A Pseudorange Difference Positioning Algorithm for Automatic Driving

Yi Chen(✉), Yong Wang, Wei He, Qing Jiang, and Mu Zhou

School of Communications and Information Engineering,
Chongqing University of Posts and Telecommunications, Chongqing, China
`751796746@qq.com`

Abstract. Real-time and accurate positioning is very important for automatic driving. Traditional positioning methods, such as radar and inertial sensor, have limitations in universality and accuracy. Therefore, this paper proposes a pseudorange difference positioning algorithm, which combines Global Positioning System (GPS) receiver with reference station. The proposed algorithm achieves sub-meter positioning accuracy that providing a guarantee for automatic driving. The feasibility of the proposed algorithm is verified in static and dynamic environments, respectively. The results show that the positioning error is less than one meter.

Keywords: Automatic driving · Pseudorange difference positioning · Reference station

1 Introduction

Automatic driving is an inevitable trend of human development and progress that will lead us into a new era. In the process, lots of difficulties need to be solved. A serious problem is how to achieve high accuracy and real-time positioning when car is running. Another one is how to achieve the ability of compatibility and adaptation for various complex environments. Although researchers in this field have made great efforts, there are still so many worth works need to be done. Li et al. in [1] study the problem of positioning latency for real-time position. Zhang et al. in [2] analyze the precise point positioning(PPP) of Global Positioning System (GPS). Misra et al. in [3] and Parkinson et al. in [4] analyze the pseudorange difference positioning in detail. The authors in [5] and [6] discuss various high-precise positioning methods of GPS. Satellite-terrestrial communication systems, joint cooperative spectrum sensing and channel selection optimization have been proposed in [7–9]. However, the above mentioned works cannot solve the problem of how to apply their positioning algorithm in practice and how to achieve the high accuracy with sub-meter even sub-centimeter.

Therefore, this paper proposes a pseudorange difference positioning algorithm for automatic driving. Firstly, a car terminal collects the observation pseudorange data of GPS receiver and reference station simultaneously. Then, by using the proposed algorithm to build the trilateration localization equations with pseudorange difference positioning model, we can obtain the positioning results. Experiments show that the proposed algorithm gives a positioning accuracy with error less than one meter. The

M. Jia et al. (Eds.): WiSATS 2019, LNICST 280, pp. 218–225, 2019.
https://doi.org/10.1007/978-3-030-19153-5_22

rest of the paper is organized as follows. In Sect. 2, we describe the whole system framework of pseudorange difference positioning. The experiment results show the static and dynamic positioning accuracy in Sect. 3. And Sect. 4 concludes this paper.

2 System Description

The pseudorange difference positioning system framework is shown in Fig. 1, which can be divided into three parts: car terminal, reference station and the pseudorange difference model. Firstly, pseudorange observations of GPS satellites and ephemeris data including the satellite position information, can be obtained through GPS car terminal. At the same time, the car terminal needs use public network to obtain the observation and location of reference station through the NTRIP protocol. Finally, the pseudorange difference model is utilized to obtain the real-time position of car terminal with the pseudorange observation of reference station and car terminal.

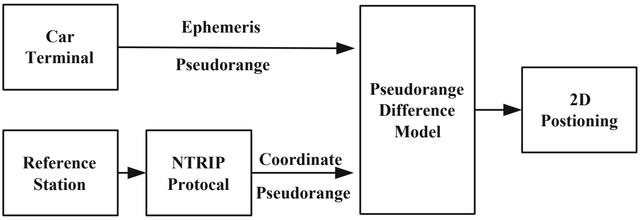


Fig. 1. System framework

2.1 Reference Station Data

Data Collection

Since Pseudorange difference positioning algorithm requires a reference station to provide real-time pseudorange observation data, we can use the strong spatial correlation between the car terminal and reference station to eliminate various errors such as satellite clock error, ionospheric delay and tropospheric delay. Generally speaking, the service of reference station is provided by professional location service companies (such as QianXun), which can provide many benefits, such as reducing the cost of difference positioning and the complexity of achieving high-precision positioning, or increasing the widespread use of difference positioning [10].

As shown in Fig. 2, the observation data of reference station follows an NTRIP protocol. The NTRIP protocol is built on the HTTP protocol and is specified for difference positioning. The car terminal establishes communication connection with the reference station using the public network. The detailed communication process can be divided into three steps which is given as follows.

