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# The Role of Location Based Technologies in Intelligent Transportation Systems

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**Abstract:** Information Technology (IT) has played a significant role in enhancing the efficiency of modern day transportation systems. Recent advances in sensors, communication and information systems have enabled transportation systems to be more intelligent. Various location technologies and data integration methods (also known as map-matching algorithms) are used to support the navigation modules of such transport systems. This study provides a survey of location based technologies that encompass an Intelligent Transportation System (ITS) and provides an insight into the Required Navigation Performance (RNP) parameters that are required for decision-making in efficient delivery of transport systems. The reseachers also describe how various location sensors and map-matching algorithms are capable of supporting the navigation modules of ITS.

**Key words:** GPS, Intelligent Transportation Systems (ITS), positioning technologies, map-matching algorithms, sensors, navigation

## INTRODUCTION

Intelligent Transport Systems (ITS) have the potential to improve safety, mobility and efficiency and at the same time are able to reduce congestion and environmental impacts through the use of advanced computer, communication, navigation, information and vehicle sensing technologies (Sussman, 2005). Most ITS services such as navigation and route guidance (In car navigation such as TomTom), bus arrival information at bus stops (Countdown in London), fleet management (GPS based taxi dispatching service in Singapore) and distance based car insurance premiums (Norwich Union in the UK) require positioning data while travelling on a road network to perform a specific task. Positioning data for ITS applications are normally obtained from a range of location sensors such as Global Navigation Satellite System (GNSS), gyroscopes, vehicle odometer, accelerometers, network-wide static sensors or through a combination of these sensors. Apart from the GNSS, there are also several network technologies that can be successfully used for positioning measurements. Cellular networks use a method known as Cell Tower Triangulation where the cell towers which receive a phone's signal may be used to calculate its geophysical location. In Wireless Local Area Networks (WLAN), location determination can be measured by using the signal strengths of the radio signals from at least one of the multiple access points. The exact location is then obtained using measurements from several access points or through finger printing where the measured signal strength values are compared with stored signal strength values from calibrated points. In Ultra Wide Band (UWB) systems, location determination can be measured by using the accurate Time of Arrival (ToA) which is used for estimation of distance or Time Difference of Arrival (TDoA) used for distance difference estimation of the received signals from several base stations. Bluetooth which was originally developed for short-range wireless communication can be employed for locating mobile devices in a certain cell area that is represented by the range of the device which is typically <10 m.

Location sensors play a critical role in the successful introduction of ITS services. It is important to get good quality of real-time vehicle positioning data obtained from location sensors. The quality of such data is normally demonstrated by several parameters such as accuracy, integrity, continuity and availability. These quantities are usually referred to as Required Navigation Performance (RNP) parameters (Ochieng and Sauer, 2002; Kibe, 2003; DOT (Department of Transportation), 2004). It is essential to fully understand these RNP parameters in the context of road transport applications for the successful deployment of location based ITS services. In addition to this, it is also important to map a wide range of positioning requirements against the performance offered by different positioning technologies and sensors or map-matching methods. In order to establish the degree to which they are able to meet the RNP standards for a range of ITS applications; this study reports the results of a literature review on performance of navigation sensors and their integration.

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## SURVEY OF TECHNOLOGIES THAT ARE BEING USED BY EXISTING (ITS)

The integration of GPS with spatial road network data along with computer, communication, information and vehicle sensing technologies is regarded as one of the key enabling technologies in ITS (Klein, 2001; Chowdhury and Sadek, 2003; Quddus, 2006).

