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MULTI-CRITERIA FUSION FOR THE SELECTION OF ROADS OF AN ACCURATE MAP

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Abstract: To localize a vehicle on a map, a reliable road selection system is essential. For this purpose, the article presents a credibilist multi-criteria association algorithm that performs data association between the infrastructure information (the map) and the noisy measurements of two sensors (DGPS, Odometer). The algorithm takes into account the inaccuracy, the uncertainty and the redundancy of the data. The multi-criteria fusion process is realized using Belief Theory and Dempster-Shafer's rule. A local strategy is developed to allot believes to two criteria. Experimental results show that the credibilist roads around an estimated position are well selected. *Copyright © 2002 IFAC*

Keywords: Multi-Sensor Fusion, Uncertainty Modeling, Belief Theory, Map-Matching, Vehicle Localization.

1. INTRODUCTION

Advanced on-vehicle sensors, such as radar or video cameras, have made great advances in giving a vehicle some local representation of its situation with respect to the road and the other vehicles. However, these sensors are inherently limited by their range. For example, an obstacle detection system may fail because of a sharp bend. Using an accurate digital map with DGPS may be a solution to enable the provision of advance warning to drivers of features that are beyond current visibility.

Any perceptive method, dedicated to a safety application, must provide judicious information in order to take a decision. This perception function is generally realized with a set of homogeneous or heterogeneous sensors. It provides the decision module an image of the physical environment observed. This representation cannot be perfect because it is built with data from inaccurate and uncertain information sources. Moreover, the representation of the environment is perhaps erroneous if the information source is degraded, or if it is subject to harmful external influences. In all these cases, the system has to consider the inaccuracy and the uncertainty of the data and the reliability of the sensors.

Current commercially-available maps have a good coverage for many countries around the world. Their accuracy and details will be improve in the next 5-10 years. Many studies have been carried out in this field as exemplified by Rogers (2000).

In this paper, we anticipate the potential performance of the positioning systems by using a DGPS receiver and a precise map "Géoroute" provided by the French National Institute of Geography (IGN). The relative precision of the IGN data-base is better than 5 meters and that of the DGPS is close to one meter (with more than 5 satellites in view and in an optimal configuration). Moreover, we use the ABS sensors to help the DGPS receiver when the satellite constellation is unfavorable (Bonnifait, et al., 2001).

The goal of this research is to develop a robust method to localize the vehicle. We focus on the selection of the roads also called Road Reduction Filter (Taylor, et al., 2000) by using a data fusion technique based on Belief Theory and a fuzzy information representation. To carry out this fusion process, many architectures are possible: centralized (global processing), decentralized (local processing), open-loop or closed-loop (i.e. the history of the trajectory of the vehicle is used or not). Usually, the choice of one architecture rather than another depends on precision, sensitivity to measurements degradation, computing complexity and load of communication. We propose a decentralized and an open-loop architecture because it is a good response to the constraints of information conservation and reliable fusion. In Fig. 1, x and y correspond to the position co-ordinates, θ is the heading of the vehicle, P_{xy} is the co-variance matrix and S_i is the *i*th segment of a linear.

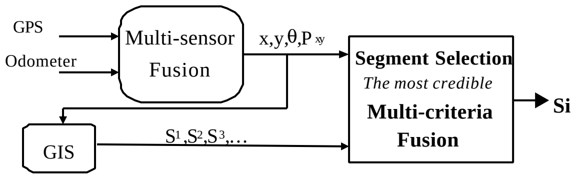


Fig. 1. Architecture of the selection process.

In order to speed up the treatments (a map contains thousands of roads), we apply a filter which selects the road segments that are located within a radius of 100 meters. The center of the circle is the estimate of the current position (x, y).

The paper is organized as follows. Section 2 is dedicated to the presentation of Belief Theory. In the third part, two criteria are developed and the decision rule is presented. The fourth section presents experimental results obtained with an experimental car.

2. BELIEF THEORY

Theory of evidence is a mathematical theory which allows one to reason with uncertainty and which suggests a way for combining uncertain data. This is the reason why it used as a basic tool for multi-sensor data fusion in situation assessment process.

