A fast approach to generate large-scale topographic maps based on new Chinese vehicle-borne LIDAR system

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Abstract. Large-scale topographic maps are important basic information for city and regional planning and management. Traditional large-scale mapping methods are mostly based on artificial mapping and photogrammetry. The traditional mapping method is inefficient and limited by the environments. While the photogrammetry methods (such as low-altitude aerial mapping) is an economical and effective way to map wide and regulate range of large scale topographic map but doesn’t work well in the small area due to the high cost of manpower and resources. Recent years, the vehicle-borne LIDAR technology has a rapid development, and its application in surveying and mapping is becoming a new topic. The main objective of this investigation is to explore the potential of vehicle-borne LIDAR technology to be used to fast mapping large scale topographic maps based on new Chinese vehicle-borne LIDAR system. It studied how to use the new Chinese vehicle-borne LIDAR system measurement technology to map large scale topographic maps. After the field data capture, it can be mapped in the office based on the LIDAR data (point cloud) by software which programmed by ourselves. In addition, the detailed process and accuracy analysis were proposed by an actual case. The result show that this new technology provides a new fast method to generate large scale topographic maps, which is high efficient and accuracy compared to traditional methods.

Keywords: New Chinese Vehicle-borne LIDAR, Large Scale Topographic Map, Point Cloud, Fast Mapping.

1. Introduction

1:500 topographic maps are one kind of basic information for city or regional planning and management [1]. Usually, low-altitude aerial mapping is an economical and effective way to map wide and regulate range of large scale topographic map surveying and updating. However, this method doesn’t work well in the small area, because of the heavy expense [2]. Currently, it usually uses artificial field measurement method to map 1:500 large scale topographic map revisions and supplementary. While its efficiency is relatively slow and limited by the operating environments [3]. It analyse how to use the new domestic vehicle-borne LIDAR measurement technology to map 1:500
topographic maps. The detailed process and accuracy analysis were proposed by an actual case. This new technology provides a new method to generate large scale topographic maps.

2. The vehicle-borne LIDAR Technology principle and accuracy analysis

2.1. The vehicle-borne LIDAR technology

Recent years, with the development of navigation and positioning technology, the vehicle-borne LIDAR technology also has a rapid development, which has already come into commercial operation mode from research stage during a few years, such as Street-Mapper system, Lynx system, the IPS-the S2 system, MMS, SSW series, which all have made a successful commercial operation ‘[4-6]’. A large number of Google earth street scenes demands promote the application of the vehicle-borne technology. Until now, vehicle-borne LIDAR has been used in topographic mapping, highway tunnel surveying, road monitoring, 3D modeling of the building, street scene reconstruction, the overpass surveying, power line measurement, mine surveying, etc. ‘[7]’. The vehicle-borne LIDAR system application in the production of large-scale topographic maps is still on the preliminary stage, and its accuracy and stability control are key issues.

It researched the application of the domestic vehicle-borne LIDAR system SSW (Shoushi SiWei, Figure 1) and the measurement accuracy of this kind system was analyzed. SSW is made by Chinese Academy of Surveying and Mapping and Capital Normal University ‘[8]’, which is a new kind of vehicle-borne LIDAR system. Now the system has come into the domestic market, and Beijing Institute of Surveying and Mapping is the industrial base of the system. This system is a multi-sensor integrated system, which is integrated by a Chinese high-precision laser scanner, a domestic high precision IMU, six color area CCD cameras, a Trimble GPS receiver, a precision wheel odometer and other ancillary equipment composition. Position sensors consist of the IMU, GPS and odometer. And IMU records the instantaneous attitude of the carrier, the GPS records the instantaneous position of the carrier, the odometer records instantaneous vehicle running distance information, these three sensors tightly integrated into the navigation system, which can better solve the GPS signal loss of lock and greatly improve the positioning accuracy.

![Figure1. The Vehicle-borne 3D data acquisition system SSW](image)

2.2. The principle of the vehicle-borne LIDAR technology

The main vehicle-borne LIDAR data acquisition sensors are three-dimensional geometric information gathering sensors (3D laser scanner), texture acquisition sensors (color CCD camera). And the positioning sensor consists of GPS, IMU and one distance measuring instruments. 360 ° laser scanner rotating in a high speed, with mobile of the carrier, collects 3D point position. Meanwhile the laser scanner emits synchronization pulse to trigger these six cameras to expose. In order to achieve the time synchronization, GPS, IMU and odometer all have time information recorded in the laser scan data in accordance with frequency. This system must be calibrated in order to get accurate sensor relative position ‘[5]’.

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After the field work, all the point cloud data must be converted to the local coordinate system for mapping, the work flow is as following:

![Diagram of coordinate conversion](image)

**Figure 2. The flow of the coordinate conversion**

Where, Laser scanning instantaneous coordinate system is the coordinates of the laser footprint in the coordinate system of the instantaneous laser beam, \((x_{SL}, y_{SL}, z_{SL})^T\); Laser scanner reference coordinate system is the coordinates of the laser footprint in the reference coordinate system, \((x_L, y_L, z_L)^T\); Inertial platform coordinate system (IMU coordinate system) is the coordinates of the laser footprint in the inertial platform reference coordinates system, \((x_I, y_I, z_I)^T\); Local level reference coordinate system is the coordinates of the laser footprint in the local level reference coordinate system \((x_{LH}, y_{LH}, z_{LH})^T\); WGS-84 coordinate system is the coordinates of the laser footprint in the WGS-84 coordinate system \((x_{84}, y_{84}, z_{84})^T\).

