

Technical Scheme for 3D Digital Map Production Based on the SSW Vehicle-mounted LiDAR Mobile Mapping System (VMMS)

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Keywords: 3D Digital Map, SSW VMMS (Vehicle-Mounted Mobile Mapping System), Urban Roads, Point Cloud Data, Panoramic Images

ABSTRACT

To meet the growing demand for 3D digital map applications and to better understand the multi-level spatial structure of cities, some cities have implemented citywide 3D digital map programs. In 3D digital map production, vehicle-mounted mobile surveying is a key component. Drawing with a practical project, this paper proposes a technical scheme for road data acquisition and processing based on the SSW VMMS (Vehicle-mounted Mobile Mapping System). Through integrated processing steps, including combined navigation solution, point cloud correction, image coordinate calculation, image deblurring, point cloud coloring, point cloud denoising, and Orbit GT data preparation, the rapid production of colored point cloud data with georeferenced coordinates, 360° panoramic image data, and individual image data is achieved. A technical scheme suitable for 3D digital map production along urban roads was developed and validated. The results produced by this scheme have passed inspection and acceptance, and were released to the public free of charge as the first batch of visualized 3D map data on the Common Spatial Data Infrastructure Portal (portal.csd.gov.hk), receiving widespread attention and positive recognition from various sectors of society. This scheme not only promotes the broader application of the SSW VMMS but also provides effective reference for similar urban vehicle-mounted mobile mapping projects.

1. Introduction

At present, the production of 3D digital maps mainly relies on oblique photogrammetry systems, airborne LiDAR systems, mobile mapping systems (MMS), backpack 3D laser scanning systems, handheld laser scanning systems, and other surveying technologies to acquire and process aerial, ground, and indoor data. Different systems have their own strengths and limitations, and they complement each other in practical application. Oblique photogrammetry system mainly uses to acquire multi-angle aerial images constructing the overall 3D scene model, but they are relatively weak in capturing the lower parts of buildings and fine façade textures. Airborne LIDAR systems are primarily used to obtain accurate elevation, but they lack complete 3D structures and texture representation; VMMS can obtain fine 3D structures and texture images of buildings along roadsides, but it lacks a macroscopic 3D perspective. Backpack and handheld 3D laser scanning systems are mainly used for the acquisition in confined spaces and indoor environments, and are therefore not suitable for the large-scale outdoor 3D digital map production. Since each system has its own focus, the production of full-coverage 3D digital maps in practice requires their integrated application in a complementary manner.

Focusing on the mobile mapping operation of the Provision of Services for the Generation of 3D Digital Map in East Kowloon for the Lands Department as a case study, this paper mainly introduces the use of the SSW vehicle-mounted laser mobile mapping and modeling system for data acquisition, the generation of high-precision colored point cloud data, 360° panoramic images, and individual image products, and the

development of a mobile mapping technical scheme applicable to urban scenarios.

2. Research Status

The earliest emergence of ground-based mobile measurement technology can be traced back to the 1980s. With the technical development of the GNSS, INS, LIDAR, mobile measurement system gradually becomes an important tool for acquiring 3D geospatial data efficiently. The limitations of traditional surveying methods in operational efficiency and the scope of the coverage have greatly promoted the widely application of MMS in the field of surveying & mapping and transportation (El-Sheimy, 2005).

VMMS mainly uses to acquire the 3D structure and detailed texture information of buildings, roads and auxiliary facilities. This system integrates GNSS, IMU, laser scanner, etc. (Duan et al., 2015). It can rapidly acquire the spatial position and attribute information of roads and surrounding features while the vehicle is moving at high speed. The advantages and limitations of this technology were analyzed and examined (Duan et al., 2015; Lu et al., 2012; Wang et al., 2021; Xie, 2019; Zhang and Li, 2019). Firstly, its high data acquisition efficiency enables the rapid collection of large volumes of spatial information. Thereby meeting the requirement of modern surveying and mapping; secondly, its high acquisition accuracy makes it possible to provide high quality measurement data; in addition, it offers strong mobility and operational feasibility, allowing it to adopt to various complex surveying environments.

