Comparison of integrated GPS-IMU aided by map matching and stand-alone GPS aided by map matching for urban and suburban areas

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Abstract

An essential process in vehicle navigation is to map match the position obtained from GPS (or/and other sensors) on a digital road network map. GPS position is relatively accurate in open sky conditions, but its position is not accurate in dense urban canyon conditions where GPS is affected by signal blockage and multipath. Inertial navigation system can be used to bridge GPS gaps. However, position and velocity results in such conditions are typically biased, therefore, fuzzy logic based map matching, is mostly used because it can take noisy, imprecise input, to yield crisp output. Stand-alone GPS positioning and integrated GPS and IMU positioning aided by fuzzy logic based map matching for urban and suburban areas are done in this paper. Stand-alone GPS aided map matching algorithms identifies 96.4% of correct links for rural area and 92.6% for urban area (car test). Integrated GPS and IMU aided map matching algorithms identifies 97.3% of correct links for rural area and 94.4% for urban area (car test).

Keywords: GPS, IMU, map matching, fuzzy logic

1. Introduction

Land vehicle navigation systems have been a hot topic and high demand for research over the past decade for a lot of applications. The aim of such a system is to correctly select the road link and locate the vehicle on it (Syed, 2005). GPS positional error can reach several tens of meters. In case of digital maps, various factors like errors in digitizing map and the distance from the road centerline to the both end of the road makes the positional error of nearly 20 meters. Therefore position data need to be corrected with various methods to match with a digital map and we call this procedure, map matching. Algorithms of the map matching have been developed continuously and they can be classified roughly into three categories (Quads, 2006). 1) Geometric map matching which consider only geometric relationships between vehicle position and a digital map. 2) Topological map matching which consider not only geometric relationships but also the topology of the road network and the history of GPS data. 3) Advanced map matching that use more refined concepts such as a Kalmam Filter (e.g., Krakiwsky et al., 1988; Tanaka et al., 1990; Jo et al., 1996, Kim et al., 2000), a fuzzy logic model (e.g., Zhao, 1997; Kim et al., 1998, Kim and Kim 2001, Syed and Cannon, 2004). The most popular positioning technology used is the Global Positioning System (GPS), because of its high accuracy positioning capability (Zhao et al., 2003). However, GPS-based vehicular navigation systems are subject to severe performance degradation in environments like urban canyons, tunnels, under bridges and streets with dense tree coverage so frequent complete or partial GPS outages is unavoidable. To overcome this limitation, GPS is often integrated with an inertial navigation system (INS), in which GPS facilitates the in-motion calibration of the INS, while the INS provides a continuous navigation solution. Another advantage of GPS-IMU over stand-alone is producing more precise car azimuth (which is a significant parameter in map matching) especially at low speeds (Quddus, 2006). Stand-alone GPS positioning aided by map matching and integrated GPS and IMU positioning aided by map matching for urban and suburban areas are done in this paper and the results are compared.

2. GPS-IMU integration

In this paper, loosely coupled method is used for GPS-IMU integration. In this method, IMU's output including angle increment and velocity increment are processed using strap down INS algorithm. GPS observables are processed using least square method or Kalman filtering in order to obtain $\lambda_{GPS}, \varphi_{GPS}$. The output of two systems enters a Kalman filter (Jekeli, 2001). INS error dynamics makes system model and GPS latitude and longitude make measurement model in Kalam filter.

3. Fuzzy logic based map matching

The fuzzy logic based map matching algorithm has two steps: (1) the identification of the correct link and (2) the determination of the vehicle location on the selected link (Quddus et al., 2006). These two steps are described below:

3.1 Identification of the Correct Link

The map matching algorithm which was used in this paper consists two distinct steps. (1) The initial map matching (IMP) and (2) The subsequent map matching (SMP) (Quddus et al., 2006).

3.1.1 Initial map matching

Selecting an initial link for the initial position fix is known as the initial map-matching process (IMP). The fuzzy inference system (FIS) state input variables for IMP are (Quddus et al., 2006):

1) The heading error which is the difference between vehicle heading and link azimuth, (HE in degrees)
2) The speed of the vehicle, v (m/sec)
3) the perpendicular distance from vehicle position to the link, PD (m)
4) HDOP

A zero-order Sugeno fuzzy model was used in this paper. Six fuzzy rules are formulated for IMP (Quddus et al., 2006): (L1 is likelihood of matching the position fix to the link)

1) If HE is small and v is high then L1 is average.
2) If HE is large and v is high then L1 is low.
3) If PD is short and HDOP is good then L1 is average.
4) If PD is long and HDOP is good then L1 is low.
5) If PD is short and HE is small then L1 is high.
6) If PD is long and HE is large then L1 is low.

