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High Precision Vehicle Location Technologies Based on Traffic Lights

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ABSTRACT According to the low positioning precision and high cost of traditionall 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 vehiclepositioning 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 revolutiontheory were discussed to overcome the deficientin 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-timehigh-precision positioning performance, and could meet the requirements of the intelligence transportation system.

KEYWORDS

Vehicle positioning

Traffic light

Message gateway

TDOA

Visible light communication

INTRODUCTION

High precision, high reliability and vehicle location information provided by Intelligent transportation systems (Intelligence Transportation System, ITS) is a basic condition for vehicle location and navigation. It is also the foundation to achieve traffic diversion, urban traffic intelligent scheduling, motor control and other uses [1-2]. Due to the usual building block for positioning signals, the existed satellite positioning systems which is most extensive and most widely used could not be used well in high-rise cities with tunnel, underground car park and other closed areas. And civilian business positioning accuracy is of less than 10 meters, which has been unable to meet ITS increasing accuracy requirements of the system [3]. Existing wireless location technology mainly uses infrared [4], electromagnetic waves [5] [8], magnetic field [9], sound wave [10],ultrasonic wave [11] and other forms to send positioning signal. And also could realize high precision of wireless positioning [13] through real-time image information [14]. But these positioning technology need to install additional signal launch device, increasing the complexity of the system and the implementation cost. Radio frequency identification technology [5], wlan positioning technique [8], wireless sensor network location technology [6, 13] and uwb positioning technology [7] based on electromagnetic wave signal will also occupy a certain communication bandwidth, reducing the bandwidth of the communication system efficiency. And due to electromagnetic interference effect, it could not be applied to hospitals, airports and other environment where the RF signal was strictly limited. Positioning technology based on real-time image information necessary to locate the environment to build a huge database of images with poor real-time performance. To overcome the lack of the above positioning algorithm, combined advantages of the newly arisen visible light communication like no extra transmitter needed, no electromagnetic interference and free license [14], this paper proposes a traffic light based wireless location technology and improved techniques for non-coplanar problem, which can achieve real-time positioning with high accuracy to meet the ITS system for vehicle location requirements.

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1. Introduction

nolHigh precision, high reliability and vehicle location information provided by Intelligent transportation systems (Intelligence Transportation System, ITS) is a basic condition for vehicle location and navigation. It is also the foundation to achieve traffic diversion, urban traffic intelligent scheduling, motor control and other uses [1-2]. Due to the usual building block for positioning signals, the existed satellite positioning systems which is most extensive and most widely used could not be used well in high-rise cities with tunnel, underground car park and other closed areas. And civilian business positioning accuracy is of less than 10 meters, which has been unable to meet ITS increasing accuracy requirements of the system [3]. Existing wireless location technology mainly uses infrared [4], electromagnetic waves [5] [8], magnetic field [9], sound wave [10], ultrasonic wave [11] and other forms to send positioning signal. And also could realize high precision of wireless positioning [13] through real-time image information [14]. But these positioning technology need to install additional signal launch device, increasing the complexity of the system and the implementation cost. Radio frequency identification technology [5], wlan positioning technique [8], wireless sensor network location technology [6, 13] and uwb positioning technology [7] based on electromagnetic wave signal will also occupy a certain communication bandwidth, reducing the bandwidth of the communication system efficiency. And due to electromagnetic interference effect, it could not be applied to hospitals, airports and other environment where the RF signal was strictly limited. Positioning technology based on real-time image information necessary to locate the environment to build a huge database of images with poor real-time performance. To overcome the lack of the above positioning algorithm, combined advantages of the newly arisen visible light communication like no extra transmitter needed, no electromagnetic interference and free license [14], this paper proposes a traffic light based wireless location technology and improved techniques for non-coplanar problem, which can achieve real-time positioning with high accuracy to meet the ITS system for vehicle location requirements.

2.Vehicle location technology based on the traffic light

The vehicle positioning technology based on traffic lights is to use two optoelectronic receivers （Photodiode，PD） installed on the vehicle to receive the positioning signal from the traffic lights at the same time. According to the time difference of arrival (TDOA) between the two PD, compute the location relationship between the target vehicle (defined as the geometric center of two PD receivers) and the traffic lights. Finally, calculate the true position information of the target vehicle's location based on real information visible light communication technology acquired traffic lights (or on behalf of the position coordinate ID information).It can be divided into single lamp positioning technology and multi-lamp positioning technology according to the number of traffic lights.

