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Study on the Application of Simultaneous Localization and Mapping Solution for Surveying Tasks: A Case Study of RS10 3D Handheld SLAM

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ABSTRACT

The article assesses the suitability of handheld SLAM for surveying tasks, focusing on visual observation and elevation accuracy from point cloud data. The study uses an RS10 handheld SLAM device, an integrated solution of GNSS technology, IMU sensors and three cameras to scan about one hectare using either real-time kinematic or post-processing kinematic working modes at approximately 4 Km/h speed. The elevations extracted from point cloud data are compared to those of 108 checking points measured by GNSS-RTK single base with 4G working mode at a close distance. Results showed the RS10's feasibility for surveying due to its accuracy and visual capabilities. Using different thresholds for assessment shows that 50 points (46.3%) deviate ≤ 0.010 m. 87 points (80.56%) deviate ≤ 0.020 m. 98 points (90.74%) deviate ≤ 0.030 m. 106 points (98.15%) deviate ≤ 0.040 m. Only points 85 (0.045 m) and 91 (0.052 m) deviate significantly. The standard deviation of 108 checking points is only 0.016 m. These results, excellent even without control points to adjust elevation elements, highlight the RS10's ability to provide detailed, feature-rich point cloud data along the scanning route.

1 Introduction

Total station, level, and global navigation satellite systems (GNSS) are the main choices for collecting data in the conventional survey methods. These methods have high accuracy but cannot meet point density requirements and are sometimes unsafe during the survey process although were used and standardised by Circular 68/2015 of the Ministry of Environment and Natural Resources [1]. Regarding terrestrial laser scan (TLS), high accuracy can easily be achieved

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especially for monitoring and inspection purposes [2, 3]. These two solutions (GNSS-RTK and TLS) require high stability at the RTK measuring points or the scanning stations which is very hard to get due to meteorological factors, especially with single-base GNSS-RTK working mode when the distance from base to rover increases. For TLS, the number of scanning stations will increase rapidly when applied to large-scale areas. As a result, the accuracy will decrease due to the registration process during data processing on the software. Regarding point density, it is an obligation to build a current status 3D model which cannot be solved with normal measuring methods. Decision 258/QĐ-TTG of the Prime Minister signed a decision approving the roadmap for applying the building information model (BIM) in construction activities to improve the quality of design products, which was released in 2023. Thus, applying BIM is obligatory for level 1 and 2 works [4] and the level of detail of the 3D current status model increases in different phases [5]. This means the point cloud is one of the most important input data that affects the quality of the work to be used in the following stages. Point cloud density and elevation accuracy are two important factors that should be achieved to build a model of the objectives. For these purposes, the above conventional methods cannot be used.

SLAM (*Simultaneous Localization And Mapping*) is a combination of different parts including sensors, and laser and is used for automatic mapping with some steps [6]. Regarding the use of SLAM, it can be applied to many applications including offline and online SLAM for map acquisition [7] especially for real estate surveying and smart city planning [8-10], generating a mapping of tree positions [11]. Based on the integration of technologies such as GNSS, and IMU sensors, SLAM currently can be installed and operated on various carrying devices like UAVs, handhelds, cars and robots [12, 13]. In 2023, a comparative study was performed between HF1 SLAM and 3DX330 TLS on point cloud density, loop closure requirement and accuracy. Study results showed the accuracy of HF1 affected by SLAM drift while the TLS solution has the highest quality but requests more time for preparation [14]. Having a look at the progress of SLAM technology, there were many advancements from offline to online mapping, from the need for loop closure to free loop closure, from control points for adjustment to without control points based on the integration of GNSS real-time kinematic technique. Challenges in the past regarding large-scale areas, filtering [15] is currently not an obstacle based on the advancement of new processing algorithms and their structure design [16, 17]. Recently, the combination of SLAM and other sensors can be applied to autonomous driving [18]. In the past, most SLAM devices did not consist of a GNSS module. This means ground control points are obligated to adjust point cloud data. The number of these points will be significantly increased when scanning a large-scale area. Besides, loop closure also is an obligation to ensure accuracy.

