Map Matching Algorithm for the ”Spar på farten” Intelligent Speed Adaptation Project

Nerius Tradišauskas[1], Jens Juhl[1], Harry Lahrmann[1], Christian S. Jensen[2]

[1]nerius@plan.aau.dk, jj@land.aau.dk, lahrmann@plan.aau.dk
Department of Planning and Development, Aalborg University

[2]csj@cs.aau.dk
Department of Computer Science, Aalborg University

Abstract

The availability of Global Navigation Satellite Systems (GNSS) enables sophisticated vehicle guidance and advisory systems such as Intelligent Speed Adaptation (ISA) systems. In ISA systems, it is essential to be able to position vehicles within a road network. Because digital road networks as well as GNSS positioning are often inaccurate, a technique known as map matching is needed that aims to use this inaccurate data for determining a vehicle's real road-network position. Then, knowing this position, an ISA system can compare speed with the speed limit in effect and take measures against speeding.

This paper presents an on-line map matching algorithm with an extensive number of weighting parameters that allow better determination of a vehicle's road network position. The algorithm uses certainty value to express its belief in the correctness of its results. The algorithm was designed and implemented to be used in the large scale ISA project ”Spar på farten” . Using test data and data collected from project participants, the algorithm's performance is evaluated. It is shown that algorithm performs correctly 95 % of the time and is capable of handling GNSS positioning errors in a conservative manner.

Keywords: Intelligent Transportation Systems (ITS), Intelligent Speed Adaptation (ISA), Map Matching

1 Introduction

The proliferation of mobile computing devices and the increased accuracy of Global Navigation Satellite Systems such as the Global Positioning System (GPS) open new opportunities for traffic telematics applications. Systems to monitor and track the movements of vehicles is one of many such opportunities. Knowledge of a user's position enables content providers to offer location-based services. Recently, the traffic research community has developed a substantial interest in Intelligent Speed Adaptation (ISA).

ISA systems use a vehicle's road network position to extract the speed limit in effect and thus enabling various solutions to prevent drivers from speeding. A digital road network with comprehensive speed limit information and the vehicle's GPS position are used to determine the vehicle's road network location. The allowed speed limit is then extracted from the digital road network and compared to the actual driving speed. If speeding occurs, depending on the ISA type, the system takes action, ranging from signaling the speeding to the driver through an information device to physically limiting the speed of the vehicle. It is very important to identify the correct speed limit, to increase the performance and user acceptance of the ISA system. ISA trial projects take place in many different countries around the world ([1, 2, 11, 12, 13, 18, 19]).

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After the selected availability was switched off in May 2000, GPS position accuracy improved dramatically. Using an off–the–shelf standard GPS receiver, the positioning error can vary from 5 to 25 meters [5, 7]. In urban areas, constructions such as high buildings, ramps, and tunnels obscure the line of sight to the satellites, which may result in signal multipaths or even a loss of signal. This increases the positioning error or might lead to a complete blackout where no position is provided. To avoid a total loss of positioning, GPS is sometimes coupled with a dead reckoning (DR) unit that provides vehicle speed and movement direction information. Using sophisticated methods such as Kalman Filter [10] it is possible to fuse GPS and DR information to track the position of user quite accurately, even if the GPS positioning has been unavailable for some time.

ISA systems are real-time systems, meaning that positioning on the road must be done every time a GPS/DR position is received. This is quite challenging, as GPS positions sometimes deviate from the actual vehicle location by more than 50 meters [10]. The real-time algorithm that performs the positioning in the road network is called on-line map matching. This contrasts off-line map matching which is done after a trip is over and all the positions from the start to end point are known. Off-line map matching is more accurate than on-line map matching as more information (i.e., concerning the future movement) is available.

The initial problem of map matching was perhaps first defined by Bernstein and Kronhauser [3]. Later followed improved techniques, by White et al. [6], that pay special attention to intersection area. Taylor et al. [15, 16] propose a novel map matching procedure that uses differential GPS. The proposed road reduction filter algorithm uses differential corrections and height, which leads to improved performance. A complex off-line map matching algorithm was recently developed by Bratkatsoulas et al. [4] that uses the Fréchet distance to map match GPS data samples recorded every 30 seconds. Quddus et al. [14] provide a summary of different on-line and off-line map matching algorithms and give a list of disadvantages of each approach.

