Accurate Intelligent Map Matching Algorithms for Vehicle Positioning System

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Abstract

The purpose of a navigation system installed on a car is to help drivers in order to select an optimal path to reach the destination. In most of these systems, Global Positioning System (GPS) are used to determine vehicle position. There are number of error sources that undermine the quality of GPS measurements for car navigation systems. For this reason, technique like Map Matching (MM) is required to identify the road of a car is that moving on, with a high degree of confidence. MM in car navigation systems, has a task of determining the current position of vehicle on the city's map. In this paper, two new MM methods based on Fuzzy Logic (FL) and Neural Network (NN) are proposed to solve the matching problem in car navigation systems. For the experiments, a car navigation system is implemented with a low cost GPS receiver. The proposed fuzzy algorithm is easy to calculate. It requires little computation time without need to extra sensors and can find effectively the mobile exact position which moves on the road.

Keywords: *GPS, Map Matching, Fuzzy Logic, Neural Network.*

1. Introduction

Along with the development of Global Positioning System (GPS) technology nowadays, the positioning and navigation systems for vehicles have become the main applications in the intelligent transportation system, which brings great benefits in technology and economy, and get more and more attentions from the public. Therefore, high system performance is required urgently, especially the aspect of GPS positioning accuracy which is the key factor that affects the whole system accuracy [1].

As a matter of fact, the positioning error in GPS caused by various reasons is inevitable such as inherent errors from satellite ephemeris or GPS receiver, propagation delay through the ionosphere or any other complex unknown factors [2,3]. Existing methods applied in foreign Vehicle Navigation Systems (VNSs) have been proved effective in improving the GPS positioning accuracy by using of dead reckoning technique, differential GPS, the radio beacon or high-precision carrier phase receiver, etc [4,5]. As a result, the direct overlay of positional data obtained from GPS is not reconciled with a digital map. Therefore GPS data need to be corrected with various methods to match with a digital map.

One of the important parts in the car navigation system is determining the position of the car on the map. The methods to find car's location can be classified: dead-reckoning that calculates car's location according to its direction and distance travelled, and radio navigation that pinpoints the location of a car in terms of absolute position through radio waves [6], and GPS. The GPS receiver output is then map matched to the road network in order to give the drivers information about their location on the map [7,8].

In VNS, Map Matching (MM) approach plays an important role. It is a method of using digital map data and GPS satellite signal to locate the vehicle on proper position related to digital map. MM is a technique that well performed in estimating the actual vehicle location from GPS position in use of the road information contained in the digital map according to the spatial relationship between the GPS position and the roads. Compared to the other methods in this field, there are no additional equipment costs and optimization in solving MM problems is obvious, the request for digital maps is much easier to be applied with an acceptable performance. However, MM methods usually cost a lot due to their dependence on external assist devices and the related technologies are also a bit complicated, which unfortunately limit their promotions in practical applications [9].

Fuzzy Logic (FL) is one technique that is an effective way to deal with qualitative terms, linguistic vagueness, and human intervention [10]. Neural Network (NN) is an information-processing device composed of highly interconnected nodes, the processing elements, that is inspired by the way biological nervous systems process information, such as the human brain [1]. FL and NN have been successfully applied to a large diversity of applications including interpolation, chaotic time-series modeling, system identification, control engineering, electronic device parameter modeling, channel equalization, speech recognition, image restoration, shape from-shading, 3-D object modeling, motion estimation and moving object segmentation, data function, and etc.

In this paper, two new methods based on MM are proposed to reduce the positioning error by position correction in use of FL and NN. This paper is organized as follow. Section 2 explains MM principle. Problem is described in section 3. Proposed MM algorithms based on NN and FL are presented in sections 4 and 5, respectively. The experimental results of navigation system are explained in section 6. Section 7 reports conclusions.

2. Map Matching Principle

MM algorithm 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, find the road where vehicle runs and shows the real-time location of vehicle. MM process based on the principle can be divided into two relatively independent processes. First, to find the road of currently vehicles traveling. Second, to project current positioning point to the road of vehicles traveling [11,12].

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 locations of road A → B →C.

