Multipurpose Remotely Piloted Aircraft System Integrated Navigation System Development and Testing

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The paper presents development of prototype of integrated inertial-satellite navigation system that contains 3-axis accelerometers, gyros, magnetometers, barometric altimeter and GNSS (Global Navigation Satellite System) receiver. Navigation system testing procedure by means of flight at airdrome at small remotely piloted aircraft system (RPAS) is described, and data processing details with results are submitted. These results received from the data post-processing had approved the efficiency of integrated navigation system functioning in normal navigation mode, i.e. during availability of GNSS measurements. It has been shown as well that after approximately 10 s of autonomous MEMS inertial navigation system (INS) functioning accuracy of velocity and position calculation degrades significantly.
Keywords: remotely piloted aircraft system (RPAS), integrated navigation system, strapped down inertial navigation system (SINS), global navigation satellite system (GNSS), MEMS sensor, logistic.

1. INTRODUCTION

Scientific and technological progress speed-up is always inseparably connected with new scientific achievements introduction and advanced technologies implementation. Remotely Piloted Aircraft Systems (RPAS) represent new aviation area that progresses a lot due to appearance of modern electronics, materials, information and computer technologies. Using the RPAS in different military and civil applications is an urgent issue that requires a lot of tasks to be solved.

RPAS are mostly used now for military purposes but they have also a great potential for civil applications, which are starting to develop intensively, driven by both state and commercial interests. These applications include border control, fire fighting, precision agriculture and fisheries, monitoring tasks, infrastructure inspection, communications and broadcast services, wireless communication relay and satellite augmentation systems, digital mapping, land and wildlife management, air quality management/control. Hundreds of potential civil applications have been identified and many more are expected to emerge once the technology is widely disseminated [1]. One of these potential applications is logistics [2-3].

The emerging technology of Remotely Piloted Aircraft Systems (RPAS) applied to the development of civil aerial applications is expected to bring important benefits to European citizens and the European economy as a whole. However, the current market for commercial RPAS services is practically non-existent due to difficulties for RPAS to obtain flight permissions and their restriction to segregated airspace. In addition it is necessary to develop and implement operational concepts and associated technical enablers as well as specific rules for RPAS operations in non-segregated airspace. It is expected that once the barriers limiting RPAS flight are removed the understanding of the RPAS potential will quickly spread amongst potential users creating new markets of aerial services [1].

Single European Sky Air Traffic Management Research Program (SESAR) believes that a lot of technical questions need to be considered for efficient RPAS integration in Single European Sky. Among them are questions concerning RPAS specific but interoperable surveillance, communications and navigation solutions, security threats to the RPAS integration in non-segregated airspace leading to hazards in terms of loss of control, communication, navigation or surveillance capabilities.

2. INTEGRATED NAVIGATION SYSTEM DEVELOPMENT

Integrated navigation system development is an urgent problem, since the goal is always to improve the integrated navigation solution accuracy, reliability and anti-jamming performance while keeping low-cost, light weigh of the airborne equipment. Relying on internationally established practice is has been decided to use MEMS IMU with 3-axis accelerometers, gyros, magnetometers, barometric altimeter and GNSS (Global Navigation Satellite System) receiver as a basic structure (fig. 1) of small integrated navigation system (fig. 2), the prototype of which has been created in Aerospace Center of National Aviation University, Kyiv, Ukraine.

Integrated navigation system prototype includes: Analog Device inertial measurement unit ADIS16362 [4], the Honeywell HMC5843 3-axis magnetometers [5], the Bosch Sensortec barometric pressure sensor BMP085 [6] and Novatel GNSS receiver OEM-V1 [7].