It can be seen that SLAM's applications are popular in many fields, for various purposes from the civil to the military sector. However, almost all previous studies used SLAM devices without GNSS technology integration and had a lower accuracy requirement. There were also few studies on the applications of SLAM for surveying purposes such as 3D mapping. Especially, elevation accuracy, an important element in three-dimensional space was not mentioned before. RS10 system is an integrated solution of GNSS technique, IMU technology and laser scan system, and was released in 2024. This device can be operated using different modes including the RTK method (*single cors and NET-cors*) and PPK mode to improve accuracy. Ground control points are not an obligation when scanning outdoors or indoors separately. The article assesses the ability of the RS10 system for survey purposes regarding two aspects including the ability of visual observation and the accuracy of elevation elements extracted from point cloud data after processing in open-air conditions. In this study, the results of point cloud data were directly calculated by the RTK method without any ground control points.

2 Device and methodology

2.1 RS10 device

RS10 system is an innovation, that brings a new approach to geospatial surveying by integrating GNSS-RTK, laser scanning and visual SLAM technologies into only one platform. Based on the 4th generation of GNSS antenna, it allows to receive GNSS signals from multi-constellations and get better than 3cm accuracy in challenging environments [19]. RS10 has a 0.05 m to 120 m range laser scanner, 16 channels, a high-sensitivity IMU system of 200 Hz, and three cameras. Due to the integration of GNSS and IMU, the point cloud from RS10 can be directly generated during scanning and observed on the controller's screen in the local coordinate system. More especially, RS10 can be used with different working modes including GNSS-RTK single base, NET-RTK, using control points or without GNSS. This means RS10 can be used in various environmental conditions. IMU technology allows users to move continuously during scanning and does not need to hold the device upright. RS10's different parts can be observed in Figure 1.

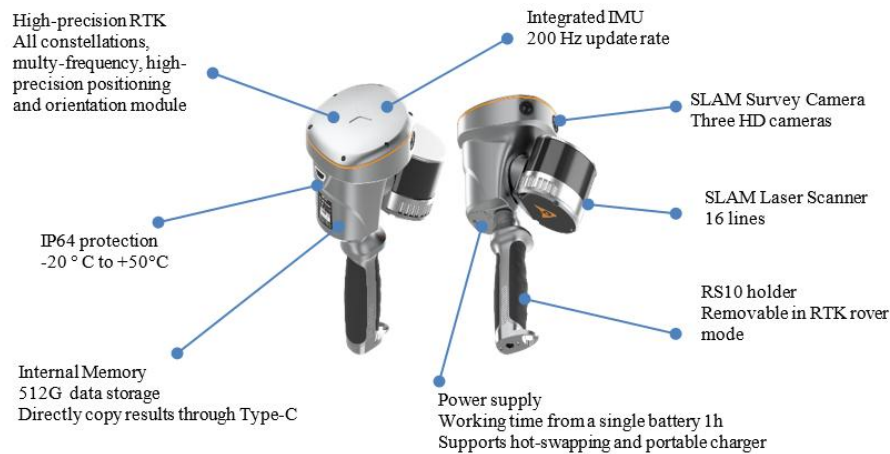


Fig. 1 – RS10 device with detail.

Theoretically, multi-frequencies and satellite constellations enhance the accuracy of the output data, especially in hard areas such as under tree sand near buildings. High-sensitivity IMU frees the operator from holding the device upright during scanning. 16 lines of laser scanners ensure the density of point cloud data and display full details of the objectives in the scan range. Three 5-MP cameras play an important role in RGB displaying mode for visual observation and clarify different objectives. Table 1 details the basic specifications of four main parts: GNSS, laser, IMU, and camera.

Table 1 – RS10 specifications [19]

GNSS	Laser	IMU	Camera)
1408 channels	Range: 0.05 m – 120 m	200 Hz	Number of cameras: 03
Real-time kinematic (RTK) H: 8 mm + 1 ppm RMS V: 15 mm + 1 ppm RMS	Channel: 16 FOV (horizontal): 360 ⁰ FOV (Vertical): 30 ⁰	Auto initialization	Resolution: 5 MP*3 Sensor size: 2592 (H) × 1944 (V)
Post-processing kinematic (PPK): H: 3 mm + 1 ppm RMS V: 5 mm + 1 ppm RMS	Thickness: 0.02 m Wavelength: 905 nm	After post-processing: 0.010 m RMS horizontal, 0.020 m RMS vertical	Pixel size: 2.0 μm FOV: 210° × 170°

