UDC: 621.396.98(043.2)

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Acceleration of GNSS applications development and facilitation of their broad acceptance in Ukraine through international cooperation and own experience

GNSS are used around the globe in a variety of applications and the number of GNSS enabled devices tends to grow dramatically in the nearest years. This article aims to present the experience of NAU in development and research of GNSS applications and technologies together with international cooperation.

Global Navigation Satellite System (GNSS) is a system that provides users having compatible devices with their position, velocity and local time. GNSS is a term that combines global positioning systems, such as GPS (USA), GLONASS (Russia), Galileo (Europe) and BeiDou (China), together with Satellite-Based Augmentation Systems (SBAS), such as EGNOS (Europe), WAAS (North America), GAGAN (India) and MSAS (Japan) [1-3].

GNSS is used around the globe, with 3.6 bln GNSS devices in use in 2014. By 2019, this is forecasted to increase to over 7 bln – for an average of one device per person on the planet [3]. Numerous GNSS applications have already been identified, including aviation, rail, road, maritime, agriculture, location based services, emergency, security and humanitarian services, fisheries, surveying, ground mapping, aerial photogrammetry, geospatial information systems, science, environment, weather, etc. [3-5]. It is impossible to describe all GNSS applications here, since the list is certain to grow, limited only by the imaginations of engineers and innovative entrepreneurs.

National Aviation University (NAU) participates as one of the partners in international project UKRAINE (UKraine Replication, Awareness and INnovation based on EGNSS), which is a part of Horizon2020 program. The objectives of the UKRAINE project, in line with GALILEO-3-2014 Call, are to foster application development through international cooperation and to create a broad acceptance of EGNSS in Ukraine, creating at the same time opportunities both for knowledge building and at commercial level. Research and training center "Aerospace center" [6] is a structural part of NAU that conducts fundamental and applied research in the priority areas of science, engineering and technology. One of the main directions of the "Aerospace Center" activity is a satellite navigation systems and technologies. Having wide experience in this sphere center represents NAU in UKRAINE project. The experience of "Aerospace Center" of NAU in GNSS technologies will be represented below.

GNSS experimental monitoring complex contains antennas (fig. 1), base station (fig. 2), all necessary software and hardware means. It allows: monitoring of satellite radio navigation systems (GPS, EGNOS, GLONASS) navigation field; analysis of GNSS quality characteristics (accuracy, integrity, availability, continuity), providing differential mode of GNSS and a lot of other applied tasks.

According to the Order from 28.08.2013 № 650 of the Cabinet of Ministers of Ukraine, the scientific object "Global navigation satellite systems experimental monitoring complex of National Aviation University" is in Ukrainian State register of objects that are National inheritance.