This theory was introduced by Dempster (1968,1976) at the end of the ninteen and was mathematically formalized by Shafer in 1976 (Shafer, 1976). It is the generalization of the Bayes Theory in the treatment of the notion of uncertainty. It allows to take into account the uncertainty of partial knowledge. Generally, this theory is used in a multisensor context to fuse heterogeneous information in order to obtain the best decision.

The basic entity, in Dempster-Shafer Theory, is a set of all possible answers (also called hypotheses) to a specific question. This set is called the *frame of discernment* and is denoted *Q*. All the hypotheses must be exclusive and exhaustive and, each subset of the frame of discernment can be a possible answer to the question. The degree of belief of each hypothesis is represented by a real number in [0,1]. A mass function *m(.)* is also defined. It satisfies the following rules:

$$m(f) = 0 \qquad \sum_{A \subseteq \Theta} m(A) = 1 \quad (1)$$

A mass function is defined for all the different evidences. Each evidence *A*, for which *m(A) ¹ 0*, is called a focal element.

Associated with each basic assignment *m*, the belief (*Bel*) and the plausibility (*Pl*) are defined by:

$$Bel(A) = \sum_{B \subseteq A} m(B) \qquad Pl(A) = \sum_{B \cap A \neq f} m(B) \quad (2)$$

The belief and plausibility are interrelated by the relationship:

$$Pl(A) = 1 - Bel(\overline{A}) \quad (3)$$

where $\overline{A}$ denotes the complement of *A*.

To obtain a better information from two different single sources S1 and S2, a combination of their mass function is performed according to the Demspter-Shafer rule:

$$m_\Theta(A) = \sum_{A_i \cap B_j = A} m_\Theta^{S_1}(A_i).m_\Theta^{S_2}(B_j) \quad (4)$$

If there are some conjunctions that are empty of focal elements, a step of re-normalization is necessary to fulfil the rule m(*f*)=0. The coefficient of re-normalization is called k_q and is defined as:

$$k_q = \sum_{A_i \cap B_j = f} m_\Theta^{S_1}(A_i)m_\Theta^{S_2}(B_j) \quad (5)$$

It represents the incoherence between the different sources. If we set $K_q = \frac{1}{1-K_q}$, we obtain the following normalized expression of the combination:

$$m_\Theta(A) = k_q \cdot \sum_{A_i \cap B_j = A} m_\Theta^{S_1}(A_i).m_\Theta^{S_2}(B_j) \quad (6)$$

This combination rule is independent to the order in which evidences are combined when more than two evidences are involved.

After the combination step, several decision rules can be used to obtain the final result. It is then possible to adjust the wanted behavior for the decision step. If one wants to have an optimistic decision, the maximum of plausibility must be used and for a pessimistic decision one can use the maximum of belief. Many other decision rules exist in the Belief theory, especially for non-exhaustive frames of discernment. More information about them can be found in (Fabiani, 1996).

3. ROAD SELECTION USING MULTI-CRITERIA FUSION

Map matching techniques vary from those using simple point data, integrated with optical gyro and velocity sensors (Kim, 1996), to those using more complex mathematical techniques such as Kalman filters (Tanaka, et al., 1990; Betaille and Bonnifait, 2000). Systems that use only an geometric information utilize the "shape" of line segments (road center-lines) that define the road network (Bernstein, et al., 1998).

The first step is to determine which road center-lines are candidates for the location of the vehicle. The shortest Euclidean distance from the estimated position to each road segment is computed. It is not simply a matter of finding the line segment nearest to the estimated position. This will often give an incorrect result.

The method proposed in this paper fuses several criteria using Belief Theory for the road selection process. As the application is related to road safety, only geometrical criteria are used because they are not influenced by human errors. This means, for example, that a criterion such as *the speed of the vehicle is in agreement with the speed limitation* is not considered.

The two criteria presented in this article can be formulated as follows:

1-the vehicle location is close to a segment of the neighborhood,

2-segments on which the vehicle can be located are those which have an angle close to the heading of the vehicle

The Belief Theory needs the affectation of elementary probabilistic masses defined on [0,1]. The mass notion is very near to the probabilistic mass notion, exception that it is not shared only on single hypotheses but it is possible to attribute a mass for an union of hypotheses: this is the main difference with Bayesian theory.

