Map Matching Algorithm and Its Application

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Abstract

Map matching is a technique combining electronic map with locating information to obtain the real position of vehicles in a road network.This paper provides an overview on the map matching technique and its applications,and discusses some typical algorithms with experiments analysis.

Keywords: Map matching, Intelligent transportation system, Vehicle navigation system,Global positioning system.

1. Introduction

In a motor vehicle multimedia system, VPS(Vehicle Positioning System) technology is the basis for the entire system,and accuracy is a prerequisite of almost all system functions in the vehicle positioning. Vehicle positioning navigation system is the most basic function, all other functions are based on the accurate positioning.Vehicle Navigation System[1]-[6] may employ a variety of vehicle location, such as the global positioning system GPS, GPS / INS and GPS / Dead Reckoning DR. However, as the use of sensors there is a measurement error of the vehicle's location obtaining through Vehicle navigation systems. So it is necessary to rectify the error by a software tool which is map-matching algorithm (Map Matching). As in the actual system geographic information systems based on vector maps have become important vehicle navigation components, So map matching also use vector map information integrating various positioning sensor positioning data to produce the best position to estimate vehicle .

2. Map Matching Principle

Map matching algorithm[10]-[12] is based on the theory of pattern recognition. The location of the vehicle or truck traveling paths getting from other orientation methods (such as GPS) compares with electronic map road data of vehicle, and seeks matching metric degree. regarding combination lines of the greatest matching metric degree as current vehicles traveling routes,and then find the road where vehicle runs, and show the real-time location of vehicle. Map matching process based on the principle can be divided into two relatively independent processes: First, find the road of currently vehicles traveling; Second, project current positioning point to the road of vehicles traveling.

The first process is the key to the process,as shown in Fig. 1,the road passed by vehicle is road A → B →C, but the measurement track as shown in the curve does not coincidence with the actual path.The process of finding current vehicles traveling road is equal to eliminating the deviation between the measurement position and the actual position, then correcting the measurement position to match position by matching behavior, it means that correcting the cars trajectory line represented by the dotted line (with a positioning error of observation points) to the three actual location of road A → B →C.

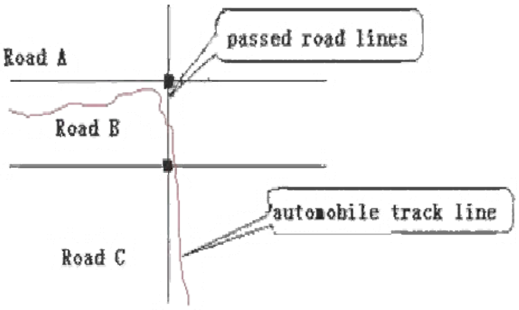

Fig. 1: Automobile track lines and passed road lines.

The second process is that use simple foot projection principle of point to straight line, and take projection pedal line in the selected road line of measurement position point as the matching points.But the true position with the match position might still exist a gap. In fact map matching technology will only solve the vertical positioning error, not directly address the radial positioning error. Figure 2 illustrates this process.

Generally, map-matching algorithm should include the following process in the matching:

- Through preprocessing ,feature extraction and so on the step carry on the analysis and description to all candidate road sections and extract the corresponding position or shape features.

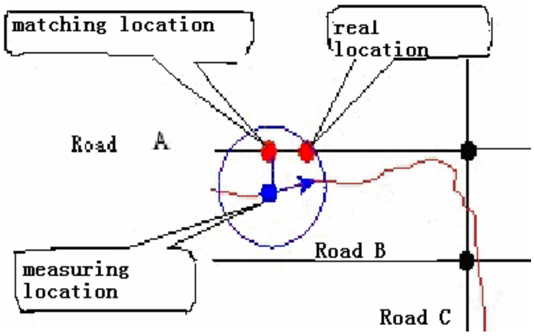

Fig.2: The matching process of the measurement location to the road line.

- Based on the matching rules of the algorithm,calculate the matching similarity in turn between the vehicles path and all candidate road sections.
- Select the biggest position or path about cost function as the matching or classification results of vehicle location points or trace curve.