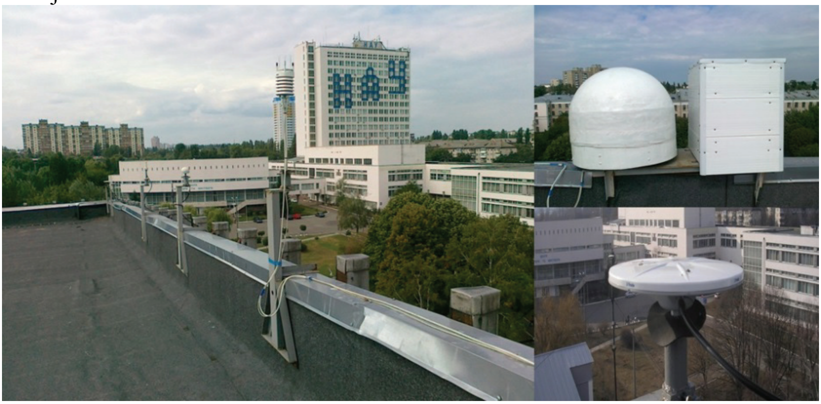

Figure 1 - Antennas of the GNSS experimental monitoring complex of NAU

Figure 2 - Base station of NAU in the network of CNMSU stations

We cooperate as well with the State Space Agency of Ukraine and particularly with National Center for Control and Testing of Space Vehicles. Our base station belongs to the network of coordinate navigation maintenance system of Ukraine (CNMSU) stations (fig. 2). The specified set of data is transferred to the center of control of Ukraine's navigation field. This center is intended for GNSS integrity monitoring and forming differential corrections information (DCI) for the increased accuracy of positioning. Beside of that our base station forms such differential corrections information in autonomous mode and provides it to different users in particular for geodesists. It can provide differential mode of GNSS in real time mode and in post-processing mode. The equipment of the base station includes GNSS receiver NovAtel DL-V3, antenna NOV702GG.

A lot of simulations of GNSS technologies have been performed. Some of them will be represented here. You can see the results of GLONASS investigation at the fig. 3. The simulation has been performed in Matlab software package and experimental validation – using Novatel CDU. It can be seen that for specified time and coordinates of observer the location of satellites is the same that proves the correctness of simulations. The results of GALILEO and GLONAS investigations through simulation in Matlab are represented at the fig. 4. The GALILEO satellites orbits for 3 days are represented at the left part of the figure, and the model of GLONASS satellite orbital rotation is depicted on the left part.

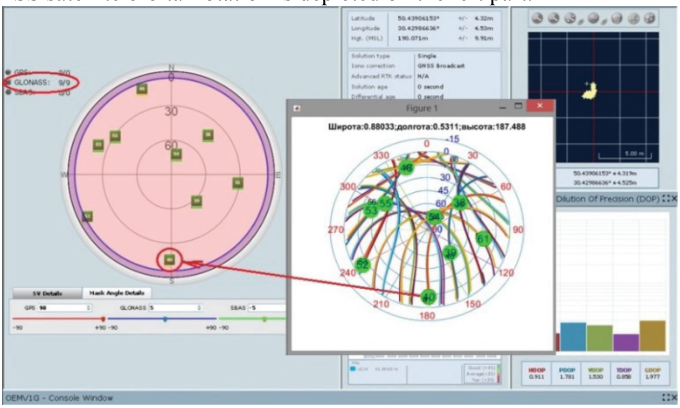

Figure 3 - The results of simulation and experimental validation of GLONASS

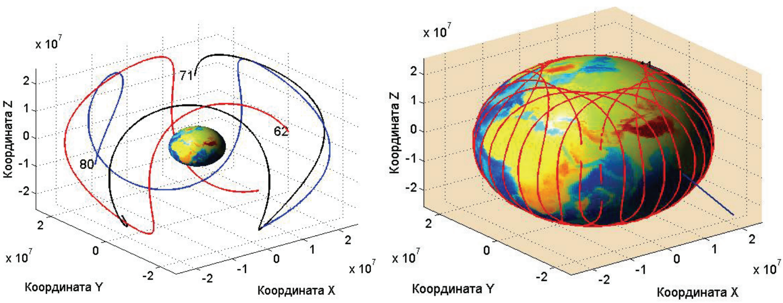

Figure 4 – Simulation of satellites' orbits: GALILEO (Left); GLONASS (Right)

The investigations of jamming resistance have been performed. It can be seen from the fig. 5 that in case if there is no any disturbance, satellites' health is good and position is calculated (fig 5.a), with the increase of noise intensity (fig 5.b, c) the number of satellites and their health have decreased. With the noise exceeding the signal strength or even stronger than the signal (fig 5.d) there are no satellites available and position cannot be calculated.

