Research on Calibration Method of Vehicle Mapping System based on Special Target

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ABSTRACT

In order to obtain the high-accuracy 3d data of roads and buildings, it is necessary to calibrate the relative parameters of the vehicle mapping system named MMS. At present, there are many disadvantages in most of the methods used in system calibration, such as the calibration points can not be picked with high precision, absolute precision is low and the method is hard to use. The paper explored a kind of rapid, convenient and accurate method of calibrate the relative parameters of the mobile mapping system. The analysis of precision experiments show that this method can make up for the shortcomings, applicability and practicability of the method compared with the traditional method. The overall level of precision is 0.05 m below the elevation accuracy reaches 0.06 m below. The accuracy and applicability of this method is fully satisfied with the precision requirement of the mobile's scanning system.

INTRODUCTION

Mobile mapping system is the most mainstream way to collect high precision point cloud of city roads, highways and buildings. Figure 1 shows the MMS, which integrated by GPS, inertial navigation, scanners and other sensors. Meanwhile, it shows the schematic from the original data ([X_laser Y_laser Z_laser]^T) to the final point cloud ([X_b Y_b Z_b]^T) under Beijing urban coordinate system. Formula 1 shows the specific principle of point cloud data collection and it is also the calibration model.

\[
\begin{bmatrix}
X_b \\
Y_b \\
Z_b
\end{bmatrix} =
\begin{bmatrix}
X_{gps} \\
Y_{gps} \\
Z_{gps}
\end{bmatrix} + R_M \begin{bmatrix}
X_{laser} \\
Y_{laser} \\
Z_{laser}
\end{bmatrix} + R_O \begin{bmatrix}
\Delta X_{LI} \\
\Delta Y_{LI} \\
\Delta Z_{LI}
\end{bmatrix} + \begin{bmatrix}
\Delta X_{IG} \\
\Delta Y_{IG} \\
\Delta Z_{IG}
\end{bmatrix} \quad (1)
\]

Generally, it can be known that the original data can be accurate obtained by processing the raw data of the scanner. The matrix from the reference frame coordinate system to the local horizontal coordinate system R_N and the matrix from the local horizontal coordinate system to the WGS84 longitude and latitude coordinate system R_M could be known by calculating the IMU data. The position of the GPS antenna [X_{gps} Y_{gps} Z_{gps}]^T could be gained by calculating the differential GPS data. Therefore, it is important for the system by calibrate the installation error include the installing shift parameter [\Delta X_{LI} \Delta Y_{LI} \Delta Z_{LI}]^T, [\Delta X_{IG} \Delta Y_{IG} \Delta Z_{IG}]^T and the installing rotate parameters R_O.
There are many methods to calibrate the mobile scanning system. In the literature [1], it proposed the method of calibrate the external position element by using the control point. In literature [2], it proposed the method of calibrate the external position element by using feature surface. Literature [3] proposed a method to dynamically calibrate the external side parameters with a small Angle correction, and verified the calibration model of 12 parameters. Literature [4] proposed a method to calibrate the external position element by using three dimensions of vertical wall.

According to the installing rotate parameters, the paper proposed a calibration method of mobile scanning system by using a special spherical target. It can solve the problem such as hard to get the coordinates of the feature point/surface in high precision and so on.

THE METHOD AND EXPERIMENTAL DEMONSTRATION

The Method

The target is designed by using a level bubble to connect the spherical target and the reflector plate above which can make the center of them on the same plumb line as the Figure 2 shows. The real center coordinates of target can be measured by the total station. And the initial value of it can be obtained by fitting target. Because the fitting precision is high enough, it can solve the problem of obtaining the initial target data with high precision.

According to the calibration model, only $R_0$ needs to be calibrated, so the other values have to be given the exact value first. For the spherical target, the initial parameter $R_0$ can be obtained by the design value and the installing shift parameters also can be achieved by handheld scanner with millimeter accuracy. The position of GPS antenna $[X_{gps} Y_{gps} Z_{gps}]^T$ and $R_M R_N$ could be calculated by the distance ratio.
between the center coordinates to the nearest two target section plane. The original data could be calculated by inverse calculation of the calibration model. The next step is calculate the finial installing rotate parameters by using the least squares principle of indirect adjustment. Last step is reprocessing the data by the parameters after the calibration. The Figure 3 shows the flow diagram of the method.

![Flow diagram of the method.](image)

**Figure 3.** The flow diagram of the method.

**Experimental Demonstration**

In order to verify the feasibility of the method, choosing a road as the calibration field. The special targets were placed in both sides which distribution are as Figure 4 shows. At the beginning of the experiment, the real value of the target could be confirmed through the reflector plate measured by the total station minus the fixed difference, then calibration started.

