Relative Accuracy of Mobile Device Reality Capture

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SUMMARY

The past five years has seen an exponential rise in the availability and adoption of mobile device reality capture solutions. The applications leverage in-built LiDAR and camera sensors to produce visually rich 3D models of small, localised areas. While using mobile devices provides a simple efficient method of capturing data, surveyors are often on the side of caution due to uncertainties regarding positional accuracy. Advancements in RTK rover receivers have significantly improved providing centimetre absolute accuracy although there is still ambiguity when determining relative accuracy between points. Typically, in photogrammetry, relative accuracy ranges between 2-3x the GSD (Ground Sampling Distance) however with the inclusion of LiDAR and non-linear sensor movement further analysis is required. As adoption of reality capture increases, this study aims to determine the relative accuracy of mobile devices when compared with traditional methods and highlight potential factors to consider.

A 4x3 grid of structural monitoring points were installed on a masonry wall to allow for relative comparison of set points along the structure, coupled with wider point cloud analysis. Primary Data for analysis was collected using the Emlid Reach RX, with Pix4D Catch utilising GNSS and RTK modes at three proposed camera locations, 1, 2, and 3 meters away from the structure. Secondary Control data for comparison was captured utilising a TOPCON MS05 AX monitoring station for high precision coordinates, and TOPCON GLS-2000 LiDAR scan for point cloud comparison.

Photogrammetry data processing was conducted utilising primarily Pix4D Matic and Epic Games Reality Scan for comparative data. Created models underwent manual selection of coordinates within subsequent models, allowing for relative accuracies of coordinates between different methods. Coordinate differences were measured and compared with all platforms across the 4x3 grid, with distances ranging from 200-1050mm in horizontal and vertical planes to determine any discrepancies in accuracy. Further cloud-to-cloud analysis was undertaken on cloud-to-cloud volumetric changes, measurement of model deformation, and the impact of GSD on the overall relative accuracy of outputs.

The results showed a consistent sub-centimetre accuracy across all marked points and average relative distances across samples to be between 0.5-3mm across all testing methodologies. Wider point cloud analysis indicated some section loss across mobile device solutions, with

some model deformation noted, particularly in GNSS samples and further disparity of results utilising different processing solutions.

Comparative Study of Relative Accuracy of Mobile Device Reality Capture

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1. INTRODUCTION

The use of mobile device reality capture is experiencing accelerated growth partially attributed to their accessibility and affordability when compared with survey grade instruments. Coupled with a compact RTK receiver such as the Emlid RX Reach, small localised areas can be surveyed with ease with minimal training or equipment calibration. Furthermore, Suppliers claim centimeter absolute positional accuracy, enticing surveyors and contractors alike to integrate these solutions into their workflows.

Due to the infancy of the technology, minimal research has been conducted into the overall accuracy of a mobile device and relative accuracy remains insufficiently explored. As adoption continues to grow and reality capture replaces traditional methods, confidence in the accuracy of the deliverables is vital to it's success. Therefore, it is important to understand the achievable relative accuracy of a model and the enviromental factors that may affect performance. By informing the industry on both strengths and limitations, professionals will have the knowledge to leverage this technology and tailor it to their requirements.

Through a controlled field experiment, this study aims to evaluate the relative accuracy and precision of both GNSS and RTK mobile device surveys at various distances and identify potential affecting factors to be considered in the future. All data was obtained using an iPhone 12 Pro and Emlid RX Reach Rover using the Pix4D Catch application and processed in Pix4D Matic. All points of interest were surveyed using a Topcon MS05AX creating a baseline data set for direct comparison.

This study provides a detailed analysis of mobile device relative accuracy when compared with traditional surveying techniques, providing an understanding of relative accuracy capabilities. Furthermore, this research shall provide practical insights on capture methods and environmental factors by analaysing the effect of proximity to an area of interest and vertical surface generation. This paper is organised as follows: Section 2 explains the methodology including site location and data capture, section 3 details data presentation and post processing, section 4 details the analysis of the results and section 5 concludes with technical considerations, industry application, limitations and recommendations for future research.

2. METHODOLOGY

For this study, an iPhone 12 Pro was selected as the mobile device due to the integrated LiDAR sensor and compatibility with the software. To facilitate GNSS RTK, the device was coupled with an Emlid RX Rover Receiver receiving corrections from an RTK network provider. The surveys were conducted using the Pix4D Catch application, producing 3 data sets for both RTK and standard GNSS. All data including the baseline survey was obtained during one day to mitigate movement of the control points due to environmental factors.