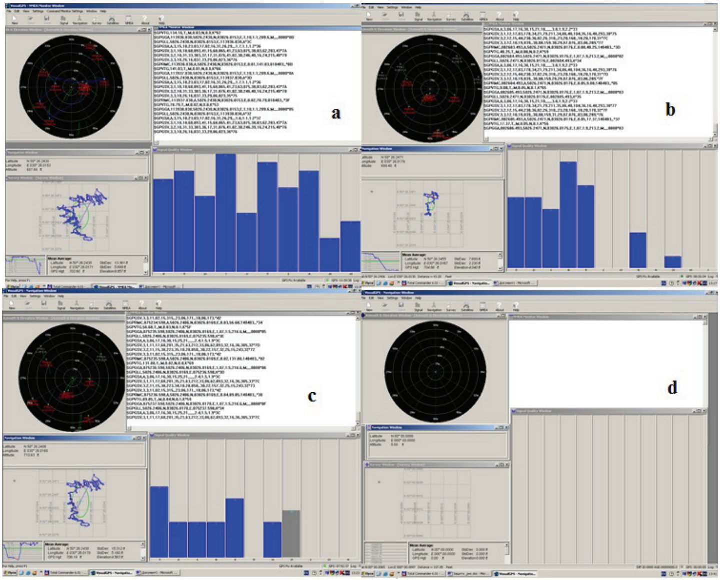

Figure 5 – The results of jamming resistance investigations: a) no disturbance; b) small disturbance; c) moderate disturbance; d) strong disturbance

The scheme and prototype of the 4-element adaptive antenna array, which can actually “adapt” to noise sources, are given on fig. 6.

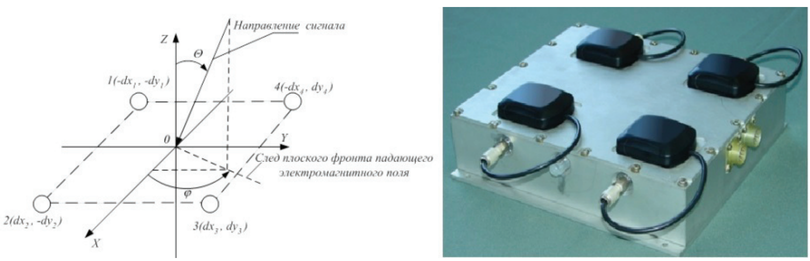

Figure 6 – The prototype of 4-element adaptive antenna array

On left part of figure 7 we can see the radiation pattern of directed four-element antenna array, which "cuts" the noise source, which comes from one of the directions. On the right part of the figure 7 we can see the radiation pattern of multi-element antenna array, which was adapted to receive signal from 4 directions.

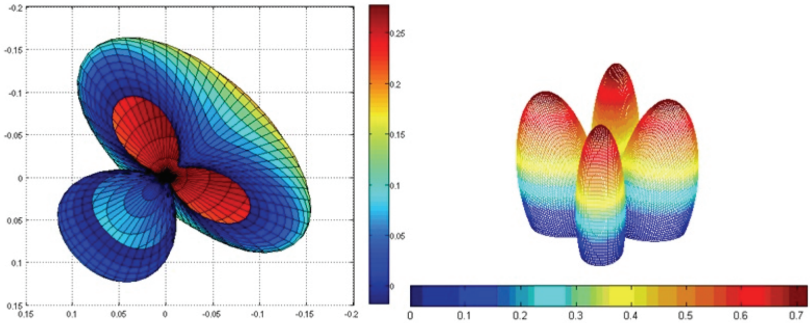

Figure 7 –The radiation patterns of the adaptive antenna array for the protection of satellite navigation receivers against noise (jamming)

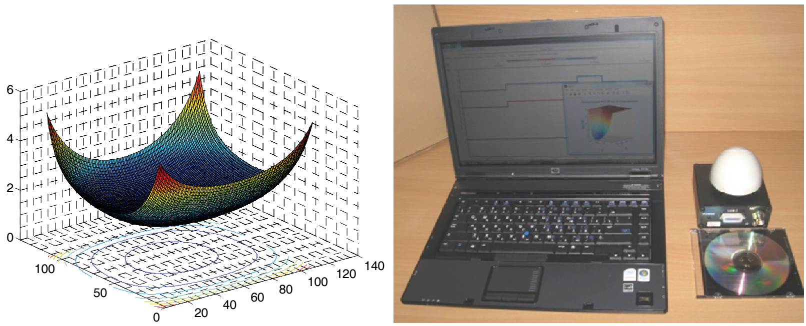

Figure 8 – Automatic forecasting system of GNSS

Automatic forecasting system of GNSS availability (fig. 8) at aircraft's route helps to plan optimal flight route on the basis of predicted data of GNSS availability for solution of navigation task.