The frame of discernment $\Theta=\{H_1,\ H_2,\ \ldots,H_n\}$ is composed of exclusive and exhaustive hypotheses $H_i \cap H_j = \emptyset,\ \forall i \neq j$ (the solution of the problem $H_i \in \Theta$).

The mass assignment is computed on the definition referential 2^{Θ}.

$2^{\Theta}=\{\emptyset,H_1,H_2,\ldots H_n,H_i \cup H_2,\ldots,H_i \cup H_j \cup H_k \cup H_l \cup \ldots H_m,\ldots,\Theta\}$.

This distribution is a function of the knowledge about the source to model. The whole mass obtained is called "basic mass assignment". The sum of these masses is equal to 1. Each expert (or each source of information) defines a mass assignment according to its opinion about the situation.

The frame of discernment that we use is Θ = {*Yes*, *No*, *Perhaps*} corresponding to the answer of the following question: *is this segment the good one?*

To build functions of mass assignment corresponding to Θ, we propose to consider the inaccuracy of the various information sources (DGPS, Odometer and Geographical Information System - GIS) and physical observations (for example, a car with a 40 m/s speed cannot be orthogonal to the direction of the segment). With this approach, information sources are criteria worked out from sensors.

The problem of mass assignment of each criterion can be tackled in a global or local way. The global strategy consists to consider together all the segments selected around an estimated position when affecting the masses. The local strategy separately treats each segment with respect to the criterion considered.

3.1. Proximity criterion

The proximity criterion is based primarily on the measurement of the Euclidean distance between the estimated position and each segment taken in the road data base.

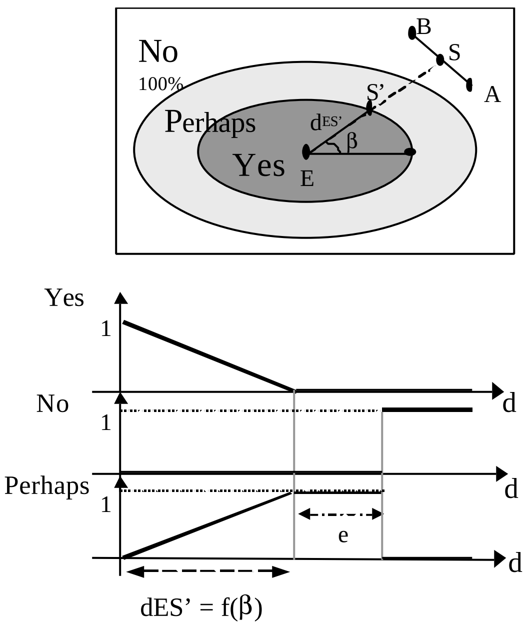


Fig. 2. Mass assignment of the proximity criterion.

The estimated error of the position is quantified by an ellipse of 99% equi-probability produced by the DGPS receiver (drawn in dark gray Fig. 2). The estimated position E is at the center of the ellipse.

To allot a mass to a candidate segment [AB], we proceed in the following way. Let us note d the distance between the segment and the point E:

$$d = \left\| \overline{SE} \right\| = d_{ES} .$$

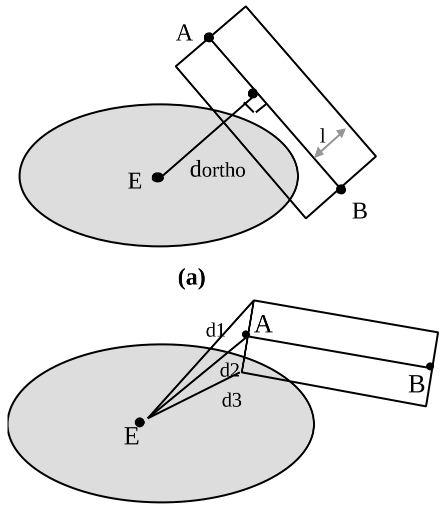
The point S' falls at the intersection between the segment [ES] and the ellipse (Fig. 2). The distance $d_{ES'}$ depends on the angle β which forms the segment [ES'] in the ellipse co-ordinates system. In the zone $d < d_{ES'}$, with a fuzzy modeling obtained by transformation probability-possibility (Dubois and Prade, 1993; Lassere, 1997; Zadeh, 1986), the degree of membership is quantified using the ellipse.

