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# APPLE iPHONE 13 PRO LIDAR ACCURACY ASSESSMENT FOR ENGINEERING APPLICATIONS

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**Abstract:** 3D modelling has become a favoured way of analyzing 3D data, where users can collect more data with high accuracies in less time than other surveying methods. Technologies capable of providing 3D data such as Terrestrial Laser Scanners (TLS) are often expensive; thus, encouraging users to seek affordable alternatives while achieving their desired accuracies. Today, mobile phones and tablets are now becoming more capable of 3D modelling, and the most recent iPhone 12/13 Pro and iPad Pro now provide an integrated LiDAR sensor. However, with no known geometric accuracies stated from Apple, curiosity towards its modelling capabilities surfaced. In this project, an accuracy assessment using an iPhone 13 Pro was performed to test for its relative (geometric precision of the device itself) and absolute (concerning surveyed control) accuracies using Modelar's scanning application. Modelar Technologies is a software development firm whose first product is *Modelar*, a real-time 3D mapping package for consumer mobile devices. Additionaly, a TLS survey was included to compare the two devices. To test and analyze Modelar's application, a surveying lab at the University of New Brunswick's Head Hall was chosen, containing a control network of sub-millimetre geometric accuracy. Results showed that with Modelar's laser scanner application, absolute accuracies of ± 3 cm horizontally and ± 7mm vertically is achieved, while also achieving a relative accuracy of ± 3 cm. These results determined that using Modelar's 3D modelling methods can benefit in certain reality capture applications where it may be deemed accurate and cost-efficient.

**Keywords: iPhone 13; LiDAR sensor; Modelar; 3D accuracy assessment; 3D modelling**

## 1. INTRODUCTION

3D modelling is becoming more useful given the amount of information available in the data, the time it takes to collect the data, and the achievable accuracies. 3D data comes at an expensive cost due to the technology capable of collecting it, technologies such as a TLS. With the technologies that continue to grow and advance in 3D modelling capabilities, handheld devices such as mobile phones or tablets have been recently showing their potential in 3D modelling.

As of 2020, Apple released the iPhone 12 Pro and iPad Pro with an integrated LiDAR sensor, purposed for Augmented Reality (AR) with no specifications on relative and absolute accuracies. Later versions of the iPhone today such as the iPhone 13 Pro also carry the integrated sensor. With no detailed accuracies of the sensor, curiosity surfaced in the geoscience community, testing the sensor's capabilities to determine its usefulness in 3D modelling applications.

To determine the accuracies of the iPhone and TLS, a dense control network in room A-17 at the University of New Brunswick Fredericton campus was utilized to compare one device with another. Room A-17 is a survey engineering lab that provides students the opportunity to perform numerous surveying practices such as baseline calibrations and control surveys in areas of limited extents. Wilkins (1989) initially established the coordinate system using industrial metrology techniques as a result of forming a portion of a nuclear accelerator. The result of the 67 targets established in A-17 were within the tolerances less than 0.1mm. Since then, the room has been continuously re-surveyed with precision surveying techniques that maintain this level of accuracy. The room provided an opportunity to test the iPhone carefully in a controlled environment where no outside influences, such as weather, would skew results. The room also provided a challenging test for the iPhone in determining how well it can identify features such as columns, pillars, and objects of various sizes.

## 1.1 Background

The project's industry partner *Modelar* created their own mobile laser scanning application that may improve timing and accuracy. With an iPhone 13 Pro, their application *Modelar – 3D LiDAR Scanner* offers a chance to explore the sensor’s characteristics using a Synchronized Localization and Mapping (SLAM) approach. SLAM is the process of mapping while the location of the moving device is known (GEO SLAM n.d.). Additionally, a TLS survey will be assessed, comparing industry standard equipment to the performance of the iPhone’s sensor. The point clouds produced by both the iPhone and TLS in A-17’s reference frame will be compared to the total station which surveyed the control network, considering it as ground truth. Recent studies have assessed the iPhone’s sensor with other devices such as a TLS or camera.

The study by Spreafico et al. (2021) assessed the iPhone by comparing it with the TLS. 5 Ground Control points (GCPs) and 4 Check Points (CPs) were set up around an area of interest outdoors. Using the *SiteScape* scanning application, the resulting absolute accuracies of the control points from the iPad scans were a Root Mean Square (RMS) error value lower than 2 cm and a standard deviation lower than 1 cm.