3. Map Matching Algorithm

From the category perspective of matched samples, map matching algorithm can be divided into: matching position[13] and track curves match.The commonly used position matching methods include direct projection,probability statistics and the fuzzy logic method and so on;the commonly used track curve matching methods include geometric matching,correlation coefficient method and so on.Position match algorithm is logic simple, timeliness good, but in such circumstances: intensive road, complex shape road and intersections road,the match accurate rate is lower.Accurate matching rate of track curve matching algorithm is high, but it is complex and large amount of computation. It is very difficult to meet the real-time requirements.

3.1. Position Matching

Fig.3 shows the position matching algorithm basic tenets.Point p is the GPS point to match.L1,L2 stand for the road close to the GPS point.

In position match algorithm, P makes projection to all roads nearby and calculate the projection distance r_i between GPS point and every road and the angle θ_i between traffic direction and every road,then select r_i, θ_i value less than the threshold set for all roads and calculate every candidate road's distance degree λ_i by following formula (1):

$$\lambda_i = \omega_r \cdot r_i + \omega_\theta \cdot \theta_i \qquad (1)$$

ω_r and ω_θ respectively stands for the weight of projection distance and the direction angle.Choose the

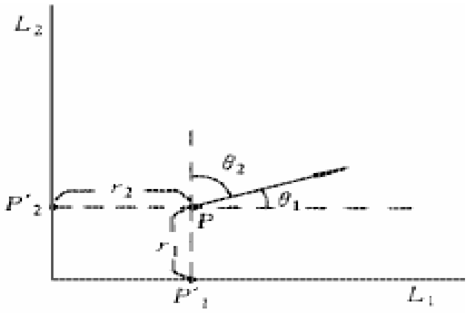

Fig.3: position matching principle

road which has the smallest value in all candidate roads as the match road, namely that the vehicles are roadworthy.

At this time, the so-called match is that replace vehicles track with the projection point of road line, or trajectory point is corrected to the corresponding projection points. The road line where vehicles travel actually is defined as matching section.All road sections located in the rectangular region (motion window) which take the measuring point as a center are called candidate road sections. Match road section is from the candidate road sections. The matching design of algorithm is calculating the match degree of all the candidate road sections to decide which candidate road section is the best.The matching degree is a concept to measure the possibility of a candidate section to be a matching road.There are mainly three types of data to design matching degree:

- The projection distance of measuring point to candidate road section
- The angle between measuring point travel direction and candidate road section direction
- The topological connectivity between candidate road section and preceding matching road section

Thereinto the first and second lists respectively explains the matching degree between matching road section and candidate section.The smaller the distance between the two curves is,the more similar the two curves is.Angle between the two curves smaller also shows the two more similar. The following (Fig. 4) is example:

The spacing distance between two curves is described by the distance of each track point on the line to its pedal on the road. The vertical length respectively is d0,d1,…d5 in Fig.5. As the track points jitter, the vertical length is different.Take the average vertical length D as the curve's similarity metric.

$$D = \frac{1}{6}\sum_{i=0}^{5} d_i \qquad (2)$$

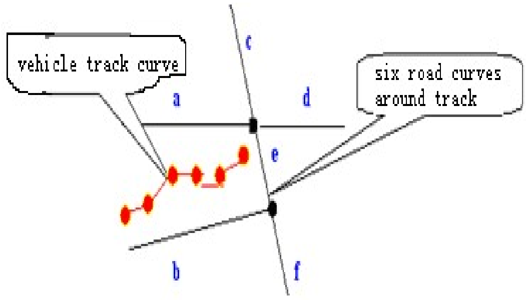

Fig.4: a simple example of position matching.

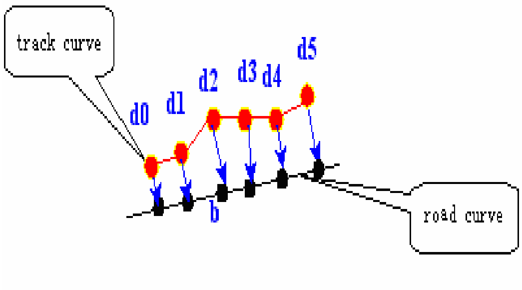

Fig.5: the approach degree described by vertical distance.