2.1 Survey Site

A masonry wall at the University of Derby was selected due to the number of variables that could be controlled. The site is accessible only by university staff and students allowing ease of access and minimal disruption during the survey. A strong mobile data signal and view of the visible hemisphere was also available maximising the capabilities of the RTK receiver. When tested prior to the survey, the device displayed RTK positional errors of <30mm, which is to be expected from a Network RTK connection. By reducing the positional errors in the raw data, the processing software will require less adjustment of the cameras position improving the accuracy of the model.

To compare relative distances, 12 DEMEC discs used in masonry and structural monitoring, were installed on the wall in a 4x3 grid (Figure 1) using a strong adhesive, to act as POI's (Points of Interest) for relative monitoring. The grid was created with an approximate 350mm and 200mm spacing in the horizontal and vertical planes respectively to align with the centre of a brick. Each DEMEC disc was 6.1mm in diameter with a domed head and 1mm centre hole, ideal for producing a sub-millimetre accurate baseline data set for this study.

2.2 Total Station Survey

To obtain accurate distances for the baseline data set, a Topcon MS05AX monitoring station was selected due to its availability and high level of accuracy. The instrument has an angular accuracy of 0.5" and can measure to 0.0001m providing sub-millimetre measurements between the control points.

For the survey, the instrument was positioned approximately 1.5m from the masonry wall central to the control grid. All measurements were taken from an arbitrary position using the survey basic function as absolute positioning was not required for this study. Each POI's data set comprised of 3 sets of face left and face right readings including horizontal/vertical angles and slope distances. This mitigated the risk of any poor or incorrect readings from the surveyor as averages could be taken identifying any anomalies in the data set. Furthermore, the surveyor recorded all observations with a camera to minimise errors during data entry.

2.3 Mobile Device Data Capture

For each scan with the mobile device, the surveyor used the Pix4D Catch application leveraging both the inbuilt LiDAR and wide lens camera to capture the data. To reduce human error, the application automates the capture of images based on the overlap parameter and number of common features in the field of view. To maintain consistency, each survey was conducted with an 80% image overlap, which is common practice for photogrammetry.

To conduct each survey, the device was held from a stationary position moving in an orbital motion to capture a 360º view of the area. Prior to the survey, 4 GCPs (Ground Control Points) were placed around the perimeter of the 3 proposed capture locations. Each GCP was non-registered with the purpose of providing additional tie points rather than global positioning. The inclusion of GCPs and a wider field of view will provide the software with additional common features, aiming to improve the geometry and scale of the models.

Six surveys were conducted using the Pix4D Catch method to analyse the impact of both device positional accuracy and distance from the control points. 3 stationary points were marked 1, 2 and 3m away from the control grid and a data set was produced for RTK and standard GNSS. As the distance increases from the wall the Ground Sampling Distance (GSD) will increase effecting the detail and accuracy of the model. Typically, the relative accuracy of a photogrammetry survey is 2-3x the GSD value however with the inclusion of LiDAR this may be improved.

2.4 Terrestrial LiDAR Scan

Although total stations have the capability for <1mm accurate measurements, they lack the ability to produce 3D reality data. Therefore, to determine relative accuracy when compared to points captured within a model, a secondary baseline data set would be required using a terrestrial LiDAR scanner. A Topcon GLS-2000 Laser scanner with a surface accuracy of ±2mm was positioned in a similar location to the total station producing a 360º scan of the environment. Coordinates could then be extracted from the point cloud for analysis.

2.5 Data Processing

Processing of data utilised multiple tools due to signifcant differences in data analysis methods along the POI's or wider wall and utilising the multi-modal comparisons of RealityCapture, Total Stations, and LiDAR models.

2.5.1 Pix4D Matric

The photogrammetry processing software was Pix4D matic, due to integration with the Pix4D catch software used for the data collection and ability for further multi-modal integration including LiDAR data for further aspects of the paper. All 6 models were processed utilising the same parameters to create, a mesh and dense point cloud, which was used for later identification of POI's and quality reports exported for further analysis of GSD's and overall point cloud quality.

Dense point clouds and mesh models were utilised to identify the POI’s within the model (Figure 1) and points were selected, based on the centre-most point of the POI within the area containing the DEMEC discs, or the holowed centre point (if visible on closer point clouds). Coordinates were then tabulated for each POI (Table 1), for furhter analysis of relative differences within Microsoft Excel.

