Application of Backpack Mobile System for Tree Survey

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SUMMARY

In this work, an emerging Backpack Mobile Mapping System (Backpack MMS) was employed to collect individual tree information in a man-made slope area. Attributes, including location, diameter at breast height (DBH), crown spread and tree height were extracted from the point cloud data collected by the single head LiDAR backpack equipment. To assess the accuracy of the backpack mobile mapping data, reference point clouds were surveyed by using Terrestrial Laser Scanning (TLS) method. The results presented in this paper indicate that the Backpack MMS is an efficient approach for tree data collection with a reasonable accuracy.

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1. BACKGROUND

Detailed tree information including location, diameter at breast height (DBH[1]), crown spread and tree height, can support economical, environmental and sustainable decision for site-specific management (Hyyppä et al., 2020). Conventional field measurements using total stations and measuring tapes are laborious and expensive for tree inventories. Alternative methods for the tree data collection, such as drones and mobile laser scanning, have been studied intensively in recent years.

In Hong Kong, the government has begun explored the use of advanced technologies for tree inventories and risk management. In this work, an emerging Backpack Mobile Mapping System (Backpack MMS) was employed to collect detailed tree information in a man-made slope area. The objective of this paper is to evaluate the accuracy and feasibility of the Backpack MMS for tree inventories in challenging environments.

2. BACKPACK MMS

Mobile Mapping Systems (MMS) are the integration of various navigation and remote sensing technologies on a common moving platform (El-Sheimy, 2005). They are capable of providing fast and efficient data collection. As a supplement of vehicle-borne method, Backpack MMS has wide application prospects in pedestrian areas, such as footpath, stairway and some rural areas that are inaccessible by vehicles.

Common georeferencing methods available for Backpack MMS can be divided into direct georeferencing and SLAM-based georeferencing. Direct georeferencing generally refers to pose estimation using on-board sensors. Since the early days of MMS, the sensor combination of GNSS and INS (also known as GNSS/INS-based MMS) has been widely used for direct georeferencing. This method works well in outdoor environments with an open-sky view. However, the accuracy of direct georeferencing method strongly relies on GNSS reception. In GNSS restricted areas, such as highly unbanised areas like Hong Kong or forested areas with thick canopy layer, the accuracy of direct georeferencing approach can degrade from the centimetre level to the decimetre or even metre level.

Simultaneous Localization and Mapping (SLAM) is a technique that can map an unknown environment and at the same time localize the system (Chen et al., 2019). Cadena et al. (2016)

[1] DBH is the most common method of measuring tree dimension apart from tree height. It is measured at 1.3 m above ground.

give an overview of different SLAM approaches based on various sensors, such as LiDAR and optical. At present, most SLAM-based MMS use LiDAR as primary sensors for georeferencing.

SLAM estimates sequential movement, which includes some margins of errors. The errors accumulate over time and therefore, the mapping data may also be deteriorated or even distorted after a long journey. A loop shaped trajectory then plays an important role in adjusting the accumulated errors. Furthermore, geometric properties of the environment affects the accuracy and robustness of the 3D LiDAR SLAM. High geometric variability with clear corners, edges and surfaces improves the accuracy (Blaser et al., 2020).

Some of the main characteristics of the georeferencing methods discussed above are summarized in Table 1.

	Direct	SLAM-based
Sensor	GNSS receiver, IMU	LiDAR, optical
Accuracy level	cm to dm	cm to dm
Optimum operating environments	Outdoor with good open sky view	Areas with high geometric variability (LiDAR)
Reference frame	Global	Local

Table 1 – Summary of the main characteristics of the georeferening methods.

Some GNSS/INS-based MMS also featured SLAM technology. This integrated approach may improve the accuracy of mapping data in GNSS-restricted areas. However, such kind of multi-sensor Backpack MMS is much more expensive and requires additional post processing.