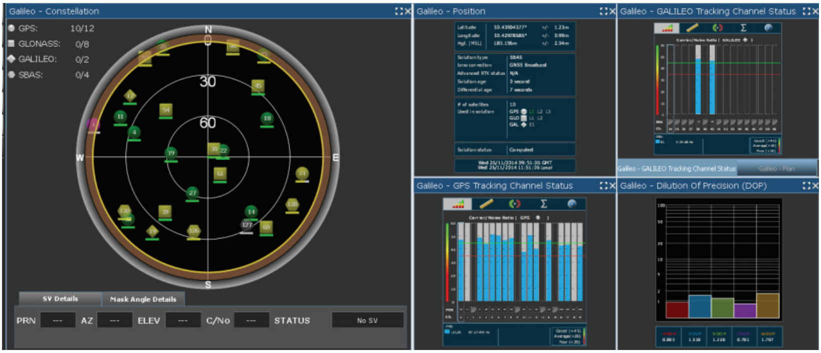

Figure 9 – Novatel CDU screen during the experiment

EGNOS - European Geostationary Navigation Overlay Service. EGNOS is one of the cost-effective enablers for PBN. ICAO recommends deploying satellite-based approaches with vertical guidance at all runway-ends. EGNOS currently provides performance on the level of APV-2, and is expected to provide Cat – 1 performance soon. EGNOS will soon be a viable and cheap replacement of the ILS systems. Though, it will still require to design some precision approaches for specific airdromes. The transition for pilots would be much easier as both EGNOS and ILS provide a similar interface. In Kiev we have investigated the current performance of EGNOS.

It's necessary to note that the most important feature of the SBAS for common GPS users is the IONO correction grid. Since the selective availability is deactivated, the largest single source of error in GPS position determination is the signal delay in the ionosphere [1, 2]. Being able to correct these errors significantly increases the accuracy of every GPS receiver that is able to process WAAS/EGNOS data [1, 2]. Unfortunately, Ukraine is at the border of Ionosphere Grid Point (IGP) availability, which can be seen from the IGP availability grids for 2009 and 2014 years that are represented at the fig. 10. The figures had been received from receiver recordings' after processing by PEGASUS tool developed by Eurocontrol. It's necessary to notice that there are no any RIMS at the territory of Ukraine – the closest to us is located at Warsaw, Poland.

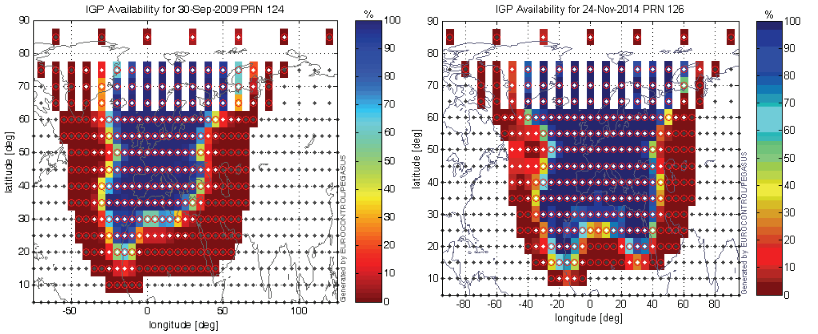

Figure 10 - IGP Availability:
Left part - for 30 September 2009; Right part – for 24 November 2014

One of the main concerns, which arises while using GPS or GLONASS without additional systems, is integrity. This parameter provides us with a measure of trust, which we can place in our research, allowing the use of satellite-based systems for safety-critical operations. We haven't found any integrity issues during our research of EGNOS from 2009, which is an extremely good sign for the system future. Other interesting parameter is availability. This parameter indicates the possibility of system use under specific typical operations like APV-1 or APV- 2. On figures 11, 12 we can find integrity and availability information for two researches, one in 2009 and other in 2014. Detailed information is given in reference [7, 8].