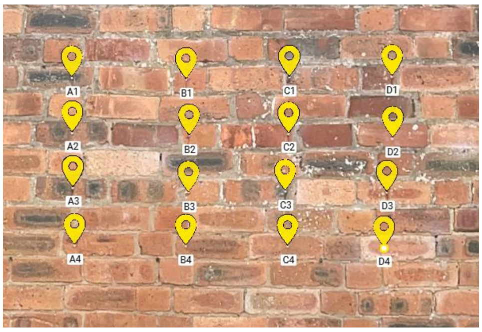

Figure 1 Pix4D Matic MESH with POI's Identified

Table 1 POI Example Co-Ordinates

POI Ref	X (m)	Y (m)	Z (m)
A1	600903.4510	5865384.1630	109.0550
A2	600903.4530	5865384.1750	108.8730
A3	600903.4500	5865384.1790	108.6960
A4	600903.4470	5865384.1860	108.5090
B1	600903.1510	5865384.3940	109.0520
B2	600903.1470	5865384.4060	108.8680

<u>2.5.2 Excel Processing</u>

Relative differences between pointd were calculated utilising a distance formula shown within Equation 1.

$$D = \sqrt{(x_2 - x_1)^2 + \ (y_2 - y_1)^2 + (z_2 - z_1)^2} \quad (1)$$

Equation 1 Distance Between Two Points

With data from the above equation, a pairwise distance matrix between all points was created (Table 2) for each of the six mobile device capture clouds, LiDAR cloud, and total station co-ordinates.

Table 2 1m GNSS Pairwise Distance Matrix

	A1	A2	A3	A4	B1	B2	B3	B4	C1	C2	C3	C4	D1	D2	D3	D4
A1		0.1815	0.3588	0.5479	0.3802	0.431	0.537	0.664	0.7109	0.7309	0.7903	0.8915	1.0335	1.0552	1.0853	1.1516
A2			0.1773	0.3664	0.4118	0.3814	0.4256	0.5199	0.7268	0.7004	0.717	0.7875	1.042	1.0293	1.0304	1.0705
A3				0.1891	0.5099	0.4141	0.3773	0.4118	0.7866	0.7183	0.6884	0.7193	1.0833	1.0377	1.0092	1.0197
A4					0.6527	0.5132	0.4129	0.3629	0.886	0.7828	0.7078	0.6911	1.1563	1.0796	1.0209	0.9982
B1						0.1803	0.3644	0.5392	0.3308	0.3718	0.482	0.6286	0.6533	0.6836	0.736	0.8325
B2							0.1841	0.354	0.381	0.3201	0.365	0.4779	0.6804	0.6514	0.6659	0.7246
B3								0.1754	0.4922	0.3707	0.3115	0.3621	0.7442	0.6709	0.6321	0.6494
B4									0.6401	0.4905	0.3677	0.3282	0.853	0.7448	0.666	0.6353
C1										0.1836	0.3688	0.545	0.3226	0.3814	0.4829	0.626
C2											0.1852	0.3614	0.3735	0.3291	0.3644	0.4757
C3												0.1766	0.4967	0.3773	0.3208	0.3615
C4													0.635	0.4785	0.3593	0.3071
D1														0.1979	0.3701	0.5477
D2															0.1727	0.3502
D3																0.1776
D4																

2.5.3 Cloud to cloud

All point cloud analysis was conducted using Leica Cyclone 3DR, maintaining consistency and precision across the study. Both the GNSS and RTK data sets were assessed independently followed by a direct comparison of the 1m point clouds. Although RTK was used in this study, significant positional discrepencies were exhibited between each of the models requiring realignment to the GCP's using the N-Point Registration tool. All point clouds were then cleaned, isolating the wall from the rest of the model preparing the data for cloud – cloud analysis.

Point clouds within each file underwent cloud – cloud analysis using the in-built feature in the software. The baseline for this analysis was the 1m data sets due to the quality of the model and minimal noise. To further improve this process, the force projection tool allowed for the analysis to focus on deviations in the direction perpendicular to the wall. The result for each process was a highly detailed heat map and deviation graph highlighting vertical discrepencies across the surface of the wall.

