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Research Article

Dynamic Navigation Method with Multisubstations Based on Doppler Shift

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The mobile terminals must be compensated for the Doppler effect in their moving communication. This special characteristic of mobile communication can be developed in some new applications. This paper proposes methods to realize mobile navigation calculation via Doppler shifts. It gives the theory of relationship between the motion parameters, like directions and speed, and frequency shifts caused by multibase stations. The simulation illustrates how to compute the movement parameters of numerical calculation and what should be care for the problem near angle 90 degree. It also gives an application with Google map and dynamical locating position and direction on a mobile phone by public wireless network. Given the simulation analysis and navigation test, the results show that this method has a good effect.

1. Introduction

The problem of Doppler shift should have its dualities. On the one hand, mobile terminal needs to solve the problem of frequency shift to realize the communication. Many literatures have proposed different calculation methods about frequency shift in mobile communication. Hua Jingyu and You Xiaohu who are in the National Key Laboratory studying about mobile communication in Southeast University utilize a frequency shift calculation system CP-SCBT in [1] by calculating the concomitant difference of time sequence and an algorithm about estimating the square root of the dynamic window oversampling [2]. On the other hand, since the Doppler shift is related to speed and direction [3], it must have value in fields of navigation and positioning. The research of these fields has not been adequately concerned. This paper tries to find the relationship between the motion parameters and frequency shift of multibase stations and then proposes a scheme about mobile terminal autonavigation technology and realization without GPS.

At present, the major global position systems are GPS and AGPS (assisted GPS). The GPS system receives signal from at least three satellites to combine and calculate its own space position. The AGPS is based on network to track record for reducing time cost of position and its dependence on satellites. Sakamoto et al. once proposed TDOA Location method upon multisubstations [4, 5]. Some scholars [6–8] discuss and illustrate possibilities and fundamental limitations with mobile positioning in available wireless network measurements. System-specific, low-layer techniques for how these are computed for second generation (2G) and [9, 10] for third generation (3G) can be found, respectively.

However, they have not provided navigation parameters like speed, direction, and so forth. Mobile system gets navigation with the best receptivity for the reason that mobile terminals have provided the real-time estimate of Doppler shift in moving process and uses it to optimize the system parameter. Hence, the system is applied to frequency channel measurement, resource allocation, handoff decision power control, and so on [11–13]. The research of Doppler shift navigation not only gets a good use of mobile terminal frequency shift estimation and some correlation properties but also uses 3G/4G mobile communication system to constitute the mobile navigation system.

2. Theory and Calculation of Mobile Navigation

Mobile terminal must estimate Doppler shift which reflects the speed of the channel parameter change. When the moving of terminal is quicker, the Doppler shift is bigger. The mobile terminal can automatically compensate the change of parameter coursed by frequency shift.

2.1. Relationship between Doppler Shift and Parameters. The purpose of researching the relationship between Doppler shift and position is to apply the result of frequency shift to estimate navigation and position of mobile terminal. The method is integrated estimating parameters of position, speed, and direction by different frequency shift of several adjacent base stations to solve the problem of mobile terminal continuous dynamic position.

It is shown as in Figure 1 that frequency shift, transmitting frequency, speed, and direction have the following relationship known from Doppler effect:

$$f_d = \frac{f}{C} v \cdot \cos\alpha. \tag{1}$$

In (1), α is the angle between the moving direction of terminal and spreading direction of signal, v is the moving direction of terminal, C is spreading direction of electromagnetic wave, and f is frequency of carrier.

When the user mobile terminal UE moves in the direction of O_2O_1 at speed of v, the frequency shifts f_{d1}, f_{d2} related to base stations Nodes B_1 and B_2 are produced as in the following equations:

$$\begin{aligned} f_{d1} &= \frac{f}{C} v \cdot \cos\alpha_1, \\ f_{d2} &= \frac{f}{C} v \cdot \cos\alpha_2. \end{aligned} \tag{2}$$

