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THE TEST PROGRAMME CONCERNING AIRCRAFT POSITIONING AND TRAFFIC MONITORING – PART II

Summary. This paper presents the results of studies on the determination of an aircraft's trajectory and positioning accuracy. The PPP method was applied to determine the aircraft's position in kinematic mode for code observations in the GPS system. Computations were executed in the "PPP_KINEMTIC" software, whose source code was written using the Scilab 5.3.2 platform. The PPP_KINEMTIC software allows for the latitude coordinate to be estimated with accuracy between 1 and 6 m, the longitude coordinate to be estimated with accuracy between 0.5 and 2.5 m, and the ellipsoidal height to be estimated with accuracy between 1 and 7 m. The average value of the MRSE term equals 5 m with a magnitude between 1 and 8.5 m. In the paper, general libraries of the PPP_KINEMTIC application were presented and the PPP method was characterized too.
Keywords: GPS, PPP method, accuracy analysis, aircraft trajectory monitoring, safety, risk, threats, Global Navigation Satellite System (GNSS)

1. INTRODUCTION

The main aim of the study was to test the functioning of a system for monitoring aircraft and other vehicles after the installation of a new, modified software produced by the Samset company. The most crucial element was to carefully check the radio link and determine the exactitude, continuity, availability and credibility of the system being developed. In the tests, the aircraft's trajectory was registered during a test flight and the material collected was used to analyse the accuracy of this air traffic monitoring system.

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2. ANALYSIS OF RESEARCH RESULTS ON TECHNICAL CONDITIONS

Three points spread evenly along flight trajectories (VirA, VirB, Base) functioned as the Earth reference stations (Fig. 1). Stations VirA and VirB used in the research were virtual points, whose observations were generated in the POZGEO-D service of the ASG-EUPOS system, while station Base (Fig. 2) was a local physical station placed near the runway at Mielec Airport, where a geodetic receiver, Topcon HiPerPro, was placed. The data from all base stations were recorded in one-second intervals.

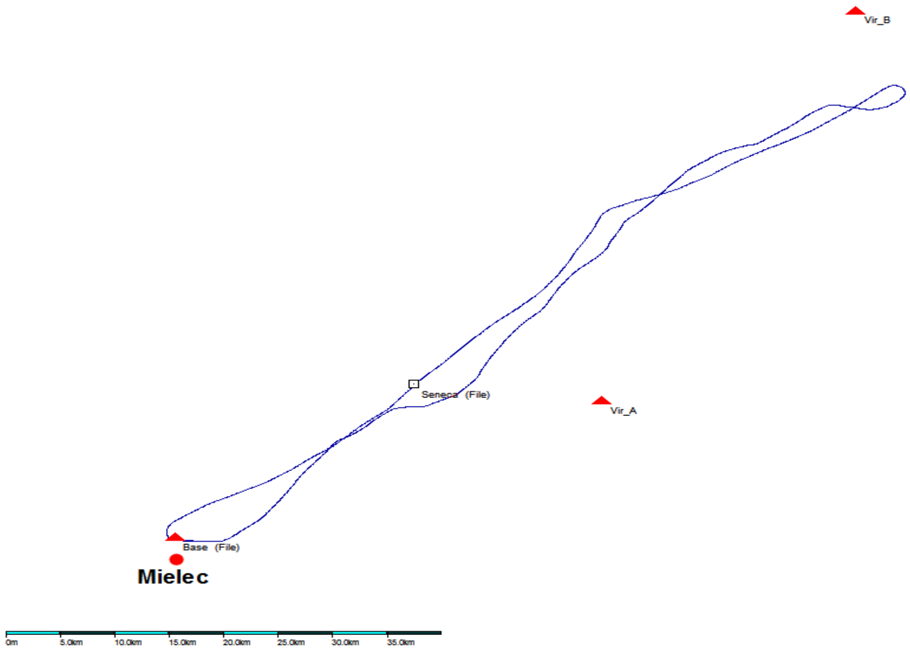

Fig. 1. Trajectory of the Seneca Piper PA34-200T airplane and placement of the three base stations [2]

Fig. 2. Local reference station: Base, located at Mielec Airport [4]

The exact coordinates of the reference points (determined to the nearest centimetre) are presented in Table 1.