2.5.4 GSD Calculations

During the photogrammetry process, average GSD values were calculated and logged in the quality report however this encompassed the entire site. To understand the effect of GSD at set distances, further calculations were required to a higher precision. Using Equation 2 and the devices camera parameters, a python program was written to calculate the GSD at each measured distance from the wall. The result was a more accurate value that would further complement the analysis.

$$GSD = \frac{S}{N} * \frac{D * 1000}{f} \; mm/pixel \qquad (2)$$

Equation 2 Ground Sampling Distance Equation

Where:

S/N - Pixel pitch: The physical sensor width (4.992 mm) divided by the image width (1920 px) gives a pixel pitch of 2.6 µm (0.0026 mm) per pixel.

D*1000 - Distance conversion: Distances were 1 m, 2 m and 3 m from the wall. Distances were converted to millimeters by multiplying by 1000.

***f* - Optimized focal length:** The focal length values from the quality reports were used.

3. DATA PRESENTATION

3.1 Excel Sheet

Across the excel comparisons, the total station data was utilised as a datum for comparison of discrepancies in differences, due to the greater accuracy and precision of this data. Both GNSS and RTK measurements at the three distances each followed the process below, to allow for analysis of the same method.

<u>3.1.1 Distance Matrix Comparisons</u>

Discrepancies in differences between the surveys are compared based on the pairwise distances matrices of the total station data and each mobile capture pairwise matrices giving, with differences between points showcased within a new matrix (Table 3). Averages and standard deviations of all datasets are calculated in both absolute and non-absolute formats and tabulated.

Table 3 Distance Discrepancies Matrix for Mobile Capture 1m GNSS to Total Station

	A1	A2	A3	A4	B1	B2	B3	B4	C1	C2	C3	C4	D1	D2	D3	D4
A1		0.0009	0.0006	-0.0014	-0.0016	-0.004	0.0005	-0.0015	0.0061	0.0029	0.0008	-0.0013	0.0072	0.0055	0.0036	0
A2			-0.0002	-0.0022	0.002	-0.0033	0.0019	-0.0007	0.0093	0.0044	0.0038	0.0006	0.0096	0.0085	0.0057	0.002
A3				-0.0019	0.0023	-0.0032	0.0019	-0.0004	0.0094	0.0035	0.005	0.0014	0.009	0.009	0.0055	0.0023
A4					-0.0002	-1E-04	-0.001	-0.0021	0.0066	-0.0001	0.0035	1E-04	0.0057	0.0068	0.0029	0.0006
B1						0.004	0.003	0.0019	0.0077	0.0059	0.0017	0.0008	0.0088	0.0071	0.006	0.0023
B2							-0.001	0.003	0.0051	0.0067	-0.0006	0.0009	0.0038	0.0084	0.0003	0.0005
B3								-0.001	0.0079	0.0008	0.0031	-0.0013	0.0068	0.0074	0.0035	0.0002
B4									0.0077	0.0004	0.0062	0.0022	0.007	0.0091	0.005	0.0028
C1										0.0076	0.0004	0.0021	0.0012	0.0006	0.0026	1E-04
C2											-0.007	-0.0054	0.006	0.004	1E-04	-0.0043
C3												0.0015	0	0.0029	0.0005	-0.0006
C4													0.0017	0.0054	0.0012	0.0006
D1														-0.0039	0.0013	-0.0011
D2															0.0053	0.003
D3																-0.0023
D4																

For each distance discrepancy matrix standard mean averages and absolute mean averages were calculated, alongside standard deviations to determine discrepancies across the entire wall and results for all methods tabulated, as shown in Table 4.

Table 4 Mobile Capture Methods Whole Wall Average Discrepancies vs Total Station Data

	RTK 1m	RTK 2m	RTK 3m	GNSS 1m	GNSS 2m	GNSS 3m
ABS Average	0.001783	0.001927	0.001059	0.001942	0.001029	0.001569
Average	0.002448	0.001477	0.000592	0.001568	0.000639	0.002187
SD	0.003575	0.003513	0.002505	0.004658	0.002458	0.002906
ABS SD	0.002615	0.002369	0.001553	0.003018	0.001543	0.002143

3.1.2 Vertical and Horizontal Differences

Distance discrepancies of the POI's were further broken down into horizontal and vertical components of between one point vertically e.g. 1 to 2, 2 to 3, and 3 to 4 and two spaces vertically e.g. 1 to 2 and 2 to 4. Averages were calculated between each of the line variance and as the two collectives (one space and two spaces), as shown in Table 5 to determine any discrepancies in distance. This process was repeated for horizontal data sets with one space (A to B, B to C…) and two spaces (A to C and B to D). Full extremes in distances (A to D and 1 to 4) were not utilised due to extremes in differences and no way to measure for anomalies within datasets.