A number of navigation sensors are normally used to obtain positioning data for these services including:

- Dead Reckoning (DR) systems which use a relative positioning technique to determine the location of a moving vehicle requiring vehicle speed and its direction of movement at each point
- Ground based beacon systems
- Global Navigation Satellite Systems (GNSS) such as GPS, Global Navigation Satellite System (GLONASS) and Galileo system (to be operational in the near future)

The details of positioning technologies can be found in Chadwick (1994), Drene and Rizos (1997), Zhao (1997), Farrell and Barth (1999), Kealy *et al.* (2001), Greenfeld (2002), Zhao *et al.* (2003), Mintsis *et al.* (2004), Godha and Cannon (2005) and Kaplan and Hegarty (2006). Recently GNSS has become more popular as it offers a fast and convenient method of obtaining positioning data that is well-suited for viewing in a Geographic Information System (GIS). As of 2011, the United States GPS is the only fully operational Global Navigation Satellite System (GNSS). GLONASS is in the process of being restored to full operation. The third satellite based navigation system, the Galileo system is in the initial development phase and is scheduled to be operational by 2012. However, the performance of stand-alone GPS especially in dense urban areas is not so good due to signal masking and multi-path errors (Chen *et al.*, 2003; Zhao *et al.*, 2003; Li *et al.*, 2005; Quddus *et al.*, 2006; Nassreddine *et al.*, 2008).

Therefore, it is often necessary to integrate GPS with other positioning systems such as DR to improve the vehicle location information in the absence of signal availability (Zhao *et al.*, 2003; Phuyal, 2002). A data integration method or Map-Matching (MM) algorithm is then used to augment positioning data from a navigation system (either GPS or GPS/DR) with spatial road network data.

The general purpose of a map-matching algorithm is to identify the correct road segment on which the vehicle is travelling and determine the vehicle location on that segment (Greenfled, 2002; Quddus *et al.*, 2003; Fu *et al.*, 2004; Marchal *et al.*, 2005; Taghipour *et al.*, 2008; Zuyun *et al.*, 2008; Pink and Hummel, 2008; Newson and Krumm, 2009; Velaga *et al.*, 2009; Fouque and Bonnifait, 2010; Velaga *et al.*, 2011).

A literature review was conducted on the performance of existing positioning systems and map-matching algorithms. The available measures in the literature are shown in Table 1. The performance measures are primarily expressed in terms of the identification of correct road segments (%) and 2D horizontal accuracy (95%).

Table 1: The performance of existing map matching algorithms

| Researcher and year | Navigation sensors used | Test environment | Correct link identification (%) | 2D horizontal accuracy (m) |
|---|---|---|---|---|
| White *et al.* (2000) | GPS | Suburban | 85.5 | - |
| Kim *et al.* (2000) | GPS | Suburban | - | 10.6 (100%) |
| Kim and Kim (2001) | GPS/DR | Urban and suburban | - | 15.0 (100%) |
| Pyo *et al.* (2001) | GPS/DR | Urban and suburban | 88.8 | - |
| Taylor *et al.* (2001) | GPS+Height | Suburban | - | 11.6 (95%) |
| Bouju *et al.* (2002) | GPS | Suburban | 91.7 | - |
| Quddus *et al.* (2003) | GPS/DR | Urban | 89.0 | 18.1 (95%) |
| Yang *et al.* (2003) | GPS | Suburban | 96.0 | - |
| Srinivasan *et al.* (2003) | GPS | Suburban (On university roads) | 98.5 | - |
| Syed and Cannon (2004) | GPS/DR | Urban and suburban | 92.8 | - |
| Ochieng *et al.* (2003) | GPS/DR | Urban and suburban | 98.1 | 9.1 (95%) |
| Yin and Wolfson (2004) | GPS | Urban | 92.0 | - |
| Basnayake *et al.* (2005) | GPS/DR | Urban and suburban | 95.0 | - |
| Blazquez and Vonderohe (2005) | DGPS | Urban and suburban | 98.0 | - |
| Chen *et al.* (2005) | GPS/DR | Urban | 95.0 | - |
| Quddus *et al.* (2006) | GPS/DR | Suburban | 99.2 | 5.5 (95%) |
| Yu *et al.* (2006) | GPS/DR | Urban | 95.6 | 10.0 (95%) |
| Taylor *et al.* (2006) | GPS+Odometer+Height | Urban | - | 10.1 (95%) |
| Haibin *et al.* (2006) | GPS | Urban | 100.0 | - |
| Wu *et al.* (2007) | GPS | Urban | >90.0 | - |
| Liu *et al.* (2008) | GPS/DR | Suburban | 98.0 | - |
| Fouque and Bonnifait (2010) | GPS/DR | Suburban | 99.7 | - |
| Yuan *et al.* (2010) | GPS | Urban | 86.0 | - |
| Velaga *et al.* (2010) | GPS | Urban | 97.8 | 9.1 (97.5%) |