2.1 Single lamp positioning

As shown in figure 1, F1 and F2 are two PD receivers symmetrically distributed on the X axis at the start moment, with a space of 2 C, moving along the positive direction of Y axis with a speed of V. F_1' and F_2' are two PD receivers at t moment, and T1 is the traffic light for sending positioning signal. According to the TDOA of visible light signal between the starting and t moment, Δt1 and Δt2, two hyperbolic curves with centrifugation rate of e1 and e2 are determined (Respectively correspond to the above and below hyperbolic in figure 2, and the vertical dashed line is the left quasi line of the e1 hyperbolic curve).

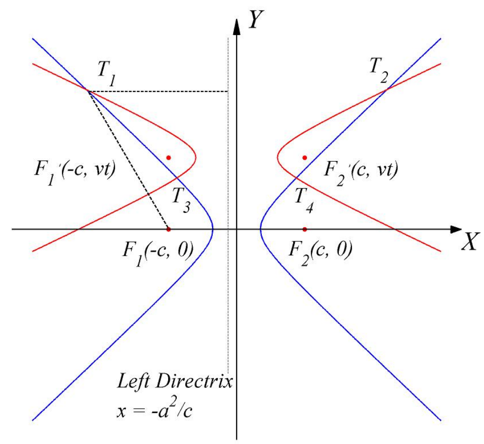
$$\sqrt{\left[x-(-c)\right]^2+y^2}=e_1\cdot\left[x-\left(-a_1/e_1\right)\right] \qquad (1)$$

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

In which, Δ y = v × t is the moving distance of receiver in t interval time. The eccentricity $e=\frac{c}{a}$, a = C · Δ t is half the distance difference of two hyperbolic focus from any point on the hyperbolic.

C = 3 × 108 m / s is the velocity of propagation of visible light, and Δ t is the time difference from Visible light signals to the two PD receivers. The four intersection points of two hyperbolas, t1, t2, t3 and t4 are four solutions to the equations 1 and 2,

Because the travel time of visible light signal from detector F1 is less than from detector F2, the traffic lamp should is located within x < 0 of left half plane, on the left half of hyperbolic curve, which can effectively remove the two fake solutions, t2 and t4; And non-full to receive of PD receiver decided traffic lamp should is located in receiver of maximum depending on field angle (Field of View, FoV) within, that y > 0 and y > Δy, which can effectively remove the false solutions t3. It determines the location of traffic light t1 on the XY coordinate system coordinates, as well as the location relationship between traffic lights t1 and PD receiver. Combined with the real location information (X, Y) of traffic lightsT1, final the real location



information (X - x, Y - y) of target can be calculated (coordinate origin).

Figure 1 Single Lamp Positioning Technology

2.2 Multi-lamp positioning

When PD receiver can detect multiple transmit positioning signals from traffic light (at least two), you can determine a plurality of hyperbolic and finally calculate the real location information of the target according to the TDOA of visible signal between the two PD receivers.

As shown in figure2, F1 and F2 two PD receivers symmetrically distributed on the X axis, T1 and T2 are two different traffic lights emission positioning signal. According to the TDOA of visible signal at T1 and T2 between the two PD receivers, Δt1 and Δt2, determine eccentricity two hyperbolic with e1 and e2.

$$\sqrt{\left[x_1-(-c)\right]^2+y_1^2}=e_1\cdot\left[x_1-\left(-a_1/e_1\right)\right] \qquad (3)$$

$$\sqrt{\left[x_2-(-c)\right]^2+y_2^2}=e_2\cdot\left[x_2-\left(-a_2/e_2\right)\right] \qquad (4)$$

