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A New Approach to Map-matching and Parameter Correcting for Vehicle Navigation System in the Area of Shadow of GPS Signal

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Abstract— **A new approach to map-matching and DR error calibration is proposed in this paper. This method compares the dead reckoning (DR) tracks and all possible route candidates in digital map to find out the best matching route through correlation analysis. It makes use of first order difference to decompose the rotation angle of track curve relative to candidate route curve. The DR sensor error parameters can also be calibrated with the matched routes on digital map. A case study demonstrates that the proposed map matching method is efficient and robust to noise.**

I. INTRODUCTION

RECENTLY, the Global Position System(GPS) has been widely used to the vehicle navigation. However, due to the blockage and multi-path of GPS signals, Dead Reckoning (**DR**) technology has been widely used to aid to the vehicle navigation. The positioning errors with a **DR** system increase dramatically with time, and the sensor error parameters of **DR** have to be calibrated frequently to reduce the accumulative errors. When **GPS** signals are available, the **DR** sensor errors can be calibrated by **GPS** positions. On the other hand, when there is no **GPS** signal for a long time (especially in urban environment), it is difficult to correct these parameters. In this paper, we will describe a new method of map-matching, and apply this method to correct the **DR** sensor errors based on accurate digital map, especially in areas of blockage and multi-path of **GPS** signals. This paper is organized as follows. Section II describes the background on map-matching in vehicle navigation systems. Section III proposes a new map matching algorithms based on correlation analysis. In section IV, a method for calibration **DR** sensor errors is given. In Section V, a test case in vehicle navigation based on the proposed method is given. The conclusions are given in Section VI.

II. BACKGROUND

In vehicle navigation systems, **GPS** and **DR** systems have been widely used to obtain vehicle positions. Due to the errors of **GPS** (multi-path and bad geometry) and drift errors of **DR** sensors (odometer and gyrometer), navigation systems can produce vehicle locations with very large errors, Therefore, when vehicle locations displayed on a digital map, the locations can be far away from the road vehicle traveled in the map. Map matching is a process to find correct route and coordinate in digital map for the vehicle by using the relationship between estimated vehicle coordinate (with errors) and candidate routes.

The basic ideal of conventional map matching is to search for the nearest route around the coordinates in digital map, as in [1]. In 1989, R.L. French addresses the semi-deterministic map-matching algorithm in [5][7]. In 1997, ZHAO describes the probabilistic and fuzzy-logic-based map matching algorithm in [6][2]. However, in these methods only consider the relationship between the latest track point (not curve) and candidate routes in each time.

Recently, R.R.Joshi introduced a map matching method that considers the difference of tangent angle on corresponding point between last vehicle track curve and the candidate route curve, as in [3][4]. This method tries to consider the relationship between track curve and route curve to form a curvature match. However, due to the randomicity of sensor errors, it is difficult to apply to **GPS**/**DR** navigation system directly. In this paper, a new approach to this problem will be given. The basic idea of the proposed method is to evaluate respectively the relationships between the Last Segment Track (**LST**) of vehicle and each candidate route. Here, we only consider the coordinates of dead reckoning. Under this case, the coordinate and **LST** can be calculated by following equation, as in [6]:

$$X_i = X_{i-1} + d * \cos\alpha$$
$$Y_i = Y_{i-1} + d * \sin a$$

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where ,d is the moving distance of vehicle along heading α , α is the heading of vehicle.

Map-matching used in this paper is defined as to find a section of route in digital map that is the best matched to the vehicle trajectory obtained based a **DR** system. The best matching is evaluated through correlation coefficient (defined in Section III) between the vehicle track curve and the route curve in digital map. The candidate route segment with the maximum correlation is defined as the Best Matching Segment (**BMS**). The length of **LST** (L) is determined by the capability of processor and the complexity of road network.

