Establishment of Coordinate Relationship with Accelerometer

Xiaojie Zong[1] ,Xiangji Wen[2] ,Tiezhu Zhang[1]

[1]School of Computer Science & Information Engineering,Zhejiang Gongshang University,Hangzhou, China

[2]Department of Control Science and Engineering,Zhejiang University,Hangzhou, China

zju_wxj@163.com,zxj6330@163.com ,Ztz0647@qq.com

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Abstract. Driving status recognition, driving route tracking and traffic flow detection application, and so on, are strict with the smartphone orientation. In order to achieve a good performance, we should learn its orientation in advance. In this paper, we propose a new approach to estimate the smartphone orientation by detecting the vehicle starting action. Instead of compass, we utilize the accelerometer to obtain coordinate relationship between smartphone and vehicle. In this way, we can overcome the environment impact, because the compass is essential to the environment and can't achieve a high accuracy. Comparing with previous work, our approach reduces the requirement for starting period. Upon data processing, for example, action recognition, data filtering and parameter optimization, the experiment result shows a good performance, for example, high sensitivity and accuracy.

Introduction

In recent years, mobile applications get an unprecedented development. Burke proposed participant sensing firstly in 2006 [1]. He introduced the concept of participatory sensing, which take advantage of smartphone to form participatory sensor networks. It enables users to collect information, and after gathering and analyzing it will make the information public.

According to the participant sensing, Herrera conducted an experiment in 2009 to monitor the highway traffic condition using smartphone [2]. The experimental result shows that a 2-3% penetration is enough to estimate the traffic condition. Thiagarajan proposed VTrack in 2009 [3]. He used WIFI and GPS signal to learn the vehicle location and utilized some algorithm to estimate the congestion scale and reduce the energy consumption. There are still many other researches in the traffic condition evaluation [4][5][6].

Driving status recognition also attached the public attention. Taking advantage of acceleration information in advanced direction of the vehicle, Mohan proposed an activity recognition algorithm in 2008 [7], and the experimental result shows a good performance. Through that we can learn braking activity, stop-and-go activity and bump activity. As well, the bump activity could reflect the traffic accident. Xiang Liu also proposed a driving status recognition algorithm in 2012, and classified the driving status into five modes, including turning, braking, temporary parking, traffic congestion waiting and traffic lights waiting. These modes have greatly improved traffic condition evaluation [8]. There are still other researches on the behavior recognition [9][10]. In another word, the acceleration information could evaluate the driving status and even provide some bases for traffic accident monitoring and traffic management.

All of the above are the extension of participatory sensing. They bring our life much convenience and have become one part of our life.

As one part of the participatory sensing research, the coordinate relationship between the smartphone and vehicle is also important. It could help recognize the driving status, traffic condition monitoring and behavior of one person.

However, the compass and the orientation sensor data are susceptible to the environment where the TV tower, radio station, radar station, high tension line and transformer substation are located, and in addition the electromagnetic equipment in the car can also bring an impact on the magnetic field. Therefore, the magnetization would bring a serious error in these environments. Based on this consideration, we need other methods to calculate the orientation.

Instead of the compass, the accelerometer is not sensitive to the environment and has better feasibility [7][11]. There are still some problems on evaluating their relationship by acceleration. How to obtain the effective information and enhance the estimated accuracy are the tough problems. In this paper, we put forward a new approach which could obtain their relationship by detecting the starting action. Comparing with the approach proposed before, we could calculate the parameters of their relationship when the acceleration is over $0.5m/s^2$ which can be achieved easily.

The main contributions of our work are:

1) An effective and practical approach is proposed by detecting the starting action in normal.

2) Combined with the GPS module and compass sensor, a new data processing algorithm is put forward, which could improve the estimated accuracy.

3) The effect of the GPS latency time of the smartphone on the starting period is investigated.

4) The proper range of the compass fluctuating scope is proved through lots of experiment and analysis.

The remainder of this paper is composed as follows. Section II shows the framework of coordinate relationship establishment, and Section III describes our approach in detail. Section IV introduces the experiment and experimental result. Section V describes its performance and application of the coordinate system relationship. Section VI summarizes the conclusion and future work.

The Framework of Coodinate Relationship Establishment

In this section, we describe the framework of coordinate relationship establishment. As described in section I, the coordinate relationship between smartphone and vehicle is essential. Driving status recognition, traffic condition estimation and behavior recognition all need to know the coordinate relationship in advance. Compass is an important sensor to learn the smartphone orientation. However, it is sensitive to the environment. Instead, the accelerometer can provide some available information to their coordinate relationship. Unfortunately, it has a strict requirement for the starting and braking action, and we need to select the effective states.