![Distribution of the target.](image)

**Figure 4.** The distribution of the target.

Follow the flow chart above, the first step is to extract and fitting the target data into sphere. The initial value of the center of the sphere also could be achieved. Then classifying the scan line identified by ID. The second step is to fit each scan line into the plane. After fitting the plane, calculating the distance value between the center point of fitting sphere and the plane, through comparing the distance, calculate the ratio of the distance which are the two smallest. The third step is the interpolation. The BLH value can be inverse calculated whose name is \( R_M \). Because the mobile scanning system is in continuous movement, so the attitude of the inertial navigation value, Roll Pitch Heading value, is also in continuous smooth change, and after interpolation, attitude values can be considered as smooth value directly in 0.001 seconds, so the attitude value of the center of the target sphere, Roll Pitch Heading value, can be obtained by using the previous ratio, thus \( R_N \) values can be obtained. In the end, the last parameters should be known firstly is the points in the original virtual scanner space coordinate can be achieved by calculating the inverse calibration model with the previous parameters in it. The Figure 5 shows the detail of calculating the spherical parameters.
The TABLE I shows that the overall accuracy is relatively poor by comparing the initial data with real data. The high accuracy of the whole station and the control network conform to the point accuracy of the calibration field. So some target were chosen as a calibration target. Making the point data collected by the total station with 0.5 second level accuracy as true value and making the initial spherical coordinates as observed values calculated by original parameters, using the method for calibration, through constant iterative calculation of the ultimate rotation parameters.

Through the calculation above, put the parameters into the calibration model, then calculating the model by using the least squares principle of indirect adjustment. In this step, the value obtained by the total station should be the known values and the center of target coordinates should be the observed value. Meanwhile, the installing rotate parameters should be the parameters need to be solved.

The observation equation in Matrix form is as follows:

\[ V = BX - L \]  \hspace{1cm} (2)

Access:

\[ X = (B^T B)^{-1} B^T L \]  \hspace{1cm} (4)

After solved the normal equation, what need to do is to put the X into the observation equation, the final result can be achieved. Then set the adjustment threshold, compare the difference between the adjustment result and the initial
parameter with the threshold, if it is bigger than threshold, put the final parameter back to adjust again until it is smaller than the threshold and it is the final parameter we need.

Because the design of this experiment is relatively perfect, the distribution of the target is reasonable, and the IMU system runs well, and it does not cause big disturbance to the final result as the TABLE II shows.

### TABLE II. CALIBRATION PARAMETERS.

| Parameter value | Initial α | Initial β | Initial γ | Post calibration α | Post calibrations β | Post calibration γ |
|-----------------|-----------|-----------|-----------|--------------------|--------------------|--------------------|
| -30             | 180       | 0         | -27.59452 | -180.48123         | -1.52136           |

### TABLE III. COMPARISON OF CALIBRATION DATA ERRORS

| Post-calibration Spherical Coordinates | Total Station Coordinates | Error |
|----------------------------------------|---------------------------|-------|
| X | Y | H | X | Y | H | ΔX | ΔY | ΔH |
| 494135.1102 286493.7494 45.0654 | 494135.0958 286493.7013 44.9733 | 0.0144 | 0.0481 | 0.0921 |
| 494172.8213 286450.9204 44.8377 | 494172.7810 286450.9111 44.8758 | 0.0403 | 0.0093 | -0.0381 |
| 494135.102 286437.4281 44.6543 | 494135.0464 286437.3864 44.7004 | 0.0556 | 0.0420 | -0.0461 |
| 494117.8120 286442.7071 43.1421 | 494117.8125 286442.7427 43.1901 | -0.0005 | -0.0356 | -0.0480 |
| 494127.2825 286449.2623 42.8631 | 494127.3120 286449.2930 42.8220 | -0.0295 | -0.0307 | 0.0411 |
| 494136.2509 286466.8692 43.3799 | 494136.2870 286466.9100 43.4460 | -0.0361 | -0.0408 | -0.0661 |
| 494135.1089 286493.8044 44.9286 | 494135.0973 286493.6966 44.9779 | 0.0116 | 0.1078 | -0.0493 |
| 494135.102 286437.4281 44.6543 | 494135.0464 286437.3864 44.7004 | 0.0556 | 0.0420 | -0.0461 |
| 494117.8120 286442.7071 43.1421 | 494117.8125 286442.7427 43.1901 | -0.0005 | -0.0356 | -0.0480 |
| 494127.2825 286449.2623 42.8631 | 494127.3120 286449.2930 42.8220 | -0.0295 | -0.0307 | 0.0411 |

Figure 6. The error curve in three direction.

After calibrating the parameters of the model, the data is reprocessed and also fit the coordinates of the center of the sphere target again.

It can be concluded from the above table and chart named TABLE III and Figure 6 that all the spherical target error in all direction were in reducing and all the error value are around ±0.05m. The details are as follows: the mean square error in the X direction is 0.037113; the mean square error in the Y direction is 0.033806; the mean square error in the H direction is 0.048856; all the mean square error are under 0.05m. For the whole target, after the calibration, the error in the X direction is around ±0.05m, the error in the Y direction is around ±0.05m, the error in the H is around ±0.07m and the mean square error in the X direction is 0.036042m, the mean square error in the Y direction is
0.048423m, the mean square error in the H is 0.065878m. The accuracy can fully satisfy the needs of mobile scanning system. The calculation and analysis shows that the precision of MMS are very high, and the validation of the calibration method is successful.

CONCLUSIONS

This paper discussed the new method of calibrate three parameters of the mobile scanning system by the special spherical target. The method is verified through the calibration experiment used the special spherical target in different positions and directions. The accurate three parameters were obtained by calibrating the mobile scanning system. It shows that comparing with the point cloud data which were collected by the MMS without calibration, the accuracy of the point cloud data obtained by the mobile scanning system which were calibrated by using the method in this paper were improved both in absolute accuracy. It provides a strong guarantee for the rapid collection and application of 3d data.

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