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Cite article:
Daulet, A., Meirbek, M., Denis, Y., Dinara, Z., & Rimma, K. [2021]. Investigation of lane–level gnss positioning of vehicle in urban area. *Journal of Applied Engineering Science*, 19(2), 515 - 521. DOI:10.5937/jaes0-25205

Online aceess *of full paper is available at: www.engineeringscience.rs/browse-issues* doi:10.5937/jaes0-25205

Paper number: 19(2021)2, 819, 515-521

INVESTIGATION OF LANE–LEVEL GNSS POSITIONING OF VEHICLE IN URBAN AREA

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High quality GNSS (Global Navigation Satellite System) positioning can be useful for numerous engineering tasks, for example, in transport applications concerned to monitoring and optimization of road traffic. In this case lane-level positioning is a relevant task and its solution should satisfy a wide range of users, and thus should be low-cost and easy to use. In this paper the solution of accurate GNSS positioning of the car with the use of differential correction of navigation data in order to provide positioning by the lane level in urban areas of Kazakhstan is investigated. A smartphone is considered as low-cost navigation aid. Navigation data obtained using a smartphone were differentially corrected using the developed software of the Control System for Reference GNSS Station Network relative to one reference station. It is shown that using a smartphone as a navigation aid with further differential correction of data relative to one reference station allows positioning vehicles in motion with an error of 1.4 meters. The result is valuable as a basis for developing intelligent transportation systems.

Key words: high accuracy positioning, lane-level positioning, differential GNSS, vehicle navigation

INTRODUCTION

Developed and implemented in the second half of the last century, GNSS (Global Navigation Satellite System) GPS (Global Positioning System) and GLONASS (GLObal NAvigation Satellite System), as well as the later Beidou and Galileo systems, nowadays solve a wide range of tasks of navigation and coordinatetime support. To determine the location of objects, satellite navigation systems use two types of positioning: absolute and relative (differential), which use data from both code and more accurate phase measurements. Differential positioning, which consists in processing (differential correction) of GNSS signals using reference stations with known coordinates, is characterized by higher accuracy [1]. Among the technologies providing high accuracy of navigation determinations are considered technologies of navigation of dynamic objects RTK (Real Time Kinematic) and NRTK (Network Real Time Kinematic) described in details by [2] and static objects PPP (Precise Point Positioning) examined in [3, 4], the use of which can provide accuracy at the level of decimeters and centimeters, and sometimes even millimeters.

High-accuracy positioning technologies developed by GNSS have opened up new possibilities, being amply applied in such applications as surveying, e.g. creation of geodesic networks, leveling works and study of geodynamic processes [5, 6], mapping, e.g. land management and cadastres [7], precision agriculture, e.g., soil sampling, yield monitoring and chemical and fertilizer application [8, 9], environment monitoring [10, 11]. In addition, GNSS solves many transport tasks, the most striking example of which is personal vehicle navigation. The application of high accuracy GNSS considerably expands the available possibilities, for example, it makes it possible to develop systems of remote control and monitoring of unmanned vehicles (self-driving cars) and aircraft (drones), so-called unmanned ground vehicles (UGV) and unmanned aerial vehicles (UAV) studied by [12, 13], as well as intelligent transport systems for various purposes according to [14, 15].

Different transport tasks require different levels of accuracy. For example, 15 m accuracy provided by cheap receivers is quite enough for creation the route from point A to point B, and expensive navigation sensors and controlled operation conditions are necessary for implementation of unmanned systems as pointed out by [16]. At the same time, there are intermediate tasks as defined in [17], e.g. control and navigation of transport at lane-level, which requires submeter-accurate positioning. In particular, lane-level vehicle positioning requires the accuracy of navigation determinations at the level of 1-3 m as per [16, 18].

The relevance of developing lane-level positioning of vehicle technologies lies in providing drivers of vehicles with information that will allow them to optimize the traffic route. In particular, the application of lane-level positioning will make it possible to assess the congestion of individual road lanes, to predict changes in the situation on individual road lanes and to prevent collisions with obstacles in a certain lane as also noticed by [16, 18]. Such information is particularly important in order to improve the efficiency of emergency service vehicles to get to the right place as quickly as possible, but will also be used by ordinary users and will make it possible to control dedicated public transport lanes [19]. Thus, the wide spread of lane-level positioning will make it possible to significantly improve the existing geo-information systems, which currently provide information on traffic congestion by dividing them only by traffic directions.

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Although, in massive applications the corrections are needed in real time, post-proposing can also be useful, for example, to collect statistical data on the traffic load on individual lanes, which can be used to plan the repair of the roadway, to justify the need for the construction of junctions, to improve the efficiency of traffic management systems, etc.

