A high precision vehicle positioning method based on traffic light

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Abstract. According to the low positioning precision and high cost of traditional vehicle positioning technologies, and combined advantages of the newly arisen visible light communication like no extra transmitter needed, no electromagnetic interference and free license, this paper proposed a vehicle positioning method based on traffic light, which could generate the vehicle’s position with the time difference of arrival of the signal light. Also its improved methods based on plan revolution theory were discussed to overcome the deficient in non-coplanar condition and improve the positioning precision. Simulation results showed that these methods, with simple computation and low implementation cost, could realize a real-time high-precision positioning performance, and could meet the requirements of the intelligence transportation system.

1. Introduction
The high-precision and high-reliability vehicle position information in the ITS (Intelligence Transportation System) is the basic condition for realizing vehicle positioning and navigation, and is also an important basis for the realization of passenger flow grooming, urban traffic intelligent dispatching, and automatic motor vehicle control.[1-6] The positioning technology based on real-time image information needs to establish a huge image database for the positioning environment, and the real-time performance is poor. In order to overcome the shortcomings of the above positioning algorithms, combined with visible light communication technology, no need to install additional signal sources, no electromagnetic interference, no spectrum licensing, etc. This paper proposes a wireless positioning technology based on traffic lights and its improved technology for non-coplanar problems.[7-10] It can realize high-precision real-time positioning and meet the requirements of the ITS system for vehicle positioning.

2. Vehicle positioning technology based on traffic lights
The traffic light-based vehicle positioning technology simultaneously receives the positioning signal at the traffic light using two photoelectric receivers mounted on the vehicle, and calculates the target vehicle based on the time difference between the positioning signals reaching the two PD receivers. Finally, according to the real position information of the traffic light obtained by the visible light communication technology, the real position information of the target vehicle is converted. According to the number of traffic lights, it can be divided into single lamp positioning technology and multi-lamp positioning technology.

As shown in Fig. 1, F1 and F2 are two PD receivers with a pitch of 2c symmetrically distributed on the X-axis at the starting time, and move in the positive direction of the Y-axis at the velocity v, and $F'$
and \( F' \) are received at the time of PD. The position of the machine, \( T_1 \) is the traffic light that emits the positioning signal, then the two eccentricities \( e_1 \) and \( e_2 \) can be determined according to the time difference \( \Delta t_1 \) and \( \Delta t_2 \) of the two PD receivers at the initial time and the time \( t \) at the visible time. Curves (corresponding to the hyperbola of the upper and lower sides in Figure 2, respectively, the vertical dashed line is the left guideline of the curvature \( e_1 \) hyperbola).

\[
\sqrt{(x - (-c))^2 + y^2} = e_1 \cdot \left[ x - \left( -\frac{a_1}{e_1} \right) \right],
\]

(1)

\[
\sqrt{(x - (-c))^2 + (y - \Delta y)^2} = e_2 \cdot \left[ x - \left( -\frac{a_2}{e_2} \right) \right],
\]

(2)

In the formula, \( \Delta y = v \times t \) is the moving distance of the receiver in the time interval \( t \), the eccentricity \( e = \frac{c}{a} \), \( a = C \times \Delta t \) is half of the difference between the two focal points on the hyperbola from any point to the hyperbola. \( C = 3 \times 10^8 \text{ m/s} \) is the propagation speed of visible light, \( \Delta t \) is the time difference between the visible light signal and the two PD receivers. The four intersections \( T_1, T_2, T_3 \) and \( T_4 \) of the two hyperbola are the four solutions satisfying Equations 1 and 2. Since the visible light signal reaches the detector \( F_1 \) for less than the detector \( F_2 \), the traffic light should be located at the left of \( x < 0 \). In the half plane, that is, the left half of the hyperbola, the two false solutions \( T_2 \) and \( T_4 \) can be effectively removed; the non-omnidirectional receiving PD receiver determines that the traffic light should be within the maximum field of view of the receiver, ie \( y > 0 \) and \( y > \Delta y \), the false solution \( T_3 \) can be effectively removed, the position coordinates of the traffic light \( T_1 \) on the XY coordinate system, and the positional relationship between the traffic light \( T_1 \) and the PD receiver are determined. Combined with the real position information of the traffic light \( T_1 \), the real position information of the positioning target (ie, the origin of the coordinate system) can be finally calculated.

![Figure 1. Single lamp positioning technology](image)

When the PD receiver can detect a plurality of traffic lights transmitting the positioning signals, the time difference between the two visible light signals transmitted by the different traffic lights can be
determined, and multiple hyperbolic curves can be determined, and the true position of the positioning target is finally calculated. Information.

