APPLICATION OF GNSS SYSTEMS IN LOGISTICS

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Abstract The paper presents an analysis of the fields of application of GNSS systems (Global Navigation Satellite Systems) in logistics, with particular focus on GPS and GLONASS. It identifies advantages gained from GNSS systems and possible problems in the operation of the systems related to their deficiencies. One of the ways to enhance the precision of GNSS operation is to integrate data from various systems. The paper outlines the results of own research, which provide conclusions on how integration of GPS and GLONASS may affect the functioning of logistics and increase in its effectiveness and efficiency.

Keywords: Logistics, GNSS systems, application, GPS, GLONASS

1. INTRODUCTION

In this paper, attention will be focused on addressing the issues pertaining to the application of GNSS systems in logistics. Its objective will be to outline the areas of logistics in which it is possible to apply GPS and GLONASS systems, as well as advantages to be obtained therefrom. A separate issue to be addressed in the paper concerns problems which arise during the application of GNSS systems that are related to their deficiencies, and thus negatively influence logistics chains, as well as manners of preventing these problems.

The paper poses the following research problems:

- What problems occur during the operation of GNSS systems in logistics?
- How can these problems be solved?

2. ESSENCE OF GNSS SYSTEMS

GNSS stands for Global Navigation Satellite Systems [1]. The notion was first used in 1991 during a meeting of the International Civil Aviation Organisation - ICAO [2]. The notion denotes all satellite navigation systems that are of a global nature, and thus may be applied on all continents and in all states of the world. The sole condition is their coverage of specific areas, and their user having relevant types of receivers. The operation of these systems provides scope for determining the current position of a certain point on Earth, regardless of the status of the weather and time of the day. This is done through measuring the distance travelled by a signal from a satellite located on a specific orbit to the antenna of the receiver placed on Earth. Notably, GNSS systems enable not only determining the position of a point located in one place, but also establishing the position of moving objects [1, 3, 14]. Presently, GNSS are made up of several systems. Considering that this paper will focus on two of the systems (i.e. GPS and GLONASS), it is the two systems that will be described here briefly. Although the systems are slightly different, the fundamental principles concerning their functioning share similar bases. This relates, in particular, to the elements that the systems comprise and that make it possible to determine position on Earth. These are the so-called segments, including:

- Space Segment - its operation is based on orbiting satellites,

- Control Segment or Operational Control Segment - operates using different stations which are located on Earth, and which condition the effective functioning of the entire system and performing constant monitoring within its scope,
- User Segment - made up of all receivers which, using built-in antennae, may pick up signals emitted by satellites [4, 5, 13].

As regards GPS, it should be noted that its development has occurred since the 1970s, though considerably earlier technologies and systems, for instance, the TRANSIT system, have been applied in the process. In 1978, the first satellite of the system was launched into orbit, and in 1993, the service of SPS (Standard Positioning Service) positioning was enabled worldwide. Currently, the GPS system comprises 32 satellites following 6 orbits, and 22 Earth stations [6, 7, 10]. In turn, referring to the GLONASS system (abbreviation for the Russian Globalnaja Nawigacionnaja Sputnikowaja Sistema and the English Global Orbiting Navigation Satellite System), it should be emphasised that, similarly to GPS, it began to be developed in the 1970s. The first satellite of the system was launched into orbit in 1976, with the launch of the system itself taking place in 1996. At present, it comprises 28 satellites, including 23 operational satellites (following 3 orbits), and 17 Earth stations [1, 8, 9].