We are not aware of any proposals of a map matching algorithm for ISA systems. Rather, reports on ISA projects tend to concentrate on the social aspects, performance, and acceptability of the overall system. In contrast, we present an on-line map matching algorithm that has been shown to perform successfully in ISA trials [9]. The algorithm uses sophisticated map matching techniques covering a wide variety of parameters. It adopts a self-evaluation mechanism that uses a unique certainty value that reflects the belief in the correctness of the map matching.

The performance of the algorithm is studied empirically using a large amount of data collected in various areas in the North Jutland, Denmark. These areas include different types of roads, e.g., city streets with nearby tall buildings, roads in forests, a tunnel (length: 582 meters), and open rural roads with good visibility. This is important to ensure a thorough evaluation of proposed algorithm.

The paper is outlined as follows. In Section 2 the proposed on-line map-matching algorithm is presented and explained in detail. A thorough analysis of the algorithm is provided in Section 3. Conclusions and possible directions of future work are covered in Section 4.

2 Map Matching Algorithm for "Spar på farten" Project

The developed algorithm is used for the "Spar på farten" [9] ISA project that takes place in the North Jutland, Denmark. Project is aimed to reduce speeding among young drivers. Drivers get an on–board unit (OBU) installed into their car that tracks user position and extracts speed limit information from a digital road map. If users obey speed limits, they get a discount on car insurance. The "Spar på farten" project uses on-line map matching algorithm to detect user position on the road and select the actual speed limit.

As an input map matching algorithm receives position fix from a GPS/DR unit every second. A GPS unit is a 12-channel receiver that sends all the information available and a DR unit consists of odometer and sends vehicle speed value. The polylines are extracted from a speed

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map of the North Jutland. All registered roads (road polylines) of the North Jutland have speed values assigned for each allowed movement direction. For the rest of the Denmark only highway information is stored. For all the other areas of Denmark speed value is set to 80 km/h. For areas outside of Denmark map matching and speed control is not done. Map matching and other system maintenance functions are made by the OBU. The OBU has weak computational power (only integer representation, lack of trigonometrical functions) and small memory buffer (up to few hundreds of kilobytes). The map matching algorithm is performed within a second and consists of six steps (see Figure 1).

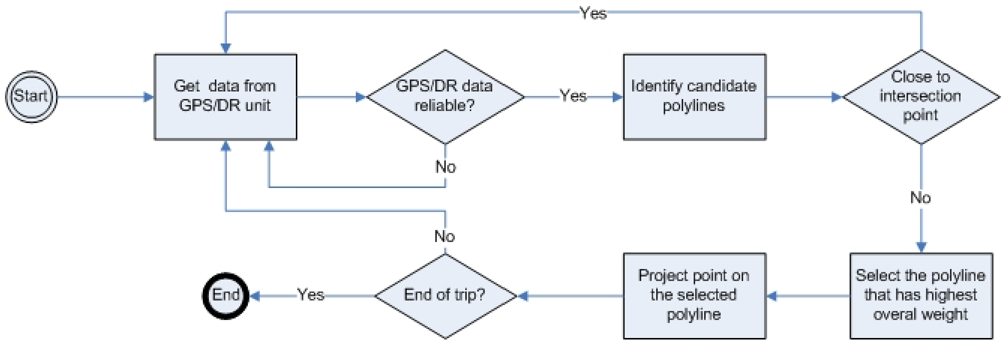

Figure 1: Steps of map matching algorithm

The initial step is extraction of data and conversion to common measure units.

The first step is to check if the GPS data are reliable. This is made by comparing the GPS speed data with the odometer speed data. The allowed difference in speed shouldn't be more than 5 km/h threshold value. If the speed difference is within the allowed threshold the angle direction change is checked. The *direction_change* is a value representing difference between previous and current directions and is proportionally connected with the speed: $direction\_change * speed < 1000$. This formula works only if speed is expressed in km/h and direction change is an angle in degrees. This equation checks that cars are not making turns with higher than .5G force. If a sharp turn is detected and the equation is violated, then this is most probably a GPS position outlier. If any of these checks fail, then algorithm stops map matching and returns error code (via certainty value). The ISA system is responsible of gracefully handling the situation when the map matching is not possible.