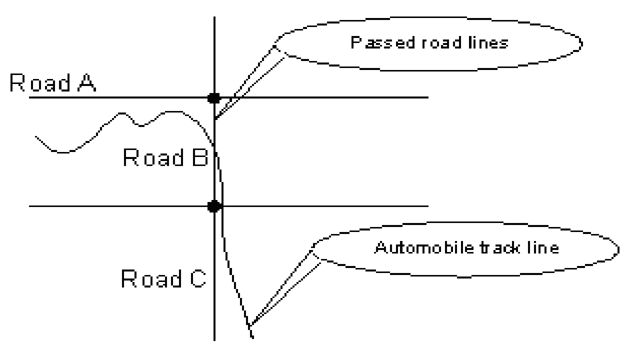

Fig. 1 Automobile track lines and passed road lines.

3. Problem Description

θ is error between the mobile measured position and the desired route. Also, d is the mobile measured position distance to the desired route. The relationships between the obtained trajectory vector (AB) and the reference vector (r) are shown in Fig.2.

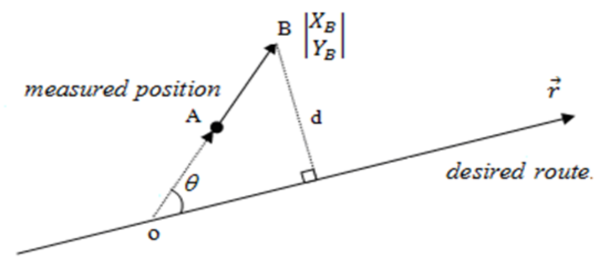

Fig. 2 θ and d parameters definition.

The calculations for θ and d are explained below. Note that θ and d are positive and negative values and have same sign and $\vec{r} = ax + by + c$. As evidenced in Fig.2, θ and d obtain as follow:

$$d = \frac{aX_B + bY_B + c}{\sqrt{a^2 + b^2}} \quad (1)$$

$$\theta = Sin^{-1} \frac{d}{\left|\overrightarrow{OB}\right|} \quad (2)$$

4. Proposed Map Matching Algorithm based on Neural Network

Radial Basis Function (RBF) emerged as a variant of ANN in late 80's. However, their roots are entrenched in much older pattern recognition techniques for example potential functions, clustering, functional approximation, interpolation and mixture models. RBF's are embedded in a two-layer NN, where each hidden unit implements a radial activated function. The output units implement a weighted sum of hidden unit outputs. The input into an RBF network is non-linear while the output is linear. Their excellent approximation capabilities have been studied in. Due to their non-linear approximation properties, RBF networks are able to model complex mappings, which perception NNs can only model by means of multiple intermediary layers. A RBF NN is shown in Fig.3.

In order to use a RBF network, we need to specify the hidden unit activation function, the number of processing units, a criterion for modeling a given task and a training algorithm for finding the parameters of the network.

Finding the RBF weights is called network training. If we have a set of input-output pairs, called training set in hand, we optimize the network parameters in order to fit the network outputs to the given inputs. The fit is evaluated by means of a cost function, usually assumed to be the Mean Square Error (MSE). On-line training algorithms adapt the network parameters to the changing data statistics. After training, the RBF network can be used with data whose underlying statistics are similar to the training sets [13,14]. The inputs to the proposed NN are in from of GPS receiver to provide continuous navigation. The NN outputs are the matched positions. In this paper, NN has three layers: input layer with 2 neurons, hidden layer with 15 neurons and output layer with 2 neurons.

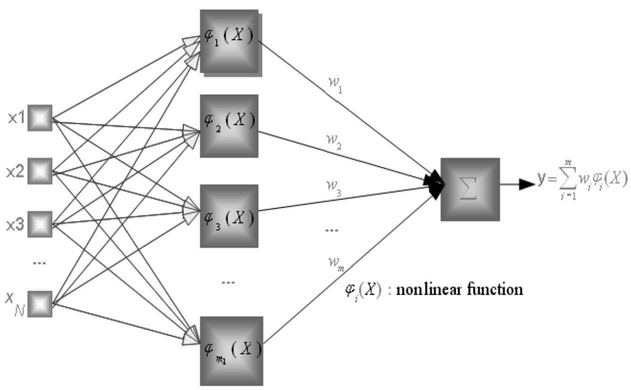

Fig. 3 A RBF NN architecture.