According to this, taking advantage of the speed, acceleration and orientation sensor data in its starting period, we propose a high-precision approach which could obtain the relationship between smartphone coordinate system and vehicle coordinate system. The coordinate relationship and parameter calculation framework are showed in the following paragraph.

A. Coordinate System Relationship

As mentioned above, the coordinate relationship is very essential. In this section, we describe their coordinate systems and their relationship.

Figure 1 shows the coordinate systems of the vehicle and the experimental smartphone based on Euler angles [12][13], and figure 2 presents their relationship. Firstly, the taxi coordinate system (x, y, z) rotates around the z axis by α angle clockwise, and turn to (x_1, y_1, z_1) coordinate system. Secondly, the (x_1, y_1, z_1) coordinate system rotates around the x_1 axis by β angle clockwise, and turn to (x_2, y_2, z_2) coordinate system. Finally, the (x_2, y_2, z_2) coordinate system rotates around the y_2 axis by γ angle clockwise, and turn to (x', y', z') coordinate system, and coincides to the smartphone coordinate system.

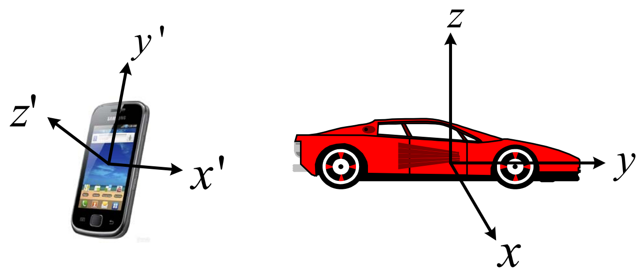


Figure 1. The coordinate systems of the taxi and experimental smartphone.

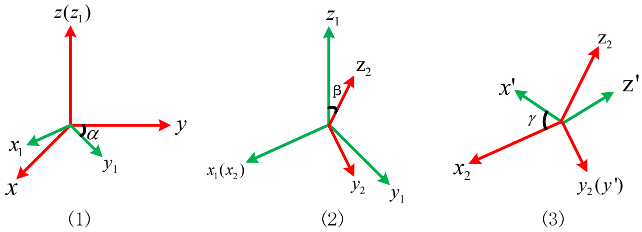


Figure 2. The relationship of the two coordinate systems.

Utilizing the calculated value of α、β and γ, we could get the coordinate transformation relationship between the taxi coordinate system (x, y, z) and the smartphone coordinate system (x', y', z'). It shows as follows,

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} \cos\alpha & \sin\alpha & 0 \\ -\sin\alpha & \cos\alpha & 0 \\ 0 & 0 & 1 \end{bmatrix} * \begin{bmatrix} \cos\gamma & 0 & -\sin\gamma \\ \sin\beta\sin\gamma & \cos\beta & \sin\beta\cos\gamma \\ \cos\beta\sin\gamma & -\sin\beta & \cos\beta\cos\gamma \end{bmatrix} \begin{bmatrix} x' \\ y' \\ z' \end{bmatrix} \quad (1)$$

B. Framework of Coordinate System Relationship

The parameters of their relationship can be measured by compass. However, it is sensitive to the environment, and sometime even gets a wrong evaluated result. Comparing with compass, accelerometer is relatively more accurate. It collects the acceleration in the starting or braking period, and regards the detected data as the acceleration of the vehicle in the advanced direction in this period. And the relationship can be estimated based on this theory. We could calculate the parameters of α、β and γ based on the acceleration components falling on the coordinate axes of the smartphone in the starting period. There is some related work in previous research.

The approach Prashanth proposed has not conducted the data processing experiment. He calculated the parameters only relying on the accelerometer and didn't judge if the action is effective. Besides, it needs a sharp braking to obtain the coordinate relationship.

Analyzing the acceleration value in the braking period of vehicle, Prashanth put forward a new approach for coordinate relationship establishment in 2008 [7]. However, he realized the goal by detecting the sharp braking action of the car. Without data processing, some braking states may be illegal and it may lead to relatively large calculation error. Furthermore, even though it could achieve a good precision, his method needs the sharply braking action, so the volunteers need do some experiment deliberately. It is not practical because of its inconvenience.

In this paper, combined the accelerometer with the GPS module and compass, we propose a new approach. The GPS module and compass can help us find the effective information and get a good performance. Referred to the parameter calculation method, we make a data filtering criterion to delete the invalid data and improve the parameter precision.

Comparing with the method Prashanth proposed, our approach has a low threshold, and a starting period with slow acceleration can also realize the relative orientation calculation with a high accuracy. We cloud get the coordinate relationship with a normal starting action.

As figure 3 (dotted portion represents the process of parameter regulation) shows, the process of establishing coordinate transforming relation contains four procedures. Firstly, we optimize the value of sensitivity setting. Secondly, we evaluate whether the starting mode is effective. And next, we optimize the fluctuating scope of compass when driving straight and GPS latency time when starting. At last, we could calculate the parameters.