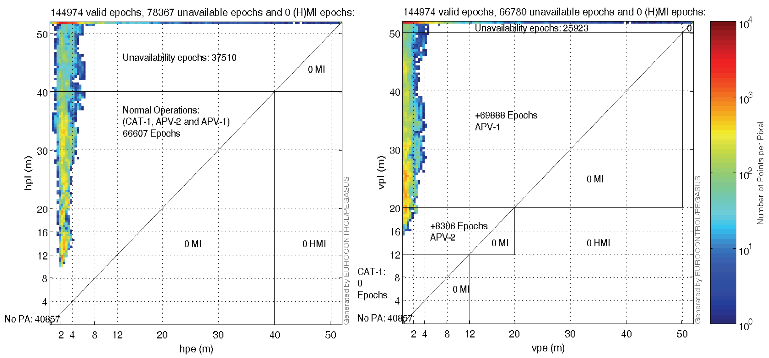

Figure 11 – Horizontal (left) and Vertical (right) Stanford plots for 2009 year

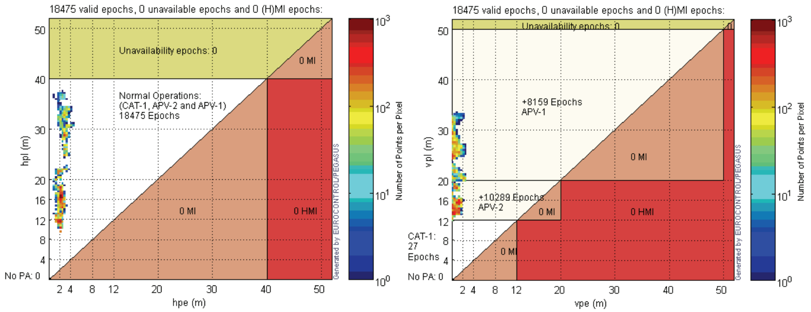

Figure 12 – Horizontal (left) and Vertical (right) Stanford plots for 2014 year

The hardware-software complex for special moving vehicles monitoring and control [9] provides tracking of vehicles and other moving objects of special destination in real time. It can block vehicles' actuating devices in case when it crosses prohibited areas or performs unauthorized actions. The experimental validation of this complex had been performed in Boryspil airport.

Figure 13 – Hardware-software complex for special moving vehicles monitoring and control

Unmanned aerial vehicles (UAVs) are intensively and successfully exploited in different spheres of humans' life and activities, including different monitoring tasks, precision agriculture, digital surveying and mapping, entertainment, etc. A number of other potential civil applications have been identified and many more are expected to emerge once the technology is widely disseminated [10].

To perform some specific tasks UAV has to rely on accurate navigation data. Therefore the design and implementation of a navigation system with the optimal balance of cost, weight, accuracy, integrity, and reliability parameters is a key issue. A navigation system uses a selected sensors set and airborne computer to calculate current velocities, position and orientation parameters. For a small and medium

UAV according to the classification in paper [11] the following sensors have been chosen: MEMS-type inertial measurement unit (IMU) with 3-axis accelerometers, gyros, magnetometers, barometric altimeter and GNSS receiver. The prototype of UAV integrated navigation system with abovementioned sensor set and software modules has been designed in the Research Training “Aerospace Center” of the National Aviation University (NAU), Kyiv, Ukraine. Integrated GPS/INS navigation system provides the following parameters: Orientation angles (Range: roll ±180°, pitch ±90°, yaw 0°…360°; Accuracy: roll, pitch – 0.5 - 1°; yaw – 0.5 - 2°); Ground speed (Range: 0…400 m/s; Accuracy – 0.1 m/s); Coordinates (Accuracy: 5 m, depends on GNSS availability); Angular Velocities (Range: ±450 °/s; Accuracy: 0.16 °/s); Linear Accelerations (Range: ±18, ±10 g; Accuracy: 1.5 mg); Barometric height (Range: 0…3500 m; Accuracy: 3 m); UTC-time.