The current trend in high precision positioning technology is the spread of high accuracy GNSS positioning on mass market applications. The implementation of high precision positioning in the mass market involves the use of an inexpensive navigation receiver, which will be available to users without experience on professional navigation equipment. In this regard, the authors of many works were faced with the task of using inexpensive receivers for high precision GNSS positioning for various applications. For example, the authors of [20, 21] consider the possibility of using low-cost GNSS receiver for geodetic applications and geomatics, in low-cost GNSS receivers for local monitoring for detecting displacements [22] and in [23] the subject of research was the implementation of local monitoring of displacement, for example, landslides, using GNSS positioning with low-cost GNSS receiver.

Thus, in this paper the task of studying the possibility of using a smartphone with a standard single frequency navigation receiver to determine the location of the vehicle on the lane level with an accuracy of 1-3 meters.

RELATED STUDIES

Vehicle navigation in urban environments involves positioning in open terrain and difficult terrain characterized by densely planted trees, densely constructed buildings and other conditions affecting the propagation of the GNSS signal. In open terrain, the accuracy of navigational definitions can be only slightly affected by its landscape, while when there are many obstacles to the spread of the GNSS signal, there are two problems. The first problem is the ability to block the signals of a significant number of satellite spacecraft, resulting in too few visible navigation satellites to accurately calculate trilatation. The second problem is that there are many flat surfaces that reflect GNSS signals, which contributes to the determination of pseudo-range and thus position. When reflecting GNSS signals, the end user receives either only re-reflected signals (non-line-of-sight reception) or direct and re-reflected signals at the same time, resulting in multipath interference at the receiving location [17, 24, 25]. Error of location associated with these effects could reach from several tens to 100 or more meters [25, 26].

Non-line-of-sight reception and multipath interference are mostly evident in urban canyons, which are characterized by the close proximity of a lot of skyscrapers. Under these conditions, high accuracy of navigation definitions can only be achieved using satellite navigation data along with additional information. For example, GNSS trajectories can be matched to road networks, i.e. map matching can be applied. One of such algorithms is considered in [27]. In [28] satellite navigation data is processed along with additional lane-level digital map information from camera. This method provides achieving submeter level of positioning accuracy. Also, the authors [17, 25] propose to improve the accuracy of GNSS positioning by taking into account the tall buildings using 3D map of the city buildings, which allows to take into account the spread of GNSS signals. It is shown that the navigation of the vehicle using a method that combines GNSS data and 3D maps is performed with an error of up to several meters. In addition, for navigation tasks in urban canyons, methods using a combination of GNSS with various sensors, such as gyroscopes, accelerometers, odometers, etc., are considered [29], and they can also be supplemented with 3D map data.

In the case of semi-urban and residential areas, precision positioning error is less affected by non-line-of-sight reception and multipath interference. Therefore, in these areas high-precision positioning is, as a rule, implemented with the use of GNSS receiver and differential correction technologies of navigation data [30-33]. Often, for transport purposes, researchers consider as a rover high-priced professional receivers that provide accurate positioning at the level of centimeters and millimeters. For example, in [30] it was used an expensive GNSS receiver of geodesic class Trimble R10 and as a result of kinematic measurements in urban residential area it was shown that multi-constellation GNSS in the selection of the optimal mask angle and data processing using RTK technology allows to achieve accuracy at the level of a few centimeters in harsh environments with tree canopies. In work [31] Topcon HyperPro+ was used as a rover and, having supplemented the obtained results with odometry data, the accuracy of navigation definitions was also obtained at centimeter level. Such solutions are relevant for navigation of unmanned moving objects (i.e. UAV and UGV), however, for the purposes of lane-positioning there is no need in centimeter accuracy, and the use of high-precision professional navigation equipment will not allow to introduce a mass application of high-precision positioning system, so a solution available to a large number of users is necessary. In this regard, options for high-precision positioning of moving vehicles in an urban environment are being studied, where a rover can be an ordinary smartphone [32, 33, 34], which is currently the most common navigation device for average users. At the same time, an important fact is that the use of a smartphone not only allows users to significantly reduce the financial cost of using a system of lane-level positioning, but also does not require experience in working with complex navigation equipment.

Vehicle navigation in dynamic mode in urban environment with a smartphone with standard positioning technique is carried out with an accuracy of 10-15m [34]. High precision positioning using a smartphone is difficult without any external hardware and data correction [35]. For lane-level vehicle positioning, the differential correction of navigation data relative to one reference station is effective. For example, in the works [32, 33] by processing raw navigation data obtained with a smartphone by RTK technology has reduced the error of positioning of a moving object in an urban environment to 1m.