3. THE SURVEYS

The pilot test was conducted at a tree site along Chui Chuk Street, Wong Tai Sin in Hong Kong (Figures 1a and 1c). The test site is a roadside artificial slope with an area of about 0.6 hectares and a gradient of about 32 degrees. It consists of seven berms and one stairway crossing the berms. The stairway was very narrow and only about 0.5 meters wide between the third berm and the seventh berm (Figure 1b). There is a total of 250 individual trees of 29 genera and 34 species in the tree site. The most common species are *Acacia confusa* (ca. 24 % on the whole), *Lophostemon confertus* (ca. 12 %) and *Schima superba* (ca. 12 %). The tree canopies cover about 85% of the subject area and the tree heights range from 3 meters to 15 meters.

3.1 The Backpack MMS Surveys

In view of the site environment as described in the paragraph above, SLAM-based Backpack MMS was used in this pilot. Table 2 shows the specification of the equipment.

Due to site constraints, a loop-closure for the SLAM-based Backpack MMS is not feasible. To minimize accumulated errors of the SLAM-based georeferencing method and ensure sufficient overlapping for linking up the scans, the survey was split into ten paths (Figure 2). The surveyed point cloud data were aligned using ‘cloud-to-cloud’ registration method. The overall registration error was about 0.14 meters. The surveyed point clouds were then georeferenced to the Hong Kong 1980 Grid System using point cloud data along Chui Chuk Street that was captured by another GNSS/INS-based Backpack MMS for further analysis. The tree survey using SLAM-based Backpack MMS, including the field work and office work, was completed in two days. Figure 3 shows the result of the SLAM-based Backpack MMS.

(a) Location Map

(b) Stairway crossing the berms

(c) Orthophoto of 2020 with basic map features

Figure 1 – The Subject Site

Laser Sensor	
No. of Sensor	Single Head
Channels	16
Range Accuracy	±3cm
Horizontal Field Of View (FOV)	360°
Vertical FOV	± 15°
Scan Range	100m
Camera Sensor	
FOV	Full Panoramic
Resolution	4320 X 2160
Frame Rate	25 fps