## REQUIRED NAVIGATION PERFORMANCE (RNP) PARAMETERS

The RNP navigation system performance parameters (Accuracy, Integrity, Continuity and Availability) defined by FRP (Federal Radionavigation Plan) (1999), Ochieng and Sauer (2002), Kibe (2003), Ochieng *et al.* (2003), DOT (Department of Transportatiom) (2004) and Quddus (2006) in the context of land navigation are summarised below.

Accuracy can be defined as the degree of conformance between the estimated or measured position of a point at a given time and its true or standard position. The true or standard position can be obtained from an independent source of high accuracy measurement such as GPS carrier phase observables (i.e., observations with accurate GPS) or high-resolution satellite imagery.

Integrity is the ability of a system to provide timely warnings to users when the system should not be used for navigation or positioning. Integrity has three components: Alert Limit (AL), Time To Alarm (TTA) and Integrity Risk (IR). AL is the error tolerance not to be exceeded without issuing an alert to the users. It represents the largest error that can support safe operation. TTA is the duration between the onset of a failure (i.e., error greater than Allowable error (AL) limit) and an alert being issued by the user's receiver. IR is the probability that an error exceeds the alarm limit without the user being informed within the time to alert.

Continuity is the ability of a total system to perform its function without interruptions during the intended period of operation. Continuity Risk (CR) is the probability that the system will be interrupted and will not provide guidance information for the intended period of operation. CR is the measure of system uncertainty.

The availability of a navigation system is the percentage of time that the services of the system are usable within a specified coverage area. The service is available if the accuracy, integrity and continuity requirements are satisfied.

The RNP parameters such as accuracy, integrity, continuity and availability for various ITS services each with unique positioning requirements are shown in Table 2. It is noticeable from Table 2 that the requirements for only two RNP parameters (Accuracy and availability)

Table 2: Required Navigation Performance (RNP) parameters for ITS

| | | | Integrity | | | | |
|---|---|---|---|---|---|---|---|
| ITS user group | Source | Accuracy in m (95%) | Alarm limit (m) | Time to alarm (sec) | Integrity risk (Per 1 h) | Continuity risk (Per 1 h) | Availability (%) |
| **Highway** | | | | | | | |
| Navigation and route guidance | DOT (Department of Transportation) (2004) | 1-20 | 2-20 | > = 5 | - | - | >95.0 |
| | Quddus (2006) | 5-20 | - | 1-15 | - | - | 99.7 |
| | FRP (Federal Radionavigation Plan) (1999) | 5-20 | - | - | - | - | - |
| | Ochieng and Sauer (2002) | 5 | - | 1 | - | - | 99.7 |
| | Feng and Ochieng (2007) | 5-20 | 7.5-50 | 10 | $10^{-6}$ | $10^{-5}$ | 99.7 |
| Automated vehicle identification | DOT (Department of Transportation) (2004) | 1 | 3 | > = 5 | - | - | 99.7 |
| | FRP (Federal Radionavigation Plan) (1999) | 30 | - | - | - | - | - |
| | Sheridan (2001)[1] | 10-50 | 50 | 300 | - | - | >99.0 |
| Automated vehicle monitoring | Ochieng *et al.* (2007)[2] | 5 | - | - | - | - | - |
| | DOT (Department of Transportation) (2004) | 0.1-30 | 0.2-30 | 5-300 | - | - | >95.0 |
| | FRP (Federal Radionavigation Plan) (1999) | 30 | - | - | - | - | - |
| | Feng and Ochieng (2007) | 30 | 75 | 10 | $10^{-6}$ | $10^{-5}$ | 99.7 |
| Emergency response | DOT (Department of Transportation) (2004) | 0.3-10 | 0.5-10 | Near zero | - | - | 99.7 |
| | Ochieng and Sauer (2002) | 5 | - | 1 | - | - | 99.7 |
| | Quddus (2006) | 5-10 | - | 1-5 | - | - | 99.7 |
| Collision avoidance | DOT (Department of Transportation) (2004) | 0.1 | 0.2 | 5 | - | - | 99.9 |
| | FRP (Federal Radionavigation Plan) (1999) | 1 | - | - | - | - | - |
| | Quddus (2006) | 1 | - | 1-15 | - | - | 99.7 |
| | Feng and Ochieng (2007) | 1 | 2.5 | 1 | $10^{-7}$ per case | $10^{-5}$ | 99.7 |
| Accident survey | DOT (Department of Transportation) (2004) | 0.1-4 | 0.2-4 | 30 | - | - | 99.7 |
| **Transit** | | | | | | | |
| Vehicle command and control | DOT (Department of Transportation) (2004) | 30-50 | - | - | - | - | 99.7 |