2.2 Experiment procedure scanning area

The experiment procedure can be seen in Figure 2

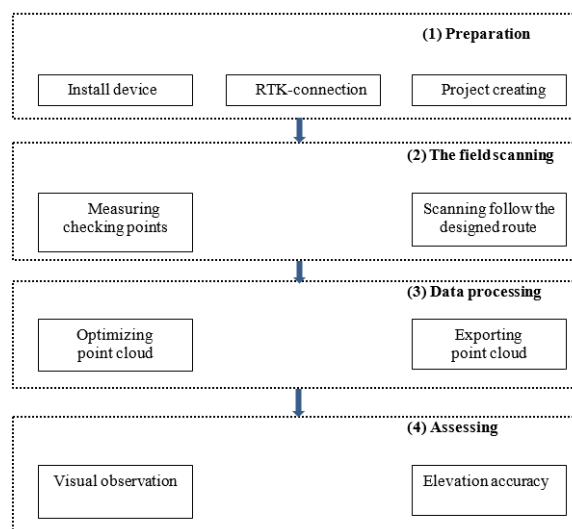


Fig. 2 – Scanning area and operator at the starting point

RS10 was operated in normal environmental conditions (around 300C) and moved in good GNSS signal conditions without under canopies or big trees. To reduce fatigue during scanning, the RS10 is installed on a shoulder attachment. The left red line is the image of the scan line. During the scanning process, RS10 was directly used with RTK working mode at a more than 200 m distance from the base station to the RS10 GNSS antenna without any ground control point on the field. The total length of the scanning route is about 743m, at 4 Km/h moving average speed. The fixed solution is maintained without interruption during scanning. In Fig 2, the RTK connection uses the single-cors method, and a fixed solution is maintained during the scanning process. In the scanning phase, measuring checking points using the same base as the RS10 device, viewing and displaying modes are adjusted by a table RS10 controller. Point cloud data is processed using Copre software including using PPK (if needed), filtering noise, and colouring point cloud in the third phase. The last phase is performed by Coprocess.

To assess the accuracy of point cloud data, RS10 was used to scan more than one hectare as in Figure3. The scanning area is quite flat with small differences in heights. The three images below (left to right) are the scanning route after finishing and the operator at the starting point respectively.



Fig. 3 – (a) Scanning area on Earth, (b) Scanning route, (c) Operator at the starting point

2.3 Method for accuracy assessment

108 checking points are evenly distributed across the scanning area as in Figure 4. Their three-dimensional coordinates are measured by the GNSS-RTK method in the local coordinate system. The distance from the base station to the rover testing device is about 200 m only.



Fig. 4 – (a) Measuring checking points (RTK method), (b) Checking points on Earth, (c) Checking points on point cloud

In Fig 3, the left image is an i90 GNSS-RTK for measuring checking points using the single base method, the middle and right images are the distribution of checking points on the Earth and point cloud. Theoretically, 108 checking points measured by the RTK method consist of fewer errors than those compared to the RS10 system. Based on error theory, the elevations of 108 checking points can be considered as the true values to compare with elevations extracted from point cloud data after processing by Eq.(1) [20].

$$m = \pm \sqrt{\frac{|\Delta \times \Delta|}{n}} \quad (1)$$

$$\Delta_i = H_{RTK} - H_{PC} \quad (2)$$

where:

H_{RTK} : Elevations of checking points measured by GNSS-RTK method

H_{PC} : Elevations of checking points extracted from point cloud data

n : The number of checking points

The checking points were measured from 14:38:57 to 15:06:34 on June 24, the same day with scanning, with fixed solutions only. The result summary is in Table2.

Table 2 – The results summary

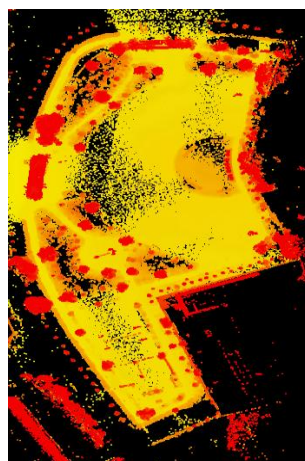
Specs	Max	Min
HRMS	0,024	0,011
VRMS	0,033	0,018
Number of satellites	35	28
PDOP	1,485	1,075
HDOP	0,667	0,535
VDOP	1,326	0,933
TDOP	1,915	1,205
GDOP	2,367	1,615

The statistic indices in Table 2 show that checking points are positioned with the highest quality thanks to close distance between single base and the RS10 GNSS antenna.

