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ANALYSIS OF SATELLITE NAVIGATION SYSTEMS USABLE IN GENERAL AVIATION

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Abstract

This paper is mainly focused on solving the current issues of satellite navigation systems and subsequent analysis. The paper is systematically divided, while the first chapter focuses mainly on the definition of satellite navigation systems, their use in general aviation and introduction of specific examples, their division in terms of operation and a description of advanced satellite navigation systems. The second chapter deals with the methodology of work, analyzes the sources and the chosen procedure for solving and researching the issue. The third chapter is the main one and is focused on the analysis and research of satellite navigation systems, defining input parameters such as: accuracy, continuity, or integrity of navigation services. It also compares research with the current state of the issue and evaluates analyses, suggests possible changes and directions of further research in satellite navigation industry.

Keywords

GNSS, Accuracy, Integrity, Continuity, Availability, Analysis, Comparison, Starlink, Multi-GNSS

1. INTRODUCTION

Satellite navigation systems - this is the convenience of civilization of the 21st century. They are the pinnacle of cutting-edge science and technology and are currently part of our lives. They make our functioning easier and many of us can no longer even imagine life without them. These systems allow us to navigate quickly, accurately and, in addition, easily. Positioning with them is very accurate and easy. The advantage is that the determination does not only apply to the earth's surface, but satellite navigation systems are also able to determine the position in the air. That is why they are widespread globally and we will meet them in every industry. GNSS (Global Navigation Satellite System) today includes the following systems: NAVSTAR GPS, GLONASS, GALILEO, COMPASS, IRNSS, QZSS. This huge development of satellite navigation systems has been caused by the huge growth of aviation, whether civil or military. Operators therefore needed to reduce fuel consumption, emissions, and eliminate flight delays. All this resulted in a huge increase in the number of aircraft in the air, which required an increase in airspace capacity. In addition, the enormous increase in airspace use by aircraft has created a significant need to improve communication, navigation, and surveillance equipment. As a result of all these requirements, a GNSS global navigation system has been developed that supports positioning applications and is also the basis for performance-based navigation (PBN), automatic dependent tracking (ADS-B and ADS-C). GNSS also offers us a time reference that is used to synchronize systems, avionics, communications networks, and operations. In addition, it supports a myriad of opportunities for use outside the aviation sector. In my paper, I will focus on the above-mentioned satellite navigation systems, in which we will approach their use, describe the procedure, which I will then follow with practical examples. We will also divide them all from the point of view of operation, into civilian and military. We will also look at what advanced satellite navigation systems are. Subsequently, we move on to the practical part of my paper, whose task will be to analyze satellite navigation systems in terms of usability in general aviation, where we define the input parameters, which include accuracy, continuity of navigation services. After completing this analysis, we interpret all the results. At the end of this paper we will create a discussion where we will compare our findings with the current state in the world of satellite navigation systems and think about how these devices and systems could be improved in the future to work more efficiently, faster and easier, and also where we should direct our future research so that we can achieve our stated goals.

2. MATERIALS & METHODS

I used several methods to create my paper. First it was necessary to study the literature and then in the next stages I used the method of comparison or comparison of information from available sources about satellite navigation systems, their extensions (augmentation), division, their implementation or performance navigation. In the process of summarizing the facts obtained, I also used the method of analysis. The submitted paper consists of three main chapters. In the introduction I deal with a general presentation of the issues addressed in my work, I explained the reasons for choosing the topic. The second chapter discusses materials and methods which were used to write this paper. The third chapter analyzes and solves the parameters of satellite navigation systems. This is developed based on selected input parameters, as well as the way in which the values of these parameters are obtained. Subsequently, a comparison is made using the obtained facts and values. These are inserted into several tables, based on which we can draw a conclusion and the analysis itself. In the fourth, and therefore my last, chapter, I discuss and analyze the very results of my previous research. I will compare the results with the current state of the problem and propose changes for future improvements to satellite navigation systems.

As I already mentioned in my paper, to create an accurate analysis, it is necessary to choose the input parameters based on which we will create the analysis. I chose four basic parameters from the environment of satellite navigation systems, namely: accuracy, integrity, continuity, availability, which we will describe in more detail.