Table 1.
Coordinates of the reference stations' points used in the experiment

Point number	*Latitude (B)*	*Longitude (L)*	*Height (h)*
VirA	50° 28' 00",00000	22° 00' 00",00000	200,000
VirB	50° 52' 00",00000	22° 20' 00",00000	200,000
Base	50° 19' 36.58544"	21° 27' 02.76915"	201.481

Three autonomic OTF positions made it possible to determine the average error of the average position for each second of the flight. The average errors were calculated separately for each of the coordinates, i.e., B, L, h (ellipsoidal height). To evaluate the accuracy of the calculations, the following parameters were taken into account:

- the average errors of individual geocentric components mx, my and mz (if necessary, mB, mL and mh of the geodetic components),
- the error in the receiver aerial position (understood as the error resulting from the airplane's position).

The values of average errors of components (mx, my and mz) were appointed in the geocentric system according to the following dependencies [8]:

$$\begin{cases} Cx = m0 \cdot N^{-1} \\ mx = \sqrt{Cx(1,1)} \\ my = \sqrt{Cx(2,2)} \\ mz = \sqrt{Cx(3,3)} \end{cases} \tag{1}$$

where:

$m0$ = average error of adjustment (standard deviation of measurement)

$$m0 = \sqrt{\frac{[vv]}{n-k}} \tag{2}$$

n = number of observations

k = number of appointed parameters

v = correction to the pseudo-distance observed

Values (mB, mL i mh) are appointed in the geodetic system according to the transformation [8]:

$$\begin{cases} Q = R \cdot Cx \cdot R^T \\ mB = \sqrt{Q(1,1)} \\ mL = \sqrt{Q(2,2)} \\ mh = \sqrt{Q(3,3)} \end{cases} \tag{3}$$

where:

R = matrix of transformation from the geocentric system to the geodetic system (coefficients in the matrix are dimensionless)

$$R = \begin{bmatrix} -\sin(B)\cos(L) & -\sin(B)\sin(L) & \cos(B) \\ -\sin(L) & \cos(L) & 0 \\ \cos(B)\cos(L) & \cos(B)\sin(L) & \sin(B) \end{bmatrix} \tag{4}$$

The received values of the errors in geodetic coordinates B, L, h are presented in Figure 3. The blue colour represents the average error of component B, the yellow colour represents that of component L, and the red colour that of component h.

The average errors of coordinates B, L, h for the reference position of a flying airplane were approximately 2-3 cm for the horizontal coordinates and 4-6 cm for the vertical coordinate. The results obtained for each second of the flight are presented in Figure 3.

