МІНІСТЕРСТВО ОСВІТИ І НАУКИ УКРАЇНИ
НАЦІОНАЛЬНИЙ АВІАЦІЙНИЙ УНІВЕРСИТЕТ

Факультет аеронавігації, електроніки та телекомунікацій

Кафедра аеронавігаційних систем

ДОПУСТИТИ ДО ЗАХИСТУ
Завідувач кафедри АНС
д-р техн. наук, проф.
______________ Ларін В.Ю.
«____» ____________ 2022р.

ДИПЛОМНА РОБОТА

(ПОЯСНЮВАЛЬНА ЗАПИСКА)

ВИПУСКНИКА ОСВІТНЬОГО СТУПЕНЯ «МАГІСТР»
за освітньо-професійною програмою
«ОБСЛУГОВУВАННЯ ПОВІТРЯНОГО РУХУ»

Тема:
Позиціонування рухомих об’єктів у повітряному просторі за даними сенсорів мобільного пристрою

Виконавець: Проценко Ейжена Костянтинівна

Керівник: Остроумов Іван Вікторович

Керівники спеціального розділу

д.т.н. проф. Остроумов Іван Вікторович

д.т.н. проф. Шмельова Тетяна Федорівна

Нормоконтролер Аргунов Геннадій Федорович

Київ-2022

НАЦІОНАЛЬНИЙ АВІАЦІЙНИЙ УНІВЕРСИТЕТ

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Кафедра аеронавігаційних систем

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ЗАТВЕРДЖУЮ
Завідувач кафедри АНС

_________________В.Ю. Ларін
«____»______________ 2022 р.

ЗАВДАННЯ

на виконання дипломної роботи

Проценко Ейжени Костянтинівни

1. *Тема дипломної роботи*: **«Позиціонування рухомих об'єктів у повітряному просторі за даними сенсорів мобільного пристрою»** від "20" вересня 2022 р. № 1594/ст

2. *Термін виконання роботи:* 05.09.2022 – 30.11.2022

3. *Вихідні дані до роботи:* документи Міжнародної організації цивільної авіації, Європейської організації з безпеки польотів і технічна інформація .

4. *Зміст пояснювальної записки:* аналіз методів позиціонування в цивільній авіації, аналіз структури повітряного простору, позиціонування за персональними кишеньковими пристроями, екологічна безпека, охорона праці, автоматизована обробка великих даних в аеронавігації, ефективність позиціонування рухомого об'єкта в повітряному просторі за даними з датчика кишенькового пристрою.

5. *Перелік обов'язкового графічного (ілюстративного) матеріалу:* графіки результатів даних, таблиці, формули.

6. Календарний план-графік

№ п/п	Завдання	Термін Виконання	Відмітка про виконання
1.	Підготовка та написання 1 розділу «Аналіз методів позиціонування в цивільній авіації»	05.09.22-09.09.22	виконано
2.	Підготовка та написання 2 розділу «Аналіз структури повітряного простору»	10.09.22-15.09.22	виконано
3.	Підготовка та написання 3 розділу «Позиціонування за персональними кишеньковими пристроями»	16.09.22-22.09.22	виконано
4.	Підготовка та написання 4 розділу «Спеціальний розділ»	23.09.22-13.10.22	виконано
5.	Підготовка та написання 5 розділу «Охорона праці»	14.10.22-20.10.22	виконано
6.	Підготовка та написання 6 розділу «Охорона навколишнього середовища»	14.10.22-20.10.22	виконано
7.	Підготовка презентації та доповіді	21.10.22-30.11.22	виконано

7. Консультанти з окремих розділів

Розділ	Консультант (посада, П.І.Б.)	Дата, підпис	
		Завдання видав	Завдання прийняв
Автоматизована обробка великих даних в аеронавігації	д.т.н. проф. Остроумов Іван Вікторович	23.09.22	20.10.22
Ефективність позиціонування рухомого об'єкта в повітряному просторі за даними з датчика кишенькового пристрою	д.т.н. проф. Шмельова Тетяна Федорівна	23.09.22	20.10.22

8. Дата видачі завдання: «_05_ » _вересня_ 2022 р.

Керівник дипломної роботи ___________ __Остроумов Іван Вікторович
(підпис керівника) (прізвище, ім’я, по батькові)

Завдання прийняв до виконання __________ Проценко Ейжена Костянтинівна
(підпис студента) (прізвище, ім’я, по батькові)

РЕФЕРАТ

Пояснювальна записка до дипломної роботи «Позиціонування рухомих об’єктів у повітряному просторі за даними сенсорів мобільного пристрою»: 101 сторінок, 33 рисунків, 10 таблиць, 67 використаних джерел, 2 додатка.

Об’єкт розробки – процес вимірювання координат місцеположення літального апарату цивільної авіації.

Предмет розробки – оцінювання позиції динамічного об’єкту у просторі за допомогою вимірювань сенсорів мобільного пристрою.

Мета роботи – розробка структурної схеми визначення координат місцеположення рухомих об’єктів у повітряному просторі за даними сенсорів мобільного пристрою.

Метод дослідження – комп’ютерне моделювання та експерементальне випробування.

Точність і доступність позиціонування безпілотного літального апарату (БПЛА) є важливими складовими успіху місії та безпеки авіації. Я розглядаю можливість використання сенсорного блоку персонального кишенькового пристрою для прямого вимірювання та дистанційної обробки даних для позиціонування та навігації БПЛА. Глибока інтеграція персонального кишенькового пристрою (PPD) у життя людини та різноманітність PPD, доступних на ринку, знижують ціну навігаційної системи БПЛА та роблять можливим віддалену обробку даних незалежно від моделі/типу PPD. Я описую інерційний навігаційний підхід як резервний для випадку блокування GNSS з обробкою даних у обчислювальному кластері та дистанційним датчиком, жорстко закріпленим на корпусі БПЛА.

Завдання позиціонування безпілотного літального апарату (БПЛА) можна назвати одним із найважливіших завдань навігації. Точність і доступність системи позиціонування безпосередньо пов'язані з успіхом місії та безпекою авіації. У даний час в структурі навігаційної системи використовується багато різних методів для визначення положення рухомого об'єкта в повітряному просторі. Найбільш часто використовуваними системами позиціонування є методи визначення різниці в часі прибуття, часу прибуття та кута прибуття. Усі

ці методи використовують природні або штучно створені радіо- чи світлові сигнали, доступні в точці розташування об’єкта в повітряному просторі. Крім того, всі ці методи залежать від точно відомих координат джерел (передавача) навігаційних сигналів. У своєму дослідженні я розглядаю застосування основних датчиків персональних кишенькових пристроїв, які в основному є датчиками на основі сили Коріоліса для позиціонування БПЛА та проектування системи автопілота з метою зниження ціни навігаційної системи. Також я розглядаю застосування фільтра Альфа/Бета/Гамма у вигляді фільтра Калмана для фільтрації координат БПЛА з метою підвищення точності позиціонування.

МОБІЛЬНИЙ ПРИСТРІЙ, КООРДИНАТИ МІСЦЕПОЛОЖЕННЯ, ЛІТАК, СИСТЕМА ПОЗИЦІОНУВАННЯ, СЕНСОРИ.

АРКУШ ЗАУВАЖЕНЬ

MINISTRY OF EDUCATION AND SCIENCE, OF UKRAINE
NATIONAL AVIATION UNIVERSITY
Faculty of Air navigation, Electronics and Telecommunication
Air Navigation System Department

PERMISSION TO DEFEND
GRANTED
Head of the Department
___________V.Yu. Larin
“__”______________2022

MASTER’S DEGREE THESIS

Theme:

“Moving object positioning in air space by data from pocket device sensor”

Completed by: Protsenko E.K.
Supervisor: Ostroumov I.V.
Supervisors of special chapter
Ostrumov I.V.
Shmelova T.F.

Standarts Inspector: Argunov H.F.

Kyiv 2022

NATIONAL AVIATION UNIVERSITY

Faculty of Air navigation, Electronics and Telecommunication

Air Navigation Systems Department

Specialty: 272 “Aviation transport”

APPROVED BY

Head of the Department

_____________ V.Yu. Larin

“__”___________________2022

Graduate Student’s Degree Thesis Assignment

Protsenko Eizhena

1. *The Project topic:* “Moving object positioning in air space by data from pocket device sensors” approved by the Rector’s order of 20.09.2022 № 1594/st.

2. *The Project to be completed between:* 05.09.2022 – 30.11.2022.

3. *Initial data to the project:* documents of the International Civil Aviation Organization, the European Aviation Safety Organization and technical information.

4 *The content of the explanatory note (the list of problems to be considered):* basics of analysis of positioning methods in civil aviation, analysis of airspace structure, positioning by personal pocket devices, environment safety, labor precaution, automated big data processing in air navigation, effectiveness of moving object positioning in air space by data from pocket device sensor.

5. *The list of mandatory graphic (illustrated) materials:* graphs of results data, tables, formulas.

6. Calendar timetable

№	Completion stages of Degree Project	Stage completion dates	Remarks
1	Preparation of chapter 1: “Analysis of positioning methods in civil aviation”	05.09.22-09.09.22	completed
2	Preparation of chapter 2: “Analysis of airspace structure”	10.09.22-15.09.22	completed
3	Preparation of chapter 3: “Positioning by personal pocket devices”	16.09.22-22.09.22	completed
4	Preparation of chapter 4: “Special chapter”	23.09.22-28.09.22	completed
5	Preparation of chapter 5: “Labor precaution”	14.10.22-20.10.22	completed
6	Preparation of chapter 5 “Environment safety”	14.10.22-20.10.22	completed
8	Preparation of report and graphic materials	21.10.22-30.11.22	completed

7. Consultants from separate departments

Chapter	Consultant (position, full name)	Date, signature	
		Task issued	Task accepted
Automated big data processing in air navigation	D. Sc., prof. Ivan Ostroumov	23.09.22	20.10.22
Effectiveness of moving object positioning in air space by data from pocket device sensor	D. Sc., prof. Tetyana Shmelova	23.09.22	20.10.22

8. Assignment accepted for completion “20” September 2022

Supervisor____I.V. Ostroumov

Assignment accepted for completion ________________________E.K. Protsenko

ABSTRACT

Explanatory note to the master’s thesis, “Moving object positioning in air space by data from pocket device sensor”: 101 pages, 33 figures, 10 tables, 67 references, 2 appendixes.

Development object – the process of measuring the coordinates of the location of a civil aviation aircraft.

Development subject – the estimation of the position of a dynamic object in space using measurements of mobile device sensors.

Purpose of the work – the development of a structural scheme for determining the coordinates of the location of moving objects in the air space based on the data of the sensors of the mobile device.

Investigation method – computer modeling and experimental testing.

Unmanned aerial vehicle (UAV) positioning accuracy and availability are critical components of mission success and aviation safety. I am considering using a personal handheld device sensor unit for direct measurement and remote data processing for UAV positioning and navigation. The deep integration of the personal pocket device (PPD) into human life and the variety of PPDs available in the market reduce the price of the UAV navigation system and make remote data processing possible regardless of the PPD model/type. I describe the inertial navigation approach as a fallback to the GNSS lock case with data processing in the compute cluster and a remote sensor rigidly mounted on the UAV body.

The task of positioning an unmanned aerial vehicle (UAV) can be called one of the most important navigation tasks. The accuracy and availability of the positioning system are directly related to mission success and aviation safety

Currently, in the structure of the navigation system, many different methods are used to determine the position of a moving object in the air space. The most commonly used positioning systems are time-of-arrival, time-of-arrival, and angle-of-arrival methods. All of these methods use natural or man-made radio or light signals available at the location of the object in the airspace. In addition, all these methods depend on precisely known coordinates of sources (transmitter) of navigation signals.

In my research, I consider the application of core sensors of personal handheld devices, which are mainly Coriolis force based sensors, for UAV positioning and autopilot system design in order to reduce the price of the navigation system. I am also considering the use of an Alpha/Beta/Gamma filter in the form of a Kalman filter to filter UAV coordinates in order to improve positioning accuracy.

MOBILE DEVICE, LOCATION COORDINATES, AIRCRAFT, INERTIAL NAVIGATION SYSTEM, SENSORS.

NOTES

CONTENT

LIST OF ABBREVIATION

ATC – Air Traffic Controller

VOR – Very High Frequency Omni-directional Radio Range

DME – Distance Measuring Equipment

GNSS – Global Navigation Satellite System

FAA – Federal Aviation Administration

ICAO – International Civil Aviation Administration

WAAS – Wide Area Augmentation System

INS – Inertial Navigation System

PBN – Performance-Based Navigation

RNAV – Area Navigation

UAV – Unmanned Aerial Vehicle

PPD – Personal Pocket Device

NAS – National Aviation System

GLS – GNSS Landing System

GIS – Geographical Information System

UHF – Ultra High Frequency

AGL – Above Ground Level

ECEF – Earth-Centered Earth-Fixed Coordinate System

ENU – East-North-Up

INTRODUCTION

Thesis actuality. An accuracy and availability of positioning of Unmanned Aerial Vehicle (UAV) are important components of mission success and safety of aviation. I consider a possibility to use a sensor assembly of Personal Pocket Device for direct measurement and remote data processing for UAV positioning and navigation. Deep integration PPD in human life and variety of PPDs available in market reduce price of UAV navigation system and makes possible to remote data processing independently from PPD model/type. I describe inertial navigation approach as a stand-by for case of GNSS lock with data processing in computation cluster and remote sensor assemble hard fixed with UAV body.

The task of Unmanned Aerial Vehicle (UAV) positioning can be referred to as one of the most import tasks of navigation. Accuracy and availability of positioning system directly connected with mission success and safety of aviation

Nowadays, there are a lot of different methods are used in navigation system structure for moving object position in airspace. The most frequently used positioning systems are grounds on Time Difference of Arrival, Time of Arrival, and Angle of Arrival methods [49, 50]. All these methods use natural or artificially generated radio or light signals available at point of object location in airspace. Also, all these methods depend on precisely known coordinates of sources (transmitter) of navigation signals.

In my research, I consider application of the main personal pocket device sensors that is basically Coriolis-force-based sensors for UAV positioning and autopilot system design in order to reduce price of navigation system [35-37]. Also, I consider application Alfa/Beta/Gamma filter in form of Kalman filter for UAV coordinates filtering in order to improve accuracy of positioning [60]. According to the modern tendency, design of independent and cheap positioning technology is a key element of UAV navigation in case of GNSS unavailability [57, 59].

Thesis relation with scientific research programs, schedules and themes

Scientific research was done in the framework of international fundamental researches of the international organizations monitoring the state of moving object positioning.

Development subject – the estimation of the position of a dynamic object in space using measurements of mobile device sensors.