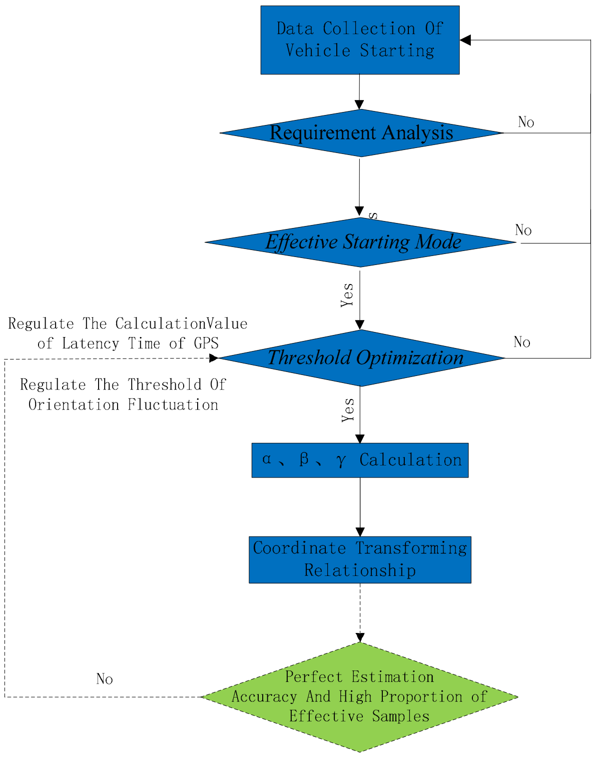


Figure 3. Coordinate relationship establishment.

The Process of Relationship Establishment

As mentioned in section II, the process of relationship establishment contain five segments, including sensitivity setting, effective starting mode recognition, effective data recognition and parameter calculation. Now we will show the five segments in detail.

C. Requirement analysis

In this section, we describe the properties of our approach. Similar with other researches, the estimated result should achieve high precision. Besides, the practicability is also important. It should eliminate the impact of the noise and have high sensitivity to reach the goal with ease.

As we all know, the vehicle keep driving straightly in the braking state in most situation. Previous research concentrates on the braking state in consideration of noise interference.

In this paper, we propose a new approach taking advantage of the information in the starting period. There is a sharp acceleration during vehicle starting, and many kinds of cars can reach to 100km/h within 10 seconds. Generally speaking, the average value of the acceleration is $2.78m/s^2$ in this period. In our experiment, the taxi driver has a good driving habit and drive the taxi in a very smooth state. But even so, the acceleration is overwhelming above $1m/s^2$ in this period. In our approach, we select $0.5m/s^2$ as a threshold of starting action. In other words, if the speed ranges from 0 to 1.5m/s in 3 seconds, we will classify this period to starting state.

The selected threshold is much less than the general acceleration in this state. The threshold could make most starting data available and ensure its high efficiency and sensitivity.

D. Effective Starting Mode Recognitiont

All kinds of statuses of taxi parking exist in the experiment, including roadside parking, waiting at red lights and parking in parking lot. Therefore, all kinds of starting states also exist, for example, starting with straight driving, starting with turning around, starting with turning a corner, starting with reversing, starting with overtaking, starting with slow acceleration, starting with sharp acceleration and starting as normally.

We need recognize the starting mode and reject the invalid states. There are many invalid states needed to be analyzed, for example, turning around, backing up and so on to choose the legal action. Based on this consideration, we design an algorithm to recognize the straight driving status and discard the invalid data.

The threshold of $0.5m/s^2$ mentioned in section III.A can eliminate the state of starting with slow acceleration. Furthermore, the compass value can reflect the variation of the driving orientation, and we take advantage of the compass value to delete some starting states, for example, turning around, turning a corner and overtaking. We perform statistical analysis on the $w_{z'}$, which could reflect the α value. And then, if the taxi driver back the car at first, and then drives away straightly, we would draw a distinctly conclusion. To avoid this error, we evaluate whether the vehicle is backing up by GPS latency time.

In most cases, the vehicle keeps a low speed. Generally speaking, when the speed changes from zero to none-zero, the GPS will have a long latency time. If the speed will keep a low value in the starting period, the GPS latency time will be longer. Therefore, we could eliminate the baking up state by GPS latency time.

The effectiveness of starting states is recognized by the diagram as shown below.

