ROAD VEHICLE POSITIONING AT THE LANE LEVEL BASED ON GNSS INTEGRATION WITH ENHANCED MAPS

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ABSTRACT

The determination of the vehicle position at the lane level is an important challenge in road navigation that can bring new possibilities for collision avoidance or advanced driver assistance systems. An interesting approach of this problem is the combination of GNSS with enhanced maps that include precise lane information. This paper presents a novel method for map-matching and positioning at the lane level based on the integration of GNSS and dead-reckoning measurements with a novel highly accurate road description. Experimental results in complex scenarios with multiple lanes show the suitability of the proposed method.

KEYWORDS vehicle positioning, map-matching, enhanced maps, GNSS

INTRODUCTION

The CVIS (Cooperative Vehicle Infrastructure Systems) integrated project of the 6th framework program aims at the creation of a unified technical solution that allows vehicles and infrastructural elements of the road to cooperate by exchanging information uninterruptedly in a transparent way by means of different communication links and enhanced localisation systems [1]. The investigations presented in this paper were realized within the frame of the CVIS project and particularly, the subproject POMA (POsitioning and MApping). This subproject is dedicated to research, development, test and validation of advanced solutions to the problems of positioning and mapping of road vehicles. The localization information provided by the POMA positioning and mapping solutions will be available for a set of Location Based Services not only onboard the vehicle, but also for the infrastructure. More precisely, this paper deals with the localization and mapping of vehicles at the lane level, one of the current big challenges regarding positioning for transportation systems. This possibility opens a new panel of Advanced Driver Assistance Systems, for instance "Enhanced Driver Awareness" warning the driver of any danger or obstacle that can be potentially found on the trajectory, or new services called "Lane utilization information", "In-vehicle variable speed limit information" or "Intelligent speed alert with links to infrastructure". The solution proposed to the problem under consideration focuses on two main aspects:

- An enhanced map (Emap) with accurate lane level information and valuable for a map-matching algorithm at this level.

- A positioning algorithm capable to benefit from the precise Emap information.

In this article we present the feasibility of a new Map Aided Localization (MAL) that extends the original concept to Emap (EMAL). With this concept, both ego-positioning of the vehicle and map-matching are achieved together in a unique process. Due to its accuracy and its completeness, the Emap offers a priori information of great interest with regard to the on-board sensors fusion algorithm, in the core of which it will be considered as a constraint. Additionally, a multiple hypotheses Emap tracking will be performed, using particle filter: here, this filtering strategy appears all the more interesting since the map itself contains many more alternatives than standard maps.

The core of the paper is organized as follows: Firstly, the Emap contents and its creation process are summarized. The proposed data fusion algorithm that employs GPS/EGNOS, dead-reckoning and Emap observations is then briefly explained. Finally, selected results achieved in our experiments and the conclusions obtained from them are discussed.

ELABORATION OF AN ENHANCED MAP

The concept of Emap was introduced with one main objective: it should characterize roads, first, with more completeness, and second, with more accuracy. Emap should represent every road lane, with an accuracy of less than half a meter and a continuous geometric description made of clothoids, which makes it possible exact interpolation, whereas current database supply road description limited to one polyline per separated carriageway, with an inaccuracy up to several meters. The Emap construction process that has been experienced by the LCPC is based on mobile mapping. GPS solutions, computed in post-process kinematic mode with dual-frequency, are combined with inertial measurements or dead-reckoning (odometer plus gyroscope), which enable continuous trajectory determination. Once this is done, series of clothoids are extracted by a dedicated Kalman filtering process. This geometrical construction is controlled manually at junctions, so that every lane is represented, and no lane is represented twice. Finally, a second algorithm is operated with the aim of computing the topological relations between clothoids. The last version of our application creates a list of neighbours for every clothoid, indicating whether these neighbours are situated in front, left or right hand respect to the current clothoid. This information will fasten further the map-matching process run in real-time.

Figure 1 includes a plot of the Berlin Emap provided by the LCPC for CVIS POMA tests campaign. Figure 2 shows in detail one area of interest where two junctions are visible. Crossroads, as one sees, are not represented in the Emap, neither roundabouts. In the current version of the application, they are considered as open spaces for vehicles, with a priori no lane description.

For a comprehensive description of the process of Emap creation, the readers are welcome to visit [2].