In the second step the candidate polylines are identified. The algorithm selects at most 12 nearest polylines from the vehicle GPS position. Due to specific map format candidate polylines can be no further than 750 meters away. These polylines are used to assign weights and the one with the highest overall weight is selected. If no candidate polylines are found within threshold value, map matching algorithm stops map matching and returns error code via certainty value.

The third step checks the distance to the intersection point. Usually the end points of polyline are considered as intersections, but in speed map we are using this is not the case. Some end points represent the end or start of speed limit validity on given road Thus polyline end points, that connect only two polylines with the same street code are not interpreted as intersection points. Polyline end points that intersect with others polylines that have other street code are considered as intersection. Street code represents the street naming in real world. If any intersection point is closer than a threshold value from a given GPS position algorithm stops working and returns error code through certainty value. This threshold value is by default set to 10 meters.

If all the previous steps succeed the map matching can be done. Algorithm proceeds analyzing candidate polylines with different criteria and assigning weights to each. The polyline with the highest final weight value is selected and its matching certainty value is calculated. The bigger is the difference between two greatest weight polylines with different speed values

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the more secure the map matching result is.

The last step of map matching algorithm is to calculate the point position on the selected road polyline. Vehicle position is acquired by simply projecting the point onto selected polyline. If the point is projected to an extension of a polyline, then closest end point of polyline is selected.

As the output result, algorithm returns map matched position, certainty value, and speed limit on the polyline the vehicle is driving. ISA system uses latest securely map matched speed limit if map matching algorithm stops working due to reasons mentioned above.

The following paragraphs describe the criterion and their weight values that each polyline out of candidate polyline set is assigned in fourth step of map matching algorithm. For more information on the exact weight calculation and a map matching framework for the "Spar på farten" ISA system refer to [17].

Weight for Proximity of a Point and Polyline The polyline is assigned a weight $W1$ for the proximity to a point. It is natural to assume that the closer the polyline is to the point the higher the assigned value should be. The distance is calculated between point on the polyline, that is the closest to the GPS position. The weight $W1$ value can vary from 0 to 105 points.

Weight for Continuity of the Polyline The weight $W2$ is assigned to each polyline for being a continuation of previously map matched polyline. This weight represents the reasoning, that users tend to drive on the same road most of the time. If the polyline has the same road number as previously map matched polyline maximum weight of 30 is added. If the polyline is not an extension of previous one, but has an end point near the user position, then weight of value 10 is assigned. Else zero weight is assigned. The weight $W2$ can vary from 0 to 30 points.

Weight for Speed Limit Change The weight $W3$ is assigned to polylines according to their speed limit value. Polyline that has the same speed limit value as the previously map matched polyline gets non zero weight value. The weight is calculated differently for two speed groups: urban (all speeds limits that are lover or equal to 80km/h) and rural (all speed limits are greater or equal to 90km/h). This variation was made to give higher weight value for the cars driving on rural roads and highways. The weight nicely complements the $W2$ weight, as it assumes that cars are driving on the highway rather than an exit from the highway. The odometer speed is selected as a vehicle speed. The weight $W3$ can vary from 0 to 60 points.

Weight for One–way Streets Polylines that represent the one–way roads have zero speed limit to the direction that is prohibited to drive. A conservative approach is considered for one–way streets as there might exist an error in the map. This weight also helps to correctly identify the correct polyline on the highway. If a polyline is a one–way and its direction is against the vehicle movement direction then the weight $W4$ is set to be -100 (a total weight is decreased by 100 points), otherwise the weight is set to zero.

Weight for Direction Similarity Polylines whose bearing is similar to vehicle movement direction are assigned higher weight $W5$ value. There exist a well known problem of GPS position dilution while the vehicle is stationary [14]. To deal with this problem we check odometer speed and if the vehicle is stationary (speed is zero) then direction of last non stationary position is chosen. For the highway polyline 4 degrees adjustment is made to produce better results at an exit ramps. The weight $W5$ can vary from 0 to 150 points.

Weight for Topology The weight $W6$ for topology consists of two parts: forward and backward polyline connection similarities. Weight is added to polylines that have the same intersection point as the previously map matched polyline end point forward (or backward) to vehicle

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movement direction. If the polyline has no common connection point, then zero weight is added. If there is a connection between polylines through intermediate polyline(s) it is not taken into account and polylines are considered as disconnected. The weight is especially useful at intersection area, as polylines that intersect with map matched polyline get higher weight and became more likely to be selected. The weight $W6$ can vary from 0 to 300 (2x150) points.

