Identification of the Impact of GNSS Positioning on the Evaluation of Informative Speed Adaptation

Jamal Raiyn
Computer Science Department, Al Qasemi Academic College, Israel

Keywords: GNSS Data, Positioning Performance, Autonomous Vehicle, ISA.

Abstract: Autonomous vehicles (AVs) are self-driving vehicles that operate and perform tasks under their own power. They may possess features such as the capacity to sense environment, collect information, and manage communications with other vehicles. Many autonomous vehicles in development use a combination of cameras, various kinds of sensors, GPS, GNSS, radar, and LiDAR, with an on-board computer. These technologies work together to map the vehicle's position and its proximity to everything around it. To estimate AV positioning, GNSS data are used. However, the quality of raw GNSS observables is affected by a number of factors that originate from satellites, signal propagation, and receivers. The prevailing speed limit is generally obtained by a real-time map matching process that requires positioning data based on a GNSS and a digital map with up to date speed limit information. This paper focuses on the identification of the impact of GNSS positioning error data on the evaluation of informative speed adaptation. It introduces a new methodology for increasing the accuracy and reliability of positioning information, which is based on a position error model. Applying the sensitivity analysis method to informative speed adaptation yields interesting results which show that the performance of informative speed adaptation is positively affected by minimizing positioning error.

1 INTRODUCTION

For most intelligent transport systems (ITSs), the impact of the quality of the positioning information on ITS user service-level performance cannot be easily estimated. However, it can be of fundamental importance for critical services, and therefore calls for detailed analysis. Over the last few years, various geo-positioning technologies have been used to estimate the location of vehicles (Du et al. 2004; Quddus et al., 2007), such as satellite-positioning technologies (i.e. global navigation satellite systems [GNSSs], and global positioning systems [GPSs](Ramm and Schwieger, 2007), wi-fi positioning systems, and cellular positioning systems(Alger, 2014; Zandbergern, 2009). Some of the methods for collecting data on road traffic flow involve fixed-point modes, with high costs and limited regional coverage, such as induction loops and radar and video techniques (Fleming, 2001; Groves, 2013). In contrast to these fixed-point modes, we have introduced a system of floating data management based on augmented GNSS-based terminal positioning to improve the estimation of vehicle location, for road ITSs (Raiyn, 2016). The advantages of GNSS-based positioning are: accuracy and low processing time complexity. The basic operating principle of satellite navigation systems is to calculate a user's position from a GNSS signal. However, the quality of raw GNSS measurements (also called observables) is affected by several factors that originate from satellites, signal propagation, and receivers.

This paper is organized as follows: Section 1 gives an overview of the technology used to estimate AV positioning; section 2 explains the collection of raw GNSS data; section 3 describes the system model; section 4 presents the method for identifying GNSS positioning error; section 5 discusses the results of the implemented informative speed adaptation and section 6 concludes the paper.

2 GNSS POSITIONING DATA

In transportation, positioning can be monitored everywhere, and the number of road transport systems using positioning systems, for the most part

Raiyn, J.
Identification of the Impact of GNSS Positioning on the Evaluation of Informative Speed Adaptation.
DOI: 10.5220/0007656903050311
In *Proceedings of the 5th International Conference on Vehicle Technology and Intelligent Transport Systems (VEHITS 2019)*, pages 305-311
ISBN: 978-989-758-374-2

based upon GNSS, is almost infinite. The requirements of these systems with respect to the positioning information provided by the positioning terminal can vary from decimetres to hundreds of metres, depending on the application. Some of these systems are critical in terms of the need for safety, liability or security, and they depend on accurate and reliable positioning information to function effectively. For ITSs and LBSs, a standard in 2015 is a single-frequency GPS L1 receiver, with increasing SBAS and dual-constellation (with GLONASS) capabilities. LBS receivers (smartphones) are also often assisted (A-GNSS) by and even hybridized with positioning based on communication networks. The ability to use multiple GNSSs improves the accuracy, integrity and availability of positioning, especially in urban areas. There is a very large offer of different types of GNSS receivers today, with highly variable performances and costs. The performance of a GNSS may be improved by data fusion, namely by integrating sensor measurements, other positioning means or a priori data such as digital data bases. This data fusion brings enhancement at three levels: (1) standard position, velocity and time (PVT) are improved in terms of availability, accuracy, and integrity; (2) additional information, such as attitude angles, may be provided, and (3) the output rate is increased by one or two orders of magnitude. One of the most influential trends in GNSS is the use of multiple systems to achieve better error mitigation (e.g. multipath), resistance to interference and positioning accuracy. Ground and satellite based augmentation systems will also be used more in the future to improved position accuracy and integrity. Furthermore, in this project we will consider cyber and information security in an augmented GNSS, which may influence PVT.

