Geometric validation of a mobile laser scanning system for urban applications

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ABSTRACT

Mobile laser scanning (MLS) technologies have been actively studied and implemented over the past decade, as their application fields are rapidly expanding and extending beyond conventional topographic mapping. Trimble's MX-8, as one of the MLS systems in the current market, generates rich survey-grade laser and image data for urban surveying. The objective of this study is to evaluate whether Trimble MX-8 MLS data satisfies the accuracy requirements of urban surveying. According to the formula of geo-referencing, accuracies of navigation solution and laser scanner determines the accuracy of the collected LiDAR point clouds. Two test sites were selected to test the performance of Trimble MX-8. Those extensive tests confirm that Trimble MX-8 offers a very promising tool to survey complex urban areas
Index Terms—Mobile laser scanning, Trimble MX-8, Positional accuracy, point accuracy

1. INTRODUCTION

These Laser scanning technologies have become well established surveying techniques for the acquisition of spatial geospatial information since Global Position System (GPS) technologies have been widely commercially used in the early 1990s [1]. Compared to photogrammetry and field surveys, laser scanning, as an active remote sensing technology, captures very highly accurate three-dimensional (3D) point clouds with a high point density in a relatively short amount of time [2-4]. The term "mobile laser scanning (MLS)" means a laser scanning system is mounted on any moving platforms like vehicles and boats, but aircrafts excluded. Here, the MLS system implies that the laser scanning system is deployed on the top of a land-based vehicle [5]. In recent years, MLS has become a rapidly developing technology, particularly for accurately mapping highways and roads. As one of 3D data acquisition technologies, the MLS system not only has the advantages of TLS system characterized by high accuracy and point density, but also has advances in rapidly and cost-effectively capturing dense 3D point clouds for a large area. Although a variety of MLS systems have been built by diverse manufacturers, nearly all of them are based on navigation systems through integration of Global Navigation Satellite System (GNSS) and Inertial Measurement Unit (IMU) for directly obtaining geo-referenced LiDAR point clouds.

In this paper, a study on assessing the performance of Trimble MX-8 has been undertaken in two test sites. The study was carried out on behalf of Beijing TiTest Technology Corporation. Point clouds were collected and tested by the Trimble and the TiTest Technology in this study, and the delivered data would be a "commercial" product in the not distant future. Thus, it is necessary to validate the delivered data for the ground-level applications, including street-scene object inventory, 3D digital city, utility asset management, terrain survey and road /railroad construction. The clients would range from all-level governmental divisions to companies. From the client's point of view, the delivered data

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from MLS systems is expected to satisfy the requirements of practical production. In this study, the Trimble MX-8 MLS system was employed in the urban areas for road network update and management that includes extraction of digital terrain models, measurement of tunnel height and road width, detection of traffic signs, reconstruction of 3D building models, monitoring of landside, and configuration of utility.

2. TEST SITES AND REFERENCE POINTS

2.1. System Description

The MLS system used in the study was the Trimble MX-8 [6], operated by Trimble Corporation located in Unite States and TiTest Technology Corporation located in Beijing. The system used in this study comprised two Riegl® VQ-250 laser scanners, four 4 × Point Gray Grasshopper ® GRAS-50S5C CCD cameras, and a set of Applanix® POS LV 520 processing system, composed of two GNSS antennas, IMU and DMI. Integrated with POS Computer System (PCS), these components are integrated within a case and mounted on the roof of a vehicle, as seen in Fig. 1. The accuracy of the resultant position and orientation information largely determines the overall performance of the MX-8 system.

Rather than one of these components alone, the integration of an IMU, two GNSS antennas and a DIM allow exploiting the complementary nature of those sensors. Although the GNSS receiver can provide highly position information in an open environment, it suffers when satellite signals are blocked by high-rise buildings, vegetation, tunnels, and other obstacles. On the other hand, the IMU does not require satellite signals system to sense 3-axis accelerations and 3-axis angular rotations; however, the accuracy of position and orientation degrades with the time. Thus, GNSS positions are augmented by the IMU in periods of poor satellite conditions, while the GNSS provides updated position information to the IMU. Compared to the ALS and TLS systems, the MLS systems have DMIs that can constrain the error drift, especially during vehicle stoppages in areas of intermittent GNSS coverage