The vehicle tracks' azimuth is different from the road lines corresponding pedal point'azimuth.So we can use the angle difference to describe the approach degree of two curves. The angle difference respectively is g0,g1,…g5. As the track points jitter, these angle differences are different and take the average of angle differences G as the curve's similarity metric.

$$G = \frac{1}{6}\sum_{i=0}^{5} g_i \tag{3}$$

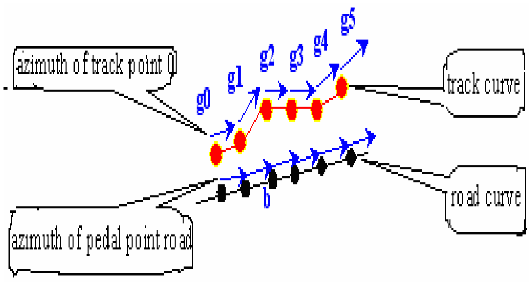

Fig. 6: the approach degree described by angle.

Due to the complexity of the road network and the uncertainty of vehicle trajectory, it is not an accurate judgment for curve similarity with a single matched metric D or G, therefore usually unify the two to describe two curves'degree of similarity. Generally speaking, the smaller the projection distance and the angle of candidate sections are,the greater degree of matching.It also means the possibility of candidate sections becoming matching sections is greater than others, vice versa. In addition, the candidate road section which is two covalently linked or topology linked with preceding matching road is more possible to become matching road section.

In sum, matching degree is defined as the function of projection distance r and the angle between the direction θ:

$$f(r,\theta) = \omega_r r + \omega_\theta \theta \tag{4}$$

The expression indicates that the matching degree of each candidate road section is decided by projection distance r and the angle θ. The samller projection distance and the angle are, the greater matching degree of candidate road sections. The possibility of candidate sections becoming matching sections is greater than others, and vice versa. f (r, θ) is the matching degree measuring function of the candidate sections, $\omega_r$and ω_θ respectively is the weight of projection distance r and angle between the direction θ in f. It meets the relationship:

$$\omega_r + \omega_\theta = 1 \tag{5}$$

3.2. Curves Matching

Because it does not account for traffic history information, position matching is lack of enough informations which result in matching accuracy not high when the road is complex shape and intersections. In order to obtain more abundant amount of informations and more effective map-matching to improve accuracy, researching curves matching algorithm is necessary.

The track curve matching is to compare the vehicle history travel path with the path data which saves in the digital map, seeking reasonable matching algorithm, determining the road where vehicles drive,and showing the real-time location of vehicle. In general, traveling curve can be obtained as follow: Firstly gain the vehicle current locating point, and take out N recent localization records, connect the locating point to form curve by the time order.The N's value is determined according to the sensor sampling intervals.Then determine a region with a special definite distance value R to curve, search all the roads in the region,determine candidate roads based on certain criteria and algorithm, match the candidate sections and curve, seek the best match section as the current road route.The point that current positioning points projct to the driving route is the matching points.

3.2.1 Geometric Matching

Regarding the track curve matching, the route distance is quite short between the localization curve and the digital map really walks line,therefore inspecting match degree between vehicles localization path and candidate road section from their distance.Locating track curve constituted by continual locating point on the recently candidate road essentially is to seek one reasonable definition method, which makes two curves objectively matching are indeed smaller distance.There are many kinds of definitions way about the distance measure of lines, such as,defining the smallest distance of arbitrary two point between A and B as the distance of localization track A and road B.The method is simple, but it will obviously prone to misusing match. Another definition way is the average distance of all points in A and B:

$$\|A - B\| = \int_0^1 \|a(t) - b(t)\| dt \qquad (6)$$

This definition is more reasonable, but it doesn't account for direction and network topology information, sometimes it produces unpredictable matching errors.