3 Results and discussions

3.1 Point cloud and visual observation

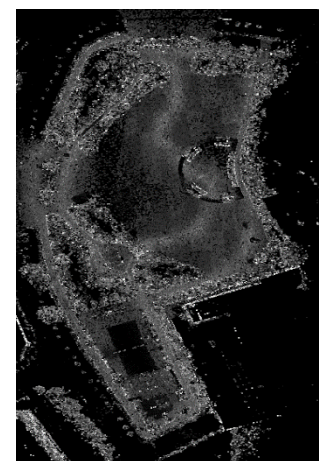
Regarding these purposes, the level of detail of the objectives in the scanning area will be displayed in different modes including elevation, RGB, and intensity mode as in Figure 5,6,7. The images of the yard surface and objectives along the scanning route are fully displayed on the point cloud with high resolution. Based on the high speed of the laser scanner, 360° field of view of the laser scanner and three 15MP resolution cameras with 2.0 μm pixel size, 210° × 170° field of view, RS10 releases point cloud data at a high level of detail, easy to observe, detect and classify.



(a)Elevation mode



(b)RGB mode



(c)Intensity mode

Fig. 5 – Point cloud of the yard surface

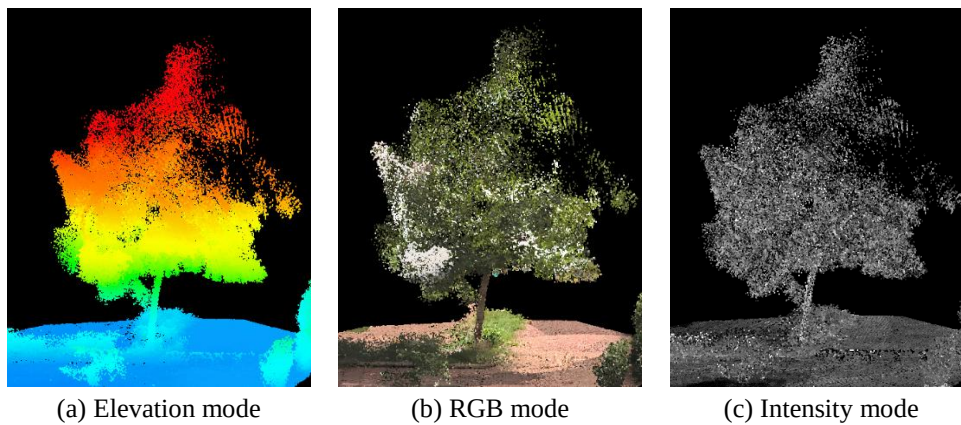


Fig. 6 – Point cloud of a big tree

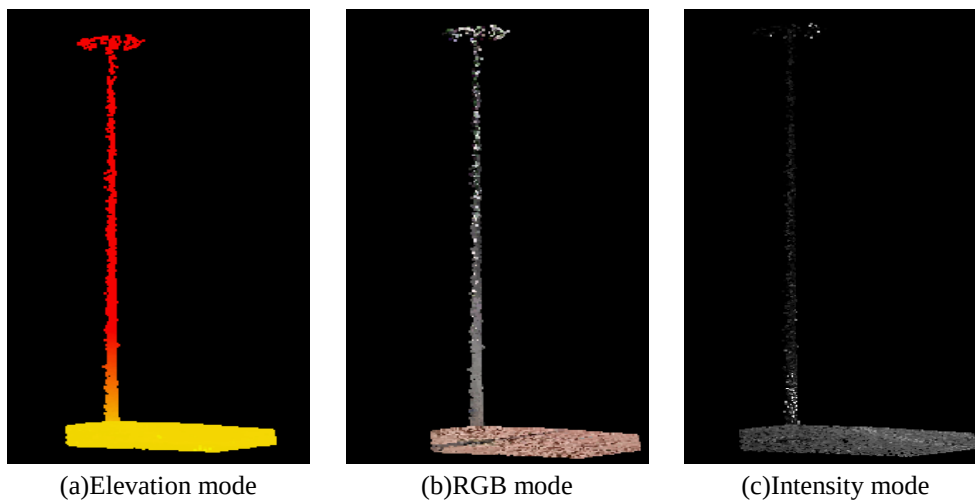


Fig. 7 – Point cloud of a light pole

Thanks to 16 channels and 320000 points/second measurement rate, every objective in the scanning area was fully recorded in output point cloud data. For more details, take a look at Figure 8.