Table 5 Vertical Differences GNSS 1m to Total Station

Vertical Differences					Line Averages				Area Averages			
	A	B	C	D	Average	S Dev	ABS Average	S Dev	Average	S Dev	ABS Average	S Dev
1 to 2	0.0009	0.004	0.0076	-0.0039	0.00215	0.004222	0.0041	0.002374	0.000167	0.00387	0.00305	0.002388
2 to 3	-0.0002	-0.001	-0.007	0.0053	-0.00073	0.00436	0.003375	0.002853				
3 to 4	-0.0019	-0.001	0.0015	-0.0023	-0.00092	0.001477	0.001675	0.000482				
1 to 3	0.0006	0.003	0.0004	0.0013	0.001325	0.001023	0.001325	0.001023	0.000462	0.002773	0.002363	0.001523
2 to 4	-0.0022	0.003	-0.0054	0.003	-0.0004	0.003583	0.0034	0.0012				

3.2 Cloud to Cloud

All point cloud information was presented in Leica Cyclone 3DR using the cloud - cloud analysis feature. This produced a surface deviation heat map and distribution graph (Figure 2) for each data comparison.

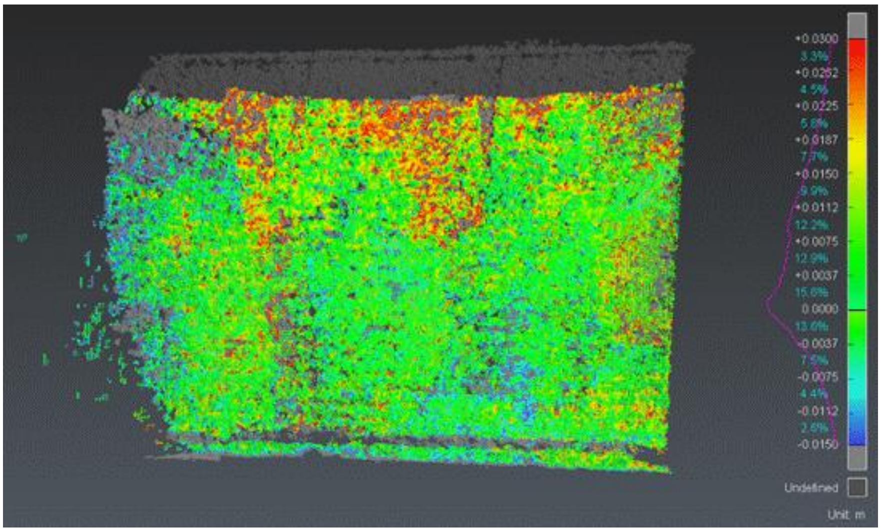

Figure 2: Cloud – Cloud Analysis Example

3.2.1 Others vs 1m

Both the GNSS and RTK data sets used the 1m model as the baseline for comparison followed by 2/3m comparisons for further analysis. Each deviation graph was reduced to view 90% of the distribution exaggerating the colors on the heat map to identify areas of poor surface construction. Furthermore, Upper/Lower limits and the mean average were extracted from the distribution graph and tabulated below (Table 6) for direct comparison.

Table 6: Point Cloud Analysis Results

Comparison	Lower Bound (mm)	Upper Bound (mm)	Mean Average (mm)
RTK 1m Vs RTK 2m	-20	20	5
RTK 1m Vs RTK 3m	-20	20	0
RTK 2m Vs RTK 3m	-20	20	0
GNSS 1m Vs GNSS 2m	-15	20	10
GNSS 1m Vs GNSS 3m	-15	20	10
GNSS 2m Vs GNSS 3m	-10	30	0

3.2.2 Reality Scan vs Pix4D

During processing, points A1 and A2 could not be extracted from the RTK 2m data set due to a missing section of the wall. The raw data was processed twice to potentially resolve this however the same issue occurred highlighting a potential issue with the data or the processing algorithm. To assess this, Epic Games Reality Scan was selected to further investigate the issue. Due to the software limitations, depth maps were incompatible therefore only image data was processed. The outcome was a significantly larger area of the wall with both A1 and A2 fully rendered in the model. Both models were compared in Cyclone resulting in the heat map.