Fig 1. Overview of the Trimble MX-8

Based on aided inertial technology, the system provides continuous and accurate vehicle position and orientation information through areas of poor or no GNSS service. This includes areas of total GNSS satellite blockage and extended stretches of availability of less than four satellites, such as: urban canyons, full tree canopy, tunnels and bridges. In Fig. 1, two Riegl VQ-250 laser scanners were symmetrically configured on the left and right sides, pointing towards to the rear of the vehicle at an angle of approximately 145º in heading. It is called "Butterfly" or "X" configuration pattern. The full specification of Riegl VQ-250 can be found at the Riegl website. Note that the field of view of Riegl VQ-250 is 360º, also termed as "full circle" owing to motorized mirror scanning mechanism. Thus, the scanned data of two scanners look like a slant grid-like pattern. According to pulse per second (PPS) from the primary GNSS receiver, the scanning data is synchronized with position and orientation information from the POS LV 520 system.

2.2. The Description of Test Sites

The Trimble MX-8 survey team was commissioned to acquire two datasets, as seen in Fig. 2. The MX-8 integrates two Riegl VQ-250 laser scanners that can produce 600 000 points / sec, as a result, the collected data can reach up to 35 Gigabytes in twenty minutes, plus images from four CCD cameras. Considering limitations of LiDAR point cloud's post-processing, twenty-minute recording was considered as a reasonable time section. The first twenty-minute dataset was collected on June 28, 2012. In the following day, we collected the second one-hour dataset and divided them into three sections. The two independent datasets were allowed to analyze the consistency of the captured data in terms of data accuracy. During the first survey, a complete survey was collected back and forth on one street. The street, located in suburban area, has fewer high-rise buildings and vegetation scattered along its two sides; thus, this environment contributed to positioning accuracy of GPS due to more satellites in view. Moreover, a good traffic condition in this street was also beneficial to the survey. The second survey mostly runs through residential and commercial areas. Thus, we selected the two different areas to assess the performance of the Trimble MX-8 under good and bad GPS conditions.

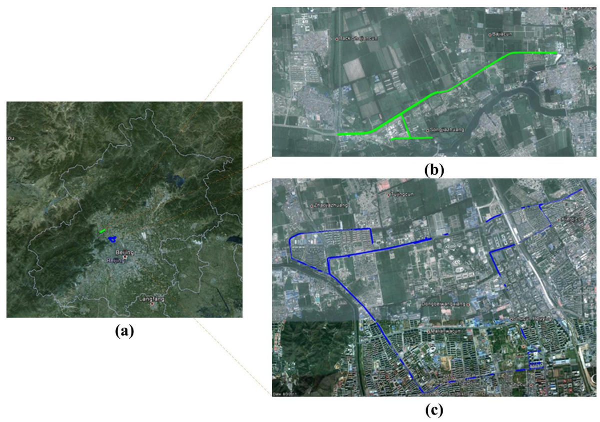

Fig 2. An overview of study areas: (a) study area(Beijing, China), (b) test site 1, and (c) test site 2

The first test site, located on Fengtai District, northwest of Beijing, is featured by wide streets with four lanes and a wide greenbelt. Residential buildings (about 5- 6 floors) were interspaced at the right end of the street, as well as large industrial manufactories and warehouses at the left end of the street. The test area was measured approximate 6.5 km west to east, and its elevation fluctuated approximately from 47m to 51m. The surveyed street was 10 km in length. The sky view across the street was considered as a good case for capturing more GPS signals although a small amount of overhanging vegetation was located along the street that restricted visibility. During this survey, the speed of the vehicle varied from 30km/h to 80 km/h for assessing the performance of data collection. The collected data included 30 Gygabyte(GB) LiDAR data for two laser scanners and 11GB image data for four cameras.