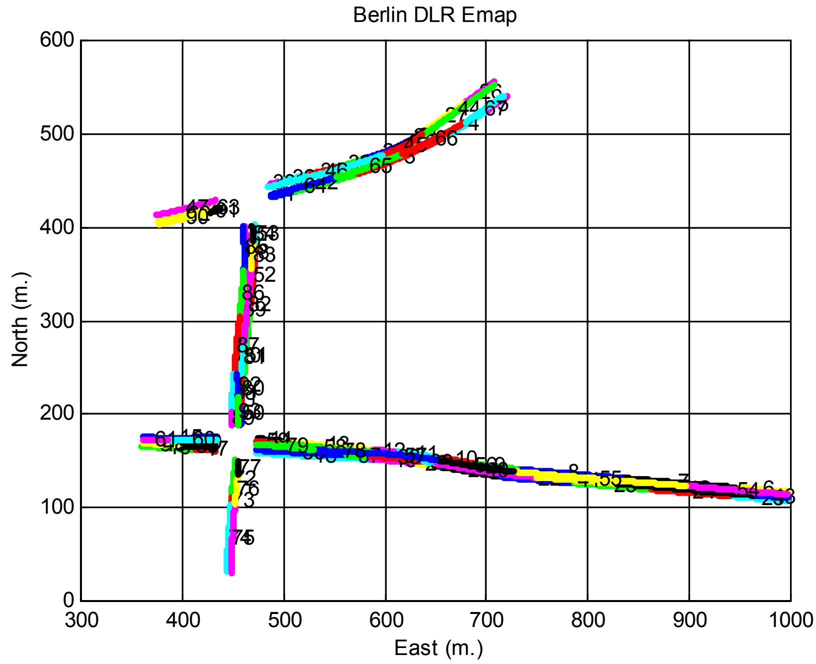

Figure 1 – Emap in Berlin. Segments are identified with different colours and numbers.

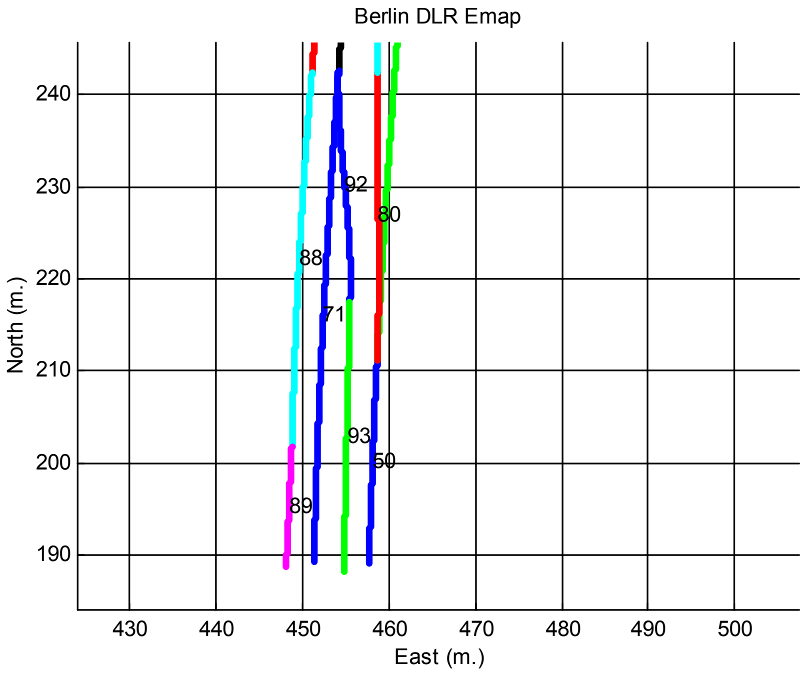

Figure 2 – Detail of the Emap in Berlin. Segments contain information about the topology of the carriageway. At the points where the topology changes, new segments are created to describe the lanes and their relations.

LANE LEVEL POSITIONING BASED ON EMAP

The most usual process to represent the position of road vehicles in a local reference consists in the estimation of the vehicle positioning by fusing GNSS (Global Navigation Satellite

System) and some other aiding sensors data, and the subsequent projection of these values on the map by applying map-matching techniques. However, it is possible to benefit from map information also during the process of fusing data for positioning. Our proposal for lane level positioning is based on a dual representation of the vehicle position that is related to two reference frames:

- A traditional navigation frame, the variables of which are northing, easting, heading.
- A lane segment oriented frame which defines the position of the vehicle as the minimum distance (*d*) from the vehicle position to the centreline of the segment to which it is associated (*m*), and its abscissa in the segment frame *l* (that can be calculated as the distance to the beginning of the current segment by following its centreline).

