A Map Matching Algorithm Combining Twice Gridding and Weighting Factors Methods

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Abstract. Current map matching algorithms suffer the problem that matching accuracy and matching efficiency cannot be achieved both in the face of massive floating car data. A novel map matching algorithm combining twice gridding and weighting factors methods has been proposed in this study, selection of candidate road segments and determination of the shortest path are based on twice gridding method; Factors of driving direction and trajectory angle are served as improvement of weighting factors method, and matching accuracy rate in specific situations such as parallel road segments, intersection areas, intensive road segments and large positioning errors has been improved. Meanwhile, to avoid driving direction and trajectory angle failing at low speeds, which results in interference problems with map matching, the weights of driving directions and trajectory angle are dynamically adjusted by instantaneous speed and interval length between the trajectories. Through map matching case study of actual data, results show that the improved weighting factors method in this study performs outstandingly in improving the matching accuracy rate, and combining the method of twice gridding effectively improves matching efficiency in principle, which makes the map matching algorithm in this study can balance the matching accuracy and matching efficiency well when facing massive floating car data.

Keywords: Map matching · Weighting factors · Twice gridding · Floating car data

1 Introduction

Nowadays, urban congestion has become an increasingly severe problem, and have caused serious impacts on urban economic development. The grasp of urban traffic conditions can provide reliable technical support for the strategy formulation to alleviate traffic congestion. As a main way of traffic information collection, floating car technology can provide data support for urban traffic analysis. Map matching is the basis of data processing for floating car data, and its accuracy has a significant impact on the results of data analysis.

The location information is acquired by the position sensing device based on mobile phone, on board unit (OBU) etc., which is the original GPS positioning data, coupled with road network data, constraints are established based on correlation

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between GPS positioning data and network data, then a travel path that conforms to the road network structure can be found. This technology is called map matching [1]. The constraint function system formed by the integration of multiple constraint functions that are established to reduce data errors is called a map matching algorithm. According to the basic principles, map matching algorithm can be divided into three types: simple map matching algorithm, weighting factors map matching algorithm and advanced map matching algorithm [1].

The simple map matching algorithm is dependent on a single element with fewer constraints to determine matching results. The original simple map matching algorithm is a point-to-point map matching algorithm proposed by Kim [2] and Bernstein [3]. The principle is to select the network node which is closest to GPS positioning point as the matching node. White [4], Toylar [5] and Miwa [6] improved the simple map matching algorithm, proposing point-to-line, line-to-line, map matching algorithms based grid. Because the simple map matching algorithm can not fully achieve high matching accuracy, to solve this problem, Greenfeld [7] proposed an weighting factors map matching algorithm considering driving direction, distance, angle (the angle between the line direction from GPS positioning point to intersection and the direction of road segment). Quddus [8] improved Greenfeld [7]'s method, making the algorithm more simpler and applicable. Although the weighting factors algorithm can achieve higher precision, there are still a certain number of matching errors in parallel road segments, intersections, intensive road segments network and large error of positioning data. In order to achieve higher matching accuracy, many scholars have proposed the advanced map matching algorithms that are different from the basic principles of the first two map matching algorithm. For example, Syed [9] and Ren [10] proposed a map matching algorithm based on fuzzy logic; Ren [11] and Wu [12] proposed a map matching algorithm based on Markov model.

The performance of map matching algorithms requires high matching accuracy and high matching efficiency. The simple map matching algorithm can't meet the matching precision requirement. However, most weighting factors map matching algorithm applies the probability ellipse or quadrilateral error region to select the candidate path, for each GPS positioning point, the candidate range needs to be recalculated, it reduces matching efficiency, and they could not meet the accuracy requirement on specific road network due to the static weight of the algorithm. The advanced map matching algorithm often need the calculation of multiple GPS positioning points to determine one GPS point actual location, which means they are more complicated in read data and calculation. Those complexity not only reduce advanced algorithm efficiency but also make algorithm's applicability has limitations.