3.1.2 The subsequent map-matching process

After the successful implementation of IMP, the subsequent map-matching process (SMP) will start. There are two types of subsequent map-matching processes: 1) SMP along a link (SMP-1) and 2) SMP at a junction (SMP-2) (Quddus et al., 2006). The fuzzy inference system (FIS) state input variables for SMP1 are:

1) The heading increment which is the difference between vehicle heading at the current epoch and previous epoch (HI) (degrees)
2) The speed of the vehicle (v) (m/sec)
3) The gyro-rate reading (Δθ) (deg/sec)
4) The distance difference (Δd=d1-d2)[1] (m)
5) angle α between current point, previous map matched point and junction (degree)
6) angle β between current point, junction and previous map matched point
7) HDOP.

The following rules were applied to SMP1 which are taken from Quddus et al, 2006.

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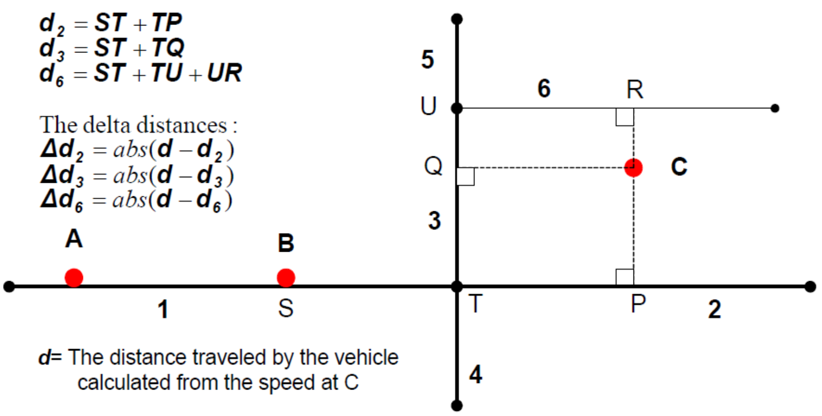
[1] d1 is the distance from the last map matched position to the junction, d2 is distance that was travelled by vehicle in one second.

Rule number 10 and 11 were modified in this paper. (L2 is likelihood of matching the position fix to the link):

1) If α is below 90 and β is below 90 and Δθ is small then L2 is high.
2) If Δd is positive and α is above 90 and Δθ is small then L2 is low.
3) If Δd is positive and β is above 90and Δθ is small then L2 is low
4) If α is below 90 and β is below 90 and HI is small then L2 is high.
5) If Δd is positive and α is above 90 and HI is small then L2 is low.
6) If Δd is positive and β is above 90 HI is small then L2 is low
7) If α is below 90 and β is below 90 and Δθ is high then L2 is low.
8) If α is below 90 and β is below 90 and HI is large then L2 is low.
9) If v is zero and HDOP is good then L2 is high.
10) If Δd is negative and HDOP is good then L2 is low.
11) **If Δd is positive and HDOP is good then L2 is average.**
12) If HI is small and v is high then L2 is average.
13) If v is high and HI is 180 and Δθ is high and HDOP is good then L2 is high.

The SMP-2 starts when the vehicle is either about to cross or has just crossed the junction. The purpose of SMP-2 is to select a new link among the candidate links by using the same FIS as used in IMP. But there are two more input parameters in SMP-2. They are the link connectivity and distance error (Quddus et al, 2006) as shown in Figure 1.

Figure 1: SMP2 at junction



The term d in Figure 1 represents the distance travelled by the vehicle from the last epoch and it is calculated by taking the speed of the vehicle at C. The term d2, d3 and d6 are the shortest path distances travelled by the vehicle, if the vehicle is on link 2, 3 and 6 respectively. The absolute difference between d and d2 (or d3 or d6) is the distance error associated with each link as shown in Figure

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1. The lower the distance error for a link the higher the probability that the vehicle is on that link. Ten rules are used for the FIS of SMP-2, where the first six rules are same as the rules that were presented for the FIS of IMP. The four additional rules are presented below which are taken from Quddus et al, 2006. (L3 is likelihood of matching the position fix to the link)

1) If the connectivity with the previous link is high then The L3 is high.
2) If the connectivity with the previous link is low then the L3 is low.
3) If the distance error is high then L3 is low.
4) If the distance error is low then The L3 high

3.2 Link Determination of the vehicle location on the selected link

In this paper, after the determination of the correct link, the perpendicular projection to the selected link from the position fix is used in order to determine the vehicle location on the selected link.

4. Results

Several tests were done by car for urban and suburban areas. Finally, the results were compared. BT-338 Bluetooth GPS and ISIS-IMU were used for these tests. A reference ("true") trajectory that was determined by high accuracy GPS carrier phase positioning is used to validate the results.