This redundant representation brings several benefits, at the expense of a more complex algorithm. In our approach, the innovative fusion process we have developed, based upon particle filtering, is capable to deal with dead-reckoning inputs, GNSS and Emap observations in both references at the same time, while guaranteeing the coherence of the solution.

Figure 3 shows the concept of our dual representation.

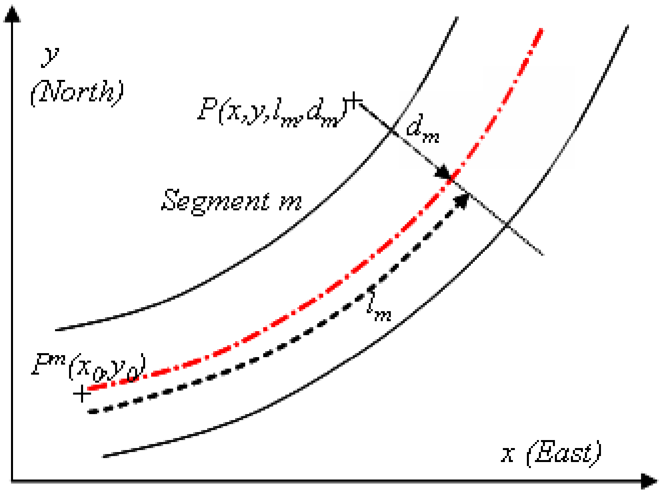

Figure 3 – Dual representation of the vehicle position in East, North and in the segment reference.

Relation between Frenet/Cartesian reference systems

The filter is implemented by means of the well-known particle filter. For further information about this filter the readers can read [3].

Taking into account the proposed particle filter based implementation, the notation of state vector for a particle *i* at instant *k,* and allocated to a segment *m* will be given by

$$X_k^i = [x_k^i, y_k^i, \varphi_k^i, l_k^{m,i}, d_k^{m,i}, m_k^i] \qquad (1)$$

These state variables (see Figure 2) represent what follows:

- $X_k^i = [x_k^i, y_k^i, \varphi_k^i]$ stands for the Cartesian part of the state vector, representing East, North and heading angle respectively at the middle point of the rear wheels axle of the vehicle in the navigation frame.
- $X_k^i = [l_k^{m,i}, d_k^{m,i}, m_k^i]$ stands for the Frenet part that represents the values of abscissas and ordinates referred to the lane segment *m*.

It is possible to relate both Frenet and Cartesian representations of the same point by means of next expressions:

$$
\begin{aligned}
x &= x_0^m + \int_0^{l,m} \cos(\tau(l^m))dl - d^m \sin(\tau(l^m)) \\
y &= y_0^m + \int_0^{l,m} \sin(\tau(l^m))dl + d^m \cos(\tau(l^m))
\end{aligned} \tag{2}
$$

where:

- x_0^m, y_0^m are the East and North coordinates of the initial point of the road segment,
- $\tau(l^m)$ is the azimuth angle of the segment at abscissas l^m, given by

$$\tau^m(l^m) = \tau_0^m + \kappa_0^m l^m + \frac{c^m \cdot (l^m)^2}{2} \tag{3}$$

being $\tau_0^m, \kappa_0^m, c^m$ shape parameters of the clothoid definition of segment *m*, and representing initial heading, initial curvature, and linear curvature rate respectively. These are the parameters that define the clothoid description of the road shape (see Figure 3).

For a more detailed explanation of each filtering step, the readers are welcome to check [4].

EXPERIMENTAL RESULTS

Main objectives of the experiments carried out are:

- Validation of the proposed map model based on sets of interconnected clothoids to describe precisely the horizontal alignment of the road at lane level.
- Analysis of the EGNOS capabilities as the plausible GNSS data source for lane level based services, taking into account aspects such as its accuracy, coverage, and integrity.
- Evaluation of the proposed GNSS/DR/Emap data fusion filter with real data sets in a complex scenario with multiple lane roads.
- Determination of the capabilities of the particle filter as the data fusion technique for fusing GNSS/DR/Emap, taking into account computational aspects.
- A comparison between integrated GNSS/DR and GNSS/DR/Emap based solutions to the problem of lane level positioning of a road vehicle.