$$\sqrt{(x_1-x_2)^2+(y_1-y_2)^2}=\sqrt{(X_1-X_2)^2+(Y_1-Y_2)^2} \qquad (5)$$

$$\frac{x_1-x_2}{X_1-X_2}=\frac{y_1-y_2}{Y_1-Y_2} \qquad (6)$$

In which, (x1, y1) and (x2, y2) are the location of traffic lights T1 and T2 in the XY coordinate system. (X1, Y1) and (X2, Y2) are the real location of T1 and T2. Similar to a single light positioning technology, due to the non-omni directional reception PD receiver restrictions, there is y1 > 0, y2 > 0; At the same time, if the TDOA of the visible light signal is Δt1 > 0 and Δt2 > 0, there is x1 > 0, x2 > 0; If the TDOA is Δt1 < 0, Δt2 < 0, there is x1 < 0,x2 < 0. Solve the above equation of false solutions and remove the fault solutions to get the position of traffic lights T1 and T2 on the XY coordinate system, (x1, y1) and (x2, y2). Combined with the real location information of traffic lightsT1 (X1, Y1) and T2 (X2, Y2), calculate (coordinate origin) the real location information (X1 - X1, Y1 - Y1) or (X2 - X2, Y2 - Y2) of the target.

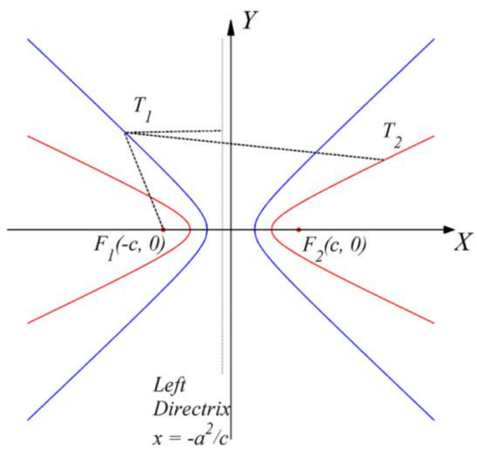


Figure 2 Multi-lamp positioning technologies

3.Problems for non-coplanar positioning technology improvements

Based on the above traffic light positioning technology is only applicable to the condition that traffic lights and the receivers are on the same plane. However as shown in Figure 3 and 4, in practical applications, traffic lights and receivers are often in different planes, the computer model to be modified. In this section the improvement of positioning technology under non-coplanar condition will be discussed.

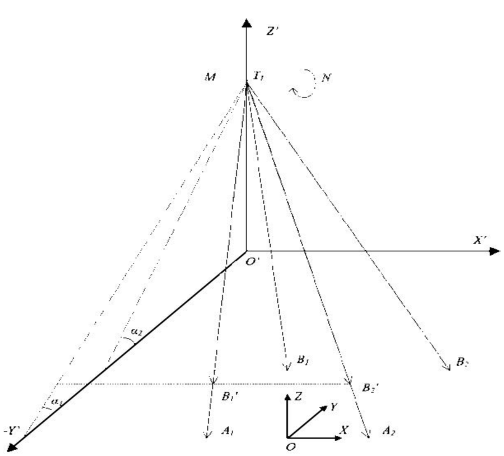


Figure. 3 single lamp positioned to improve technology

As shown in figure 3, ways to improve the TDOA of single lamp positioning technology, A1 and A2 are two receivers (-c, 0,0) and (c, 0,0) symmetrically distributed in the X-axis coordinate XYZO in the starting time. To simplify the calculation, it is assumed that both receivers moves along the Y axis in XOY plane with the speed of v, then the position of the two receivers at t are B1 (-c, Δ y, 0) and B2 (c, Δ y, 0). The coordinates of traffic light T1 on the XYZO coordinate system is (x, y, z), the angle between the T1A1A2 plane and the XOY plane is $\alpha_1 = \arg\tan\left(\frac{z}{y}\right)$, and the angle between the T1B1B2 plane and the XOY plane is $\alpha_2 = \arg\tan\left(\frac{z}{y-\Delta y}\right)$ Along with the intersection line MN between T1A1A2 plane and T1B1B2 plane, rotate the plane T1B1B2 with Δ α = α2 - α1, then coincides with the plane T1A1A2, getting the mapping points B_1' and B_2' of receivers B1 and B2. According to the coordinate transformation theory, the mapping points B_1' and B_2' Coordinates on the coordinate system XYZO are $\left(x_{B1}', y_{B1}', z_{B1}'\right)$ and $\left(x_{B2}', y_{B2}', z_{B2}'\right)$