The GNSS positioning principle relies on trilateration by which an unknown point location (receiver) is estimated using distance measurements observed from known point locations (satellites)(Groves, 2013). The basic observable of the system is the travel time required for a signal to propagate from the satellite to the receiver multiplied by the speed of light to compute distance. The receiver could then be located anywhere on the surface of a sphere centered on the satellite with a radius that equals this distance. The quality of raw GNSS observables is affected by several factors originating from satellites, signal propagation, and receivers. The signal transmitted by a satellite propagates through the atmosphere, where it is subject to delays caused by the ionosphere and troposphere. The effects of these delays are only partially compensated for by global models in single frequency receivers.

At the ground level, multipath, namely the reception of signals reflected from objects like buildings surrounding the receiver, can occur, inducing one of the largest errors that is difficult to model, as it is strongly depends on the receiver environment. The worst situations are experienced when only reflected signals are received (non-line-of-sight signals, or (NLOS) signals, resulting in pseudo-range errors of several tens of metres or greater in extreme cases.

Finally, random errors are encountered at the receiver level due to receiver thermal noise. The receiver clock offset (much larger than that of the satellite) does not create any error, since it is considered as an unknown and is calculated together with the position. The position error that results from the measurement errors above, which is referred to as dilution of precision (DOP) depends also on the relative geometry between the receiver and the satellites. Accuracy is maximized when the directions to tracked satellites are more uniformly spread around the receiver.

The main task of a GNSS is to provide localization and time synchronization services. There are multiple GNSS systems available. The most well-known one is the global positioning system (GPS). GPS data is transmitted via coarse/acquisition (C/A) code, which consists of unencrypted navigation data. The encrypted (military) signal is called the precision-code, which is also broadcast by every satellite. It has it is own PRN codes, but it is in the order of 1012 bits long. When locked onto the signal, the receiver receives the Y code, which is an encrypted signal with an unspecified W code (Loukas et al., 2013; Humphreys, 2013). Only authorized users can decipher this. In later GPS satellites, extra features were added (Radoslav et al., 2014; Uma and Padmavathi, 2013). There are several methods of augmenting GNSS data to get better estimates of location. Three of these are satellite-based augmentation systems (SBASs), assisted-GPS, and differential-GPS. SBASs were the first type to be developed; these systems are commonly used in airplanes, for critical phases such as the landing phase. They consist of a few satellites and many ground stations. A SBAS covers a certain GNSS for a specific area, and for every GNSS, accuracy depends heavily on, and is influenced by external factors (Grove, 2013). These factors affect not only GNSS applications, but also every other wireless transmission application. Furthermore, the satellites orbit the earth at a height of approximate 20.000 km, and at this height, signals can be affected in many ways. According to (Grove, 2017), “space weather”, and solar conditions affect signals too. A GNSS requires exact timing on the order of nanoseconds to determine position, but when, a satellite signal reaches earth, it can reflect from buildings and other objects, causing an increase in travel time and influencing measurements.

3 SYSTEM MODEL

In this model, the urban road is divided into sections, and each road section is assigned an intelligent vehicle agent (IVA). The goal of the IVA is to manage the adaptive traffic and to serve the autonomous vehicle.

