Calibration method of simulation data of virtual GPS and truth value in real world

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Abstract. At present, the complexity of the research and development process of the intelligent connected vehicle and the diversity of research methods increase the difficulty of establishing, integrating and verifying of virtual simulation experiments. In view of the deviation of the virtual vehicle sensor in the simulation experiment to the restoration of the real environment, this paper proposes to use the multi-point positioning method for data calibration, use the least square method to estimate the unknown point position in complex situations, and according to the error size after calibration, specific evaluation criteria are given. Finally, the scene verification and simulation evaluation of the calibration method of the GPS simulation data in the virtual environment and the truth value in the real world were carried out. The results show that this method effectively improves the restoration degree of the virtual simulation sensor to the real environment.

1. Introduction

Autonomous driving simulation experiment [1] is the only way for the development of autonomous driving technology. It uses computer modeling and virtual engine technology to digitally restore the real world, and then uses the high reproducibility and execution of the simulation environment, at the same time, it combines vehicle dynamic simulation [2], sensor fusion simulation [3], parallel acceleration computing and other technologies to carry out objective test and verification [4], and evaluates algorithms [5] related to automatic driving. Self-driving vehicles are usually driven in complex traffic environments. On-board sensors need to interact with the environment in real time to dynamically sense the surrounding environment [6]. In addition, there will always be certain deviations when the sensors actually sense. If the vehicle is driving fast on highway with limited width, such deviations are likely to cause traffic accidents, so the sensor’s perception accuracy must be improved. Corresponding to the simulation environment, the degree of restoration of the virtual sensor’s perception results to the truth value needs to be calibrated. The virtual sensor’s product-level simulation degree needs to be evaluated.

2. Autonomous driving simulation scene

At present, there are hundreds of test scenarios in the scene library of self-developed intelligent connected vehicle simulation software. The logistics park simulation scenario is also one of the typical scenarios for testing. The logistics park in the real world and the virtual logistics park in the simulation environment are shown in the following figure. The logistics park in the real world is about 670 meters long and 240 meters wide. If the ground fluctuations are ignored, they can be approximated on the same level.
3. Calibration principle of GPS
At present, there is a certain deviation between the virtual GPS data in the logistics park of simulation scene and the real GPS data of the logistics park in the real world. In this experiment, the multi-point positioning method is used for calibration, and the least-square method is used to estimate the unknown points in complex situations.

3.1. Multi-point positioning
The multi-point positioning method takes three-point positioning [7] as an example, and its principle is briefly described as follows:

It uses the coordinate position information of three points A, B and C to calculate the current position information of point O, that is, the known three point position coordinates \( A(x_1, y_1) \),
B(x_2, y_2), C(x_3, y_3) and the unknown point O(x, y) distance to three points d_1, d_2, d_3. Then use d_1, d_2, d_3 as the radii to make three circles, and the formula for calculating the position coordinates of the unknown point O can be obtained:

\[
\begin{align*}
(x - x_1)^2 + (y - y_1)^2 &= d_1^2 \\
(x - x_2)^2 + (y - y_2)^2 &= d_2^2 \\
(x - x_3)^2 + (y - y_3)^2 &= d_3^2
\end{align*}
\]

In this way, the positioning problem is transformed into the problem of finding the coordinates of the intersection point of the three circles. Finally, the coordinate value of the unknown point O(x, y) is obtained, and the GPS coordinates of the unknown point can be obtained through coordinate conversion.

3.2. Least Squares

The basic idea of Least Squares [8] is: when given a set of experimental data, these data are often ordered number pairs, according to the principle of squared error minimization, find the best function match for these data.

The mathematical principle of least squares is: suppose given a set of data:

\[[x, y] = (x_i, y_i) (i = 1, 2, ..., n)\]

Let its empirical equation is \(F(x)\), The equation contains some undetermined coefficients \(a_n\). Substitute \((x_i, y_i)\) into the equation to find the difference \(y_i - F(x_i)\). In order to consider the overall error, the sum of squares can be taken. The reason for the square is to consider that the plus and minus of the error directly add to each other causes mutual cancellation, so the error is written:

\[e = \sum (y_i - F(x_i))^2\]

By finding the minimum value of \(e\), \(a_n\) can be obtained, so as to find the best fitting function of the set of data, which minimizes the sum of squared errors.

4. Calibration method of GPS

Specific to the intelligent connected vehicle autonomous simulation software, there is a certain deviation between the data output by the virtual GPS in the simulation scenario and the real GPS data in the real world. This experiment divides the GPS calibration work into 3 parts: point measurement, data calibration, calibration evaluation.

4.1. Point measurement

According to the principle of multi-point positioning, this experiment will measure 6 points in the real logistics park, 3 of which are used for positioning and 3 for verification. The specific points to be tested are shown in the figure below:

![Figure 4. Bitmap of the points to be tested in real logistics park.](image)

This experiment uses a coordinate collection vehicle equipped with a high-precision integrated
navigation system to measure. When the collection vehicle is close to the point to be measured, record the GPS coordinates displayed by the navigation system and the distance and orientation of the collection vehicle relative to the point, and then according to the vehicle size and the actual position of the navigation system in the vehicle, the GPS coordinates of the point to be measured can be calculated.

