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Offset Eliminative Map Matching Algorithm for Intersection Active Safety Applications

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Abstract

Digital map information and Continuous Positioning Systems (CPS) are being increasingly used in active safety applications. However due to imprecision associated with digital road maps and inevitable inaccuracies in CPS positions, a map matching algorithm is essential for these applications.
One field of active safety in which navigation information can be used is Intersection Active Safety Applications (IASA) which requires a precise position of vehicle relative to road network in an intersection. In this paper a novel map matching algorithm for an IASA is presented.
To determine the vehicle trajectory relative to the road network, the proposed map matching algorithm calculates the general offset between digital road map and the CPS given vehicle trajectory by fusion of local offsets with a Kalman filter, incorporating their respective uncertainties. The created offset eliminative map matching algorithm was tested on a complex urban trajectory and showed very encouraging results.

1. Introduction

Digital road maps are used in land navigation systems as an additional sensor which utilize the restriction of land vehicles to the road network and provide information about the vehicle's position relative to the road network. However, there is also imprecision with digital road maps due to road curvature approximation with piece-wise linear segments, single line modeling of multi lane roads, lack of information about intersections geometry, etc. Moreover, even with very good sensor calibration and data fusion algorithms, inaccuracies are often inevitable in CPS given positions. Hence, positioning results do not always match onto the digital road map. Therefore, map matching algorithms are usually used to match the positioning results with digital road map to determine the location of a vehicle with respect to the road network.

Map Matching (MM) algorithms vary from simple point-by-point matching to shape matching and from position-only matching to position and velocity mapping. Ochieng et al. (2003) and Basnayake et al (2003) have discussed some of these algorithms. In all of these map matching algorithms, the given vehicle position by CPS is matched on the road's centerline, in other words the given vehicle trajectory by these map matching methods follows the roads' centerline pattern and vehicle maneuvers on the road such as lane changing and turning in an intersection can not be presented. For example vehicle turning in an intersection will be presented by an in place turning on the node where centerlines of intersected roads meet.

However in an Intersection Active Safety Application (IASA), vehicle's trajectory nearby an intersection is of great importance. Therefore in the proposed map matching algorithm in this paper, the vehicle trajectory pattern is kept as estimated by CPS and only the offset between CPS estimated trajectory and digital road map is eliminated.

Another important factor in an IASA is accuracy of estimated distance to upcoming intersection. Large errors in estimation of distance to upcoming intersection can cause incorrect application of intersection countermeasure logic, which are invoked when the vehicle is within a certain distance to upcoming intersection.

The proposed map matching algorithm enabled laser radar application and driver behavior study in intersections which require an accuracy of 2 meters in estimation of vehicle distance to upcoming intersection. This accuracy was achieved by the implementation of the proposed map matching algorithm on the given trajectory by the CPS system developed by the authors [1].

2. Proposed Map Matching Algorithm

In this section the proposed map matching algorithm is presented.

2.1. Algorithm Inputs

The inputs of the proposed map matching algorithm are the digital map information and the locational data given by a CPS, including position, heading and associated uncertainties. The utilized information from digital map includes road centerline, directions of travel on each road (two ways/one way) and speed limit from which the road width was estimated.

The Continuous Positioning System employed an Extended Kalman Filter, developed by the authors, to fuse data from GPS receiver, fiber optic gyro, accelerometers and wheel odometer. For more information regarding the sensor fusion algorithm refer to [1].

2.2. Test Trajectory

To compare the CPS results with the digital map, a test was conducted in Alingsås, Sweden. Figure 1 shows the full test trajectory which was close to 2 km long and included 14 turns in intersections. A comparison between the estimated vehicle trajectory by CPS and the digital road map, shown in Figure 2, indicates a general offset between them. The proposed MM algorithm estimates this offset to determine the vehicle location relative to the road network. This offset, referred to as Common Offset in this paper, is calculated as explained in the following section.