When vehicle is moving with relatively high velocity, stand-alone GPS and integrated GPS and IMU give more and less the same results, but when vehicle is moving slowly or is in the stationary mode, especially at the junctions, integrated GPS and IMU gives better results as shown in Figure 2 At the junction, in Figure 2, the vehicle was moving slowly and stand-alone GPS was unable to find the correct link for 5 epochs.

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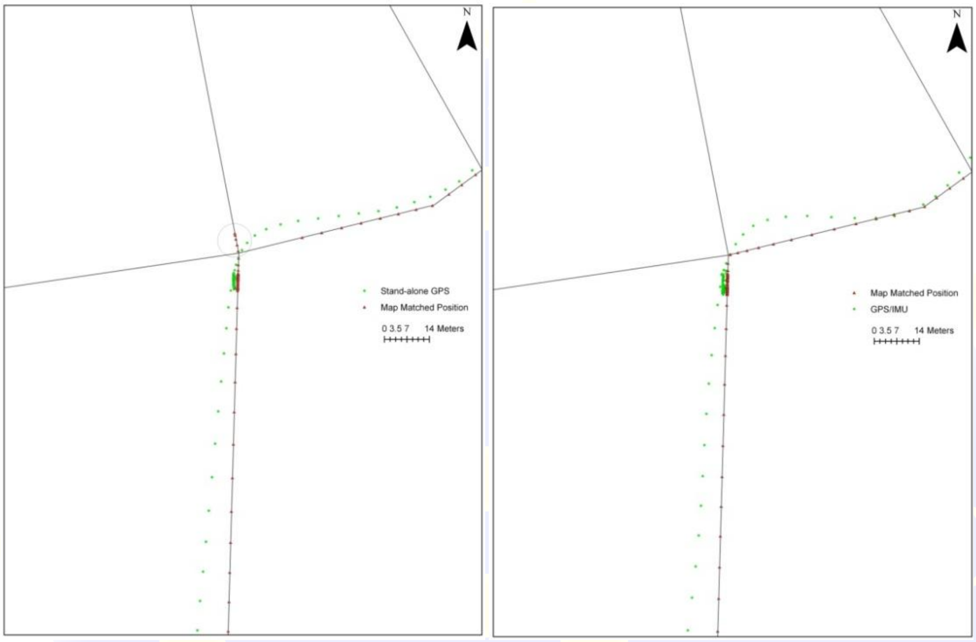
Figure 2. Comparison of the performance of Stand-alone GPS and Integrated GPS and IMU at a Junction in rural area.



Stand-alone GPS and integrated GPS-IMU test were done around half an hour for rural area. The summary is shown in the table 1 below:

Table 1. Map Matching result comparison for Stand-alone GPS and GPS-IMU for rural area.

	Total Number of links	incorrectly matched links	accuracy
Stand-alone GPS	2149	78	96.4%
Integrated GPS-IMU	2137	58	97.3%

Map matching results for stand-alone GPS and integrated GPS and IMU for urban areas are shown and compared in Figure 3. As we can see in the Figure 3, 11 links are selected incorrectly by stand-alone GPS but 8 links are selected incorrectly by integrated GPS and IMU which is better than stand-alone GPS.

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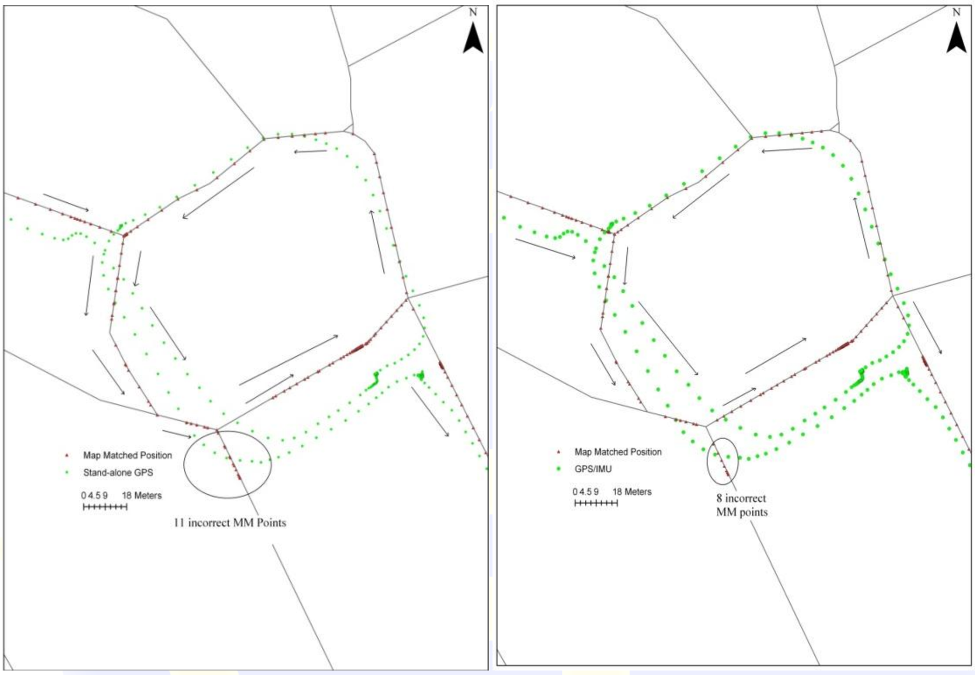
Figure 3. Comparison of the performance of Stand-alone GPS and Integrated GPS and IMU at a Junction in rural area