The distance of two base stations is S. The distance between user mobile terminal and base stations Node B_1 and Node B_2 can be tested as L_1 and L_2 via the phase difference of mobile terminal pilot frequency yards. The following formula can be derived by triangle:

$$\cos(\alpha_2 - \alpha_1) = \frac{L_1^2 + L_2^2 - S^2}{2L_1L_2}. \tag{3}$$

In theory, the frequency shifts f_{d1}, f_{d2} can be measured and the speed v and direction angles α_1, α_2 can be calculated by (4). As a result, the position and direction location is realized:

$$\begin{aligned} f_{d1} &= \frac{f}{C} v \cdot \cos\alpha_1, \\ f_{d2} &= \frac{f}{C} v \cdot \cos\alpha_2, \\ \cos(\alpha_2 - \alpha_1) &= \frac{L_1^2 + L_2^2 - S^2}{2L_1L_2}. \end{aligned} \tag{4}$$

In fact, the calculating process is more complex than that mentioned above. The reason is that (4) is a transcendental equation. It needs appropriate transform and the arithmetic solution can be obtained by iterative methods.

Let

$$\Delta = \alpha_2 - \alpha_1 = \cos^{-1}\left(\frac{L_1^2 + L_2^2 - S^2}{2L_1L_2}\right). \tag{5}$$

The following formula can be achieved by simultaneous equations (4) and (5):

$$\begin{aligned} \cos\alpha_1 \cos\alpha_2 &= \frac{1}{2}\left(\cos(\alpha_2 + \alpha_1) + \cos(\alpha_2 - \alpha_1)\right) \\ &= \left(\frac{C}{fv}\right)^2 \cdot f_{d1} \cdot f_{d2}, \end{aligned} \tag{6}$$

or

$$\begin{aligned} \cos(2\alpha_2 - \Delta) + \cos\Delta &= 2\left(\frac{C}{fv}\right)^2 \cdot f_{d2} \cdot f_{d1} \\ &= 2\left(\frac{C}{fv} \cdot f_{d2}\right)^2 \cdot \frac{f_{d1}}{f_{d2}} \\ &= 2\cos^2\alpha_2 \cdot \frac{f_{d1}}{f_{d2}} \\ &= (\cos 2\alpha_2 + 1) \cdot \frac{f_{d1}}{f_{d2}}. \end{aligned} \tag{7}$$

Then

$$\cos(2\alpha_2 - \Delta) + \cos\Delta = (\cos 2\alpha_2 + 1) \cdot \frac{f_{d1}}{f_{d2}}, \tag{8}$$

$$\cos 2\alpha_2 \cdot f_{d1} - \cos(2\alpha_2 - \Delta) \cdot f_{d2} = f_{d2} \cdot \cos\Delta - f_{d1}. \tag{9}$$

It just needs to select different values of the formula $\alpha_2 \in [0, 180]$ in the order of the smallest to the largest and then calculate the value of the two ends. When the different value reaches the required error, the value is the solution as (9). Then all will be calculated when substituting α_2 to formula (3). The speed v and direction angles α_1, α_2 will be calculated through (2). The moving parameter can be expressed according to $M(v, \alpha_1, \alpha_2)$.

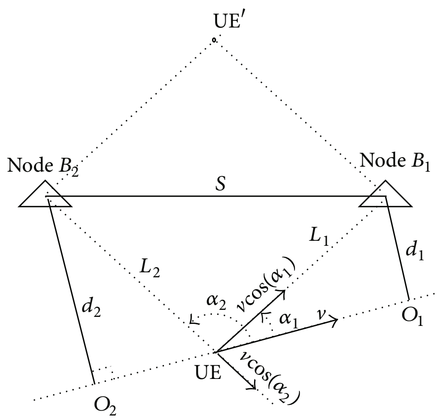

Figure 1: Relationship between mobile terminal and base station.

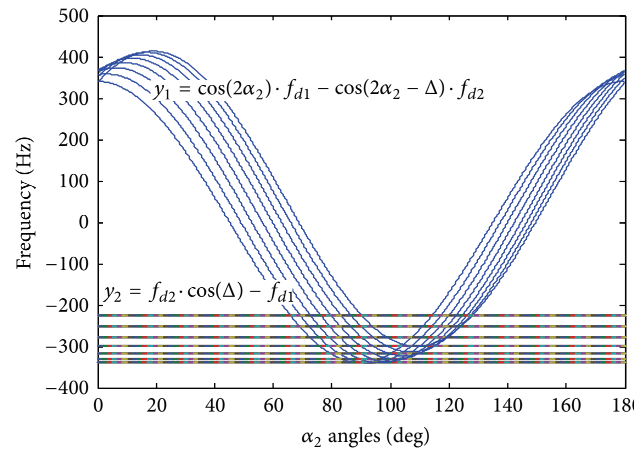

Figure 2: Relationship between direction angle and frequency shift in the moving process.