Development object – the process of measuring the coordinates of the location of a civil aviation aircraft.

Purpose of the work – the development of a structural scheme for determining the coordinates of the location of moving objects in the air space based on the data of the sensors of the mobile device.

Science research novelty – results of work indicate that mobile phone sensors can be used for real time moving object in air space.

Investigation method – computer modeling and experimental testing.

Practical results of science research. The results of scientific's work was published in APUAVD-2019 6th International Conference of IEEE. 2019, represented in the scientific conferences and computer program received an authorship license.

This new program for the construction of software for inertial positioning systems and navigation systems.

CHAPTER 1. ANALYSIS OF POSITIONING METHODS IN CIVIL AVIATION

1.1. Positioning of airspace users

Positioning is a process of coordinates measuring of airspace users on-board or remotely. Also, it can be defined as a surveillance of all aircraft movements in the airspace and on the ground with data collecting and displaying it on the air traffic control (ATC) operator's monitor screen, using the automated means which ensure safety control.

The necessity to monitor air objects arise from the moment the air objects themselves appeared, and were solved using such tools as radio communication, radio direction finding, radar and others [1].

Determination of the location and parameters of aircraft movement in space is one of the main tasks of navigation. Geotechnical, astronomical, radio and lighting aids for navigation can be used for the purpose of ground determination of the location and movement parameters of the aircraft. The most common are radio navigation aids, based on the emission and reception of radio waves by airborne and ground radio equipment and the measurement of the parameters of a radio signal that carries navigation information.

Currently, the aircraft flight monitoring is carried out using the following systems:

– short-range navigation and landing radio systems (VOR/DME-VHF Omni-directional Radio Range/Distance Measuring Equipment and ILS-Instrument Landing System);
– long-range navigation radio systems;
– satellite radio navigation systems.

Aircraft positioning systems using the modern avionics have to provide:

– automatic transmission of information from the board of aircraft about its location and planned maneuvers;
– extended mode of operation of the Secondary Surveillance Radar (SSR);
– the presence of Traffic alert and collision avoidance system [14, 46].

- Thus, users get a number of significant advantages:
- three-dimensional location and velocity vector determination occurs in real time;
- communication, navigation and surveillance system has unlimited capacity and high noise immunity;
- on-board navigation equipment is relatively inexpensive;
- guaranteed reliable and high-quality data exchange between the aircraft and ground services;
- flight safety is ensured, despite the increase in air traffic intensity [3].

1.2. Global Navigation Satellite System

The role of satellite technology in air navigation every year is becoming more important. Currently a Global Navigation Satellite System (GNSS) is the most generally used positioning system, because, in contrast with other systems, it can guarantee the high level of accuracy, availability, and continuity of position measurement in airspace. With the help of global navigation satellite systems (GNSS) navigation is carried out at all stages of flight up to the landing of aircraft in the first category. For instance, the satellite landing system GLS (GNSS Landing System) is assured for monitoring the aircraft in the first category of ICAO [6].

GNSS is available through GPS, GALILEO, GLONASS, and Beidow applications. GNSS uses Time of Arrival method. GNSS receiver calculates its own location by time measurements when the signals were sent from the artificial satellites. Howsoever, the effect of different factors such as ionospheric and tropospheric errors, the interference of radio waves or unintentional jamming of signals may decrease the performance of positioning at particular part of airspace or may totally block positioning system.

GNSS satellites have two carrier waves fixed in the L band, called L1 and L2. The main purpose of these two wavebands is to transmit signals from a connected satellite to the surface of the earth. Using L-band technology can reduce overhead while providing a reliable connection that is less prone to interruptions. Implementing L-bands with the right antenna placement brings a number of benefits for agricultural drones, marine technology, remote monitoring, and more. On the other hand, GNSS receivers placed on the earth's surface consist of an antenna and a processing unit. The purpose of the antenna is to receive coded signals from connected satellites, and the task of the processing unit is to decode the signals into meaningful information (Fig.1.1).

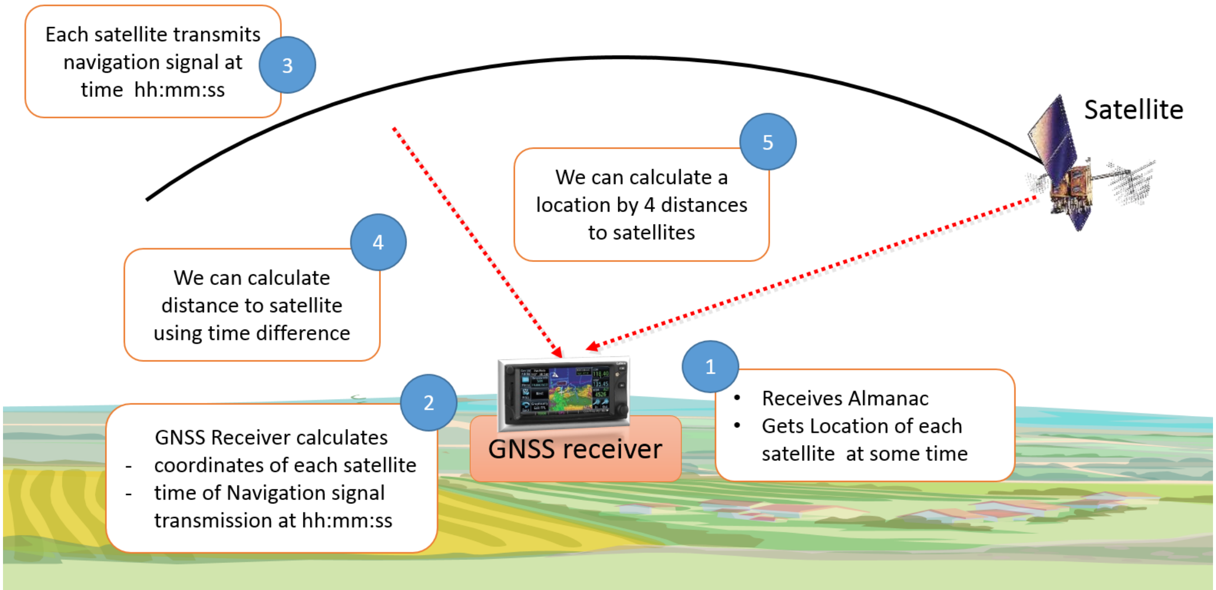


Figure 1.1 – Principle of operation of GNSS

The processing unit translates the receiver's location in terms of latitude, longitude, and altitude, as the receiver is positioned exactly relative to the satellite. The aircraft (ACFT) receiver calculates the time difference between broadcast time and coded signal reception time. Based on this simple concept, each GNSS works on the surface of this planet.

WAAS provides additional information to GPS/WAAS receivers to improve the accuracy and integrity of current position estimates. Using the data from Federal Aviation Administration (FAA), in contrast to traditional ground-based navigation aids, the Wide Area Augmentation System (WAAS) provides navigation services throughout the National Airspace System (NAS).

Main features and benefits:

– Line of sight between points is not required.
– By automating measurements, observer errors are minimized.

- Allows around the clock under any weather conditions to determine the coordinates of objects anywhere in the world.
- The accuracy of GNSS determinations is little affected by weather conditions (rain, snow, high or low temperatures, and humidity).
- GNSS can significantly reduce the time of work compared to traditional methods.
- GNSS results are presented in digital form and can be easily exported to cartographic or geographic information systems (GIS).

To determine the spatial position with higher accuracy, it is necessary to perform measurements in the differential mode (have two receivers, one of which acts as a base receiver and must be installed at a point with given coordinates, and the second acts as a rover (mobile) to determine the coordinates points of interest, with both receivers operating simultaneously). There are two measurement modes: post-processed and real time. While using the post-processing mode, field measurements of points of interest are first performed, and then the data is transferred from the receiver to a computer, and the measurements are processed using specialized software. Real-time mode allows you to get the coordinates of points directly in the field, this requires either a radio connection or a connection between the base and rover equipped with radio or GSM modems.

The accuracy of determining the GNSS coordinates is given in Table 1.1 Errors in determining the spatial coordinates of points by satellite methods, depending on the type of signal and measurement mode.

On the whole GNSS consists of three segments:

- segment of space vehicles;
- segments of management and control;
- segments of users.

The segment of space vehicles consists of the determined amount of space satellites.

They perform the duty of lighthouses, that radiate navigation signals by means of that the transceiver of satellite signals determines the location.

Table 1.1 – Determination accuracy of the GNSS coordinates

Method name	Coordinate errors	
	Phase measurements	Code measurements
Absolute method	Solution with accurate ephemeris 0.6 - 4 cm.	– 2 - 18 m; – 4 - 40 m; – 12 - 100 m.
Differential method	Method statics (fixed solution) – Static (floating solution) 7 - 50 cm; – kinematics, 0.6 - 5 cm.	- DGPS code smoothed by phase 0.2 - 1 m; - DGPS 0.6 - 5 m.

The segment of management and control consists of the surface stations accommodated in different parts of earth surface thus, to provide connection with all artificial GNSS. The surface stations control position and parameters of every artificial satellite. For determination of user coordinates necessary information is about the exact residence of every artificial satellite.

The surface stations of supervision by means of exact radiolocation equipment determine positions of every artificial satellite and through substations of loading of information pass them on artificial satellite.

The segment of user consists of unlimited amount of transceivers of satellite signals.

Principle of action of GNSS consists in the range-finder method of positioning.

Determination of user coordinates is based on being of distance from aerial of user to navigation artificial satellite.

User coordinates determine by a decision the systems of equalizations [58]:

$$\begin{cases} R_A^2 = (x_0 - x_A)^2 + (y_0 - y_A)^2 + (z_0 - z_A)^2; \\ R_B^2 = (x_0 - x_B)^2 + (y_0 - y_B)^2 + (z_0 - z_B)^2; \\ R_C^2 = (x_0 - x_C)^2 + (y_0 - y_C)^2 + (z_0 - z_C)^2. \end{cases}, \qquad (1.1)$$

where R is the distance from artificial satellite to aerial of user; x, y, z are coordinates of artificial satellite; x_0, y_0, z_0 are user coordinates.

With including of transceiver of GNSS it begins to take navigation signals over satellite. In addition, from satellite an almanac is accepted and loaded.

The almanac of GNSS contains exact information about every satellite, in particular his position in set time. After the known coordinates of satellite on set time of twenty-four hours with the use of equalization of trajectory of motion of satellite exact position of satellite settles accounts on current time (Fig 1.2) [58].

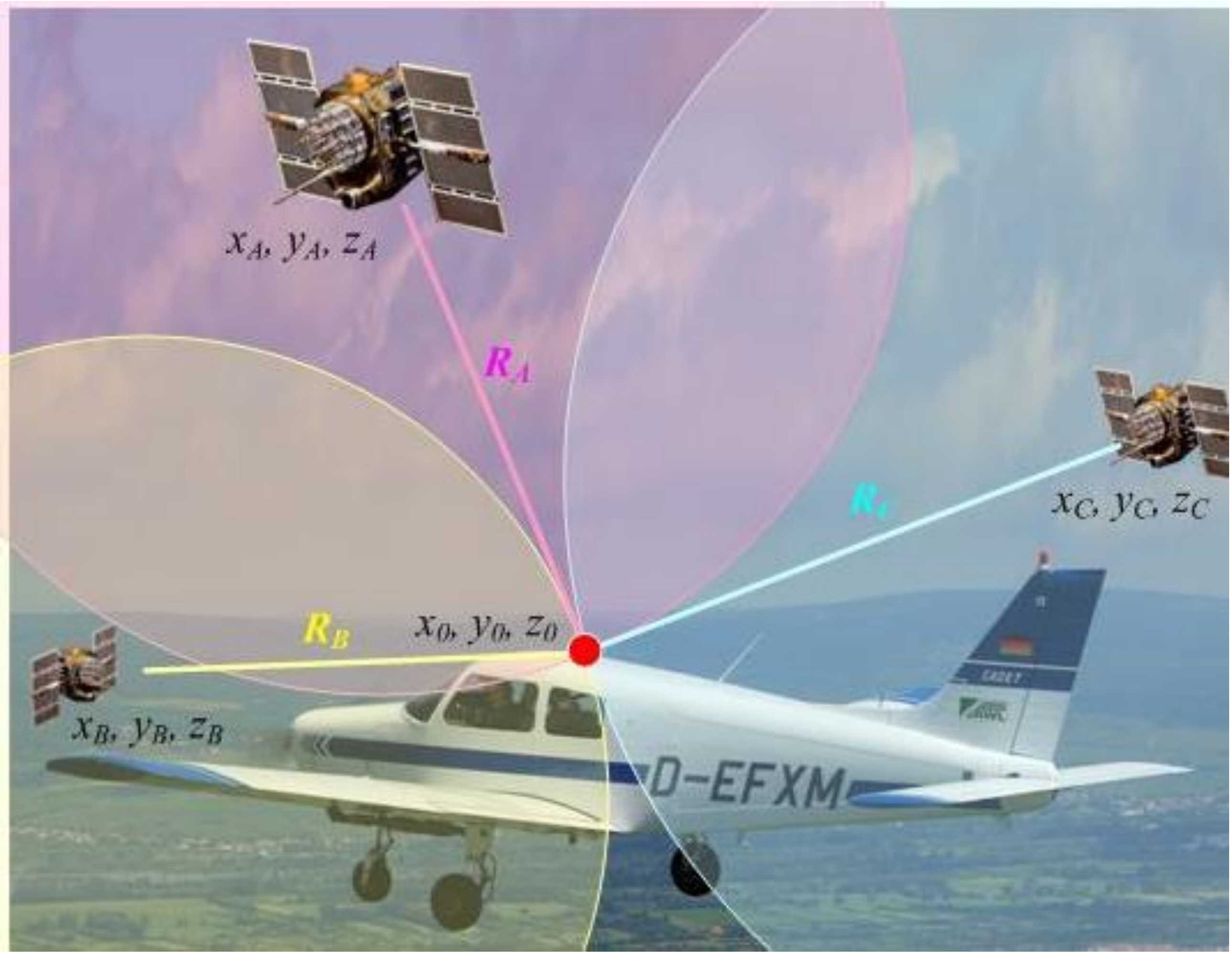


Figure 1.2 – Principle of obtaining aircraft coordinates by GNSS [58]

Thus, the transceiver of GNSS gets actual information about position of every satellite. Distance from satellite to the user is determined by measuring of time-of-flight of navigation signal. A transceiver of GNSS knows t_s time, when a signal on satellite will be emitted. In this time a transceiver by means of internal timers generates an analogical navigation signal and gives it on a delay line. Each of satellite in strictly set time radiates a navigation signal is certain. After taking of navigation signal over satellite the accepted signal is compared to detained through the calculation of auto correlation.