The functionality of the system model works on three levels: the performance of the GNSS- based positioning terminal, and the performance of the system at the service error level. Autonomous vehicles (AVs) are sometimes referred to as *driverless vehicles* or *self-driving vehicles*. They offer many advantages and are expected to appear on the commercial market by 2030. Comfort is one obvious advantage, but in the current society, the practical advantages of AVs become clearer every day. Due to increased congestion on roads, productivity decreases and money is wasted on fuel and time. Cooperative AVs (Jawhar et al., 2013) enhance traffic flow, and in regard to road safety, smart vehicles are likely to decrease the number of injuries and fatalities. AVs collect information from the environment during their activity. However, these autonomous technologies are subject to malicious input, and are lacking in security. From a security-by-design perspective this is wrong, because a decision made by an AV is only as good as the sensors can perceive. A faulty observation can lead to dangerous situations.

4 METHODOLOGY

The performance of any system can be characterized with respect to different features, or characteristics. For ITS and mobility applications, the most relevant performance features are availability, accuracy and integrity. These features can be relevant for different outputs of the terminal, such as horizontal position, altitude, longitudinal speed, etc. As a result, a large number of combinations of features and outputs can be assessed during the performance characterization of a positioning terminal. Each characterization process calls for a performance metric (or indicator). A performance metric involves a precise definition of the means of measuring a given performance feature of a given system output. A performance metric is necessarily associated with a standardized test protocol defining the test procedures and means (test vehicle, simulator, record and replay equipment, etc.), the test scenario and the way the test results will be transformed into indicators. The test scenario should precisely define the set-up conditions of the terminal (in particular of the GNSS receiver antenna), the trajectory, the sample size, the environmental conditions, the interference conditions, so forth. It should reflect as faithfully as possible the real operational conditions under which the ITS system using the positioning terminal will operate.

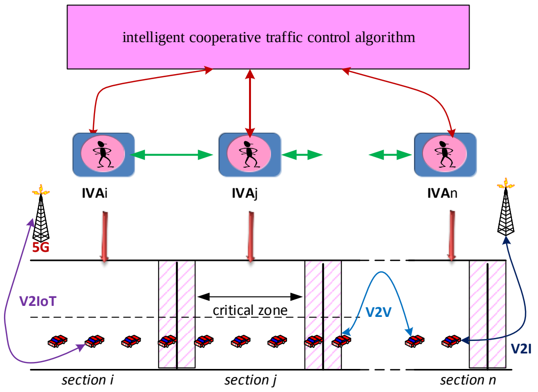

Figure 1: System model.

- Availability in ITS

Availability refers to the percentage of time during which the output of the positioning terminal is available. This feature can be defined in many different ways according to the needs of the application. In general, availability refers to the percentage of the measurement epochs (time periods) when the considered output is delivered with the required performance. A more straightforward metric would simply be the percentage of the measurement epochs when the considered output is delivered by the terminal, regardless of its quality.

- Accuracy in ITS

This feature refers to the statistical representation of the merit of position error, velocity error or speed error. Accuracy metrics have to be constructed based on the statistical distribution of errors.

- Integrity in ITS

The concept of integrity was introduced in civil aviation to measure performance affecting safety, for example, executing a safe landing. It is not enough that errors be small on average (accuracy); they must remain small for every landing (integrity). Given the focus of this document, dedicated to road transport and mobility, the definitions for integrity are inspired by, but significantly simpler than, the definitions used by the civil aviation community. High accuracy does not mean high integrity.

4.1 Positioning Error Modelling (PEM)

Position error modeling is mandatory for a sensitivity analysis that checks for the compatibility of a given position terminal with a given application algorithm in a given environment. In view of what we have mentioned in previous sections, it is challenging to model errors at the level of raw measurements (or observables) and to propagate this model through the navigation algorithm, which most of the time is unknown and is always non-linear. The most efficient method is to identify a model that captures real errors observed at the position error modeling level as closely as possible. The proposed methodology applies to various environments, which calls for a variety of models.

Figure 2 illustrates the sensitivity analysis, which is based on field tests of a GNSS-based positioning terminal (GBPT) carried out under real conditions to identify a positioning error model.