To validate its performance a lot of experiments have been conducted [12-15], including the laboratory, on-ground and flight tests. Here the results from the car (fig. 13) and flight tests (fig. 15, 16) are presented.

Figure 13 – Reference trajectory of car motion in GrafNav/GrafNet [16]

Reference trajectory has been calculated using raw measurements from GNSS receiver and GrafNav/GrafNet software package by Novatel. It can process data from the most of commercial single and dual frequency GNSS receivers, also program support universal receiver data format RINEX. This software allows obtaining highly accurate coordinates both of stationary and moving points in a post-processing mode. Reference coordinates estimation is performed using data from navigation receiver with the known coordinates, i.e. base station. In our case the base station from the "Global navigation satellite systems experimental monitoring complex of the National Aviation University" [9] that according the Order from 28.08.2013 № 650 of the Cabinet of Ministers of Ukraine belongs to the National inheritance objects had been used.

At the fig. 14 you can see GNSS/INS navigation system prototype (left part) and small UAV (right part) used for its experimental testing and performance validation.

Figure 14 – Small UAV used for the experimental testing of GNSS/INS navigation system prototype

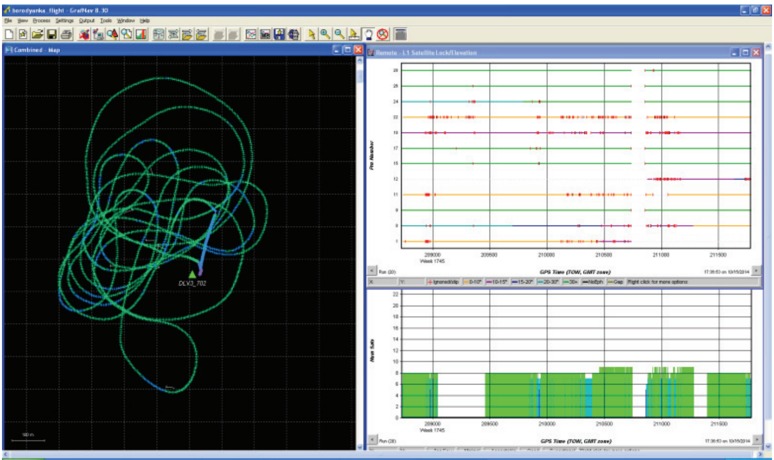

Figure 15 – Flight track in GrafNav/GrafNet

On the figure 15 the flight trajectory processed in GrafNav/GrafNet package after the experiment is represented together with the plots of satellites availability and health during one of the flight stages. The same flight track has been calculated in a real-time mode in the prototype of GPS/INS navigation system, it can be seen on the fig. 16 in GoogleEarth.