3. PROBLEMS RELATED TO OPERATION OF GNSS SYSTEMS

During the application of GNSS systems to achieve objectives connected with logistics, various problems may become visible. The problems result primarily from the deficiencies of the system, which may negatively influence the accuracy of measurements, thus implying obstacles to the functioning of undertakings, or organising and performing rescue actions. Among the problems is, among other things, the phenomenon particularly noticeable in urban environments, i.e. where there are many buildings, including high office buildings or blocks of flats. Due to the phenomenon, the effects of the so-called radio shadowing and signal multipath may occur, causing a signal sent by a satellite to reflect from high buildings and bend, and reach a receiver via different paths and with different delays. It has a negative influence on the accuracy and quality of measurements, and leads to, for example, setting incorrect coordinates of a receiver. A particularly unfavourable situation with respect to emission of signals sent by the satellites of GNSS systems occurs inside various buildings and tunnels or underpasses. Then, the satellite signal may disappear intermittently, making it impossible to establish the position. Within logistics, it may have a particularly negative influence when, for instance, a vehicle carrying certain goods is in a long and splitting tunnel [15]. Another problem concerns DOP (Dilution of Precision), i.e. the error of precision dilution. It results from an unfavourable position of satellites sending signals (the most optimal position is an even placement of satellites on the entire celestial sphere), and consists in the fact that a position determined via GNSS is at the point of intersection of the surfaces of spheres with the radii equal to measured distances between satellites and an antenna, and since measurements are never entirely error-free, the spheres are diluted and instead of a point there is an area of intersection of positioning surfaces [4]. Also GPS or GLONASS receivers themselves may be subject to various disturbances, which implies problems related to inaccuracy of measurements. The disturbances to, for example, receivers placed in individual vehicles, include:

- electromagnetic disturbances generated by a broadband receiver,
- electromagnetic disturbances generated by a narrowband receiver,
- transient disturbances conducted along supply lines,
- disturbances related to electromagnetic radiation [11, 12].

Other problems connected with the application of GNSS systems within logistics should further include problems referring to the phenomena defined as jamming and spoofing.

As regards jamming, it refers to jamming signals sent by satellites to particular receivers. Its main aim is to interrupt the accessibility of a signal that reaches the receiver, which occurs as a result of making it impossible for the receiver to decode any signal, with the phenomenon leading to even damaging the receiver [16, 17, 18]. Spoofing, in turn, consists in falsifying information in order to set incorrect coordinates. This takes place through comparing falsified data in the process of replicating the GPS or GLONASS code, which leads to setting an incorrect position of the receiver [16, 17, 19]. Considering all problems described above, it is reasonable and necessary to use all methods to make determining position more precise and subject to relatively low risk of error. The methods include integrating GPS and GLONASS [20, 21]. An example of such integration will be described in the subsequent point of the paper.

4. DEVICE DESIGN

Using generally available components and applying the popular Arduino Leonardo platform, a device has been constructed to enable integration of GPS and GLONASS signals, accompanied with a presentation of the results on an LCD display and a record of the data entered into a memory card.

A diagram of the device has been depicted below:

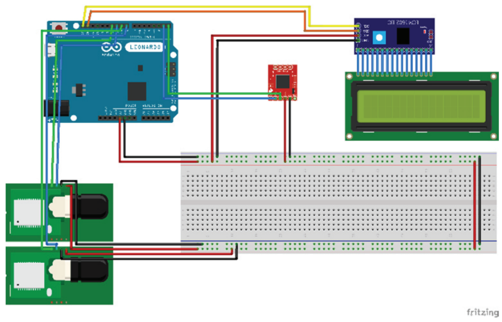

Figure 1 Diagram of a device constructed on the basis of the Arduino Leonardo platform

The device was equipped with two identical GPS/GLONASS - NEO-7M-C UART modules with a built-in antenna. Such modules were necessary to enable simultaneous collection of data from two different systems (only 8th generation u-blox modules enable simultaneous reception of GPS and GLONASS signals). Appropriate configuration of particular modules to operate in the specified systems and reception of certain data occur upon starting the device with the UBX command. The device is also equipped with a 2 x 16 character LCD display used to present a currently calculated position, and a recorder with an OpenLog memory card by SparkFun.

