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APPLICATION OF POCKET DEVICE SENSORS FOR MOVING OBJECT POSITIONING IN AIR SPACE

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Abstract

Purpose:*Localization and positioning of movable objects in air space are one of the main navigation tasks. In our research, we consider the application of accelerometers and gyroscopes sensors for finding the position of the object in space using the personal pocket device. The personal pocket device is plugged to the object body and location of an object is associated with the pocket device location. The personal pocket device includes sensors and performs measurements, but localization function is performed at the remote ground station. The data exchange between the pocket device and computation service is supported by WiFi network.* ***Methods:****Object position detection is grounded on inertial navigation approach.Also, we use experimental research and statistical analysis of the obtained data.* ***Results:****developed math model is applied in software that supports data exchange with android compliant personal pocket devices.The software initiates measurements of acceleration and object orientation in space at personal pocket device side and estimates object position in a local Cartesian coordinate system by inertial navigation approach.****Discussion:*** *the proposed approach can be used in new positioning systems structure for tracking of small movable objects in air space.*

Keywords: navigation; inertial navigation; positioning; sensors; gyroscope; accelerometer; personal pocket device

1. Introduction

Object localization in space is of the most import task of navigation and surveillance. Nowadays, there are multiple methods of movable object localization are used to detect position as a specific coordinate system. The most useful of them are Time Difference of Arrival (TDOA), Time of Arrival (TOA), Angle of Arrival (AOA), AOA/TOA and inertial. Practical implementation of these methods has found at numerous systems.

Today a Global Navigation Satellite System (GNSS) is the most commonly used positioning system, because, in comparison with other systems, it can guarantee the high level of accuracy, availability,and continuity of position measurement in airspace [1]. However, the effect of multiple factors such as ionospheric delays [2], tropospheric errors [3], the interference of radio waves or unintentional jamming of signals degrades the performance of positioning at some volumes of airspace [4,5] or may cause a positioning lock [6].

Positioning by a ground-based network of beacons is commonly used in civil aviation in case of GNSS lock [7-11]. Special interrogation sensors (Distance Measuring Equipment) or direction finding equipment (VHF omnidirectional range, Automatic Direction Finder) are required to be installed on board of flying object to support positioning. These sensors make the impossible implementation of this positioning principle for small fly object due to valuable weight and size of sensors.

Inertial navigation approach is another positioning algorithm that may be used for coordinates determination [12, 13]. Inertial navigation approach is implemented in Attitude and heading reference system (AHRS) on board of airplane or may be integrated into GNSS receiver to improve positioning performance. Inertial navigation uses measurements of acceleration and orientation of the body in space to estimate changes in coordinates between iterations. Inertial sensors may be fixed on the tracked object, but position estimation can be performed remotely in order to reduce the weight and size of moving equipment.

Today AHRS became very popular at variousapplications. AHRS is used in aviation, astronautics, cars, ships, robotics, and even medicine. According to the modern tendency, design of independent and cheap positioning technology is a key element of movable object navigation.

2. Aim of work

Aim of work is to use inertial navigation approach for position detection of the remote object, that is equipped with a set of accelerometers and gyroscopes.

3. Positioning by Inertial Navigation

An inertial navigation approach for position estimation grounds on force measurement that interrogate with research inertial mass. Force action can be a result of acceleration changes. Position detection of moving an object in space uses a calculation of path components by the axis of some coordinate system, that is the result of integral from velocity or double integral from acceleration by the time between iterations [13]:

$$S(t_i) = \int_{t_{i-1}}^{t_i} V_{ENU}(t_i)dt = \iint_{t_{i-1}}^{t_i} A_{ENU}(t_i)dt^2,$$

where V is velocity; A is acceleration.

We consider East-North-Up (ENU) coordinate system. Axis X is directed to the geographical East. Axis Y is directed to the Noth. Z axis is up by normal to the horizontal axis. The reference point of the Cartesian coordinate system is placed at the point of initial measurement (Fig.1).