Razali, Idris, Nor, & Ghazali (2021) compared target line distances between a total station and TLS on various materials including wood, aluminum, glass, cement wall, and cotton canvas. The results when comparing the distances produced by each method were centimetric.

In the study done by Nagymáté, Tuchband, & Kiss (2018), a sub-millimetre triangulation control network was created to determine the absolute accuracy of a motion camera using a total station. The average standard deviation for each measurement was 0.4 mm. After processing, the uncertainty of the control network was 0.75 mm.

In a different study performed by Abd-Elmaaboud et al. (2019), an accuracy assessment of the TLS was completed and compared to other traditional surveying instruments such as a total station and RTK-GPS. The results found that the Root Mean Square Error (RMSE) for the TLS in measuring terrains was about 15 cm. In vertical cut measurements, the TLS achieved a RMSE of 6 mm, performing better timewise than other instruments.

With a precise control network established in A-17, absolute accuracies of the TLS and iPhone can be determined, comparing them to the coordinates produced by the total station, considering it as ground truth.

Additionally, this study will also compare the target line distances between different CPs, also using the total station as ground truth when assessing the TLS and iPhone.

## 2. METHODOLOGY & FIELD WORK

### 2.1 Control Survey

Using room A-17 to establish GCPs and CPs ensured that all the coordinates would be in the same reference system and based off a reliable network. 24 Checkerboard targets were set up at different heights and positions around room A-17. This was to ensure that different depths were used to exclude correlated errors in the assessment. Figure 1 below shows the network targets and checkerboard targets used.

Figure 1: High precision network target (left), checkerboard target (right)

Establishing the checkerboard targets was done by performing resections and intersections using the high precision network's targets. This precision surveying technique used is called *triangulation*, a surveying method that only involves angular measurements. It was the best approach to obtain high accuracies without the use of Electronic Distance Measurements (EDM). Precise EDM's require specialized equipment (e.g., laser trackers), which was not accessible at the time of the survey. In this case, the Trimble S9 total station was used, which has an angular accuracy of 0.5 arc seconds.

The instrument setups were pre-planned to ensure that intersecting rays would be capable of determining the positions of interest. Simply, it made sure that the instrument was placed so that intersecting rays would resemble a 90-degree angle. To guarantee quality results, every target visible from each instrument setup was recorded; this means that measurements outside the ± 10 arc second threshold between face left and face right were not accepted. As a result, the checkerboard accuracies were below 1 mm quality after a least squares adjustment.

### 2.2 iPhone Survey

As explained in Section 1.1, SLAM allows mapping to occur while the device is moving. The measuring range depends on the depth of the sensor, which for the iPhone has a maximum range of 5 m. Apple does not provide any further information on the LiDAR sensor apart from depth. However, Gollob et al. (2021) discovered through reverse engineering that the LiDAR sensor consists of an emitter (vertical-cavity surface emitting laser with diffraction optics element, VCSEL DOE) and a receptor (single-photon avalanche diode array-based near infra-red complementary metal-oxide-semiconductor image sensor, SPAD NIR CMOS). With the wide and ultrawide camera module, colorized 3D models can be created (Gollob, et al. 2021).

Using the Modelar laser scanning application, five separate passes around room A-17 using the iPhone 13 Pro were conducted, taking approximately 8 minutes with each pass, ensuring complete coverage of the room. The passes were done at the standard (22500 pts/frame) point density. Modelar only captures a new frame when the devices register sufficiently large angular or positional displacements. Approximately 57 million points were collected in total. The coloured 3D point cloud was exported in PLY format. The result of the uncorrected model of A-17 is shown in Figure 2.

Figure 2: Uncorrected model of A-17 from Modelar

### 2.3 Terrestrial Laser Scanner Survey

A Trimble TX5 TLS was used for the accuracy assessment. The TLS was stationed around the room in locations where at least three targets could be seen from two different setups. Figure 3 displays the TLS setups from S1 to S7 and the checkerboard targets placed with the numbering format *P####*. The TLS was set up using a 10 m profile and the 360-degree dome feature, allowing for full visuals of the room. The vertical and horizontal scans were set at a resolution of 10,240 x 4,239 points, setting the scan size to be 43.4 mega points at a point distance of 6.136 mm/10m.