Table 2: Continue

| ITS user group | Source | Accuracy in m (95%) | Integrity: Alarm limit (m) | Integrity: Time to alarm (sec) | Integrity: Integrity risk (Per 1 h) | Continuity risk (Per 1 h) | Availability (%) |
|---|---|---|---|---|---|---|---|
| | Quddus (2006) | 30-50 | - | 1-15 | - | - | 99.7 |
| | FRP (Federal Radionavigation Plan) (1999) | 30-50 | - | - | - | - | - |
| Automated voice bus stop announcement | DOT (Department of Transportation) (2004) | 5 | - | - | - | - | 99.7 |
| | Quddus (2006) | 5-10 | - | 1-15 | - | - | 99.7 |
| Emergency response | DOT (Department of Transportation) (2004) | 75-100 | - | - | - | - | 99.7 |
| | FRP (Federal Radionavigation Plan) (1999) | 75-100 | - | - | - | - | - |
| Data collection | DOT (Department of Transportation) (2004) | 5 | - | - | - | - | 99.7 |
| | FRP (Federal Radionavigation Plan) (1999) | 5 | - | - | - | - | - |

Automated vehicle identification for road tolling and taxation purpose; Vehicle monitoring for GPS based VRUC

are fully reported in the literature for the case of land transport. There is partial information (Alarm limit and time to alarm) on the integrity parameter for some services. Interestingly, there are no definitions of the requirement for continuity in the literature. This suggests that the impact of continuity (i.e., the consequence of a loss of either system accuracy or integrity) on the performance of a system is yet to be determined for road transport systems.

As shown in Table 2, the level of accuracy, integrity and availability required for different ITS applications vary significantly. For instance, the values of accuracy (0.1-20 m, 95% of the times) and availability for vehicle navigation and route guidance are high (i.e., low requirements) compared with those of collision avoidance service. This is because safety is the most critical criterion for the collision avoidance service.