III. CORRELATION COEFFICIENT AND MAP MATCHING

Correlation coefficient can be used to describe relationship of two stochastic series or variables. The correlation coefficient of stochastic series of variables x and y is defined as ρ

$$\rho = S_{xy} / \sqrt{S_{xx} S_{yy}}$$

where S_{xy} means covariance of variable x, y

S_{xx} means variance of variable x

S_{yy} means variance of variable y

The values of ρ near +1.0 are indicative of a strong relationship between the two variables.

Map matching is to find the **BMS** from all candidate routes in digital map and that can divided into two problems:

1) There are many different routes in the digital map. Which route can become candidate route?
2) There are many different candidate segments in the same route, if divide the route into the segment about L (say 30m, for example). Which segment is the best matching?

The first problem can be solved easily through the continuity of track. It is because the candidate routes and vehicle current location are always connected except the vehicle departing from route. In figure 1, when the vehicle travels from RP to the Current Vehicle Location (**CVL)** along route RP-B-E, we can get the **LST**, such as LST2. (Due to the accumulative errors, of cause, there are a number of LST candidates, i.e. LST1, LST3 or LST4 in figure 1). According to topology of the routes, we may enumerate all continuous routes based on the Reference Point (**RP**) as the candidate routes, i.e. selecting curve ABC, ABD, ABE, ABF as candidate routes. The setting of point A, C, D, E, F relies on **RP**. The length from **RP** to point A is ΔL1. The length from **RP** to point C, D, E or F is L+ΔL2 if the length of **LST** is L meter. The length of each candidate route is about L+ΔL1+ΔL2 meter. The length of candidate route is ΔL1+ΔL2 meter longer than that of **LST**, so that we can match **LST** to the best match segment in the same candidate route. The **RP** is always corresponding to starting point of **LST** and changes with the **LST** updating. After all candidate routes are found, we can compute the correlation coefficients between **LST** and each candidate route. In data processing, we use an arc with a given radius to replace the sharp angle of candidate routes at crossing road in the digital map, as shown in figure 2.

We assume the **LST** is track LST2 in figure 1. Because the track LST2 is obtained in the process of vehicle traveling

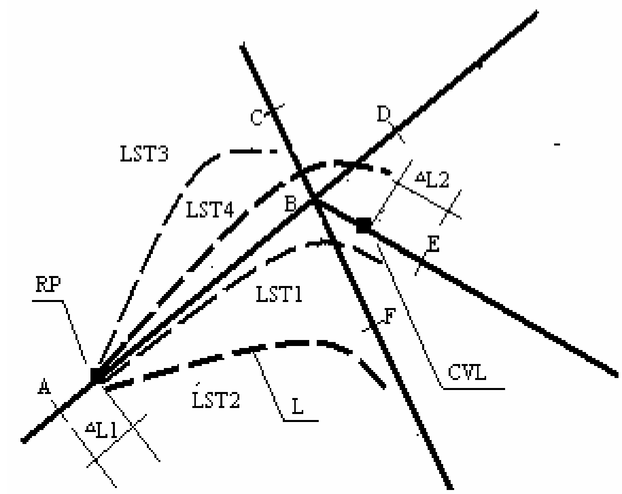

Fig.1. Show the candidate routes and the LST

route ABE, according to where to get track, where to match the track, we consider route ABE should resemble track

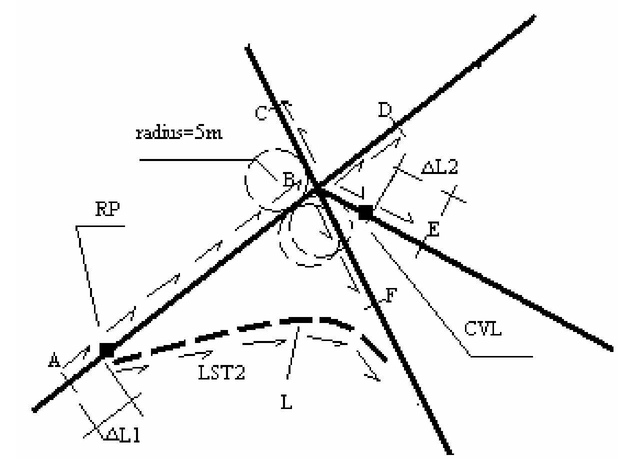

Fig.2. Show the candidate routes and the LST

LST2 in shape.