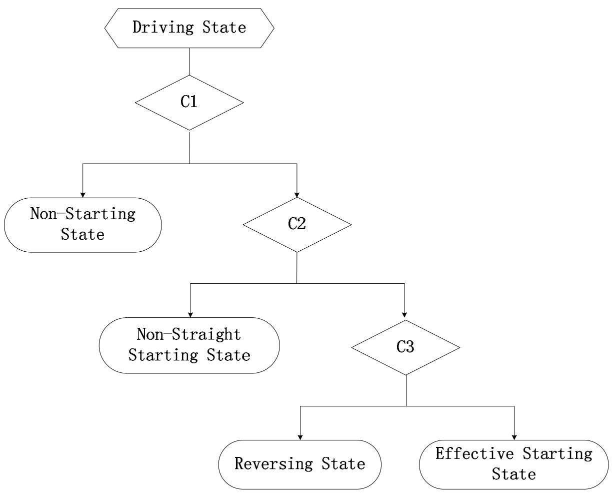


Figure 4. Effective Starting Mode Recognition

C1: average (acceleration in the starting period) >=T1

When the speed changes from zero to non-zero, if the acceleration in the first three seconds is above $0.5m/s^2$, we regard the driving state as starting status.

C2: fluctuating scope (compass value in the starting period) <=T2

If the fluctuating of compass value is lower than T2 in the starting period, we would look this state as starting straightly status. The value of T2 will be discussed in section III.C.

C3: time (GPS recognized) - time (accelerometer recognized)) <=T3

We regard the GPS latency time, the time difference the starting state is recognized by GPS and accelerometer, as the basis of the effectiveness judgment. If the GPS latency time is lower than T3, the starting state is regarded as effective starting status. The value of T3 will be discussed in section III.D.

E. The Threshold of T2 Optimazation

In the process of relationship establishment, the smartphone is fixed in the vehicle. The value of the compass represents the angle of the coordinate system rotating around the z' axis from north clockwise and can reflect the fluctuating scope of the driving direction.

In this section, we analyze the orientation sensor data of starting state to realize the effective starting mode. The value of orientation sensor data the experimental smartphone collected is represented by the symbol of ($w_{x'}$, $w_{y'}$, $w_{z'}$). $w_{x'}$ represents the angle of the coordinate system rotating around the x' axis from the horizontal plane anticlockwise. $w_{y'}$ represents the angle of the coordinate system rotating around the y' axis from the horizontal plane anticlockwise. $w_{z'}$ represents the value of the compass.

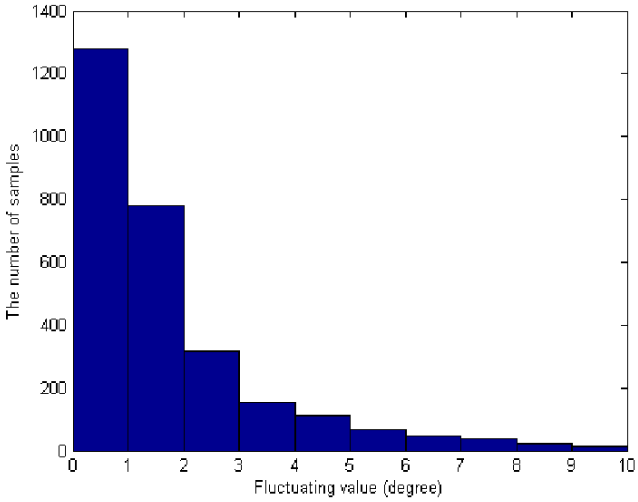


Figure 5. Fluctuating value of the compass

In 4732 starting experiments, there are only 2832 experiments whose fluctuating scope of the compass is lower than 10 degrees. Obviously, the samples they are not straight driving state, for example, turning around or turning a corner, when their fluctuating scope is over 10 degrees, and we obtain 2832 samples whose fluctuating scope is below 10 degrees in total.

The figure 5 shows the relationship between the number of samples and the fluctuating scope, which represents the difference between the max value and the min value of w_z' in the starting state. The picture can reflect their relationship when the fluctuating scope is below 10 degrees.

According to the picture, their connection is much similar with the parabola. In the 2832 starting experiments, the fluctuating scopes of 72.7 percent samples are within 2 degrees, and the fluctuating scopes of 83.8 percent samples are within 3 degrees. There are 89.2 percent samples whose fluctuating scopes are within 4 degrees. And the fluctuating scopes of 93.1 percent samples are within 5 degrees. According to the statistic, those samples whose fluctuating scope are between 5 degrees and 10 degrees are overtaking other vehicles or avoiding barriers. Apparently, slower the fluctuating scope is, and higher the accuracy of estimated parameter is. On the other hand, the effective samples will be fewer if the T2 value decreases.