In order to solve the fore-mentioned problems, this study proposes a novel map matching algorithm that combines twice gridding and improved weighting factors method. The algorithm acquires candidate road segments based on small grid, it only needs to calculate the candidate road segment selection range once; Weighting factors map matching algorithm is improved by dynamically adjusting the factors weights by instantaneous speed, interval length, etc., those problems of parallel road segment jump, intersection mismatch, intensive road segment mismatch and poor fault tolerance when the positioning error is large have been overcome, and the optimal matching road segment can be determined; Large grid is used to match the shortest path.

Following section introduces the principle of matching algorithm and the improvement of the factor weighting method in this study, then the next is the case study, matching example verification and result analysis is shown, and final section is conclusion. The algorithm proposed in this study has good performance in both matching accuracy and efficiency, and has great value on practical application.

2 Principle of Matching Algorithm

The main contents of the map matching algorithm combining twice gridding and weighting factors methods proposed in this study are: 1. Obtaining candidate segments based on small grids; 2. Based on improved factors weighting algorithm, local map matching determines matching road segments; 3. The large grid determines the candidate path range, and the shortest path is selected as the matching path. Detailed flow chart of the algorithm is given in Fig. 1.

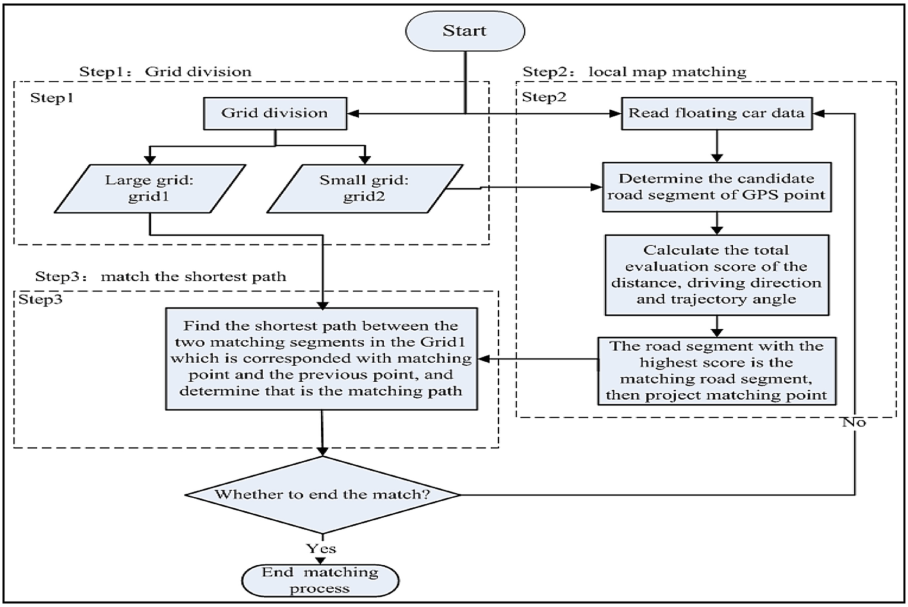

Fig. 1. Map matching algorithm flow chart

2.1 Grid Division

Conventional weighting factors map matching algorithm [2–8] uses probabilistic ellipse or quadrilateral to acquire candidate segments, which reduces computational efficiency. Cao [13], Zhao [14] proposed a gridding map method, using grid as error region to determine candidate road segments, which improving the algorithm efficiency. Cao's twice gridding method [13] is applied in grid division to determine the candidate road segments in this study. The twice gridding method refers to dividing the research area into M × N equal-sized grids, the attributes of the intersected road segments can be found in the grid, searching capability is strengthened. There are two types grids: large grid (grid1) and small grid (grid2). Grid1 determines candidate path range; Grid2 determines candidate road segment range in the algorithm.

2.2 Local Map Matching

The process of local map matching consists of two main parts: finding candidate road segments and obtaining matching road segments.

Finding candidate road segments: Finding the Grid2 which containing positioning point, obtaining road segments from this Grid2 and its eight neighboring Grid2, selecting candidate road segments based on the distance from the positioning point to the road segment and the length of the road segment, forming a candidate road segment set [13].