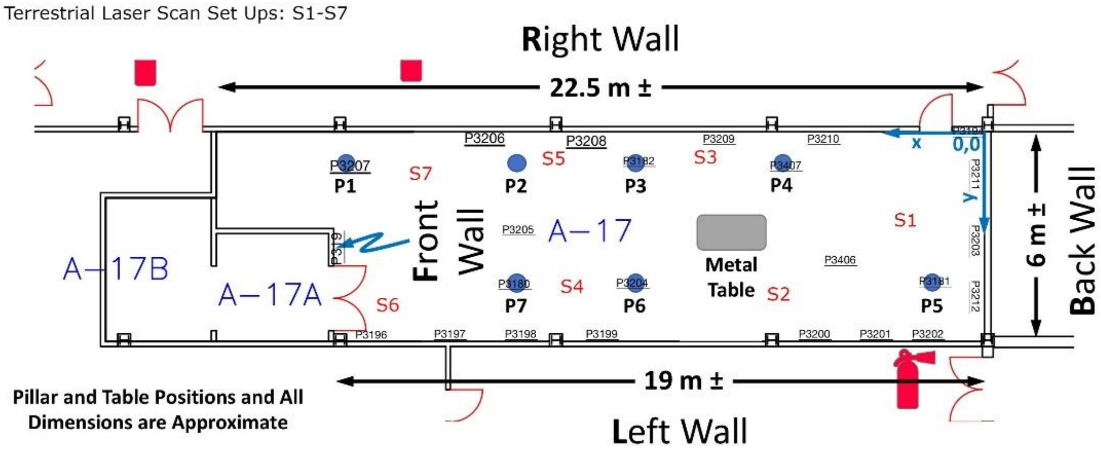

Figure 3: Terrestrial laser scanning setups, checkerboard target locations

## 3. PROCESSING

### 3.1 iPhone

The iPhone LiDAR processing was completed using Modelar's own software. The point clouds were corrected using an iterative optimization algorithm that adjusts the camera positions estimated by the phone's SLAM system. The optimization algorithm attempts to converge to a threshold by minimizing the differences between the estimated and surveyed control point positions while considering the successive camera positions that were estimated by the SLAM system. This allows the positions of the control targets to be identified during the scan to match their defined surveyed positions. The scan started and ended near P3206 in a closed loop format, like a traverse loop. Loop closures are helpful in path optimization because they can be used to prove that the camera parameters at two different times are strongly related. It is possible to perform loop closure optimization without the need to provide ground control points. This can be done by detecting times in the scan when the device is looking at the same object using CV techniques and computing the relative camera parameters using ICP. The scan path was optimized using control points P3206, P3196, P3407, P3182 and P3206. Once this step was complete, the full point cloud was exported to a PLY format. A complete workflow can be seen below in Figure 4.

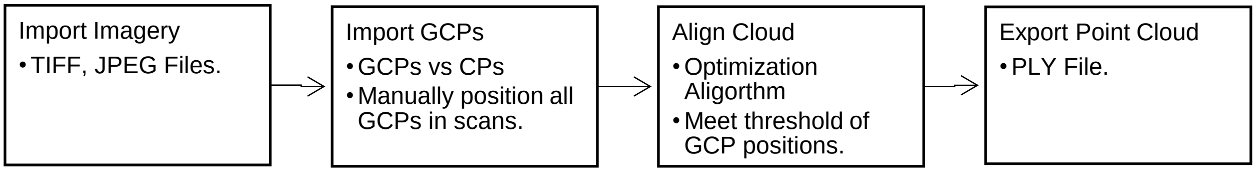

Figure 4: iPhone LiDAR Processing Workflow

## 4. POINT CLOUD ANALYSIS

Both the TLS and iPhone’s point clouds were assessed with the help of *CloudCompare*. Figure 5 shows the workflow followed in CloudCompare when assessing the point clouds. Additionally, Microsoft Excel was used to aid in calculations with the information obtained from CloudCompare.