There is another more reasonable algorithm re-defining the distance between the curves.As shown in Fig.7, Suppose the initial point of vehicles P^0 is the overlapping node of multi-strip path A, B, C, D (node is beginning point or ending point or multi- strip path intersection). P^1 , P^2 , P^3 are continuous positioning points. The definition of distance between the curves is that: Link P^0, P^1, P^2,P^3 to form positioning track curves,then start from p0 to make the same length of line sections with p^0~p^3 respectively in road A,B,C,D,as shown in Fig.8. Each section is divided into a number of the same length, three here, trajectory were calculated positioning of the subdivision points to each section of the division of the distance between points. Take the average distance as the distance between the curves, the minimum distance for matching sections of the road.In Fig.8,A is the best matching point. This method of matching geometric properties although improved,the initial point of information is very sensitive, once the initial mistakes it will lead to a series of matching errors.

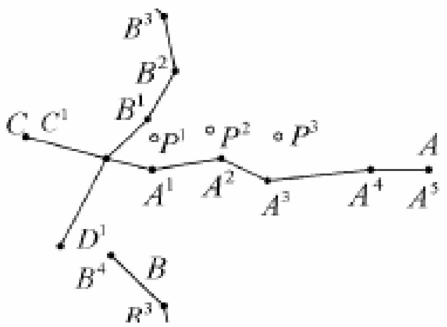

Fig.7: geometric matching example of curve to curve.

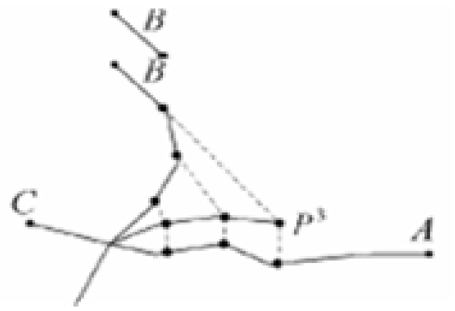

Fig.8: geometric matching example of curve to curve.

3.2.2 Area Matching

It is difficult to define and calculate the distance between lines, and is not suitable for all situations. Cartography can be used in the method for calculating the area of positioning curves and digital maps of the path between the candidates distance, and thus determine the distance criteria.According to distance thereby determine a certain candidate road matching with the location matching curves.

The distance based on the areas between the two lines is defined as :

$$d = S / L \qquad (7)$$

Among them, S is area of the polygon surrounded by the corresponding two lines linking nodes. L is the average length of the two lines. Clearly two lines are farther apart, the area surrounded is larger,the value calculated from (7) is greater distance. For vector digital map data, length of linear elements L can be cumulated by the point to point straight-line distance. Polygon area S is facial features, denoted with contours of the border arc posed by polygon. If the two lines intersect,then separate concave polygon into convex polygon, each area will receive positive.S is the sum of every part's area.As shown in Fig.9, the area surrounded by two lines is the sum of two shaded areas. For each convex polygon with N vertices, the formula for calculating the area is:

$$S = \left| \frac{1}{2} \sum_{i=1}^{N-2} (x_i y_{i+1} - x_{i+1} y_i) + (x_N y_1 - x_1 y_N) \right| \qquad (8)$$

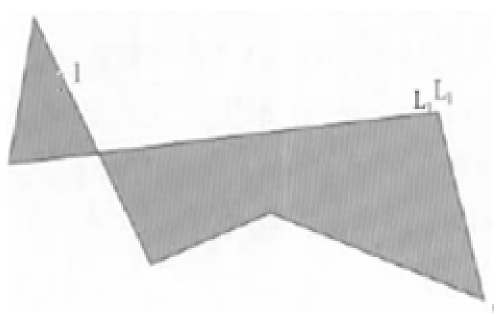

Fig.9 the area surrounded by two intersecting lines

When determine the distance between the two lines using area method, if only evaluate similarity matching briefly with the above definition,it will not get good results.Distance is sensitive to the situation about a line with long tail, as shown in Fig.10.