Figure 1. Test Trajectory, Alingsås, Sweden

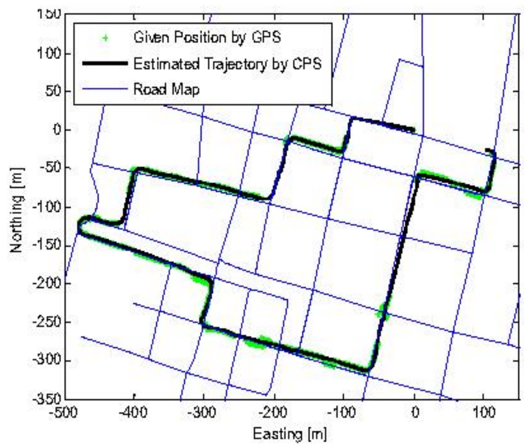

Figure 2. CPS estimated trajectory and digital roadmap

2.3. Offset Eliminative Algorithm

Offset between CPS positions and traveling road can be both in lateral and longitudinal direction. Lateral offset can be simply estimated as the minimum lateral displacement which should be applied on a given position to shift it within the road width and on the correct side of the road centerline. Longitudinal offset can not be estimated as easily as lateral offset, however knowing the longitudinal offset is of great importance in an IASA and can

lead to elimination of error in calculated distance to upcoming intersection.
When a vehicle turns, the lateral offset between vehicle position and its respective point on the traveling road will become a longitudinal offset. Considering this fact, in the proposed MM algorithm, common offset is calculated by addition of local offsets as explained in the following example.

Assume that the ABC trajectory in Figure 3 is given by CPS. With a simple comparison between this trajectory and road map, it can be inferred that the real trajectory should be EFG.

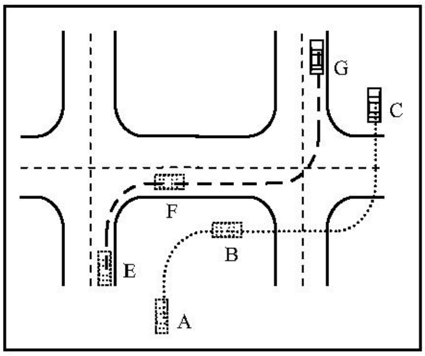

Figure 3. Typical CPS trajectory (ABC), road map and real trajectory (EFG)

A map matching which only removes lateral offsets will result in the trajectory HIJKJL shown in Figure 4. As it can be seen, this estimated trajectory has a longitudinal error equal to JK (=HA); so while the vehicle is in second intersection, the positioning system assumes that intersection has been passed and IASA will not take any actions.

On the contrary, the proposed offset eliminative MM will succeed in matching the BC trajectory in second intersection, to OP (see Figure 5), by utilizing calculated common offset in first intersection. This process can be summarized to the following steps: When the algorithm starts point A is matched to point M and $\vec{AM}$ is saved as common offset. So the AB trajectory is matched to MN. But in point N, the second lateral offset, $\vec{NO}$, is added to common offset, so point B is matched to point O and common offset becomes $\vec{AM} + \vec{NO}$ which is equal to $\vec{CP}$ offset at point C.

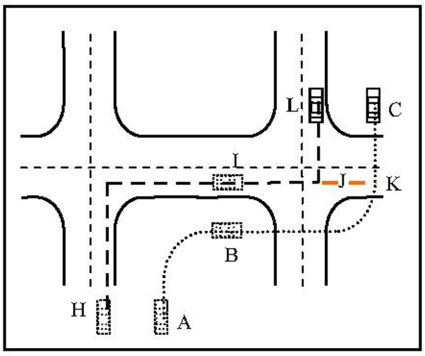

Figure 4. Typical CPS trajectory (ABC),road map and lateral offset removal MM solution trajectory (HIJKJL)

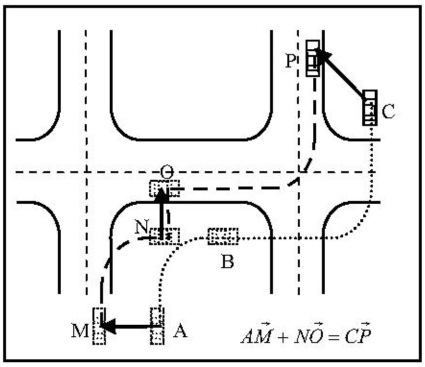

Figure 5. Typical CPS trajectory (ABC),road map and offset eliminative MM solution trajectory (MNOP)

In the algorithm local offsets are calculated when the vehicle is not turning and is in a straight section of a road. The offset eliminative algorithm was improved by incorporating the uncertainties in given positions by CPS in the addition process of lateral offsets. In other words, the lateral offsets were not directly added and in order to fuse them in an optimal manner a Kalman filter was established. In the established Kalman filter, common offset is considered as state vector, x, lateral offset as measurement vector, z, with the uncertainty equal to uncertainty on respective position given by CPS.

