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Hardware and Software Complex for Laboratory of Satellite Technologies

Volodymyr Kharchenko, Valeriy Konin, Olexiy Pogurelskiy
National Aviation University Kiev, Ukraine

Satellite technologies of communication, navigation and surveillance play an important role in modern transport, and particularly in aviation. High effectiveness of global air navigation system is provided by applying data broadcasted from great numbers of satellites, located on Earth orbits. The totality of existing satellite navigation system forms global radio navigation field which parameters should be constantly monitored and controlled for providing safety requirements. The aim of this article is to share experience of creating a laboratory of satellite technologies at the National Aviation University that performs simultaneously educational and scientific tasks.

Keywords: *satellite technologies, laboratory, GNSS*

1. INTRODUCTION

The National Aviation University (NAU) in Kyiv is one of the most powerful educational authorities that prepares specialists for aviation and transport fields in Ukraine. Following the information on the university's website (https://nau.edu.ua), more than 25,000 local and international students study here each year.

The department of air navigation system in structure of NAU provides learning of future air traffic controllers, personnel of aviation safety, and operators of unmanned aviation vehicles. These specialties require knowledge and skills in the field of air traffic management (ATM). Today, the main functions needed for an efficient ATM are advanced surveillance, communication and navigation skills, and in order to perform them over the entire Earth, including areas (such as oceans and desert regions) not covered by ground stations, it is recommended to exploit the potential advantage of satellite technology. In order to educate students in the theory of functioning, and providing them with practical skills of operating with satellite receiving equipment, the laboratory of satellite technologies was founded in 2004. Now we are not only educational but also scientific centre, with experience of taking part in international research programs such as Horizon 2020 (project UKRAINE - *UKraine Replication, Awareness and INnovation based on EGNOS).*

The key element of laboratory that enables providing high level of education and performing scientific tasks is a complex of receiving equipment installed inside classroom, where students get both theoretical knowledge and practical skills (Figure1).

Fig. 1. The view of the laboratory equipment complex

2. HARDWARE AND SOFTWARE FACILITIES

Originally, the main factor determining choice of specific equipment for laboratory of satellite technologies is a list of tasks that should be performed based on research goals. And on the other hand, we also need to consider requirement to their periodical repetitiveness based on training goals for students. The common list of equipment functions could be as following:

- Preliminary simulation of satellite signal availability and prediction of time intervals for communication with certain space vehicle (SV);
- Simulating satellites geometry impact on results of navigation measurements;
- Receiving satellite signals and estimating their parameters (signal/noise ratio, spectrum);
- Decoding, processing and storing digital data from received messages;
- Applying obtained data for evaluating radio navigation field and signal-in-space (SIS) performances (accuracy, integrity, availability, and continuity);
- Visualizing graphical results of calculation and simulation.

Analysing possible ways of obtaining and processing satellite data we can determine the main elements of hardware and software complex for laboratory of satellite technologies. It allows defining the order of satellite data interchanging between the main elements of hardware and software complex in the form of block diagram shown in fig. 2

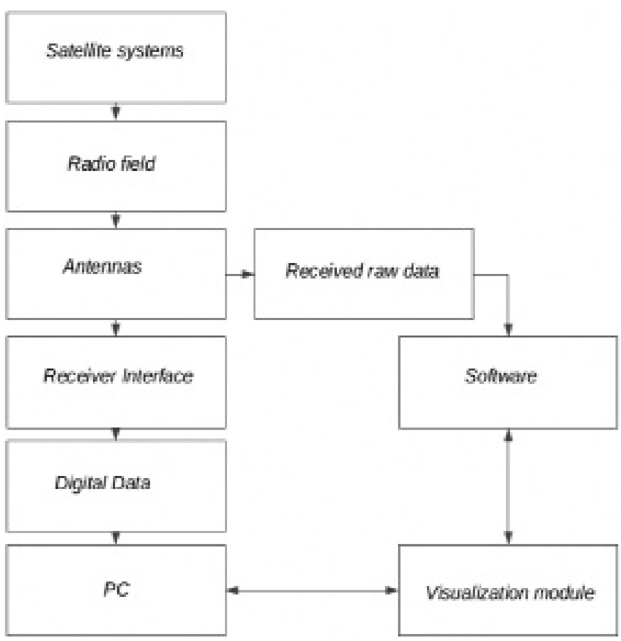

Fig. 2. The data flow between the main elements of hardware and software complex.