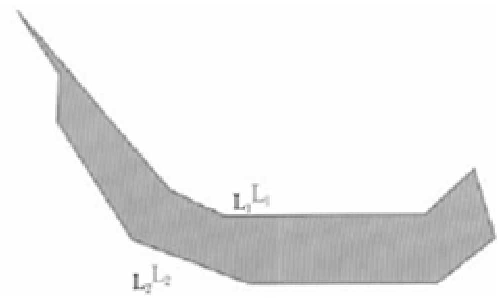

Fig.10 line with a long tail

Modify the area method. As shown in Fig.11, L is positioning curves, L_1 is section of the candidate. Correction: Firstly,the first endpoint P_1 makes projection to candidate section L_1, getting projection point R_1 to replace the original starting point Q_1; the end point P_m makes projection to L1, gettiong point R_2 to replace the original end point Q_m;reform the vehicle track curves and the candidate sections.Compute the area of positioning curves and the distance between the candidates path,then compare the distance values.The candidate path with smaller distance value is the track vehicle covered. Positioning points make projection to the selected candidate path which will be the current vehicles points. After that the method is not a simple line of the last two points connected, after projection,redefinition the area of two lines(shaded area in Fig.11). Meanwhile, the line study has also undergone a change from study of line L and L1 to studies of line P_1P_4 and R_1R_2, and the length of the road has changed.

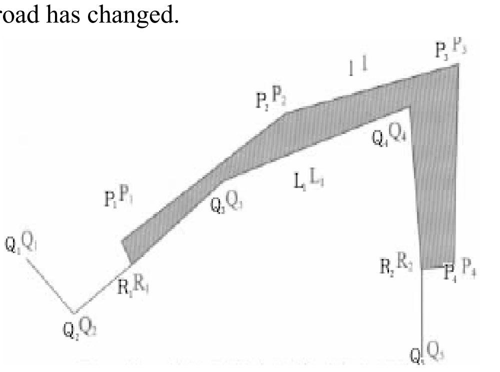

Fig.11 modified area method

After amended the area method is of obvious advantages: the re-definition lengths of two lines are convergence with no existence of the long tail line. The area size of two lines more objectively reflect the matching degree; the whole distance between the two lines is described, it is not sensitive to the wave of certain anchor points.

The theory basic of the distance definition based on the area method is that although there are errors in the anchor points.Statistically they are limited in certain values.The tracks formed by the anchor points ought not departure the actual way and wave around the actual path.Accordingly, the distance between the track and the actual path based on area should be small, and it has more possibility of matching. The experiment shows that the whole positioning precision after applying this method can almost get 90%, and it is superior to the positioning precision of GPS. Table 1 shows the positioning precision statistical results derived from the track curve matching arithmetic in different way conditions.

Road Conditions	Section volume curves	Matching degree %
Straight Line	500	92.5
Cross Road	250	87.9
Malformations Intersection	300	79.5

Table 1: matching results statistics.

The result shows that as the positioning precision is low and the characteristics of the way is complicate，making full use of the history positioning results and the track curve matching arithmetic, the reliability of the matching results can be improved further; meanwhile there are some problems, such as the time-delay[14] is relatively serious, even when the characteristics of the way is too complicated, it perhaps can not match or do wrong matching, so the positoning points methods should be combined, or study the feasibility of the matching principle from the direction features[15].

4. Application and Prospects

The most basic application of map matching technology is achieved in the electronic tracking of vehicles on the map marked in the Intelligent Transportation System(ITS).Match the vehicles on its traveling road through map-matching technology. It can help drivers along scheduled routes and guide vehicles to arrive at the destination in car navigation system[23]; In automatic scheduling of the public transportation system, using map-matching technology and dead reckoning technology can access to public transportation vehicles fast and accurately.It also can be used on Assisted Dispatching bus or bus to achieve automatic reporting station based on the road and the location of the historical record of passengers[21]; In UAV reconnaissance images of the system[22],using map-matching techniques can achieve the simulated landscape images display real-time dynamically compared to the GIS map.

Map matching technology has been widely applied to the GPS navigation system. Judging from the current development, further study of the vehicle control system is to achieve vehicle auxiliary safe driving and automatic drive by combining the matching maps and GIS information with the network,such as obstacles reminded or crossroads reminders along with the road network as the bend and adjusting speed.With map-matching technology and GIS / GPS combination,the use of electronic maps and databases of road traffic information with automatic traffic will be driving a new development direction.

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