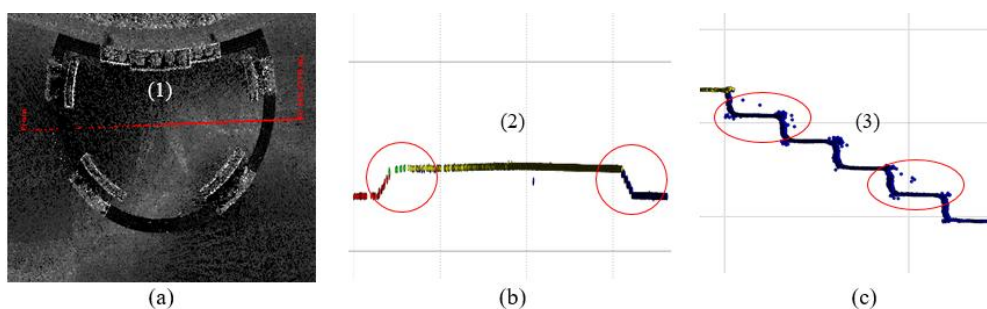


Fig. 8 – (a) A cross-section on the point cloud, (b) fully displaying, (c) detail on one side

Select a cross-section at the location where there is an elevation change (Figure 8-a). The change in point density can be observed at two equivalent locations (Figure 8-b). The upward direction (red circle on the right side of Figure 8-b) has a higher point density than the downward direction (red circle on the left side of Figure 8-b). In addition, looking more closely, the steps have noise points (red circle in Figure 8-c). Taking a look at the RGB displaying mode, different objectives can be easily detected and classified due to pictures from three 5-MP cameras

3.2 Accuracy assessment of elevation

The elevations of 108 checking points measured by the GNSS-RTK method are used to compare with those extracted from point cloud data. The automatic comparison was done by the “height inspection” function in Coprocess software. Using coordinates of the checking points to input into Coprocess software as in Figure 9.

Num	Y	X	Z
1	2321119.389	581089.782	6.315
2	2321119.389	581089.783	6.313
3	2321129.165	581094.539	6.325
4	2321146.168	581104.689	6.279
5	2321156.451	581103.767	6.254
6	2321163.874	581100.998	6.279
7	2321169.389	581094.034	6.332
8	2321180.999	581077.774	6.395
9	2321173.171	581080.085	6.379
10	2321165.444	581082.384	6.389
11	2321157.653	581084.672	6.383
12	2321149.867	581086.945	6.345
13	2321142.116	581089.251	6.307
14	2321134.360	581091.550	6.303

Num	Y	X	Z
15	2321132.957	581085.620	6.297
16	2321140.416	581083.404	6.361
17	2321148.590	581080.969	6.393
18	2321155.905	581078.821	6.426
19	2321164.077	581076.423	6.429
20	2321171.518	581074.216	6.434
21	2321179.272	581071.906	6.420
22	2321186.969	581069.640	6.410
23	2321185.275	581063.846	6.408
24	2321177.577	581066.106	6.422
25	2321169.369	581068.531	6.458
26	2321162.037	581070.707	6.453
27	2321154.232	581073.040	6.447
28	2321146.428	581075.304	6.438
29	2321138.638	581077.581	6.393

Fig. 9 – Automatically input checking point into a point cloud

Elevations of 108 checking points on the point cloud are automatically matched and compared as in Figure 10.

Num	Y	X	Z	MatchZ	DeltaZ	DeltaXY
1	2321119.389	581089.782	6.315	6.296	0.019	0.006
2	2321119.389	581089.783	6.313	6.296	0.017	0.006
3	2321129.165	581094.539	6.325	6.289	0.036	0.006
4	2321146.168	581104.689	6.279	6.267	0.012	0.004
5	2321156.451	581103.767	6.254	6.246	0.008	0.009
6	2321163.874	581100.998	6.279	6.263	0.016	0.047
7	2321169.389	581094.034	6.332	6.311	0.021	0.054
8	2321180.999	581077.774	6.395	6.404	-0.009	0.063
9	2321173.171	581080.085	6.379	6.369	0.010	0.039
10	2321165.444	581082.384	6.389	6.378	0.011	0.032
11	2321157.653	581084.672	6.383	6.385	-0.002	0.050
12	2321149.867	581086.945	6.345	6.343	0.002	0.071
13	2321142.116	581089.251	6.307	6.333	-0.026	0.020
14	2321134.360	581091.550	6.303	6.311	-0.008	0.046

Fig. 10 – Automatically match, compare, and export results

These results are excellent after 11 minutes of scanning at approximately 4 Km/h. The difference in elevations can be seen in Figure 10. Using Eq. (1) to calculate the standard deviation of 108 checking points, this value is 0,016m. In Figure 10, Z is the elevation measured by the RTK method, matchZ is the elevation extracted from the point cloud, and the deltaZ column is the difference in elevation between the two methods. The comparison of 108 checking points is in Figure 11.