The first curve presented in Fig. 2 assigns a mass to the assumption *Yes*. In complementing the mass of *Yes*, the mass of the assumption *Perhaps* is allotted. Then, the mass of *Perhaps* remains constant for $d_{ES'} < d < d_{ES'}+e$, in order to consider the projection error and the errors of the co-ordinates segments in the data-base (these errors are denoted e).

Finally, the mass of assumption *No*, is a step function starting from the distance $d = d_{ES'} + e$.

Therefore, the mass assignment of the proximity criterion depends on two variables:

- the distance d between the center of the ellipse and the segment.
- the angle β between the distance support and the major axis of the ellipse.



(b)

Fig. 3. Computation of the distance *d* with the road-box.

The problem becomes more complicated when considering the width of the road. We propose to model the road by a box centered on the segment, the length of which is equal to the one of the segment. The exact influence of the width of the road *l* is difficult to take into account in the computations of the criterion because *l* modifies the values of *b* and *d*. To simplify, we have chosen the following strategy:

1) The orthogonal projection of *E* exists inside the [*AB*] segment. In this case, *d* = *dortho–l* (Fig. 3a).

2) The orthogonal projection of *E* does not exist inside the [*AB*] segment. In this case, *d* = *min(d1,d2,d3)* (Fig. 3b).

3.2. Angular and velocity criterion

In this section, a mass assignment function is proposed to express the fact that the possible segments are those that have an angle close to the heading of the vehicle. Figure 4 represents the computation of *DHeading*:

$$DHeading = min(|a-q|\,,\,|a-q+p|) \quad \text{with } q \in [0,\pi]$$

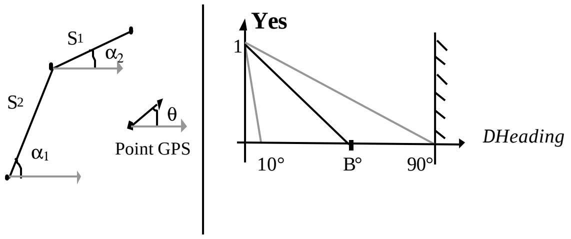


Fig. 4. Mass assignment of *Yes* for the angular and velocity criterion

Figure 4 also presents the fuzzy modeling of the absolute value of the difference between the heading of the vehicle and the heading of the candidate segment. This curve is an adaptive one according to the speed of the vehicle. B represents the angular limit tolerated at a given velocity:

$$B(V) = 90°\text{-k.}V \quad \text{with k} = (90\text{-}10)/V\text{max}$$

DHeading < B, The *Perhaps* mass assignment is done by computing the complement of the mass of *Yes*. The mass of *No* starts from the limit angle tolerated for a given speed (B) and it reaches 1 when the anglei s equal to 90° (Fig. 6).

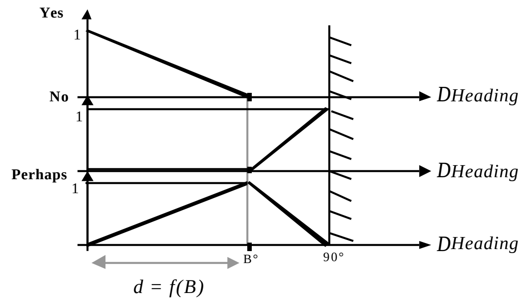


Fig. 5. Mass assignment for the angular and velocity criterion.

3.3. Decision rule

In the decision-making, the strategy adopted to keep segments among the candidates, is to keep the most credible segments according the law of *ideal* decision.