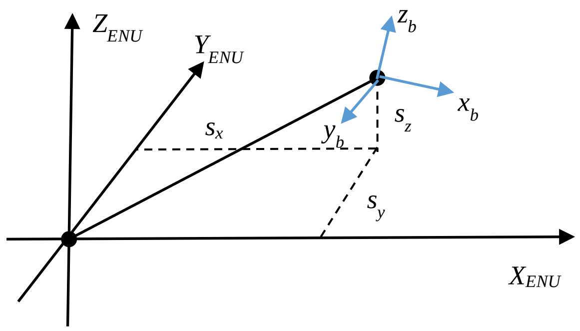

Fig.1. Basics of inertial navigation

In general case,an accelerometer is a sensor for measuring components of acceleration of an object to which sensor is attached. According to Newton's second law ($F=mA$) sensor for measuring acceleration (A) is based on the definition of force (F), acting on a mass (m). Zero acceleration occurs when the force F has no effect on weight. Acceleration is directly proportional if the force has constant weight. Methods of construction accelerometers are many, but common to them is based on usage inertial mass in their structure.

If we can measure the vector of accelerations by axis, we will get components of the path:

$$S(t_i) = \iint_{t_{i-1}}^{t_i} A_{ENU}(t_i)dt^2 = \Delta t V_{ENU}(t_i) + \\ + \frac{\Delta t^2}{2} A_{ENU}(t_i) \quad , (1)$$

where $A_{ENU}=[a_x, a_y, a_z]$is a matrix of accelerations by the axis of the coordinate system; $V_{ENU}=[v_x, v_y, v_z]$is a matrix of velocities;$\Delta t = t_i - t_{i-1}$.

Position of an object can be estimated by simple adding a path component by each direction to the previous location:

$$X_{ENU}(t_i) = X_{ENU}(t_{i-1}) + S(t_i), \quad (2)$$

where $X_{ENU}(t_{i-1})$ and $X_{ENU}(t_i)$ are coordinates of object location at previous and current iteration correspondently; $S=[s_x, s_y, s_z]$ is a matrix of path component by each direction.

Using (1) in equation (2) object location can be obtained as follows:

$$X_{ENU}(t_i) = X_{ENU}(t_{i-1}) + \Delta t V_{ENU}(t_i) + \\ + \frac{\Delta t^2}{2} A_{ENU}(t_i) \quad , (3)$$

We consider a strap-down inertial navigation system architecture. In this case, accelerometers assembly is properly fixed on the body of an object to sense applied components of acceleration. All sensors are measuring in the body Cartesian coordinate system. Also, an assembly contains a set of gyroscopes to measure object orientation in space. Orientation matrix includes pitch, roll and yaw angles. All of these angles are used for accelerometer data transformation from the body to the ENU coordinate system [13, 14]:

$$A_{ENU}=[T_1,T_2,T_3]\ A_b\ , \quad (4)$$

$$T_1 = \begin{bmatrix} \sin\psi\cos\theta \\ \cos\psi\cos\theta \\ \sin\theta \end{bmatrix},$$

$$T_2 = \begin{bmatrix} \cos\varphi\cos\psi + \sin\varphi\sin\psi\sin\theta \\ -\cos\varphi\sin\psi + \sin\varphi\cos\psi\sin\theta \\ -\sin\varphi\cos\theta \end{bmatrix},$$

$$T_3 = \begin{bmatrix} -\sin\varphi\cos\psi + \cos\varphi\sin\psi\sin\theta \\ \sin\varphi\cos\psi + \cos\varphi\cos\psi\sin\theta \\ -\cos\varphi\cos\theta \end{bmatrix},$$

where $A_b$is a matrix of acceleration in the body reference frame; ψ is a yaw angle;φ is a roll angle;θ is a pitch angle.

Obtained acceleration matrix A_b after the measurement is transformed by (4) to A_{ENU} with the help of a rotation matrix. Than $A_{ENU}$is used in (3) for position updating from previous to the current iteration.