In recent years, vehicle-mounted surveying equipment has developed rapidly. The leading international brands are mainly concentrated in countries such as the United States, Switzerland, Japan, and Austria. Representative products include the Trimble MX90 and Trimble MX60 from the United States, Leica Pegasus TRK Neo and Leica Pegasus: Two Ultimate from Switzerland, Topcon IP-S3 and Topcon IP-S2 HD from Japan, RIEGL VMX-2HA and RIEGL VMY-2 from Austria and StreetMapper, jointly developed by 3D Laser Mapping (UK) and IGI (Germany). The major domestic brands in China include the AU20 MMS and AP70 MMS from Huace Navigation, the HiScan-R and HiScan-X from Hi-Target, the SSW system developed by Academician Liu Xianlin's Team, the Flashman system developed by Academician Li Deren's Team, and the VSurs system developed by Professor Xiushan's Team, etc. Overall, these products feature comprehensive product lines, focus on high precision and multi-scenario adaptability, and have been widely applied in high-end surveying and mapping, high-precision geospatial data acquisition and related fields.

Among these systems, the SSW vehicle-mounted laser modeling and mapping system was developed by the team of Academician Liu Xianlin in China and has been in practical application since 2011. It is a mobile mapping system with many years of experience in road-related applications, characterized by broad applications and high operational efficiency. It has become one of the most representative mobile mapping systems (Ma, 2021). SSW system integrates multiple types of sensors, including an IMU, GNSS, laser scanners, 360° panoramic camera, area scan cameras and an odometer. It is used to acquire high-precision georeferenced point cloud data, panoramic image data and individual image data, thereby presenting a realistic and comprehensive 3D environment of urban roads. The system has been widely applied in many fields, including surveying and mapping, transportation, autonomous driving, urban management.

3. Regional Overview

The vehicle-mounted mobile mapping survey area of the project covers 27 km², requires the collection of 3D structural and texture detail information for 284 km of roads, roadside ancillary facilities, and buildings. The study area is densely populated with building clusters, narrow streets, and heavy traffic, which result in uneven scanning vehicle speeds, poor GNSS positioning signals, and severe occlusions in the acquired 360° panoramic and individual images, thereby posing significant challenges to both data collection and subsequent data processing.

4. Technical Scheme

To effectively carry out vehicle-mounted mobile mapping operations, meet production requirements, and generate high-precision and high-quality colored point cloud data, 360° panoramic image data, and georeferenced individual image data, this paper presents the operational workflow of the SSW Vehicle-Mounted LiDAR Mapping and Modeling System from two aspects: data acquisition and data processing. The workflow includes point cloud and image data acquisition, integrated navigation solution, point cloud correction, image coordinate calculation, image deblurring, point cloud coloring, point cloud denoising, and Orbit GT data preparation for the production of 3D digital maps. The technical framework is shown in Figure 1.

5. Field Data Acquisition

Field data acquisition begins with the formulation of an operational plan based on the conditions of the study area. Subsequently, point cloud data, 360° panoramic images, and individual image data are collected using the SSW Vehicle-Mounted LiDAR Modeling and Mapping System, while base stations, control points, and check points are surveyed using RTK (Real-time Kinematic) technology and traverse surveying methods.

5.1 Field Reconnaissance and Data Collection Plan

Before the operation, field reconnaissance is carried out in accordance with the project requirements and the conditions of the study area in order to develop a vehicle-mounted mobile mapping plan. Based on the road distribution, occlusions from high-rise buildings and tall trees, and the level of operational difficulty identified during field reconnaissance, the data collection route is designed, base station locations are determined, operation sub-areas are divided, personnel and equipment are reasonably allocated, and a data collection plan is prepared.

5.2 Layout and Measurement of Base Stations, Control Points, and Check Points

Base stations are used to improve and ensure the accuracy of the vehicle scanning trajectory, control points are used to correct LiDAR point cloud data to real-world geographic coordinates, and check points are used to verify the accuracy of data results.