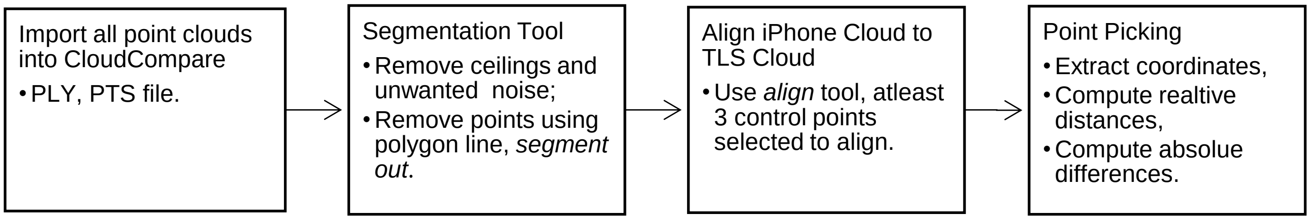

Figure 5: Workflow followed in CloudCompare

The first task was to import the two point clouds into CloudCompare. Figure 6 below shows both imported, unedited point clouds. In order to assess the absolute accuracies, both point clouds had to be in the same reference frame. Upon importing, the iPhone point cloud was flipped sideways relative to the TLS point cloud, which was in the A-17 reference frame.

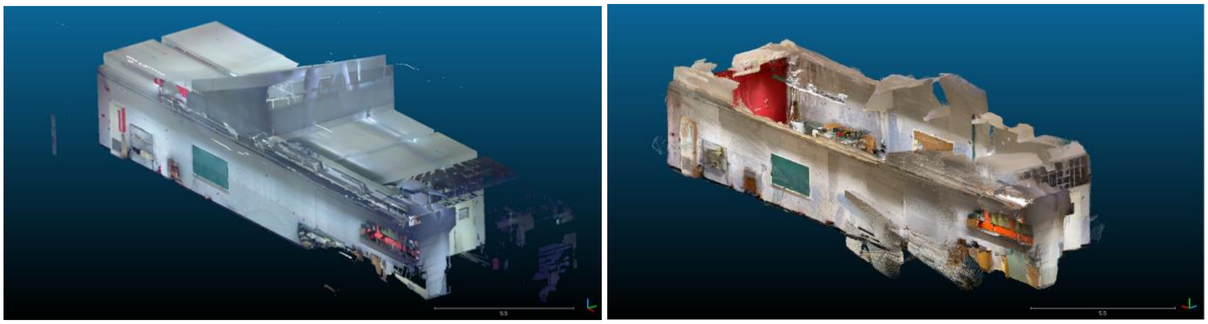

Figure 6: Unedited point clouds of A-17. TLS point cloud (left) and Modelar’s iPhone point cloud (right)

Next, both point clouds needed cleaning to easily see inside room A-17 to manually identify control points. The ceilings were removed since no control points were placed there using the *segment* tool. Further, it improved the performance of the software because it reduced the size of point clouds. Figure 7 shows the results of the cleaned and segmented clouds.

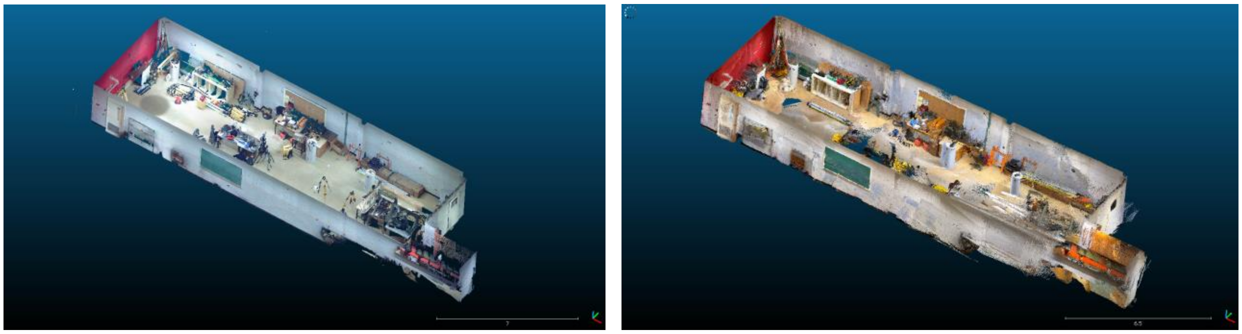

Figure 7: Segmented point clouds of A-17. TLS point cloud (left) and Modelar's iPhone point cloud (right)