Figure 6 shows the common offset vector, $\vec{O}$, in global (XY) and vehicle body (uv) coordinates. Equations 1-15 are Kalman filter [7] equations for estimation of common offset.

The linear plant and measurement model are:

$$x = [O_X \quad O_Y]^T \tag{1}$$

$$x_k = \Phi_k x_{k-1} + w_{k-1} \tag{2}$$

$$z_k = H_k x_k + v_k \tag{3}$$

Where O_x, O_y denote components of common offset vector in X and Y direction respectively. Φ is the state transition matrix, H is the measurement sensitivity matrix and w, v are zero mean white noises.

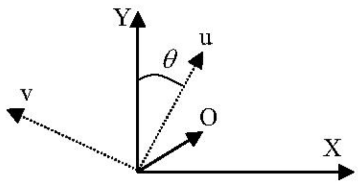

Figure 6. Body coordinate system (uv), global coordinate system (XY) and offset vector (O) and heading direction (θ)

Initial estimate for x and error covariance matrix, P, are:

$$\hat{x}_0 = E\langle x_0 \rangle \tag{4}$$

$$P_0 = E\langle \tilde{x}_0 \tilde{x}_0 \rangle \tag{5}$$

Equations 6-8 describe prediction step of Kalman filter in which Q is dynamic disturbance covariance matrix.

$$\hat{x}_k(-) = \Phi_k \hat{x}_{k-1}(+) \tag{6}$$

$$\Phi_k = I \tag{7}$$

$$P_k(-) = \Phi_k P_{k-1}(+)\Phi_k^T + Q_{k-1} \tag{8}$$

Correction step of Kalman filter can be described by equations 9-14 where K is Kalman gain, R is measurement uncertainty matrix and O_v, lateral offset in body coordinate, is the available measurement.

$$z_k = [O_v] \tag{9}$$

$$H_k = [\cos\theta \quad -\sin\theta] \tag{10}$$

$$\overline{K}_k = P_k(-)H_k^T(H_k P_k(-)H_k^T + R_k)^{-1} \tag{11}$$

$$\hat{x}_k(+) = \hat{x}_k(-) + \overline{K}_k[z_k - H_k \hat{x}_k(-)] \tag{12}$$

$$P_k(+) = P_k(-) - \overline{K}_k H_k P_k(-) \tag{13}$$

$$P_k(+) = P_k(-) - \overline{K}_k H_k P_k(-) \tag{13}$$

$$R_k = [\sigma_{O_v}^2] \tag{14}$$

Uncertainty in measurement of lateral offset in body coordinate, σ_{O_v}, is the projection of uncertainty in estimated position by CPS in lateral direction, v. This uncertainty is shown in Figure 7 along the test trajectory. Equation (15) describes the relationship between σ_{O_v} and σ_{O_x}, σ_{O_y} the uncertainties in estimated longitude and latitude components of given position by CPS and the heading direction [3].

$$\sigma_{O_v}^2 = \cos^2\theta . \sigma_{O_X}^2 + \sin^2\theta . \sigma_{O_Y}^2 \tag{15}$$

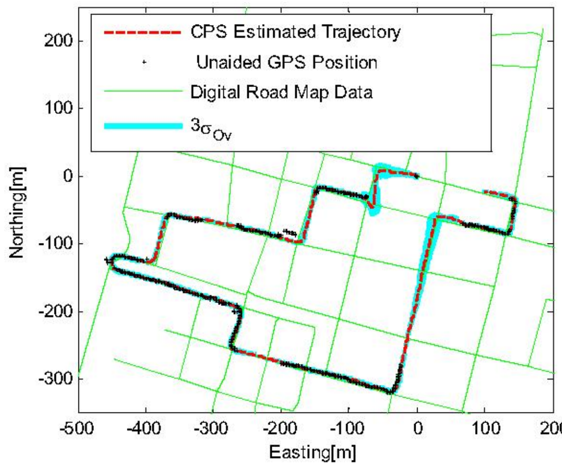

Figure 7. CPS position estimation uncertainty projected on lateral direction, σ_{O_v}, which is used as uncertainty of lateral offset measurement in Kalman filter of map matching algorithm.