5. INTEGRATING GPS AND GLONASS

Integration of GPS and GLONASS navigation systems is a relatively complex task. The major problem is the different structure of navigation data, different coordinate reference systems, and time. Integration of positioning methods used to examine GLONASS and GPS signals is nevertheless very similar to the standard positioning method of GPS itself. Both systems are based on the principle of triangulation, which calculates the distance between a satellite and a receiver, and the time shift.

$$S_r = \sqrt{(X_s - X_r)^2 + (Y_s - Y_r)^2 + (Z_s - Z_r)^2}$$

Where: X_s, Y_s, Z_s - the coordinates of the satellite, X_s, Y_s, Z_s - the coordinates of the device receiving the signal

$$\Delta T_S^R(t) = T_R(r) - T_S(s)$$

Where: $T_R(r)$ - the clock of the device receiving the signal, $T_S(s)$ - the satellite clock

In order to establish the location of a receiver on the basis of values received from GPS and GLONASS, the least squares method is used:

$$\bar{x} = (H^T W H)^{-1} H^T W \bar{v}$$

Where: H is the designed matrix, W is the matrix weight for specified GPS and GLONASS satellites, whereas $\bar{x}$ is the vector $\bar{x} = [\Delta x, \Delta y, \Delta z, \Delta t_{gps}, \Delta t_{glonass}]$, $\bar{v}$ is the pseudorange residual vector, α is the observation value of GPS/GLONASS satellites).

The designed matrix H comprises the coordinates of both GPS and GLONASS.

$$H = \begin{bmatrix} \alpha_x^{gps1} & \alpha_y^{gps1} & \alpha_z^{gps1} & 1 & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \alpha_x^{gpsN} & \alpha_y^{gpsN} & \alpha_z^{gpsN} & 1 & 0 \\ \alpha_x^{glonass1} & \alpha_y^{glonass1} & \alpha_z^{glonass1} & 0 & 1 \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \alpha_x^{glonassM} & \alpha_y^{glonassM} & \alpha_z^{glonassM} & 0 & 1 \end{bmatrix}$$

As it was mentioned at the beginning, GPS and GLONASS systems also have different coordinate reference systems. GPS uses the WSG84 system, while GLONASS uses the PZ90 system. Therefore, additional transformation between needs to be performed between them in order to obtain the same spatial references. This is done through the use of the Helmert transformation, outlined below:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{WSG84} = \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{PZ90} + \begin{bmatrix} S & -R_Z & R_Y \\ R_Z & S & -R_X \\ -R_Y & R_X & S \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}_{PZ90} + \begin{bmatrix} T_X \\ T_Y \\ T_Z \end{bmatrix}$$

6. RESULTS OF DEVICE OPERATION

The research was performed with the use of the device described in point 6, along with the use of an application written in C++, and the libraries of the Essential GNSS Project, TinyGPS and Zenautics Matrix. Observations were carried out in the very centre of Warsaw on 7-8 November 2016. Calculations of the integration of GPS/GLONASS systems were performed at 60 second intervals. The results were subsequently recorded on the memory card. **Figure 3** presents the number of visible GPS satellites and their comparison with respect to visible GPS/GLONASS satellites in the period from 9:00 am to 3:00 pm.

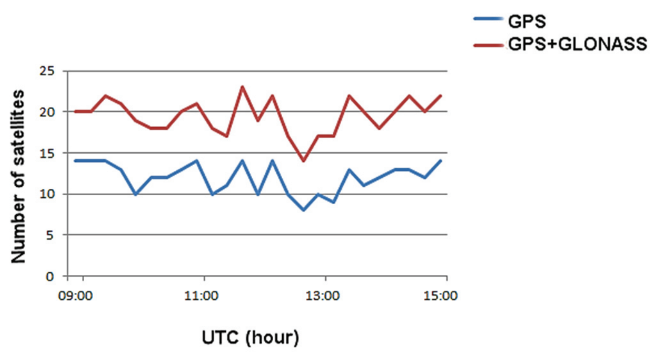

Figure 2 Number of visible GPS and GLONASS satellites during observations

Another diagram provides a comparison of positioning results for the device placed in the centre of Warsaw among high buildings in a situation of applying the GPS system exclusively, as well as using the system integrating the operations of GPS and GLONASS.