4. Sensors of personal pocket device

Widespread of multiple pocket devices in our life makes simple access to motion data remotely. Common examples of the personal pocket device are smartphones, tablets, watches, bracelets, glasses, and others hold all required accelerometers and gyroscopes for position tracking.

Nowadays at the software level operation system of the device makes possible to access the live data from sensors. Depend on device type different communication technology (WiFi, Bluetooth, 3G) can be implemented for data transfer. In our research, we will consider network supported by WiFi, that uses one access point, one cable connection to computation facilities and multiple remote terminals in a wide range of communication covered volume (Fig.2).

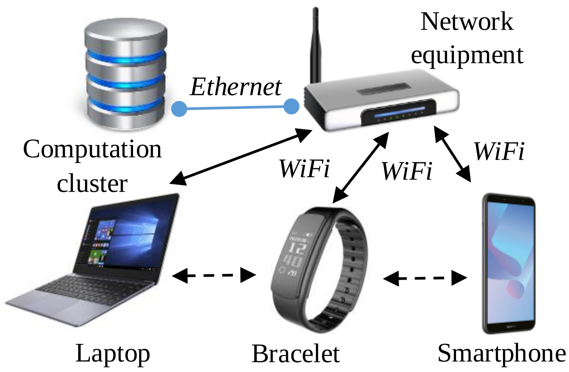

Fig. 2. Data exchange level

Each device has his unique IP address in the network that makes possible to easy access to any device in the network.

A sensor assembly in a smartphone may be used for measurements in different location of body systems that depend on operation system type and version. The common body reference frame is represented on Fig. 3.

Various software can provide a different possibility for orientation and inertial data. Some of them can provide raw data with rotation velocity around the different axis from gyroscopes, other makes possible to use pitch, roll and yaw angles. Also, some software supports clear acceleration matrix in body frame, other includes components of gravity that can degrade data.

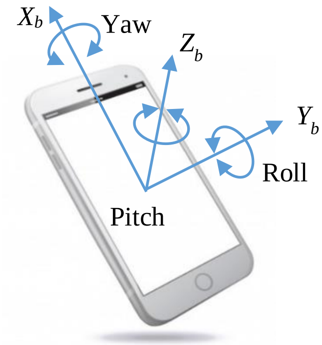

Fig.3. Body coordinate system

5. Numerical demonstration

In the beginning, our work with sensors of our pocket device, have set up the connection between the computer and mobile device with the help of Matlab software on our computer and smartphone. It is important to notice that for the successful realization of our experiment, on our computer we needed to install the version of Matlab package not earlier than the 2014 year of release. Next, we set up the secured connection between sensors of our mobile device with the computation facility (Fig. 4).

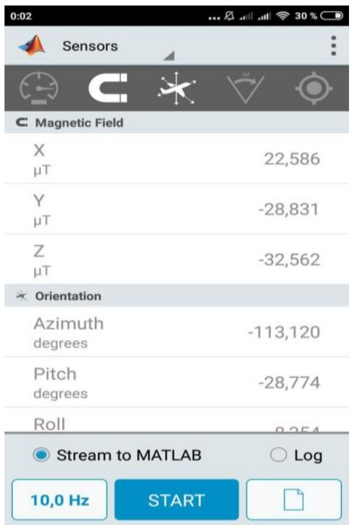

Fig. 4. Sensor data sharing screen in Matlab mobile

Matlab environment served connection to remote terminals with Matlab mobile software.For example function *mobiledev()* allowed to read data from remote sensors, and manage these sensors, for instance, using the command *AccelerationSensorEnabled* chooses acceleration sensors, *OrientationSensorEnabled* chooses pitch, roll, and yaw sensors. The measurement process can be logging at the file or received live.

Results of directional acceleration measurement are represented on Fig. 5. Elements of the rotation matrix are represented on Fig. 6. Results of path calculation by (1) are represented on Fig.7. The estimated trajectory of moving an object by (3) indicated on Fig. 8.