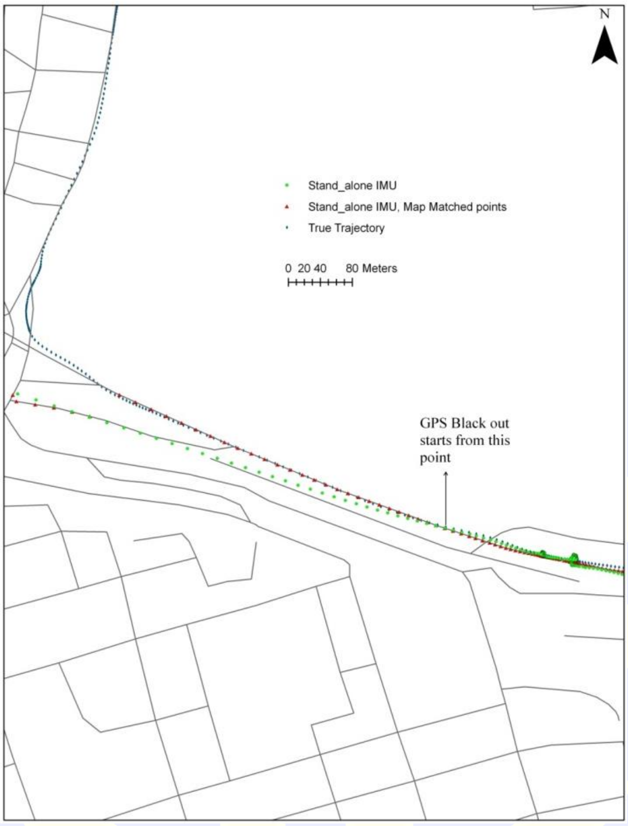
Stand-alone GPS and integrated GPS-IMU test are done for 40 minutes in urban area. The summary is shown in the Table 2:

Table 2. Map Matching result comparison for Stand-alone GPS and GPS-IMU for urban area.

	Total Number of links	incorrectly matched links	accuracy
Stand-alone GPS	2374	175	92.6%
Integrated GPS-IMU	2360	132	94.4%

While no GPS signal is available, GPS-IMU shifts to stand-alone IMU (only prediction step of Kalman filter is done) for positioning, so it can select correct link for some seconds especially if the link is selected correctly before GPS black out. To test this scenario, GPS was disconnected. As shown in Figure 4, 28 true links are selected after GPS black out. When there is no GPS update, the IMU errors grow rapidly. After 28 seconds, the position accuracy (evaluated by true trajectory) is 34.9 m. Furthermore, there are five more rules based on gyro rate in SMP1 of GPS-IMU map matching, which makes it more reliable.

Figure 4. Results of map matching after GPS black out for GPS-IMU map matching



5. Conclusion and future work

It is found from the results that the stand-alone GPS aided map matching algorithm sometimes does not work correctly at the intersections especially when the vehicle speed is low (less than 3 m/sec). Azimuth produced by stand-alone GPS, is not reliable when the vehicle speed is low. But in the case of integrated GPS and IMU, the calculated vehicle heading is more accurate and the algorithm selects the correct link. Furthermore, in SMP-1 of integrated GPS and IMU aided map matching algorithm, there are five extra fuzzy rules out of thirteen rules using gyro-rate. These extra rules give better performance in the SMP-1 process to check whether the current vehicle position should match with the previously identified link. As a result of the experience gained during this paper, the issues that are recommended for the further research are discussed below:

1) The integration of GPS and IMU was done by using loosely coupled approach (positioning domain). However the integration can be done by us-

ing tightly coupled approach. Tightly coupled filter will not go to the prediction mode (in Kalman filter) when only 3 or 2 satellites are tracked.

2) Some extra road design parameters such as turn restriction at junctions, roadway classification (one way or two way) and under pass and over pass information can also be used as input in map matching algorithm, which can improve the performance of map matching algorithm.
3) High accurate digital road network can be used in order to increase the accuracy of map matching.
4) One gyroscope (or magnetometer) and odometer can be used instead of using IMU to reduce the cost.

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