2.1. Accuracy

GNSS position accuracy is defined as the difference between the calculated and actual position. Ground systems such as VOR and instrument landing systems (ILS) have relatively fixed error characteristics. These characteristics can therefore be measured during flight control and subsequently monitored electronically to ensure signal accuracy. However, GNSS errors can change over the hours due to satellite motion and ionospheric influences. Augmentation systems are designed to monitor and compensate for these changes [9].

2.2. Integrity

Integrity is a measure of the confidence that can be placed in the accuracy of information provided throughout the system. Integrity includes the ability of a system to notify the user when the system should not be used for the intended operation. In the case of a conventional device such as ILS, the accuracy of the signal can be monitored at specific points. In contrast, GNSS integrity is based on avionics performing complex calculations to ensure that the error in the calculated position does not exceed the maximum allowed for the current operation [9].

The required level of integrity for each operation is determined with respect to specific vertical guidance approaches, vertical warning limits. Avionics continuously calculates the appropriate protection levels. They are used with ABAS and SBAS. Protection levels are upper confidence limits for position errors; alert limits define the maximum position error allowed for an operation. When any level of protection exceeds the applicable warning limit, the avionics must provide a warning and the flight crew must follow the prescribed procedures [9].

Time-to-alert, or time to alert, is also part of the integrity requirement; it is the maximum time allowed from the beginning of the fault condition to the announcement in the aircraft. Other system integrity requirements are, for example, Error tolerance or Risk probability. Error tolerance or error tolerance expresses to us how much the system can respond to user errors and then correct them. On the other hand, probability risk or probability of risk is the probability that some risk will occur that could affect the integrity of the system [9].

2.3. Continuity

Continuity is the ability of a system to perform its function without unplanned interruptions during an intended operation, expressed as a probability. For example, there should be a high probability that guidance will remain available throughout the instrument approach process. In the case of ABAS, continuity depends on the number of satellites monitored. For GBAS and SBAS, continuity also depends on the redundancy of the components of the expansion system [9].

The continuity requirements are less stringent for airspace on a low-density route and more stringent for areas with high-density and airspace complexity where the failure could affect many aircraft. The requirements are also more stringent for approach operations [9].

If there is a high degree of reliance on GNSS for en-route and terminal navigation, loss of service can be achieved by using alternative means of navigation or by using radar and ATC intervention to ensure that the separation is maintained. This is not possible when ADS-B is the only source of tracking because GNSS provides ADS-B location [9].

For APV and CAT I GNSS-based approaches, a missed approach is considered normal operation because it occurs whenever the aircraft drops to the approach decision height and the flight crew is unable to proceed with visual orientation. The continuity requirement for these operations refers to the average risk of loss of service, normalized to a 15-second exposure time. The specific risk of loss of continuity for a given approach could therefore exceed the average requirements without necessarily affecting the security of the service or access provided. The safety assessment carried out for one system led to the conclusion that, in the circumstances set out in the assessment, continuing to provide the service was safer than withholding it. The anticipated failures for which the pilot message is distributed are not considered in the continuity calculation [9].

2.4. Availability

Service availability is the part of time that the system simultaneously provides the required accuracy and integrity. In fact, integrity always determines availability. Some applications have specific continuity requirements that must be met for the service to be available. The movement of the satellites relative to the coverage area complicates the availability of GNSS, as well as the potential delays associated with returning the faulty satellite. The level of availability in each airspace at a given time should be determined through design, analysis, and modeling rather than measurement [9].

In determining airspace specifications, countries should consider traffic density, available conventional aids, radar surveillance coverage, potential duration and geographical size of outages, as well as flight and ATC procedures [9].

3. RESULTS

In this part of my paper, we will look at the comparison of GPS, Galileo, GLONASS and Bei Dou systems in terms of all pre-selected input parameters.

3.1. Comparison of Accuracy

In this section, we compare the values obtained in terms of accuracy of individual systems. We will consider the average values from the accuracy measurements of all satellite navigation systems, while the GPS system will consider only the most current measurements.

Table 1: Average accuracy values of the investigated systems.