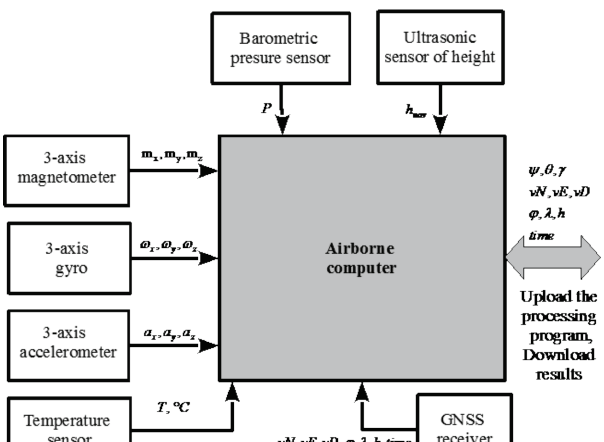

Fig. 1 Structural scheme of integrated navigation system

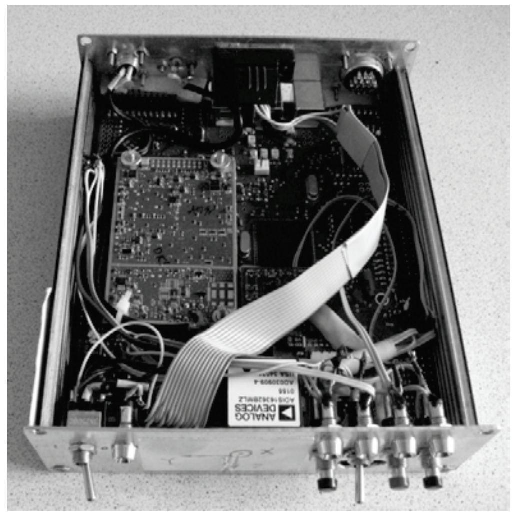

Fig. 2 Photo of navigation system

3. EXPERIMENTAL VALIDATION OF INTEGRATED NAVIGATION SYSTEM PERFORMANCE

A series of experiments and laboratory studies have been performed to validate the efficiency of using the proposed algorithms and method in constructed integrated navigation system. The last of them represents flight of small RPAS at aerodrome.

Fig. 3 Photo of small RPAS

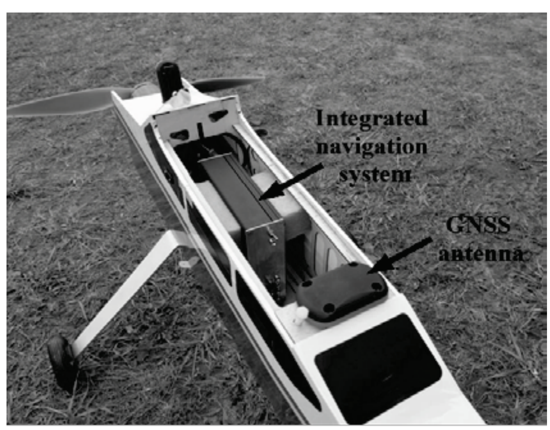

Fig. 4 Photo of RPAS with equipment

During the experiment first 2 min static data were gathered for initial alignment, and then small RPAS with integrated navigation system on board flew in air. Sensors data of navigation system prototype have been recorded at flash card, and then have been post-processed.

4. DATA PROCESSING

Recorded binary data with the C language program have been converted in text format for further processing with Matlab software package. For each of sensors separate file has been created where new parameter has been represented by a column and new measurement – by a row. Internal device timer has been synchronized with the global GNSS time with the help of GNSS receiver signals. Timer resolution was 1 ms.

GNSS data file contained GNSS time (week seconds), XYZ coordinates in ECEF (Earth Centered Earth Fixed) coordinate system, estimated coordinate RMS (m), velocities in ECEF, estimated velocities RMS (m/s), solution status and type of navigation task according to [5]. IMU data file contained time (week seconds), angular velocities (rad/s) and specific force (m/s^2) along the measurement axes. Magnetometer data file contained time (week seconds) and measurements of the intensity of the magnetic field (mG) along the measurement axes. In such form data have been transferred for the processing in Matlab. The algorithms used for sensors data processing are described in [8–11].

Magnetometer and IMU data rate was 50 Hz (therefore, $\Delta t = 2 \cdot 10^{-2} c$), GNSS data rate – 1 Hz. Magnetometer measurements contained errors which were random Gauss distributed values $N_{mag}(M_{mag}, \sigma_{mag})$, where M_{mag} - mathematic expectation, σ_{mag} - RMS of magnetometer measurements in static:

$$M_{mag} = [-242.31 \quad 70.66 \quad 597.94]\,mG;$$

$$\sigma_{mag} = [5.88 \quad 5.45 \quad 4.36]\,mG$$

Mathematical expectations of sensor measurements here and further in the present article have been calculated by finding the average of static data segment with the help of “mean”, RMS – by means of “std” commands in Matlab software package.

Height measured by the barometric altimeter contained errors which were random variables with Gauss distribution $N_{baro}(M_{baro}, \sigma_{baro})$, with zero mathematical expectation $M_{baro} = 0\ m$, and $\sigma_{baro} = 0.5\ m$.