2.2. The Parameter Calculation Steps of Mobile Terminal Navigation and Position

Step 1. Receive the carrier frequency signals of the two base stations through antenna unit and then calculate frequency shifts f_{d1}, f_{d2}. At last, calculate α_1, α_2 through formula (2).

Step 2. If it receives signal from only one base station, it needs to test frequency shift f_{d1} (or f_{d2}) to confirm α_1 (or α_2). And then, using equations (2) and (9), calculate the f_{d2} (or f_{d1}) of the neighboring base station and α_2 (or α_1).

Step 3. Calculate $L_1 - L_2$ by measuring cost time from stations to moving terminal and then calculate the L_1, L_2 with (5).

Step 4. Calculate speed v and direction angles α_1, α_2. The relative position of the mobile terminal $p(x, y)$ can be calculated when using $M(v, \alpha_1, \alpha_2)$ expressing the moving parameter. If $B_1(x_1, y_1), B_2(x_2, y_2)$ are known, then

$$\begin{aligned} L_1^2 - (x - x_1)^2 - (y - y_1)^2 &= 0, \\ L_2^2 - (x - x_2)^2 - (y - y_2)^2 &= 0. \end{aligned} \tag{10}$$

It is expressed in parameter form as follows:

$$p(x, y) = f(B_1, B_2, L_1, L_2). \tag{11}$$

3. Simulation Analysis and Navigation Test

3.1. Case I: Navigation Parameters Calculating. If $S = 5\,\text{km}$, $L_1 = 4\,\text{km}$, $L_2 = 3\,\text{km}$, $f_{d1} = 104\,\text{Hz}$, and $f_{d2} = -38\,\text{Hz}$, simulation calculation will get the following:

$v = 59.9773\,\text{km/h}$, $\alpha_2 = 110.0079$ degrees, and $\alpha_1 = 20.0079$ degrees,

or $v = 1.7049e + 004$, $\alpha_2 = 90.0117$, and $\alpha_1 = 0.0117$.

The second solution speed above is out of reality obviously. The reason is that there is a critical problem when α_2 is close to 90 degrees. The change of $f1$ is so quick that tiny calculation error will cause a big error of the speed calculation while α_2 is near 90 degrees.

Table 1: Data range of direction angles and frequency shifts.

α_1	f_{d1}	α_2	f_{d2}	O_2O_1 direction
[0, 90]	≥0	[0~90]	≥0	**Synchrony**
		(90~180]	<0	
(90, 180]	<0	[90~180]	<0	
[0~90]	≥0	[0, 90]	≥0	**Reverse**
(90~180]	<0			
[90~180]	**<0**	**(90, 180]**	**<0**	

3.2. Case II: Navigation Parameters Calculating. If UE as MT (mobile terminal) moves in the O_2O_1 direction, the solution α_2, one of the MT moving parameters α_2 will be the point of intersection. Distance of UE to base stations Node B_1 and Node B_2 is that $d_1 = 2$, $d_2 = 4$. As shown in Figure 2, there are two points of intersection of line y_1 and line y_2. One is close to 90 degrees and the other is the solution we require. The test process needs to consider this situation. The methods of continuous forward and backward ruin are needed to solve this problem. The detailed discussion is shown as follows.

Direction angles α_1 and α_2 of the equation solution may have two solutions. At the time, we need to use the positive or negative of the frequency as judgment. The total possible conditions are shown in Table 1. When α_2 is close to 90 degrees, the arithmetic of example will be replaced by curve ruin method to get the approximate solution.