Let us consider each element as proposed in Figure 2 block diagram and define its functions.

Satellite systems are modern space-based systems for providing global communication and navigation services. In the nearest future we are planning to add here also satellite systems of Earth remote sensing. But now we have focused on receiving and processing data from Global Navigation Satellite Systems (GNSS), such as GPS(USA), GLONASS (RF), BeiDou (PRC) and Galileo (EU) that are currently in either full operational capability or near it. There were already over 100 GNSS satellites in orbit [1]. GNSS space constellation contains all satellites from various navigation systems that are presently in space and perform the function of broadcasting special navigation messages. All of these satellites are sources of information that users need to make the calculations. The complex created should be geared towards receiving data from all possible satellite navigation systems and their combinations. If data is received from only one or more systems, then the results must be specified for which configuration the integrity assessment is obtained.

Radio field is formed as a result of summing signals from all active GNSS satellites in space. There are public free-for-all signals in each system with access for any user without fees. Therefore, we can state that around the Earth there is a field of radio navigation signals (or simple radio navigation field) that could be applied for solving navigation tasks.

Antennas provide receiving of satellite messages. Recommendations as far as location and way of installing them are concerned contain requirements as for conditions of best sky observation. The good placement is a roof of a building, or open space without any shadowing objects. The antenna system could apply built-in algorithms for resistance to multipath signal distortion. At the stage of installing we should remember about this unwanted effect.

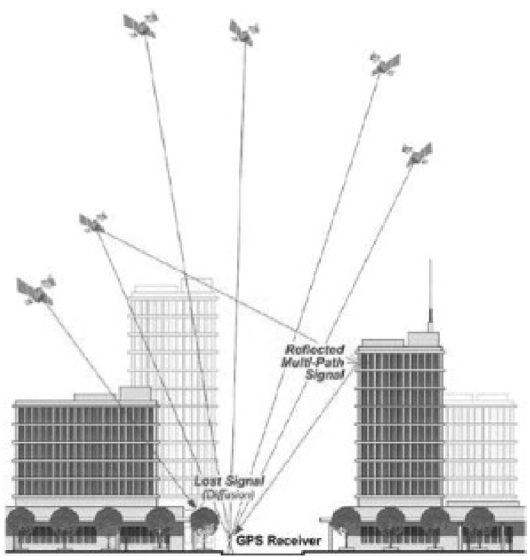

Fig. 3. Not optimal location of receiving antenna.

Digital data is information that has been received from satellites with the help of an antenna system. This information should be recorded and transited for follow operations of decoding by complex software facilities. The composition of navigation data is subject to change so we need the ability to specify message ID, or set from several messages that should be recorded.

Receiver interface enables sending requests for specific data before it would be obtained with the help of receiving equipment. Novatel Connect Interface is convenient and widely used software facility for data interchange with Trimble receivers' family. Dependently on the version, the view could be different but it has to include function of data set formation (so named *log-file*). It should be underlined that log-file also may contain data obtained in result of calculations performed by receiver navigation processor.

Received raw data is obtained after response request, and includes result of measurements performed by navigation receiver. These data will be collected for alternative processing by software of developed complex with the aim of their verification or comparing with results obtained in another way, and also for the visualization that would follow.

Personal computer (PC) is a workplace equipped with facilities of data input and output, recording and storage, processing and visualization, etc. Whereas part of data would be received from specialized Internet servers, we also need to provide ability of connection PC to local or global network resources.

Software of developed complex contains programs for processing and decoding data obtained from navigation satellites, with the help of a PC. The main part of programs in our laboratory is original and own created.

Visualization module is used for representing obtained results of calculations in a form of graphs, diagrams or plots. Charting is a function of visualization module that could be represented as especially created scenarios being run with the help of a PC.

Hardware of developed complex contains facilities described below.

GNSS antennas and cable connections

The most studies for example such as research of full scale radio navigation field parameters require receiving signals from a maximum number of visible satellites. Therefore, it is appropriate and more practical to apply antennas installed on roofs of buildings. The example of such a location is shown in fig. 4.