In fact, contrary to the probability theory, the likelihood of singleton assumption is characterized by two quantities: credibility and plausibility which are calculated using the set of masses. These quantities respectively correspond to the minimal probability and the maximum probability of that assumption to be true. Consequently, a decision without ambiguity is obtained when an assumption have a credibility higher than the plausibility of any other assumption (Zadeh 1986).

The Dempster-Shafer fusion rule introduces a conflict parameter. This parameter is large if the two criteria are in total confusion. Therefore, we eliminate the segments which present an important conflict. Experimentally, we have taken a threshold equal to 0,4.

4. EXPERIMENTAL RESULTS

The algorithm works in real time conditions at 1 Hz frequency under WIN NT (Pentium III 700 MHz). The DGPS receiver used was a Trimble AgGPS132.

Fig. 7. Experimental situation on the “IGN Géoroute” map (The DGPS points are dotted).

The following figures present the treatments of several segments around a DGPS point at a precise moment (the speed of the vehicle is 60 km/h).

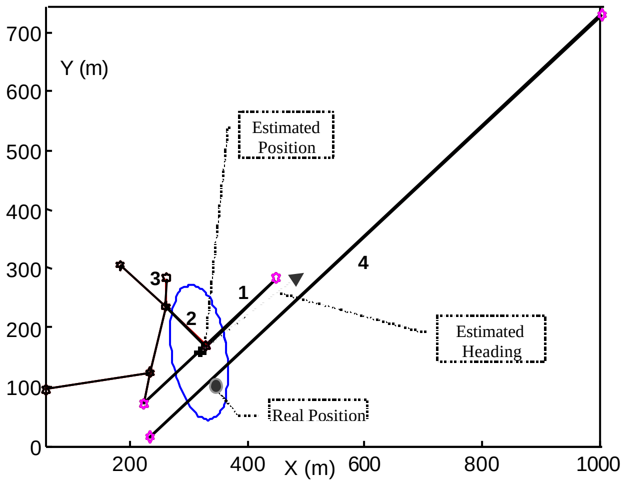


Fig. 8. DGPS point, 99% error ellipse and candidates segments at a given moment.

This situation is very ambiguous because two near segments have their heading close to the heading of the car (n°1 and 4) and because the segment n°2 is very close to the center of the ellipse. As opposed to what one can conclude in regarding Fig. 8, the road on which the vehicle was located corresponds to the segment n°4 (and not to the segment n°1). To illustrate the method, let us consider one by one the segments (1,2,3,4).

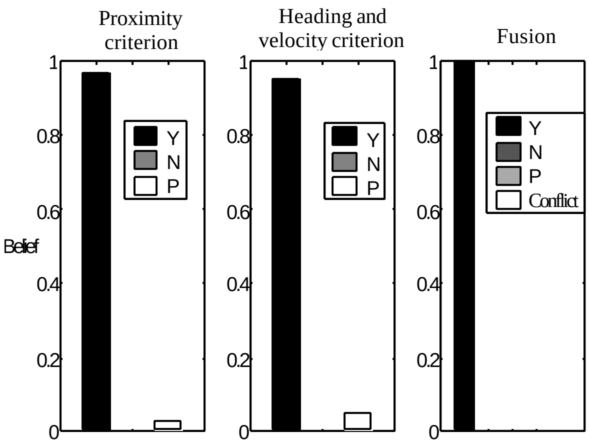


Fig. 9. Fusion of the two criteria for the segment n°1.

On Fig. 9, segment n°1 is fully credible: the two criteria have little doubt and fusion confirms this belief. Moreover, there is no conflict.

The angular criterion estimates that the segment n°2 is not a good candidate (Fig. 10). On the other hand, this segment has an extremity close to DGPS point: the proximity criterion estimates that is a very good candidate. The fusion produces a mass of conflict higher than 0.4. The two criteria are in total disagreement; segment 2 is noncredible. When the conflict is significant, the confidence given to the masses for *Yes*, *No* and *Perhaps* assumptions must be weak because of the normalization operator of Dempster-Shafer.