In such case when both signals will be compared at one and the same time, the value of autocorrelation function will equal unit. At the same time of *t* turns out from a delay line, for what navigation signal from satellite came to the transceiver.

In that way, distance to the navigation companions is calculated after equalization:

$$R_{(A,B,C)} = ct_{(A,B,C)}\ , \quad (1.2)$$

where *c* is the propagation speed of radio waves in space.

Since the internal clock in the navigation signal receiver cannot accurately determine the time for synchronization, the error of the user's clock must be taken into account when determining the range. A single clock is used to determine the distance to different satellite, then the time error can be determined by adding another equation [43-45]:

$$\begin{cases} (R_A + c\Delta t)^2 = (x_0 - x_A)^2 + (y_0 - y_A)^2 + (z_0 - z_A)^2; \\ (R_B + c\Delta t)^2 = (x_0 - x_B)^2 + (y_0 - y_B)^2 + (z_0 - z_B)^2; \\ (R_C + c\Delta t)^2 = (x_0 - x_C)^2 + (y_0 - y_C)^2 + (z_0 - z_C)^2; \\ (R_D + c\Delta t)^2 = (x_0 - x_D)^2 + (y_0 - y_D)^2 + (z_0 - z_D)^2; \end{cases}, \quad (1.3)$$

where *Δt* is an error that takes into account the inaccuracy of the internal clock of the GNSS receiver. Accordingly, in order to determine the location of the user, it is necessary to receive signals from at least four navigation stations.

The accuracy of GNSS positioning is highly dependent on numerous errors. Some of them are related to the geometry of the location of the radio station above the user and local errors caused by the passage of the radio signal through the atmosphere.

1.3. Inertial reference system

For a long time, the lack of accurate information about the location of an aircraft or helicopter was a serious obstacle to the development of aviation. The operators needed a navigation system that would not depend on terrestrial landmarks. The invention of autonomous inertial navigation systems was a big step in the history of aviation.

Inertial navigation - a method of navigation and control their movement, based on the properties of inertial bodies, is autonomous, is does not require external landmarks or signals coming from outside.

Non-autonomous methods of solving navigation problems are based on the use of external landmarks or signals (stars, beacons, radio signals, etc.). These methods are quite simple, but in some cases cannot be used due to lack of visibility or interference to radio signals. The need to create autonomous navigation systems has led to inertial navigation [7].

The essence of inertial navigation is to determine the acceleration of the object and its angular velocities using devices and devices installed on the moving object, and according to these data - the location (coordinates) of the object, its course, speed, distance traveled etc. Also, in determining the parameters needed to stabilize the object and automatically control its movement (Fig.1.3).

This is done with the help of:

- linear acceleration sensors (accelerometers);
- gyroscopic devices;
- computing devices (computers), which by acceleration (by integrating them) find the speed of the object, its coordinates and other motion parameters.

The advantages of inertial navigation methods are autonomy, noise immunity and the ability to fully automate all navigation processes. Inertial navigation is becoming more widely used in the navigation of surface and submarines, aircraft, spacecraft and other moving objects.

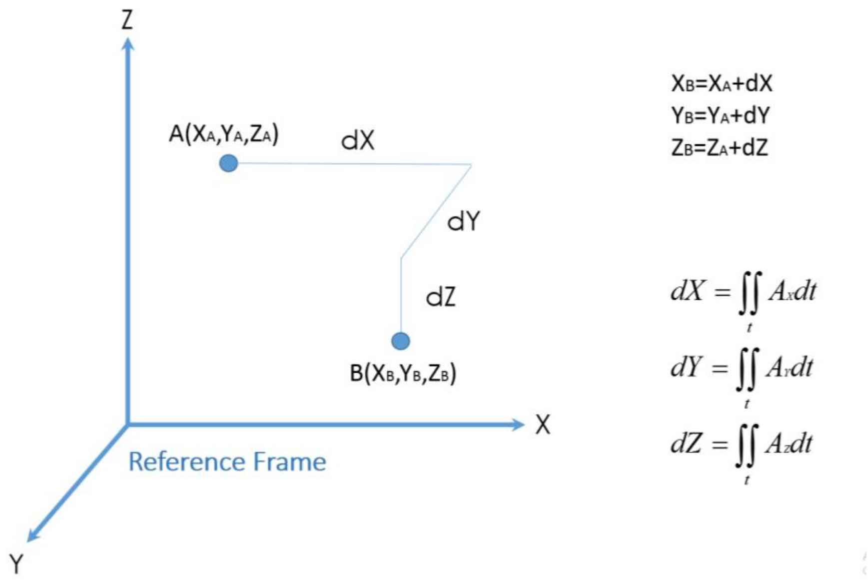


Figure 1.3 – Principle of operation of INS

The basis of the work of the Inertial Navigation System (INS) is to measure the acceleration of the aircraft and its angular velocities relative to the three axes of the aircraft in order to determine the location of the aircraft, its speed, heading and other parameters based on these data. Based on the results of the analysis, the object is stabilized, and automatic control can be used [8].

To collect information about the flight, the INS includes accelerometers that read linear acceleration, and gyroscopes that allow you to determine the angles of inclination of the aircraft relative to the main axes: pitch, yaw and roll (Fig.1.4). The accuracy of the information obtained depends on the characteristics of these instruments. The data is analyzed by a computer, which then corrects the movement of the object according to certain navigation algorithms [10].

INSs are divided into platform and strap down. The basis for platform INSs is a gyro-stabilized platform. In strap down systems, accelerometers and gyroscopes are rigidly connected to the body of the device. Platform functions are modeled mathematically by a computer system. Strap down systems favorably differ in their lower weight and dimensions, as well as the ability to work with significant overloads.

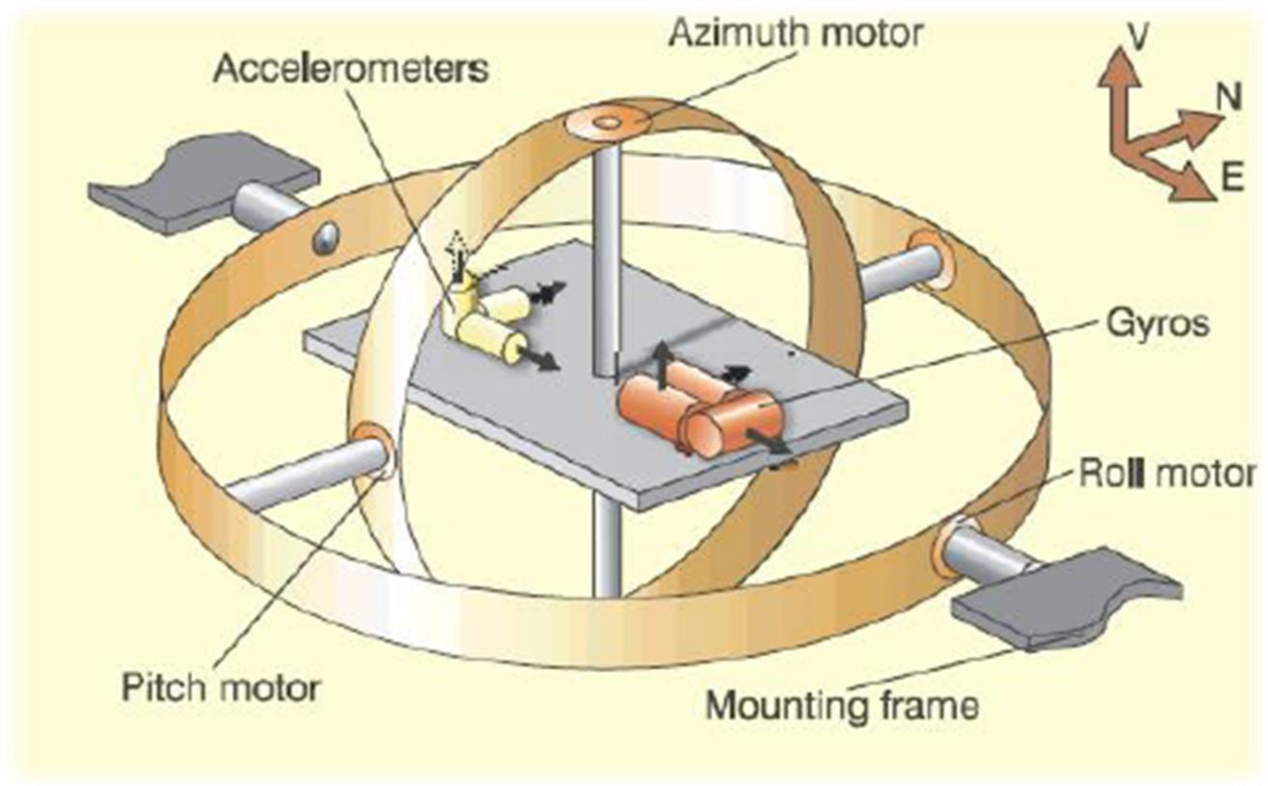


Figure 1.4 – Sensors of INS

Platform INSs use a special "plate" suspended in a gimbal, which provides free rotation in three spaces. A group of three accelerometers for measuring components of acceleration along the X, Y, Z axes and a group of three gyroscopes for measuring angular velocities are placed on the platform. Electric motors rotating the platform are placed in the joints of the cardan suspension.

Gyroscopes follow the rotations of the platform and engage electric motors, keeping the platform in a fixed orientation relative to the selected coordinate system. Accelerometers stabilized and displayed in a certain coordinate system measure the corresponding accelerations.

Using the measured accelerations (*ax(t), ay(t), az(t)*) at a certain moment in time (*t*) according to initial values, that are known, of the parameters ($V_x(t_0)$, $V_y(t_0)$, $V_z(t_0)$), the velocities are estimated:

$$V_x(t)=V_x(t_0)+\int_{t_0}^{t} a_x(t)dt, \quad V_y(t)=V_y(t_0)+\int_{t_0}^{t} a_y(t)dt, \quad V_z(t)=V_z(t_0)+\int_{t_0}^{t} a_z(t)dt \tag{1.4}$$

Based on the obtained velocity components, position coordinates are estimated, taking into account the known positions at the previous moment in time (*X(t₀)*, *Y(t₀)*, *Z(t₀)*):

$$X(t) = X(t_0) + \int_{t_0}^{t} V_x(t)dt \; ; \quad Y(t) = Y(t_0) + \int_{t_0}^{t} V_y(t)dt \; ; \quad Z(t) = Z(t_0) + \int_{t_0}^{t} V_z(t)dt \qquad (1.5)$$

The advantages of INS over other navigation systems are their complete independence from external data sources, increased protection against interference, high information content and the ability to transmit information at high speed. The absence of any radiation during the operation of the INS ensures the secrecy of the object on which it is used.

The disadvantage of INS is the errors that accumulate over time in the information received from the instruments (Fig.1.5). It can be methodological errors and errors associated with incorrect initial equipment settings.

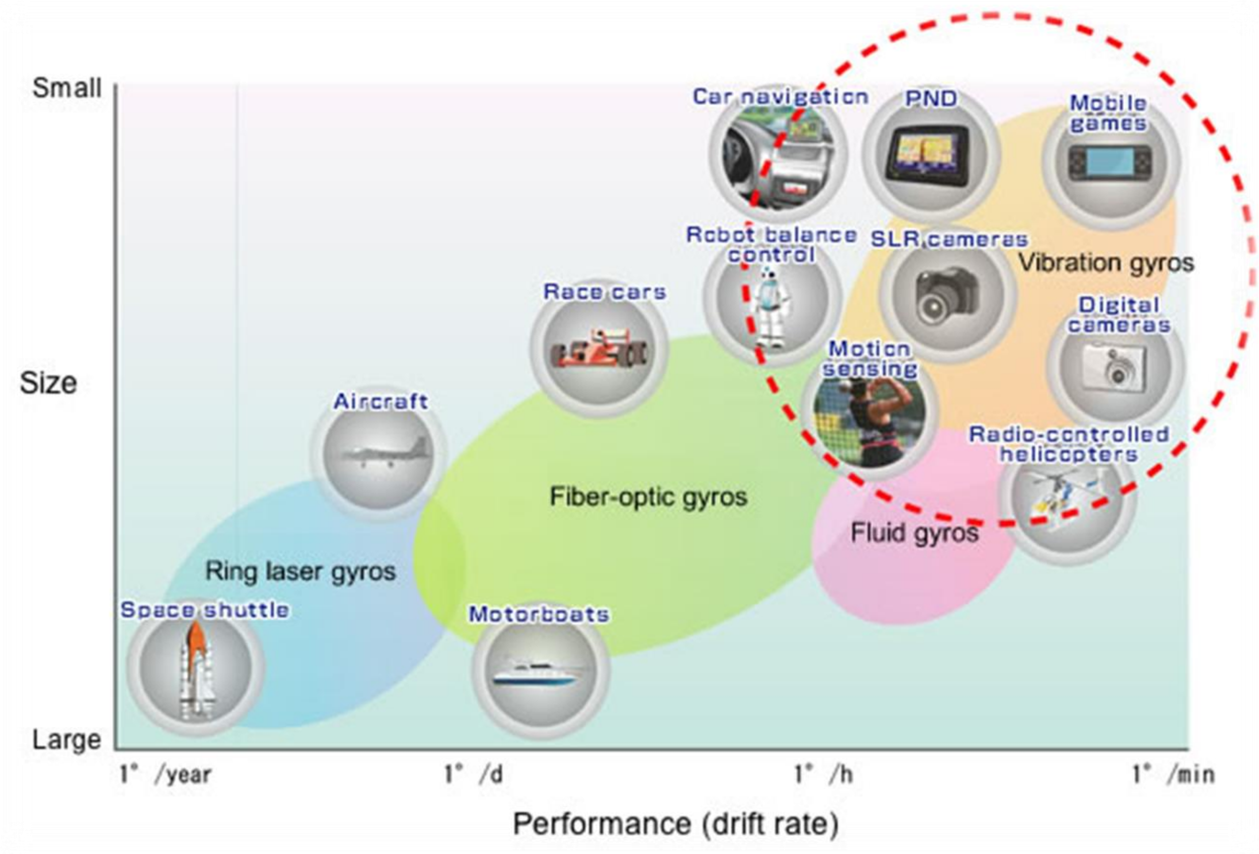


Figure 1.5 – Performance of gyroscopes [68]

To correct them, integrated navigation systems are created, where the data received by the INS are supplemented by data coming from non-autonomous systems, such as satellite navigation. Another relative disadvantage of INS is the high cost of the equipment inside their composition.