This study uses distance, driving direction and trajectory angle as the factors of weighting factors algorithm. On this basis, instantaneous speed attribute, which has greater correlation with the driving direction, is applied to control driving direction factor, and driving distance attribute, which has greater correlation with the trajectory angle factor, is applied to control the weight of trajectory angle factor, then matching precision can be improved in some conditions (parallel road sections, intensive road sections and large positioning errors, etc.), which improves the precision and efficiency of algorithm to some extent. Detailed formula of improved weighting factor algorithm proposed in this study is shown as follows:

$$w_{sum} = \alpha_{distance} w_{distence} + \alpha_{direction} w_{direction} + \alpha_{angle} w_{angle} \tag{1}$$

w_{sum}: Total similarity score of distance factor, driving direction factor and trajectory angle factor.

$w_{distence}, w_{direction}, w_{angle}$: Similarity scores for distance, driving direction, and trajectory angle factor respectively.

$\alpha_{distance}, \alpha_{direction}, \alpha_{angle}$: Value of weighting factors for distance, driving direction, and trajectory angle factor respectively.

The trajectory angle factor and the driving direction factor are easily affected by the low driving speed in offline map matching. In contrast, the distance factor is more stable than the trajectory angle factor and the driving direction factor in such cases, so the $\alpha_{distance}$ is 1.2. The specific calculation formula of $w_{distance}$ is shown as follows:

$$w_{distance} = \frac{1}{\left(1 + \left(\frac{d}{\varepsilon}\right)^2\right)} \tag{2}$$

d: Distance between the positioning point and candidate road segment.

ε: Radius of floating car data error.

It is proposed that the driving direction accuracy in the collected information has apparent relation with the floating vehicle instantaneous speed in existing researches [15]. With higher instantaneous speed value, the collected driving direction is closer to actual driving direction. Consequently, this study uses the instantaneous speed factor to adjust the calculated value of $\alpha_{direction}$ to improve the calculation of driving direction factor. The specific calculation formula is shown as follows:

$$\alpha_{\text{direction}} = \begin{cases} 1 & v_s > v_2 \\ 1 \times \left(\frac{v_2 - v_s}{v_2 - v_1}\right) & v_2 > v_s > v_1 \\ 0 & v_1 > v_s \end{cases} \tag{3}$$

$$w_{\text{direction}} = \cos\left(\frac{\Delta\alpha}{2}\right) \tag{4}$$

v_2: Preset speed threshold value, when the instantaneous speed value is higher than the threshold, the driving direction factor has higher reliability.
v_1: Preset speed threshold value, when the instantaneous speed value is less than the threshold, the driving direction factor has lower reliability.
v_s: Instantaneous speed value of floating car.
$\Delta\alpha$: The angle between driving direction of floating car and direction of road segment.

The trajectory angle factor are easily affected by elements such as collection frequency, driving speed and interval length of the adjacent floating car positioning points. It can also be more credible with reduction of collection frequency within certain range, increase of driving speed and extension of interval length [16]. Therefore selecting interval length to adjust the value of α_{angle} improves the calculation of α_{angle}, it can avoid the effect of trajectory angle factor in local map matching process when the trajectory angle feature is at low precision. The trajectory angle factor is calculated as follows:

$$\alpha_{\text{angle}} = \begin{cases} 1 & s \geq s_0 \\ \sqrt{\frac{s}{s_0}} & s_0 > s \end{cases} \tag{5}$$

$$w_{\text{angle}} = \cos\left(\frac{\Delta\beta}{2}\right) \tag{6}$$

s: Interval length of time-adjacent positioning points.
s_0: Present maximum interval length of time-adjacent positioning points.
$\Delta\beta$: The angle between the direction of road segment and the direction from last matched positioning point to pre-match positioning point.

According to the above formula, for a single positioning point, the total similarity score for each candidate road segment can be obtained, and the road segment with the highest total similarity score is selected as the matching road segment.