GPS	Galileo	GLONASS	BeiDou
1.2m	0.5m	17.7m	12m

From table no. 1 we can clearly compare the accuracy of individual systems and we can deduce which system lags in which area and what are its shortcomings. GPS and Galileo are the clear leaders in accuracy with average deviations of 1.2 and 0.5 meters. The GLONASS and Bei Dou systems are slightly worse with deviation values of 17.7 and 12m [1][2][3][4][5].

3.2. Comparison of Availability

For a detailed comparison of systems in terms of availability, we insert the values of the systems into the table.

Table 2: Values of availability of investigated systems.

System	GPS	Galileo	GLONASS	BeiDou
Interval	1,00	0.8151 – 0,9996	0,99 – 1,00	0,96 – 1,00

From table no. 2 we can very easily obtain information about the availability of individual satellite navigation systems. The best of the analyzed systems in terms of availability came the GPS system, although as I mentioned above, the measurement of this system took place in the shortest time of all systems. On the contrary, the Galileo system came out worst in this comparison, precisely because of the already mentioned incident of this system, which caused a relatively long-term loss of system availability in the measured area [1][6].

3.3. Comparison of Continuity

Based on the available information, we were able to determine the values of continuity measurements in various satellite navigation systems. The continuity data for the GLONASS and Bei Dou systems are the most relevant for us, as they were performed over a long period of time, while the GPS system, which showed 100% continuity in the tests, was tested in the study only for a short time [1][6].

Table 3: Comparison of continuity values of GLONASS and Bei Dou systems.

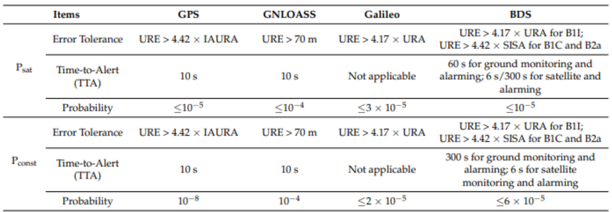
System	GLONASS	BeiDou
Interval	0,9958 – 0,9998	0,996 – 0,999

Table no. 3 shows that the GLONASS and Bei Dou systems are almost identical in the long run. Even though the GPS system was tested only for a short time, we can deduce that the long-term value of continuity and the degree of reliability of this system would be almost identical to those of other satellite navigation systems [1][6].

3.4. Comparison of Integrity

When comparing systems in terms of integrity, it is important to be aware of the integrity requirements for each system and whether the system meets them [1][7][8].

Table 4: Integrity requirments for each system.



	Items	GPS	GNLOASS	Galileo	BDS
P_{sat}	Error Tolerance	URE > 4.42 × IAURA	URE > 70 m	URE > 4.17 × URA	URE > 4.17 × URA for B1I; URE > 4.42 × SISA for B1C and B2a
	Time-to-Alert (TTA)	10 s	10 s	Not applicable	60 s for ground monitoring and alarming; 6 s/300 s for satellite and alarming
	Probability	$\leq 10^{-5}$	$\leq 10^{-4}$	$\leq 3 \times 10^{-5}$	$\leq 10^{-5}$
P_{const}	Error Tolerance	URE > 4.42 × IAURA	URE > 70 m	URE > 4.17 × URA	URE > 4.17 × URA for B1I; URE > 4.42 × SISA for B1C and B2a
	Time-to-Alert (TTA)	10 s	10 s	Not applicable	300 s for ground monitoring and alarming; 6 s for satellite monitoring and alarming
	Probability	10^{-8}	10^{-4}	$\leq 2 \times 10^{-5}$	$\leq 6 \times 10^{-5}$

In table no. 4 we can see the integrity requirements for the individual systems GPS, GLONASS, Galileo and Bei Dou. The most important factor when comparing integrity is to determine whether the system has met its own requirements [1][7][8].

Table 5: Meeting the requirments of individual systems.

System	GPS	GPS/GLONASS	BeiDou
Met/Did not met	✓	X	✓

From table no. 5 It follows that the only system that did not meet these system integrity and monitoring requirements is the combined GPS / GLONASS system [1][7][8].