1.4. Positioning by navigational aids

VOR/DME: One of the oldest and most useful navigation tools is the Very high frequency Omni-directional Radio Range (VOR) system [19, 20]. The system was built after World War II and is still in use. The omnidirectional VOR is a type of short-range radio navigation system for an aircraft that allows an aircraft with a receiver to locate itself and stay the course by receiving radio signals transmitted by a network of stationary ground beacons. Uses frequencies in the very high frequency (VHF) range from 108.00 to 117.95 MHz. The VOR is the world standard for an air navigation system used in both commercial and general aviation. In two thousand year, there were about three thousand VOR stations worldwide, including one thousand in the United States, by 2013 their number was reduced approximately to 967 [28-30].

The VOR/DME positioning algorithm is adopted on ICAO's recommendation as the primary standard navigation system for aircraft safety in areas and on high-intensity routes [21, 22]. The foreign VOR/DME system, standardized by ICAO, belongs to the azimuth-homogeneous class and uses the azimuth phase method (VOR channel) and the temporal range method (range channel) (Fig. 1.6).

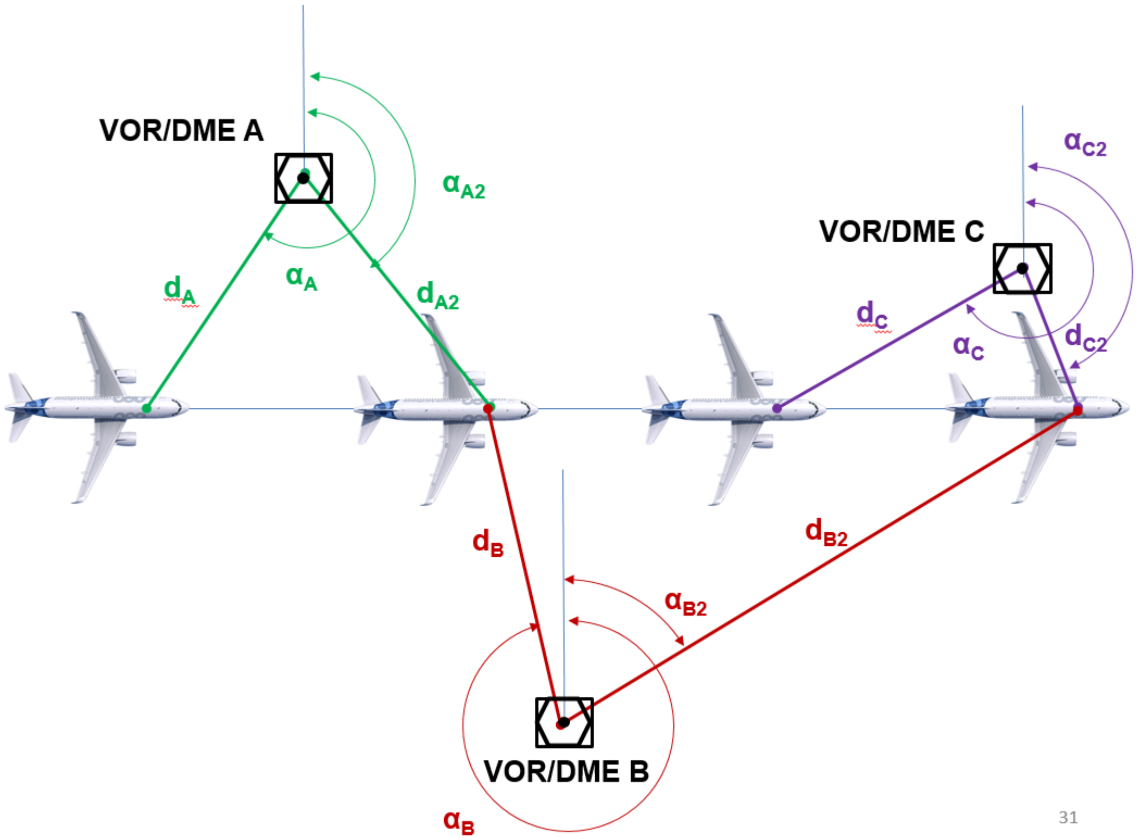


Figure 1.6 – Principle of operation of VOR/DME

The function of the location calculation is to determine the best estimate of the aircraft location and calculate the accuracy of this estimate.

Each FMS calculates the aircraft's own position and accuracy using three sources inertial using the ADIRS correlation system (Air Data and Inertial Reference System) global GPS positioning system with multi-mode MMR receiver radio navigation using NAVAIDS radio navigation aids [32, 36].

The positioning accuracy of the angular method depends on the accuracy of determining the azimuths (ΔA, ΔC) and the geometry of the location of ground radio beacons relative to the ACFT. Errors in determining the azimuth by the on-board equipment form two sectors of the location. The intersection area of the location sectors indicates the possible location of the ACFT.

DME/DME: The DME/DME range finder method (at ranges up to two DME beacons) provides higher positioning accuracy than the goniometric range finder method [15-18]. This is due to the rather high accuracy of measuring ranges and the relatively slow increase in errors as the range itself increases. So, near the beacon, the mean square error of measuring the range is about 0.1 NM, and at a distance of 140 NM - about 1.8 NM [26].

To determine the location by the rangefinder method, the aircraft must be at the same time in the areas of operation of two beacons. All over the Europe and the United States, this condition is usually provided with excess, so the DME/DME method is considered by ICAO as one of the main Area Navigation (RNAV) methods in continental regions along with satellite navigation methods (Fig.1.7) [12,13].

Consider the basic criteria of the Performance based navigation (PBN) concept related to DME/DME in RNAV 1 and 2 flights [53].

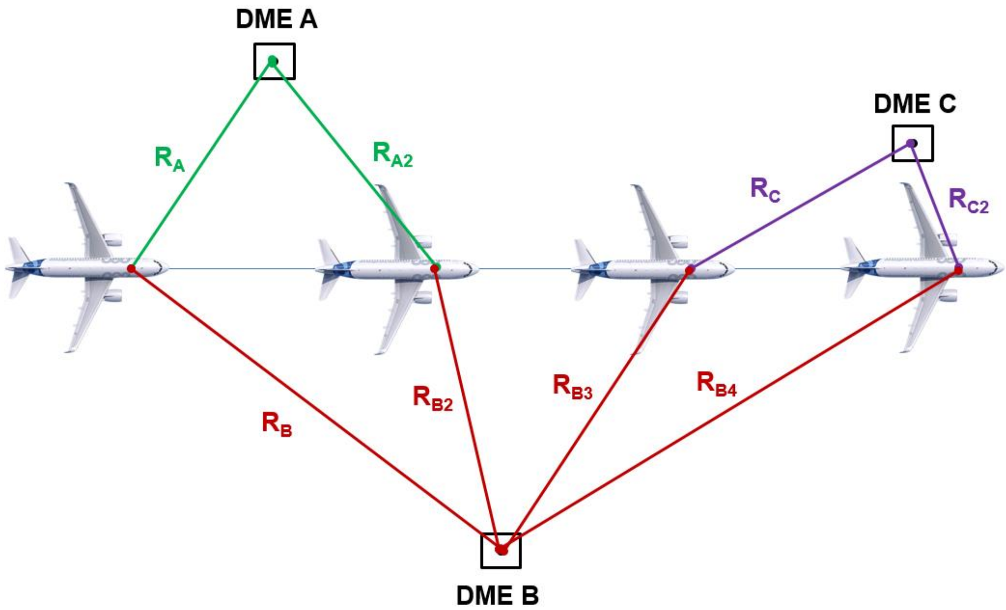


Figure 1.7 – Principle of operation of DME/DME

RNAV DME/DME system must [31]:

– update the location within 30 seconds from the moment of configuration to the navigation tools DME;
– automatically tune to multiple DMEs;
– provide continuous DME/DME location update.

The third DME object or the second pair should operate at least the previous 30 s and there should be no interruption in determining the DME/DME location when switching the RNAV system from one DME station/pair to another.

DME/DME RNAVs should only use the DMEs specified in state AIPs. DME station coordinates and DME height must be published [61, 63].

Systems should not use the means defined by the state in AIP as unsuitable for RNAV 1 and/or RNAV 2 operations, or the means associated with an ILS or MLS system that uses range offset [39-41]. This can be done by:

– exclusion from the onboard navigation database of specific DMEs known to have a negative impact on the navigation solution when RNAV routes are within the receiving area of these DMEs;
– use of the RNAV system, which performs acceptance tests to detect errors in signals received from all DMEs, and, if necessary, excludes these tools from the navigation positioning solution (for example, does not allow tuning to the common DME channel when signals in DME space overlap).

If it is necessary to generate a DME/DME position lock, the RNAV system must use at least DME with a relative intersection angle of 30-150 ° (Fig. 1.8).

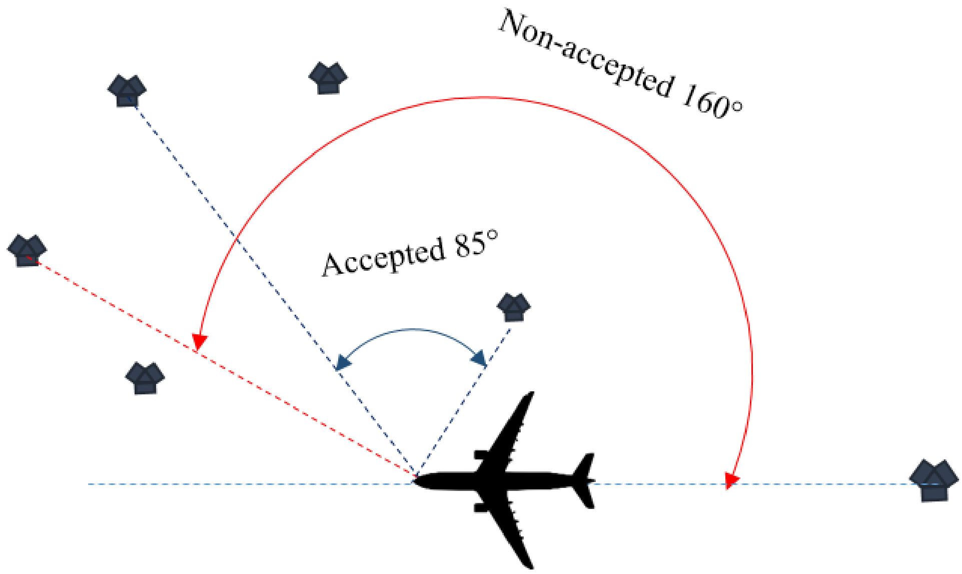


Figure 1.8 – Positioning by pair of DME

The principle of determining ACFT coordinates based on DME ground radio beacon signals is based on the long-range positioning method. During the flight, the onboard equipment analyzes all available DME ground radio beacons at its location. The available ground radio beacons are used by the onboard equipment to determine the inclined distance between the ACFT and the radio beacon using a time criterion.

In the case of the availability of two radio beacons, the result of the development of the navigation equation will be two location points, one of which is rejected by the algorithm for tracking the trajectory of the ACFT. It should be noted that for positioning by two radio beacons can be used exclusively by radio beacons, the angle between which and ACFT is in the range from 30 ° to 150 °, which corresponds to the permissible level of accuracy according to RNAV.

Determining the coordinates of the ACFT location (x_{ACFT}, y_{ACFT}, z_{ACFT}) in the ECEF global geocentric coordinate system in the case of a larger number of radio beacons (more than two) is obtained by solving the navigation equation of the form:

$$D_i^2 = \left(x_{ACFT} - x_{\mathrm{DMEi}}\right)^2 + \left(y_{ACFT} - y_{\mathrm{DMEi}}\right)^2 + \left(z_{ACFT} - z_{\mathrm{DMEi}}\right)^2, \qquad (1.7)$$

where x_{DMEi}, y_{DMEi}, z_{DMEi} are the coordinates of the location of the i-th DME ground radio beacon; D_i is the inclined distance between the i-th radio beacon and the ACFT.

Conclusions to chapter 1

In this chapter were determined the main positioning methods in aviation, like satellite positioning and positioning by navigational aids. Besides, there was explained the inertial method of positioning. In the chapter were underlined how is important to use GNSS, inertial navigation system, VOR and DME positioning systems. There is a description about their working modes, the components, accuracy and principle of operation.

CHAPTER 2. ANALYSIS OF AIRSPACE STRUCTURE

2.1. Classification of private flight vehicles

A motor glider is an aircraft with a rigid wing that heavier oppose to air and equipped with a propulsion system and provided for a long flight, just like a regular glider. Most motor gliders have a propeller; to reduce frontal resistance in unpowered flight, the propeller is retracted into the fuselage, or its blades are flexed or folded. The motor glider gives an opportunity the pilot, using the thrust of the engine, to overcome the shortcomings of ordinary gliders. For instance, to ensure a reliable return to the airfield of the base despite bad weather or low professionalism in the control of the glider, thereby significantly reducing the financial costs and time spent on evacuation from the landing site of a conventional glider [33].

Motor gliders with a conventional or flying propeller are usually classified as tourist motor gliders. They are provided for independent take-off and cruise flight with traction, as in a conventional aircraft, but unlike the latter, they are capable of long-term planning with the engine turned off. Such a motor glider is usually equipped with one engine with a pulling propeller on the nose, similar to light aircraft, but a larger wing span (or, more precisely, a larger wing extension) increases the maximum aerodynamic quality. Most tourist motor gliders have engines with a power from sixty to one hundred hp, a cruising speed of about one hundred and sixty up to one hundred and ninety km/h, fuel tanks with a volume of fifty up to one hundred liters, which allow them to fly up to eight hundred and thirty km.

Some motor gliders are equipped with a folding wing that allows it to be placed in a standard hangar.

The ability to take off independently allows the pilot to do without a tow plane or ground launch equipment, but it increases the cost, complexity and weight of the aircraft, and also worsens aerodynamics compared to a conventional engineless glider.

The retractable propeller is usually installed in the motor glider on the mast, which is raised when it is used, and lowered inside the fuselage through the hatch when planning. At the same time, the propeller is driven through a belt drive from the engine, which is also installed inside the fuselage. To avoid overheating, the radiator in such structures is installed on the same mast (see figure on the right).

In some designs, the propeller installation is fully extended, exiting upwards from the space of the fuselage behind the crew cabin. Unlike a tourist glider, this type of glider is usually equipped with a tow hook (Fig. 2.1):

Figure 2.1 – A motor glider

Flight and technical characteristics of the motor glider AC-7 is given in Table 2.1.

Table 2.1 – Flight performance characteristics of a motor glider AC-7

Parameter	**Value**
Crew, person	2
Length, m	6,5
Span, m	17,7
Wing area, sq.m.	13
Operating overload range, units	+5,2..-2,8
Maximum speed, km/h	220
Landing speed, km/h	65

A hang glider is the simplest means of air transportation, the flight control of which is carried out by shifting the center of mass due to the movement of the pilot relative to the suspension point.