2.3 Match the Shortest Path

The algorithm in this study utilizes method of matching shortest path part in algorithm [13], in which Grid1 delineated by the twice gridding is treated as candidate path searching region, then the Grid1 corresponding to the adjacent GPS points will be combined as the path searching range, and the Dijkstra algorithm is applied to find the shortest path to determine the matching path. Based on above method, additional method of dividing the adjacent GPS points whose driving distance interval is too long into different trajectory chains is applied, as a improved measure to avoid the unnecessary matching error and computation time caused by long driving distance.

3 Case Study

3.1 Introduction of Data

The data used in this study is selected from floating car data of Urumqi, Xinjiang province, and data collection time is January 2nd, 2016, with collection cycle of 30 s. Basic information of floating car data is shown in Table 1.

Table 1. Basic information of floating car data

Collecting date	Collecting time	License Plate	Longitude	Latitude	Speed (km/h)	Driving direction
20160102	215422	新AN542*	43.8235764	87.6345465	29	186
20160102	215452	新AN542*	43.8216593	87.6342880	24	183

Note: The first two digits of collecting time indicate the hour in 24-h, the next two digits of collecting time indicate minute, and the last two digits of collecting time indicate second.

3.2 Parameter Setting

In this paper, the urban area is divided into 140 × 160 Grid1 with a geometrical parameter of 285 m × 250 m. When searching for the shortest path, it will expand to the larger grid with geometrical parameter of 855 m × 750 m. Based on the grid structure, it can be seen that at least the shortest path can be found when the adjacent GPS points are within 500 m (the speed value is below 60 km/h). According to the speed distribution (Table 2), it is known that at least 96.44% of the shortest paths between adjacent GPS points can be found, which ensures the connectivity of the road network and the continuity of the trajectory. Urban area of Urumqi is divided into 1400 × 1600 Grid2 with a geometric parameters of 28.5 m × 25 m. When searching for matching road segments, it will expand to 85.5 m × 75 m. In this paper, the floating car positioning error radius is 30 m, whereas candidate range is 85.5 m × 75 m, larger than the error range, thus the possibility of missing the correct road segment is avoided when selecting the candidate road segment.

Table 2. Instantaneous speed distribution

Instantaneous speed interval	Cumulative number	Number in intervals	Proportion in intervals	The cumulative proportion
<=10 (km/h)	69306	69306	39.37%	39.37%
>10 &<=20 (km/h)	89653	20347	11.56%	50.93%
>20 &<=30 (km/h)	112003	22350	12.70%	63.63%
>30 & <=40 (km/h)	141662	29659	16.85%	80.48%
>40 & <=50 (km/h)	160190	18528	10.53%	91.01%
>50 & <=60 (km/h)	169756	9566	5.43%	96.44%
>60 & <=70 (km/h)	174230	4474	2.54%	98.98%
>70 (km/h)	176020	1790	1.02%	100.00%

According to the collected data attribute, the floating car positioning error radius ε is 30 m. Ochieng et al. [15] proposed that when instantaneous speed value is equal to or greater than 10.8 km/h (3 m/s), it can be ensured that the difference between the driving direction of the floating car record and the actual direction is less than 30°. According to the relationship description between the actual speed value and the driving direction error value in the Ochieng's study [15], the relationship between that two are shown in Fig. 2. Based on the variation trend, when instantaneous speed reaches 80 km/h (22.2 m/s) or higher, driving direction error is less than 5°, and direction accuracy is approximately 95%. Therefore, the speed threshold v_1 is 10.8 km/h (3 m/s), and the speed threshold v_2 is 80 km/h (22.2 m/s).