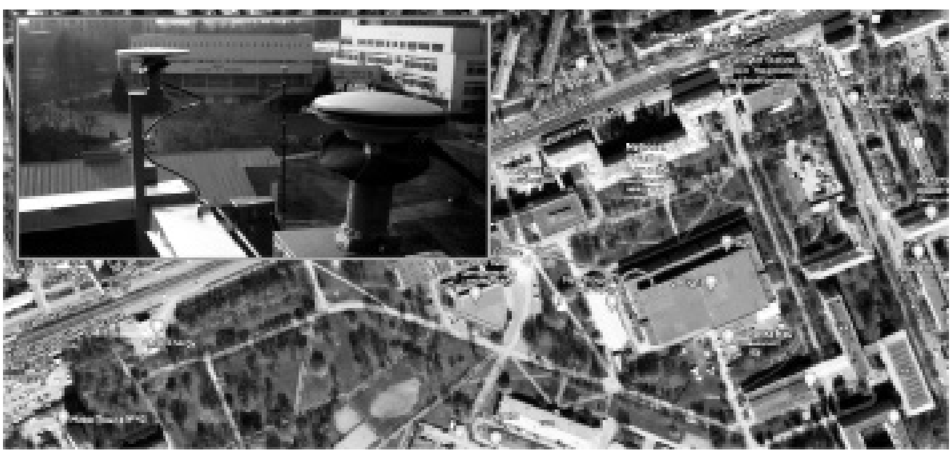

Fig. 4. GNSS antenna on the roof of building 11 of National Aviation University

Connection with receivers installed inside laboratory is realized with the help of cables and distributed between several receiving stations with the help of active splitters, as it is shown in Figure 5.

Fig. 5. Distribution of the received satellite signals between equipment inside laboratory

GNSS receivers are key elements in the structure of hardware and software complex. Note, that to successfully complete the tasks we need special receivers with the ability to get raw navigation data, measurements and other service information. Our experience allows to state that Novatel GNSS, such as receiver ProPack G2 (Figure 6) satisfy most of the requirements.

Fig. 6. Receiver Novatel ProPak G2

A PC equipped workplace is used for processing the received data, where it is stored and analysed. The examples of such workplaces are shown in Figure 7, 8. A PC also is used for storage of software components, scenarios and results of processing.

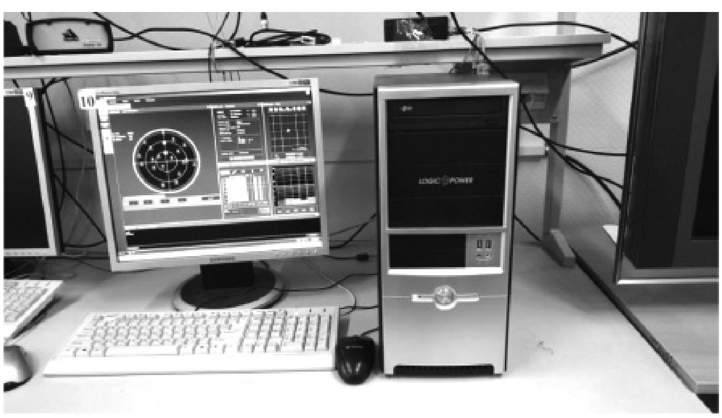

Fig. 7. Example of workplace №1.

Fig. 8. Example of workplace №2.

The hardware and software complex is a tool for performing scientific and education tasks. It contains original, own-created MatLab programs and functions that realize algorithms of decoding, processing and visualization of the data received from navigation satellites, with the help of GNSS receivers or from other sources. Another type of tasks is transforming data formats with the aim to apply them in program products of third developers. A part of these program products is freely distributed and could be found in specialized Internet resources. MatLab programs from developed complex in such case are used for refreshing initial data as almanac, ephemeris, or various types of corrections.

Full-scale software set of developed complex is a computer model of a GNSS receiver. It contains functions created in MatLab, that provide stages of secondary processing data traditionally performed by navigation processor inside a GNSS receiver. These MatLab functions are based on algorithms recommended by developers of satellite navigation systems, and distributed in official documents. The most known and widely used one is Interface Control Document (ICD).