Weight for Shortest Distance If the polyline with the shortest distance is not the polyline with the highest weight, then special weight $W7$ is added. The initial value of weight is 5, and is increased by 5 every time the same polyline is closest but not with the highest weight. The weight is reset if the closest polyline has changed. This weight was added to avoid problems with parallel connected roads.

Total Weight Calculation The weights are calculated for each candidate polyline and a total weight is obtained by summing all the weights:

$total\_weight = W1 + W2 + W3 + W4 + W5 + W6 + W7$

The polyline with the highest *total_weight* is selected and vehicle position on the selected polyline is determined by projecting GPS point to the closest point onto the selected polyline.

This map matching algorithm was developed for ISA system with the main interest in extraction of correct speed limit. Certainty of map matching is done by comparing weights of two polylines. The weight of selected polyline (polyline with maximal *total_weight*) is compared with the polyline that has the greatest weight value with different speed limit than the selected one. The bigger the difference between these two weights is, the more reliable the map matching is. If all the candidate polylines have the same speed limit, the certainty value is maximal. The value of certainty varies from 0..100, where 0 represents low and 100 high certainty. If certainty value is equal to or below the threshold value set to 25, then the ISA system does not trust the map matching and no actions for possible speeding are taken. Negative certainty values are used to express the insufficient or unreliable data.

All the constant numbers in our individual weight calculation algorithms are selected to provide the best results for a given speed map of the North Jutland. Other maps or more tests with parameter values may lead to a different set of parameters to show the best performance of map matching algorithm.

3 Evaluation of Map Matching Algorithm

This section reports on empirical evaluations of the map matching algorithm. We first analyze the map matching using a known route. We performed visual inspections to check the correctness of the map matching, and we report failures using statistical analysis. Second, we use data received from vehicles participating in the "Spar på farten" project. This data covers much of the North Jutland. In both parts, the data used is real, and the map matching was performed while the vehicles involved were driving using the project equipment. As the algorithm was specifically developed for an ISA system, the most important criterion is the correct speed extraction from the digital road network.

The digitalized speed map covers the entire North Jutland, which has an area of 6,170 km^2 and 22,000 km of roads (approx. 12,000 km of public and 10,000 km of private roads). A total of 80 % of these roads are rural roads and have a speed limit of 80 km/h [8]. In addition to these roads, also the national and county roads outside the North Jutland are contained in the map if they have a speed limit that exceeds 80 km/h. The "Spar på farten" project is thus one of the first ISA-projects that deals with a larger rural area.

The "Spar på farten" project uses a 12–channel, single frequency GPS receiver and a vehicle odometer as the DR unit. GPS/DR unit information is received every second, and map matching

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is done using an on-board unit. The current speed information is displayed on a screen in the vehicle. If the map matching is uncertain or there are errors, the most recent speed limit is displayed in parentheses, and the ISA system takes no action in case of speeding.

Map matching errors occur due to high positioning or map errors. The certainty value is used to inform about the errors. The value -1 is returned if no road near the GPS/DR position is found. The value -11 is returned when there is a too large difference between the odometer and the GPS speed values. The value -12 is returned if the direction change is too fast for the given speed (handling of GPS position outlier). The value -15 is returned when there are too few satellites to get a position. The value -16 is returned if the first positions are blocked by a tunnel, a garage, or other outdoor objects. The value -17 is returned when the GPS speed exceeds 220 km/h. The value -18 is returned when the GPS position is not accurate and the horizontal dilution of precision (HDOP) value is greater than 5 and proper GPS positioning is unlikely to be possible. Finally, the value -99 is returned when vehicle is driving outside territory of Denmark.