Gyros measurements contained errors which were random variables with Gauss distribution $N_{gyro}(M_{gyro}, \sigma_{gyro})$, where M_{gyro} - mathematical expectation, σ_{gyro} - RMS of gyros measurements in static:

$$M_{gyro} = [\ -0.0025 \ \ 0.0014 \ \ -0.0029]\ rad/s;$$

$$\sigma_{gyro} = [\ 0.0151 \ \ 0.0121 \ \ 0.0128]\ rad/s.$$

Accelerometers measurements contained errors which are random variables with Gauss distribution $N_{accel}(M_{accel}, \sigma_{accel})$, where M_{accel} - mathematical expectation, σ_{accel} - RMS of accelerometer measurements in static:

$$M_{accel} = [\ -1.2701 \ \ 9.7096 \ \ -0.161]\ m/s^2;$$

$$\sigma_{accel} = [\ 0.0192 \ \ 0.0181 \ \ 0.0224]\ m/s^2.$$

Gyros measurements in °/s ($\omega = [\omega_x \ \omega_y \ \omega_z]$) are represented at fig. 5. Accelerometers measurements in m/s^2 along the body measurement axes ($f = [f_x \ f_y \ f_z]$) are represented at fig. 6.

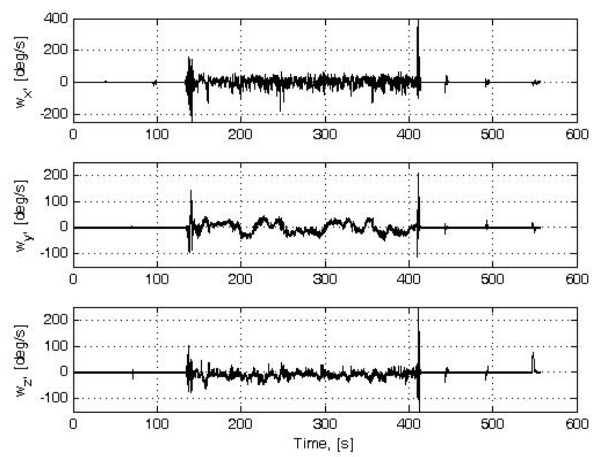

Fig. 5 Gyros measurements, deg/s

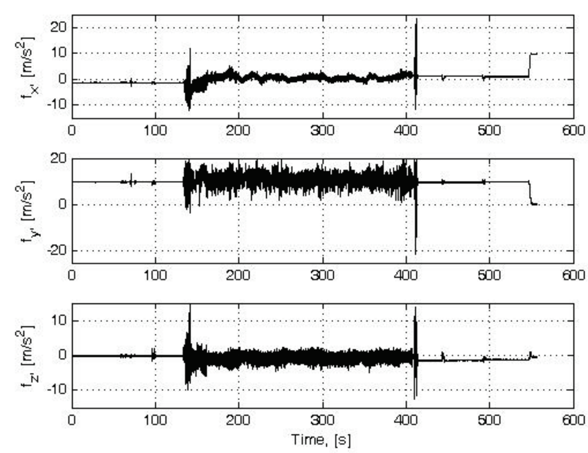

Fig. 6 Accelerometers measurements, m/s^2

All calculations have been performed in NED coordinate system with the origin at the point of start in WGS-84. Therefore before running navigation parameters estimation algorithms all data from GNSS file and reference trajectory file were transformed to NED.

Common duration of the experiment was about 500 s where at normal conditions inertial navigation system has been corrected every 1 s from GNSS receiver, magnetometer and barometric altimeter, in case of absence of GNSS signals INS functioned in autonomous mode.

5. RESULTS

Results of data processing in NED are represented in figures 7-10. Time dependences of estimated linear velocities in NED are represented at fig. 7. Here black solid line with dots at measurement points depicts measurements from GNSS receiver, and grey solid line – linear velocities estimated by SINS. It can be seen that in a normal mode of SINS functioning these velocities practically coincide, and downward component V_down estimated by SINS has even more smooth form. It is necessary to note as well that after GNSS signal reacquisition SINS corrected its solution according to the new measurement and continued working in a normal mode.

Time dependences of estimated coordinates in NED are represented at fig. 8. Here black solid line with dots depicts GNSS receiver measurements, and grey solid line – SINS estimated linear velocities. It can be seen as well that they practically coincide in a normal mode.