$$\begin{aligned}\left(x_{B1}', y_{B1}', z_{B1}', 1\right) &= \left(x_{B1}, y_{B1}, z_{B1}, 1\right)\cdot R\left(\Delta\alpha\right)\\ &= \left(-c, \Delta y, 0, 1\right)\cdot T \cdot R_x\left(\Delta\alpha\right)\cdot T^{-1}\end{aligned} \tag{7}$$

$$\begin{aligned}\left(x_{B2}', y_{B2}', z_{B2}', 1\right) &= \left(x_{B2}, y_{B2}, z_{B2}, 1\right)\cdot R\left(\Delta\alpha\right)\\ &= \left(c, \Delta y, 0, 1\right)\cdot T \cdot R_x\left(\Delta\alpha\right)\cdot T^{-1}\end{aligned} \tag{8}$$

which $T = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & y & z & 1 \end{bmatrix}$ and $R_x\left(\Delta\alpha\right) = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\left(\Delta\alpha\right) & \sin\left(\Delta\alpha\right) & 0 \\ 0 & -\sin\left(\Delta\alpha\right) & \cos\left(\Delta\alpha\right) & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$ are respectively transformation matrix and rotation matrix, $T^{-1} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & -y & -z & 1 \end{bmatrix}$ is the inverse matrix of transformation matrix T. When the true height of traffic lights Z and the receiver z is known, the distance difference between the traffic lights and the two receivers' mapping point B_1' and B_2'

$$\begin{aligned}a_2' = \frac{1}{2}\Bigg[&\sqrt{\left(x - x_{B1}'\right)^2 + \left(y - y_{B1}'\right)^2 + \left(z - z_{B1}'\right)^2}\\ &-\sqrt{\left(x - x_{B2}'\right)^2 + \left(y - y_{B2}'\right)^2 + \left(z - z_{B2}'\right)^2}\Bigg]\end{aligned} \tag{9}$$

Rewrite the formula (1) and (2)

$$\sqrt{\left[x - \left(-c\right)\right]^2 + y^2 + z^2} = e_1 \cdot \left[x - \left(-a_1 / e_1\right)\right] \tag{10}$$

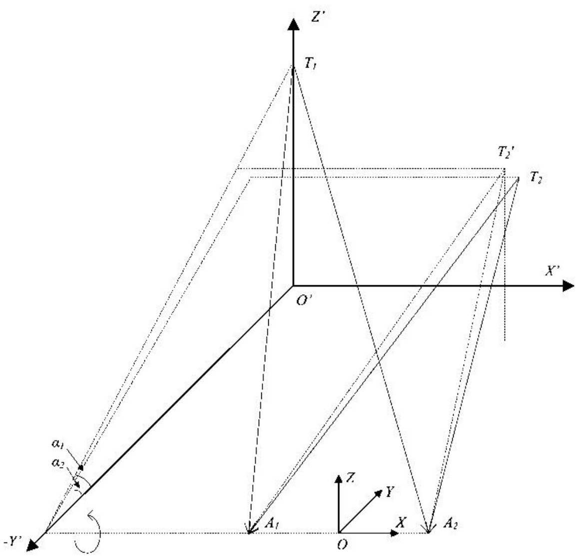
$$\begin{aligned}&\sqrt{\left(x - x_{B1}'\right)^2 + \left(y - y_{B1}'\right)^2 + \left(z - z_{B1}'\right)^2}\\ &= e_2' \cdot \left[x - \left(-a_2' / e_2'\right)\right]\end{aligned} \tag{11}$$

In which, $e_2' = \frac{c}{a_2'}$ is the eccentricity of the hyperbolic determined by traffic lights T1And two receivers mapping point B_1' and B_2'. Solve the above equations and use similar restrictions of single lamp coplanar positioning technology, the position coordinates (x, y, z) of traffic light T1 on XYZO coordinate can be calculated. Combined with the true position (X, Y, Z) of traffic lights T1, finally obtain the actual position (X - x, Y - y, Z - z) of conversion target (XYZO coordinate origin).