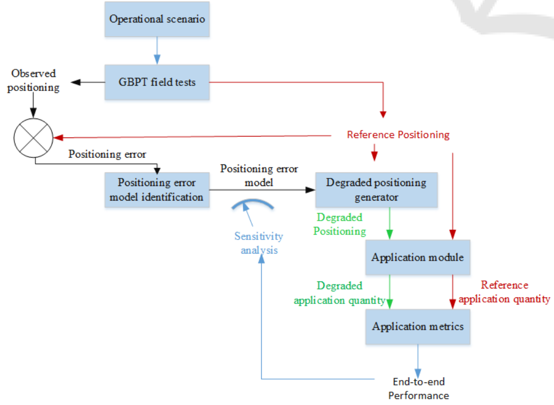

Figure 2: Operational scenario.

4.2 Quality of GNSS Data

AVs may receive data from various sources. The central monitor has the task of measuring the quality of received data in the AV network. There are two kinds of data: data for travel forecasting (Broggi et al., 2013; Ramm and Schwieger, 2007) and data for vehicle positioning estimation (Alger, 2014). In general, data quality is defined as data that is suitable for use (Raiyn, 2017). In AVs data quality involves delivering the right data to the right user at the right time and correct data enables the making of reliable, and accurate decisions. Low quality data can lead to traffic congestion and collision. In general, there are three main approaches that use performance metrics to test the global performance of a GNSS-based positioning terminal: filed tests, lab tests, and record and replay tests. This section discusses the impact of these approaches.

- Field Tests

Field tests were performed by SaPPART to collect data. The car used was equipped with uBlox and smartphones. Figure 3 illustrates the data collection in North Paris. The data are incomplete due to urban noise produced by network tunnels.

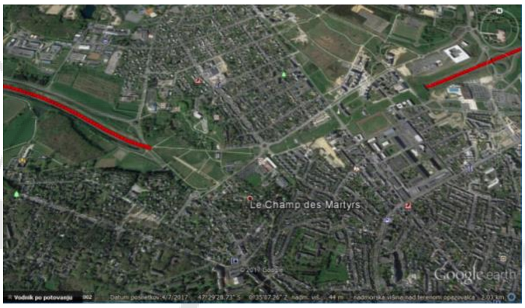

Figure 3: Field tests.

- Lab Tests

Simulations were carried out using MATLAB, due to the fact that the observations of the traffic were incomplete and were a noisy function of the unobservable state process which can be observed only through noise measurements. In cases where the system received incomplete GNSS data as illustrated Figure 4, the system combined historical GNSS data with map matching to supply the missing data.

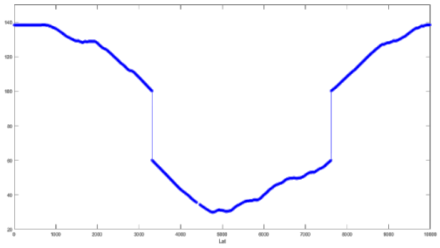

Figure 4: Lab tests.

The newly received data set was compared to the available data set. Innovative data were characterized by statistical measurement as illustrated in Figure 5.

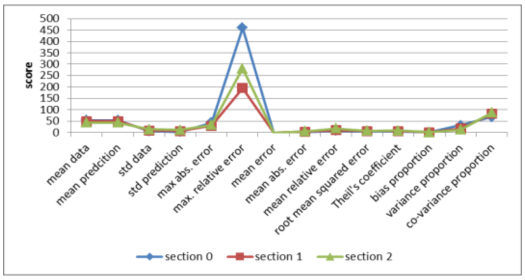

Figure 5: Data analysis based on SEM.

4.3 Algorithm Description

The algorithm describes the message exchanges between an intelligent vehicle agent (IVA) and an AV. The IVA updates the AV about the urban road traffic through a communications protocol based on message exchanges.