In order to search for which segment is the BMS from all candidate routes (ABC, ABD, ABE, and ABF), an intuitive method is to calculate the degree of resemblance between **LST** and candidate route. Here, we calculate their Correlation coefficient.

To do so, firstly, divide the curve LST2 into L segments (say 1-meter interval), and calculate the tangent vector angles of each segment to get tangent vector angle series T_{LST2} . Secondly, divide the each candidate route curve(ABC, ABD, ABE or ABF) into many segments in the same interval (such as 1 meter), and calculate tangent vector angles of each segment to get tangent vector angle series

$T_{ABC}, T_{ABD}, T_{ABE}, T_{ABF}$. Figure 3 shows tangent vector angle series. Thirdly, using $S(i) = T(i+1) - T(i)$, compute first order

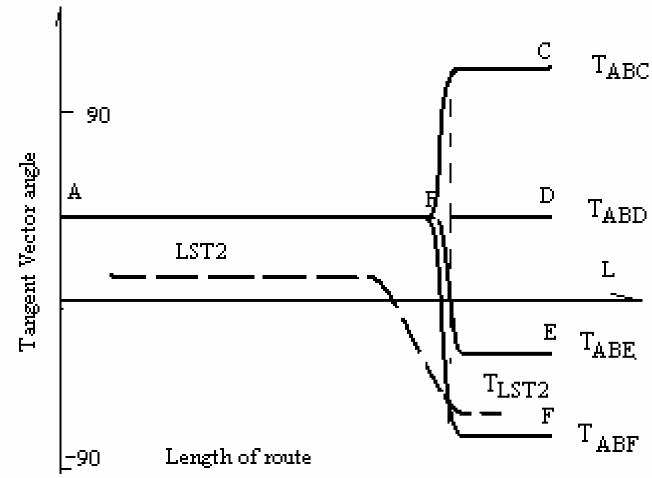

Fig.3. Show tangent vector angle series along length

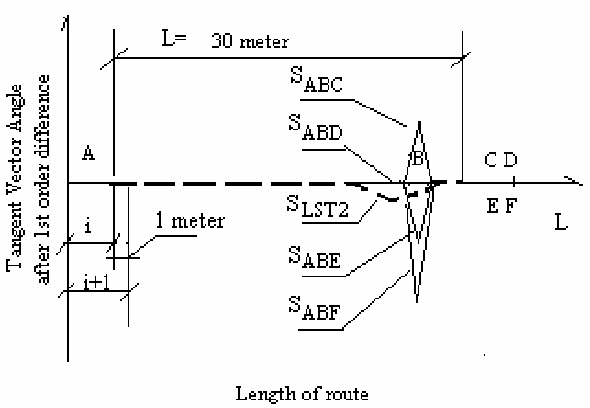

Fig.4. Show curves of new series after first order Difference.

difference on every series respectively in order to decompose rotation angle of every curve, and produce new series $S_{LST2}, S_{ABC}, S_{ABD}, S_{ABE}, S_{ABF}$. Where, i is index of series. Figure 4 shows curves of new series after first order difference. From Figure 4, if we only search for which one in all candidate routes can match LST2, we may do integral along horizontal axis by using equation 1, then compare ϕ_{LST2} with other integral value ($\phi_{ABC}, \phi_{ABD}, \phi_{ABE}, or\phi_{ABF}$). The closest is the best matching route. However, this method cannot decide which segment on a given candidate route is the BMS.

$$\phi_{LST2} = \int_{LST2} S_{LST2} dL, \qquad (1)$$

$$\phi_{ABC} = \int_{ABC} S_{ABC} dL, \quad \phi_{ABD} = \int_{ABD} S_{ABD} dL,$$

$$\phi_{ABE} = \int_{ABE} S_{ABE} dL, \quad \phi_{ABF} = \int_{ABF} S_{ABF} dL$$

To search for the BMS in all candidate routes, move S_{LST2} along horizontal axis in figure 4, and calculate respectively correlation coefficient between S_{LST2} and $S_{ABC}, S_{ABD}, S_{ABE}, S_{ABF}$. Because each candidate series is $\Delta L1 + \Delta L2$ meter longer than series S_{LST2}, we may move the S_{LST2} step by step from i=0 to i=9 along horizontal axis while $\Delta L1 + \Delta L2$ is 10 meter, for example, and obtain correlation coefficient series in figure 5.

