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Original Research Paper

Context-aware GPS integrity monitoring for intelligent transport systems

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ARTICLE INFO

Article history:
Received 13 April 2015
Received in revised form
2 July 2015
Accepted 30 September 2015
Available online 14 January 2016

Keywords:
Speed integrity
GPS Doppler
Location-based ITS applications
GPS integrity
Map matching algorithms

ABSTRACT

The integrity of positioning systems has become an increasingly important requirement for location-based intelligent transport systems (ITS), for example electronic toll collection (ETC), public transport operations and traffic control services. In ITS, satellite navigation systems, such as global positioning system (GPS), are used to provide real-time vehicle positioning information including details of longitude, latitude, direction and speed. Map matching algorithms are used to integrate the positioning information into the digital road map. However, the navigation systems used in ITS cannot provide the high quality positioning information required by most services, due to the various types of errors made in the map matching process and experienced by GPS sensors such as signal outage, and errors due to atmospheric effects and receiver measurement errors, all of which are difficult to measure. An error in the positioning information or map matching process might lead to the inaccurate determination of a vehicle location. This could have legal or economic consequences for ITS applications such as traffic law enforcement systems (e.g., speed fining). Such applications require integrity when measuring the vehicle position and speed information and in the map matching process when locating the vehicle on the correct road segment to avoid errors when charging drivers. Consequently, the integrity algorithm for the navigation system should include a guarantee that the systems do not produce misleading or faulty information as this may lead to significant errors in the ITS services provided. In this paper, a high integrity GPS monitoring algorithm based on the concept of context-awareness that can be applied with real time ITS services to integrate changes in the integrity status of the navigation system was developed. Results suggest that the new integrity algorithm can support various types of location-based ITS services (e.g., route guidance).

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Peer review under responsibility of Periodical Offices of Chang'an University.
http://dx.doi.org/10.1016/j.jtte.2015.09.002

1. Introduction

The growth of intelligent transport systems (ITS) in the last decade has resulted in a significant improvement in road safety and monitoring, as it plays a key role in avoiding many transportation problems, such as road accidents and traffic congestion (Qureshi and Abdullah, 2013). ITS services include traffic management, electronic payment, route guidance, fleet management, and emergency management vehicle services. These services are mainly supported by positioning and navigation capabilities, and most require real time positioning data, which can be referred to as location-based ITS services.

Two main components are found in any location-based ITS used in vehicle navigation systems and services, namely (i) a geometric positioning system, such as a global positioning system (GPS) or an integrated navigation system, such as dead reckoning (DR) and (ii) a geographic information system (GIS) based on digital road maps (Taylor and Blewitt, 2006). Another essential component of ITS services is a map matching (MM) algorithm, which is used to determine the correct road segment and road link on which a vehicle is travelling to integrate this positioning information into the digital road map (Quddus et al., 2006).

Therefore, ITS services (e.g., route guidance) can affect the efficiency of the route guidance service and may confuse the driver depending primarily on the positioning data received from a positioning system (e.g., GPS) (Velaga et al., 2012). However, a stand-alone GPS cannot provide the high quality positioning data required by most ITS services (Feng and Ochieng, 2007; Li et al., 2013). This is due to the various types of errors associated with the received positioning data such as signal outage, and errors due to atmospheric effects, receiver measurement errors, and multipath errors (Kaplan and Hegarty, 2006). Digital road maps are more reliable than a stand-alone GPS, thus map matching algorithms can contribute to improving the accuracy of positioning data (Bastiaansen, 1996; Bullock and Krakiwsky, 1994; Yu et al., 2006). This is because map matching algorithms consider different types of information including position, speed, and direction in the matching process in order to identify the location of the vehicle on the road segment (Quddus et al., 2006). However, map matching algorithms, may locate the vehicle on a wrong road segment due to the poor quality of input data (Chen et al., 2005; Quddus et al., 2006, 2007; White et al., 2000) which can lead to significant errors in ITS services (Velaga, 2010). Therefore, it is important to check and monitor the quality of the positioning information obtained from the GPS sensor and other input data to the map matching algorithm in order to detect any misleading or faulty information and notify the user, thus increasing the integrity of the system (Ochieng and Sauer, 2002). According to Yu et al. (2006), the integrity of a system refers to its ability to detect blunders in input data and faults in the map matching process.

Studies have been carried out to monitor and improve the integrity of in-vehicle navigation systems. These studies have either focused on improving the integrity of raw positioning data (Andrés and Daniel, 2012) and the integrity of the map matching process (Jabbour et al., 2008; Yu et al., 2006), or combination of both (Quddus, 2006; Velaga, 2010). Moreover, Velaga (2010) has considered the complexity of the road network (urban and rural areas) in the integrity process in addition to the integrity of raw positioning data and map matching process. These researchers including Quddus and Velaga used speed to calculate distance in the map matching process, but they did not check the integrity of the speed measurements. Quddus (2006) has mentioned that speed is an essential factor in enhancing the map matching algorithm. Indeed, monitoring speed integrity is vital. According to Li et al. (2013), failure in any factor in the map matching process can lead to defects throughout the whole process. Thus, checking the integrity of the speed measurements has the potential to improve the overall integrity process and lead to more accurate outcomes.

Yet, to the best of the authors' knowledge, there is no existing method for monitoring the integrity of in-vehicle navigation systems taking into account the integrity of the vehicle speed. In the light of this, the main aim of this study is to contribute to the improvement of the integrity of in-vehicle navigation systems in order to support the positioning requirement of location-based ITS services. This can be achieved by developing a robust and reliable GPS integrity monitoring algorithm based on the concept of context-awareness. Context-awareness can provide ITS applications adequate information about the current integrity status of the navigation system (Hong et al., 2009). The proposed algorithm will ensure the integrity of in-vehicle navigation systems by taking into account three types of information-vehicle position, vehicle speed, and the result of the map matching process. Existing methods focus on monitoring the integrity of positioning information, the map matching process or both. However this algorithm will incorporate a new layer to monitor the integrity of the speed measurements, which can significantly enhance the performance of the map matching algorithm and the overall integrity process.

The algorithm is divided into three integrity phases, including (i) the positioning integrity phase, (ii) the speed integrity phase and (iii) the map matching integrity phase. Each phase uses different techniques to examine the consistency of the GPS information. A receiver autonomous integrity monitoring (RAIM) algorithm, which is an algorithm used to measure the integrity of GPS signal, is used to measure the quality of the GPS positioning data. GPS Doppler information (Doppler Effect), which refers to the difference between the calculated frequency at the GPS receiver and the satellite carrier frequency (Chalko, 2007), is used to check the integrity of the vehicle speed measurements. The final phase in the integrity algorithm is intended to verify the integrity of the map matching process. In this phase, fuzzy logic is also used to measure the integrity level, which guarantees the validity and integrity of the map matching results.

The system architecture of the proposed GPS integrity monitoring algorithm is designed on the basis of the five layered context-aware framework (Dey et al., 2001) (Fig. 1). The architecture is composed of three main subsystems: sensing subsystem, reasoning subsystem, and application subsystem. These subsystems correspond to the main phases of the context-aware system. The first subsystem is