DIFFERENTIAL CORRECTION OF NAVIGATION DATA

Differential correction of navigation data of rover is made by applying transient corrections to the current coordinates, resulting in the formation of true coordinates. To calculate the transient corrections, the reference stations are needed, which are set at a point with accurately known coordinates. The reference stations receive navigation information from the same constellation of satellites as the rover, and then this navigation data and information about the precise location of the reference station are used to calculate the transition corrections.

The Control System for Reference GNSS Station Network (hereinafter referred to as the System) developed by the authors of this paper is used to apply differential correction of navigation data. The System consists of a network of GNSS reference stations, control center, computing center, system users, communication network. The System operates under the control of the control center, which is a remote control point and transmits commands to the computing center, which are then transmitted to the network of GNSS reference stations. GNSS reference stations provide search, capture and registration of GNSS signals at L1 and L2 frequencies with given period of time, convert navigation data in unified formats, measure external environment parameters and telemetry parameters about the state of GNSS station nodes, save the measured data in the internal memory and transmit them in real time with given period of time to the computing center. Input data from the network of GNSS reference stations is transmitted to the computing center via data transmission channels for processing and storage (i.e. data integrity control, calculation of navigation solutions, archiving). The computing center performs application software algorithms and implements functions of data collection, storage, processing and display, performs operations of data reception and transmission via communication channels. Output data is provided to users connected to the system via a web browser in the screen form of a personal account on the information portal of the System after passing the identification, authentication and authorization.

The System allows for differential correction of navigation data in network mode, which provides flexibility of the system operation and the possibility of expanding the territory of its operation. At the same time, the system provides differential correction of navigation data from an unlimited number of users even when using the nearest single GNSS reference station (near mode). The coverage area of one single GNSS reference station is 30km, so it is possible to use near mode in the city.

EXPERIMENTAL PART

In order to verify lane positioning using a smartphone and differential correction of navigation data from the System, an experiment was conducted. To perform the experiment the following items were used: u-blox 6 receiver with an antenna, smartphone Xiaomi Redmi Note 4X with NMEA Tools installed, Trimble BD930 receiver with an antenna, Control System for Reference GNSS Station Network.

The u-blox 6 receiver is a dual-frequency navigation receiver that operates only on GPS signals and is characterized by 2.5 m positioning accuracy. The Xiaomi Redmi Note 4X smartphone's GNSS receiver receives signals from multiple GNSS (GPS+GLONASS+BeiDou+A-GPS). Other information about the navigation module characteristics in the smartphone is not provided by the manufacturer, but it is known that it belongs to the group of code receivers [34] with accuracy only at meters' level. Trimble BD930 receiver is a dual-frequency receiver that supports GLONASS, GPS, BeiDou and Galileo signals and provides high accuracy (2-3 cm).

The smartphone and u-blox 6 receiver served as a rover and were installed inside the car for the duration of the experiment in order to study the possibility of using the system in real operating conditions (fig.1). Trimble BD930 receiver acted as a reference GNSS station and was installed on the roof of the Institute of Space Technique and Technologies in Almaty, Kazakhstan. The coordinates of Trimble BD930 receiver are shown in table 1.

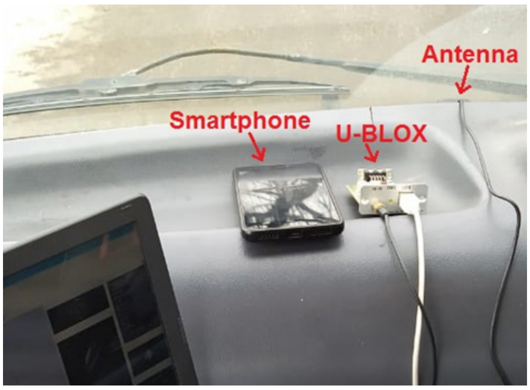

Figure 1: Receiver u-blox 6 with antenna and smartphone Xiaomi Redmi Note 4X, installed in the car interior

Table 1: Positioning and dilutions of precision of Trimble BD930 receiver

Parameter	latitude	longitude	height, m	datum	PDOP	HDOP	VDOP	TDOP
Value	43° 15' 18.284" N	76° 51' 23.853" E	727.675	WGS-84	0.9	0.4	0.7	0.4

Table 2: Main experimental conditions

Parameter	Track number		
	1	2	3
Road width	Two-lane road (one line in each direction)	Eight-lane road (four lanes in each direction)	Six-lane road (three lanes in each direction)
Track length, km	2,4	7,0	5,2
Surrounding area	Buildings no higher than two floors, few trees	Five-storey residential buildings, densely planted trees	Open terrain
Speed of car, km/h	30–40	40–50	40
Distance to the reference station, km	0,5-1	1-3	> 4

The experiment consists of the following: the smartphone and receiver installed inside the car simultaneously record data in NMEA format when the car is moving in the middle of one of traffic lanes on three types of roads at different distances from the reference station in Almaty (table 2). The city of Almaty is the most densely populated and built-up city on the territory of Kazakhstan, so it is assumed that the successful use of the considered method of navigation of vehicles in Almaty is obviously determines that this method will be equally effective in other cities of Kazakhstan. The roads selected for the experiment reflect the main types of roads in Almaty and their surrounding area. The location of the reference station and the remoteness of the roads selected for the experiment are shown in fig. 2.

