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Validating the efficacy of GPS tracking vehicle movement for driving behaviour assessment

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ABSTRACT

Vehicle movement trajectory recorded by GPS maps the vehicle's lane position in time sequence, therefore theoretically can be used to assess driving behaviour. However, the data quality level which can be achieved for vehicle movement tracking by different GPS receivers and positioning techniques hasn't been fully explored and documented. This study systematically validated the efficacy of GPS recording vehicle movement using different types of receivers and positioning techniques. The receivers include both recreational and professional devices; the positioning techniques refer to Single Point Positioning (SPP), Differential GPS (DGPS) and Real-time kinematic (RTK) solutions. The field trials tested the positioning accuracy as well as the quality of trajectory tracking by comparing the recorded positions to benchmarks. The study findings indicate that vehicle movement trajectories recorded by recreational-grade GPS receivers can only match other spatial information at low resolution, which is limited to the assessment of wayfinding and navigation behaviour. In contrast, the SPP, DGPS and RTK techniques undertaken by professional receivers can raise horizontal accuracy to the metre, decimetre, and centimetre level respectively. For under open sky road driving, the RTK solution generated accurate and precise vehicle movement trajectories sufficient for extracting vehicle lane position, speed, acceleration/deceleration, so as to detect detailed driving events and quantitatively assess individual driver behaviour. This paper serves as a critical reference for other researchers on the different types of GPS receivers and solutions prior to engaging a GPS in their studies.

1. Introduction

There is a growing trend of using spatial tracking technology to record the patterns of moving objects, such as animal movements, human mobility, and in recent decades to track vehicle movements in transport management and traffic safety studies (Gonzalez et al., 2008; Juang et al., 2002; Kageyama et al., 2001). Within those applications, the most commonly used technology is the GPS (Global Positioning System) or GPS embedded mobile devices tracking (e.g. smartphone with GPS app) (Herrera et al., 2010; Ryan et al., 2004). GPS allows researchers to continuously measure the vehicle speed, acceleration and location (Ogle et al., 2002). It can be comparably low-cost and ecologically valid to assess driving behaviours using GPS tracking vehicle movement. Since many transportation-related problems, including traffic congestion, vehicle collisions and crashes, energy consumption, and vehicle emissions, are directly related to driver behaviours (Jun et al., 2006), GPS tracking can empower the data-driven research in the transport and traffic behaviour studies. The potential of GPS data can be maximized even more when compiled in a GIS (Geographic Information System) to be overlaid with other spatial data, such as built environment (Duncan et al., 2009). Integration of GPS data into a GIS allows researchers to categorize, visualise and model their data based on location. Likewise, other data can be geocoded with the reference of GPS locations to obtain new attributes.

While the majority of the users were excited about the rich datasets of GPS tracking, the accuracy of GPS tracking seems to be neglected in many applications. This is perhaps due to the continuously and comparably more accurate positions and timestamps from GPS recording, compared to which the conventional surveys or retrospective questionnaires can bring about. However, since the GPS positions are determined from the signals transmit-

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ted between the satellites and GPS receivers, multi-factors may cause positioning errors at different levels. GPS recording does raise concerns over accuracy depending on the application requirement. On the other hand, the nature of GPS recording offers possibilities and opportunities to expand its application by enhancing its accuracy level, as Zito et al. (1995) stated earlier that corrections can be applied to the GPS observations when accuracy is a particular concern. With the advent of advanced positioning techniques, such as Differential GPS (DGPS), Real-time kinematic (RTK) and the possibility of multi-GNSS (Global Navigation Satellite System), more accurate and precise data for tracking moving trajectories can be achieved to fit many applications' needs: fleet tracking, lane departure warning, driverless car controlling and on-road driving behaviour assessment, etc.

In previous work, GPS or the combination of GPS plus video recording can provide a means to assess driving behaviours by tracking vehicle movement (Cruz et al., 2013; Grengs et al., 2008; Mudgal et al., 2014; Naito et al., 2009; Porter and Whitton, 2002). While there are a wide range of commercial GPS receivers available, they literally differ in the costs of devices and data collection accuracy. Despite the minimal information regarding the positioning accuracy reported in the manuals by the manufacturers, mostly under optimal static recording, studies on the details of the reliability and capability of GPS tracking vehicle kinematic trajectory are rare. In fact this is particularly important for risky driving detection in order to avoid misleading results caused by GPS errors. Although a few earlier studies investigated the GPS accuracy for such concerns (Ogle et al., 2002; Porter et al., 2004; Zito et al., 1995), the data quality level which can be achieved for vehicle movement tracking by different GPS receivers and positioning techniques hasn't been fully explored and documented. Standing from the users' (but not GPS experts) perspective, we comprehensively looked into some off-the-shelf GPS receivers, both recreational and professional-grade devices, and positioning solutions from different techniques (SPP, DGPS and RTK), aiming to evaluate the GPS capability in tracking vehicle movement trajectory for the application of assessing driving behaviours. Here, we tested five types of receivers: Garmin 76 and 72H, Mobilemapper 100 from Ashtech, Trimble R10 and JAVAD DELTA-3. The positioning techniques were applied to the latter two survey-grade receivers. A field trial for the absolute accuracy evaluation was undertaken by comparing the GPS recordings to the benchmark of a pillar station. The tracking ability was examined by a series of driving trials with the comparisons between GPS/GIS derived vehicle movement trajectories and a benchmark line. The objectives are as follows:

- Tracking vehicle movement using various GPS receivers and positioning techniques and computing the trajectories in GIS.
- Developing methods to evaluate the extent of data quality in GPS tracking vehicle movement, so as to reveal the least and the ultimate accuracy from GPS tracking.
- Validating the efficacy of the GPS recorded vehicle trajectories in driving assessments.

2. Research context

GPS can be used to measure positions through its array of navigational satellites from the 31 current operational satellites (GPS.GOV, 2015). Orbit and clock data are transmitted by each satellite in the GPS receiver's field of view. GPS device receives the satellite signals and computes the receiver position, velocity and time estimates through trilateration between four or more satellites. In theory, GPS can track vehicle movements and detect events on the vehicle trajectories which may imply certain driving behaviours. A number of studies have used vehicle movement data recoded by GPS to classify driver behaviour (Cruz et al., 2013; Jensen et al., 2011; Lotan and Toledo, 2006; Ma and Andréasson, 2007; Rigolli et al., 2005; Wang et al., 2010). Rigolli et al. (2005) integrated video surveillance of daily traffic activity with vehicle trajectory analyse from GPS recording and found that GPS recording offered better performance in terms of accuracy and speed than human observations. Jensen et al. (2011) pointed out that objective data collection can be applied in several different ways, from specific manoeuvre deficiencies such as lane changes to overall driver risk, depending on the precision and details of the collected data.

GPS positioning errors have usually been calculated for stationary positions, examinations of kinematic positions, is more important for the assessment of driving to detect variables like velocity and acceleration (Porter et al., 2004). Zito et al. (1995) firstly reported the reliability and usefulness of GPS data for obtaining information on the position and speed of vehicle movements. By acknowledging the possibilities of using GPS in vehicle monitoring they further suggested that the minimum degree of accuracy needed by the application must be known, therefore the questions like whether the positioning accuracy is required and whether the GPS data can be post-processed should be considered. In a drivers' speeding behaviour research, Ogle (2005) gathered vehicle GPS coordinates and speeds to correlate speeding behaviour to crash rates. As a part of the project, Ogle et al. (2002) tested the reliability of speed and acceleration from four GPS packages with different combinations of receiver setting, both error corrected and uncorrected. They suggested that GPS can be used to obtain results within a reasonable range of the requirements. Porter et al. (2004) noted that GPS tracking could be advantageous in detecting driving behaviours of different types of drivers, they compared corrected (Differential GPS) and raw positions and addressed that error correction should be done if positional information is needed.

To date, most on-road driving assessments have only a pass or fail outcome that was based on driving evaluators' observation and subjective evaluation. In contrast, a standardized on-road driving assessment with a quantifiable score based on the velocity, acceleration/deceleration variables derived from GPS tracking would allow for driving assessment in an objective or blinded fashion (Porter and Whitton, 2002).

Table 1 below presents five categories related to critical driving abilities to test during on-road driving assessments; a series of driving events associated with each category can be scored using vehicle movement trajectories recorded by GPS and computed in GIS, and the variables are extracted from the driving trajectory, e.g. the duration and smoothness (vehicle lane deviations) of the events, the speed changes in the vehicle movement, and the speed at which the manoeuvre was performed.

To provide sufficient parameters for driving behaviour assessments, Table 1 depicts the requirement of GPS data for each category. For example, when turning, it is important to make the turn as accurate as possible, wide turns or cutting a turn too sharply are considered to be inappropriate behaviours. Thus, an accurate vehicle trajectory with precise curvature is required in order to evaluate the quality of turning behaviour. GPS/GIS derived vehicle movement trajectory provides possibilities to quantitatively assess such on-road driving behaviour. However, the GPS observations contain errors and noise, which would affect the validity of assessment. The accuracy of the GPS data depends on many factors, the quality of the GPS receiver, the position of the GPS satellites at the time the data was recorded, and the characteristics of the surrounding landscape which can either block the signals or cause multipath errors as illustrated in Fig. 1. In addition, errors in satellite clocks and orbits, the trips through the layers of the atmosphere, and some other sources contribute to inaccuracies in the GPS signals by the time they reach a receiver. Currently positioning using GPS can be performed through Single Point Positioning (SPP)