- Step 1: The car terminal sends a request connection to obtain difference data sources. The reference station gives concrete parameters of data source table, such as mount point, difference data type and transmit frequency.
- Step 2: According to the concrete parameters, the car terminal selects a mount point with professional account and password to request login operation. The "ICY 200 OK" message will be responded after confirming that the account information is correct.
- Step 3: After receiving the confirmation information, the car terminal sends a GPGGA message, which includes imprecise location information of car terminal, to get the reference station location and real-time pseudorange observation data for solving car terminal position.

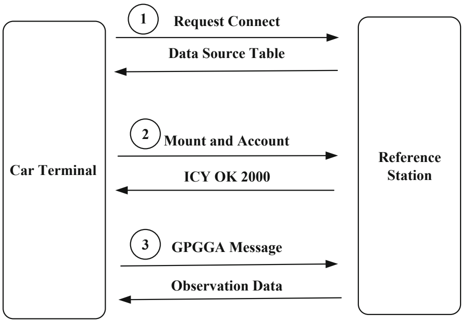


Fig. 2. NTRIP communication process.

Data Decode

The difference data acquired by the car terminal through the NTRIP protocol conforms to the RTCM32 standard, which is an internationally common standard difference data format. The data format [11] consisting of five parts is shown in Table 1.

Table 1. Data format

Guide words (8 bit)	Reserved (6 bit)	Msg length (10 bit)	Var length (0–1023 byte)	CRC (24 bit)
11010011 (0XD3)	000000	Msg size	Msg content	G(X)

The difference data is mainly derived from message 1005 and message 1074 after decoding the reference station data. The message type can be obtained by the first 12 bits of the variable length part. Message 1005 mainly contains the location information of reference station in the WGS84 coordinate system, whose concrete data protocol definition can be further explained in the document RTCM STANDARD 3.2 [12]. Message 1074, containing the real-time pseudorange observation information of reference station for GPS satellites, can be divided into three parts: message header, satellite data and signal data. Message header includes GPS epoch information of the observation satellite, the number of observation satellites and the type of observation data at the current time. Satellite data includes the number of integer milliseconds in GPS satellite rough range and GPS satellite rough range modulo 1 ms. Signal data mainly contains the precise pseudorange observation and signal-to-noise ratio. The accurate pseudorange measurement can be obtained by using above data, and the calculation formula can be expressed as

$$P = \left(Nms + \frac{Roughrange}{1024} + 2^{-24} \times Fine\_Pseudorange \right) \times c/1000, \tag{1}$$

where P is the pseudorange and $c = 299792458\mathrm{m/s}$ is the speed of light. Nms is the number of integer milliseconds in GPS satellite rough ranges, $Roughrange$ is the GPS satellite rough ranges modulo 1 ms, $Fine\_Pseudorange$ is the measurement part with more high accuracy.

2.2 Pseudorange Difference Positioning Algorithm

Positioning Principle

According to the trilateration localization theory, the car terminal needs to solve the specific location of each visible satellite and the precise distance between the satellite and the car terminal. The satellites position and the distance between satellites and the car terminal are the key factors to solve car terminal position. GPS satellites will broadcast ephemeris data every two hours which can be used to calculate the real-time position of every satellite. And the pseudorange observed by the car terminal is used to approximate the actual distance. Therefore, the single point positioning algorithm actually solves the following nonlinear equations:

$$\begin{aligned} \sqrt{(x^1 - x)^2 + (y^1 - y)^2 + (z^1 - z)^2} &= \rho^1 \\ \sqrt{(x^2 - x)^2 + (y^2 - y)^2 + (z^2 - z)^2} &= \rho^2 \\ \sqrt{(x^3 - x)^2 + (y^3 - y)^2 + (z^3 - z)^2} &= \rho^3, \end{aligned} \tag{2}$$

where $X = [x, y, z]^T$ is the unknown car terminal position, $X^n = [x^n, y^n, z^n]^T, n = 1, 2, 3$ is the position of satellite, ρ^n is the pseudorange between satellite n and the car terminal. Obviously, ρ^n is not very accurate on standing for the actual distance because of the various errors, resulting in the poor positioning accuracy.

Pseudorange Difference Model

Assume that the pseudorange measurement of reference station from satellite n is p_r^n, which can be modeled as

$$\rho_r^n = R_r^n + c(\delta_{t_r} - \delta_{t^n}) + I^n + T^n + \varepsilon^n, \tag{3}$$

where R_r^n is the actual distance between reference station and satellite n, δ_{t_r} and δ_{t^n} are the receiver and satellite n clock error, respectively, I^n and T^n are the ionospheric and troposphere propagation delays, respectively, ε^n accounts for modeling errors (e.g., satellite clock modeling error and orbit prediction error) and other effects(e.g., receiver noise and multipath) [10]. Due to the strong spatial correlation between the car terminal and the reference station, the pseudorange difference positioning model can eliminate these errors, which ensures sub-meter accuracy on positioning.

