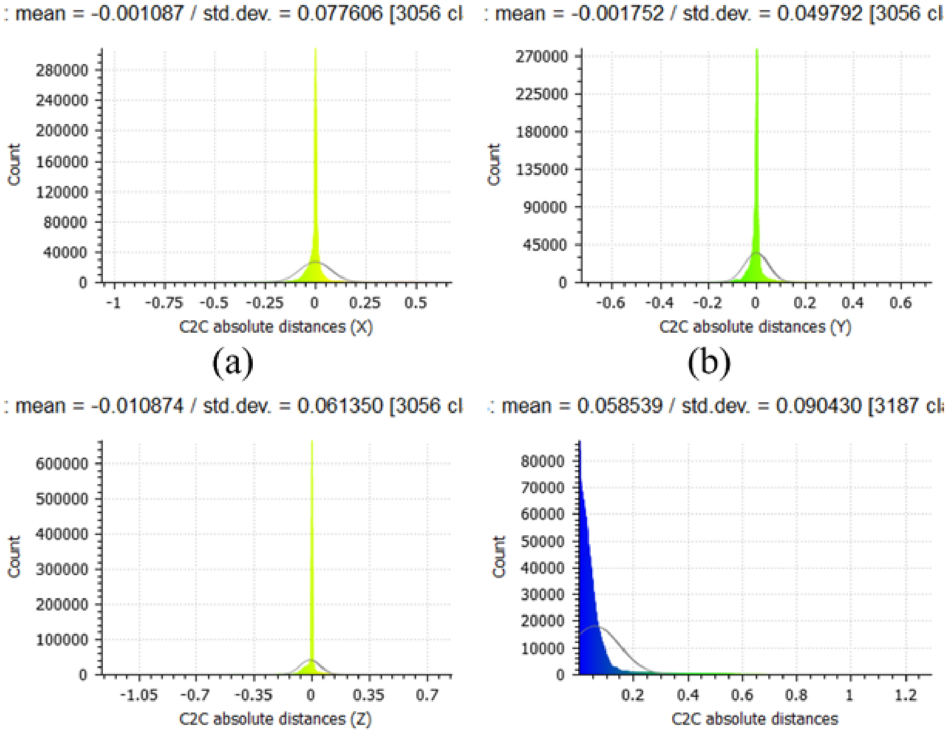
However, this type of accuracy assessment is highly influenced by operator ability to select exact points as well as point cloud density. In order to gain deeper insight in obtained results cloud-to-cloud comparison was performed. The *cloud couture* tool was used to create horizontal and vertical cross sections of the room (Figure 2). As it can be seen, Focus M 70 cross sections provide almost regular shape of room. The largest deviation of rectangular shape can be noted for vertical profile due to present object which enabled penetration of laser beam. The calculated area was 0.4% higher than true value, while the perimeter was 5% higher. On another hand, iPhone cross section resulted in irregular room shape due to higher level of noise (Figure 2.). Due to noise level the iPhone floor plan resulting in 8% larger surface area and 21% larger perimeter.



(a) (b)

Figure 2. *(a) horizontal cross section, (b) vertical cross section. Red line – Focus M70, Blue line – iPhone 13 pro*

The distance between the reference (Focus M70) and target (iPhone 13 pro) point cloud was calculate using C2C tools. The spatial distribution of the results of the C2C comparison along axes are shown in Figure 3. Mean absolute difference 6 cm with standard deviation of 10 cm. The largest absolute distance was 1.29 m. However, the visual inspection shows that there is only few point with distance larger that 0.6 m. Those points are result of the noise. Among axis, the largest standard deviation (7 cm) was obtained for X axis (Figure 3).