For simplicity, $\Delta\alpha$ denotes series S_{LST2}, $\Delta\beta$ denotes series S_{ABC}, and yields the correlation coefficient series $(\rho_0, \rho_1, ... \rho_9)_{ABC}$:

$$\rho_i = s^i{}_{\Delta\alpha\Delta\beta} / \sqrt{s^i{}_{\Delta\alpha\Delta\alpha} s^i{}_{\Delta\beta\Delta\beta}} \qquad (2)$$

where $i \in (0,9)$ means the number of moving steps

$s^i{}_{\Delta\alpha\Delta\beta}$ is covariance of series S_{LST2} and S_{ABC}.

$$s^i{}_{\Delta\alpha\Delta\beta} = \sum_{t=1}^{L} (\Delta\alpha_t - \Delta\overline{\alpha})(\Delta\beta_{i+t} - \Delta\overline{\beta}_i)$$

$s^i{}_{\Delta\alpha\Delta\alpha}$ is variance of series S_{LST2}.

$$s^i{}_{\Delta\alpha\Delta\alpha} = \sum_{t=1}^{L} (\Delta\alpha_t - \Delta\overline{\alpha})(\Delta\alpha_t - \Delta\overline{\alpha})$$

$s^i{}_{\Delta\beta\Delta\beta}$ is variance of series S_{ABC}

$$s^i{}_{\Delta\beta\Delta\beta} = \sum_{t=1}^{L} (\Delta\beta_{i+t} - \Delta\overline{\beta}_i)(\Delta\beta_{i+t} - \Delta\overline{\beta}_i)$$

$\Delta\overline{\alpha}$, $\Delta\overline{\beta}$ is mean of series S_{LST2}

Similar to the correlation coefficients $(\rho_0, \rho_1, ... \rho_9)_{ABC}$, calculate the correlation coefficients $(\rho_0, \rho_1, ... \rho_9)_{ABD}$, $(\rho_0, \rho_1, ... \rho_9)_{ABE}$, $(\rho_0, \rho_1, ... \rho_9)_{ABF}$. Figure 5 shows these correlation coefficient curves.

Compare all the correlation coefficients including $(\rho_0, \rho_1, ... \rho_9)_{ABC}$, $(\rho_0, \rho_2, ... \rho_9)_{ABD}$, $(\rho_0, \rho_2, ... \rho_9)_{ABE}$, $(\rho_0, \rho_2, ... \rho_9)_{ABF}$. if maximum correlation coefficient ρ_{max} is in series $(\rho_0, \rho_2, ... \rho_9)_{ABC}$,

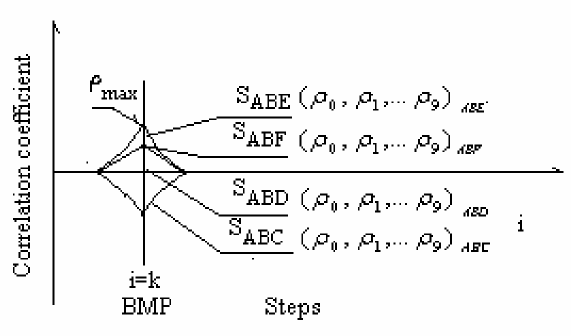

Fig.5. Show the correlation coefficient series

the route ABC matches the LST2. If maximum correlation coefficient ρ_{max} is in series $(\rho_0, \rho_2, ... \rho_9)_{ABE}$, the route ABE matches the LST2. For example, in figure 5, the maximum correlation coefficient ρ_{max} is in series $(\rho_0, \rho_2, \ldots \rho_9)_{ABE}$, so the route ABE matches the LST2. The figure5 still illuminates the matching reaches the best in k^{th} step.. This point is defined as the best map-matching point (**BMP**), and the route segment (the length is L meter) following **BMP** is defined as the best matching segment (**BMS**).