In the WGS84 coordinate system, the real position (x^n, y^n, z^n) of satellite n can be obtained in real-time through the ephemeris data and the real position of reference station is (x_r, y_r, z_r). So the true geometric distance from satellite n to reference station r is

$$\mathrm{R}_r^n = \sqrt{(x^n - x_r)^2 + (y^n - y_r)^2 + (z^n - z_r)^2}. \tag{4}$$

Obviously, the difference correction between the pseudorange observation ρ_r^n and actual real distance R_r^n is denoted as

$$\Delta p^n = \rho_r^n - \mathrm{R}_r^n, \tag{5}$$

where Δp^n is the difference correction including various errors. Substituting Eq. (3) into Eq. (5), we can obtain

$$\Delta p^n = c(\delta_{t_r} - \delta_{t^n}) + I^n + T^n + \varepsilon^n. \tag{6}$$

So the pseudorange observation of the car terminal after difference correction is

$$\mathrm{\rho} = \rho_i^n - \Delta\rho^n. \tag{7}$$

The corrected pseudorange can be substituted into Eq. (2) to solve the precise position of car terminal.

3 Experiment Results

In order to verify the feasibility of the proposed algorithm, we first collect data of the car terminal and reference station simultaneously, and then test the positioning error of static and dynamic environments in the roof of a building with latitude 29.5316° and longitude 106.5849°.

3.1 Static Positioning Test

In the static environment, the GPS receiver is installed in the car terminal and the car is static. We collect the observation data of GPS receiver and reference station simultaneously. The datasets are divided into three groups for positioning error comparison of the proposed algorithm. The results are shown in Figs. 3, 4 and 5.

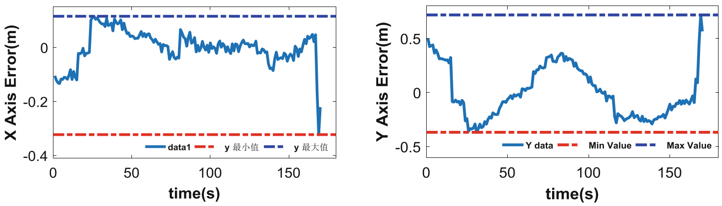


Fig. 3. Group 1

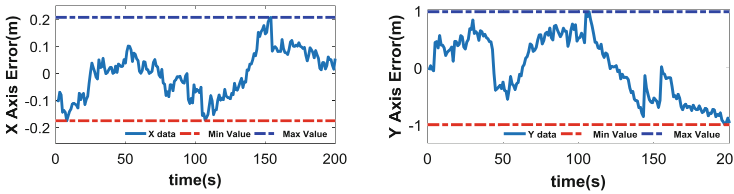


Fig. 4. Group 2

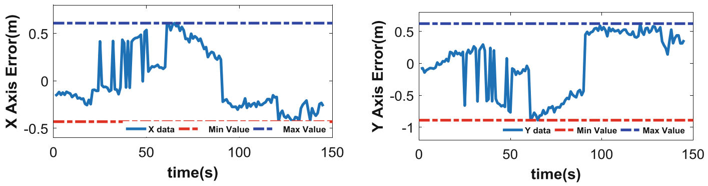


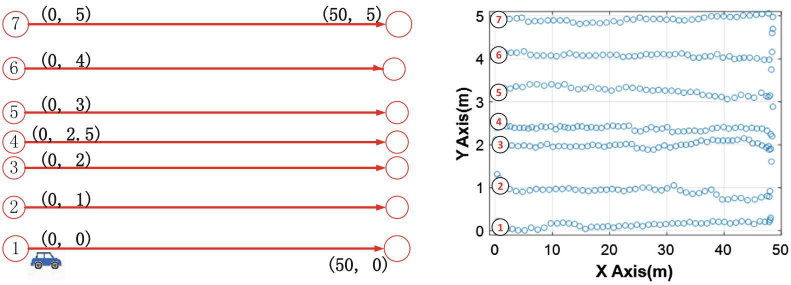
Fig. 5. Group 3

We can observe from Figs. 3, 4 and 5 that group 1 shows X axis error is −0.3 m–0.1 m, and Y axis error is −0.4 m–0.6 m. For group 2, X axis and Y axis error is −0.18 m–0.2 m and −0.91 m–0.92 m, respectively. Similarly, for group 3, X axis error is −0.45 m–0.55 m and Y axis error is from −0.9 m–0.6 m.