3.3 GSD Calculations

Using the process detailed in 2.5.3, the following GSD values in Table 7 were calculated for each scan position.

Table 7: Calculated GSD Values

Distance	Pix4D Quality Report GSD (cm)	Optimized focal length (mm)	GSD (mm)	GSD (cm)
1 m	0.1	3.749	0.694 mm	0.069 cm
2 m	0.2	3.751	1.386 mm	0.139 cm
3 m	0.2	3.748	2.081 mm	0.208

4. ANALYSIS OF RESULTS

4.1 Point of Interest Analysis

To determine overall accuracy of the different models, multiple parameters are tested to determine where issues within the models may arise and how accuracies of the final models can differ over distances, axes, and GNSS methodologies.

4.1.1 GNSS vs RTK

Utilising GNSS absolute average discrepancies across the entire wall and three distances from the wall resulted in 1.589mm error, with a standard deviation of 0.06 standard deviation. RTK results showed errors of 1.513mm, with a standard deviation of 0.04. While on average, both methods provided results which were similar, only being a 0.076mm difference, the extremes of the two methods had a greater variance.

GNSS performed slightly worse along all points, having both maximum discrepancies, of +15.6mm and -12.8mm, however, both were along D1, which had inconsistencies across all models, highlighting potential inaccuracies within the total station data for that specific point. Once D1 was removed from data, variations in results were +10.2mm and -9.8mm, indicating likely sub-centimeter accurate data across all models. RTK performed slightly better, with maximums of +9.4mm and -9.1mm, indicating all points achieving sub-centimeter level accuracy.

4.1.2 Vertical vs Horizontal Variations

Exploring discrepancies between horizontal and vertical variations, within the GNSS data, vertical discrepancies consistently outperformed horizontal variations, by at least 1mm across all distances away from the wall. Within the RTK versions, vertical outperformed horizontal accuracy across two of the distances, however, each distance decreased the performance from 1mm within the 1m distance to horizontal outperforming by 0.3mm in the 3m distances.

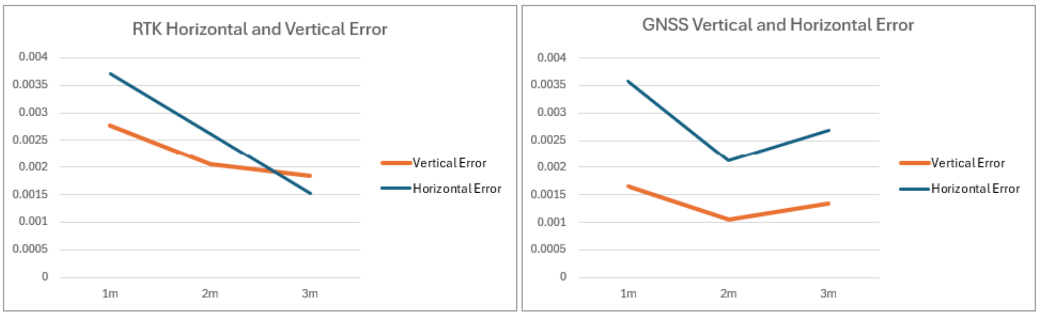

Figure 3 GNSS and RTK Horizontal vs Vertical Discrepancies

4.1.3 POI Distance Variations

Looking into discrepancies in POI distance changes, for both moving along one point e.g. A to B or 1 to 2 and two point e.g. A to C and 1 to 3, within the GNSS model, both follow similar trends to the above analysis that horizontal differences show greater error. Within the single point differences an average discrepancy of 0.99mm can be shown, while two-point differences indicate 2.1mm.