Known control points are usually selected as base stations for vehicle-mounted mobile scanning. The distance between the base station and the rover station should not exceed 5km; if conditions permit, it may be maintained within 10km. In this Project, the Hong Kong CORS (Continuously Operating Reference Stations) network was used as the reference base station, the baseline distance was controlled within 20km.

Control points and check points are usually laid out on the premise of ensuring the quality of scanning trajectories, with the aim of minimizing the number of point deployments (Yang, 2022). Control points are evenly distributed at intervals not exceeding 100 meters, while check points are evenly arranged at a density of at least 4 points per kilometer. When selecting the points locations, distinct feature points on the ground and on both sides of building should be selected. In areas lacking obvious feature points, an appropriate number of horizontal points and vertical points may be added. The horizontal and vertical errors in the point cloud shall be corrected separately in order to improve overall point cloud accuracy. For points in areas with strong CORS signals, network RTK technology is adopted for direct measurement; whereas traverse surveying is used for points in areas with weak CORS signals. The spatial datum of control points and check points is converted between horizontal coordinates and vertical coordinates using conversion software, and the resulting accuracy complies with the precision requirements specified in relevant documents, such as the project's bid documents and inception report. The maximum horizontal position error of control points and check points shall be no greater than 0.05m, and the maximum vertical error shall be no greater than 0.10m. After the completion of point measurement, the coordinate table and corresponding field photos shall be inspected and sorted out.

5.3 Data Collection by the SSW Vehicle-Mounted LiDAR Modeling and Measurement System

Before data collection, the equipment shall be inspected and testing to make sure the system in a good condition. Select a relatively open area, and perform static initialization followed by dynamic initialization on the equipment to enable dynamic alignment and gradual convergence between IMU and GNSS. The initialization location shall be selected as far as possible in open areas to ensure that the GNSS signal is not obstructed, thereby improving the solution accuracy of integrated navigation.

During data collection, a grid-shaped operation is adopted according to the road network. When encountering curved

sections, the survey vehicle shall follow broad right-angle turns in order to avoid repeated irregular maneuvers. The recommended acquisition sequence is as follows: urban ring roads, main roads, overpasses, secondary roads, general roads, and other streets. Among these, data collected while the vehicle is driving straight in the middle lane of the road exhibits the best quality. When the survey section includes auxiliary roads, overpasses, and underground tunnels, the principle of "collecting main roads, overpasses, and tunnels together" and "collecting auxiliary roads, underpasses, and outside tunnels together" are followed; for roads with four or more bi-directional lanes, two-way data acquisition shall be conducted. For roads with fewer features, narrow roads, or no central guardrails, one-way collection can be performed to ensure the integrity and completeness of the collected features.