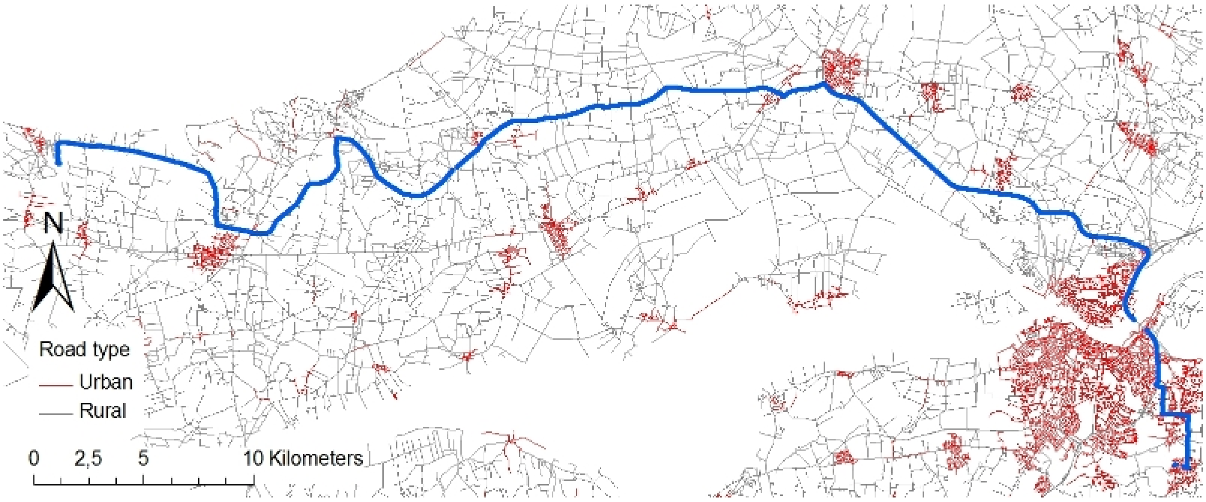

Figure 2: Test trip. Vehicle was driving from West to East.

Analysis of Map Matching Algorithm In Figure 2 the test trip can be seen. The trip is 72 km long and starts in the western part of the county and ends in an eastern suburb of Aalborg. The trip duration was 76 minutes and took place between 4 p.m. and 6 p.m. on the July 2, 2006. The average HDOP value is about 1.70, and the average number of satellites visible is 6.84. The test vehicle was driving on rural roads 90 % of the distance and was driving on urban roads the remaining distance.

During the test, the certainty value was high (interval [26...100]) 95.39 % of the time (see Figure 3(a)). The map matching had low certainty (interval [0...25]) during 0.11 % (corresponding to 5 seconds) of the trip. No map matching was performed 4.5 % of the trip due to errors (206 seconds). More than half of the errors (error -18, 63.6 %) were due to a too high HDOP value (see Figure 3(b)). Yet another source of errors is a too big difference between the GPS and the odometer speed during fast accelerations and decelerations (error -11, 31.1 %). Relatively small amount of positions had too sudden direction change at a given speed and were considered as GPS/DR positioning outliers (error -12, 2.43 %). Also a small amount of errors occured due to insufficient number of visible satellites (error -16, 0.97 % and error -15, 1.94 %). Errors with codes -1, -17, and -99 are absent in the test drive.

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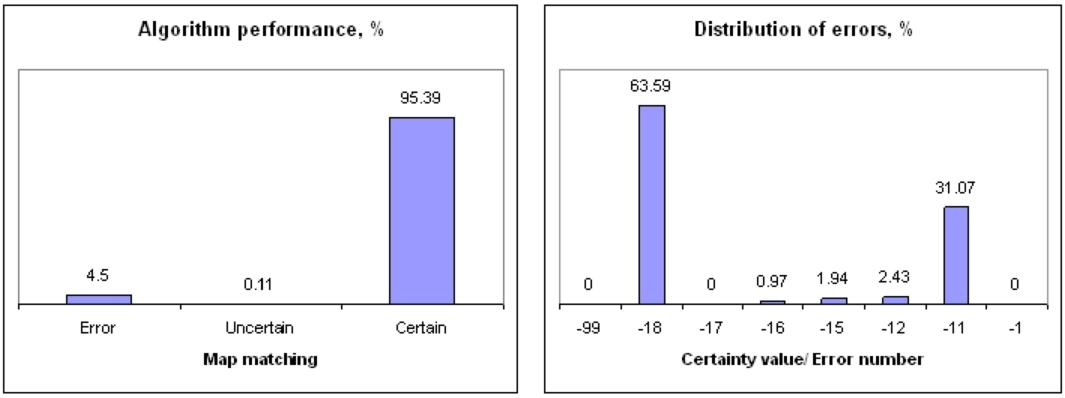
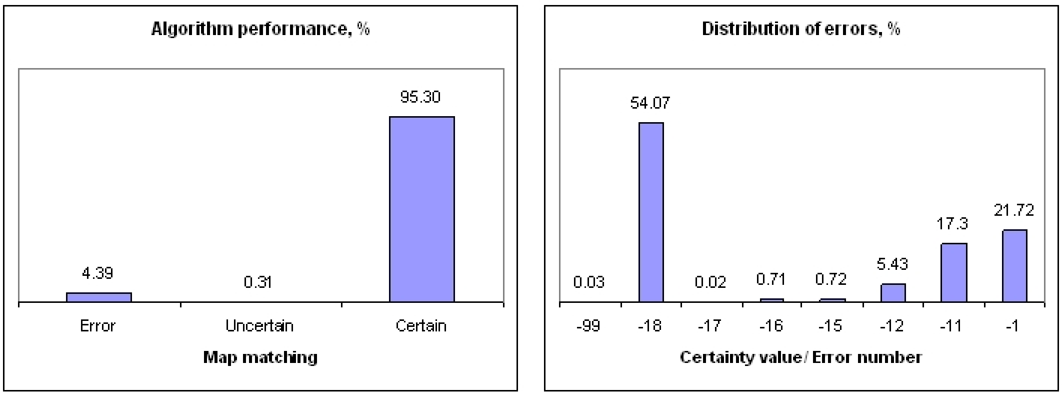