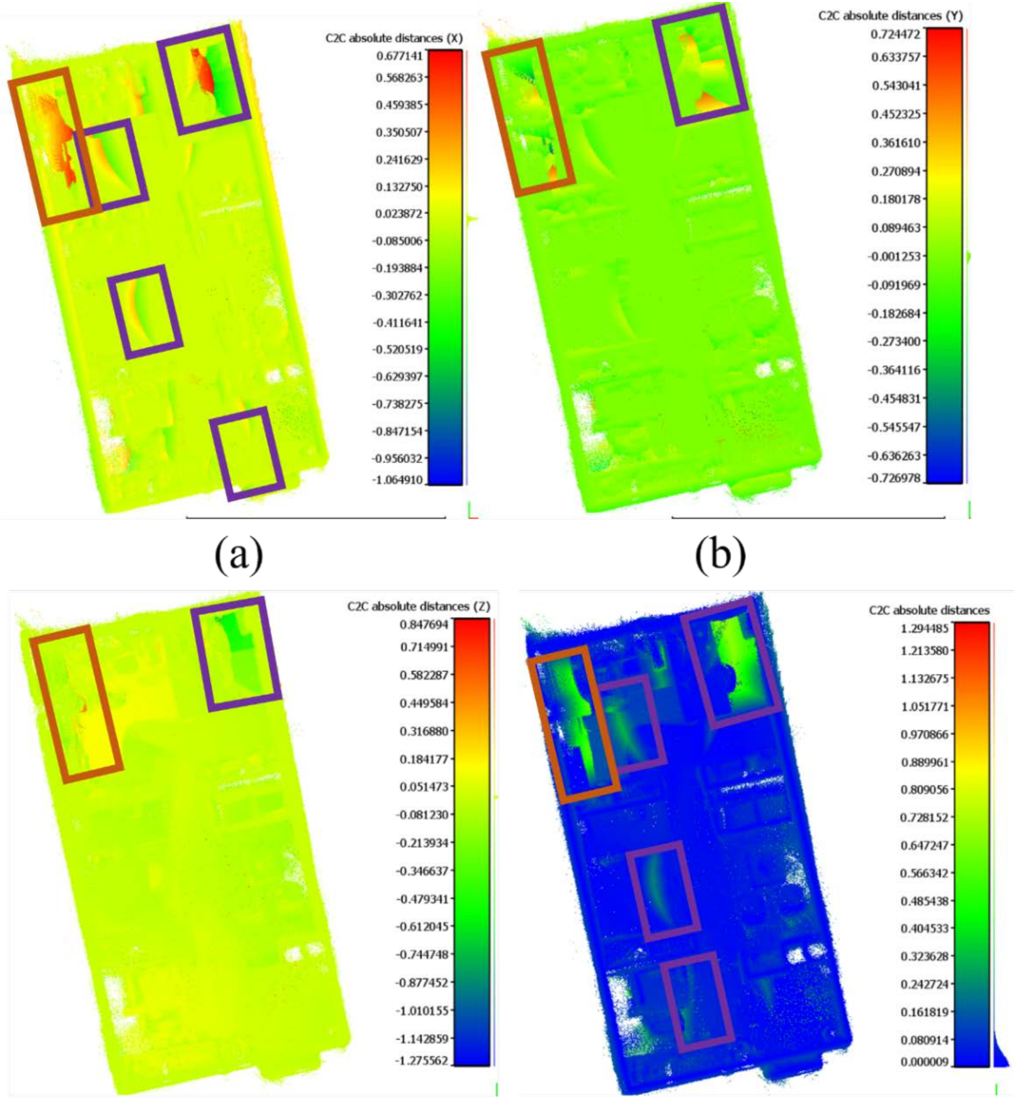


(a) (b)

(c) (d)

Figure 3. *Histogram of point distance distribution (a) along X axis, (b) along Y axis, (c) along Z axis and (d) absolute distance.*

Spatial distribution for all axis indicated that the shape of the object doesn't influence iPhone point cloud accuracy i.e. it provide stabile performance over flat and curved surfaces (Figure 4). The large difference is presented in the corners (from 0.6 m to 0.15 m) due to holes in Focus M 70-point cloud. The holes in TLS point cloud are usually caused due to limitation scanner vertical field of view and presence of object which enables the penetration of laser beam (purple rectangular).