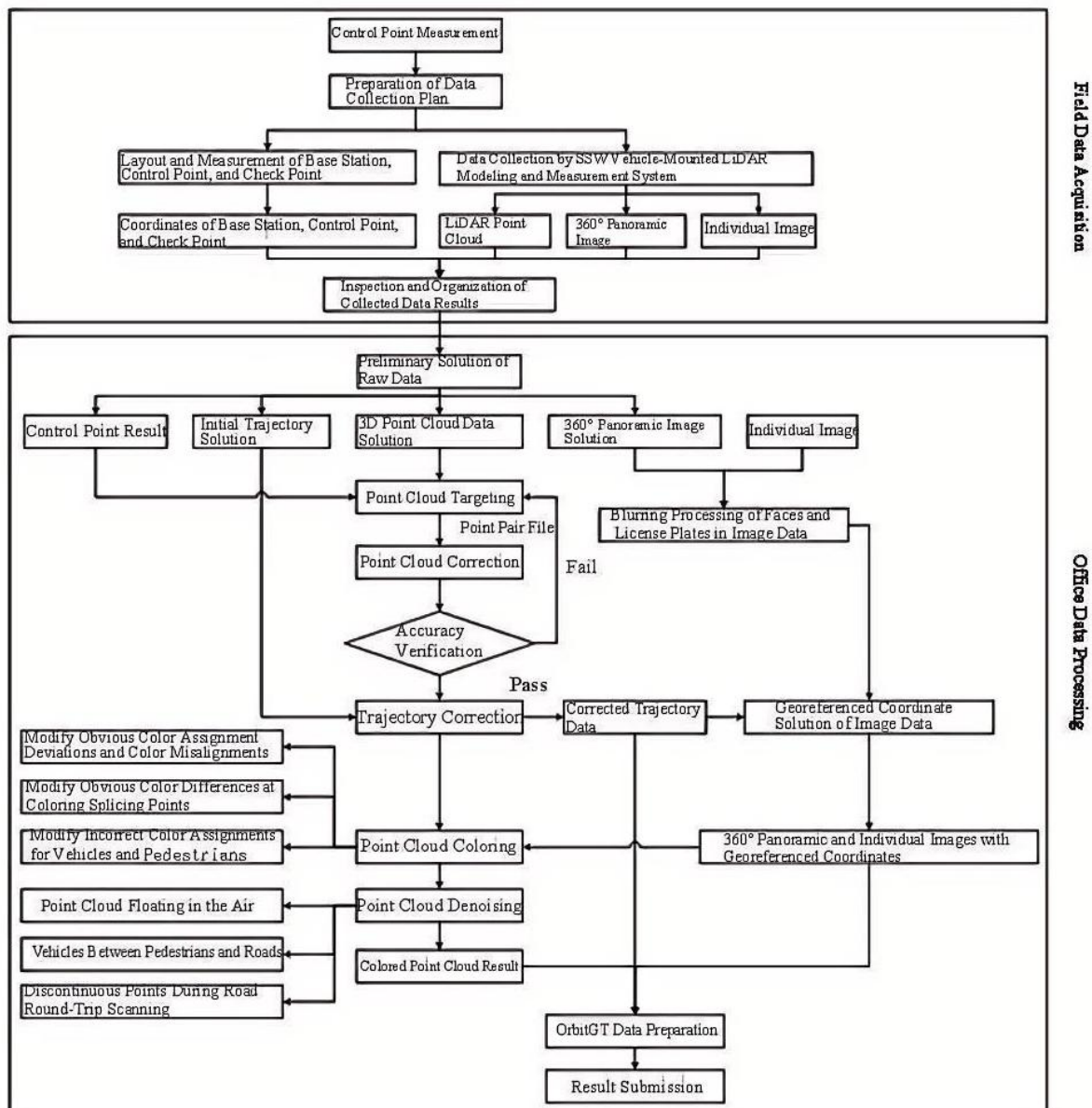


Figure 1. Technical Flowchart

Data acquisition personnel collect data and store images in accordance with relevant regulations. The speed of the survey vehicle is controlled between 20-40 km/h, and should be reduced when negotiating road curves. The survey vehicle shall

drive in the slow lane whenever possible; in areas where the lane is heavily occluded by overhanging trees, it shall travel along the centerline. During data acquisition, great care should be taken to maintain an appropriate distance from large adjacent

vehicles in order to avoid camera occlusion and the omission of target features. If lighting conditions become unsuitable during acquisition, such as in cases of severe camera backlighting, the driving plan shall be adjusted in a timely manner. When entering locations with reduced light, such as tunnels and under viaducts, the vehicle shall slow down as much as possible to allow the camera to automatically adjust the exposure.

To ensure sufficient overlap between images for point cloud coloring and texture mapping of individual models, images are captured at equal intervals with a photo interval of 4m. After the data acquisition operation is completed, the operator downloads the positioning synchronization file data of the SSW Vehicle-Mounted LiDAR Modeling and Mapping System, exports the collected data, and power off all hardware devices and system components. To avoid the adverse effects of peak-hour traffic on the quality of raw data, data acquisition in this project is carried out during off-peak traffic hours, making full use of holidays and weekends.