(a) Distribution of certainty value, % (b) Distribution of map matching errors, %

Figure 3: Test trip: certainty value and map matching error distributions

Statistical Analysis of "Spar på farten" Project Data The data analyzed in this section is log data from the "Spar på farten" project that has data from 50 participants that are located in the North Jutland. The dataset considered consists of nearly 10 million of GPS positions from the period from August 1 to December 1, 2006.

The algorithm exhibits high performance and works well in 95.30 % of the time. The rest of the time (see Figure 4(a)), the map matching certainty is considered to be insufficient; thus, the ISA system takes no action even if actual speeding occurs. In 4.39 % of the total time, no map matching is done at all, which is due to errors.



(a) Distribution of certainty value, % (b) Distribution of map matching errors, %

Figure 4: Certainty value and map matching error distributions

Figure 4(b) shows the distribution of the map matching errors. It is seen that the main reason for no map matching is a too weak GPS signal, which is expressed as a high HDOP value (error -18, 54.07 %). This can happen when driving between tall buildings in cities or on rural roads with nearby tall trees.

Another reason for no map matching is the inability to find a nearby road (error -1, 21.72 %). This can occur when the HDOP value is high or when a rural road is missing from the map or user is driving outside the area of the North Jutland. The too high speed difference between the odometer and the GPS values (error -11, 17.30 %) occurs due to fast acceleration or deceleration, especially at an intersection area. The odometer can show the speed instantly, while the GPS value lags a little. Yet another significant reason for no map matching is the so-called side

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acceleration (error -12, 5.43 %) due to too high difference in vehicle direction change at high speeds. These points most probably are GPS outliers and are thus skipped. The last four reasons occur in less than 2 % of the cases and thus are not that important.

The maximum distance between the GPS/DR point and the map matched point with low certainty values (interval [0...25]) reaches 150.62 meters; with high certainty values (interval [26...100]) the distance reaches 154.43 meters. A high maximum map matching error can be caused by a vehicle driving on a road in a rural area that is covered by tall trees and where there are no other roads to map match to. These are extreme cases and appear rarely in the test data.