Through the above positioning error analysis, we can see that the positioning error of X axis and Y axis for all data sets are less than 0.55 m and 0.92 m, respectively. It is obvious that the static results can prove our theoretical analysis accuracy with positioning error is less than 1 m.

3.2 Dynamic Positioning Test

Dynamic positioning accuracy cannot directly be measured since there is no standard anchor in this case. So this paper adopts an idea of relative positioning for measuring positioning error. Specifically, we first design the car driving trajectory as shown in Fig. 6(a) and make the car drive straightly. The straight line length is 50 m and each line is spaced by 1 m or 0.5 m. Then, we use difference positioning algorithm to test the real driving trajectory. The results are shown in Fig. 6(b).



(a) Design trajectory (b) Positioning trajectory

Fig. 6. Experiment result (Color figure online)

It can be seen from Fig. 6(b) that the positioning trajectories are very approximate to the design trajectories (red lines in Fig. 6(a)). In order to analyze the dynamic positioning error, we calculate the difference of Y axis among various positioning trajectories in Table 2.

Table 2. Dynamic positioning error

Trajectory diff	Real interval (m)	Positioning interval (m)	Error (m)
1–2	1	0.45	0.55
2–3	1	1.96	0.96
3–4	0.5	0.24	0.26
4–5	1	1.62	0.62
5–6	1	1.37	0.37
6–7	1	0.38	0.62

We can see from Table 2 that the difference between straight lines at intervals of 1 m is obvious with the errors of all trajectories no more than 0.96 m. As for the straight lines with 0.5 m interval, the difference is also clear with 0.26 m positioning error. Therefore, the results demonstrate that positioning accuracy of the proposed algorithm satisfies the theoretical sub-meter accuracy even under dynamic positioning situation.

4 Conclusions

This paper proposes a pseudorange difference positioning algorithm for automatic driving. Combined observation data of car terminal with reference station data, the positioning results could be obtained by the proposed algorithm. By combining observation data of car terminal with reference station data and utilizing the proposed algorithm, we can obtain the positioning results. And the results demonstrated that the positioning error is no more than 0.92 m and 0.96 m in static and dynamic environment, respectively. Therefore, the proposed positioning algorithm could achieve sub-meter positioning accuracy.

References

1. Li, B., Yao, D.: Calculation of vehicle real-time position overcoming the GPS positioning latency with MEMS INS. In: IEEE International Conference on Service Operations and Logistics, and Informatics, pp. 248–254. IEEE (2014)
2. Zhang, X., Pan, L., Pan, Y.: Comparison of BDS/GPS precision single point positioning convergence time and positioning accuracy. J. Surv. Mapp. **44**(03), 250–256 (2015)
3. Misra, P., Enge, P.: Golbal Positioning System-Signals measurements and Perforemance, 2nd edn. Ganga-Jamuna Press, Lincoln (2004)
4. Parkinson, B.W., Spilker Jr., J.J.: Global Positioning System: Theory and Application (Volume II). American Institute of Aeronautics and Astronautics, Reston (1996)
5. Lan, X., Zhang, B., Huang, J., Huang, X.: Experimental study on GPS pseudo-distance differential positioning technology. J. Hohai Univ. (Nat. Sci. Ed.) 300–303 (2004)
6. Jie, Y., Zhang, F.: Comparative study of high-precision GPS differential positioning technology. Mob. Commun. **38**(02), 54–58 (2014)
7. Jia, M., Gu, X., Guo, Q., Xiang, W., Zhang, N.: Broadband hybrid satellite-terrestrial communication systems based on cognitive radio toward 5G. IEEE Wirel. Commun. **23**(6), 96–106 (2016)
8. Jia, M., Liu, X., Gu, X., Guo, Q.: Joint cooperative spectrum sensing and channel selection optimization for satellite communication systems based on cognitive radio. Int. J. Satell. Commun. Netw. **35**(2), 139–150 (2017)
9. Jia, M., Liu, X., Yin, Z., Guo, Q., Gu, X.: Joint cooperative spectrum sensing and spectrum opportunity for satellite cluster communication networks. Ad Hoc Netw. **58**(C), 231–238 (2016)
10. Huang, Y., Shi, J.: Analysis of real-time observation data decoding and positioning performance under the chixun beidou foundation reinforcement network. Bull. Surv. Mapp. 11–14 (2017)
11. Yu, X., Lu, Z., Wang, B.: Introduction and decoding of DGNSS data transmission format RTCM3.2. Global Position. Syst. **40**(03), 37–41 (2015)
12. RTCM: RTCM special committee no. 104. RTCM standard 10403.2 for differential GNSS. Radio Technical Commission for Maritime Services, Arlington (2013)