(a) (b)

(c) (d)

Figure 4. *Spatial distribution of absolute distance between point clouds (a) along X axis, (b) along Y axis, (c) along Z axis and (d) absolute distance.*

In addition, the large difference (0.6 m to 0.15 m) were coursed due to iPhone 13 duplication of the object (orange rectangular). As it can be seen at Figure 5. Plain object such as white wall and black computer near the windows (direct sunlight source) were duplicated. Since looking only a homogeneous object (without clear detail or sharp edges) or noisy object such as carpet, for more than a couple of seconds can caused the iPhone's tracking to drift which will miss-align points [20]. Moreover, high level of noise in iPhone point cloud is coursed due to sensor limitations. VCSEL is based on time-of-flight distance measurement, meaning in order to measure distance diode need to ensure that detected photon have been emitted by laser and is not from any other source. Therefore, for the best signal to noise ratio the effect of Ambiental light need to be minimized. iPhone VCSEL uses 8xx nm wavelength. Since significant amount of radiation reaching the Earth's surface at 8xx nm the noise level can significantly increase at outdoor or indoor spaces on direct sunlight. Moreover, the TLS illuminate only one pixel at a time resulting much higher power per pixel while iPhone uses the array VCSEL designs resulting in less power per pixel compared to TLS and therefore larger noise level.

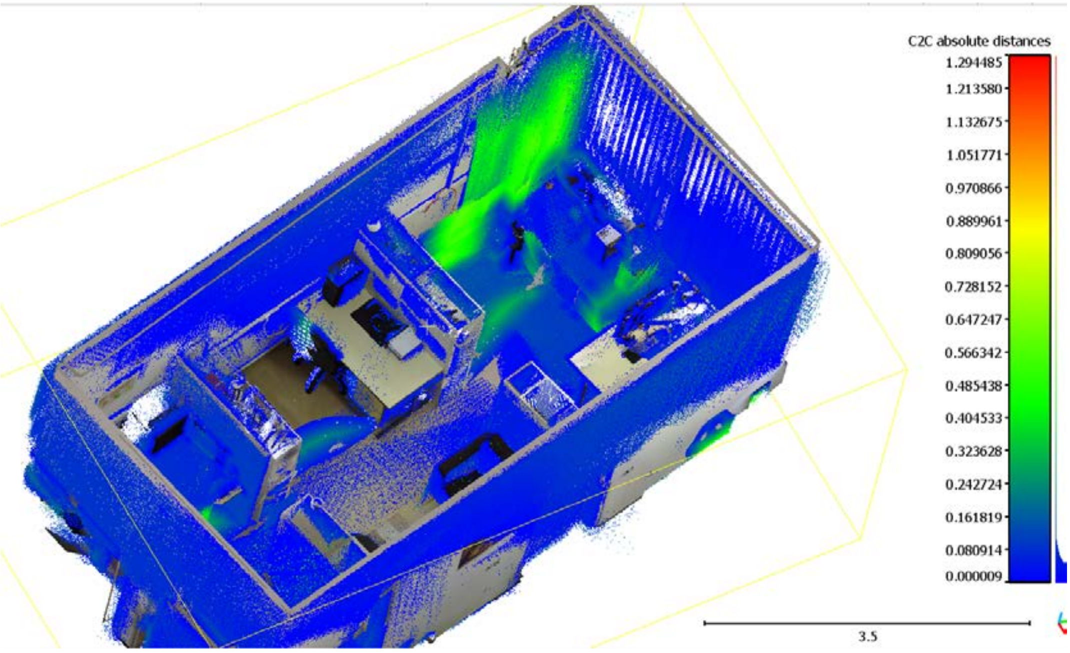


Figure 5. *Absolute distance between Focus M70 and iPhone 13 pro*

5. CONCLUSION

The increase of demand for accurate 3D indoor models in consumer, industrial and automotive markets, and therefore increasing number of applications incorporating it has led to a significant need for rapid acquisition of point clouds. This paper aims to test customer-level LiDAR devices incorporated in iPhone 13 pro. The results show that iPhone 13 pro provides a scaled point cloud with stable performance over a flat or curved surface. The mean absolute distance between iPhone and the highly accurate TLS point cloud was 9 cm. It provides an accurate point cloud over highly detailed scenes but the level of noise increases over the homogenous object. Moreover, the accuracy of the point cloud is decreased in direct sunlight causing miss-align points and drift effect. In another hand, iPhone represents the full integrated solution that provides rapid point cloud acquisition and direct export of results without post-processing. Due to its compactness and mobility, it enables a survey of hard-to-reach areas eliminating the holes and lack of data. Taking into account the price of the device (1000 vs 27 000 euros) the iPhone 13 pro LiDAR reviles the high potential for rapid, easy-to-use mapping of indoor environment whit sufficient accuracy for modeling.

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