5. Proposed Map Matching Algorithm based on Fuzzy Logic

The design and implementation procedure for the algorithm based on FL is accomplished according to the three procedure steps: (1) fuzzification of the input and output, (2) construct rule base and (3) defuzzification of the output. A Fuzzy System (FS) is the framework for systematically performing all the exercises to obtain a precise numerical output from a given input using FL [15,16]. Fig.4 shows proposed FS. θ, d and expected error ($Expected\ Error = \sqrt{Ex^2 + Ey^2}$) are FS inputs. θ' is the FS output and defined as rotation angle of trajectory vector for mapping. After fuzzification, rule inference and defuzzification, θ' is generated for rotation angle of trajectory vector. The design procedures for the FS are as follows:

Step 1: Fuzzification: A membership function is utilized to convert the input data into a fuzzy value [17,18]. The triangular shaped membership functions are defined into the five sets of Large Negative (LN), Small Negative (SN), Zero (ZE), Small Positive (SP) and Large Positive (LP) for θ, d and θ' and also two sets of Small (S) and Large (L) for e, as shown in Fig.5.

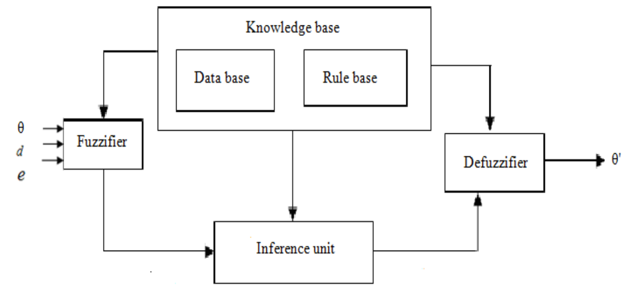

Fig. 4 Black diagram of proposed FS.

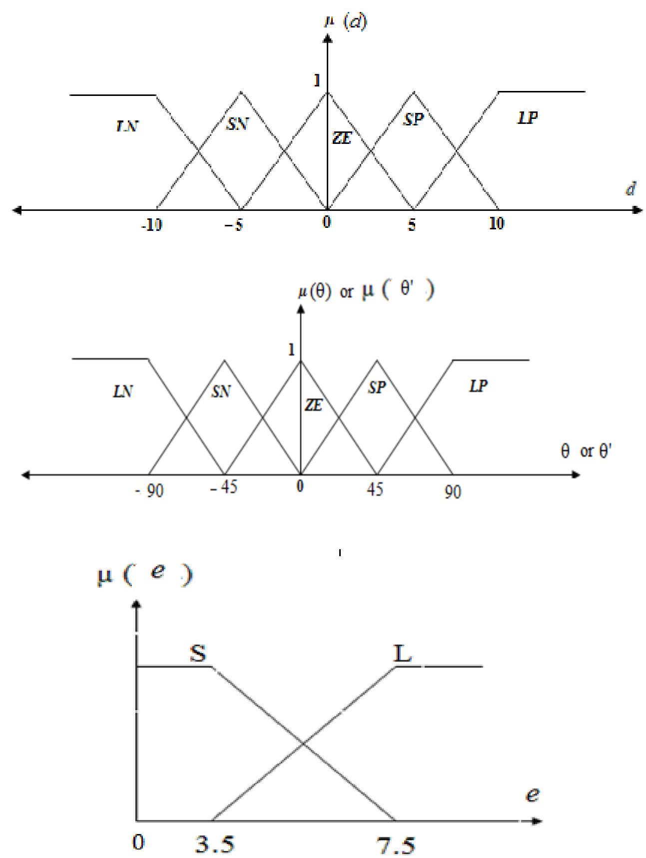

Fig. 5 Triangular shaped inputs and output membership functions.

Step 2: Fuzzy Inference: After considering the various mapping situations affectings, we are able to define the rules base as shown in Table1.

Step 3: Defuzzification: The system here utilizes the height method of defuzzification to reduce microprocessor calculation time. Since the FS rules are known to have 34 inference rule antecedent propositions, it is first necessary

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to computer the weight of membership for each inference rule proposition. The weight of the i-th inference rule is [19]:

$$W_i = \mu_{A_{i1}}(d) \times \mu_{A_{i2}}(\theta) \times \mu_{A_{i3}}(e) \tag{3}$$

Where, $\mu_{A_{i1}}(d)$, $\mu_{A_{i2}}(\theta)$ and $\mu_{A_{i3}}(e)$ are the membership values of d, θ and e in the membership functions sets Ai1, Ai2 and Ai3, respectively.

