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Current map-matching algorithms for transport applications: State-of-the art and future research directions

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Abstract

Map-matching algorithms integrate positioning data with spatial road network data (roadway centrelines) to identify the correct link on which a vehicle is travelling and to determine the location of a vehicle on a link. A map-matching algorithm could be used as a key component to improve the performance of systems that support the navigation function of intelligent transport systems (ITS). The required horizontal positioning accuracy of such ITS applications is in the range of 1 m to 40 m (95%) with relatively stringent requirements placed on integrity (quality), continuity and system availability. A number of map-matching algorithms have been developed by researchers around the world using different techniques such as topological analysis of spatial road network data, probabilistic theory, Kalman filter, fuzzy logic, and belief theory. The performances of these algorithms have improved over the years due to the application of advanced techniques in the map matching processes and improvements in the quality of both positioning and spatial road network data. However, these algorithms are not always capable of supporting ITS applications with high required navigation performance, especially in difficult and complex environments such as dense urban areas. This suggests that research should be directed at identifying any constraints and limitations of existing map matching algorithms as a prerequisite for the formulation of algorithm improvements. The objectives of this paper are thus to uncover the constraints and limitations by an in-depth literature review and to recommend ideas to address them. This paper also highlights the potential impacts of the forthcoming European Galileo system and the European Geostationary Overlay Service (EGNOS) on the performance of map matching algorithms. Although not addressed in detail, the paper also presents some ideas for monitoring the integrity of map-matching algorithms. The map-matching algorithms considered in this paper are generic and do not assume knowledge of 'future' information (i.e. based on either cost or time). Clearly, such data would result in relatively simple map-matching algorithms.
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1. Introduction

A range of intelligent transport system (ITS) applications and services such as route guidance, fleet management, road user charging, accident and emergency response, bus arrival information, and other location based services (LBS) require location information. For instance, buses equipped with a navigation system can determine their locations and send the information back to a control centre enabling bus operators to predict the arrival of buses at bus stops and hence improve the service level of public transport systems. The horizontal positioning accuracy for such ITS applications is in the range of 1 m to 40 m (95%, i.e. at the 2σ level), with relatively high requirements on integrity, continuity and system availability.

In the last few years, the Global Positioning System (GPS) has established itself as a major positioning technology for providing location data for ITS applications. Zito et al. (1995) provide a good overview of the use of GPS as a tool for intelligent vehicle-highway systems. Deduced Reckoning (commonly referred to as 'Dead' Reckoning or DR) sensors consisting of an odometer and a gyroscope are routinely used to bridge any gaps in GPS positioning (Kubrak et al., 2006). This information is then used with spatial road network data to determine the spatial reference of vehicle location via a process known as map matching.

Map-matching algorithms use inputs generated from positioning technologies (such as GPS or GPS integrated with DR) and supplement this with data from a high resolution spatial road network map to provide an enhanced positioning output. The general purpose of a map-matching algorithm is to identify the correct road segment on which the vehicle is travelling and to determine the vehicle location on that segment (Greenfeld, 2002; Quddus et al., 2003). Map-matching not only enables the physical location of the vehicle to be identified but also improves the positioning accuracy if good spatial road network data are available (Ochieng et al., 2004). This means that the determination of a vehicle location on a particular road identified by a map-matching algorithm depends to a large extent on the quality of the spatial road map used with the algorithm. A poor quality road map could lead to a large error in map-matched solutions.

A map-matching algorithm can be developed generically for all applications or for a specific application. For example, Taylor et al. (2006) developed a map-matching algorithm referred to as Odometer Map Matched GPS (OMMGPS) applicable to services where the most likely path or route is known in advance. In this paper, only generic map-matching algorithms are reviewed. A map-matching algorithm can also be developed for real-time applications or for those where post-processing is sufficient. For instance, Marchal et al. (2005) developed an efficient post-processing map-matching method for large GPS data. In the review presented in this paper, only real-time map-matching algorithms are considered as most ITS services require a map-matching algorithm that can be implemented in real-time.

It is essential that the map-matching algorithm used in any navigation module meet the specified requirements set for that particular service. Although the performance of a map-matching algorithm depends on the characteristics of input data (Chen et al., 2005), the technique used in the algorithm can enhance overall performance. For instance, the performance of a map-matching algorithm based on fuzzy logic theory may be better than that of an algorithm based on the topological analysis of spatial road network data if all else are equal. There are at least 35 map-matching algorithms produced and published in the literature during the period 1989–2006, most of which are recent reflecting the growth in the need for ITS services. The positioning accuracy and quality offered by these algorithms has also improved over the years. This is mainly due to the use of advanced techniques in the algorithms such as Kalman filtering, fuzzy logic, and belief theory, and the improvement in the performance of positioning sensors and the quality and quantity of spatial road network data.

Another important operational consideration is the sampling frequency. Although most ATT services (navigation and road guidance, distance-based road pricing, etc.) require a sample frequency of 1 Hz, some ATT services (such as bus arrival information at bus stops) only require a sample frequency of 0.3 Hz or lower. This can obviously influence the design of an optimal map-matching algorithm, as the performance of some navigation sensors vary, for example with speed. This aspect of the performance of map-matching is measured in part by the required navigation performance parameter of *continuity*.

Different algorithms, however, have different strengths and weaknesses. Some algorithms may perform very well within suburban areas but may not be appropriate for urban areas and *vice versa*. A review of the literature suggests that existing map-matching algorithms are not capable of satisfying the requirements of all ITS

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