For these purposes different campaigns were carried out in the area of Nantes, France, near the facilities of the LCPC center, and in Berlin, Germany, near the Adlershof DLR test site.

Due to space limitations, only few aspects are analyzed here. The authors encourage the readers interested in further details on the algorithm results to contact them.

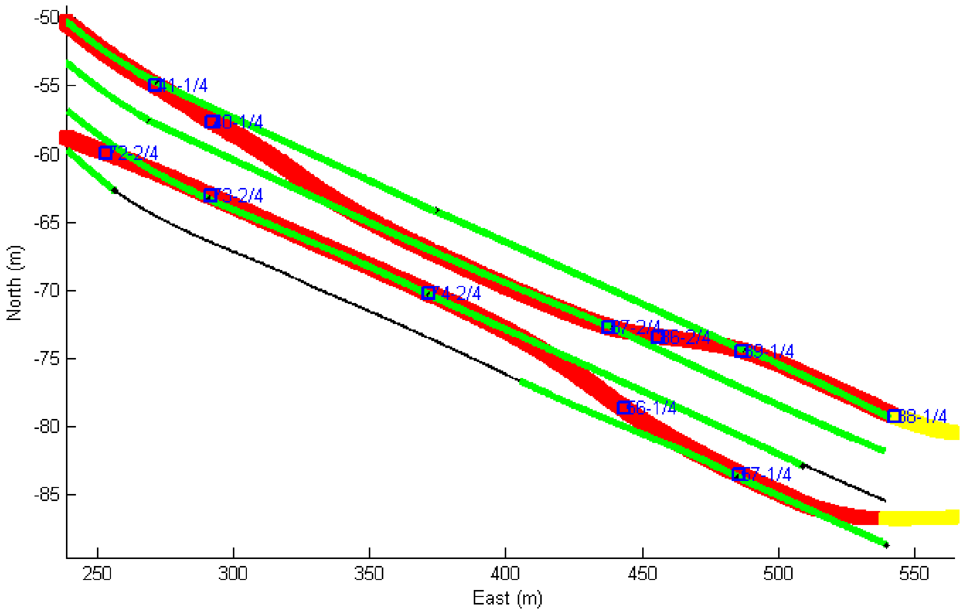

Figure 4 – Results of the combined GNSS/DR/Emap algorithm. Solid black: map representation of the road. Solid green: segment to which the vehicle is assigned in the map-matching process (end of segment is noted with a black dot). Red (resp. yellow) square: filter position output within (resp. out of) the Emap bounds. Blue square: positions where the vehicle changes lane as provided by the algorithm. Next to every blue square, the identifier of the new lane and its relative lateral position in the carriageway are shown.

Figure 4 shows some results of interest obtained in a test campaign carried out in Germany. During this stretch the vehicle left and joined again the Emap area (right side of the image), and performed several lane changes. A segment change is identified with a blue square at the position where lane allocation changes, i.e. first position when the probability of being assigned to a new segment is higher than the probability of being assigned to the previous one. This situation corresponds to lateral lane changes, but also to a longitudinal move in which the vehicle leaves its previous segment and joins the next one.
In the road stretch under consideration, two lanes are dedicated to one direction, and the other two to the other direction, although all the vehicles are allowed to use the four lanes of the road for overtaking. This is noted by the number 4 in the expressions ID - x/4, in blue in the image of Figure 4. The rest of fields represent:

- first number, the segment identification, unique for the whole Emap,
- second one, the lateral position of this segment referred to the carriageway, starting from the segment on the right.

This information can be used by services and applications oriented to lane in order to determine the relative allocation of the vehicle on the road. Last version of the algorithm under consideration includes the provision of integrity parameters that represent the confidence on the lane allocation and the vehicle position.

CONCLUSIONS

For the purpose of lane level positioning and matching, the use of enhanced road maps is proposed for specific areas. A combined positioning and matching algorithm that integrates the road shape information contained in the Emap with dead-reckoning and GNSS data (the latter when available) has been proposed. Results in real scenarios proved its capability to provide vehicle map-matched positions at the lane level, bringing new capabilities by which lane level services and applications can benefit.

ACKNOWLEDGEMENTS

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