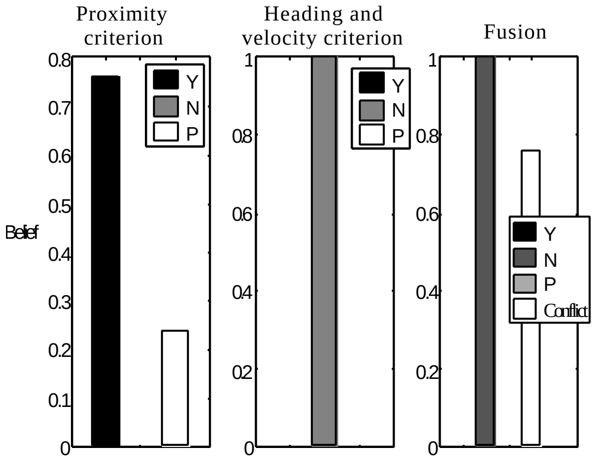


Fig. 10. Fusion of the two criteria for the segment n°2.

On Fig. 11, segment n°3 is not in the error ellipse, but the mass of *Perhaps* according to the criterion of proximity equals one because the width of the road was taken into account (by modeling roads by a boxes). The segment is not completely perpendicular to the road so the heading criterion produces an important mass for *Perhaps*. The fusion produces the same result as the angular criterion, the criterion of proximity behaving here like a neutral element. The credibility of *Yes* is not ideal and thus the segment is not credible.

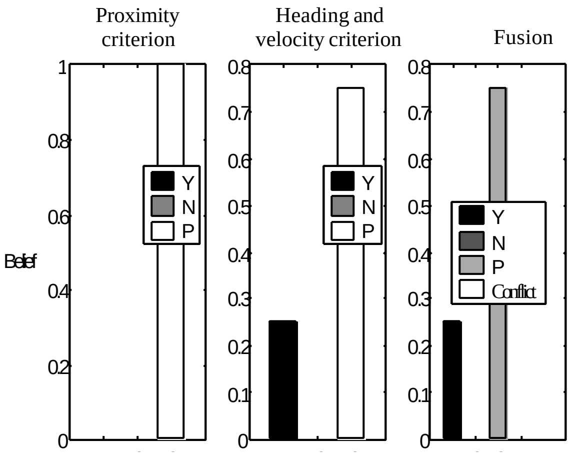


Fig. 11. Fusion of the two criteria for the segment n°3.

The segment n°4 of Fig 12 which corresponds to the real position is quite credible (even if it is less credible than the segment n°1).

In conclusion, two segments are credible: the situation is ambiguous and the system is not able to decide.

Finally, Fig 13 presents the results of the algorithm applied to sixty DGPS points. One can notice that the selection process detects correctly the ambiguous situations, mainly due to parallel roads.

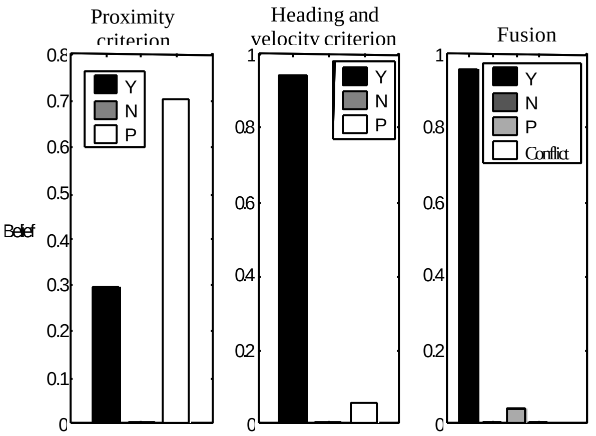


Fig. 12. Fusion of the two criteria for the segment n°4.

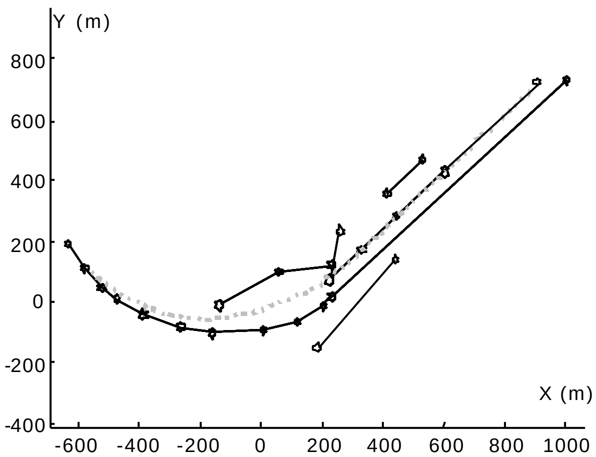


Fig. 13. Experimental Vehicle trajectory in doted and all the credible segments founded around the trajectory.