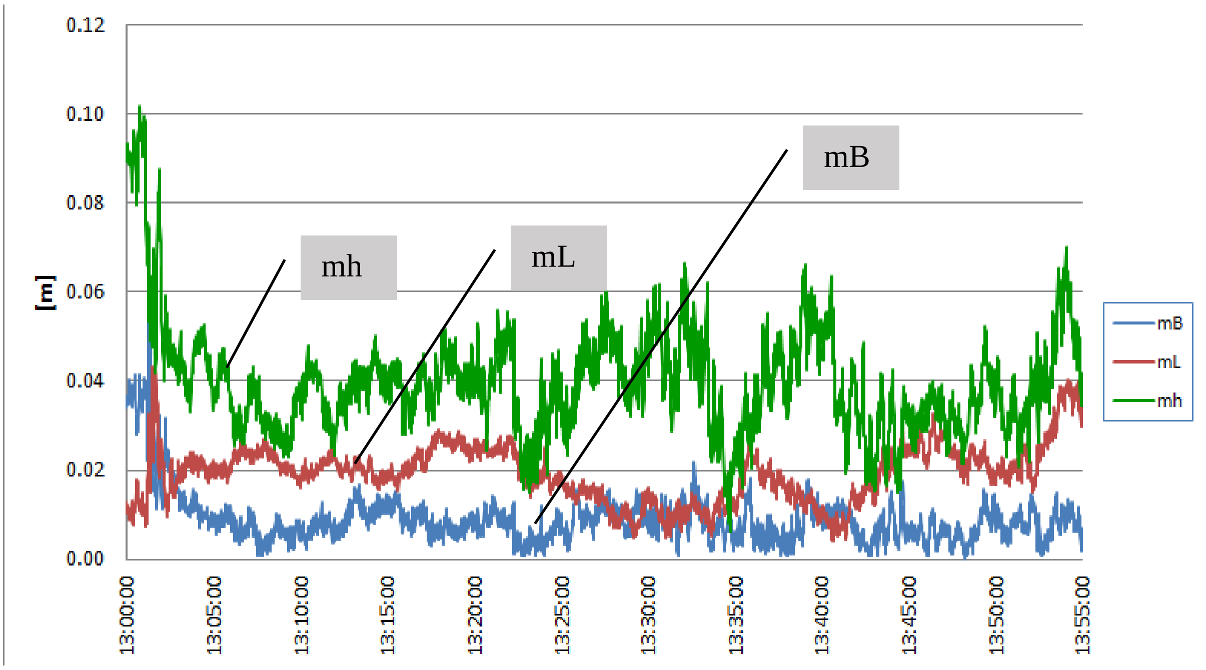

Fig. 3. Average errors of coordinates B, L, h for each second of the flight

Having determined the exact positions of the airplane (to the nearest centimetre) for each second of the flight, it was possible to estimate the accuracy of the Samset system installed on the board of the plane. During the tests, the GNSS receiver (Novatel) worked in an autonomic mode and sent the position of the plane at each second of the flight by radio through the UHF connection, using the radio modems made by Satel company. The detailed data concerning the airplane flight trajectory were registered on the server of a dispatch system. The dispatch system was, for research purposes, installed in an object at Mielec Airport, while the UHF aerial was installed at a mast next to the object.

After geodetic conversion of the coordinates into a common reference system, the coordinates received were compared with the coordinates provided by the Samset company, which were determined using the new version of the dispatch system software and a mobile unit of the system installed on the plane board.

Fig. 4. Mobile unit of the system together with the control panel installed on the plane board

While comparing the data, it turned out that the data from the dispatch system contain gaps caused by interference in the data reception from the plane. The stability of data recording in the new version of the software is much better, although minor inaccuracies occur, which is described in a later part of the report.

The biggest number of gaps was observed in the north-eastern part of the flight trajectory, when the plane was the furthest from the dispatch system aerial. In the other parts of the flight were few gaps, which usually lasted 1-2 s. The data registered also contained a few gaps lasting from a few to a few dozen seconds.

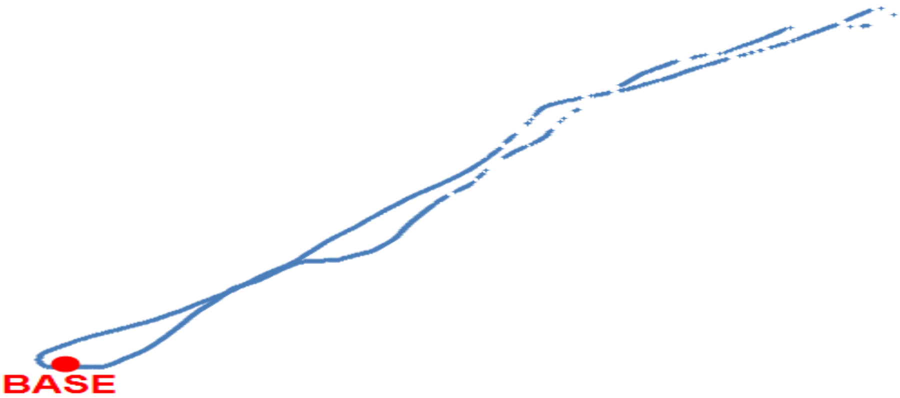

Fig. 5. Trajectory according to the Samset system (the gaps can be seen in the north-eastern part of the trajectory)

A detailed comparison showed that, for 3,301 s of the flight, 1,138 measurement epochs were registered, i.e., 66%, while, for 2,163 epochs, there were no data recorded concerning the position of the plane. The gaps in the recordings of the plane position were mostly caused by the physical reach of the radio modem of the mobile module installed on the plane board. This solution was temporary and the radio aerial was inside the cabin. The additional parameter limiting the availability of the plane position was that the plane flew at various heights, which was connected with the test of the system coverage for various cruising altitudes. During the experiments, for some measurement epochs, the time was assigned incorrectly. It is particularly visible in the initial phase of the flight, given that, later on, the situation becomes more stable and the time incorrectly assigned to the epochs rarely occurs. The incorrectly assigned time leads to the error in positioning of 40-60 m.