The relative accuracy assessment within CloudCompare was done by measuring the distances between different CPs on different walls. The points that were already picked with the *point picking* tool were used in Microsoft Excel to calculate the euclidean distances between the control points using Eq.1:

$$d = \sqrt{|x_2 - x_1|^2 + |y_2 - y_1|^2 + |z_2 - z_1|^2} \qquad \text{(Eq. 1)}$$

*Where:*
$d$ *= distance in m between two control points.*
$x_1$,$x_2$*= x coordinates of control points 1 & 2.*
$y_1, y_2$ *= y coordinates of control points 1 & 2.*
$z_1, z_2$ *= z coordinates of control points 1 & 2.*

The idea of the relative accuracy assessment is to assess the geometric precision of the sensors and to use identifiable features in the point cloud (in this case, the checkerboard targets) to compare the distances made with the distances measured by the total station. The difference in distances between each check point were assessed by taking the Root Mean Square Error (RMSE) to measure the overall accuracy of the point cloud itself, without concern of its true position. The RMSE was calculated using the following Eq. 2:

$$RMSE = \sqrt{\sum_{i=1}^{n} \frac{(X - X_i)^3}{n}} \qquad \text{(Eq. 2)}$$

*Where:*
$X = true\ value.$
$X_i = The\ individual\ measurements.$
$n = the\ number\ of\ observations.$

For the absolute accuracy assessment, coordinates were obtained from each check point in each point cloud, then compared with the coordinates produced by the total station. The difference of coordinates was then assessed by taking the RMSE of each coordinate to measure overall accuracy of the point cloud in the A-17 coordinate system.

## 5. RESULTS

Prior to assessing the iPhone’s accuracies, the point cloud needed to be aligned over the TLS point cloud in order to be in the same coordinate system. This was done in CloudCompare using the *align* tool. A minimum of 3 control points from each point cloud had to be selected in order to align the point clouds together. Table 1 shows the three points used to align both clouds and its RMS errors indicating how well the points fit between both clouds. The result of the alignment was millimetre accuracy indicating an accurate fit. It is important to note that a scale factor of 1 was fixed so that the iPhone’s cloud could keep its original shape for a proper assessment.

Table 1: RMS error after aligning Modelar’s point cloud to the TLS point cloud

| Point | RMS Error (m) |
|---|---|
| P3202 | 0.0040 |
| P3181 | 0.0039 |
| P3196 | 0.0003 |
| Final RMS Error (m) | 0.0033 |

An absolute assessment can be done now that the iPhone point cloud is in A-17’s reference frame. Table 2 and the bar graph below (Figure 8) shows how well each point cloud performed when comparing the check points to the total station. The check points used spread throughout room A-17 were P3194, P3198, P3200, P3202, P3208, and P3211. The TLS performed as expected with low mm accuracy, proving why they are the industry leading technology in 3D modelling.

Table 2: CP coordinate differences and average RMS errors of CP coordinates

| Point | TS vs. TLS | | | TS v. iPhone | | |
|---|---|---|---|---|---|---|
| | Δx (m) | Δy (m) | Δz (m) | Δx (m) | Δy (m) | Δz (m) |
| P3194 | 0.0004 | 0.0021 | 0.0044 | 0.0092 | 0.0475 | 0.0041 |
| P3198 | 0.0004 | 0.0012 | 0.0013 | 0.0347 | 0.0311 | 0.0033 |
| P3200 | 0.0016 | 0.0011 | 0.0018 | 0.0363 | 0.0217 | 0.0076 |
| P3202 | 0.0035 | 0.0019 | 0.0042 | 0.0023 | 0.0075 | 0.0113 |
| P3208 | 0.0026 | 0.0006 | 0.0014 | 0.0485 | 0.0176 | 0.0080 |
| P3211 | 0.0023 | 0.0047 | 0.0026 | 0.0015 | 0.0213 | 0.0036 |
| RMS errors (mm) | 2.1 | 2.3 | 2.9 | 28.8 | 27.4 | 7.0 |