Algorithm I: send message

```
for all $AV_i$ do
    At $ts_1$, leader sends its current acceleration and speed
    At $ts_{j-1}$, $AV_j$ receives its current speed $v_c$ and acceleration
        At $ts_j$, leader gets from $IAV_j$
End for
```

Algorithm II: received message

```
for all $AV_i$ do
    At $ts_1$, autonomous vehicle $AV_j$ receives the acceleration and
    speed $v_c$ from the leader
    At $ts_{j-1}$, $AV_j$ receives the acceleration from its precedent vehicle
    At $ts_j$, $AV_j$ transmits its current acceleration to its follower
End for
```

Algorithm III: compute forecasting speed

```
for all $AV_i$ do
    At $ts_1$, leader computes its forecasting speed
    At $ts_1$, leader sends its next acceleration and speed
    forecasting
    At $ts_j$, leader gets from $IVA_j$ computed next acceleration
    to use at the next updating cycle
End for
```

Algorithm IV: follower strategy

```
for all $AV_i$ do
    At $ts_1$, $AV_j$ receives the acceleration and speed
    from the leader
    At tsj-1, $AV_j$ computes its predicted speed based on its
    current acceleration
    At tsj-1, $AV_j$ compute its next acceleration
    At tsj, $AV_j$ transmits its next acceleration to its follower
End for
```

4.4 Informative Speed Adaption

Informative speed adaptation (ISA) uses the exponential moving average (EMA) scheme for travel speed forecasting. The algorithm forecasts travel observations based on the EMA for the designated urban road. Its procedure is as follows.

4.4.1 Short-Term Forecasting based on Historical Information

The historical database is a collection of past travel observations of the system. The exponential smoothing forecasting method gives unequal weight to the observed time series. This is accomplished by using one or more smoothing parameters, which determine how much weight is given to each observation. The major advantage of the exponential smoothing method is that it provides good forecasts for a wide variety of applications. In addition, the data storage and computing requirements are minimal, which makes exponential smoothing suitable for real-time forecasting.

$$tt(t+1,k) = \alpha * tt^{M}(t,k) + (1-\alpha) * tt^{H}(t,k) \qquad (1)$$

where $0 < \alpha \leq 1$, $tt^M(t, k)$ is the actual travel time in section k at time t, and $tt^H(t, k)$ is the historical travel time in section k at time t.

4.4.2 Short- Term Forecasting based on RT Information

The occurrence of abnormal conditions in traffic flow travel information decreases of forecasts based on historical information and may increase the complexity of the forecasting of unusual incidents. The forecasting model based on real-time information gives a little weight to historical information and great weight to real-time observations.

$$tt(t+1,k) = tt^{H}(t+1,k) + \gamma * (tt^{M}(t,k) - tt^{H}(t,k)) \qquad (2)$$

where $0 < \gamma < 1$.

4.5 Description of the Positioning Error

The ISA application is based on geo-objects specified by latitude and longitude. Positioning errors and angle errors were cloned and these clones were combined to create “clone trajectories”. The reference trajectory was used, and the clone points were computed by adding cloned radius and angles into reference points as illustrated in figure 6.

$$x_{cloned} = x_{ref} + \sin(yaw_{ref} - Angle) * Radius \quad (3)$$

$$y_{cloned} = y_{ref} + \cos(yaw_{ref} - Angle) * Radius \quad (4)$$

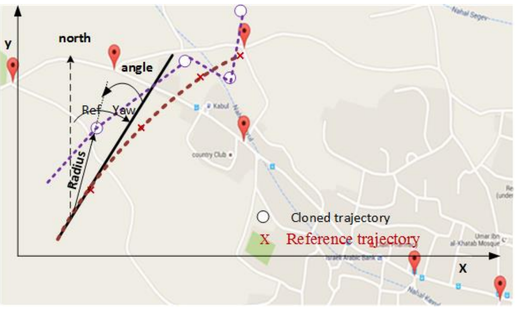

Figure 6: Positioning error model.

5 IMPLEMENTATION

This section describes informative speed adaptation (ISA). The algorithm introduced here and used for informative speed adaptation (ISA) is also known as an *intelligent speed limiter*, or *intelligent speed assistance*, or an *intelligent speed alerting* or *intelligent speed authority*. The purpose of ISA is to mitigate speeding, (i.e., drivers' travelling at speeds above the legal speed limit). This is accomplished by informing or alerting the driver, or even by taking control of the vehicle, depending on the system design. The prevailing speed limit is generally obtained through a real-time map-matching process that requires localization via GNSS and a digital map with up-to-date speed limit information. Applying a GNSS to calculate travel time has proved to be effective in terms of accuracy. In this case, GNSS data are managed to reduce traffic congestion and road accidents.