## MAPPING RNP REQUIREMENTS WITH EXISTING POSITIONING SYSTEMS

It is interesting to see whether existing positioning technologies along with available map-matching algorithms are able to support RNP parameters of various ITS applications and services discussed in the study. Table 1 shows the performance of existing positioning systems that use map-matching algorithms. The algorithm developed by Haibin *et al.* (2006) is capable of identifying the correct road segments 100% of the time. However, their study does not report the positioning accuracy offered by their algorithm. A map-matching algorithm by Fouque and Bonnifait (2010) succeeded in identifying correct road segments 99.7% of the time. However, their study was conducted in a suburban area and did not measure the horizontal accuracy. The fuzzy logic-based map-matching algorithm which takes input from GPS/DR and a high quality digital map (Scale 1:1,250) developed by Quddus *et al.* (2006) is capable of identifying 99.2% of the links correctly with the horizontal positioning accuracy of 5.5 m (95% confidence interval) for suburban road network and in case of urban road network, the algorithm can identify 98.5% of the links correctly. High accuracy map-matching algorithms developed in recent years have the potential to meet the accuracy requirements of many ITS services including stolen vehicle recovery, fleet management, parcel delivery services, taxi services, secure transport services, haulage companies, traveller services information, on-board emissions monitoring, route guidance, automatic vehicle location, accident and emergency service, electronic payment system and bus priority at junctions. However, it is obvious from Table 2 that more accurate positioning accuracy (<5 m (95%)) is required for some ITS applications. Examples include longitudinal collision avoidance, intersection collision avoidance, automated vehicle monitoring and accident survey ITS services. Moreover, none of the existing map-matching algorithms provides all the other RNP parameters integrity, continuity and availability information. But for few ITS services (Safety critical applications such as vehicle based collision warning and avoidance, intersection collision warning and avoidance, emergency vehicle routing and management and other services which commercial issues are major parameters to drive RNP such as variable road user charging, vehicle electronic parking distance based pay-as-you-go insurance scheme) informing users when the system is not useable (i.e., Performance falls below acceptable level) is mandatory. Any failure to alert users or operators could cause loss of life or errors in charging which may raise legal issues.

The alternatives to achieving RNP requirements of all the ITS services could be either the integration of enhanced DGPS (Phase smoothed code or differential carrier phase) and high-grade Inertial Navigation Systems

(INS) or development of large scale qualitative digital maps or further enhancement of map-matching methods and development of integrity method. The integrity method provides a level of trust that can be placed in the output positioning information from navigation module of ITS (Quddus, 2006). Among these options the usage of high grade GPS and INS systems is costly and it may not be feasible to use such costly equipment for land vehicle navigation. Secondly, enhancement of spatial road maps for national level is a time consuming and costly process. Anyhow, as mentioned before, the good GIS map can improve accuracy to some extent but not integrity, continuity or availability of the system.

There have been significant advances in the enhancement of map-matching algorithms over the last few years. Such enhancements to the existing methods exploit all of the relevant data available from the key elements in this process i.e., GPS, DR and spatial road network data. As no extra data from other sensors are required, the improved map-matching algorithms can be implemented at no additional cost due to either the navigation sensors or map data. It is envisaged that an improved map-matching algorithm that can eliminate constraints and limitations of existing algorithms could improve the accuracy of GPS/DR/spatial road network data while taking into account the error sources associated with each of these elements. Further, development of an integrity method can provide user confidence on positioning output from navigation sensors. Moreover, the upcoming GNSS systems such as GLONASS, Galileo system, China's Bei-Dou, India's GAGAN (GPS and Geo-Augmented Navigation) system and IRNSS (Indian Regional Navigation Satellite System) and Japan's QZSS (Quasi-Zenith Satellite System) can improve the navigation performance particularly with respect to integrity, continuity and availability with limited improvement in accuracy.

## CONCLUSION

In this study, the researchers provided a detailed survey on the role of location-based technologies for Intelligent Transport Systems (ITS). We also provided an insight into the Required Navigation Performance (RNP) parameters that are required for decision-making in efficient delivery of transport systems. A detailed understanding of how various location sensors and map-matching algorithms are capable of supporting the navigation modules of ITS are also provided. This study has revealed that existing map-matching algorithms are capable of supporting the navigation modules of many ITS services. However, further enhancements of map-matching algorithms and development of integrity methods are essential for the navigation modules of some of the intelligent transport systems requiring positioning accuracy of <5 m (95%). This suggests that further research is required in this potential area.

## REFERENCES

Basnayake, C., O. Mezentsev, G. Lachapelle and M.E. Cannon, 2005. An HSGPS, inertial and map-matching integrated portable vehicular navigation system for uninterrupted real-time vehicular navigation. Int. J. Veh. Inform. Commun. Syst., 1: 131-151.

Blazquez, C.A. and A.P. Vonderohe, 2005. Simple map-matching algorithm applied to intelligent winter maintenance vehicle data. Transp. Res. Rec., 1935: 68-76.