The advantage of this method is that, we not only consider the relationship between the newest track point and route, but also consider the relationship between a segment track before this newest point and candidate route. It is applicable especially to arc-shaped crooked roads. This kind of map matching method between the **LST** and candidate route is comparatively accurate. Under no **GPS** signal, the navigation unit can use the matching to correct some parameters in navigation unit.

IV. Dead Reckoning Parameter Correcting

In a **DR** navigation system, without **GPS** signal, it is very difficult to correct the scale factors of gyrometer and odometer. Here, we apply an approach to correcting the scale factors by using map matching. The scale factors of gyrometer and odometer (**SFOG**) can be defined as K_{gyro} , which is affected by a number of factors (i.e. temperature, incline and so on):

$$\Delta\theta = K_{gyro} * S * \Delta t + \Delta_{drift} \quad (3)$$

Where,

$\Delta\theta$ means the turned-angle in interval time Δt

S means the sampling value of gyrometer,

Δ_{drift} means the drift of angle in interval time Δt

K_{gyro} is the scale factor of gyrometer

Similarly, another scale factor K_{odo}, which is called the scale factor of odometer (**SFOO**), is applied to improve the performance of odometer. It is defined as,

$$K_{odo} = L_{curve} / \Delta NUM \quad (4)$$

Where, L_{curve} means the length of vehicle track curve,

ΔNUM means the number of pulses of odometer.

To calculate the **SFOO**, we search for the two adjacent points of inflection of **BMS**s, and use the length of map route curve between two adjacent points of inflection in digital map and the number of pulses that come from odometer to compute the **SFOO**. Figure 6 shows the **BMS**s and inflections. When the vehicle travels from inflection P1 to inflection P2, we accumulate the odometer pulses, and calculate the length of route curve between inflection P1 and P2 in the digital map

Using (5), compute the new SFOO.

$$K^i_{odo} = L(P_1, P_2) / \Delta NUM^i_{odo} \quad (5)$$

where, L(.) means the length of route along curve. Here, it can be computed in digital map through computing the length of two **BMS**s interval.

P_1, P_2 mean two inflections in different **BMS**s.

ΔNUM^i_{odo} means the number of pulses from odometer between two **BMP**s.

Similarly, the **SFOG** may be calculated by collecting the start-time, end-time, and the sampling value of gyrometer as well as the turning angle of crooked route in a **BMS**. Figure 7 shows a **BMS**. The dot line shows the track curve of **DR**. The solid line shows the route or path curve. P is the maximum curvature point in **BMS**. α is the crossing angle of two tangent lines in t0 and t_1. t_0 and t_1 are start time and end

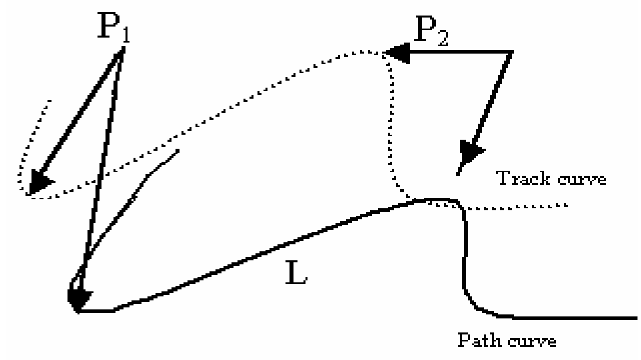

Fig. 6. Show two **BMP**s. P_1 shows the first best matching point. P_2 shows the second best matching point. L means the length of two BMPs interval along curve.