Different from the first test site, the second test site included more high-rise commercial buildings and apartments. The second test site was measured approximately 6 km west to ease, by 5 km north to south. The measured route was approximately 26.9 km long. The terrain undulations in this area were larger than the first test site, and the elevation varied from 33 m to 51 m. The city crayon can be created by narrow streets and high-rise buildings, which could limit the sky view for capturing satellite signals. There was a high bridge crossing the pass, further blocking the satellite signals. Therefore, this area can be considered as typical urban areas. The size of the measured data were a total of 120 GB, including 40 GB image files and 80 GB LiDAR point clouds. The survey was required to collect one-hour data at the speed of 40-45 km/h, a typical speed in the urban areas

2.3 Reference Data.

To evaluate the performance of the MX-8, reference data are newly collected information that at least one level more accurate than the system being tested. For example, aerial photography is often used to assess the accuracy of maps made from moderate-resolution satellite imagery [7]. Thus, in this project, Real Time Kinematic (RTK) GPS was selected as the most efficient technique to provide a consistent set of control points. With those points, the performance of the

MX-8 system could be assessed. Around 30 control points for validation were collected over the first test area. In most cases, we selected corner points of objects along the street and white road markings that could be conveniently identified in the point clouds for accuracy assessment. Those points were post-processed regarding a base station with a mean base line length of less than 6.0 km

3. EXPERIMENTS AND RESULTS

3.1. GPS Position Accuracy Assessment

The navigation solution integrated with laser scanners is a critical component for any MLS system as it is used to obtain geo-referenced coordinates of the collected LiDAR data. The overall accuracy of any integrated MLS is often determined by the accuracy of the navigation solution. However, for an MLS system, the navigation solution has to be even more sophisticated because various obstacles on the ground such as trees, high-rise buildings, bridges create periods of GPS, when satellite signals are not available to aid the navigation solution

Conventionally, GPS accuracy depends on the followings: single or differential positioning, single- or dual-frequency receivers, real-time or post-processing operation. In general, at least four satellites in view with a position dilution of precision (PODP) of six or lower are required for the standard positioning service. However, actual GPS accuracy varies with locations and the time of day. In urban canyon, we may in fact not even have four satellites in view and the PDOP may be greater than six. The variability of actual GPS accuracy from place to place and time to time is dominated by the effects of dilution of precision. According to ApplanixTM Corporation's specification, it would be acceptable for GPS accuracy when the PDOP value is less than 4. In Fig. 3 (a), PDOP values during scanning in the first test site were mainly under 4, and fluctuated at the value of 2.5. The corresponding number of satellites ranged from 6 to 10, as seen in Fig. 3 (b). When the number of satellites was 5 at the GPS time of 374 000, the PDOP value was up to 6. At that GPS time, the position accuracy decreased from 1.0 cm to 2.1cm. At that GPS time, the vehicle was driving through an overhanging bridge, as a red circle shown in Fig. 3.

As a result, the PDOP values could not be calculated, and the corresponding position accuracy also decreased dramatically. Particularly, heading position errors increased by 2.0 cm, and reached up to 3.8 cm. Although the position accuracy dropped down about 2.0 cm when satellite signals were completely blocked, the GPS accuracy could still satisfy the positioning requirements for urban surveying. This is because of Applanix POS LV 520, a special solution to employ auxiliary sensors and advanced data processing solution to maintain accuracy during periods of GPS outrages.

First, this system integrates IMU, two dual-frequency GPS antennas and DMI to generate a navigation solution, where the secondary receiver can be used to aid in heading calculation, and the DMI is used to provide accurate vehicle velocity updates. This aids in the overall solution when the vehicle is moving but the GPS quality is poor. Second, the use of POSPac MMS software tool also provides another critical component to the overall navigation solution because

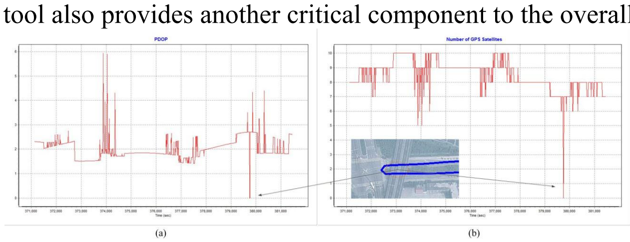

Fig 3. GPS position accuracy of the first test site, (a) PDOP, (b) number of satellites

it can simultaneously deal with the raw GPS, IMU, DMI, Base-Station data in a way of tightly coupled processing. As a result, that auxiliary information can be optimal used for the improvement of position and orientation accuracies.