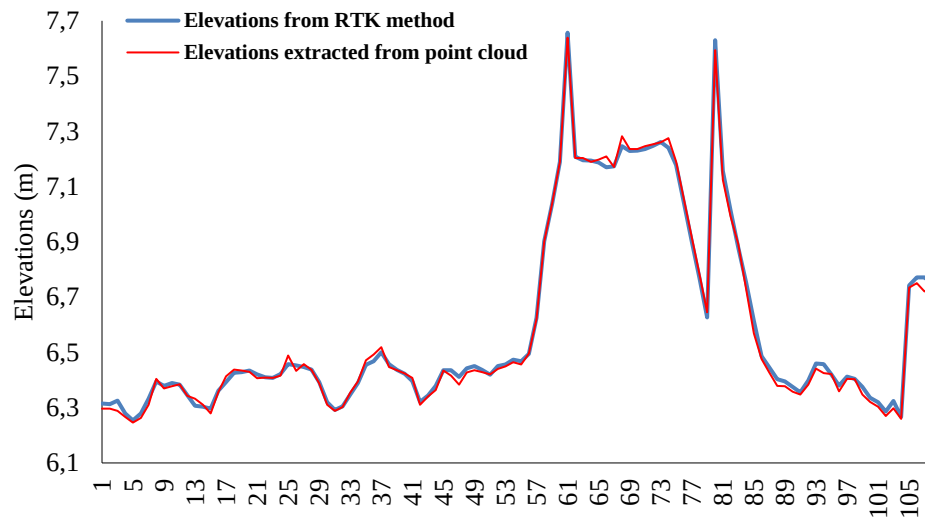


Fig. 11 – Comparison of elevations between GNSS-RTK and SLAM scanning methods

For better observation, set the GNSS-RTK heights of 108 checking points to zero, the difference in height values can be seen more clearly in Figure 12.

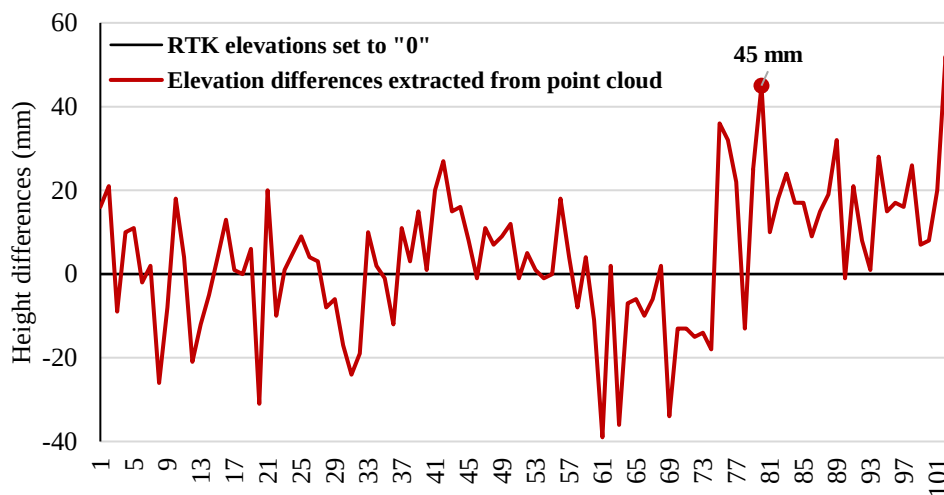


Fig. 12 – GNSS-RTK elevation of checking points set to “0” and differences between SLAM scanning and GNSS-RTK methods

Using different thresholds to assess, the percentage of deviations of 108 checking points can be seen in Table 3.