As shown in figure 4, ways to improve the TDOA of single lamp positioning technology, A1 and A2 are two receivers (-c, 0, 0) and (c, 0, 0) symmetrically distributed in the X-axis coordinate XYZO. The coordinates of LED signal light T1 and T2 on the coordinate system XYZO are (x1, y1, h1) and (x2, y2, h2). Similar to the ways to improve the single lamp positioning technology, rotate the plane T2A1A2, then coincides with the plane T1A1A2, getting the coordinates $\left(x_2', y_2', h_2'\right)$ and the real coordinates $\left(X_2', Y_2', H_2'\right)$ of mapping point T_2' of the LED signal light T2 coordinates on the coordinate system XYZO.

$$\left(x_2', y_2', h_2', 1\right) = \left(x_2, y_2, h_2, 1\right) \cdot R_x\left(\Delta\alpha\right) \qquad (12)$$

$$\left(X_2', Y_2', H_2'\right) = \left(X_2, Y_2, H_2\right) - \left(x_2 - x_2', y_2 - y_2', h_2 - h_2'\right) \qquad (13)$$



4 Multi-lamp technology to improve positioning

The distance difference between mapping point T_2' of the traffic light T2 and the two receivers

$$a_2' = \frac{1}{2}\left\{\sqrt{\left[x_2' - (-c)\right]^2 + \left(y'\right)_2^2 + \left(h_2'\right)^2} - \sqrt{\left(x_2' - c\right)^2 + \left(y'\right)_2^2 + \left(h_2'\right)^2}\right\} \qquad (14)$$

Rewrite the equation (3) to (6)

$$\sqrt{\left[x_1 - (-c)\right]^2 + y_1^2 + h_1^2} = e_1 \cdot \left[x_1 - \left(-a_1 / e_1\right)\right] \qquad (15)$$

$$\sqrt{\left[x_2' - (-c)\right]^2 + \left(y_2'\right)^2 + \left(h_2'\right)^2} = e_2' \cdot \left[x_2' - \left(-a_2' / e_2'\right)\right] \qquad (16)$$

$$\sqrt{\left(x_1 - x_2'\right)^2 + \left(y_1 - y_2'\right)^2 + \left(h_1 - h_2'\right)^2} = \sqrt{\left(X_1 - X_2'\right)^2 + \left(Y_1 - Y_2'\right)^2 + \left(H_1 - H_2'\right)^2} \qquad (17)$$

$$\frac{x_1 - x_2'}{X_1 - X_2'} = \frac{y_1 - y_2'}{Y_1 - Y_2'} = \frac{h_1 - h_2'}{H_1 - H_2'} \qquad (18)$$

In which, $e_2' = \frac{c}{a_2'}$ is the eccentricity of the hyperbolic determined by mapping point T_2' of traffic lights T2 and the two receivers. Solve the above equations and use similar restrictions of multi lamp coplanar positioning technology, the position coordinates (x1, y1, h1) and $\left(x_2', y_2', h_2'\right)$ of mapping point T_2' of traffic lights T2 and traffic light T1 on XYZO coordinate can be calculated. Combined with the true position $\left(X_1, Y_1, H_1\right)$ and $\left(X_2', Y_2', H_2'\right)$ of traffic lights, finally obtain the conversion of the receiver's position (X1 - X1, Y1 - Y1, H1 - H1) or $\left(X_2' - x', Y_2' - y_2', H_2' - h_2'\right)$.

4. Simulation and Analysis

Positioning error is defined positioning technology [15]

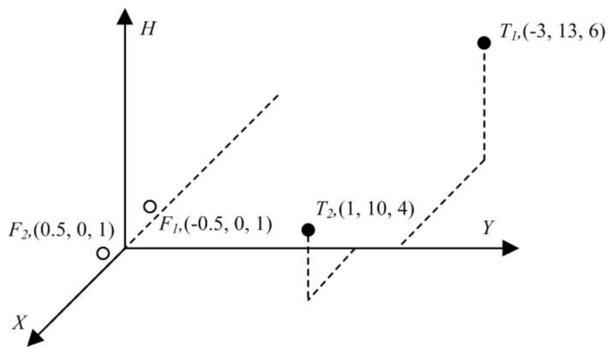
$$\text{Bias} = \sqrt{\text{Bias}_X^2 + \text{Bias}_Y^2} \qquad (19)$$

In which, Bias X and Bias Y respectively are positioning error of positioning technology in the X-axis and Y-axis. Without taking wrong place of traffic light and the TDOA of visible light signal between the two receivers into account, as shown in figure 5, set the traffic lights T1 and T2 as two receivers located on the left and right of the center of 3 m at 1 m, the receiver move along the Y axis opposite the traffic light.