Bouju, A., A. Stockus R. Bertrand and P. Boursier, 2002. Location-based spatial data management in navigation systems. IEEE Intell. Veh. Symp., 1: 172-177.

Chadwick, D., 1994. Projected navigation system requirements for intelligent vehicle highway systems. Proceedings of the 7th International Technical Meeting of the Satellite Division of the Institute of Navigation, Sept, 20-23, 1994, Salt Palace Convention Center, Salt Lake City, pp: 485-490.

Chen, W., M. Yu, Z.L. Li and Y.Q. Chen, 2003. Integrated vehicle navigation system for urban applications. Proceedings of the 7th International Conference on Global Navigation Satellite Systems, April 22-24, 2003, European Space Agency, Graz, Austria, pp: 15-22.

Chen, W., Z. Li, M. Yu and Y. Chen, 2005. Effects of sensor errors on the performance of map matching. J. Navig., 58: 273-282.

Chowdhury, M.A. and A. Sadek, 2003. Fundamentals of Intelligent Transportation System Planning. 1st Edn., Artech House, London.

DOT (Department of Transportation), 2004. Radionavigation systems: A capabilities investment strategy. A Report to the Secretary of Transportation, USA.

Drene, C. and C. Rizos, 1997. Positioning Systems in Intelligent Transportation Systems Artech House, London.

FRP (Federal Radionavigation Plan), 1999. Federal radionavigation plan. http://www.gpsworld.com/survey/the-federal-radionavigation-plan-9332.

Farrell, J.A. and M. Barth, 1999. The Global Positioning System and Inertial Navigation. McGraw-Hill, New York.

Feng, S. and W.Y. Ochieng, 2007. Integrity of navigation system for road transport. Proceedings of the 14th World Congress on Intelligent Transport Systems, Oct, 9-13, Beijing, China, pp: 1-6.

Fouque, C. and P. Bonnifait, 2010. Multi-hypothesis map-matching on 3D navigable maps using raw GPS measurements. Proceedings of the 13th International IEEE Annual Conference on Intelligent Transportation Systems, Sept. 19-22, Funchal, pp: 1498-1503.

Fu, M., J. Li and M. Wang, 2004. A hybrid map matching algorithm based on fuzzy comprehensive judgment. Proceedings of the 7th International IEEE Conference on Intelligent Transportation Systems, Oct, 3-6, 2004, Washington DC., USA., pp: 613-617.

Godha, S. and M.E. Cannon, 2005. Integration of DGPS with a MEMS-based inertial measurement unit (IMU) for land vehicle navigation application. Proceedings of the 18th International Technical Meeting of the Satellite Division of the Institute of Navigation, Sept. 13-16, Long Beach Convention Center Long Beach, CA., pp: 333-345.

Greenfeld, J.S., 2002. Matching GPS observations to locations on a digital map. Annu. Meeting Transp. Res. Board, 1: 1-13.

Haibin, S., T. Jiansheng and H. Chaozhen, 2006. A integrated map matching algorithm based on fuzzy theory for vehicle navigation system. IEEE, 6: 916-919.

Kaplan, E.D. and C.J. Hegarty, 2006. Understanding GPS: Principles and Applications. 2nd Edn., Artech House, Inc. USA., ISBN: 1-58053-894-2006.

Kealy, A., S. Scott-Young, F. Leahy and P. Cross, 2001. Improving the performance of satellite navigation systems for land mobile applications through the integration of MEMS inertial sensors. Proceedings of the 14th International Technical Meeting of the Satellite Division of The Institute of Navigation, Sept. 11-14, Institute of Navigation, Salt Lake City, pp: 1394-1402.

Kibe, S.V., 2003. Indian plan for satellite-based navigation system for civil aviation. Curr. Sci., 84: 1405-1411.

Kim, S. and J. Kim, 2001. Adaptive fuzzy-network based C-measure map matching algorithm for car navigation system. IEEE Trans. Ind. Electron., 48: 432-440.