The road is divided into sections as illustrated in Figure 7. For each section the speed has been forecast based on real-time travel observations. The IVA system updates each AV on the speed limit in each section. An intelligent vehicle agent (IVA) updates each AV on the travel speed in its road section. Figure 8 illustrates the impact of GNSS positioning error on the evaluation of ISA. In sections where the GNSS positioning error is high, the traffic congestion is greater (red color). Figure 9 shows that the performance of ISA is improved by positioning error correction. Figure 10 illustrates the short term travel forecasts for road sections. The travel forecasting is based on exponential moving average with the optimization of alpha and gamma.

Figure 11 illustrates the evaluation of the forecast scheme EMA. The root mean square error increases in sections where GNSS positioning error is high.

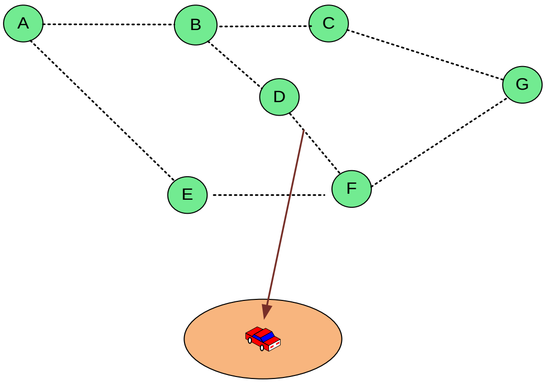

Figure 7: Road partitioning.

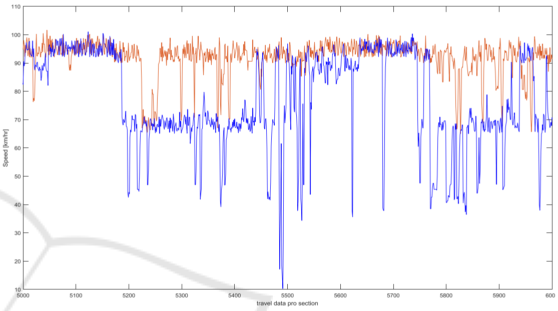

Figure 8: Travel speed.

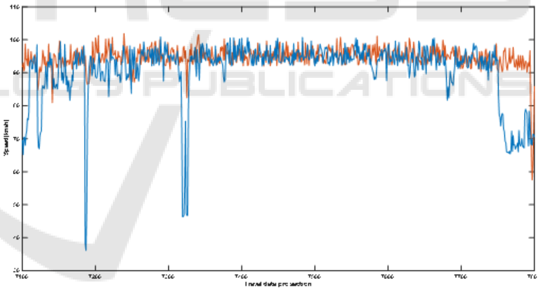

Figure 9: Positioning correction.

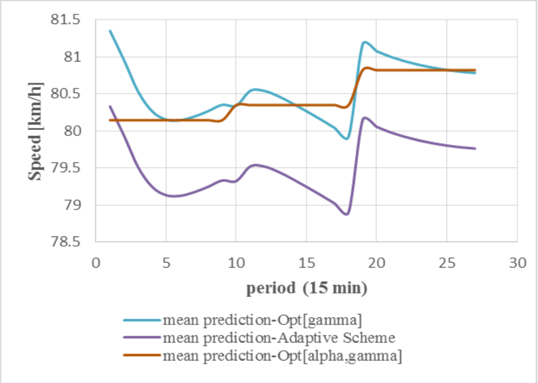

Figure 10: Mean travel speed prediction.

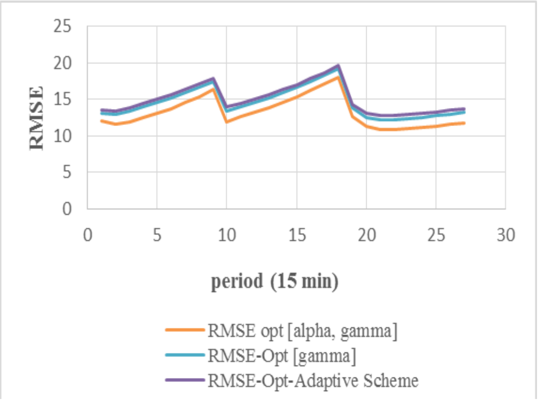

Figure 11: Root mean square error.