2.3. Different Modes of Offset Eliminative Algorithm

The developed offset eliminative map matching algorithm consists of three following modes:

1. Searching mode: In this mode, algorithm searches for the road link on which the vehicle is traveling. Algorithm will be in this mode when it starts or if the tracking fails unexpectedly.

The road link will be determined based on the vehicle position and the heading direction in a sequence of time steps. In each time step a rectangular search region based on the positioning uncertainty will be used (see Figure 8). Road links which are in search region in all time steps of the sequence will be considered for further analysis. If there is only one candidate road link, it will be considered as the actual road link, however, in the case of more than one candidate, the most appropriate road link will be the one with the least average total error which is calculated as follows:

In each time step, a total error is obtained for each road link in the search region by summing up normalized distance error and normalized heading error. Normalized distance error is the distance between the estimated vehicle position by CPS and the nearest point on the road link, divided by a nominal distance error. In a similar way, normalized heading error is the heading difference between estimated vehicle direction by CPS and road link direction, divided by a nominal heading error. Average total error for each road link will be the average of its total error in considered time steps.

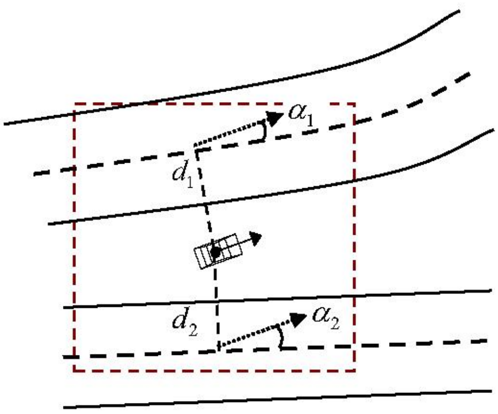

Figure 8. A search region around CPS estimated vehicle position with two roads in it, projected point of vehicle position on each road with associated distance and heading errors are shown.

If no road link is found in the search region search region will be expanded and search procedure will be repeated.

2. Tracking mode: In this mode, the vehicle will be tracked on the previously selected road and the common offset and distance to the coming intersection will be updated each time the vehicle travels a certain distance (e.g. each 20m). The algorithm will stay in this mode until vehicle is in the proximity of a coming intersection (e.g. 30m).

3. Intersection mode: In this mode, the vehicle location on the road on which it is traveling will be calculated more frequent (e.g. each 2m) until vehicle starts turning or reaches a certain distance to intersection center (e.g. 10 m). From this point on the vehicle location on the map will be calculated by adding the last obtained common offset between CPS position and digital map to each CPS position. At the end of intersection mode the road on which the vehicle is traveling, will be determined by comparison of turning magnitude and intersected roads bearing.

For more details regarding the developed map matching algorithm refer to [1].

3. Results

To evaluate the performance of the developed offset eliminative map matching algorithm, the algorithm was run for the test trajectory shown in Figure 1. The trajectory included 14 turns in intersections and the map matching results in four of them are presented as examples in Figures 9, 10, 11 and 12. In theses figures, the given trajectory by CPS and respective estimated trajectory by offset eliminative map matching algorithm are overlaid on the digital road map. The directions of travel on each road are shown by arrows.