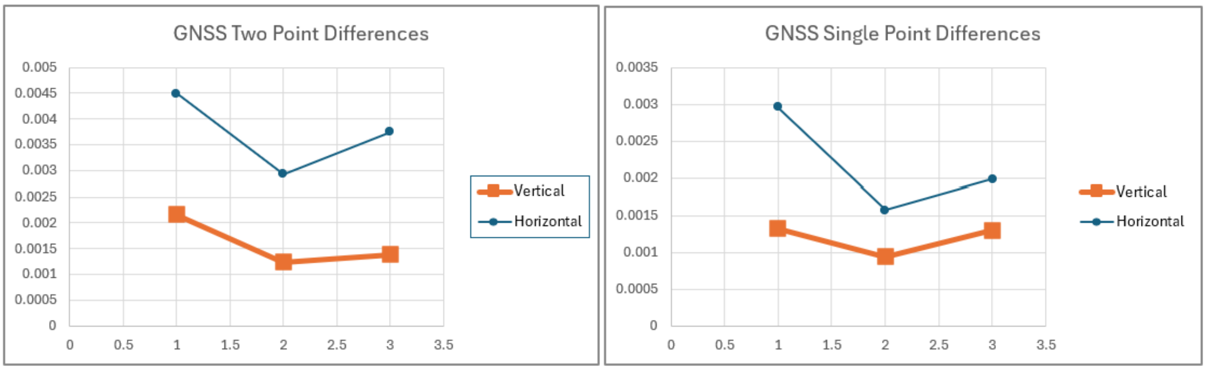

Figure 4 GNSS Two Poinit and Single Point Differences Horizontal Vs Vertical

Exploring differences between one point skipped, two, and three within the GNSS measurements show a strong linear relationship (regression value 0.98) between the distance between the points (from number skipped) and the distance discrepancy. This relationship is similarly confirmed within the RTK models, with a similar incline, however a different Y intercept. While this relationship is to be expected, the linear nature highlights the predictability of the distance errors across the wall and therefore potential for correction equations to be identified. However, this requires further work to determine scalability and causes of the error, which will not be explored within this works.

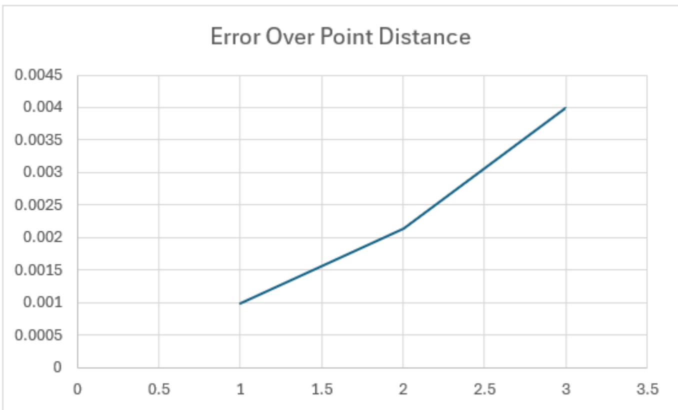

Figure 5 Error Over Point Distance GNSS

4.2 Point Cloud Analysis

4.2.1 GNSS vs RTK

Post registration, there are minor surface discrepancies between the GNSS models. Across all 3 comparisons, relative distances between each of the point clouds ranged between -15mm and 30mm. Whilst the absolute accuracy of the image positions may be very poor, the data suggests that relative scale and surface construction have the potential to still be centimeter accurate. The results highlight the potential for use without an RTK receiver for applications where absolute accuracy is irrelevant.

The RTK data sets maintained consistent deviations across all 3 data sets highlighting the subtle benefits of image positional accuracy. All graphs detailed a range of ±20mm with differing mean averages. The RTK 1-2m comparison overestimated distances by a mean average of 5mm whereas the RTK 3m maintained an even distribution in both directions. A potential source of this error stems from technical issues with Emlid RX Reach. The raw image EXIF data details positions captured in both the OSGB36 and WGS84 grids suggesting there was an intermittent connection with the NTRIP server. The result is an approximate 400m shift that will increase computation when adjusting camera positions. The interpolated values will have induced additional error possibly resulting in this overestimation.

Comparisons between the RTK and GNSS 1m models saw a significant decrease in deviations when compared to the rest of the data set. The mean average was -2.5mm with a distribution range of ±10mm. This reduction suggests that relative deviations are not the result of absolute accuracy of the images and are likely attributed to the camera parameters and proximity to the target. This indicates there is a negligible benefit of an RTK receiver on relative accuracy and further displays the potential for GNSS reality scans in relative accuracy applications.

4.2.2 Distance Analysis

Both the RTK and GNSS 1-2m cloud analysis exhibit similar deviation patterns across the surface of the wall. Both graphs display a mean average deviation of approximately 5mm demonstrating overestimation as distance increases from the wall. Upon inspection of the heat maps positive deviations typically occurred towards the upper and left extents of the wall whilst negative values were evenly distributed across the surface. The overestimation at the edges of the model suggests there is barrel distortion (Figure 6) as the distance from the target increases. This is a common issue in photogrammetry and is likely attributed to the poor quality of the iPhone's wide camera lens. As distance increases from the target, the field of view increases requiring less images to capture area however whilst this may be more efficient, the result is a warping effect reducing the verticality of the surface.