Apparently, lower the fluctuating value is when driving, greater the possibility of straight driving is, and the coordinate relationship will be more accurate as analyzed in section IV.B. According to the above analysis, the samples between 4 degrees and 5 degrees are 3.9 percent. Because of the fact that the fluctuating value of the compass is within 5 degrees when driving straightly, and only a few fluctuating values of samples fall in the scope between 4 degrees and 5 degrees, in order to obtain abundant samples to estimate the relationship with the taxi and achieve a high goal, we reject the samples whose fluctuating scope are between 4 and 5 degrees, and select 4 degree as the threshold of the fluctuating scope. In other words, if the fluctuating scope is

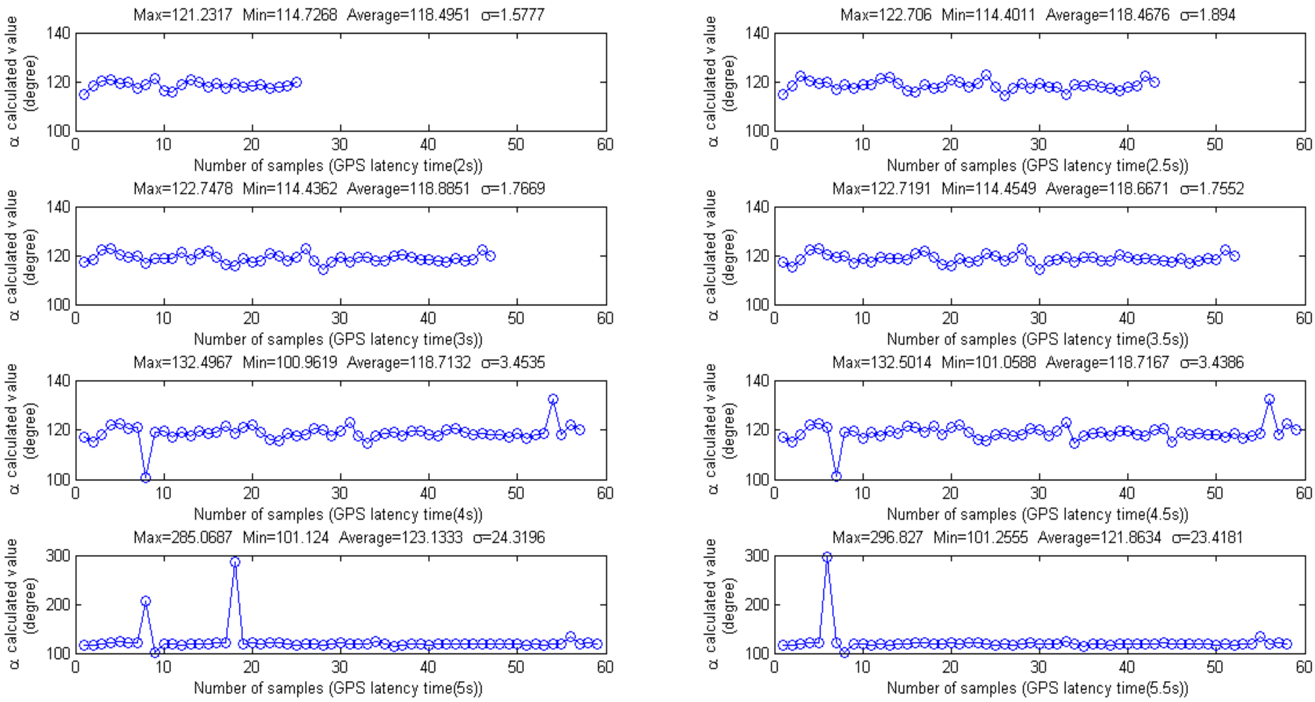


Figure 6. The relationship between the GPS latency time and the calculation result.

lower than 4 degrees in the starting state, we would regard the starting state as straight driving. Considering the fact that the fluctuating scope is below 5 degrees when driving straightly, the efficiency of availability is higher than 93.1 percent at least. Besides, the experimental result shows a satisfied performance.

F. The Threshold of T3 Optimazation

GPS latency time refers to the time difference between the time that GPS value ranges from zero to non-zeros and the time that accelerometer realizes the starting action. In order to avoid backing up action, we measured the latency time of the GPS module in the starting period and design an algorithm. According to the statistic, the acceleration value is below $0.2m/s^2$ when the taxi is in the stationary state. As mentioned in section III.A, most of the acceleration in the starting state is above $1m/s^2$. In this section we select $0.2m/s^2$ as the threshold of the starting state, and in other words, if the acceleration is above $0.2m/s^2$ at this moment and the taxi keeps in stationary state prior to this moment, we would look this moment as the real time the taxi starts. In addition, the detecting time is defined as the detecting time, when the speed of the taxi changes from zero to non-zero, which is measured by the GPS module. The difference between the real time and the detecting time is called as the latency time of the GPS module in the starting period.

Unfortunately, the latency time does not keep consistency in the starting experiments. In order to exclude the backing state and filter more illegal starting states, we analyzed the starting data after starting action recognition and straight driving recognition, and tried to find out the latency time. In the case of selecting 4 degrees as the threshold of the fluctuating scope, the relationship between the latency time and the calculation result shows in figure 6.