A hang glider is a single-seat aircraft with a swept wing, which is the basis of the entire hang glider, due to which it is able to stay in the air and maneuver. Of all the means of transportation in airspace, the hang glider is the simplest of them, since it is built from a small number of parts, there is no motor and even a seat. Structurally, it has three duralumin pipes connected to each other at the front point and forming a fan in the horizontal plane, with an angle between the pipes of ninety up to one hundred and forty degrees. A fabric of light, but dense and durable synthetic fabric is stretched between the pipes. The two side tubes and the trailing edge of the fabric form almost a triangle when viewed from above. To maintain the shape, the main pipes are fixed with smaller diameter auxiliary pipes and steel cables. The pilot in a special harness, originally borrowed from a parachute, is suspended on a rope by the central tube in a certain place, close to the center of mass of the device. The pilot's hands hold on to the trapezium - a structure of three pipes, when viewed from the front, which most often represents a triangle with a horizontal base, fixed in space with braces or steel cables with a diameter of several millimeters.

Flight control is carried out by the pilot by moving his body relative to the suspension point. Landing is on the feet. The main advantage of the hang glider is the simplicity of the design. A hang glider is cheaper than a glider and more compact; it is enough to have a car to transport it. When folded, it fits into a case two meters long and thirty up to forty centimeters in diameter, but most prefer not to disassemble the device into less than a six-meter package, which reduces the time for subsequent assembly. The weight of a modern hang glider is on average thirty up to thirty-three kilograms, although for different specific models it ranges from twenty to fifty kilograms. Low flight speeds do not allow hang gliders to operate in difficult weather conditions like wind more than fifteen m/s, strong turbulence. The use of updrafts is the main way to gain height on a hang glider in free flight. Due to its simplicity and the lack of need for refueling, this vehicle will be a good choice for a zombie apocalypse survivor.

A hang glider is a simple, but at the same time, a suitable means of transportation in a zombie apocalypse. This is largely due to its simplicity of design, thanks to which it can be relatively quickly assembled and disassembled when you need it, service it and transport the hang glider on your existing transport. The most important thing in it is that the hang glider does not need any fuel for its movement, with which there is an acute shortage in zombie apocalyptic conditions.

However, for piloting a hang glider, appropriate skills will be required, in addition, maneuvering in the air when flying on certain models of hang gliders will require significant effort for the pilot. Since, in addition to the weight of the pilot himself, the hang glider has its own weight, therefore it is not capable of carrying heavy loads, and soon all the mass it carries will quickly lower the device from heaven to earth. Furthermore, this affects the duration and speed of the flight. It should also be remembered that under certain weather conditions, planning on a hang glider is either very complicated or completely impossible, in particular, due to strong winds, it can be carried away in an unknown direction [2, 5].

A hang glider is not a common means of transportation, and therefore it is not common and is used mainly for outdoor activities or in sports. You can find various copies of this transport in some sports and other shops, resort areas and settlements with a large predominance of mountainous areas, in which, due to the complex landscape, hang gliders are used for air travel. There are several types of hang gliders that have some changes in their design: some are durable but difficult to repair, others are fast to move but difficult to pilot, others are light but unreliable, and so on. Choose wisely. You can build a hang glider yourself, but this is if you have the necessary details and knowledge in the field of mechanics and aerodynamics (Fig. 2.2):

Figure 2.2 – A hang glider

A paraglider is an ultralight aircraft that looks like a parachute. Although the parachute is the progenitor of the paraglider, they are still completely different devices. If you put a parachute and a paraglider next to each other, then the differences can be noticed without being a specialist. A paraglider is similar in shape to an elongated ellipse, while a parachute is more like a rectangle. There are actually many more differences, but the most important difference between these devices is their functional purpose: a parachute is a means of gently lowering cargo from the sky to the ground, and a paraglider is an aircraft, such as a glider or a hang glider, which means you can climb it from the ground into the sky.

The shape of the wing is an ellipse, not a rectangle like a parachute. The slings are much larger, but their thickness is less. The height from the pilot to the bottom edge of paragliders is on average seven-eight meters; in a parachute, this value is two-three times smaller, and in some extreme parachutes it is one and half meters. The speed of descent when flying on a paraglider is one m/s, which is significantly less than that of a parachute.

A paraglider consists of fabric and straps - nothing complicated. The fabric of the dome does not allow air to pass through - this is the main feature of a paraglider. If over time the fabric begins to leak air, then such a paraglider becomes unusable. Such a fabric weighs an average of forty g/m2 - it is lighter than an A4 sheet, it weighs eighty g/m2. The paraglider fabric is made using rip stop technology. Paraglider slings are one of the main elements. With a thickness of one millimeter, they can withstand up to fifty kg. Corresponding requirements for slings: strength and minimal stretching under load. Modern slings meet these requirements. The dome itself consists of upper and lower panels, which are sewn together with ribs. The rib is a transverse element of the dome that forms its profile. The ribs have holes for free air flow inside the wing - this is necessary for quick filling of all compartments of the paraglider (Fig. 2.3):

Figure 2.3 – A paraglider

A jet man is a person with wings and turbines attached to his back (Fig. 2.4). A person can develop speed up to two hundred kilometers. The only downside is that you won't be able to take off on your own. This requires the help of an airplane.

One of the features of the Jet Man project is the complete lack of wing mechanization. The aircraft is controlled by eliminating the center of mass, but unlike a hang glider, where the pilot can move under the plane of the wing, in Yves Rossi's aircraft the wing is rigidly fixed to the back, and the pilot controls the flight by only moving his arms, legs and head. At the same time, the maneuverability is sufficient to perform aerobatic figures of varying complexity.

The aircraft does not take off from the ground - it rises to the required height for take-off by plane, helicopter or balloon. A parachute is used for landing, and in addition to the landing and spare wing, Yves Rossi's wing is also equipped with its own parachute, which ensures its soft landing in case there is a need to drop the wing.

The weight of a knapsack is 55 kg with fully filled thirty liters of fuel, the wingspan is two meters. The maximum speed is three hundred km per hour, the duration of the flight with full refueling is ten minutes.

Figure 2.4 – A jetman

An unmanned aerial vehicle (UAV) is defined as a vehicle that flies without a pilot, is remotely and fully controlled from another location (ground, another aircraft, space) or is programmed and fully autonomous. UAV is a more technically accurate description preferred by specialists and professionals compared to "drone". This applies to large unmanned aerial vehicles with autopilots, which have found wider use in the civil and defense sectors.

Basically, the terms are similar, but the use of both terms should be different, based on the characteristics of the aircraft, as well as the scope of application.

Another widely used concept is UAV, that is, unmanned flying system [13, 42], which is a more complex term than UAV. The word "complex" already indicates that it is a collection of several items, that is, the UAV consists of the UAV itself, as well as the equipment necessary for its operation - a ground control station, an antenna system and a catapult.

Advantages of using UAVs:

– *Speed.* The required information from a UAV can be provided to the client more quickly using special cameras and a data channel, rather than using traditional surveying methods, which can sometimes be slower.
– *Economical.* Data is obtained faster than conventional collection methods, so different missions can be completed in a shorter period of time, thus costing less than using other vehicles.
– *Safety.* UAV operators do not need to be in an area that can be dangerous for a variety of reasons.
– *High level of accuracy.* UAVs can obtain highly accurate data. This is due to the number of overlaps received during the flight - the more overlaps, the more detailed the information recorded.

To carry out a mission or task, there is no need to involve a qualified on-board pilot, since they are unmanned, and all systems are designed in such a way that human intervention in the work is minimized (Fig. 2.5).

Figure 2.5 – Variety of UAV

The UAV is capable of flying and gathering information during rain, cloud cover, fog and darkness.

2.2. Airspace Requirements

The airspace structure is based on the criteria for the required throughput of the Air Traffic Management (ATM) system, the efficiency and regularity of air traffic, while provision of the level of flight safety. When designing airspace, ICAO recommends taking into account the following main factors given in Annex 11 to the Convention on International Civil Aviation. "Air Traffic Services" [9, 67]:

– type of air traffic services provided (control, flight information, emergency notification service);
– flight rules;
– intensity and type of air traffic (regular or episodic);
– technical characteristics of the aircraft;
– tactical and technical characteristics of radio navigation aids and ATM;
– capabilities of the air traffic controller.

Based on these criteria, the airspace in which international air traffic services are provided can be classified and designated as airspace of classes A – G [54].

Classes A - D and E airspace is controlled airspace, and Class F and G airspace is uncontrolled airspace. An airspace structure for Ukraine is represented in Fig. 2.6.

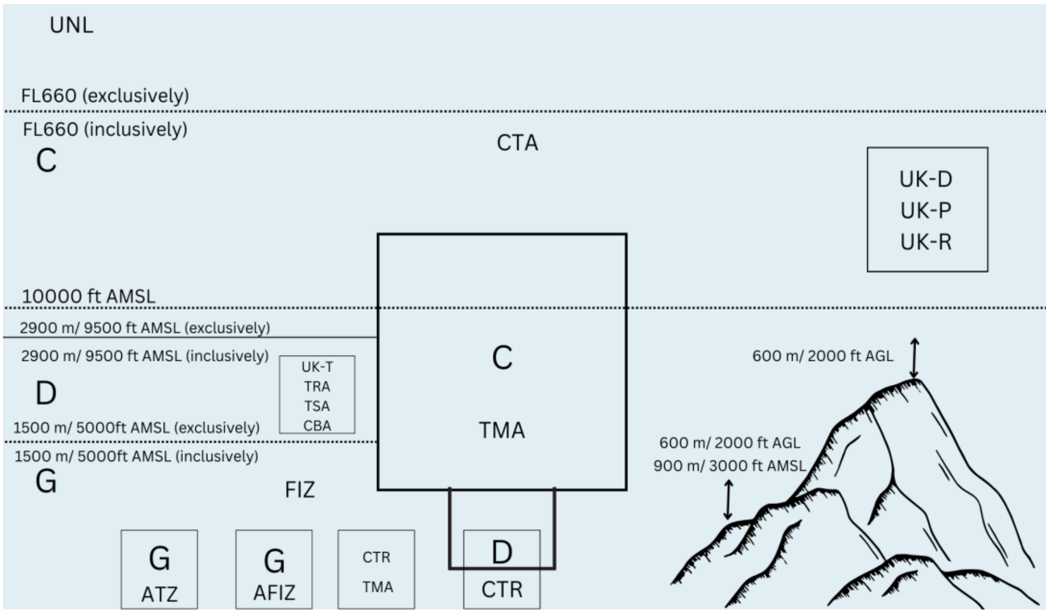


Figure 2.6 – Classification of Ukrainian airspace

Class G. The upper bound of the class G is usually the lower bound of the space E. This class is located under the rest of the spaces and starts from the surface of the earth. It covers the entire surface of the earth, repeating the relief. In remote areas, it has an altitude of 14500 mean sea level.

Class E. Class E is a large controlled airspace that is not defined as classes A - D, G. It fills the gap between the other classes. It can extend within limits not limited by other spaces. This class always has one of four lower bounds: surface, 700 above ground level, 1200 above ground level, 14500 mean sea level. Most of the E space has a height limit of 1,200 above ground level.

Class D. Class D can include the airspace of small urban airports with a control tower. Typically, the upper limit of class D is 2,500 feet. AGL over the airport, but this height may be different. Several boundaries of space D may have an elongated shape, this is due to the peculiarities of the passage of the take-off or landing routes of the airport.

Class C. Separation by altitude shows the upper and lower boundaries like in class B space. As well as in class B space, flights without controller's clearance are possible above and below the edges of class C. For general aviation flights inside this space requires approval from ATC, which can be obtained by radio station.

Class B. Class B airspace surrounds national airports and typically extends up to 10 thousand feet mean sea level, and in some cases even higher. Class B airspace may extend horizontally with a radius of up to fifteen miles from the airport tower. More precisely, it is determined specifically based on the conditions of traffic intensity, geographical or other conditions of a particular airport. Class B trespassing is a very serious offense that puts the lives of many people flying large passenger aircraft at risk [23, 24]. Where entry into Class D or E spaces would only result in a severe warning, entry into Class B or C would result in a severe penalty.

Class A. Class A space begins at eighteen thousand feet mean sea level and extends up to sixty thousand ft. mean sea level. Class A airspace covers the entire country and has a baseline of 18 thousand feet mean sea level. In this class of airspace,the air traffic control service has a fairly good understanding of the air situation through the use of mandatory air traffic control [2, 5].

2.3. Requirements for on-board positioning system

Required Navigation Performance (RNP) is a performance-based navigation data type that allows an aircraft to fly a specific route between two 3-dimensional spots in the airspace. RNAV and RNP systems are basically similar. The main difference between the two is the need for on-board performance monitoring and reporting. The navigation specification, which includes the requirements for on-board performance monitoring and reporting, is called the RNP specification [25, 27]. Those specifications that do not have such requirements are called RNAV specifications. Therefore, if radar control is not provided by ATC, the pilot must independently control the safety of terrain navigation and Required Navigation Performance must be used instead of Area Navigation.

Some oceanic airspace has an RNP value of 4 or 10. The level of RNP an aircraft is capable of determines the distance difference required between aircraft. The increased accuracy of airborne RNP systems is a significant benefit for traditional non-radar environments because the number of aircraft that can fit into the volume of airspace at any given altitude is the square of the number of separations required; that is, the lower the required navigation performance value, the lower the required distance separation standards and, in general, more aircraft can fit into the airspace volume without losing the required separation [64]. The current specific requirements of the RNP system include:

– the ability to follow the desired land route with reliability, repeatability and predictability, including curves;
– Where vertical guidance is enabled for vertical guidance, vertical angles or height limits are used to determine the desired vertical path.

Performance monitoring and alerting capabilities may be provided in various forms depending on system installation, architecture, and configurations, including:

– display and indication of both the required and estimated performance of the navigation system;
– monitoring of the system operation and notification of the crew about non-compliance with RNP requirements;
– lane deviation displays scaled to RNP, combined with separate navigation integrity monitoring and alerting.

The RNP system uses its navigation sensors, architectures and modes of operation to meet the requirements of the RNP navigation specification. RNP requirements may restrict aircraft operations, for example for low RNP where flight technical error is a significant factor and manual flight may be prohibited. Dual system or sensor installation may also be required depending on the intended operation or need [65].