Table 1: Rules base of the proposed FS of Fig.4.

d	θ	e		θ'	
LN	LN	S	L	LP	LP
SN	LN	S	L	SP	LP
ZE	LN	S	L	SP	LP
SP	LN	S	L	-	-
LP	LN	S	L	-	-
LN	SN	S	L	SP	LP
SN	SN	S	L	SP	SP
ZE	SN	S	L	SP	SP
SP	SN	S	L	-	-
LP	SN	S	L	-	-
LN	ZE	S	L	ZE	SP
SN	ZE	S	L	ZE	ZE
ZE	ZE	S	L	ZE	ZE
SP	ZE	S	L	ZE	ZE
LP	ZE	S	L	ZE	SN
LN	SP	S	L	-	-
SN	SP	S	L	-	-
ZE	SP	S	L	SN	SN
SP	SP	S	L	SN	SN
LP	SP	S	L	SN	LN
LN	LP	S	L	-	-
SN	LP	S	L	-	-
ZE	LP	S	L	SN	LN
SP	LP	S	L	SN	LN
LP	LP	S	L	LN	LN

Min operation represents the intersection of the fuzzy set to obtain minimum value. To solve for the overall inference result of θ' from each inference rule, it is derived by adding the average value, so:

$$\theta' = \frac{\sum_{i=1}^{i=34} W_i \times y^{-i}}{\sum_{i=1}^{i=34} W_i} \tag{4}$$

Where, y^{-i} is the i-th inference rule center. The θ' is used as the fuzzy controller's output signal. Fig.6 shows proposed MM algorithm for 4 points A1, A2, A3 and A4.

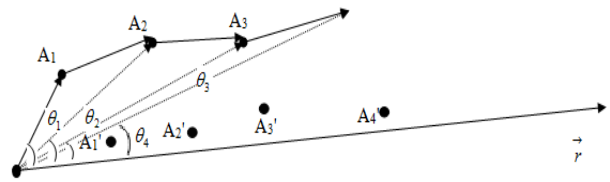

Fig. 6 The proposed MM algorithm for 4 points A1, A2, A3 and A4.

The calculations for θ and d of matched point (θ'_i, d_{2i}) are computed as follow:

$$\theta'_i = \theta_i + \theta' \tag{5}$$

$$d_{2i} = \sin(\theta_i') \times \left|\overrightarrow{OA_i}\right| \tag{6}$$

Where θ' is rotation angle.

6. Experimental Results

A field test was conducted in Iran University of Science and Technology, to validate the performance of the algorithm. The test lasted for about 15 minutes. The test was conducted at variety of speeds ranging from 10 km/h to 60 km/h. A car navigation system consists of several subsystems, such as a positioning system, a route guidance system, and a user interface system. The main role of a car navigation system is to find the car position as precisely as possible. In this research, a low cost GPS engine manufactured by Rockwell Company was used. The Rockwell "Microtracer Low Power (MLP)" is a single board, five parallel-channels, L1-only Coarse Acquisition (C/A) code capability. To read the GPS receiver data as well as to calculate the car position simultaneously at every sampling time, the developed navigation system consists of two serial ports, a sensor handling serial port for the GPS receiver and a serial port for communication to computer. A 16-bit microcontroller 80C196KB is used for the MM algorithm. All the programs for microcontroller and computer are coded in C-language and visual basic 6, respectively. As mentioned above, the developed car navigation system is a subsystem that has the positioning ability only. The mapped position from the developed car navigation system is sent to the notebook computer through RS232 serial communication. The map matched position is displayed on the notebook monitor. Fig.7, Fig.8 and Fig.9, show the measured, desired and mapped routes, respectively. Figures 10 and 11 show the measured, desired and mapped routes using the proposed FL and NN, respectively.

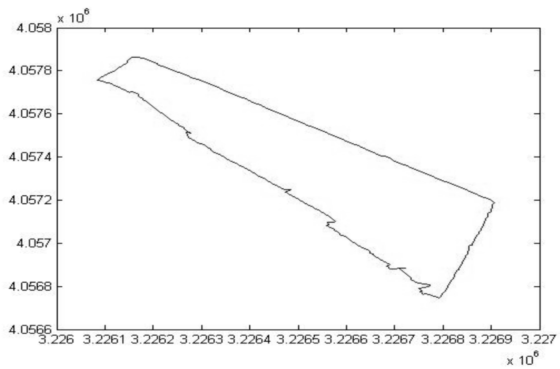

Fig. 7 The measured route for the mobile unit.