Table 2 – Specification of the SLAM-based Backpack MMS

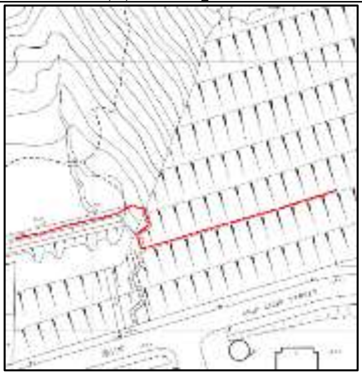
(a) 1st path

(b) 2nd path

(c) 3rd path

(d) 4th path

(e) 5th path



(f) 6th path

(g) 7th path

(h) 8th path

(i) 9th path

(k) 10th path

Figure 2 – The Survey of SLAM-based Backpack MMS

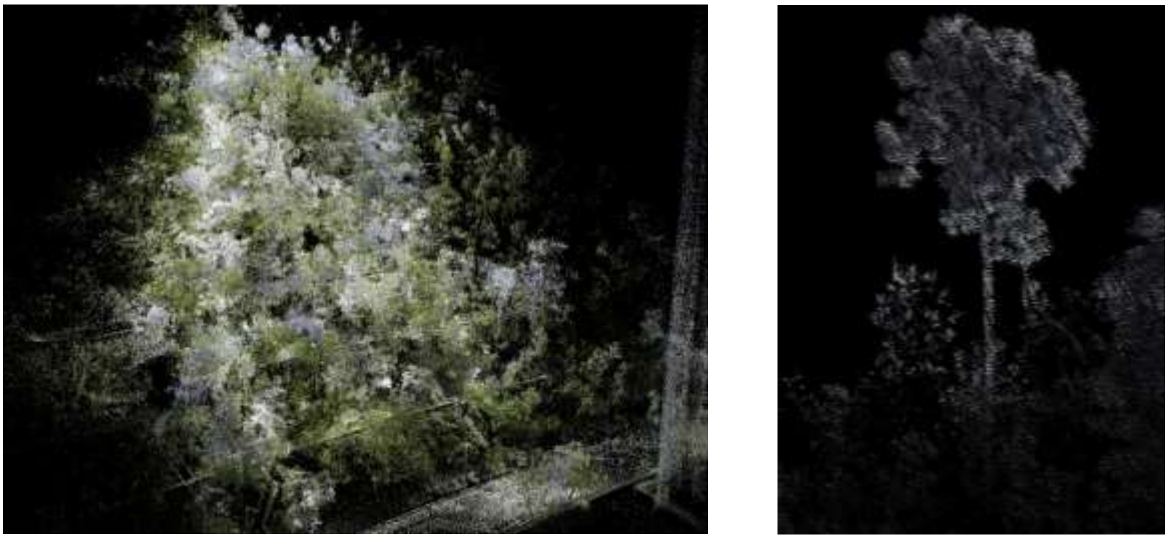
Base Map: Lands Department, HKSAR

(a) Overview *(b) Individual Tree data*

Figure 3 – Survey result of SLAM-based Backpack MMS

3.2 The TLS Survey

To evaluate the accuracy of the backpack mobile mapping data, reference point clouds were surveyed by using Terrestrial Laser Scanning (TLS) with control points established by conventional traversing and leveling. The TLS survey is consisted of 23 static scans mainly covering the eastern side of the subject site. The static scans were aligned and georeferenced through a bundle adjustment function in 3D point cloud processing software. The overall registration error was about 0.004 meters. Figure 4 shows the result of the TLS survey.



(a) Overview *(b) Individual Tree data*

Figure 4 – Survey result of TLS

4. ANALYSIS AND FINDINGS

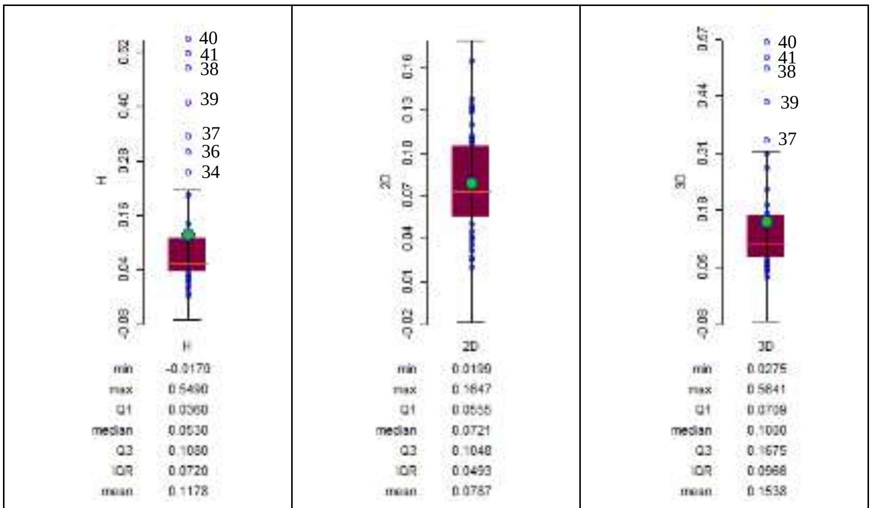
4.1 Accuracy of the Backpack MMS data

A total of 41 well-defined features, such as wall corners, building structures, steps and catchpit, were identified and selected from the SLAM-based mobile mapping data and the reference data for comparison. The check points were distributed as evenly as possible and at least 4 check points were selected in each berm. Figure 5 shows the distribution of the check points.

Base Map: Lands Department, HKSAR

Figure 5 – The distribution of the check points

The positioning errors of the backpack mobile mapping data of this survey are plotted (Figure 6). Overall, the Backpack MMS is more accurate in horizontal positioning but less accurate in vertical positioning. The Root Mean Square Errors (RMSE) in vertical and horizontal (i.e. ΔH and ΔNE) were about 0.186 meters and 0.086 meters respectively. It is worth noting that the vertical positioning error increased dramatically in the slope top area (between the 6th and the 7th berms, check point nos. 34, 36 - 41). It can be reasonably explained by: a) limitations of single head LiDAR equipment in a challenging environment, b) accumulated errors in SLAM-based georeferencing and c) alignment errors in ‘cloud-to-cloud’ registration. Backpack MMS with dual LiDAR heads and a better survey planning might improve the situation.