The way of visualization of the obtained results also is important and deserves special attention. A part of visual solutions and graphs were created especially for educational purposes to make understanding of the obtained results more convenient. The developers used here the teachers experience acquired in the National Aviation University after more than 15 years of lecturing disciplines linked with satellite technologies for aviation field specialists.

3. SCIENTIFIC RESULTS

The developed complex described above is a tool suitable for receiving data and measuring information that could be applied not only for educational, but also for scientific purposes. Some examples of such studies performed in NAU with the help of equipment of laboratory of satellite technologies are given below.

In 2015-2016 we were focused on facing different tasks in space for which we were to create a reliable way of navigation for different manned on unmanned vehicles in space [3-6]. The model presented in the works [3] was created in MATLAB software package to analyse the availability of the navigation satellites in space, to coordinate estimation and allow simulating different parameters.

The obtained results allowed concluding that satellite navigation on the geostationary orbit is only possible for limited moments of time, and even then, the possible accuracy leaves much to be desired (Figure 9). The use of only main lobe signals gives only limited results with low accuracy and availability. To solve this it may be required to use the side-lobe signals of the off-nadir satellites, which allow to improve the geometrical setup of the satellites, and, in turn, the DOP factors. It will also solve the problem with the low availability of satellites, increasing the number of visible satellites for the user.

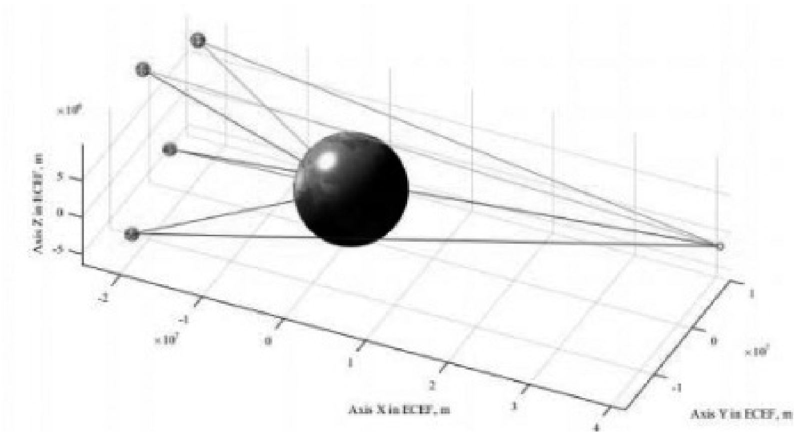

Fig. 9. Visualization of GNSS availability on the geostationary orbit

Later we continued studying problems of availability of GNSS signals in the near-Earth space and in work [7] estimated the possibility to use them on the medium Earth orbits. Our results indicated that it is impossible to use the satellite navigation for medium Earth orbits if only the main lobe signals are used. There has to be another source of signals for them to work. In this research, the side lobe signals are used to enhance the performance of the satellite navigation. They make it cheap and viable to employ this navigation type for the autonomous position determining in a spacecraft or the enhanced manoeuvre recovery, as satellite navigation only requires a sensitive on-board receiver.

In works [8-10] we stated that traditionally the second frequency of the dual-frequency receiver is used to increase the accuracy of positioning by mitigating the influence of the ionosphere and other atmospheric effects on the signal. The presence of the useful signal at both frequencies is usually taken for granted, and it is indeed true for the Earth service zone, as the satellite antennas were primarily designed to ensure stable and reliable navigation in this zone. There is a certain difference in the radiation pattern between L1 and L2 frequencies. This plays an important role for satellite navigation in near-Earth space. The work results provided the information about the use of the frequencies in the task of space navigation.

4. CONCLUSIONS

The hardware and software complex created in laboratory of satellite technologies of the National Aviation University is a combination of equipment for receiving available satellite signals and specially created software for decoding it and applying in various educational and scientific tasks. It could be applied as for getting practical skills by students who should be prepared for working with satellite receivers and sensors, also as for solving a wide variety of scientific tasks some examples of which were shown in this article.

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Volodymyr Kharchenko
National Aviation University Kiev, Ukraine
kharch@nau.edu.ua

Valeriy Konin
National Aviation University Kiev, Ukraine
vkonin@mail.ru

Olexiy Pogurelskiy
National Aviation University Kiev, Ukraine
pogurelskiy@gmail.com