6 CONCLUSION AND FUTURE WORK

In general, schemes that have been proposed involve forms of centralized management, which may achieve near- optimum performance in whole systems in regard to maximum capacity. However, as the number of vehicles increases, centralized computation may become mathematically intractable. Such schemes are also impractical when traffic varies significantly and creates difficulties for measuring actual conditions. The major disadvantage of centralized management is the occurrence of deadlock, which causes the whole system to collapse. To reduce the overload in computational management time, we consider the management of urban road traffic in distributed form, and for this, we propose the use of decentralized management. The proposed approach is based on intelligent vehicle agent techniques; it aims to reduce several types of traffic congestion and their effects, such as delays, waiting time, driver stress, air and noise pollution, and economic costs. Informative speed adaptation is used to update AVs in order to determine the shortest route from the source to the destination node based on short- term forecasting. The update phase is used to inform the AVs about new events during the trip, and the updated information is used to reduce road traffic congestion. In keeping with the updated information, vehicles are allocated the appropriate road sections, and drivers can select new sections with low traffic congestion.

REFERENCES

Alger, M., 2014. Real-Time Traffic Monitoring Using Mobile Phone Data, *Proceedings of 49th European Study European Study Group with Industry*, Oxford, United Kingdom.

Broggi, A. et al., 2013. Extensive Tests of Autonomous Driving Technologies, *IEEE Transactions on Intelligent Transportation Systems 14.3*. pp. 1403–1415.

Du, J., Masters, J. , Barth, M., 2004. Lane-Level Positioning for In-Vehicle Navigation and Automated Vehicle Location (AVL) Systems. *2004 IEEE Intelligent Transportation Systems Conference*, pp. 1–3.

Fleming, W. J. J. 2001. Overview of automotive sensors. *IEEE Sensors Journal 1.4*, pp.
296–308.

Groves, P.D. 2011. Shadow Matching: A New GNSS Positioning Technique for Urban Canyons. *The Journal of Navigation, 64*, pp.417–430.

Groves. D.P., 2013. Principles of GNSS, inertial, and multisensor integrated navigation systems. *Artech house*.

Loukas, G., Gan, D., Vuong, T. 2013. A Review of Cyber Threats and Defence Approaches in Emergency Management. In: Future Internet 5.2, pp. 205–236.

Humphreys,T.E. 2013. Detection Strategy for Cryptographic GNSS Anti-Spoofing. *In: IEEE Transactions on Aerospace and Electronic Systems 49.2* . pp. 1073–1090.

Jawhar, I., Mohamed,N., Usmani, H. 2013. An Overview of Inter-Vehicular Communication Systems, Protocols and Middleware. *Journal of Networks 8.12* (Dec. 2013), pp. 2749–2761.

Quddus, M.A. Ochieng, W.Y,. Noland, R.B.. 2007. Current map-matching algorithms for transport applications: State-of-the art and future research directions, *Transportation Research Part C* 15. pp. 312–328.

Ramm, K. and Schwieger, V., 2007. Mobile positioning for traffic state acquisition, *J. Location Serv.; 1(2)*. pp. 133–144.

Radoslav , I., Pajic, M. Lee., I. 2014. Attack-resilient sensor fusion. *Proceedings of the conference on Design, Automation & Test in Europe. European Design and Automation Association.*, p. 54.

Raiyn,J., 2016. Speed Adaptation in Urban Road Network Management, *Transport and Telecommunication*, 17, 2. pp. 11-121.

Raiyn, J. 2017. Road traffic congestion management based on search allocation approach, *Transport and Telecommunication. 18. (1)*. pp. 25-33.

Uma, M. Padmavathi,G. 2013. A Survey on Various Cyber Attacks and their Classification, *International Journal of Network Security*, vol. 15, no. 6, , pp. 391-397.

Zandbergen, A.P., 2009. Accuracy of iPhone Locations: A Comparison of Assisted GPS, WiFi and Cellular Positioning, *Transactions in GIS, 13(1)*, pp. 5-16.