A vehicle positioning algorithm based on vehicle motion state in infrastructure limited scenarios

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Abstract. Positioning technology is the basis for the application of Internet of Vehicles (IoV). The positioning accuracy is generally very low in infrastructure limited scenarios based on satellites or base stations. In this paper, a vehicle positioning algorithm is proposed that combines the information of vehicle historical trajectory and inertial navigation technology. The simulation results show that the proposed algorithm can significantly improve the positioning accuracy in infrastructure limited scenarios.

Keywords: Internet of vehicles, Infrastructure limited, Location algorithm.

1 Introduction

At present, global navigation systems (GNSS) such as global positioning system (GPS) are widely used to obtain vehicle position information. However, in densely populated urban areas, woodlands, valleys, mountain tunnels and other scenarios, the signals of navigation satellites are easily blocked, resulting in delayed data update, large positioning errors, and even weak signals, making it impossible to connect with satellites. If GPS is inaccessible or unavailable due to shape or line-of-sight conditions, how to find the location while the vehicle is moving without GPS assistance becomes very important [1].

At present, there are four common positioning methods that do not rely on GNSS: positioning systems based on wireless signals, positioning systems based on inertial navigation, fusion positioning systems and other positioning systems[2].Wireless communication technologies include Ultra-Wideband (UWB), Wireless Fidelity (WiFi), and Radio Frequency Identification (RFID). Among them, WiFi positioning technology can work in different occasions [3]. However, positioning with WiFi positioning technology requires pre-establishing a location fingerprint database containing a large amount of data information, requires pre-deployment of signal access points, and cannot penetrate concrete

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buildings or basements. Therefore, it cannot be applied to GNSS blind spot positioning [3][4]. RFID technology has ready-made infrastructure, low-cost tags and identification functions, and positioning is easy to implement, but it is susceptible to multipath interference, the accuracy is limited to meters, the positioning accuracy is difficult to be improved, and it is difficult to be used for GNSS blind spot positioning.[5].UWB technology has strong anti-multipath interference capabilities[6], extremely low power spectral density and spectrum reuse characteristics[7], and has good effects in many cases where the line of sight is blocked by objects. However, UWB-based positioning needs to complete positioning on a pre-deployed base station, so it cannot meet the positioning needs of the blind area. The inertial navigation and positioning system uses inertial sensors such as acceleration sensors and gyroscopes in the inertial measurement unit (IMU) to obtain the acceleration, angle and other information in real time to estimate the position of the sensor if the initial position is known [8][9]. The advantage of this method is that without deploying a positioning base station, inertial sensors can be used to obtain a more accurate position and historical trajectory. However, the main problem is the influence of the accumulated error on the positioning accuracy and the large amount of calculation. In order to overcome the cumulative error, an appropriate positioning technology can be selected [8]. However, this method still needs to rely on positioning infrastructure, and it is still difficult to achieve accurate positioning of blind spots. Other positioning systems mainly include ultrasonic positioning systems and magnetic field positioning systems, all of which need to rely on positioning infrastructure.

In infrastructure limited scenarios based on satellites or base stations, the relative position information between vehicles and the historical trajectory information of vehicles can be used to build a real-time position information database between vehicles [10]. In this paper, a vehicle positioning algorithm is proposed that combines the information of vehicle historical trajectory and inertial navigation technology. The known position information points in the historical trajectory of the vehicle are used as known anchor points, and the vehicle is positioned using wireless positioning technology and inertial navigation technology.

2 Positioning algorithm

If the vehicle is driving, first determine the scene whether the vehicle is located effectively based on base stations. If the vehicle travels to a scene with unrestricted infrastructure, the position of the vehicle is obtained through GPS positioning or base station positioning, and the positioning result at this time is stored as a known anchor point to provide a basis for vehicle positioning in limited infrastructure scenarios. If judging that the vehicle travels to a scene with limited infrastructure, an appropriate positioning scheme is planned and selected according to the motion state of the vehicle and the number of base stations effectively connected to the vehicle.

If the number of base stations that are effectively connected to the vehicle is less than three and GPS positioning cannot be used, the vehicle is considered to be in a scenario with limited infrastructure. If the vehicle is in a scene with limited infrastructure, the horizontal angle change range of the vehicle gyroscope is between 0° and 45°, and the vehicle can be considered to be driving in an approximate straight line; the change range is between 45° and 90°, and the vehicle can be considered to be turning. condition.