5.4 Inspection and Organization of Collected Data Results

Result inspection mainly evaluates the completeness of raw collected data, point cloud quality and image quality. Qualified data results are organized and achieved, while unqualified ones are re-measured or supplemented in a timely manner. Data completeness refers to whether the scanning routes and various types of scanning results are complete; point cloud quality refers to whether the initially processed point cloud exhibits data loss or distortion; image quality refers to whether the images exhibit deformation, overexposure, or other artifacts, and whether the overall tone remains consistent.

Data organization involves sorting and managing files such as raw LiDAR point cloud data, 360° panoramic image data, individual image data, and rover GNSS data for subsequent office-based data processing.

6. Office-Based Data Processing

Office data processing is carried out the data collected by the SSW Vehicle-Mounted LiDAR Modeling and Measurement System. First, integrated navigation processing is performed on the raw scanning data to generate LiDAR point cloud data and 360° panoramic image data. Second, the point cloud is corrected using control point data, while the vehicle trajectory data are corrected simultaneously. The georeferenced coordinates of image data are calculated, and privacy-sensitive or confidential information appearing in the images is blurred. Third, the corrected point cloud is comprehensively colored and denoised using panoramic and individual images. Finally, point cloud data, image data, and trajectory data are imported into Orbit GT software in the required output format for final result

submission.

6.1 Preliminary Solution of Raw Data

The preliminary processing stage includes integrated navigation processing for trajectory determination, joint computation of point cloud data and vehicle trajectory files to generate point cloud results, processing of 360° panoramic image data, and organization of individual image data, thereby producing the initial trajectory, point cloud, and image datasets.

6.2 Point Measurement and Correction on the Point Cloud

Using field control point results, point picking and correction are performed on the computed point cloud data. Check points are then used to verify the corrected results. Once the required accuracy is achieved, the vehicle trajectory data are corrected accordingly to ensure consistency with the point cloud data.

(1) Point Measurement on the Point Cloud: Using the point cloud workstation (SWDY), the point cloud data are packaged (i.e., organized into different LODs-Level of Details). The point cloud data are then loaded together with field-measured control point data. By referencing point coordinates and photographs, the corresponding positions on the point cloud are identified and points are picked. During point picking, multiple viewing angles must be used to ensure accurate positioning. After point picking is completed, the corresponding picked-point files and control point files are exported to generate point-pair files for point cloud correction.

(2) Point Cloud Correction: Based on the marked point-pair files, the point cloud data are corrected to the real geographic coordinate space. The corrected results are then inspected in the point cloud workstation, where check points are used to verify and to analyse accuracy. If local areas exceed the tolerance limits, the point-pair files are revised on the basis of the check points and the mesh model results of the corresponding area, and the correction is repeated until the required accuracy is achieved.

(3) Special Case Handling: In situations where the speed of the survey vehicle changes significantly due to turns, traffic lights, traffic congestion, or similar factors, and GNSS signal interference causes local planimetric misalignment, elevation jumps, or other abnormalities in the processed point cloud data, additional control points are added before and after the affected positions for correction and smoothing. The point cloud data are then reprocessed using the corrected and smoothed vehicle trajectory data. For this purpose, a trajectory correction tool based on control point correction and smoothing has been developed, which can effectively address such problems. Processing is shown in Figure 2.