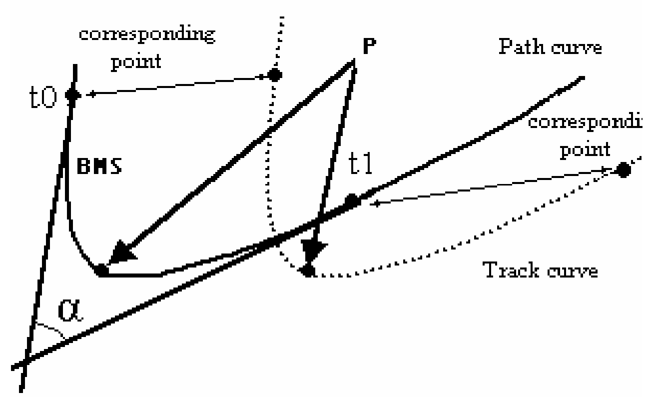

Fig.7. Show one BMS. The dot line shows track curve of dead reckoning. The solid line shows route curve. BMS means the best matching segment. A is the angle of t0 and t1. t0 and t1 are the points of corresponding to track curve.

time respectively. Neglect of drift in (5), Using (6), calculate the **SFOG** in **BMS**.

The new scale factor of gyrometer is

$$K^i_{gyro} = \alpha \Big/ \int_{t_0}^{t_1} v(t)\,dt \quad (6)$$

Where, α means a turning angle of route from t_0 to t_1 in the **BMS**, which can be calculated by route curve in digital map.

(t_0, t_1) means the start-end time to produce α ,

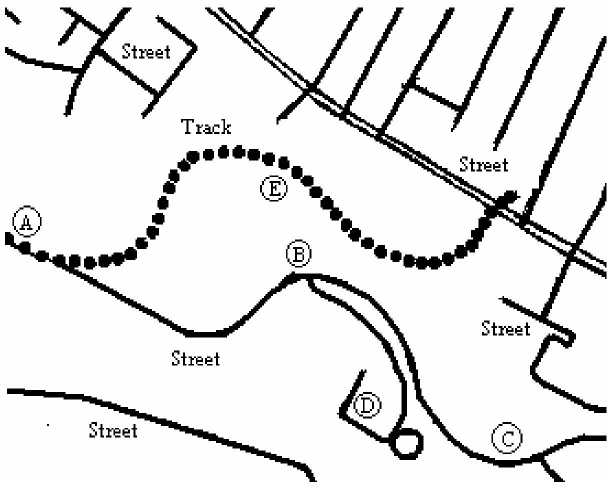

Fig.8. Show street network and the curve of dead reckoning. The dot is the track of DR. the segment ABC and ABD is part of streets at Hong Kong Island.

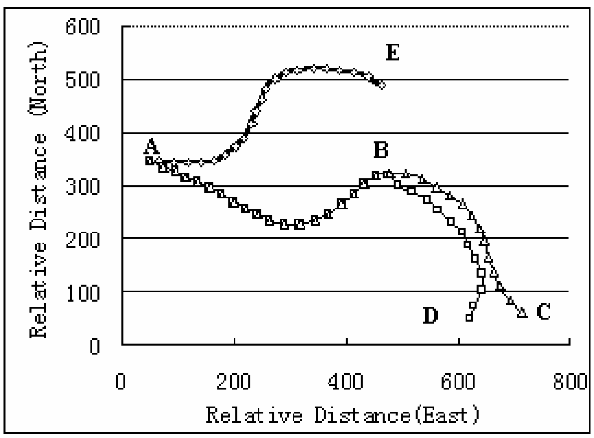

Fig.9. Show the curves of the relative distance. Segment AE shows track curve of dead reckoning. Segment ABC and segment ABD shows candidate street curves.