Table 3–The number of points and the rate of deviations by different thresholds

Thresholds (m)	$\leq 0,010$	$\leq 0,020$	$\leq 0,030$	$\leq 0,040$	$\leq 0,050$	$\leq 0,060$
The number of points	50	87	98	106	107	108
The percentage (%)	46,6	80,56	90,74	98,15	99,07	100

From Figure 11, only two points have a bigger 0,040m (Point 85 and Point 107), and 98 points (90,74%) have deviations $\leq 0,030$ m. If the 0,05 m threshold is used, the achieved is up to 99,07 %. For two points 85 and 107, taking a look at their position (figure 12), an explanation can be given.

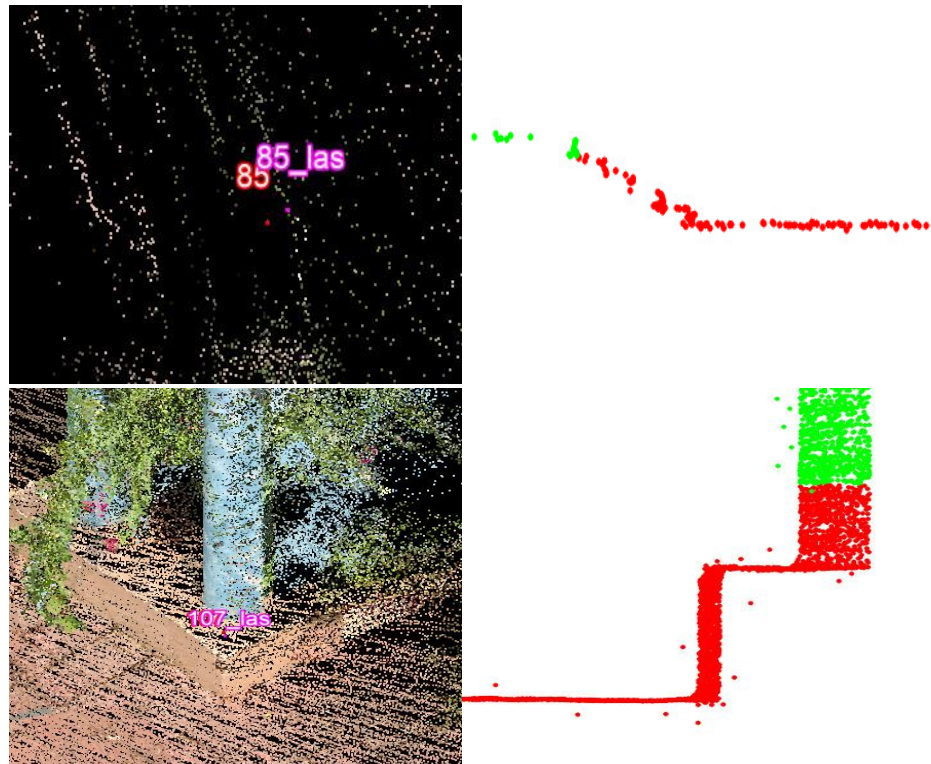


Fig. 13 – Positions of points 85 and 107

According to the scanning process, point 85 is on the steps and in the downward direction of RS10. This affects the ability to reach the subject while the RS10 is up and forward. This is shown clearly on the cross-section at point 85. With point 107, the location is on the foundation, which RS10 can access, but the small roof above affects the GNSS signal when measuring RTK.

4 Conclusions

The experiment study was performed in an open-air location with good conditions of GNSS signals, at around 4 Km/h average moving speed, and without any control point used for adjustment. Both scanning time on the field and processing time on the PC are short, around 10 minutes for each.

Compared to the conventional GNSS-RTK method, RS10 SLAM collects more data including coordinates in 3D space and images of the objectives on the scanning route. From those images and point cloud data, more indirect measurements can be done after finishing the job, and the number of direct measurements on the field can be significantly reduced. More importantly, point cloud data with high density and accuracy can be used for BIM.

Compared to the TLS method, RS10 scans continuously without static stations as the TLS. This helps save time on the field and reduces accuracy degradation during station registration. The accuracy in Table 3 proves that RS10 SLAM can be used to create survey maps at different scales.

The study achieved the initial goals, however, the influence of base distance, the influence of movement speed and the combination of indoor and outdoor were not considered. This is a limitation of the experiment study and needs to be carried out in the next studies.

The study assesses the ability to use the RS10 SLAM device for 2D and 3D surveying purposes. The results are excellent when the two aspects (visual observations and elevation accuracy) mentioned above get the best performance. Point cloud data with high resolution allows the classification and detection of different objectives while elevation accuracy meets the requirement of current standards.

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