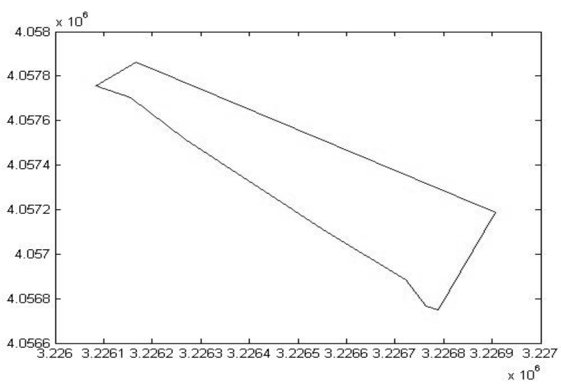

Fig. 8 The desired route for the mobile unit.

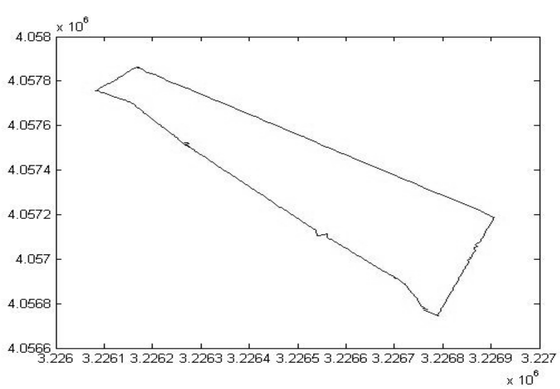

Fig. 9 The mapped route for the mobile unit.

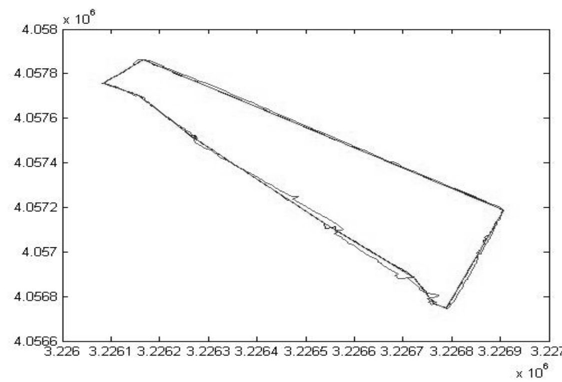

Fig. 10 Matching of Fig.7, Fig.8 and Fig.9.

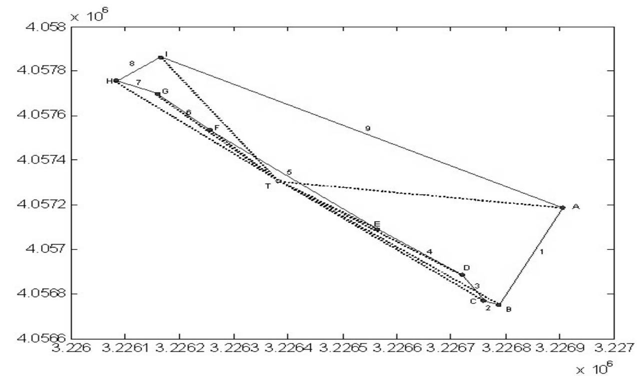

Fig. 11 MM using the proposed NN.

In these algorithms, MSE is calculated for algorithms error. These errors for each line have been reported in the Table 2.

Table 2: Proposed algorithms MSE for each line of map (in meter).

Number of line	1-2	3-4	4-5	5-6	6-7	7-8	8-9	9-1
MSE using FL	0.016	0.002	0.223	0.05	0.07	0.03	0	0.01
MSE using NN	0.272	0.632	0.752	0.539	0.890	1.203	0.528	0.836

Table 2 shows the best map matched output using the proposed FL algorithm. The algorithm gives a good map matched solution.

7. Conclusions

The GPS is having a profound impact on the development of automatic vehicle location and navigation systems. An essential process in VNS is to map match the position obtained from GPS on a road network map. MM is a technique combining electronic map with locating information to obtain the real position of vehicles in a road network. In this paper, two new MM algorithms based on FL and NN, to project the vehicle location on the digital map two-dimensional road network were successfully used. For experiments, a car navigation system was developed with a low cost GPS receiver and a microcontroller chip. The effectiveness of the proposed MM algorithms was verified with several experiments. In the experiments, mapped car position was precise; so that error is reduced from 15m to less than 0.3m. Moreover, the proposed FL algorithm needs little computation time. This feature makes it suitable for using in a car navigation system with a low power microcontroller.

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