Kim, W., G.I. Jee and J. Lee, 2000. Efficient use of digital road map in various positioning for ITS. Proceedings of the IEEE Position Location and Navigation Symposium (PLNS'00), San Deigo, CA., pp: 170-176.

Klein, L.A., 2001. Sensor Technologies and Data Requirements for ITS. Artech House, London, Pages: 549.

Li, X., H. Lin and Y. Zhao 2005. A connectivity based map-matching algorithm. Asian J. Geoinform., 5: 69-76.

Liu, S., Z. Shi, M. Zhao, W. Xu and K. Zhang, 2008. An urban map matching algorithm using rough sensor data. Proceedings of the 8th Workshop on Power Electronics and Intelligent Transportation System, Aug. 2-3, Guangzhou, pp: 266-271.

Marchal, F., J. Hackney and K.W. Axhausen, 2005. Efficient map matching of large global positioning system data sets tests on speed-monitoring experiment in Zurich. Transp. Res. Rec., 1935: 93-100.

Mintsis, G., S. Basbas, P. Papaioannou, C. Taxiltaris and I.N. Tziavos, 2004. Applications of GPS technologies in land transportation system. Eur. J. Operat. Res., 152: 399-409.

Nassreddine, G., F. Abdallah and T. Denoeux, 2008. Map matching algorithm using belief function theory. Proceedings of 11th International Conference on Information Fusion, June 30-July 3, Cologne, pp: 1-8.

Newson, P. and J. Krumm, 2009. Hidden markov map matching through noise and sparseness. Proceedings of the 17th ACM SIGSPATIAL International Conference on Advances in Geographic Information Systems, (GIS'09), ACM, New York, USA., pp: 336-343.

Ochieng, W.Y. and K. Sauer, 2002. Urban road transport navigation: Performance of GPS after selective availability. Transp. Res. C, 10: 171-187.

Ochieng, W.Y. and K. Sauer, 2003. GPS integrity and potential impact on aviation safety. J. Navig., 56: 51-65.

Ochieng, W.Y., M.A. Quddus and R.B. Noland, 2003. Map matching in complex urban road networks. Braz. J. Cartogr, 55: 1-18.

Ochieng, W.Y., R.J. North, M.A. Quddus and R.B. Noland, 2007. Technologies to measure indicators for variable road user charging. Universities Transport Study Group (UTSG) Conference, UK.

Phuyal, B.P., 2002. Method and use of aggregated dead reckoning sensor and GPS data for map matching. Proceedings of the 15th International Technical Meeting of the Satellite Division of the Institute of Navigation, Sept. 24-27, Portland, OR., pp: 430-437.

Pink, O. and B. Hummel, 2008. A statistical approach to map matching using road network geometry, topology and vehicular motion constraints. Proceedings of the 11th International IEEE Conference on Intelligent Transprotation Systems, Oct. 12-15, Beijing, pp: 862-867.

Pyo, J.S., D.H. Shin and T.K. Sun, 2001. Development of a map matching method using the multiple hypothesis technique. Proceedings of the IEEE Intelligent Transportation Systems, Aug, 25-29, Oakland, CA. USA., pp: 23-27.

Quddus, M.A., 2006. High integrity map matching algorithms for advanced transport telematics applications. Ph.D. Thesis, Centre for Transport Studies, Imperial College London, UK.

Quddus, M.A., R.B. Noland W.Y. BOchieng, 2006. A high accuracy fuzzy logic-based map matching algorithm for road transport. J. Intell. Transp. Syst., 10: 103-115.

Quddus, M.A., W.Y. Ochieng, L. Zhao and R.B. Noland, 2003. A general map matching algorithm for transport telematics applications. Earth Environ. Sci., 7: 157-167.

Sheridan, K., 2001. Vehicle performance and emissions monitoring system (VPEMS). VPEMS System Design Document, Version 2, July 2001.