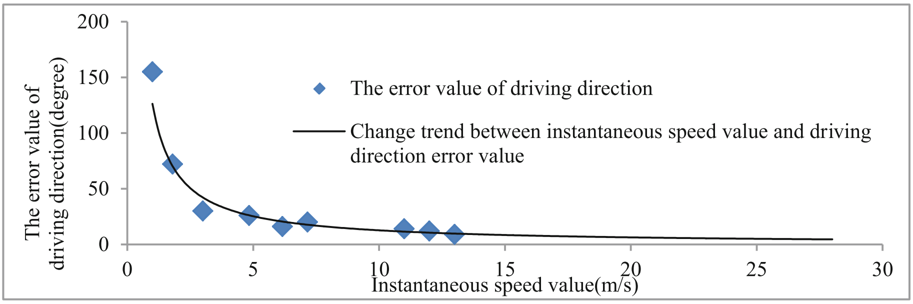

Fig. 2. Change trend between instantaneous speed value and driving direction error value

The trajectory angle factor is mainly affected by driving distance and positioning error, which is shown in Fig. 3 and Table 3. Assuming that the floating car drives in a straight road segment with an positioning error radius of 30 m. When the interval between adjacent positioning points increases, the maximum angular deviation decreases continuously until the interval length reaches 350 m, and the minimum accuracy rate reaches over 90%. However, in practice, there are driving behaviors different from going straight such as turning, then the minimum error will be less than 90%. Since the time interval of the collection is T = 30 s, considering the trajectory angle factor change interval should contain at least 95% of driving trajectory, therefore, interval length threshold is taken as 600 m (the speed is 70 km/h) to decrease the proportion of the trajectory angle factor in the overall evaluation. And Fan [16] compares and analyzes the relationship between the trajectory angle and the interval length, and confirms that the interval length threshold is 600 m to make the trajectory angle factor reliability.

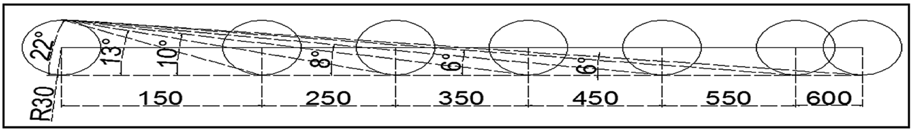

Fig. 3. The change schematic diagram of the angle and interval length on the straight road segment

Table 3. Maximum angular deviation, interval length and minimum accuracy rate change on straight road segments

The interval length	Maximum angular deviation	Minimum accuracy
150 m	22°	76%
250 m	13°	86%
350 m	8°	91%
550 m	7°	92%
600 m	6°	93%

Note: Minimum accuracy = maximum angular deviation/90°.

4 Analysis of Results

In the performance test of the map matching algorithm, it should be evaluated the matching accuracy rate.

At present, there is no uniform standard for map matching accuracy rate measurement methods, but the road segment matching accuracy rate is most measurement. The road segment matching accuracy rate refers to the ratio of correct matching number of road segments to the total matching number of road segments. Therefore, the road segment matching accuracy rate is selected as the evaluation criterion of the matching accuracy rate in this study. The data used in this paper are historical data, the actual trajectory is unavailable, but through the timing sequence of positioning point and road network connectivity, the path contains the most positioning points and with the shortest length can be known. This paper regards this kind of path as the actual driving trajectory.

Analyzing about 1000 positioning point matching results, this algorithm's correct rate reaches 99%. The accuracy rate of normal weighting factor algorithm [8, 9, 11] is about 90%, the accuracy rate of advanced map matching algorithm [14] is about 99%. The matching accuracy rate results show that the map matching algorithm in this paper is significantly higher than the normal weighting factor algorithm, and it is similar with advanced map matching algorithm, which means that the map matching algorithm in this paper has a very high matching accuracy.

The convention weighting factor algorithm leads to the imbalance between their factors due to the static weight. In specific case such as the road network structure composed of surface and elevated road, the roads are linearly similar and parallel, and intensive road segments or large positioning error, the wrong results of road segment selection often appear, which reduces the matching accuracy. The improved algorithm can avoid those problems. In the road network shown in Fig. 4, which composed of surface and elevated road, and these roads are parallel. The middle road is an elevated road, and it is impossible to turn around. But the actual trajectory has a turning round behavior. The improved algorithm finally matched surface road segments that allows U-turn as resulting road segments and without jump selection of road segment. The matching result of algorithm in this paper is shown in Fig. 5. The circled two points in Fig. 5 (left one) is far from actually driving trajectory. But final matching road segment isn't the one belong to the right-turning road, which is the closest to the point, but belongs to the straight road segment which is actually driving trajectory. The result of Fig. 5 (right one) also proves that improved algorithm has good matching performance in intensive road segments.