Areas of activity:

– *Oceanic and remote continental airspace.* Oceanic and remote continental airspace is currently served by area navigation specifications 4 and 10. Both primarily use GNSS to support the airspace navigation element. In the case of RNAV 10, no form of ATS surveillance is required. In the case of RNP 4th, the ADS contract is used.
– *Continental route.* RNAV 5 is used in the Middle East and Europe regions, but has been designated as RNAV 1 since 2007. In the United States, RNAV second maintains en-route continental airspace. Continental RNAV applications currently support airspace specifications that include radar surveillance and two way communication between controller and pilot.
– *Terminal airspace: arrival and departure.* RNAV applications are currently used in the European Region and the USA. The European terminal airspace RNAV application is known as Precision Area navigation. While the RNAV 1 specification shares overall navigation accuracy with P-RNAV, this regional navigation specification does not meet all of the requirements of the RNAV 1 specification. Basic RNP 1 was developed primarily for use in non-radar, low-density terminal airspace. More RNP applications are expected to be developed in the future for both en-route and terminal airspace [67].

Conclusions to chapter 2

In this chapter was suggested the information about private flight vehicles, included a motor glider, a hang glider, a paraglider, a jet man and unmanned aerial vehicle. I understood that other air vehicles are also important in aviation like a big aircraft, and there is a need to develop their positioning in more precise way.

Moreover, there was explained an airspace requirements and requirements for on-board positioning, included classification of Ukrainian airspace, Required Navigation Performance and Area Navigation specifications. I explained that usage of RNAV and PBN represents a major cost savings opportunity for airlines flying over oceans due to less restrictive routing.

CHAPTER 3. POSITIONING BY PERSONAL POCKET DEVICES

3.1. Personal pocked devices

No-one can imagine his life without smartphones and other Personal Pocked Devices (PPD) which makes a person's life easier. Common examples of the PPD are smartphones, tablets, watches, bracelets, glasses, and others hold all required accelerometers and gyroscopes for position tracking. We use PPD with the direct aim, but also we can consider PPD as positioning system or autopilot system for UAV applications. In common, most of PPD are equipped with proximity sensor, accelerometers, gyroscopes, temperature, light, and magnetic field sensors [70]. Moreover, PPD is not only sensor assembly, also it is based on some processing unit and memory. The hardware part of PPD is served with specific software that moves the task of navigation to software coding. In this case performance of data processing is an important element.

The sensors, mentioned above, give an opportunity to use the smartphone for reading the data from each sensor and create own navigation system.

Accelerometer tracks acceleration of the device. Such sensor gives an opportunity to speed up the processes in the device, also it can be used for the counting steps made by user. Easier to say that accelerometer deals with the orientation of the device in space.

Gyroscope determines a correct location of an object in space, its pitch, roll and yaw velocities, and angles.

Different software can provide a different possibility for orientation and inertial data. Some software supports raw data with rotation velocity around the axis from gyroscopes, other makes possible to use pitch, roll and yaw angles at different time of discretization. Usually, the sensor assembly of PPD supports measurements in local body coordinate system. Placement and orientation of body coordinate system depend on operation system type and software version. The common body reference frame is represented in Fig. 3.1.

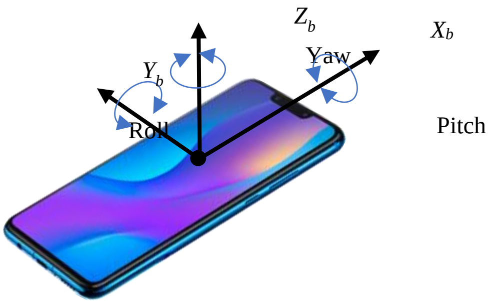


Figure 3.1 – Body reference frame

Also, some software supports clear acceleration matrix in body frame, other includes components of gravity that should be filtered from measured data.

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

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.

3.2. Inertial navigation by PPD sensors

Position estimation by inertial navigation grounds on force measurement that interrogate with inertial mass inside of sensor. Thus, force action can be a result of acceleration changes. UAV position estimation grounds on 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.

We use East-North-Up (ENU) local coordinate system for positioning purpose. 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 reference frame is located at the point of initial measurement (Fig. 3.2).

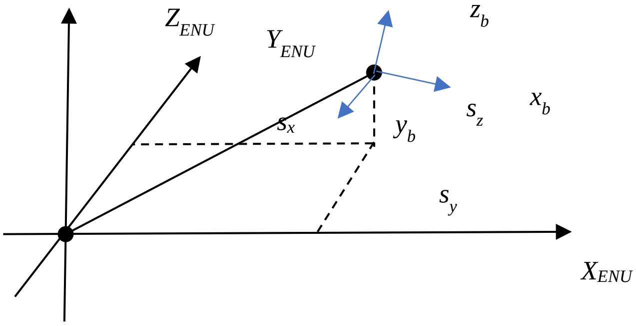


Figure 3.2 – ENU and Body reference frames

After the measurement process of accelerations by axis, we got components of the path [52]:

$$S(t_i) = \Delta t V_{ENU}(t_i) + \frac{\Delta t^2}{2} A_{ENU}(t_i), \tag{3.1}$$

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

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

$$X_{ENU}(t_i) = X_{ENU}(t_{i-1}) + \Delta t V_{ENU}(t_i) + + \frac{\Delta t^2}{2} A_{ENU}(t_i), \tag{3.2}$$

where $X_{ENU}(t_{i-1})$ and $X_{ENU}(t_i)$ are coordinates of object location at previous and current iteration correspondently.

In our research, we consider a strap-down inertial navigation system architecture therefore, accelerometers assembly is properly fixed on the body of an object to sense applied components of acceleration. All sensors are measuring in the body reference frame. Thus, we use orientation matrix from gyroscopes, that includes pitch, roll and yaw angles for acceleration data transformation from body to ENU coordinate system:

$$A_{ENU}=TA_b\ , \tag{3.3}$$

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

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

3.3. Trajectory data filtering

Measurements of acceleration and rotation include random noise, that degrades the accuracy of obtained UAV coordinates. In order to reduce the error influence we use noise filtering at upper level of trajectory data processing. Error filtering at lower (raw sensor data) level is integrated into PPD software and usually includes the most accurate sensor model.

An error filtering usually grounds on applying an object model and statistical analysis of measurements in order to predict parameter value at the time of the next measurement. Thus at time of next measurement we have both measured and predicted values, that are used in filtering.

We use an α-β-γ filter in the form of linear Kalman filter to reduce error in UAV trajectory data. Properties of α-β-γ filter provide an optimal noise reduction for object model with dynamic characteristics. Kalman filter for discrete-time describes system dynamic model as follows [47, 48]:

$$X_i=\Phi X_{i-1}+w_{i-1} \quad (3.4)$$

where X_i is a state matrix of one coordinate at time t_i; Φ is a transformation matrix; w_{i-1} is a noise.

The state matrix $X_i = [x_i,v_i,a_i]^T$ includes smoothed parameter x_i, value of velocity v_i, and acceleration a_i.

The extrapolated system state can be obtained as follows:

$$X^e_i= \Phi X_{i-1}, \quad (3.5)$$

$$\Phi = \begin{bmatrix} 1 & T & \frac{T^2}{2} \\ 0 & 1 & T \\ 0 & 0 & 1 \end{bmatrix},$$

where T is a discretization time; $X_{i-1}=[x_{i-1},v_{i-1}, a_{i-1}]^T$ is a state matrix at time t_{i-1}.

Also, we suppose that UAV coordinates estimation is linearly connected with system state by the following model [55]:

$$z_i=H_iX_i+\upsilon_i \quad (3.6)$$

where $H=[1,0,1]$ is a sensitivity matrix; υ_i is an error of measurement.

A state estimate observation update can be obtained as follows:

$$X_i= X^e_i +K_i[z_i -H X^e_i], \quad (3.7)$$

$$K_i = \begin{bmatrix} \alpha & \frac{\beta}{T} & \frac{2\gamma}{T^2} \end{bmatrix},$$

where K is a Kalman gain matrix.

Filter coefficients may be used from Gray-Murray model that includes tracking index Λ to estimate damping coefficient r. Tracking index can be estimated from statistical errors relation:

$$\Lambda = \frac{T^2\sigma_g}{\sigma_x}, \tag{3.8}$$

where σ_g *is* guidance error; σ_x *is* measurement error.

Other coefficients can be calculated as follows:

$$r = \frac{(4+\Lambda)-\sqrt{(8\Lambda+\Lambda^2)}}{4}, \tag{3.9}$$

$$\alpha=1-r^2;\ \beta = 2(2-\alpha) - \sqrt[4]{1-\alpha};\ \gamma = \frac{\beta^2}{2\alpha}. \tag{3.10}$$

3.4. Results of computer modeling

For numerical demonstration, we use quadrocopter “CTW A6” commercially available for imaging and filming production equipped with smartphone “Xiaomi redmi 4x” (MIUI 10.3, Android 7.1.2) as a PPD. In experiment PPD is used as an assembly of sensors with remote data processing in computation cluster. A structure scheme of experimental equipment is represented in Fig. 3.1.

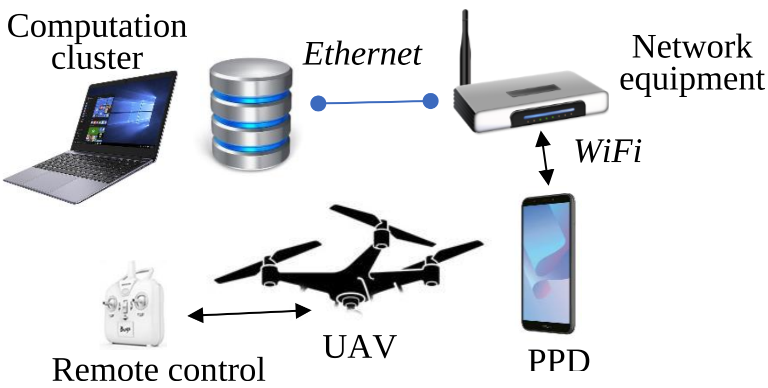


Figure 3.1 – The data exchange level

We organize computation cluster at laptop “Lenovo G580” (i3-2328M CPU 2.20 GHz, 4GB RAM) with support Matlab software. TCP/IP protocols are used for data transfer from PPD to computation cluster with the help of network equipment. WiFi line was used for PPD connection to the network and wire Ethernet line for connection with laptop.

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. 3.2).

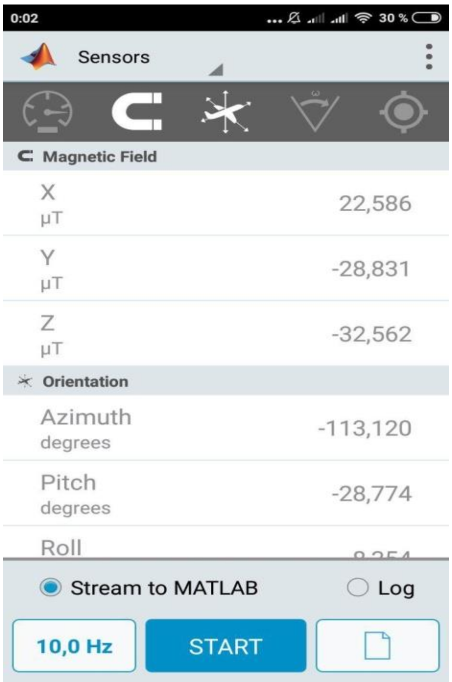


Figure 3.2 – Sensor data sharing screen in Matlab mobile

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 measurements of acceleration and rotation matrix during experimental fly of UAV are represented in Fig. 3.3. and Fig. 3.4.

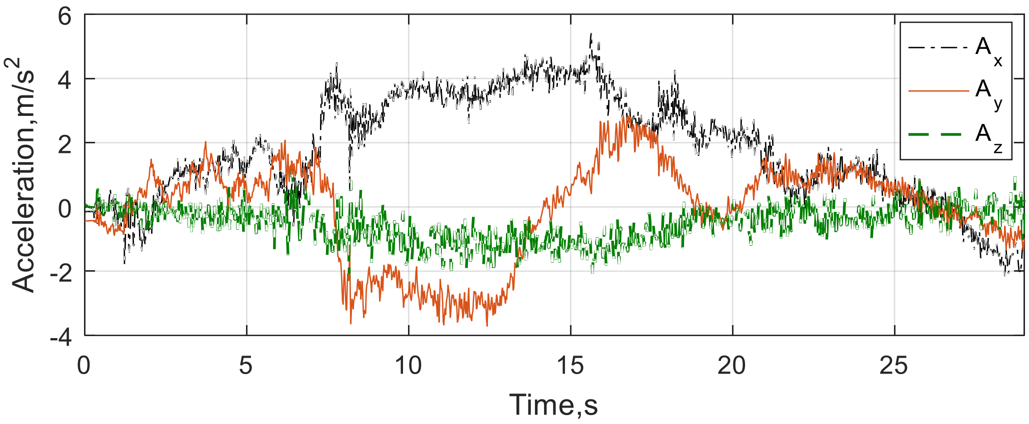


Figure 3.3 – Components of acceleration by axis

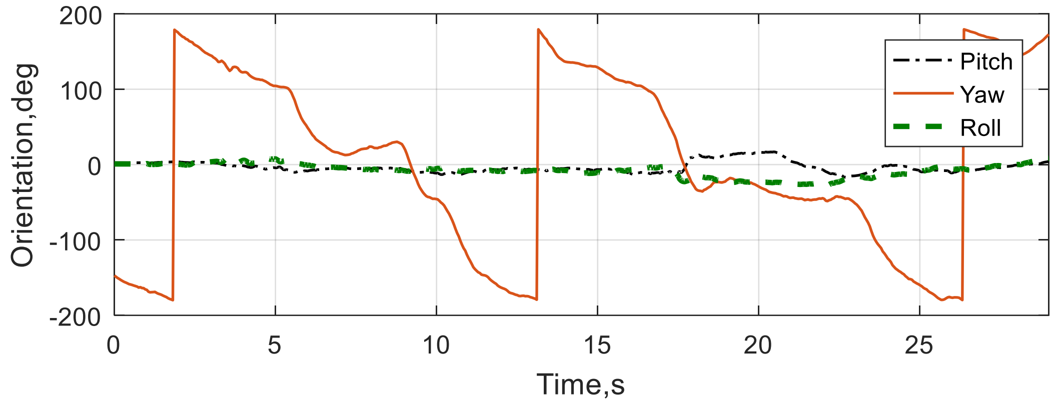


Figure 3.4 – Pith, roll, and yaw angles

Paths of UAV in ENU reference frame is calculated by (1) for measured accelerations and rotation angles are shown in Fig. 3.5.