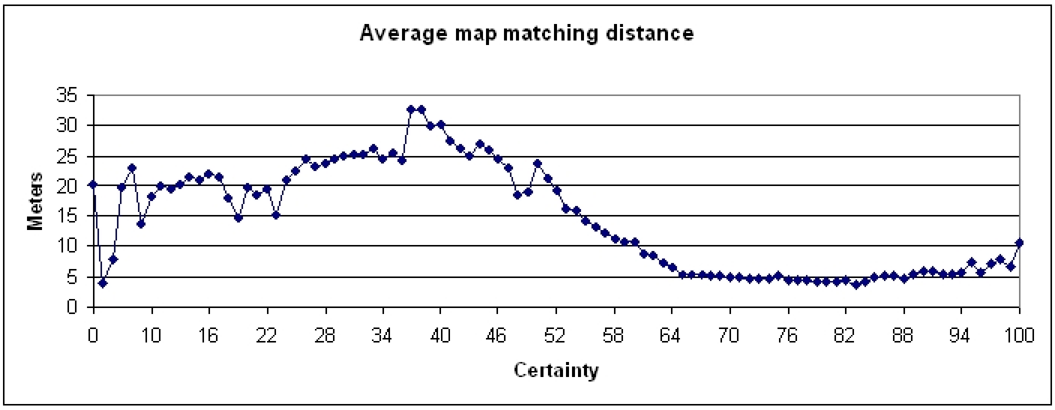

Figure 5: Average map matching distance, %

Figure 5 shows an average distance between GPS position and map matched point on road network. The average map matching distance is 18.67 meters for low certainty values (interval [0..25]) and only 9 meters for high certainty values (interval [26..100]). The overall map matching error for all map matchable certainty values (interval [0..100]) is 9.04 meters. The increase in map matching distance with higher certainty values (interval [95..100]) might be due to the case that most of the polylines are with the same speed limit and only few polylines exist with very small *total_weight* and different speed limit.

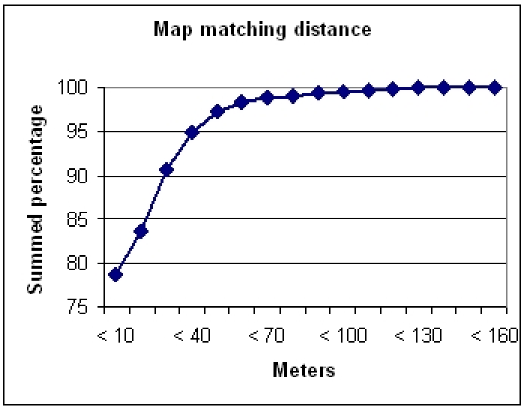

Figure 6: Map matching distance, %

Figure 6 shows the relation between the map matching distance and the percentage of points covered by that percentage. It is seen from the graph that 78.70 % of all map matched points have a matching distance that is less than 10 meters. It is also seen that 99.02 % of positions are map matched within 80 meters. And only less than 1 % of extreme cases are map matched

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between 80 and 160 meters.

At the map matchable certainty value range (interval [0..100]) the average HDOP value returned by GPS unit is 1.46 with average standard deviation of 0.65. With low certainty values (interval [0..25]) the average HDOP value is 1.46 and with high certainty value (interval [26..100]) the average HDOP value is 1.45. The HDOP value with high certainty value is a little bit better, but has no significant impact on overall map matching result. In general, the average HDOP value is quite stable and varies insignificantly (standard deviation – 0.035) with different certainty values.

4 Conclusions and Directions for Future Research

In this paper we define an on-line map-matching algorithm designed and implemented especially for ISA systems and currently being used in a large scale trial—the "Spar på farten" project [9]. The algorithm works on hardware with limited CPU and memory resources and yet performs within strict time constraints. The algorithm provides the best possible map matching. It extracts speed information for a map matched polyline and calculates a value that captures how certain the algorithm is that the extracted speed limit is correct. In case of low certainty, the ISA system takes no action to prevent speeding. The use of the certainty value also allows to deal with loss of the satellite signal and to handle GPS position outliers. The algorithm is designed to provide conservative, user beneficial speed limit selection when the certainty value is low.

Initial tests were performed on individual vehicles while developing the algorithm and fine tuning its parameters. The tweaked parameters are adopted for the road topology of the North Jutland. Starting summer of 2006, the deployment of the "Spar på farten" project began, and we currently have 50 participants. The volume of GPS position data allows thorough statistical evaluation and delivers new insights into the algorithm's performance and the ISA system performance. Performance analyses show that the algorithm performs correctly 95% of time with an average map matching distance of just a bit above 9 meters.

Based on data from the "Spar på farten" project, we have identified areas where the algorithm can be improved. As part of future work, we will continue the analysis of data and map matching quality, and we will adjust the map matching parameters. We also aim to enhance the self-evaluation capability of the algorithm. Currently, no map matching is done when the GPS signal has errors, but in some cases map matching can be improved using odometer speed and traveled distance. Small hardware enhancements like the usage of turn signal information would provide additional knowledge in situations near intersections and highway exits.

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