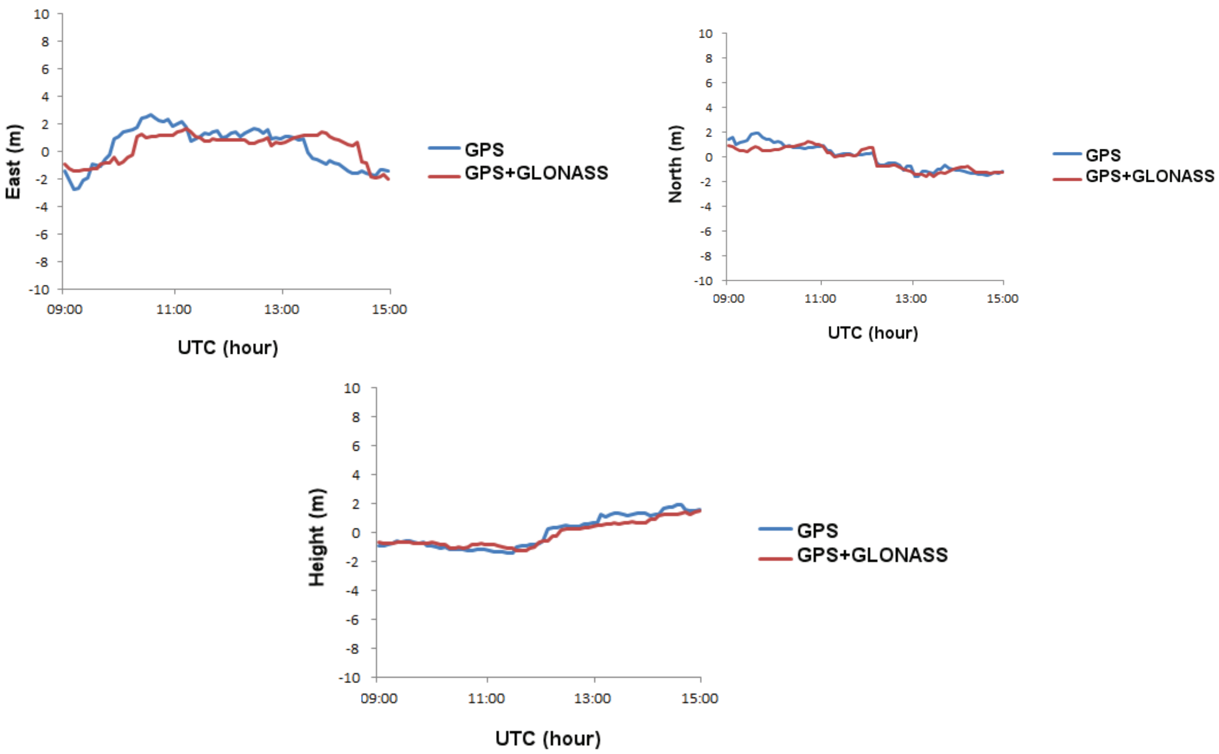

Figure 3 Comparison of results of observations with the use of GPS and the system integrating GPS and GLONASS

7. CONCLUSION

Summing up the deliberations presented above in the paper, it should be emphasised that GNSS systems are extremely widely applied within logistics. Indeed, they may be used in transport by road, rail, sea, or air, as well as in the course of storing procedures, rescue actions, or within the scope of crisis management. GNSS systems applied within logistics may bring an array of benefits to entreprises. The most important should include cost reduction, improvement in customer service, or increase in the effectiveness of logistic process performance. Despite such benefits, it needs to be noted that using systems like GPS and GLONASS may be related to an occurrence of a number of various problems. The most common include the so-called spoofing and jamming phenomena, as well as the occurrence of radio shadowing and signal multipath effects, and the so-called dilution of precision. In order to prevent the problems, it is necessary to implement certain solutions. What may be effective from among the solutions is integration of the operations of GPS and GLONASS. This is evidenced by conducted research, the results of which have been presented above. On the basis of observations made, conclusions may be drawn that - applying a relatively simple integration system - positioning exactness may be increased by about 7-10%, depending on the number of satellites used. It is worth noting that measurements for the purposes of the research were performed among urban buildings, i.e. where the problems pertaining to the occurrence of radio shadowing or signal multipath effects have particularly severe consequences. Integration of GPS and GLONASS systems may effectively prevent these problems and contribute to increasing the effectiveness of logistic process performance.

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