When the threshold of T3 selected as 5 or 5.5 seconds, there are distinct estimated results. When the threshold is selected as 4 or 4.5 seconds, there is still serious error. The difference between max value and min value is 30 degrees, which is unacceptable. The results calculated by the thresholds below 3.5 seconds are similar, and achieve a good performance. The available number reduces apparently as the threshold decreases.

In the experiment, in case of inconvenience, we can't collect the real value between the smartphone orientation and driving orientation. However, as shown in the picture, we find that the estimated results are similar with each other and have a low variance. Above all, according to section V, the acceleration value after coordinate system transformation is very similar with the real acceleration value in the vehicle coordinate system, which proves its accuracy.

In order to obtain a satisfied accuracy and effective samples as many as possible, we select 3.5 seconds as the latency time of the GPS module. This means that if the latency time we detect is larger than 3.5 seconds, we would discard the sample, and otherwise, we regard it as an effective starting. As a result, the efficiency of availability reached to 89.7 percent.

After filtering the collected data in the 4732 starting experiments with the algorithm mentioned by section III.A and section III.B, we obtained 2117 effective samples in total.

G. Parameters Calculation

Taking advantage of the effective data, we calculate the relationship between the vehicle coordinate system (x, y, z) and the smartphone coordinate system (x', y', z'), which represents by the symbol of α、 β and γ. The value of β and γ can be calculated by the $w_{z'}$ and $w_{x'}$ which are collected by the orientation sensor directly. We calculate the average of the $w_{x'}$ value as the result of the β value, and the average of the $w_{y'}$ as the result of the γ value. And then we can calculate the α value, making use of β value, γ value and the acceleration during the start period. The acceleration detected by the smartphone is denoted as $(a_{x'}, a_{y'}, a_{z'})$, which represents the taxi acceleration in the mobile coordinate system. The α value can be obtained as follows,

$$\begin{aligned} \alpha &= \arctan\left(a_{y1}/a_{x1}\right)+90, \quad a_{x1}<0 \\ \alpha &= \arctan\left(a_{y1}/a_{x1}\right)+270, \quad a_{x1}>0 \end{aligned} \tag{2}$$

a_{x1} represents the component of the acceleration along the x_1 axis in the (x_1,y_1,z_1) coordinate system; a_{y1} represents the component of the acceleration along the y_1 axis in the (x_1,y_1,z_1) coordinate system. The value of a_{x1} and a_{y1} is calculated as follows,

$$\begin{bmatrix} a_{x1} \\ a_{y1} \\ a_{z1} \end{bmatrix} = \begin{bmatrix} \cos\gamma & 0 & -\sin\gamma \\ \sin\beta\sin\gamma & \cos\beta & \sin\beta\cos\gamma \\ \cos\beta\sin\gamma & -\sin\beta & \cos\beta\cos\gamma \end{bmatrix} \begin{bmatrix} \overline{a_{x'}} \\ \overline{a_{y'}} \\ \overline{a_{z'}} \end{bmatrix} \tag{3}$$

$\overline{a_{x'}}$ represents the average of $a_{x'}$ (the acceleration along the x' axis) in the starting period.
$\overline{a_{y'}}$ represents the average of $a_{y'}$ (the acceleration along the y' axis) in the starting period;
$\overline{a_{z'}}$ represents the average of $a_{z'}$ (the acceleration along the z' axis) in the starting period.

The Experiment

Goal: *Obtaining rich data to optimize the parameters of the orientation calculation algorithm and check its estimated accuracy*

H. Experiment Setup

Figure 7. The environment of data collection.

As mentioned in section III, we evaluate the coordinate relationship and posture of the smartphone by detecting the vehicle starting action. In order to optimize the parameters of the orientation calculation algorithm and check its estimated accuracy, an abundant of traffic information need to be collected, which could reflect all kinds of starting states. It is necessary to have volunteers carry a smartphone while driving the car. We cooperate with a taxi company in Hangzhou, employing the company's taxi for the information collection. Before collecting this data, we provide the smartphones to taxi drivers since the normal use of smartphone(e.g. making a phone call, playing mobile phone games) may affect the data acquisition. The taxi driver placed the mobile phone at the fixed position before working, and took the smartphone away and turned the application off after working. Figure 7 shows the located position of the experimental smartphone in the car. The data we collected consists of the acceleration, speed and orientation in the starting action.

In order not to affect the taxi drivers when they are driving, the entire collection process would be done automatically without driver intervention. Meanwhile, we did not constrain the route and time of the driver traveling, and he could drive the taxi as usual. We collected the traffic information for more than one month and got lots of data, including starting with straight driving, starting with turning around, starting with turning a corner, starting with reversing, starting with overtaking, starting with slow acceleration, starting with sharp acceleration and starting as normally. In total, we obtained 4732 starting experiments.