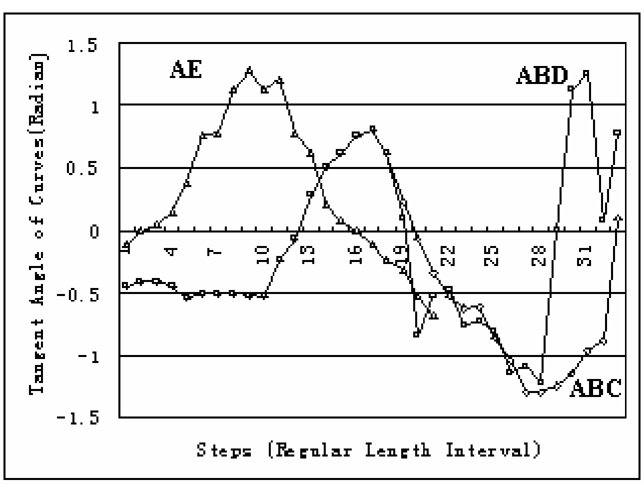

Fig.10. Show the tangent vector angle curves. The mark ‘Δ’ indicates the tangent vector angle of the track AE. The mark ‘◊’ signifies the tangent vector angle of street ABC curve, and mark ’ □’ means the tangent vector angle of street ABD curve.

v(t) means the sampling value of gyrometer.

It is clear that the method is not very accurate. So we do not use the result of **SFOO** or **SFOG** to update parameter directly in the practice. However, the result of the **SFOO** or **SFOG** denote current tendency of the real parameters.

Thirdly, we divide the **SFOO** or **SFOG** into five possible values: the greatest, greater, normal, less, the least. We choose the scale factor to calibrate them from five values according to **SFOO** or **SFOG’s** tendency by using a fuzzy classification method.

V. A TEST CASE

This section contains a case study that applies the new map matching method proposed in this paper. Figure 8 shows a part of a street network in Hong Kong island. During the period, there is no **GPS** signal available on the road. The dot mark is the **LST** obtained from a dead reckoning device. At this road in figure 8, usually, it is difficult to do map matching using traditional method because of the ABC segment being similar to ABD segment.

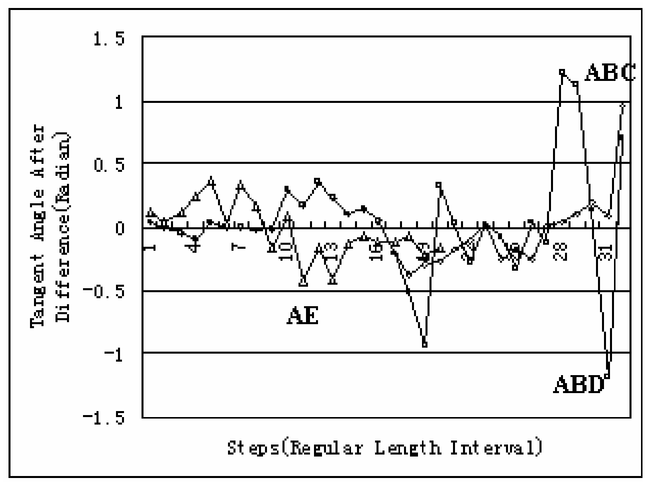

Fig.11. Show the tangent vector curves after difference. The mark ‘Δ’ indicates the angle of the track. The mark ‘◊’ signifies the angle of street ABC curve, and mark ’ □’ means the angle of street ABD curve.

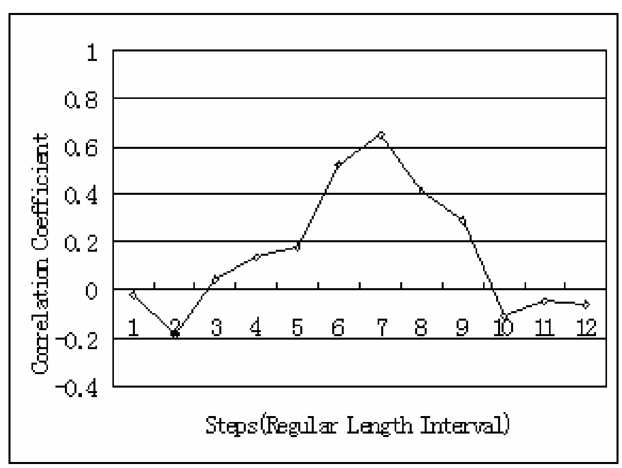

Fig.12. Show the correlation coefficient between the track curve (segment AE) and street curve (segment ABD)