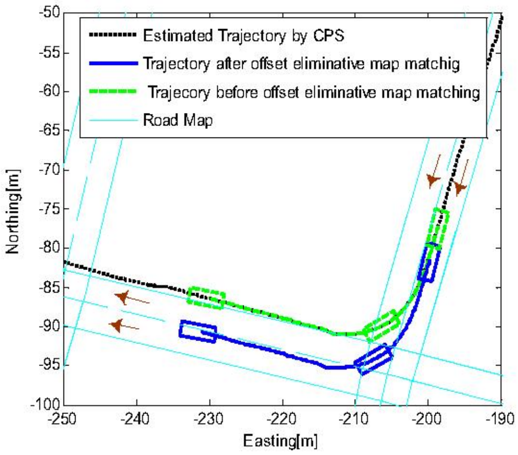

Figure 9. Result of proposed MM algorithm

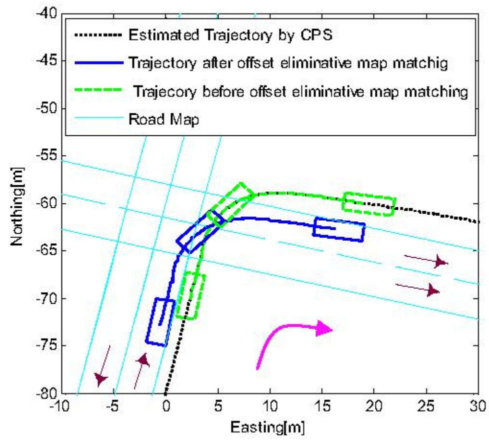

Figure 10. Result of proposed MM algorithm

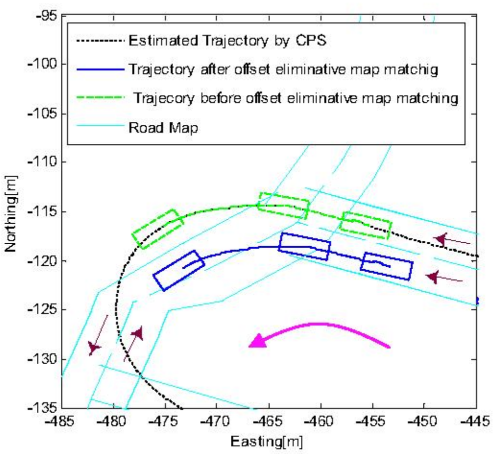

Figure 11. Result of proposed MM algorithm

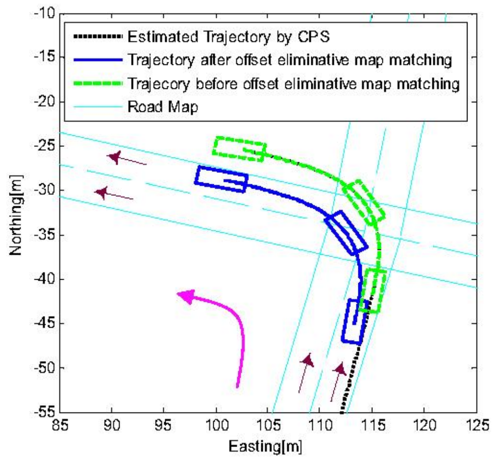

Figure 12. Result of proposed MM algorithm

As it can be seen the estimated trajectory by CPS is well matched onto the road map. Furthermore estimation of vehicle location along the road and consequently estimation of distance to coming intersection is enhanced. In 22 intersections of the test trajectory, longitudinal offset between CPS given trajectory and map data was 1 to 5 meters. By using the offset eliminative MM, longitudinal offset was reduced to 0.5 to 1.5 meter which was the uncertainty in estimation of lateral offsets. In this research, the real trajectory was assumed to be the possible trajectory with the same pattern as CPS given trajectory, which fits in the intersection geometry.

It should be noted that since the roads' width was not available in the digital map, it was estimated based on speed limit of the road. Knowing the exact road width will improve the offset eliminative map matching results significantly, due to its important role in calculation of lateral offsets.

4. Conclusion

An offset eliminative map matching method and its performance is presented. Instead of matching the CPS given vehicle positions onto the roads' centrelines, lateral offsets up to each point were summed and filtered by a Kalman filter to obtain the common offset between the CPS given vehicle position and digital road map.

The validation results indicate that by using the proposed map matching algorithm, 1 to 5 meter longitudinal offset between CPS given trajectory and road map in intersections, was reduced to 0.5 to 1.5 meter which was the uncertainty in lateral offset estimation.

Some further researches on this topic include incorporation of map information uncertainty in the map matching algorithm.

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