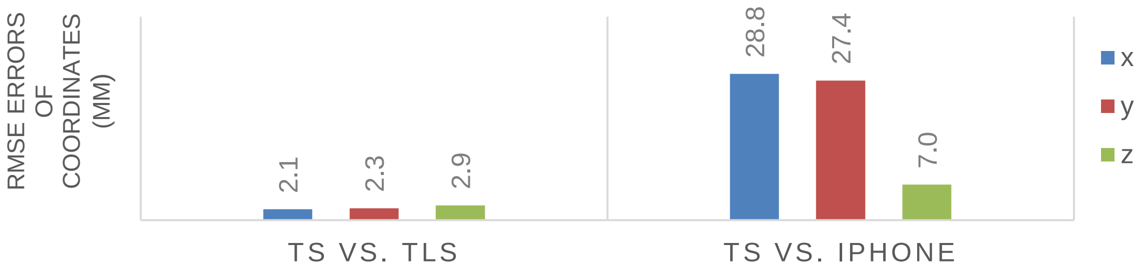

Figure 8: Average RMSE of Coordinates (mm)

The iPhone produced an average RMSE of 3 cm in the x and y coordinates and achieving an average RMSE of 7 mm in the z coordinate. Because the targets were the easiest features to identify, the relative accuracy assessment can also be done using the same CPs. A total of 15 distances were measured as shown in Figure 9.

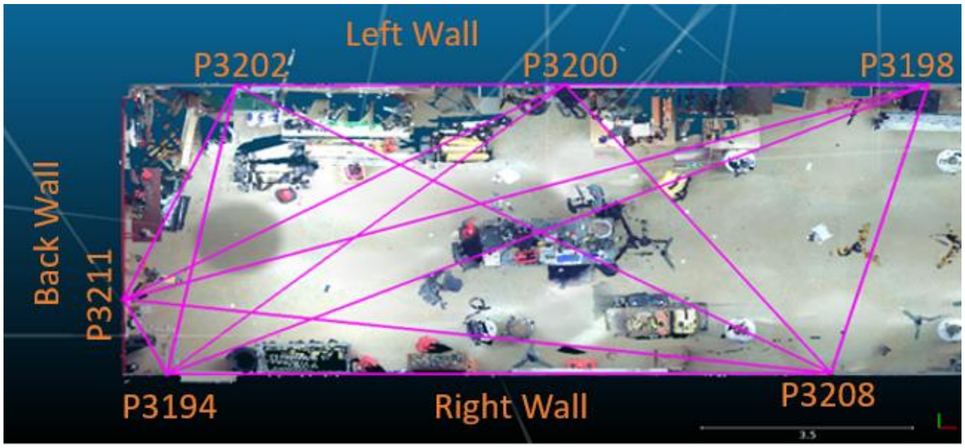

Figure 9:1 Relative distances between common check points

The distances from Modelar's iPhone point cloud were then compared to the distances measured by the total station, considering them as true values. Figure 10 and Table 3 below show the RMSE of the relative distances between CPs computed by the coordinates produced by the TLS and iPhone.

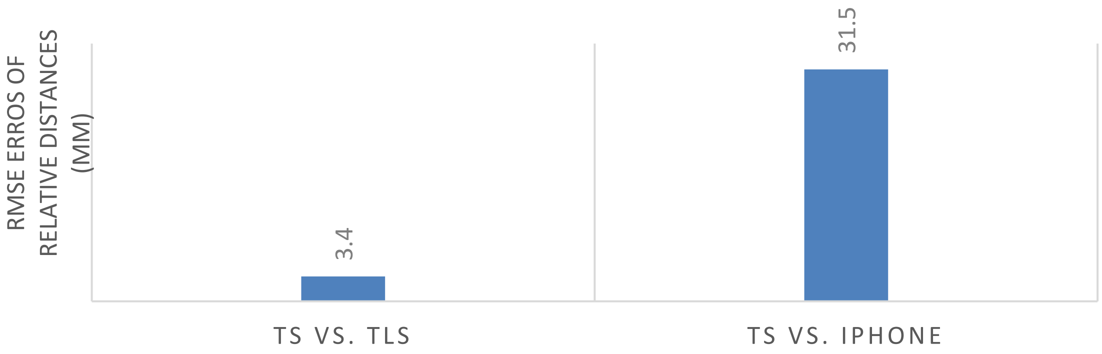

Figure 10:2 Average RMSE of Relative Distances (mm)