Srinivasan, D., R.L. Cheu and C.W. Tan, 2003. Development of an improved ERP system using GPS and AI technique. Proc. IEEE Intell. Transp. Syst., 1: 554-559.

Sussman, J.M., 2005. Prospectives on Intelligent Transportation Systems. Springer-Verlag, Berlin, Heidelberg, New York, Pages: 232.

Syed, S. and M.E. Cannon, 2004. Fuzzy logic-based map matching algorithm for vehicle navigation system in urban canyons. Proceedings of the National Technical Meeting of the Institute of Navigation, Jan. 26-28, The Catamaran Resort Hotel San Diego, CA., pp: 982-993.

Taghipour, S., M.R. Meybodi and A. Taghipour, 2008. An algorithm for map matching for car navigation system. Proceedings of the 3rd IEEE International Conference on Information and Ommunication Technologies: From Theory to Application, April 7-11, 2008, Damascus, pp: 1-5.

Taylor, G., C. Brunsdon, J. Li and A. Olden, 2006. GPS accuracy estimation using map matching techniques: Applied to vehicle positioning and odometer calibration. Comput. Environ. Urban Syst., 30: 757-772.

Taylor, G., G. Blewitt, D. Steup, S. Corbett and A. Car, 2001. Road reduction filtering for GPS-GIS navigation. Trans. GIS, 5: 193-207.

Velaga, N.R., M.A. Quddus and A.L. Bristow, 2010. Detecting and correcting map-matching errors in location-based intelligent transport systems. Proceedings of the 12th World Conference on Transport Research, July 11-15, 2010, Lisbon, Portugal, pp: 1-17.

Velaga, N.R., M.A. Quddus and A.L. Bristow, 2009. Developing an enhanced weight based topological map-matching algorithm for intelligent transport systems. Transp. Res. Part C, 17: 672 -683.

Velaga, N.R., M.A. Quddus and A.L. Bristow, 2011. Improving the performance of a topological map-matching algorithm through error detection and correction. Proceedings of the 90th Annual Meeting of the Transportation Research Board, Jan. 23-27, Washington, DC., pp: 1-19.

White, C.E., D. Bernstein and A.L. Kornhauser, 2000. Some map matching algorithms for personal navigation assistants. Transp. Res. Part C, 8: 91-108.

Wu, D., T. Zhu, W. Lv and X. Gao, 2007. A heuristic map-matching algorithm by using vector-based recognition. Proceedings of the International Multi-Conference on Computing in the Global Information Technology, March 4-9, Washington, DC., pp: 1-18.

Yang, D., B. Cai and Y. Yuan, 2003. An improved map-matching algorithm used in vehicle navigation system. IEEE Proc. Intell. Transp. Syst., 2: 1246-1250.

Yin, H. and O. Wolfson, 2004. A weight-based map-matching method in moving objects databases. Proceedings of the 16th International Conference on Scientific and Statistical Database Management, June 21-23, 2004, Santorini Island, Greece, pp: 437-438.

Yu, M., Z. Li, Y. Chen and W. Chen, 2006. Improving integrity and reliability of map matching techniques. J. Global Positioning Syst., 5: 40-46.

Yuan, J., Y. Zheng, C. Zhang, X. Xie and G.Z. Sun, 2010. An interactive-voting based map matching algorithm. Proceedings of the 11th International Conference on Mobile Data Management, May 23-26, Kansas City, MO, USA., pp: 43-52.

Zhao, L., W.Y. Ochieng, M.A. Quddus and R.B. Noland, 2003. An extended kalman filter algorithm for integrating GPS and low-cost dead reckoning system data for vehicle performance and emissions monitoring. J. Navig., 56: 257-275.

Zhao, Y., 1997. Vehicle Location and Navigation System. Artech House Publishers, Boston, London, ISBN-13: 978-0890068618, Pages: 368.

Zuyun, W., D. Yong and W. Gang, 2008. A quick map-matching algorithm by using grid-based selecting. Proceedings of the International Workshop on Geoscience and Remote Sensing, Dec. 21-22, Shanghai, pp: 306-311.