As shown in Fig. 2, F1 and F2 are two PD receivers with a spacing of 2c symmetrically distributed on the X-axis. T1 and T2 are two different traffic lights that emit positioning signals, which can be based on traffic lights T1 and T2. The time difference between the transmitted visible light signals and the two PD receivers’ \( \Delta t_1 \) and \( \Delta t_2 \) determines two hyperbolic curves with eccentricities \( e_1 \) and \( e_2 \), respectively.

\[
\sqrt{(x_1 - (-c))^2 + y_1^2} = e_1 \cdot \left[ x_1 - \left(-\frac{a_1}{e_1}\right) \right],
\]
\[
\sqrt{(x_2 - (-c))^2 + y_2^2} = e_2 \cdot \left[ x_2 - \left(-\frac{a_2}{e_2}\right) \right],
\]
\[
\sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2} = \sqrt{(X_1 - X_2)^2 + (Y_1 - Y_2)^2},
\]
\[
\frac{x_1 - x_2}{X_1 - X_2} = \frac{y_1 - y_2}{Y_1 - Y_2},
\]

In the formula, \((x_1, y_1)\) and \((x_2, y_2)\) are the position coordinates of the traffic lights T1 and T2 on the XY coordinate system, and \((X_1, Y_1)\) and \((X_2, Y_2)\) are the real position information of T1 and T2, respectively. Similar to the single-lamp positioning technology, \( y_1 > 0, y_2 > 0 \) due to the limitation of the PD receiver that is not omnidirectionally received. Meanwhile, when the visible light signal arrives at the time difference \( \Delta t_1 > 0, \Delta t_2 > 0 \), there is \( x_1 > 0, x_2 > 0 \); when the time difference \( \Delta t_1 < 0, \Delta t_2 < 0 \), there are \( x_1 < 0, x_2 < 0 \). Solving the above equations and removing the false solutions, the position coordinates \((x_1, y_1)\) and \((x_2, y_2)\) of the traffic lights T1 and T2 on the XY coordinate system can be obtained. Combined with the real position information \((X_1, Y_1)\) and \((X_2, Y_2)\) of the traffic lights T1 and T2, the real position information \((X_1 - x_1, Y_1 - y_1)\) of the positioning target (ie the origin of the coordinate system) can be calculated or \((X_2 - x_2, Y_2 - y_2)\).

![Figure 2. Multi-lamp positioning technology](image)
3. Simulation experiment and result analysis

Define the positioning error of the positioning technology:

\[ \text{Bias} = \sqrt{\text{Bias}_x^2 + \text{Bias}_y^2}, \]  

(7)

In the formula, \( \text{Bias}_x \) and \( \text{Bias}_y \) are the positioning errors of the positioning technology on the X-axis and the Y-axis, respectively. Without considering the true position error of the traffic light and the visible light signal reaching the error measurement error of the two receivers, the traffic lights \( T_1 \) and \( T_2 \) are set to be 3 m to the left and 1 m to the right of the center of the two receivers, respectively. The receiver moves in the opposite direction of the traffic light along the Y-axis.

| Parameter name                          | Value  |
|----------------------------------------|--------|
| Traffic light \( T_1 \) true height \( H_1 \) | 6 m    |
| Traffic light \( T_2 \) true height \( H_2 \) | 4 m    |
| Receiver true height \( h \)            | 1 m    |
| Two receiver spacing \( 2c \)          | 1 m    |
| Receiver measurement time interval \( t \) | 0.1 s  |

According to the system parameters given in Table 1, it can be seen that when the distance between the receiver and the traffic light is reduced, the positioning error of the positioning technique that does not use the rotation improvement will slowly increase and then increase sharply; and when the movement speed is larger. When the distance \( \Delta y \) moved by the receiver during the measurement time interval is larger, the positioning error is larger.

Figure 3. Single lamp positioning technology positioning error

Figure 4 shows the positioning error curve of the TDoA multi-lamp positioning technique caused by the non-coplanar phenomenon when the receiver moves at 10 mps and 30 mps. Also, as the distance between the receiver and the traffic light decreases, the positioning error without the use of rotationally improved positioning techniques will slow and then increase dramatically. Compared with the TDoA single lamp positioning technology, the TDoA multi-lamp positioning technology has better positioning accuracy performance. When the distance between the receiver and the traffic light is 5 m, the positioning error of the multi-lamp positioning technology without the rotation improvement is only 3.4 m. The positioning errors of the unit positioning technique without rotation improvement are 5.9 m and 8.1 m, respectively, corresponding to the receiver moving speeds of 10 mps and 30 mps. Only the multi-
lamp positioning technology under two traffic lights is studied here. The TDoA positioning technology with three or more traffic lights will have better positioning performance.

![Multi-lamp positioning technology positioning error](image)

**Figure 4.** Multi-lamp positioning technology positioning error

4. Conclusion

This paper proposes a new type of traffic light-based vehicle positioning technology and its improved technology for non-coplanar problems of traffic lights and PD receivers. The simulation experiment results show that the positioning technology can achieve higher precision real-time positioning and meet the requirements of intelligent transportation system for vehicle positioning.

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