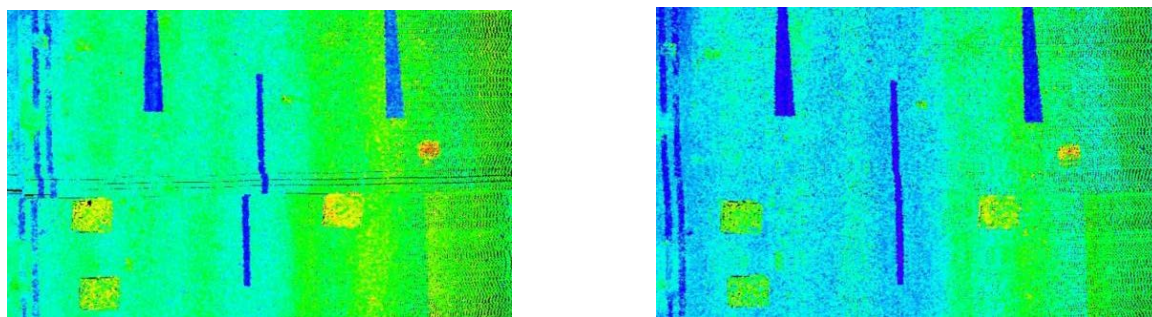


Figure 2. Comparison of point cloud plane misalignment before and after processing

6.3 Image Data Blurring Processing and Georeferenced Coordinate Solution

The georeferenced coordinates of 360° panoramic images and individual images are calculated using the corrected driving trajectory data, thereby generating image products with accurate positioning and measurement capabilities, while privacy-sensitive or confidential information in the images is blurred.

(1) Georeferenced Coordinate Solution is performed using an



image processing program based on the corrected driving trajectory data to obtain image results with accurate positioning and measurement functions, ensuring consistency between point cloud data, 360° panoramic images, individual images, and driving trajectory data. After solving the georeferenced coordinates of the images, their accuracy is detected using check points in Orbit GT software to ensure image accuracy. An example of accuracy detection for 360° panoramic images is shown in Figure 3.



Figure 3. Accuracy test of 360° panoramic images

(2) During data acquisition, private information such as human faces and vehicle license plates, as well as other confidential information not suitable for public disclosure, may be captured. We have developed a tool based on image recognition, which is optimized and trained using annotated samples. We also conduct focused identification of faces on billboards to avoid

incorrect blurring. After automated processing, manual inspection is conducted to correct individual incorrect blurring and missed blurring. The processed results are used for point cloud coloring and data release. The overall processing efficiency is improved by 90% compared with manual methods.

6.4 Point Cloud Coloring and Denoising

Point cloud coloring is performed on the corrected point cloud using images with georeferenced coordinates to obtain colored point cloud data. After point cloud coloring, obvious color assignment deviations and color misalignments are corrected, color differences at stitching boundaries are adjusted, and incorrect color assignments for vehicles and pedestrians are

processed. Denoising is performed on floating point clouds, points corresponding to vehicles and pedestrians on roads, and discontinuous points generated during bidirectional road scanning, so as to improve the clarity and cleanliness of the point cloud and produce the final-colored point cloud dataset.

(1) Point Cloud Coloring: Point cloud data contain accurate spatial structure information, while image data provide rich texture information. Point cloud coloring is carried out on the corrected point cloud data that meets the accuracy requirements and the blurred image data with georeferenced coordinates, thereby generating colored point cloud data. During coloring process, 360° panoramic images and individual images are used in combination to avoid texture loss caused by occlusions. After coloring, various color assignment errors are inspected and corrected to optimize the texture effect and ensure that the colored point cloud meets both accuracy and color quality requirements. Particular attention should be paid to handling obvious color assignment deviations and color misalignments, significant color differences at stitching boundaries, and incorrect color assignments for vehicles and pedestrians, so as to ensure accurate colors and consistent tones in the final colored point cloud data. We have developed a visual texture editing tool based on mask technology, which can intuitively and comprehensively use 360° panoramic images and individual images from different angles to perform local color adjustment

and optimize the coloring texture effect, so as to ensure that the colored point cloud meets the accuracy and color requirements. The comparison of road colorization errors before and after processing is shown in Figure 4.

(2) Point Cloud Denoising: Various types of noise points in colored point clouds can seriously affect the usability of point cloud results, and therefore must be removed through denoising. The noise points are mainly fall into three categories: floating point clouds in the air, points corresponding to vehicles and pedestrians on roads, and discontinuous points generated during bidirectional road scanning. Denoising is carried out using software to identify and remove such noise points automatically, after automated processing, the results are further checked for omissions and over-denoising, and manual adjustments are made as necessary to improve the clarity and cleanliness of the colored point cloud, thereby producing the final point cloud dataset. The comparison of pedestrian noise removal before and after processing is shown in Figure 5.