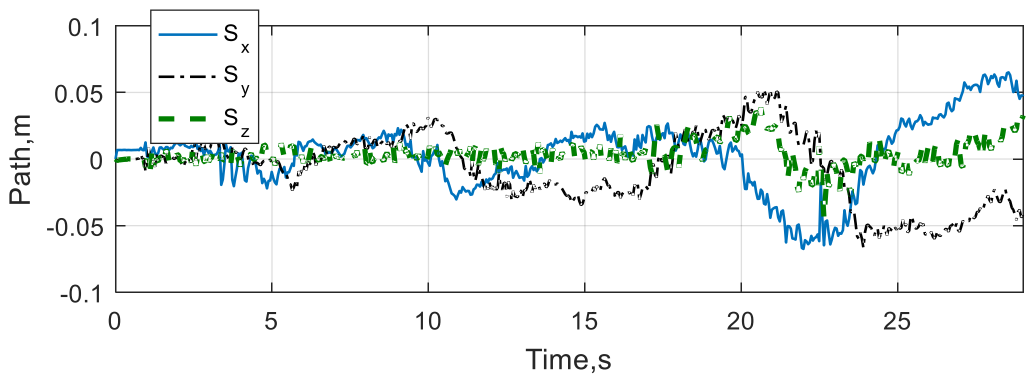


Figure 3.5 – Elements of the path

Trajectory data obtained by (2) is used for filtering in the α-β-γ filter by (7). Results of filtering trajectory data are represented in Fig. 3.6.

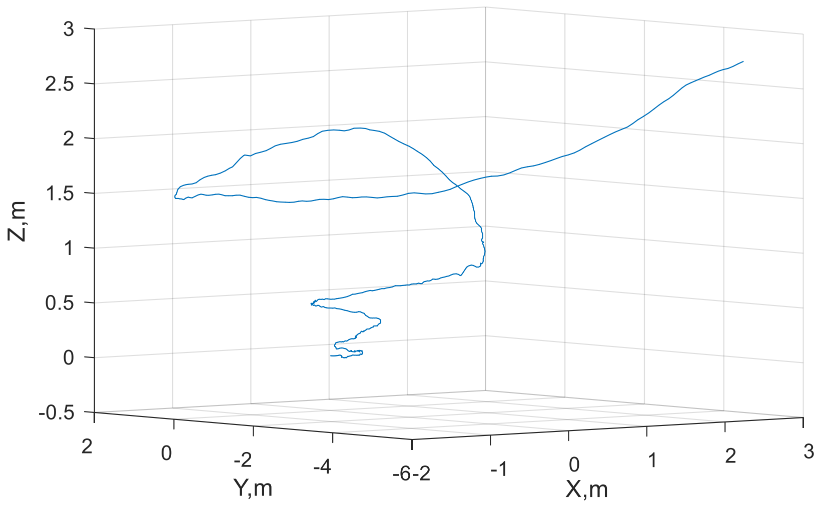


Figure 3.6 – Filtered UAV trajectory in ENU reference frame

Figures 3.7 - 3.11 present results of second experimental flight with sensors of PPD as air navigation system.

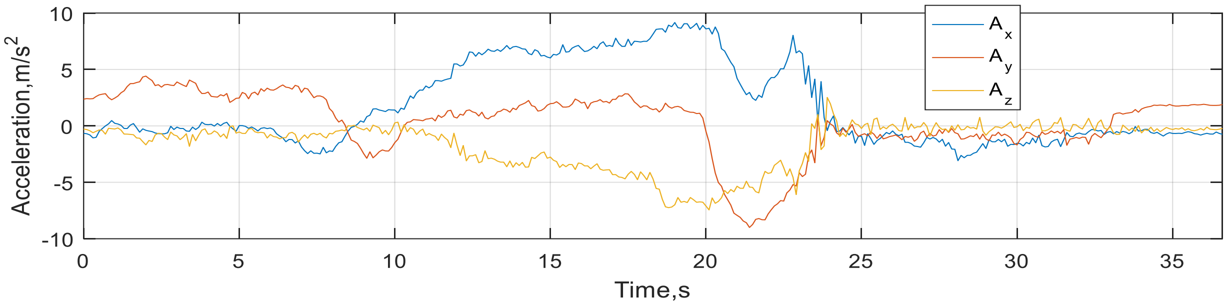


Figure 3.8 – Acceleration by axis

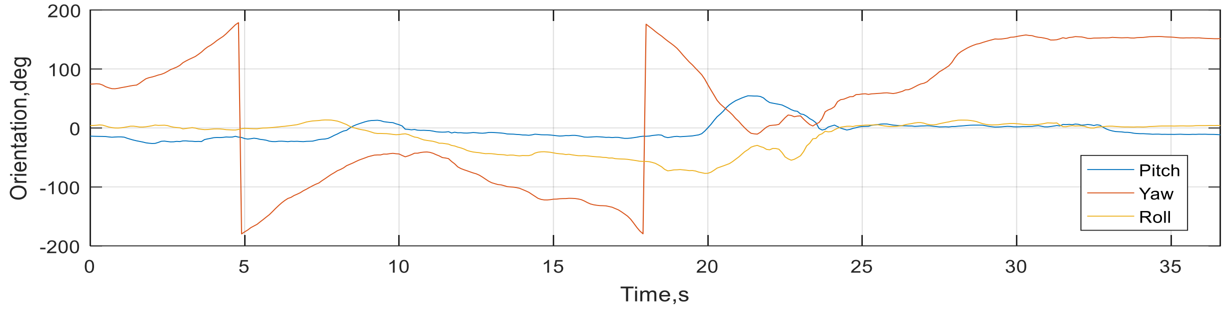


Figure 3.9 – Pith, roll, and yaw angles

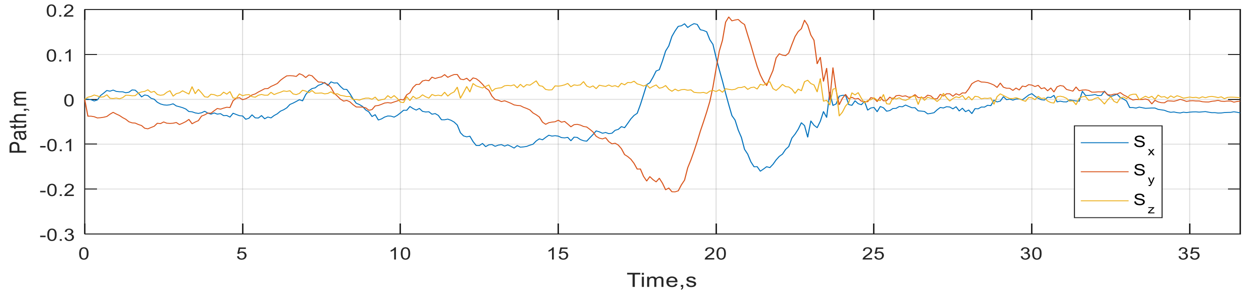


Figure 3.10 – Elements of the path at each iteration

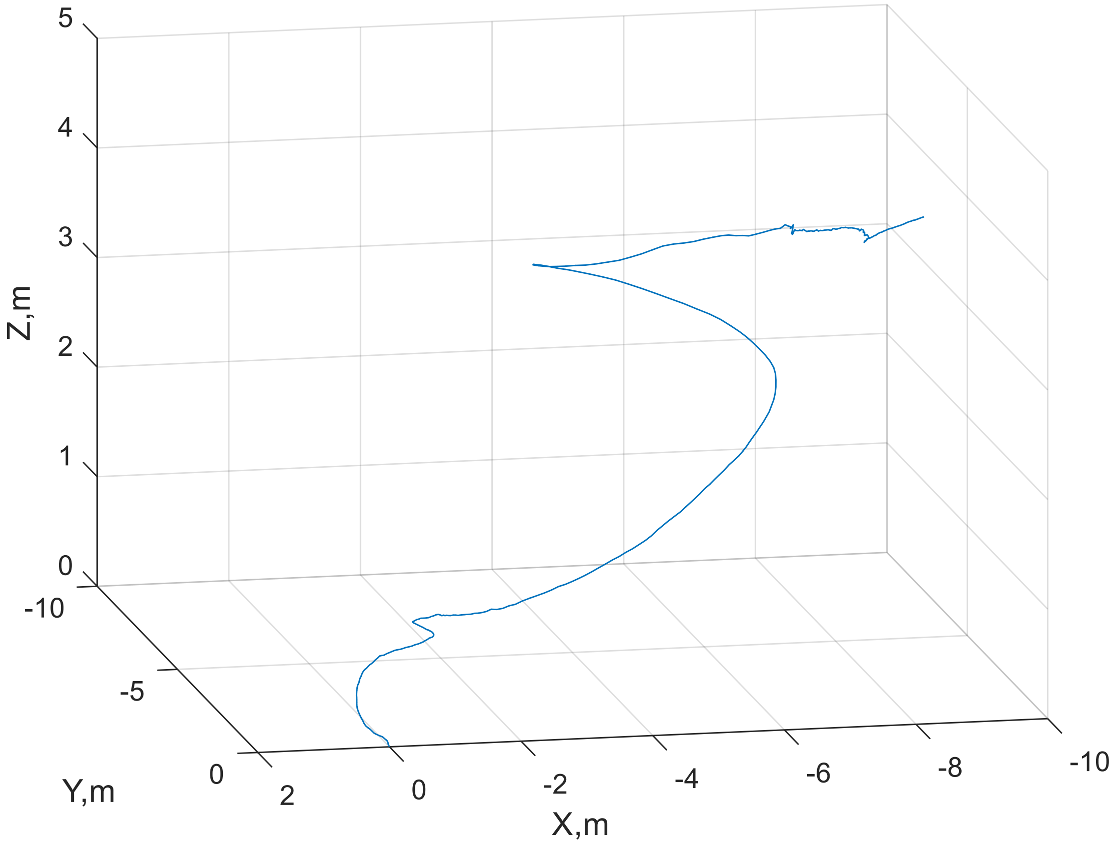


Figure 3.11 – The trajectory of moving an object

In our research, we analyze possibility to implement PPD in UAV application. In common way, PPD is equipped with various sensors. Moreover, at software level it is easy to get sensor data to provide positioning in airspace. Coordinates of UAV are estimated in ENU reference frame by inertial navigation relations. Unfortunately, errors of measurements degrade positioning accuracy progressively in time. Therefore, usage of inertial navigation is limited in time according to required performance level. Thus, considered approach may be implemented as a stand-by technique in case of GNSS lock. At upper level of trajectory data processing we use α-β-γ filter in the form of linear Kalman filter to reduce noise. Implementation of α-β-γ filter indicates optimal noise filtering for UAV with dynamic characteristics [4].

Conclusions to chapter 3

In this chapter were conducted researches using the personal pocket device and computer. There was a computer modelling that shows how the pocket device sensors influence on the positioning in airspace. The necessary calculations, using a vision of Kalman's filter, minimized errors obtained during experiment. The results were given in graphics.

In our future research we are going to consider navigation of UAVs groups with a set of various PPDs. One of the most important advantages of proposed approach is price reduction of navigation and UAV autopilot system by usage of common PPD and system flexibility in different scenarios. Also, proposed approach is a universal mean and can be implemented at various UAV classes.

CHAPTER 4. SPECIAL CHAPTER

4.1. Automated big data processing in air navigation

Automated data processing is a typical task, which is solved by modern air navigation systems. Processing of air navigation data is provided both on board airplanes in particular avionics units and in ground data processing equipment. Navigation parameters in modern systems are measured using a significant number of different sensors, which ensure creation of a data archive, the processing of which requires the use of specialized statistical data processing algorithms. Each sensor performs measurements with a certain amount of error, the effect of which cannot be excluded, but it can be reduced to an acceptable level. Therefore, the combined processing of data in the aeronautical system is performed by taking into account each sensor error. In this case, confidence bands are used, which guarantee getting a particular frame in the interval with a certain probability [42]. The most commonly used confidence band is the double root mean square deviation, which provides 95% localization of the measured values, based on the assumption of a normal distribution of errors.

The structure of each unit of avionics is more similar to the architecture of a personal computer with the corresponding elements: processor, memory, and analog-to-digital / digital-to-analog converters, which allows processing of measured data at the software level [43]. The sensor's data is converted to digital form by sampling analog values. Results of different value measurements are stored in appropriate registers, variables, matrices, or data archives.

Detection of an airplane's exact location is one of the most important tasks in civil aviation [44-45]. Continuously growing volumes of air transportation require a constant review of separation minimums to meet needs of modern air transport. Separation minimums between airplanes set up maximum permissible limits of airplane separation in space on vertical plane, lateral and longitudinal sides. One of the possible ways to solve the issue of airspace congestion is to increase the bandwidth of a particular part of the airspace by reducing the safe distances between airplanes. In practice, this is implemented by introducing more precise requirements for determining the location of airplanes in the air space. The introduction of more precise requirements for airplane positioning is possible only if there are appropriate systems capable of satisfying them. Operation of on-board positioning sensors of a civil airplane is provided by the field of aeronautical signals created in space by various systems.

As an example of big-data processing, we will use the trajectory of particular aircraft and perform its calculation using MATLAB software.

4.1.1. Input data

The safety of air transportation mostly depends on the accuracy of preplanned trajectory maintained by each airspace user. Flight technique and performance of on-board positioning sensor specify the level of airplane deviation from cleared trajectory. The receiver of Global Navigation Satellite System (GNSS) is the main positioning sensor on board a modern airplane of civil aviation. Performance of on-board positioning system specifies an area of airplane location with a certain level of probability. Airplane operation within a particular airspace volume is regulated by navigation specification which specifies requirements for the performance of on-board positioning system. To guarantee a safe flight through a particular airspace volume each user should perform navigation with the required levels of performance [62].

Measured position of an airplane is classified as critical data due to its role in the safety of the whole air transport system. According to Automatic Dependent Surveillance-Broadcast (ADS-B), the position is shared with other airspace users to guarantee surveillance and improve the safety of aviation. Today the majority of airplanes are equipped with transponders of mode 1090 ES (extended squitter). The airplane transponder transmits periodically digital message which includes a position report [46, 47, 69]. This data can be easily received and used on-board of other airplanes for improving situation awareness or can be received by ground receivers. An air navigation service provider uses a national network of ground ADS-B receivers to support surveillance and airspace user identification [48, 49].

Also, there are multiple commercial networks of ADS-B receivers, that process and collect all data transmitted via the 1090 MHz channel.

In particular, computation clusters of Flightradar24 and FlightAware companies provide simultaneous processing of data from more than 30,000 software-defined radios of ADS-B signals located all over the globe (Fig. 4.1).