3.3. Test of Navigation System. As shown in Figure 3, Huaihai South Road from (33.4980, 119.0258) to (33.5646, 119.0323) is selected for testing. The distance between base stations B_1 and B_2 is 3.38208 km. When the car with test terminal reaches point M, the calculation has been finished and shown as follows:

$$\begin{gathered} v = 60\,\text{km/h} \\ \alpha = -8.6 \\ M = (33.5293, 119, 0300). \end{gathered} \tag{12}$$

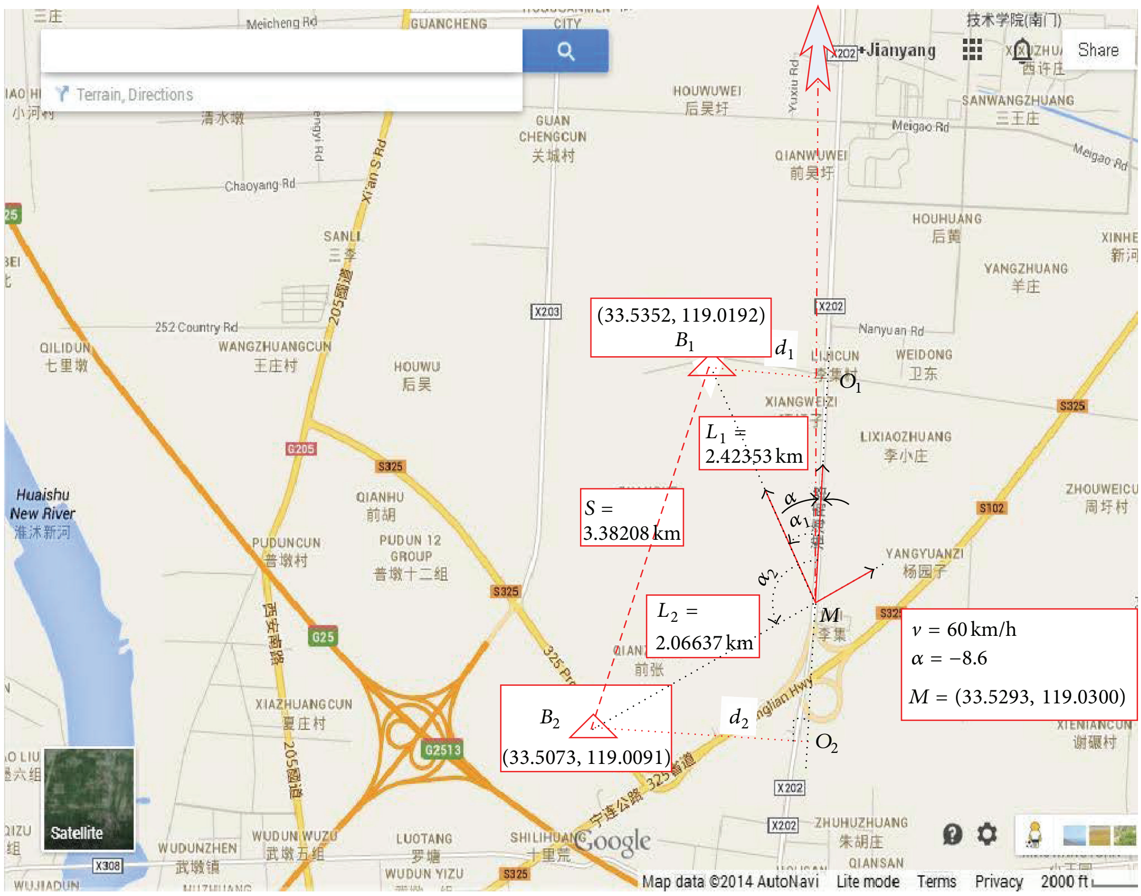

FIGURE 3: In-vehicle navigation showing with position verification.

The real speed is 60.8 km/h. The traffic map and navigation marks are produced by calculation. The test map comes from Google. Before the system running, sign four GPS points of the map which is 100 times bigger than the used part. In the test process, select a part map nearing point M and then send it to MT after overlying calculation.

4. Conclusions

MT automatically adapts the Doppler effects which can play a role in navigation and positioning. Then the MT gets value-added functions after adding little resource spending. Theoretical analysis and simulation results show that MT position method is feasible. Compared with GPS position method, the benefit of this strategy is the straightway use of mobile channel to transmit navigation and position information without special GPS receiver or communication network. The strategy of navigation position based on cloud platform is feasible through test checking.

The future work is about combining navigation arithmetic of self-adaption signal in the condition of multiroad pilot.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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