Figure 4. Comparison of road colorization errors before and after processing



Figure 5. Comparison of pedestrian noise removal before and after processing

6.5 Orbit GT Data Preparation and Result Submission

In this project, Orbit GT software is mainly used for point cloud data management, result quality inspection, and data release. Following the previous data processing, the colored point cloud data, 360° panoramic image data, individual image data, and vehicle trajectory data with georeferenced coordinates that meet the required accuracy requirements are imported into Orbit GT software, and then the data is checked to ensure the alignment of colored point cloud data, image data, and vehicle trajectory data. Any data exceeding the tolerance limits must be investigated and corrected. In Orbit GT software, the coordinates of any position in the colored point cloud and 360° panoramic image can be measured. After the data pass quality inspection, data release can be carried out.

7. Result Evaluation

7.1 Accuracy Evaluation

Accuracy is an important criterion for evaluating the quality of surveying and mapping results. The data acquisition and result production in this study area mainly follow the accuracy requirements specified in the project bidding documents and commencement reports, namely: for colored point cloud data and 360° panoramic image data, the relative accuracy requirements are a maximum horizontal position error no more than 0.05m and a maximum elevation error no more than 0.10m; the absolute accuracy requirements are a maximum horizontal position error no more than 0.15m and a maximum elevation error no more than 0.30m; the alignment error between 360° panoramic images and colored point cloud data no more than 0.05m. In this project, field-measured check points were used to

assess the accuracy of data results, and the error statistics are shown in Table 1.

Category	Maximum Planar Position Error/m	Maximum Elevation Error/m
Relative Error of Colored Point Cloud	0.043	0.051
Relative Error of 360° Panoramic Image	0.040	0.041
Absolute Error of Colored Point Cloud	0.119	0.087
Absolute Error of 360° Panoramic Image	0.131	0.107
Alignment Error of Colored Point Cloud/360° Panoramic Image	0.047	0.049

Table 1. Error Statistics

The statistical results show that the accuracy of the coloured point cloud data and 360° panoramic image products generated in this study area meets the specified requirement.

7.2 Application Evaluation

Based on the results of the Provision of Services for the Generation of 3D Digital Map in East Kowloon for the Lands Department, this paper verifies the reliability and practicality of the SSW vehicle-mounted laser mobile mapping and modeling system, as well as its operational scheme. The project outcomes have been applied in surveying and mapping, transportation, architecture, and other fields, thereby promoting the digital transformation of related industries. Meanwhile, during the project implementation, relevant software and tools for point cloud coloring, point cloud denoising, and blurred image data processing were developed and optimized, further driving technological innovation.

It should be noted that this scheme shows the best effects and accuracy when there is no occlusion on both sides of the road. If tall trees or other fixed obstacles block the roadside ancillary facilities and buildings during data acquisition, it will result in incomplete local data. In such cases, a backpack or handheld mobile mapping system shall be used to flexibly conduct supplementary acquisition for key occluded areas to complete the dataset.

8. Conclusion

Taking the mobile mapping operation of the Provision of Services for the Generation of 3D Digital Map in East Kowloon for the Lands Department as a case study, this paper proposes a method based on the SSW vehicle-mounted laser mobile mapping and modeling system for the rapid production of colored point cloud data with geographic reference coordinates, 360° panoramic image data, and individual image data. Both the point cloud and image products demonstrate high precision, and fully meet the accuracy requirements of the project.

The results were released to the public free of charge as the first batch of visualized 3D map data on the Common Spatial Data Infrastructure Portal (portal.csdi.gov.hk), drawing widespread attention and favorable recognition. The application of these results not only promotes the popularization of the SSW Vehicle-Mounted LiDAR Mobile Mapping and Modeling System, but also provides a valuable reference for similar urban vehicle-mounted mobile mapping operations.

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