The recorded navigation data from a smartphone were processed by the Control System for Reference GNSS Station Network in near mode relative to one GNSS reference station, and the data from u-blox 6 were left raw to compare the results, assuming that the accuracy it provided should be sufficient for lane-level purposes. The results were presented by map-matching on a Google Earth map and determined whether the lane determined from satellite navigation data corresponded to the real one. The accuracy of navigation definitions was assessed relative to the middle of the traffic lane using the least squares method.

Figure 2: Google Earth map: tracks are marked with a dotted line and numbered according to Table 2, in the center of the concentric circles there is the reference station, the bands between the circles represent the areas remote from the reference station at a distance corresponding to the experimental tracks

RESULTS

The experiment resulted in raw navigation data from the u-blox receiver and smartphone and processed smartphone navigation data on three road types. Figure 3 shows the trajectories of the car, obtained from raw data from the u-blox receiver and smartphone, as well as processed by differential correction smartphone navigation data.

The trajectories of the car, received according to the data of u-blox receiver, pass through the traffic lanes, on which the car actually moved in case of all three investigated road types. In this case, the surrounding roads 1 and 2 trees and buildings did not affect the result of navigation determinations of the u-blox receiver. For the u-blox receiver, the observed positioning accuracy corresponds to the specification. However, despite the fact that its accuracy provided by the manufacturer is sufficient for lane-level vehicle positioning issue, equipping a large number of private vehicles in practice will be difficult and will be a significant problem in attempting to implement automated transport systems for various purposes that require lane-level vehicle positioning. In addition, the u-blox 6 receiver only accepts data from the GPS constellation, which is also a limitation, for example, in the case of GPS suffer from prolonged outages.

At the same time, the trajectories obtained from a smartphone in all three cases do not represent reality, but pass through the neighboring lanes (roads 2 and 3) or roadside (road 1). The accuracy of the smartphone's navigation receiver is not sufficient to implement lane-level vehicle positioning. As a result of differential correction of navigation data obtained from a smartphone relative to one reference station located within no more than 5 km from the receiver, for the studied road types were obtained trajectories of the car that slightly differ from the data from the receiver u-blox and correctly represent the movement of the car within the traffic lane. Determination

Figure 3: Comparison of map-matched trajectories. Red line is the map-matched smartphone provided trajectory, orange line with square dots is the map-matched u-blox provided trajectory, green line with circular dots is the map-matched trajectory obtained by differential correction of initial (raw) smartphone navigation data. The lane in which the car was moving is enclosed between white solid lines

of the positioning accuracy of the vehicle using corrected relative to one GNSS reference station data obtained from a smartphone, showed that the positioning accuracy does not change with increasing distance between the receivers and the reference station in the studied distance range (up to 5 km). In this case, according to the results of the calculation, the positioning error is 1.4 m, which is sufficient for lane-level vehicle positioning. Thus, the differential correction processing of the results of navigation determinations obtained using smartphone allows for the positioning of transport at lane-level, and one reference station for the conditions typical for the Almaty city is enough to cover an area of 10 km in diameter.

CONCLUSION

The necessity to provide a large number of users with intermediate accuracy positioning between the geodesic-class GNSS receivers and a conventional smartphone makes the development of low-cost and easy-to-use solutions relevant. This paper shows the possibility of using a smartphone to determine the location of moving vehicles in the urban area at lane-level using differential correction of navigation data. The implementation of differential correction of navigation data was carried out from one reference station using the Control System for Reference GNSS Station Network. An experimental study showed that this method of navigation of a vehicle has a satisfactory result and allows positioning the vehicle at lane-level with an error of 1.4 m. In urban conditions typical for Almaty, increasing the distance from the reference station does not affect the accuracy of navigation definitions in the studied range and one reference station covers an area at least of 10 km in diameter.

ACKNOWLEDGMENT

This research is funded by the Aerospace Committee of the Ministry of Digital Development, Innovations and Aerospace Industry of the Republic of Kazakhstan (BR10664869 "Development of rocket and space technology components and digital technologies for space monitoring, research of objects of near-deep space").

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Paper submitted: 13.02.2020.
Paper accepted: 02.10.2021.