For simplicity, a coordination transform is made from raw data of dead reckoning into new relative position data. Take 21 points in the front of track as **LST**. Take a part of route as candidate route. Figure 9 shows curve of the new data after transform. The mark '◊' indicates the **LST** of vehicle AE. The mark 'Δ' signifies route ABC, and mark ' □' shows route ABD

Firstly, according to our approach, we calculate the angles of tangent vector at regular intervals respectively in AE and ABC, ABD . Figure 10 shows the tangent vector angle curves. Horizontal axis is the number of steps of uniform step length, and vertical axis is angle (radian). The mark 'Δ' indicates the tangent angle of the track. The mark '◊' signifies the tangent angle of route ABC, and mark ' □' means the tangent angle of route ABD.

Secondly, compute the first order difference of tangent vector angle along Horizontal axis, and get series S_{AE}, S_{ABC}, S_{ABD}. Figure 11 shows the curve of series S_{AE}, S_{ABC}, S_{ABD}. Horizontal axis is the number of steps of equal length interval, and vertical axis is angle (radian). The mark 'Δ' indicates the series S_{AE}. The mark '◊' signifies the series S_{ABC}, and mark ' □' means the series S_{ABD}.

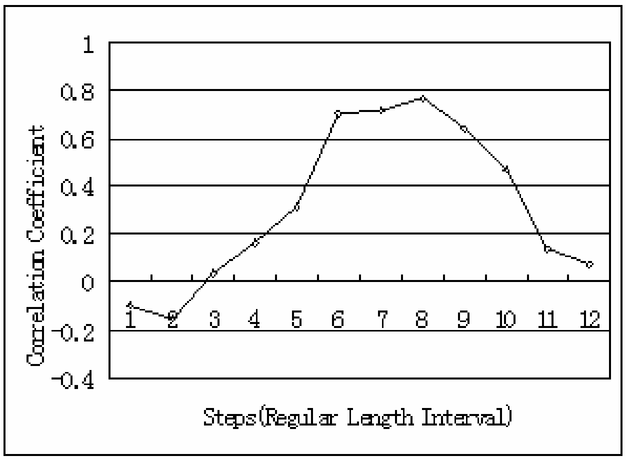

Fig. 13. Shows the correlation coefficient between the track curve(segment AE) and street curve (segment ABC)

Thirdly, in Figure 11, we move the series S_{AE} step by step at horizontal axis from left to right. In each step, using (2), compute the correlation coefficients between the series S_{AE} and S_{ABC} or S_{ABD}. Figure 12 shows the curve of correlation coefficients between series S_{AE} and S_{ABD}. Figure 13 shows the curve of correlation coefficients between series S_{AE} and S_{ABC}. Horizontal axis is the number of moving steps, and vertical axis is the correlation coefficient.

Finally, compare all the correlation coefficients in figure 12 and 13. Clearly, the maximum correlation coefficient is in figure 13. Therefore, the match of AE and ABC is a **BMS**. The correlation coefficient reaches the maximum value at step 8. It illuminates that current coordinate of **DR** has to go forward 8 steps along route. The position and heading also need to be corrected. After finishing map matching, we can use the direction of route to replace the statistical direction of vehicle. If two or more **BMS**s can be found**,** we can calculate the tendency of **SFOO** and **SFOG** , and update these parameters.

VI. SUMMARY AND CONCLUSIONS

A new method of map matching is described in this paper. The new method is based on the correlation coefficients between the last segment track of dead reckoning and each candidate route. Maximum correlation coefficient illuminates the best matching position. The new method is simple and effective. It has very robust to noise and is applicable especially for arc-shaped crooked roads. The test result shows matching between LST and candidate route is very accurate. Under no GPS signal, the scale errors of DR system ca also be calibrated by the digital map to improve positioning accuracy.

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