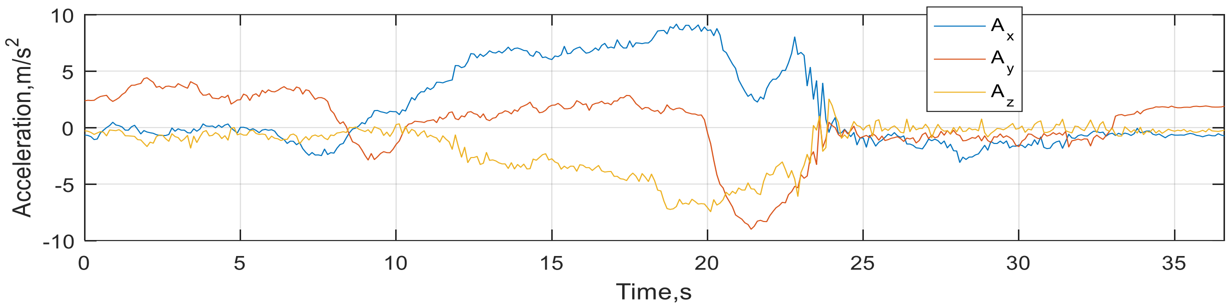

Fig. 5. Acceleration by axis

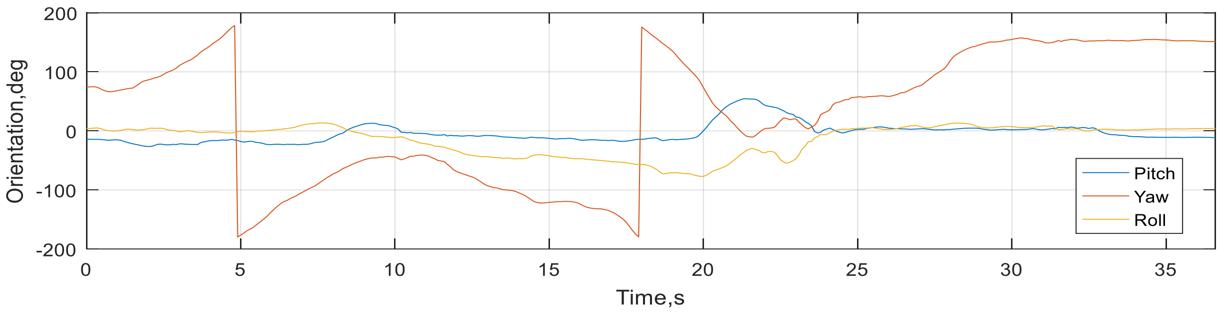

Fig. 6. Pith, roll, and yaw angles

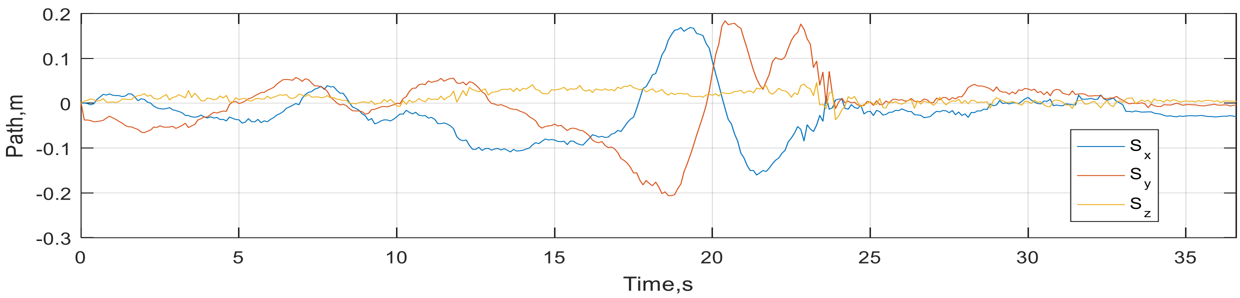

Fig. 7. Elements of the path at each iteration

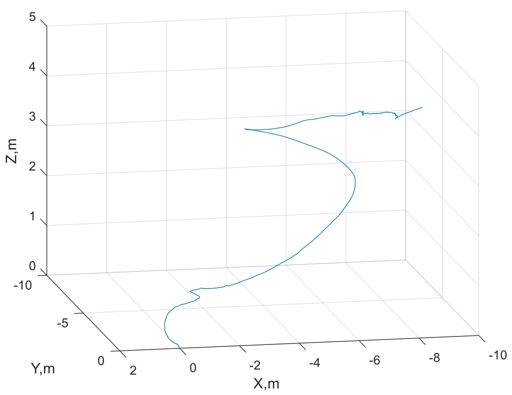

Fig. 8. The trajectory of moving an object

6. Conclusions

The widespread of personal pocket devices in our life makes the possibility to use acceleration and orientation data of an object easily. Wireless communication data lines help to share results of raw measurements with any type of devices in airspace and modern network connects remote services located in millions of NM from the sensor assembly. All of that makes possible to use multiple pocket devices as a source of raw data that can be processed remotely in a different application. In our research, we used a simple wireless network for sharing access for results ofacceleration and orientation measurements in order to localize an object in air space.

References

[1] International Civil Aviation Organization (2012) *Global Navigation Satellite System (GNSS)*. 1st ed. Doc. ICAO 9849, Canada, Montreal, ICAO Publ., 68p.

[2] Dabbakuti J. R., Ratnam D. V., Sunda S. (2016). Modeling of ionospheric time delays based on adjusted spherical harmonic analysis. Aviation, 20(1), pp. 1-7. doi:10.3846/16487788.2016.1162197

[3] Kutsenko O., Ilnytska S., Konin V. (2018). Investigation of the residual tropospheric error influence on the coordinate determination accuracy in a satellite landing system. Aviation, 22(4), pp. 156-165. doi: 10.3846/aviation.2018.7082