Since the point to be measured is the reference point used to calibrate the virtual GPS output data in the simulation scenario, the above measurement results should be as close as possible to the actual coordinates of the real road. The measurement requirements are as follows:

1. When measuring points, try to get as close as possible to objects with obvious characteristics, and give the distance and orientation of the collection vehicle to the point to be measured.

2. It is necessary to take photos of the position of the collection vehicle during the real scene measurement to verify the consistency of the reference point in the virtual scene and the real road to be measured.

3. It is recommended to measure 5-10 times for each point. After removing the maximum and minimum values in the calculation, take the average value to reduce the measurement error.

4.2. Data calibration

The first step is calibration. First, the true value of the 6 measurement points in the real logistics park is calibrated to the corresponding position of the logistics park scene in the simulation software as the reference point. The characteristics of the reference point should be as obvious as possible. The corners of warehouse or duty room are the main ones, which not only ensures the accuracy of taking points in the real scene, but also facilitates the targeted calibration in the virtual scene. The calibration result is shown below:

![Figure 5. Reference points of simulation scenario of logistics park.](image)

The second step is calculation. First select any three points in the reference points (The distribution of the three points cannot be close to a straight line to avoid affecting the measurement accuracy), we take the three points that are closer to the target point as an example, first convert the distance of the target point to the above three reference points by vector calculation in the simulation software, and then draw circles with this distance as the radius, the ideal result is shown in the figure below:
Figure 6. Calibration of target point in simulation scenario (ideal).

After getting the three circles, ideally the three circles intersect at one point, which is the target point. However, there are measurement errors in point measurement and calculation errors in the simulation scene, resulting in errors in the calculated distance, that is, there are errors in the radius, then there may be no or multiple intersection points between the drawn circles. In a complex intersection situation, there may be more than one target point at this time. The alternative description is as follows:

Figure 7. Calibration of target point in simulation scenario (non-ideal).

In fact, no matter what kind of situation determines the final positioning result is the radius of the circle. For non-ideal complex situations, we use the least square method to estimate the final coordinates of target point, and then convert the coordinates into the latitude and longitude of the target point, that is virtual GPS coordinate data.

The third step is verification. First select the remaining three reference points in the simulation software, and calculate the distance between the target point and the above three points through vector calculation:
Then repeat the process of the second step to estimate the GPS coordinates of the target point, and use this coordinate to verify the calculation result of the second step, under normal conditions, the error of the two coordinate values is similar.

4.3. Calibration evaluation

Single positioning sensors, such as GPS or BeiDou modules, often have unsatisfactory positioning accuracy in complex urban environments. In addition, drift, slow positioning, and inability to locate can often occur. Usually in an environment with weak satellite signals or no satellite signals, such as under viaducts or in tunnels, a single sensor can hardly meet the requirements for use. Therefore, for autonomous driving applications, most companies will use multi-sensor fusion technology, such as a combined navigation system that combines GNSS and INS to provide multiple navigation parameters. The single-point positioning accuracy of most products that have been mass-produced is between 1-1.5 meters, and the positioning accuracy using RTK positioning technology is about 2 centimeters.

Because the coordinates of reference point in the simulation scenario are the actual data measured by the integrated navigation system in the logistics park and the positioning system usually have a certain measurement error. In addition, there is also a certain simulation error in the GPS coordinate data estimated in the simulation environment. Therefore, the result error of GPS data calibration is:

Calibration error = measurement error + simulation error

Through the above analysis, evaluate the calibration effect of GPS coordinates, based on the final error size of calibration result, the specific evaluation criteria are shown in the following table:

| Error size | Typical error value | Calibration effect |
|------------|---------------------|--------------------|
| cm level   | 5cm                 | Excellent          |
| dm level   | 3dm                 | Good               |
| m level    | 1.2m                | Qualified          |

5. Simulation scenario verification

When measuring points in logistics park in the real world, the model of the coordinate acquisition vehicle used is GE3 (see Figure 9), and the model of the high-precision integrated navigation system is CGI-610. The dimensions of the collection vehicle and the position of the navigation system in the vehicle are shown in Figure 10:
In the self-developed intelligent connected vehicle simulation software, when verifying the GPS calibration method, the task scenario is the logistics park, and the task master vehicle is WEY VV7. The verification scenario is shown below:

When using the scene in the simulation software to verify the GPS calibration method, we selected the coordinate error of 10 points to evaluate it. The error of the virtual GPS coordinate after calibration is shown in the following figure:
6. Experimental summary
Aiming at the problem that there is a certain deviation between the virtual GPS data in the simulation scenario and the real GPS data in the real world, this paper proposes to use the multi-point positioning method for data calibration, and use the least square method to estimate the unknown point position in complex situations. According to the error size after calibration, specific evaluation criteria are given. Finally, the GPS calibration method was experimentally verified in the self-developed intelligent connected vehicle simulation software. The results show that the method of this paper can control the GPS simulation error between the cm level and the dm level, effectively improving the virtual simulation sensor to restore the true value of actual environment.

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