The accuracy achieved is quite satisfactory and, for the flight being analysed, it is about 5-10 m for the horizontal coordinates and 10-15 metres for the height. The graph comparing the system coordinates with the reference coordinates is presented in the figures below.

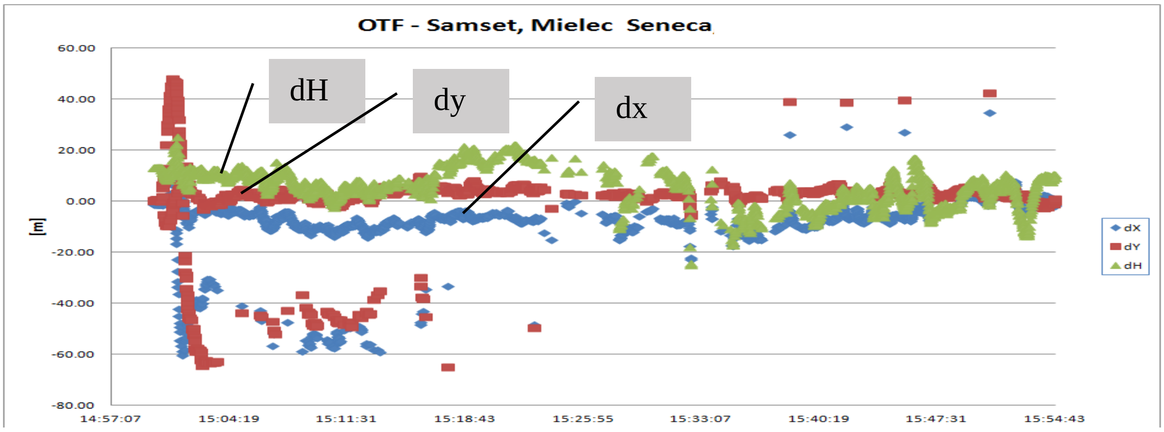

Fig. 6. Difference between the reference position (OTF) and the system position

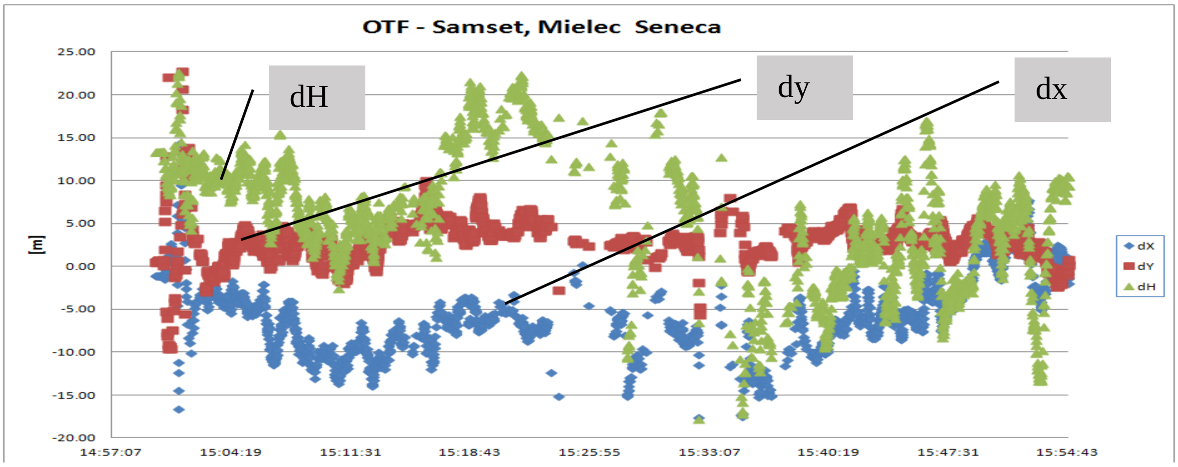

Fig. 7. Difference between the reference position and the system position (enlarged)

The results obtained show that the new software for the monitoring system is much more stable, while the errors and shortcomings only rarely occur.