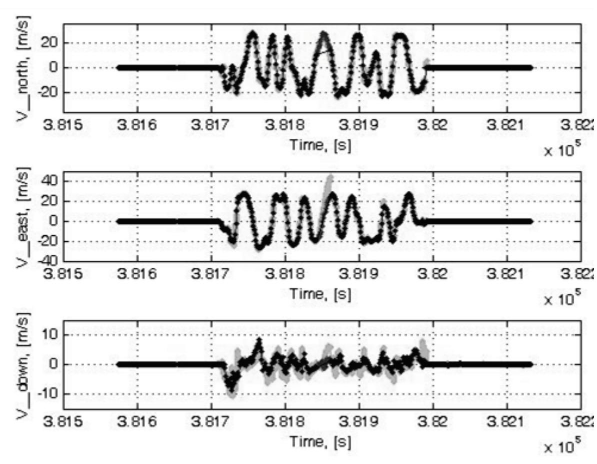

Fig. 7 Velocities in NED

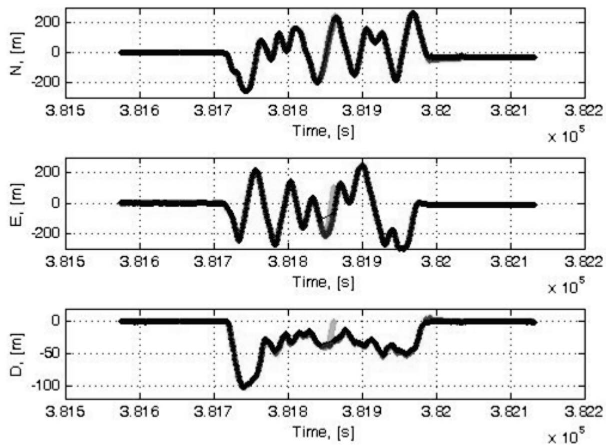

Fig. 8 Velocities in NED

Time dependences of estimated roll, pitch and yaw angles are represented in fig. 9. Trajectory of small RPAS motion in a horizontal plane (North, East) is represented in fig. 10. Here grey stars represent the coordinates from GNSS receiver, and black solid line coordinates estimated by integrated navigation system. It can be seen that the solution from integrated navigation system follows the GNSS solution quite accurately in a normal mode. To test functioning of integrated navigation system in autonomous mode of inertial navigation system during post-processing it was simulated gap of GNSS signal for 20 seconds. In fig. 10 by small circles are designated start and end of simulated miss of signal from GNSS receiver, and an arrow shows a direction of flight. Estimated coordinates during autonomous modes of functioning at the end of 20^{th} second deviated from a reference path not more than 120 m, and the direction of rotation had been estimated correctly. After the GNSS signal reacquisition SINS corrected its current solution according the received measurements of position and velocity from GNSS receiver.

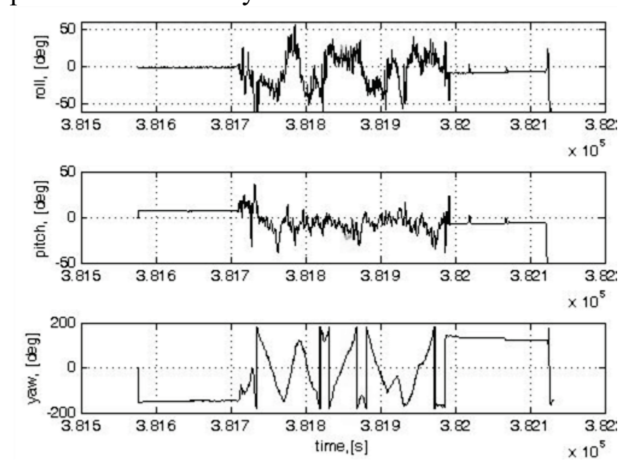

Fig. 9 Roll, pitch, yaw angles

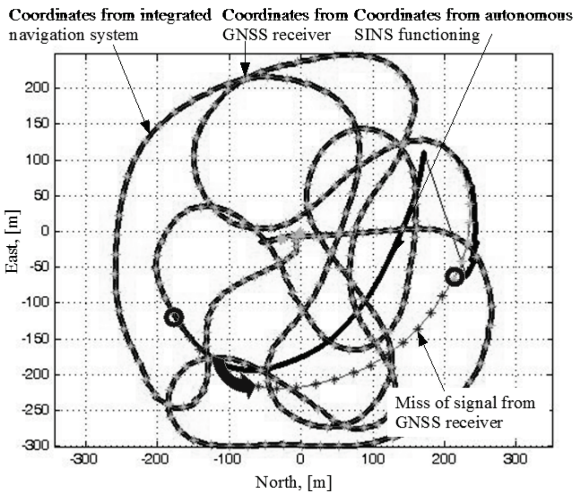

Fig. 10 Trajectory of motion in a horizontal plane

As it can be seen from the represented in figs. 7-10 results that inertial navigation system (INS) aiding algorithms work efficiently even at the presence of noise and some systematic error components at the measurements of inertial sensors. But this statement is true only at the constant availability of GNSS measurements. In other case position and velocity solution will degrade significantly after approximately 10 s of INS autonomous mode of functioning due to the presence of error components in MEMS inertial sensors measurements.

6. CONCLUSIONS

Functioning of integrated navigation system prototype had been evaluated through performing an experimental flight on small RPAS at airdrome. The results received from the data post-processing approved the efficiency of integrated navigation system functioning in normal navigation mode. Represented results could be used for production of integrated navigation system for different moving objects, including RPAS. Using of effective navigation system onboard, in turn, may facilitate integration of RPAS in Single European Sky that would bring important benefits to European citizens and the European economy as a whole.

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