\[
\begin{bmatrix}
  x_{84} \\
  y_{84} \\
  z_{84}
\end{bmatrix} = R_w R_G R_N 
\begin{bmatrix}
  0 & 0 & \Delta x_I^L \\
  0 & \Delta y_I^L & 0 \\
  \Delta z_I^L & 0 & 0
\end{bmatrix}
\begin{bmatrix}
  x_L \\
  y_L \\
  z_L \\
\end{bmatrix} + 
\begin{bmatrix}
  \Delta x_I^G \\
  \Delta y_I^G \\
  \Delta z_I^G
\end{bmatrix}
\]

So

\[
\begin{bmatrix}
  x_{84} \\
  y_{84} \\
  z_{84}
\end{bmatrix}_{Antenna phase center} + 
\begin{bmatrix}
  \Delta x_I^G \\
  \Delta y_I^G \\
  \Delta z_I^G
\end{bmatrix}_{WGS-84}
\]

Vector as follows:

\[
P_{WGS-84} = R_w R_G R_N (R_M R_L \cdot r + t_L - t_G)
\]

Where,

\(P_{WGS-84} = (x_{84}, y_{84}, z_{84})^T\) is the coordinates of the laser footprint in the WGS-84 coordinate system;

\(t_G = (\Delta x_I^G, \Delta y_I^G, \Delta z_I^G)^T\) is the offset between antenna phase center and the inertial platform reference center;

\(t_L = (\Delta x_I^L, \Delta y_I^L, \Delta z_I^L)^T\) is the offset between ten emit reference center and the inertial platform reference center;

\(r = (0,0,\rho)^T\) is the position vector of the laser footprint in the instantaneous laser coordinate system;
\( R_W, R_G \) are the coordinate rotation matrix relative to current position;
\( R_N, R_I \) are the rotation matrix of the real or interpolating attitude angle and the laser scanning angle;
\( R_M \) is the resettle errors rotation matrix.

3. The detail method using vehicle-borne LIDAR to mapping 1:500 topographic maps

3.1. The vehicle-borne LIDAR system error analysis

It divided Vehicle-borne LIDAR system error and its source into four categories:

1. Positioning error. The position sensors consist of GPS, IMU and wheel odometer. The main position error comes from the GPS positioning error.
2. The angular measurement error. It includes two important parts, GPS / INS Integrated Navigation attitude determination error and the scan angle error.
3. Ranging error. It consists of laser scanning ranging error and odometer ranging error, and the laser scanning ranging error is more important.
4. Integrated error. Here, it mainly refers to the angel error and the range error between the sensors in this whole integrated system.

In order to eliminate these errors, before using this kind of system the stand-alone calibration and system calibration must be done to eliminate the laser scanner angular measurement error and ranging error, system integration error \([9]\).

3.2. The detail working flow of vehicle-borne LIDAR technology

Usually, during the field surveying it selects at least one point in the middle of the survey area, which is not covered by other objects, as the control point and measures it by static GPS. Meanwhile, there must be one static GPS point within 5km. The detailed processes are summarized below:

![Figure 3. The work flow of the vehicle-borne LIDAR system](image)

3.3. The accuracy control of the vehicle-borne LIDAR system

According to the vital factors affect the accuracy of the vehicle-borne, it proposed the following measures to improve the accuracy:

1. High precision GPS control of the field surveying

   There must be at least one GPS static station within 5km. The GPS station guarder should pay attention to the safety and GPS signal during the data collection, if there is some accidence, he/she must keep in touch with the vehicle-borne LIDAR system in time.

2. Quality control of the coordinate system conversion
The vehicle-borne LIDAR data does not require data mosaic. It uses one series of unified control points to control the overall data, so it can remove the traditional static terrestrial LIDAR system splicing errors. And the coordinate system conversion must use high-precision ground control points.

(3) The mapping precision control.
The accuracy of the mapping is not only directly affected by the point cloud accuracy, but also by the point cloud density. So the accuracy can be improved by adjusting the density of the point cloud.

4. The successful case analysis
Pinggu District is one of the suburban counties of Beijing China, which consists of 1/3 mountain, 1/3 light the mountains and 1/3 plains. With the development of the social and economic, some sections of the 1:500 topographic maps need to be revised or complemented. The case in this paper is a shallow mountain; figure 4 shows the vehicle-borne LIDAR system point cloud of some sections (side view).

Figure 4. The side view of the surveying area

Vehicle-borne LIDAR system (SSW) has supporting application software named DY-2, which can map on the point cloud. Figure 5 is the first draft drawing of the corresponding area in this software. The first draft must be put into the AutoCAD by *.Dxf format to be revised into appropriate scale of maps, figure 6 and figure 7 are the corresponding 1:500 topographic maps.

Figure 5. The first draft of the corresponding area

Figure 6. Corresponding area 1:500 topographic map
It selected 125 plane points to participate in the calculation, and the final plane accuracy is ± 0.314m. 90 points are selected to calculation the elevation accuracy and the final elevation accuracy is ± 0.26m. Both of the accuracy can satisfy the requirement of 1:500 mapping.

5. Conclusion
The paper summarize the characteristics of vehicle-borne LIDAR technology, and then the error sources of some data acquisition are discussed from the principle of the LIDAR system itself, and these errors are analyzed 1:500 scale topographic maps is generated using the data from vehicle-borne LIDAR system and then the large scale mapping technical processes of this system and quality control methods are proposed. A real data set taken from LIDAR system is used to test the proposed method. The result shows that the LIDAR system can generate the map which the plane accuracy is about ±0.314m, and the elevation accuracy is about ±0.26m, which can meet the accuracy of 1:500 large scale topographic maps. The result of this paper could provide a reference for the application of vehicle-borne LIDAR technology in large scale mapping.

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