As shown in Figure 1, if the vehicle travels at an approximately uniform speed, the speed is v, the position of the known anchor point is (x_0, y_0), and the time from the known anchor point to the vehicle's current position is t. The position of the vehicle at the next moment can be obtained according to the kinematic formula:

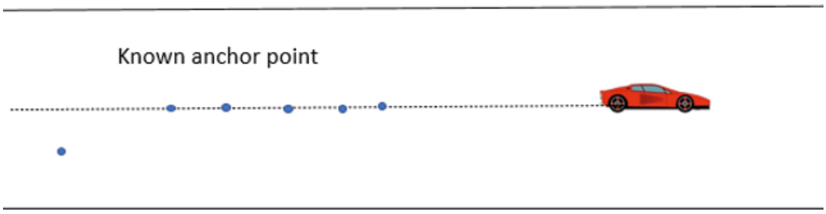

Fig. 1. The trajectory of the vehicle is approximately a straight line.

$$\begin{cases} x = x_0 + vt \\ y = y_0 \end{cases} \quad (1)$$

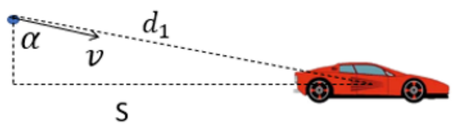

Fig. 2. The trajectory of the vehicle is not approximately a straight line.

As shown in Figure 2, if the vehicle's trajectory is not approximately a straight line with the known anchor point, the vehicle's driving angle α can be determined by the on-board gyroscope, and the acceleration a can be obtained from the accelerometer. The anchor point is known until the vehicle reaches the current position. The time is t and speed is v .

It can be seen from the figure that the position of the known anchor point is (x_0, y_0), and the time from the known anchor point to the current position of the vehicle is t . According to the laws of kinematics, the distance d_1 from the known anchor point to the vehicle can be calculated.

$$d_1 = v_0 t + \frac{1}{2}\alpha t^2 \quad (2)$$

Assuming that the known anchor points in the graph are A, B, C, the coordinates of these three anchor nodes are(x_1, y_1), (x_2, y_2) and (x_3, y_3), and the unknown node D The coordinates of is (x, y), and the distances from D to nodes A, B, and C are d_1 , d_2, and d_3, respectively. According to the distance formula between two points $(x - x_i)^2 + (y - y_i)^2 = d_i^2$, the formula (3) can be obtained.

$$\begin{cases} \sqrt{(x-x_1)^2 + (y-y_1)^2} = d_1 \\ \sqrt{(x-x_2)^2 + (y-y_2)^2} = d_2 \\ \sqrt{(x-x_3)^2 + (y-y_3)^2} = d_3 \end{cases} \quad (3)$$

From (3), the coordinate value of node D can be obtained:

$$\begin{pmatrix} x \\ y \end{pmatrix} = \begin{pmatrix} 2(x_1 - x_3) & 2(y_1 - y_3) \\ 2(x_2 - x_3) & 2(y_2 - y_3) \end{pmatrix}^{-1} \begin{pmatrix} x_1^2 - x_3^2 + y_1^2 - y_3^2 + d_3^2 - d_1^2 \\ x_2^2 - x_3^2 + y_2^2 - y_3^2 + d_3^2 - d_2^2 \end{pmatrix} \quad (4)$$

According to the number of base stations that are effectively connected to the vehicle, an appropriate number of anchor points are selected for trilateration.

If a vehicle is turning at a slower speed, the arc of a short turn can be approximated as a straight line.

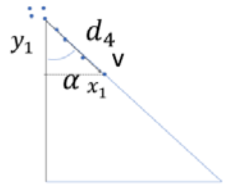

Fig. 3. Vehicle turning state.

Figure 3 shows the turning angle, the speed, acceleration, and time of the vehicle are known, assuming that the position where the vehicle is ready to turn is (x_0, y_0)

$$\begin{cases} d_4 = v_0 t + \frac{1}{2} a t^2 \\ x_1 = d_4 \sin\alpha \\ y_1 = d_4 \cos\alpha \end{cases} \tag{5}$$

From this, the positioning result (x_1, y_1) can be obtained.

3 Results and discussions

In order to verify the effectiveness of the proposed positioning algorithm, this section uses MATLAB to simulate the positioning accuracy based on different vehicle motion states. If the vehicle moves approximately in a straight line, the vehicle speed *v*=15m/s. As shown in Figure 4, the positioning accuracy changes approximately linearly, and finally tends to be stable. Among them, the curve of effective base station number N=1 and N=2 overlaps slightly in the positioning graph, and the positioning result is roughly the same. As N increases, the positioning accuracy improves, and the positioning accuracy is up to centimeter level, which is of great significance to solve the positioning in a scene with limited infrastructure.