Fig. 4. displays the PDOP values and the number of satellites, and the corresponding position accuracy. As the second test site was typical urban environment, satellite signals are often blocked by high-rise buildings, vegetation, and overhanging bridges. Especially, Beijing, as the capital of China, has developed high-rise buildings and complex multi-model road network to hold a population of almost fifteen million. In Fig. 4 (a), points (EA), (EB) and (EC) represent the worse GPS situations. The corresponding areas are highlighted in Fig. 4(d). Notice that at point (EA), the measurement vehicle was running across a commercial area called Guiguliangcheng, located at 1 Nongda Road South, Haidian District, where streets have one lane with the width of5 m, and high-rise buildings are densely allocated along those narrow streets. At points (EB) and (EC), the vehicle was passing through the overhanging bridges. Correspondingly, the largest GPS position RMS error at three points is reached up to around 0.07m in three directions, which is up to the standard of the predictive position accuracies of GPS, 0.1m in east and north, by 0.07m in elevation, according to Applanix's POS LV 520 specification.

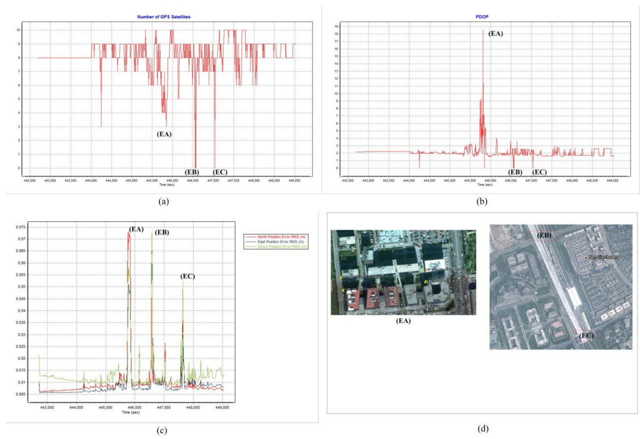

Fig 4. GPS position accuracy of the second test site,(a) number of satellites, (b)PDOP, (c) GPS position accuracy,(d) correponding images.

3.2. Lidar Point Accuracy Assessment

After field survey, the acquired MLS data were directly ground check points measured by RTK GPS. When the check points were imported into the T3D Trident Analysis, we observed that there were two points 1.0 m far away from the supposed locations. Given that the laser scanning data were consistent from start to end, we assumed the two check points as noises and removed them from the reference data. As a fact of two Riegl VQ-250 scanners located at the rear of the vehicle, two scanning data –left and right sides of the trajectory were validated from those check points. Directly making use of 3D measurement function provided in the T3D Trident Analysis software, we interactively selected those check points' neighbors to measure their elevation differences, and finally obtained the elevation accuracies of laser points. The standard deviations of elevations for all check points were calculated for representing the overall performance of the system. As shown in Table Ⅰ,

Table 1. Position Accuracy of Left And Right Laser Scanners (m)

		Mean standard deviation	Minimum standard deviation	Maximum standard deviation
Left scanner	Planimetric	0.017	0.008	0.019
	Elevation	0.042	0.025	0.057
Right scanner	Planimetric	0.021	0.007	0.025
	Elevation	0.033	0.023	0.049

the mean standard deviation for the left and right laser scanners is 0.042 m and 0.033m respectively. Compared to the validation of elevation accuracy, it is complicated for assessing planimetric accuracy of laser scanning points because identifying common points in point clouds is not straightforward. We chose check points located at the corners of road marking lines to compare with the scanned points. We first imported images to the T3D Trident Analysis software to help in finding the scanned points closest to the check points, and then measured their differences in east and north using a measurement rule. The mean standard deviation of planimetric accuracy for two laser scanners was 0.017 and 0.021, respectively. Notice that the minimum standard deviation appears at the check points measured near the base station with a good GPS coverage. In spite of errors of check points, the accuracy of lidar point is still consistent to the accuracy of the POS system and even out performs the Applanix's specification. The errors are lower than +/-5cm, and satisfy the requirements of data accuracy for the urban surveying

4. CONCLUSIONS

In this study, we evaluate whether Trimble MX-8 MLS data satisfies the accuracy requirements of urban surveying. The collected navigation data of the first test site were better than those collected from the second test site. This is because the first test site is an open area with fewer high-rise buildings, vegetation, and overhanging bridges, which contributes to obtain more satellites in view. On the contrary, the second test site is located in the urban areas. The test route was running through the main urban canyon several times. However, the accuracy of the Trimble MX8 is within 0.02-0.03 m in planimetric accuracy and within 0.04-0.05 m in elevation accuracy, which satisfies the street-grade accuracy demands, as expected.

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