I. Experimental Result

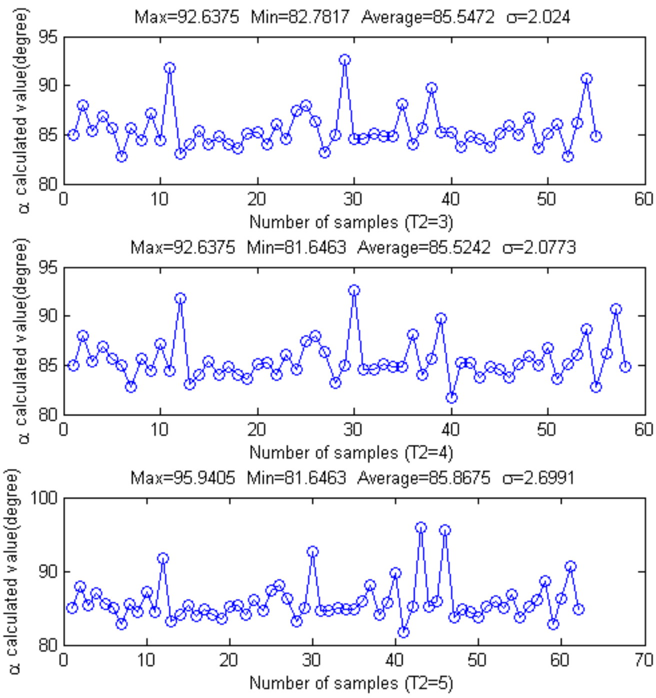


Figure 8. α value calculated by different fluctuating scope.

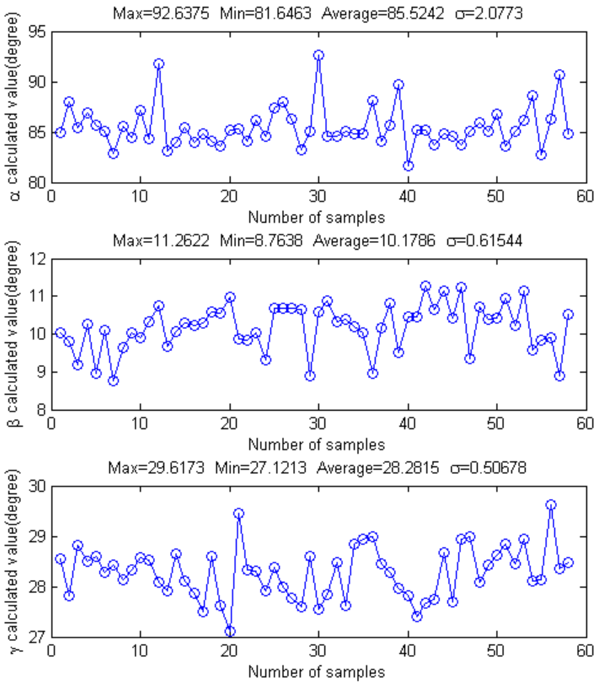


Figure 9. Estimated results for the coordinate parameters.

Figure 8 shows α value calculated by different fluctuating scope. Obviously, the result has a large variance when we select 5 degrees as T2 value, and the difference between max value and min value is more than 14 degrees. When we select 4 degrees as T2 value, the variance decreases and the difference between max value and min value is 11 degrees. Once we choose 3 degrees as T2 value, the number of available samples reduces by 3, while its performance is similar to the results calculated by T2 value of 4 degrees. In a word, T2 value of 4 degrees performs a good performance.

The parameters estimated by T2 value of 4 degrees are analyzed in this paragraph. As described in figure 9, the x-coordinate represents the number of our calculated results by detecting the multiple starting states in one day, and the y-coordinate represents the calculated values of the parameters. The accuracy of the calculated value of the parameters acquired a satisfied result. The fluctuation of α evaluated value is lower than 11 degrees and the standard deviation is about 2 degrees. Apparently, the β and γ values are more stable, and their standard deviations are all below 0.7 degrees.

Figure 10 shows the performance of previous research, the variance of Φ_{pre} value is more than 1 degree, however, the variance of γ value is only 0.5 degree. Corresponding to α value, the ψ_{post} has a larger variance, which is more than 2.8 degree. And especially, the difference between max value and min value is 17 degrees which is as 1.53 times as the difference of α value. Comparing with α value, it has a serious error. In a word, our approach makes a good performance.