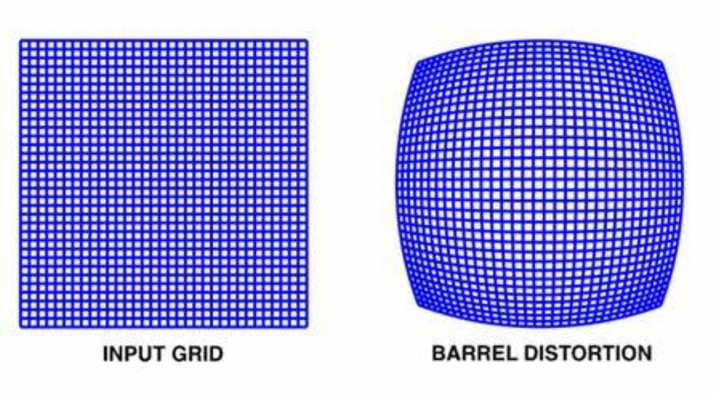

Figure 6: Barell Distortion Diagram

When inspecting the 1-3m cloud analysis, both GNSS and RTK demonstrate the same heat map patter however mean deviations differ. GNSS exhibted a mean average of 10mm wheras RTK maintained an equal distribution across both directions. This further supports the claim that increased absolute accuracy of the raw images has a minor improvement on the camera adjustment in the processing phase resulting in optimised verticality. Both heat maps also detail high deviations at the extents of the model further evidencing the effect of barrel distortion at greater distances.

4.3 Pix4D vs RealityScan

Both the Pix4D and RealityScan models were aligned using the registration feature within Cyclone 3DR, however the discrepancies were significantly higher. Unlike previous comparisons, the deviation graph displayed a multimodal distribution around a mean average of 170mm with a range of ±20mm. RealityScan significantly overestimated the distance from the sensor, highlighting potential scaling, positioning and incompatibility issues with Pix4D terrestrial data capture. Although RealityScan provided infill for the missing control points, the data demonstrates that the lack of LiDAR data and use of third-party processing algorithms can have a detrimental effect on the processed deliverables.

4.4 LiDAR vs 1m

LiDAR data shows an absolute average of 2.3mm for RTK measurements and a 3.1mm deviation within GNSS variance both at 1mm respectively. When comparing GNSS vs RTK both at 1m distance from the wall POI's show a discrepancy 1.74mm, highlighting that when comparing point clouds against one another, deformities within the model may result in further inaccuracies of data backing up earlier points of errors found within the extents of the model. This illustrates the further benefit of utilising a second and independent source of coordinate data, namely total station co-ordinates for better checks on data points, without similar errors within models being used and potentially minimising the efficacy of data.

5. CONCLUSIONS

This study demonstrates that combining mobile device reality capture solutions, when paired with GNSS receivers, final outputs can achieve within sub-centimetre relative accuracy. Accuracy variations between GNSS and RTK are shown to be negligible over the distances utilised within the study, however variance over the extremes, some benefits to RTK processes can be seen, indicating this may be more relevant over larger areas. Across all testing methods, variations in measurement averaged between 0.5mm and 3mm of relative accuracy in POI's, confirming the technology has significant promise for future geospatial and engineering applications, given the infancy of the technique.

Limitations of mobile reality capture have been identified within the study, such as model deformation, section loss, and sensitivity to factors like capture distance and the size of the object captured. Furthermore, variations in software platforms and ability to transfer between Pix4D catch and photogrammetry software remains challenging and may result in increased errors, should incompatible solutions be chosen.

5.1 Future Works

From the limitations of the study, the authors have several potential works to help answer and expand on additional research questions identified within the works, such as scalability of models and how this has an impact on POI's along larger areas and deformation of larger models. The works also focus on relative positioning, whereas larger scale models would further benefit from absolute positioning and this may have more of an impact on GNSS vs RTK model accuracies. Finally, the authors utilised one capture pattern methodology, focusing on orbital movements, however alternative methodologies, such as lateral movement or combining patterns, may provide changes to both accuracy and have greater impacts on drift for the final models.

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