5. CONCLUSION

These experimental results show the aptitude of a multi-criterion fusion technique according to Belief Theory to treat ambiguous situations frequently met by localization systems which use maps. Moreover, it can detect situations where there's no credible segment, which means that the position of the vehicle does not correspond to any road on the map.

This methodology can be considered like an excellent tool to improve the positioning reliability and it makes possible to quantify the ambiguousness of a situation.

In addition, other commonly used location technologies, like stand-alone or radio-based (Y. Zhao 2000), can also use this kind of method with adapted criteria.

Finally, future work will be dedicated to develop other criteria, using for example, the local shape of the vehicle trajectory.

REFERENCES

Bernstein, D and A. Kornhauser (1998). Map Matching for personal navigation assistants. 77th Annual meeting, The Transport Research Board, Jan 11-15, Washinton D.C.

Bétaille, D. and Ph.Bonnifait (2000). Road Maintenance Vehicles Location using DGPS, Map-Matching and Dead-Reckoning: Experimental Results of a Smoothed EKF. IAIN World Congress in association with the US ION annual meeting. San Diego, pp. 409-416, June 26-28.

Bonnifait, Ph., P. Bouron, P. Crubille and D. Meizel (2001). Data Fusion of Four ABS Sensors and GPS for an Enhanced Localization of Car-like Vehicles. IEEE ICRA 2001 23-25, Séoul. pp. 1597-1602.

Dempster A.P. (1976). Upper and Lower Probabilities Induced by a Multivalued Mapping. Annals of Mathematical Statistics, vol.38.

Dempster, A.P. (1968). A Generalization of Bayesian Inference. Journal of the Royal Statistical Society, vol.30, Série B.

Dubois, D. and H. Prade (1993). Fuzzy Sets and System Theory and Application. Mathematics in science and engineering volume 144 Academic Press, Inc.

Fabiani, P. (1996). Représentation Dynamique de l'Incertain et Stratégie de Prise d'Information pour un Système Autonome en Environnement Evolutif. PhD. Thesis Ecole Nationale Supérieure de l'Aéronautique et de l'Espace.

Kim, J.S., J.H. Lee, T.H. Kang, W.Y. Lee and Kim, Y.G.,(1996). Node based map matching algorithm for car navigation system. Proceedings of the 29th ISATA Symposium, Florence, Vol. 10,pp121-126.

Lasserre, V., G. Mauris and L. Foulloy (1997). A simple probability-possibility transformation for measurement error representation: a truncated triangular transformation. Proc. of IFSA'97, Prague, Vol. 3, pp. 476-481.

Rogers, S. (2000). Creating and Evaluating Highly Accurate Maps with Probes Vehicles. IEEE Intelligent Transportation Systems, Dearborn (MI), USA.

Shafer, G. (1976) A. Mathematical Theory Of Evidence. Princeton University Press, Princeton.

Tanaka, J., K. Hirano, T. itoh, H. Nobuta and S. Tsunoda (1990). Navigation System with Map-Matching Method. Proceedings of the SAE International Congress and Exposition, pp 45-50.

Taylor, G. and G. Blewitt (2000). Road Reduction Filtering Using GPS, 3th AGILE Conference on Geographic Information Science – Helsinki, Finland, May 25-27, 2000.

Zadeh, L.A. (1986). A Simple View of Dempster-Shafer Theory of Evidence and its Implication for the Rule of Combination. The AI Magazine.

Zhao, Y. (2000). Mobile Phone Location Determination and Its Impact on Intelligent Transportation Systems. IEEE Transaction on Intelligent Transportation Systems vol. 1, No. 1, pp. 55-64.