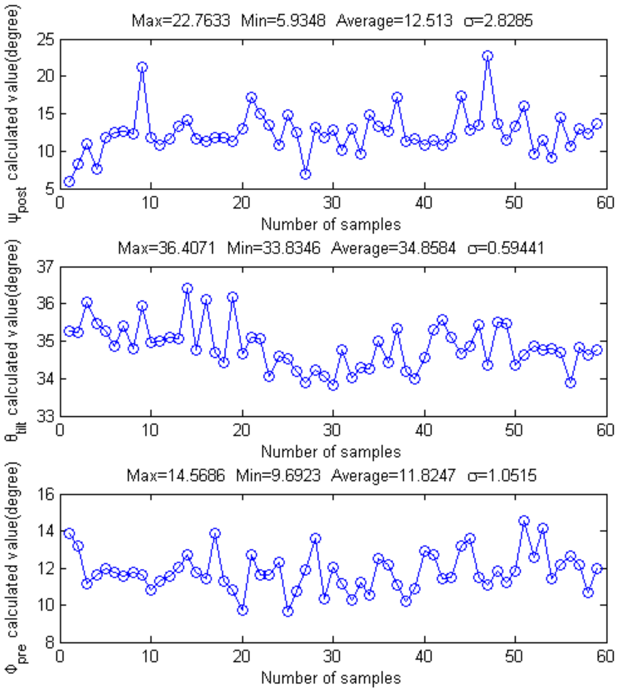


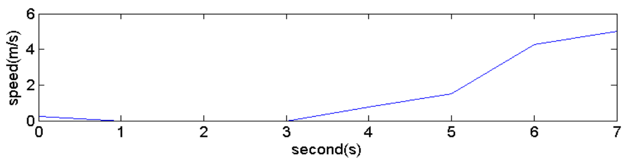
Figure 10. Estimated results for previous reaserch.

Application

Taking advantage of the calculated parameters, we could establish the relationship between the vehicle coordinate system and the smartphone coordinate system as mentioned in section II. And then with their coordinate system relationship, we could obtain the acceleration value in the vehicle advancement. The calculated result of a_x, a_y and a_z value is described in figure 11, which proves a perfect accuracy, especially in the y axis. The real acceleration values are measured by the smartphone fixed at a stationary location in the taxi, and the coordinate system of the smartphone is coincided exactly with the coordinate system of the vehicle.

The figure 11 shows the acceleration value after coordinate transformation, the real acceleration value and the acceleration value detected by the smartphone. The x-axis value represents time in all sub-graphs. The y-axis value represents the acceleration value in the sub-graph except for the first sub-graph, and the y-axis value is the speed of the vehicle in the first sub-graph. This picture describes the speed and acceleration in the starting period. The green line represents the acceleration value detected by the smartphone directly. The blue line represents the calculated acceleration value in the coordinate system of the vehicle, and the red line represents the real acceleration value in the coordinate system of the vehicle.

As described in the picture, the result after coordinate transformation is very similar with the real acceleration value. The y-axis value is nearly coincident with the true acceleration value in the driving direction of the vehicle.



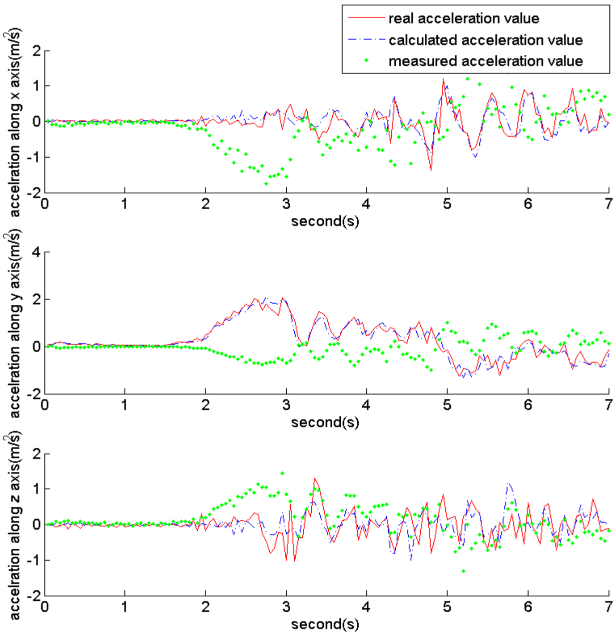


Figure 11. The acceleration value comparision diagram between estimation result and real value.

Conclusion

In conclusion, our approach achieves a good performance in the coordinate relationship establishment between the smartphone and the vehicle by detecting the starting action. Instead of compass, the accelerometer is not sensitive to the environment. Most importantly, our approach only requires an acceleration value of $0.5m/s^2$, which can be realized in most situations.

We conduct the experiment only by LG Nexus4 E960 smartphone and don't consider other types of smartphone. Besides, our approach still relies on the GPS signal to some extent. In the future, we should verify the algorithm with more smartphones, and on the other hand, we should combine the vehicle motion monitoring with the accelerometer and make the algorithm independent of the GPS signal.

Acknowledgement

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