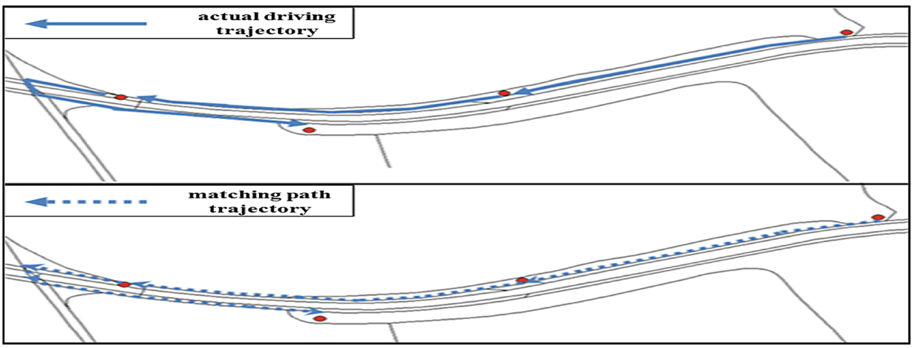

Fig. 4. Match path instance

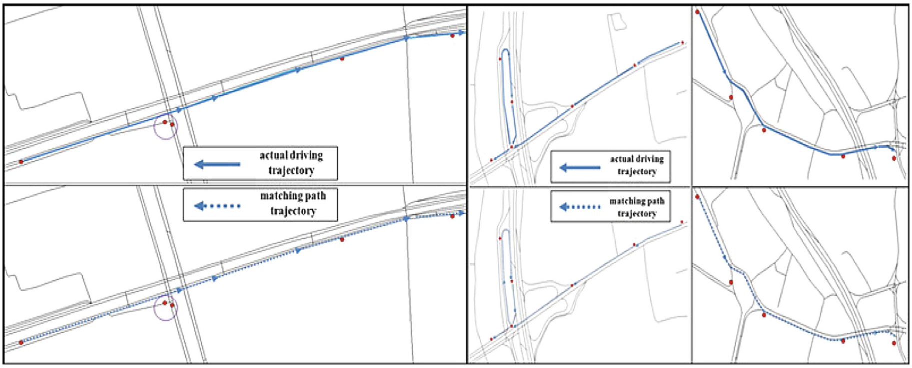

Fig. 5. Match path instance

From the matching results analysis, the improved algorithm performs excellent in the road segment matching accuracy rate on most general road network structures and the specific urban road network, even in the case of large local positioning errors. It is proved that the proposed algorithm has high overall accuracy rate.

5 Conclusion

The existing gridding map matching algorithms mostly make the shortest path as the core and cannot meet accuracy requirements. The normal weighting factors algorithm needs to construct the error region multiple times, it reduces the matching efficiency. In order to solve the fore-mentioned problems, this study proposes a novel map matching algorithm that combines twice gridding and weighting factors method, acquiring candidate road segments based on grid2, locating the shortest path by grid1. The method inherits the algorithm from the map matching algorithm based on twice gridding; Weighting factors map matching algorithm proposed in this study is improved by dynamically adjusting the factors weights by speed, interval length, etc., and integrates advantages of twice gridding method. The matching result has proven that the matching accuracy rate in specific situations such as parallel road segment, intersection area, intensive road segment or even large local positioning error is improved, and the failure of the driving direction and the trajectory angle at a low speed is avoided. The proposed algorithm outperforms the normal weighting factor algorithm, and it also has better performance in the case of similar road structure, large deviation of positioning and intensive road segment, And improve the matching efficiency by twice gridding method.

The map matching algorithm proposed in this study can provide basic technical support for urban traffic analysis, and also explores a new perspective for the map matching study. Since the data type of the algorithm in this study is offline floating car data, the next step is to handle online floating car data based on big data processing platform such as Hadoop, improve the processing timeliness.

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