Parameter No.	Evaluate
True height of traffic light T_1, H_1	6 m
True height of traffic light T_2, H_2	4 m
True height of the receiver, h	1 m
Space between two receivers, 2c	1 m
Receiver measurement time interval, t	0.1 s

Table 1 Basic system parameters

Table 1 shows the system parameters, figure 6 gives a comparison of receiver velocity for the next 10 mps and 30 mps case, and shows the error curve TDOA single lamp positioning technology caused by non-coplanar, only based on a visible light signal launched by traffic light T1. As can be seen, when the distance between the receiver and the traffic light is reduced, the error of positioning unused rotational improvements will increase slowly and then rapidly increases; and when the greater the velocity, the mobile receiver measurement time interval distance Δ y the larger, the greater the positioning error.



5 Single light positioning technology positioning error

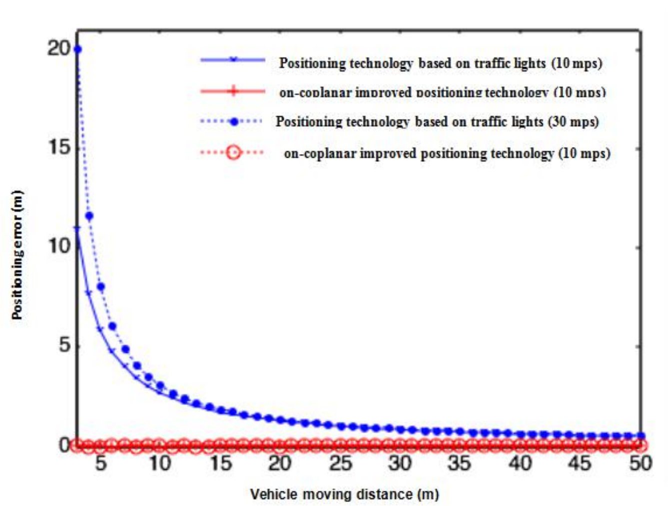
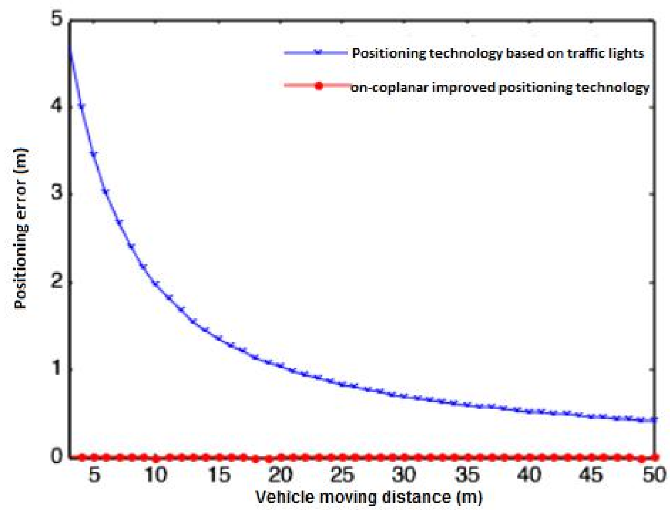


Figure. 6 Single light positioning technology positioning error

Figure 7 gives a comparison of receiver velocity for the next 10 mps and 30 mps case, and shows the error curve TDOA single lamp positioning technology caused by non-coplanar. Similarly, when the distance between the receiver and the traffic light is reduced, the error of positioning unused rotational improvements will increase slowly and then rapidly increases; Compared with TDOA single lamp positioning technology, multi-lamp TDOA positioning technology is with better positioning accuracy of performance. When the distance between the receiver and traffic lights is 5 m, the error of multi-lamp positioning technology unused rotational improvements is only 3.4 m, which corresponds to the receiver with velocity of 10 mps and 30 mps, the error of positioning unused rotational improvements of TDOA single lamp is 5.9 m and 8.1 m. Here only study analyzed the multi-positioning technology based on two traffic lights lamp. TDOA



7 Multi-lamp positioning technology positioning error

Concluding Remarks

This paper presents a novel technique based vehicle positioning of traffic lights, and improved techniques for non-coplanar problem of traffic lights and the receiverPD. Simulation results show that the positioning technology can achieve higher accuracy real-time positioning, intelligent transportation system to meet the requirements of the vehicle location.

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