[4] Lubbers B., Mildner S., Onincx P., Scheele A. (2015). A study on the accuracy of GPS positioning during jamming. Paper presented at the 2015 International Association of Institutes of Navigation World Congress, IAIN 2015 – Proceedings. doi:10.1109/IAIN.2015.7352258

[5] Narins M., Eldredge L., Enge P., Harrison M., Kenagy R., Lo S. (2012). Alternative Position, Navigation, and Timing–The Need for Robust Radionavigation. Global Navigation Satellite Systems: Report of a Joint Workshop of the National Academy of Engineering and the Chinese Academy of Engineering, pp. 119-136.

[6] Shvets V., Ilnytska S., Kutsenko O. (2019) Application of Computer Modelling in Adaptive Compensation of Interferences on Global Navigation Satellite Systems. In *Cases on Modern Computer Systems in Aviation*. IGI Global, pp. 339-380

[7] Kuzmenko N.S., Ostroumov I.V., Marais K. (2018) An Accuracy and Availability Estimation of Aircraft Positioning by Navigational Aids. Methods and Systems of Navigation and Motion Control: MSNMC 2018 5th International Conference of IEEE. 2018, pp. 36-40. doi: 10.1109/MSNMC.2018.8576276.

[8] Kuzmenko N.S., Ostroumov I.V. (2018) Performance Analysis of Positioning System by Navigational Aids in Three Dimensional Space. System Analysis & Intelligent Computing: SAIC 2018 1st International Conference of IEEE, pp. 101-104. doi: 10.1109/SAIC.2018.8516790.

[9] Ostroumov I.V., Kuzmenko N.S. (2018) Accuracy assessment of aircraft positioning by multiple Radio Navigational Aids. Telecommunications and Radio Engineering. № 77(8), pp. 705-715. doi: 10.1615/TelecomRadEng.v77.i8.40.