4. CONCLUSION

Summing up, the research focused on checking the accuracy of positioning, the reach and the workability of individual elements of the system (tests without DGPS, with DGPS and with EGNOS from various airports). The radio modem's UHF and the GSM cellular network (GPRS) were used to transmit the data between an aircraft and Earth, between an aircraft and an aircraft, and between an aircraft and a vehicle. After an appropriate adaptation, the user of the system may use his or her own transmission medium. At every stage of the tests, the revealed errors and shortcomings of the individual elements of the system were eliminated.

Depending on the method used, the accuracy achieved varied from about 0.5 to 5-7 m, while the coverage varied from about 15-30 km for UHF between the vehicles and the base station, and 40-80 km between the airplane and the base station. It is possible to increase the coverage when the plane is used as a retranslator. On-board equipment automatically registers the retranslation of the signal for other elements within its reach.

Moreover, as part of the project, flight tests on the EGNOS system were carried out, which represented some of the first tests using EGNOS for aviation needs taking place in our country.

The essence of the research was not the monitoring of vehicles itself, but the possibility of mutual coordination of activities in real time, in a limited area, in difficult conditions and with many vehicles involved. The most important tasks that the author tried to accomplish were to achieve the possibility of operating the vehicles from both the stationary and mobile stations, as well as the possibility of mutual retranslation of signals with the use of various data transmission sources (GPRS, GPS, UHF). The important point here is that it is possible to partially use the developed satellite and information technologies in practical activities by various institutions. If we take into account the fact that some airplanes have satellite equipment on their boards, the adaptation of technologies for the needs of the system will be easier. It means that, in our country, we already have the equipment that can be used at the first stage of creating the system. There is a plan to equip other aircrafts with on-board satellite receivers.

When we compare the final results of the research with presently used solutions, with regard to state official regulations (Global Air Navigation Plan for Systems CNS/ATM-Doc. 9750), which treat the GNSS satellite navigation system as a key element in communication, navigation and surveillance systems used for managing the air traffic (CNS/ATM) and also as a foundation on which countries may develop improved services for air navigation, we can see that the subject was worth tackling and the research results are satisfactory. Many countries carry out tests on the ADS-B (automatic dependent surveillance-broadcast) automatic surveillance system. The on-board GPS receiver is used as a basic source of information about the position and time within this system. The ADS-B network was created and tested in Northern Europe as part of the Northern European ADS-B Network project. According to the plans of the countries belonging to the ADS-B Network, this system will soon partially replace the traditional radar used to monitor air traffic. A crucial element in this kind of system is the GNSS. Despite suggestions to do so from the ICAO, Poland does not take part in these projects, which means that the author's attempts to address this issue is a novelty. Similar issues were dealt with during the research on the system aimed at coordinating activities by the individual elements participating in a potential rescue operation, including the surveillance of the vehicles taking part in such an operation in the Mazury Region, which was presented at the DESIW Mrągowo-Szczytno Conference, which took place from 24-26 October 2005. This research, however, ignored the aviation aspect, which is yet another argument in favour of the legitimacy of the research undertaken by the author. Furthermore, the idea of aircrafts' monitoring systems using satellite navigation systems fits perfectly with the idea of using GNSS in aviation in both Europe and the rest of the world. Furthermore, one of the main tasks of the GALILEO satellite navigation system, developed by the EU, is to support all operations connected with the safety of EU member states and citizens. In Poland, the economic situation is probably the obstacle to the fast and widespread introduction of the surveillance system. On the other hand, the creation of this system could be divided into stages and local management systems could be introduced gradually. While they are being introduced, it will be possible to guarantee safety and the effective exploitation of the system. In the future, taking into account current knowledge, it will be possible to introduce the theory and practical solutions presented in the paper to the developed complex system for monitoring aircraft and land vehicles, as well as the system for their management, which will use stationary or mobile stations created according to original solutions and commonly available means.

The system presented here has one more advantage: it is based on commonly available equipment, meaning that, with only minor adjustments, it can be widely used without high additional costs.

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