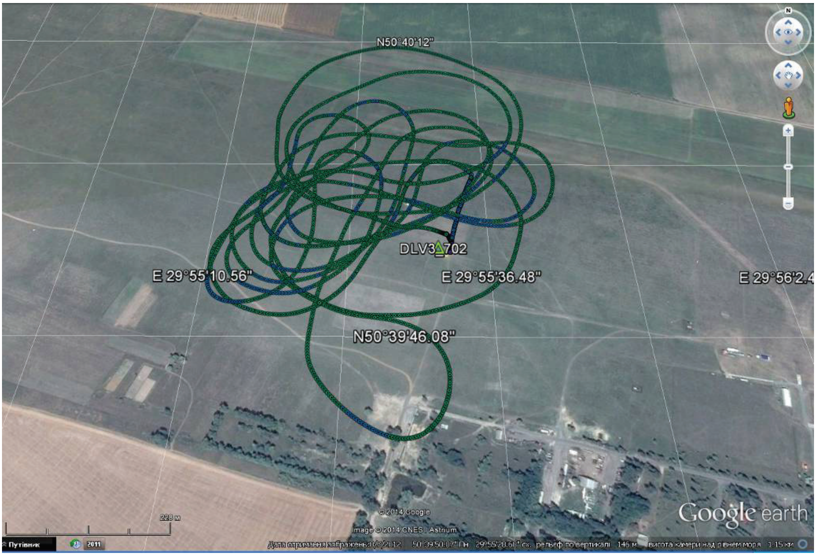

Figure 16 – Flight track in GoogleEarth

Air transport has experienced the impetuous growth, which is followed by problems for its safety. Additionally, one of its most difficult phase is landing, which starts from the beginning of the landing flare and proceeds until aircraft exits the landing runway, comes to a stop on the runway, or when power is applied for takeoff in the case of a touch-and-go landing.

One of the tasks of NAU in UKRAINE project is to estimate the benefits of operators from EGNOS implementation. The following criteria has been taken into account: guidance accuracy - a degree of conformance between the estimated or measured value and the true value; aerodrome equipment – quantity of equipment, needed for ensuring appropriate work of system; surroundings – expresses dependence of signal from obstructions around the system; operators – shows requirements of the system to its maintenance; ATC procedures – points the complexity of guidance procedures and ATCO time to be spent on it; coverage availability – means the size of area, covered by the system; effectiveness in intensive traffic – shows how the system manages loaded traffic in short terms.

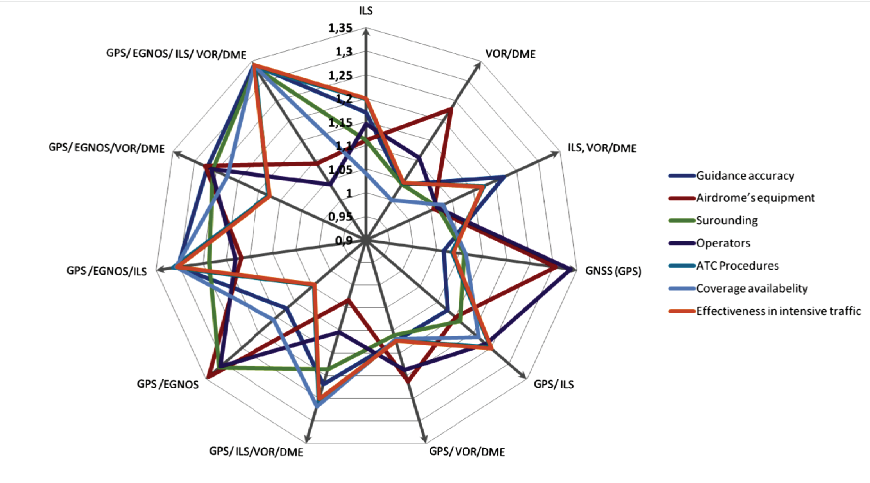

Figure 17 – Estimation all LS by all criteria for using "Spider – CIW":

The results of multicriteria estimation of all landing systems by the above mentioned criteria are represented at the fig. 17. The "Spider - CIW" is a pictorial diagram constructed in polar coordinates. The axes on which the values of the criteria are applied are directed radially from the circle center to the periphery.

Acknowledgments

A part of the research presented at the given article has been performed under the UKRAINE project. This project has received funding from the European GNSS Agency under the European Union's Horizon 2020 research and innovation programme under grant agreement No 641517.

Conclusions

Since GNSS are used around the globe in a variety of applications and the number of applications together with number of GNSS enabled devices tend to grow significantly it is very actual and perspective to perform research and development in this sphere. The given article summarizes some experience of NAU in GNSS sphere and represents some first results from the UKRAINE project where NAU is one of the partners.

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