If the vehicle turns, the vehicle speed *v*=10m/s. As shown in Figure 5, if N=0, the vehicle positioning accuracy cannot be lower than 7cm, so the positioning accuracy of N=0 during horizontal turning movement is lower than the approximate linear horizontal movement. However, as N increases, the positioning accuracy improves, and the positioning accuracy can be maintained at about 11 cm. The positioning accuracy is also approximately centimetre level. If the vehicle is turning, which requires a faster positioning rate, the proposed algorithm can meet the speed requirements to a great extent and ensure positioning accuracy due to its low complexity.

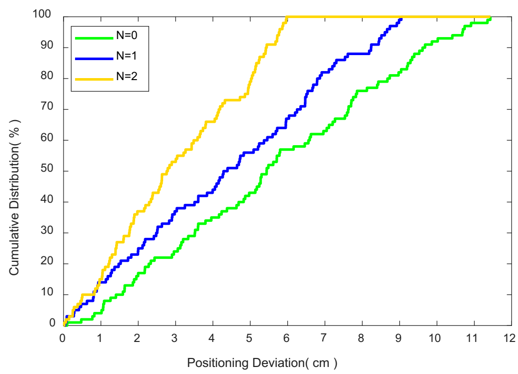

Fig. 4. The positioning accuracy if the vehicle moves approximately in a straight line.

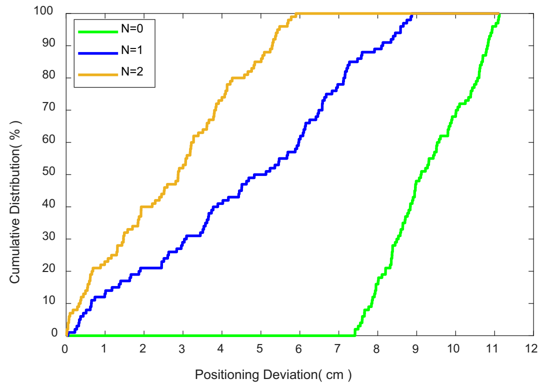

Fig. 5. The positioning accuracy if the vehicle turns.

4 Conclusion

Positioning technology is the basis for the application of IoV. A vehicle positioning algorithm is proposed based on vehicle motion state in infrastructure limited scenarios in this paper. The simulation analysis shows that the proposed algorithm can significantly improve the positioning accuracy, which is up to centimeter level with higher time efficiency. The results are of great significance for the wide application of IoV.

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References

1. Benslimane A. Localization in vehicular ad hoc networks. *Proceedings of the Systems Commun- ications*. Montreal, USA, 2005: 19-25.
2. Ferreira A F G, Fernandes D M A, Catarino A P, et al. Localization and positioning systems for emergency responders: A survey. *IEEE Communications Surveys & Tutorials*, 2017, 19(4): 2836-2870.
3. Lin P, Li Q, Fan Q, et al. A real-time location-based services system using WiFi fingerprinting algorithm for safety risk assessment of workers in tunnels. *Mathematical Problems in Engineering*, 2014: 1-10.
4. HoQ D, Gao Y, Le-Ngoc T. Challenges and research opportunities in wireless communication networks for smart grid. *IEEE Wireless Communications*, 2013, 20(3): 89-95.
5. Carotenuto R,Merenda M, Iero D, et al. Ranging RFID Tags With Ultrasound. *IEEE SENSORS JOURNAL*, 2018.18(7): 2967.
6. Briese D, Kunze H,Rose G. UWB localization using adaptive covariance Kalman Filter based on sensor fusion. *IEEE International Conference on Ubiquitous Wireless Broadband (IcUwB)*, 2017: 1-2.

7. Hirt W. Ultra-wideband radio technology: overview and future research. *Computer Communica- tions*, 2003, 26(1):46-52.
8. JENSEN C S, LAHRMANN H, PAKALNIS S, et al. *The INFATI data*.2004.
9. Bebek o,Suster M A，Rajgopal s, et al. Personal navigation via high-resolution gait-corrected inertial measurement units. *IEEE Transactions on Instrumentation and Measurement*, 2010,59(11): 3018-3027.
10. Tatchikou R, Biswas, Dion F. Cooperative vehicle collision avoidance using inter-vehicle packet forwarding. *Proceedings of the IEEE Global Telecommunications Conference (GLOBECOM'05)*. Louis, USA, 2005, 5: 5-2766.