3.5. Suggestion

To improve satellite navigation in all aspects, it would be appropriate in the future to implement a multi-frequency GNSS receiver that is able to calculate position, speed and time using a combination of signals transmitted by different satellite navigation systems, ensuring better accuracy, continuity, availability but also integrity than previously used satellite navigation systems.

3.5.1. Multi-GNSS

Until recently, the representative system for satellite navigation was the GPS system operated by the United States, but as we already know, other satellite navigation systems such as Galileo, GLONASS or Bei Dou are or will be implemented. In addition, augmentation systems such as SBAS as a network of geostationary satellite systems WAAS, EGNOS or MSAS are in operation.

a) Advantages of Multi-GNSS

Compared to positioning with a separate GPS system, it achieves higher accuracy, mainly due to the increased number of visible satellites, which also increases the success of positioning. This system receives many more satellite signals and is therefore able to determine the location in places where it has not been possible before. It is also able to withstand interference by frequency bands. In the future, this system would help industries and businesses to provide their products or services, as it is more reliable and accurate than stand-alone satellite navigation systems.

b) Multi-GNSS application options

It is certainly important to note where the multi-GNSS system could be used. This system is widely variable and could be used by many industries, such as the automotive industry, for its navigation and telemetry systems, and could also be used in regular transport for vehicle monitoring. It would also make a significant contribution to geographic information systems used, for example, in computer construction work. He would be able to sign up to save many lives in a disaster prevention management system, for example monitoring of seismic shocks, landslides or monitoring of dams.

3.5.2. Starlink

Another possible alternative is to use the Starlink system for satellite navigation in a similar way to GPS. Starlink is primarily intended for providing internet connection all over the world and especially in places not yet covered by it. Some scientists claim that they have found a way to adapt this system so that it can also be used for satellite navigation. These non-SpaceX researchers were able to triangulate signals from six Starlink satellites to focus on a single location on Earth. They achieved an accuracy of less than 8 meters. These values are very comparable to the accuracy of the GPS system itself. Another attempt to investigate the possible use of the Starlink system was carried out at the University of California, where an antenna was placed that was able to receive signals from Starlink satellites. Based on these signals, they were able to determine the position with an accuracy of 7.7m. It is worth noting that the Starlink system is not yet complete and therefore many more satellites will be in orbit. Thus, it is possible to assume that Starlink determination will become more and more accurate as Starlink itself progresses.

a) Advantages of Starlink

Traditional GPS has been around for over 30 years, so why change it? It is very simple. The GPS system has indeed been here for more than 30 years, which means that it is easy to use in smartphones or the automotive industry, but it is much more susceptible to attacks than the Starlink system. Another advantage is its height. The Starlink satellites are placed in orbit at an altitude of approximately 1,200 km from the Earth's surface and thus much closer than the GPS satellites placed in the mid-Earth orbit, which would allow the Starlink system to make more frequent hardware modifications.

4. CONCLUSION

The aim of my paper was to analyze satellite navigation systems usable in general aviation in terms of selected input parameters: accuracy, integrity, availability, and continuity of individual navigation systems. In my work, the analysis showed the need for continuous improvement of satellite navigation, especially in terms of accuracy, where I was able to demonstrate the enormous progress of the GPS system over the last decade. I have also managed to point out the need for gradual innovation and development of satellite navigation systems and their combinations. It was mainly focused on the analysis of professional literature relevant to the issue of satellite navigation systems. The main purpose of this analysis was to identify and compare satellite navigation systems in terms of selected parameters of integrity, continuity, accuracy, and availability. Emphasis was also placed on the methods used in the measurements of individual authors. These were then compared with the results and served as a tool for designing improvements to satellite navigation systems, which includes the implementation of a multi-GNSS system. It can calculate position, speed and time using a combination of signals transmitted by different satellite navigation systems availability but also integrity as previously used satellite navigation systems. The implementation of a multi-GNSS system would result in huge improvements in many industries, including automotive, construction or road vehicle monitoring. Another possible alternative is to use the Starlink system for satellite navigation in a similar way to GPS. It was created with the intention of providing an Internet connection, but scientists outside the Starlink group used its signals to determine the position with high accuracy, comparable to the GPS system.

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