[10] Ostroumov I.V. (2018) Estimation of Distance Measurement Equipment accuracy. Aerospace technology. № 146(2), pp. 71-75. doi: 10.32620/aktt.2018.2.10. (In Ukrainian)

[11] Ostroumov I.V. (2018) Analysis of prospective area navigation systems. Systems of control, navigation, and communication. № 52(6), pp. 14-19. doi: 10.26906/SUNZ.2018.6.014. (In Ukrainian)

[12] Kharchenko V.P., Ostroumov I.V. (2013) *Avionics.* Kyiv,. 281p. ISBN: 978-966-598-573-0. (In Ukrainian)

[13] Melkumyan V.G., Ostroumov I.V., Malyutenko T.L. (2016) *Navigation systems. Methods of navigation definitions using characteristics of natural phenomena: a textbook for laboratory classes.* Kyiv, 64 p. (In Ukrainian)

[14] Ostroumov I.V., Mironyuk O.O., Nychak M.V. (2015) Local magnetic field data processing. Proceedings of the National Aviation University. № 62(1), pp. 23-28. doi: 10.18372/2306-1472.62.7761.

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Застосування сенсорів кишенькового пристрою для позиціонування об’єкта, що рухається у повітряному просторі.

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Мета: Локалізація і позиціонування рухомих об'єктів у повітряному просторі є одним з головних навігаційних завдань. У наших дослідженнях ми розглядаємо використання акселерометрів і гіроскопічних датчиків для знаходження положення об'єкта у просторі за допомогою персонального кишенькового пристрою. Персональний кишеньковий пристрій жорстко закріплюється наоб'єкті, а місцеположення рухомого об'єкта зв'язується з місцем розташування кишенькового пристрою. Персональний кишеньковий пристрій містить датчики і виконує вимірювання, але функція локалізації виконується на віддаленій наземній станції. Обмін даними між кишеньковим пристроєм і обчислювальним сервісом підтримується однією з мережемих технологій. **Методи:**Визначення позиції об'єкта грунтується наінерціальному навігаційному принципу. Також ми використовуємо експериментальні дослідження та статистичний аналіз отриманих даних. **Результати:** Розроблена математична модель застосовується в програмному забезпеченні, що підтримує обмін даними з андроїд-сумісними кишеньковими пристроями. Програмне забезпечення ініціює вимірювання прискорення і орієнтації об'єкта в просторі за допомогою персонального кишенькового пристрою і оцінює позицію об'єкта в локальній декартовій системі координат за допомогою інерціального навігаційного підходу. **Обговорення:** Запропонований підхід може бути використаний в новій структурі систем позиціонування для відстеження невеликих рухомих об'єктів у повітряному просторі.

Ключові слова: навігація; інерціальна навігація; позиціонування; сенсори; гіроскоп; акселерометр; персональний кишеньковий пристрій

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Применение сенсоров карманного устройства для позиционирования объекта, который двигается в воздушном пространстве.

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Цель: Локализация и позиционирование подвижных объектов в воздушном пространстве является одной из главных навигационных задач. В наших исследованиях мы рассматриваем применение акселерометров и гироскопическихдатчиков для нахождения положения объекта в пространстве с помощью персонального карманного устройства. Персональное карманное устройство подключается к объекту, а расположение объекта связзвается с местом расположения карманного устройства. Персональное карманное устройство имеет датчики и выполняет измерения, но функция позицонирования выполняется на удаленной наземной станции. Обмен данными между карманным устройством и вычислительным сервисом поддерживается беспроводной сетью. **Методы:**Позиционирование объекта основывается на инерциальном навигационном принципе. Также мы используем экспериментальные исследования и статистический анализ полученных данных.**Результаты:** Разработанная математическая модель применяется в программном обеспечении, поддерживающем обмен данными с андроид-совместимыми карманными устройствами. Программное обеспечение инициирует измерения ускорения и ориентации объекта в пространстве с помощью персонального карманного устройства и оценивает позицию объекта в локальной декартовой системе координат с помощью инерциального навигационного подхода. **Обсуждение:** Предложенный подход может быть использован в новой структуре систем позиционирования для отслеживания небольших подвижных объектов в воздушном пространстве.

Ключевые слова: навигация; инерциальная навигация; позиционирование; сенсоры; гироскоп; акселерометр; персональное карманное устройство

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