Table 3: Relative distance differences and RMSE of differences

| Points | | Distance (m) | | | Difference (m) | |
|---|---|---|---|---|---|---|
| From | To | TS | TLS | iPhone | TS vs. TLS | TS vs. iPhone |
| P3194 | P3198 | 13.9323 | 13.9333 | 13.9217 | 0.0010 | 0.0106 |
| P3194 | P3200 | 8.9250 | 8.9258 | 8.8994 | 0.0008 | 0.0256 |
| P3194 | P3202 | 6.1394 | 6.1427 | 6.0856 | 0.0033 | 0.0538 |
| P3194 | P3208 | 11.0363 | 11.0385 | 11.0762 | 0.0022 | 0.0399 |
| P3194 | P3211 | 1.9907 | 1.9886 | 1.9689 | 0.0021 | 0.0218 |
| P3198 | P3200 | 5.9856 | 5.9867 | 5.9839 | 0.0011 | 0.0017 |
| P3198 | P3202 | 11.4146 | 11.4177 | 11.4470 | 0.0031 | 0.0324 |
| P3198 | P3208 | 6.2205 | 6.2216 | 6.1714 | 0.0011 | 0.0491 |
| P3198 | P3211 | 13.9891 | 13.9928 | 14.0041 | 0.0037 | 0.0150 |
| P3200 | P3202 | 5.4290 | 5.4309 | 5.4630 | 0.0019 | 0.0340 |
| P3200 | P3208 | 7.4303 | 7.4342 | 7.4060 | 0.0039 | 0.0243 |
| P3200 | P3211 | 8.5265 | 8.5302 | 8.5338 | 0.0037 | 0.0073 |
| P3202 | P3208 | 11.4920 | 11.4984 | 11.5183 | 0.0064 | 0.0263 |
| P3202 | P3211 | 4.7998 | 4.8054 | 4.7730 | 0.0056 | 0.0268 |
| P3208 | P3211 | 11.7634 | 11.7678 | 11.8109 | 0.0044 | 0.0475 |
| RMSE (mm) | | - | - | - | 3.4 | 31.5 |

## 6.0 DISCUSSION & CONCLUSION

Overall, the accuracy assessment on the iPhone provided additional insight into its capabilities, showing interesting results. An alignment onto A-17's reference frame permitted an assessment of the cloud's absolute accuracies, achieving accuracies between 7 mm and 3 cm. With relative accuracies achieving a RMSE of 31.5 mm, the potential the iPhone has in some applications should be considered using Modelar's laser scanning application. With only a distance range of 5 m, the iPhone is limited to smaller scale projects, much like this project performed in A-17 where the room was approximately 22 x 6 m in size. Projects such as leases, where obtaining the total area of floor space may be possible with these accuracies; Building Information Modelling (BIM) in certain cases may find the iPhone useful in generating datasets in places with easily identifiable features such as large pipes, columns, pillars, poles, etc.; and small volume surveys, where for example obtaining a 3D model of a pile of material would be easy using the iPhone.

With this sensor still relatively new, the potential it has to improve is without question, especially using Modelar's laser scanning application. The optimization algorithm had trouble when using more than 5 control points, which may be a bug in Modelar's optimization algorithm. Eventually, overcoming this issue to allow more control points to be used in the optimization may improve the results. Additionally, the visual captures of the GCP's may have introduced some error since the selection of each point was done while performing each pass and tapping on the screen where the GCP was located. Future iterations of Modelar's software should introduce an adjustment to fit the marker centre when post-processing.

Future accuracy assessments of the iPhone could improve the results further. Using CloudCompare only allowed to manually pick the centre of each target. Other point cloud handling software's that use template matching algorithms could help to automatically detect the centre of targets with higher confidence and accuracy, therefore outputting better results in absolute and relative accuracies. Even with these matters, there was still a success in exploring the capabilities of the iPhone's LiDAR sensing, and what it can potentially bring to the reality capturing industry.

## 7.0 ACKNOWLEDGEMENTS

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We would also like to thank Greg Smith for his help in providing all the equipment and supplies needed for fieldwork on the UNB campus. Likewise, we would also like to thank David Fraser for providing access to us to software programs that aided in the processing and assessment. Thank you to our faculty mentors Dr. Shabnam Jabari and Dr. Robert Kingdon for all the guidance and advice on your respective areas of photogrammetry, terrestrial laser scanning, control surveying, post-processing, and accuracy assessments. All the help this team received throughout the project is greatly appreciated.

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