(a) ΔH (RMSE: 0.186m)	*(b) ΔNE (RMSE: 0.086m)*	*(c) ΔNEH (RMSE: 0.205m)*

Figure 6 – Errors of backpack mobile mapping data

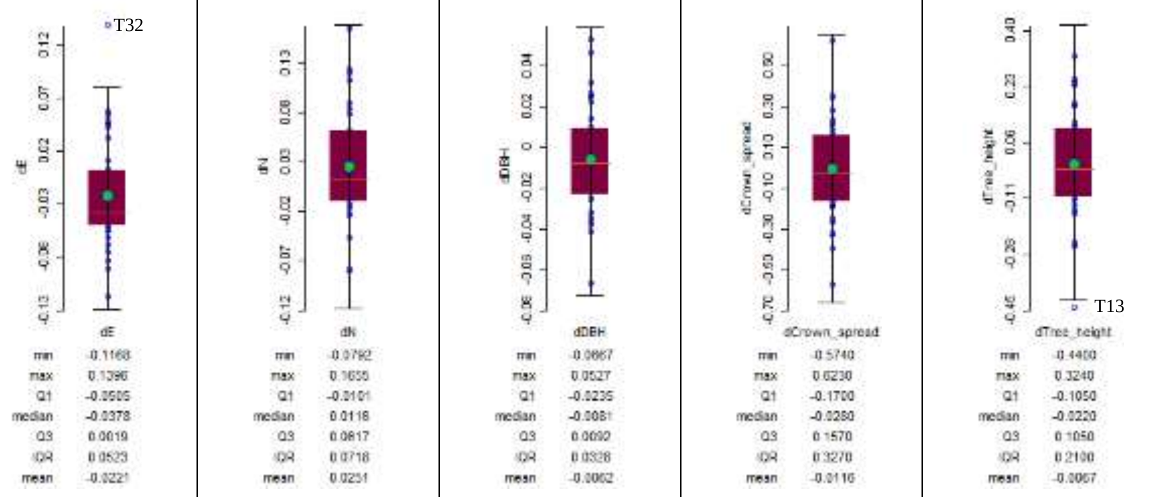
4.2 Accuracy of Tree Attribute data from the Backpack mobile mapping data

In addition, attributes of 38 trees, including location (Northing and Easting), DBH, height and crown spread, were extracted from the backpack mobile mapping data and then compared with the reference point cloud data for evaluation. The location and DBH were measured by fitting a circle at around 1.3 meters above ground level. Figure 7 shows the locations of the sample trees and Figure 8 shows the evaluation results.

As illustrated in Figure 8, the tree attribute information extracted from the backpack mobile mapping data are of high quality. The RMSEs in Northing, Easting, DBH, crown spread and tree height were 0.054m, 0.060m, 0.026m, 0.235m and 0.155m respectively. In some instances, it is inevitable that laser beams of LiDAR equipment may not be able to penetrate the canopies thus results in incomplete data. Hence, it was reasonable that the discrepancies in crown spread and tree height measurements would be larger.

Base Map: Lands Department, HKSAR

Figure 7 – The locations of the sample trees



(a) *ΔE* (RMSE: 0.054m)	(b) *ΔN* (RMSE: 0.060m)	(c) *Δ DBH* (RMSE: 0.026m)	(d) *ΔCrown Spread* (RMSE: 0.235m)	(e) *ΔTree Height* (RMSE: 0.155m)

Figure 8 – Accuracy of tree attribute information extracted from backpack mobile mapping data

5. CONCLUSION

In this pilot, the SLAM-based Backpack MMS was used for urban tree inventories in Hong Kong. The backpack mobile mapping survey was completed in two days, which covered the slope area of about 0.6 hectares with 250 individual trees. The results given in Section 4.2 also show that the tree attribute information extracted from the backpack mobile mapping data is of high quality for tree management. However, the vertical positioning error increased dramatically in the slope top area. It can be reasonably explained by the limitation of single head LiDAR equipment in a challenging environment, the accumulated errors in SLAM-based georeferencing and the alignment errors in 'cloud-to-cloud' registration. It is believed that Backpack MMS with dual LiDAR heads and better survey planning will improve the situation.

6. ACKNOWLEGDEMENT

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BIOGRAPHICAL NOTES

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