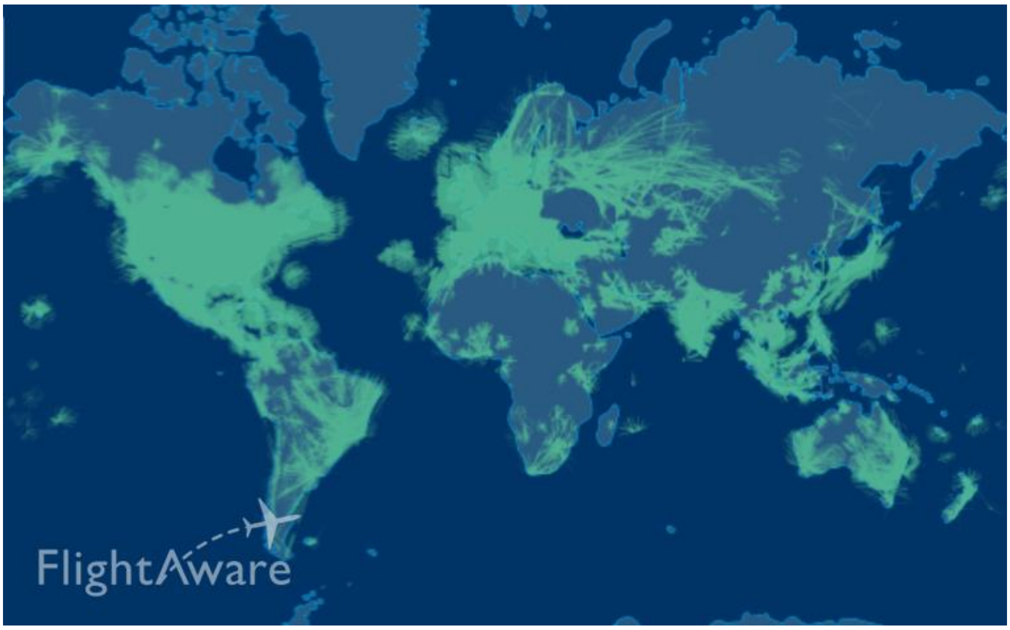


Figure 4.1 – Maps of global traffic [50]

Access to global databases of trajectory data is open and provided on a commercial basis. The application programming interface allows us to easily get any segment of trajectory data for analysis. As input, I use flight path data of AUA417/ OS417 (Austrian Airlines 417) operated by Austrian Airlines for connection between Vienna, Austria (VIE) and Paris, France (CDG).

Departure date is September 20, 2022 at 05:29PM (EST). Landing date is 20 September at 07:28 PM (BST). The flight ended on time. This flight was performed by Airbus A320 twin-jet (A320).

Input data obtained from the archive at

https://flightaware.com/live/flight/AUA417/history/20220920/1530Z/LOWW/LFPG. Table 4.1 shows the first and final 15 rows of flight raw data.

Table 4.1 – Trajectory data of AUA417 from 20 September 2022

Time (EEST)	Latitude	Longitude	Heading angle	Ground speed (kts)	Ground speed (mph)	Barometric altitude (feet)
Tue 11:41:27 AM	48.1278	16.5750	↑ 355°	155	178	1,85
Tue 11:41:43 AM	48.1407	16.5803	↗ 23°	177	204	2,375
Tue 11:41:59 AM	48.1527	16.5885	↗ 26°	191	220	2,9
Tue 11:42:15 AM	48.1652	16.5983	↗ 29°	217	250	3,225
Tue 11:42:42 AM	48.1908	16.6204	↗ 29°	218	251	4,775
Tue 11:42:58 AM	48.2046	16.6251	↑ 359°	216	249	5,55
Tue 11:43:14 AM	48.2192	16.6168	↖ 323°	223	257	6,175
Tue 11:43:30 AM	48.2334	16.5984	↖ 317°	223	257	6,575
Tue 11:43:51 AM	48.2460	16.5807	↖ 318°	224	258	7,1
Tue 11:44:09 AM	48.2620	16.5577	← 315°	224	258	7,575
Tue 11:44:26 AM	48.2737	16.5380	← 312°	229	264	7,975
Tue 11:44:56 AM	48.2967	16.4982	← 311°	264	304	8,725
Tue 11:45:14 AM	48.3115	16.4733	← 314°	268	308	8,825
Tue 11:45:44 AM	48.3393	16.4369	↖ 320°	271	312	8,85
Tue 11:46:14 AM	48.3678	16.4003	↖ 320°	268	308	8,85
…						
Tue 01:10:31 PM	49.0660	3.0344	↙ 238°	251	289	5,425
Tue 01:10:50 PM	49.0549	3.0073	↙ 243°	241	277	5,2
Tue 01:11:06 PM	49.0493	2.9816	← 259°	229	264	5
Tue 01:11:32 PM	49.0464	2.9417	← 266°	207	238	4,85
Tue 01:12:02 PM	49.0444	2.9012	← 266°	197	227	4,55
Tue 01:12:32 PM	49.0423	2.8592	← 266°	196	226	4,025
Tue 01:13:03 PM	49.0401	2.8165	← 266°	194	223	3,375
Tue 01:13:33 PM	49.0381	2.7783	← 266°	171	197	2,95
Tue 01:14:03 PM	49.0364	2.7448	← 266°	154	177	2,5
Tue 01:14:33 PM	49.0348	2.7136	← 265°	146	168	2,1
Tue 01:15:03 PM	49.0332	2.6833	← 265°	144	166	1,675
Tue 01:15:26 PM	49.0319	2.6596	← 265°	141	162	1,375
Tue 01:15:31 PM	49.0317	2.6559	← 265°	141	162	1,65
Tue 01:16:46 PM	49.0277	2.5806	← 265°	143	165	375

4.1.2. Visualization of trajectory data at specific software

Let`s import trajectory data of AUA417 from 20 September 2022 into specialized software of MATLAB [66]. Results of trajectory data visualization for flight is represented in Fig. 4.2. and vertical profile of flight is in Fig.4.3.

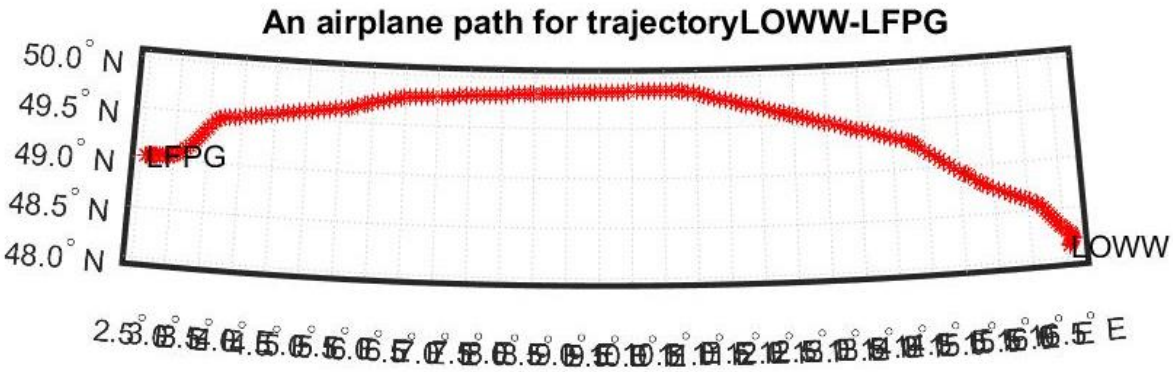


Figure 4.2 – Flight path of AUA417 (20 September 2022)

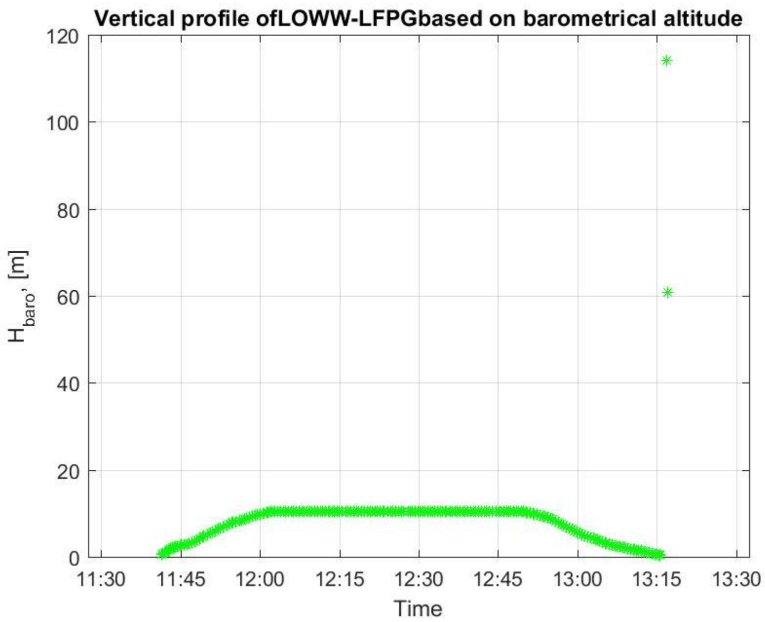


Figure 4.3 – Vertical profile AUA417 (20 September 2022)

4.1.3. Trajectory data interpolation

The digital messages transmitted within ADS-B are not synchronized in time. A transmitter of each airspace user can be set to its frequency of digital message generation. In addition, it should be noted that the frequency of 1090 MHz is quite busy, since secondary radars, airborne collision and avoidance systems [34, 38], and ADS-B use it. This leads to the fact that many digital messages may interfere with each other that destroy data transmitted inside of these messages. Therefore, ADS-B trajectory data includes many gaps in the sequence and broken messages. At the stage of data processing usually, methods of data interpolation are used to solve this problem. The interpolating function can be polynomials or spline functions. The results of interpolation of input data at a frequency of 1 Hz are shown in Fig. 4.4 - 4.6. All subsequent calculations will be performed with interpolated data. Let's display the data in the local NEU system. As the center of the system, we will use the coordinates of the first point of the trajectory. The results of visualization of the trajectory in the local system are shown in Fig. 4.7 and Fig. 4.8.

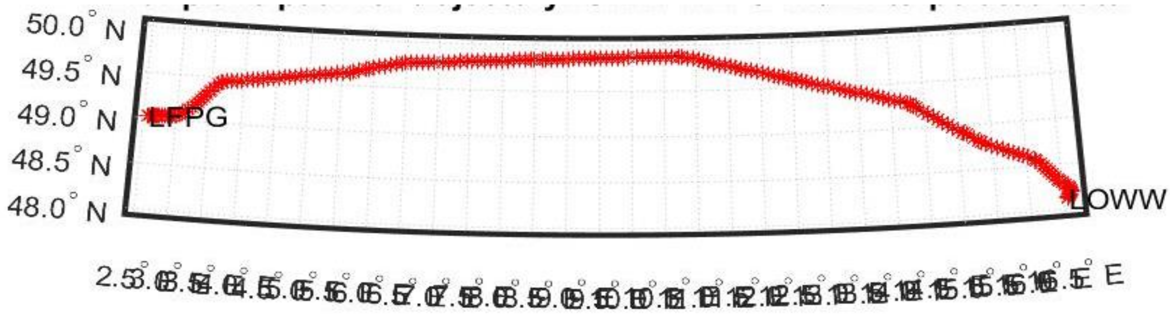


Figure 4.4 – Interpolated airplane trajectory of AUA417 (20 September 2022)

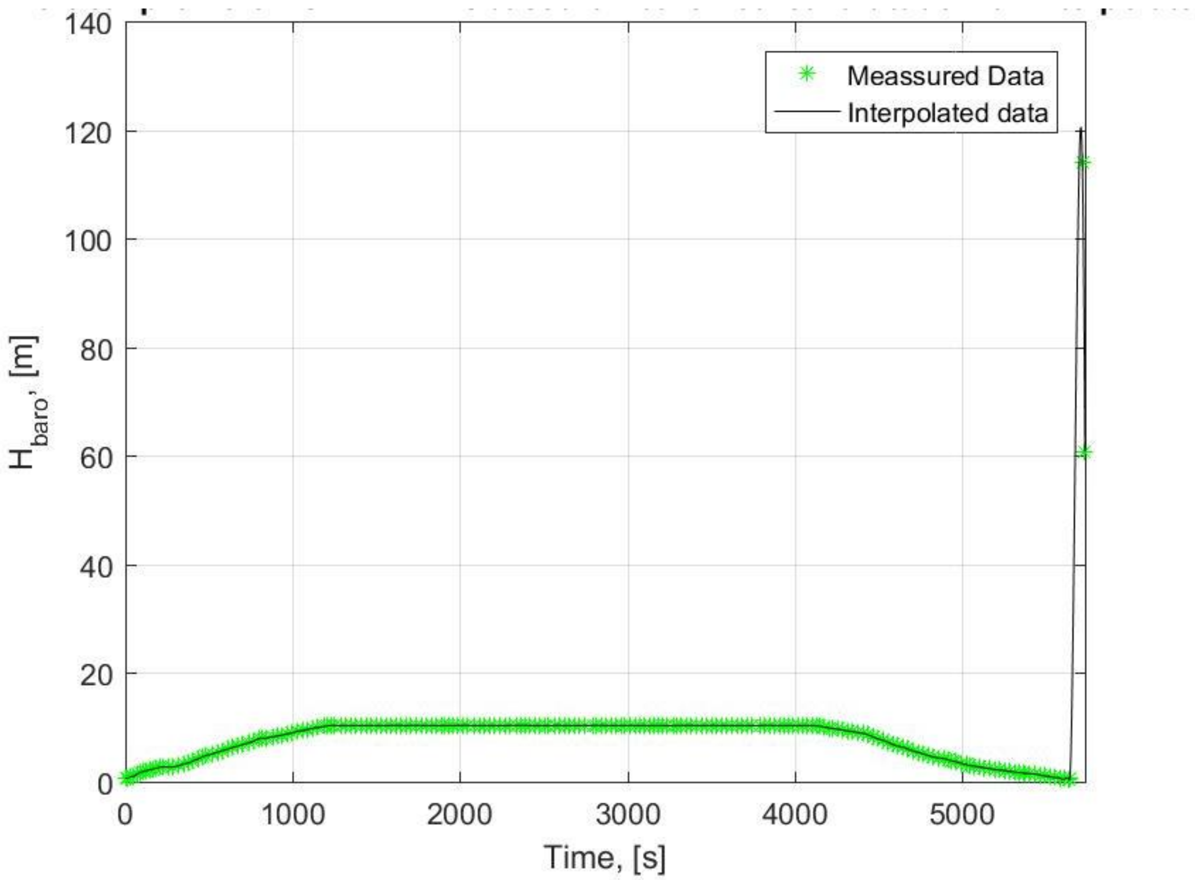


Figure 4.5 – Interpolated vertical profile of AUA417 (20 September 2022)

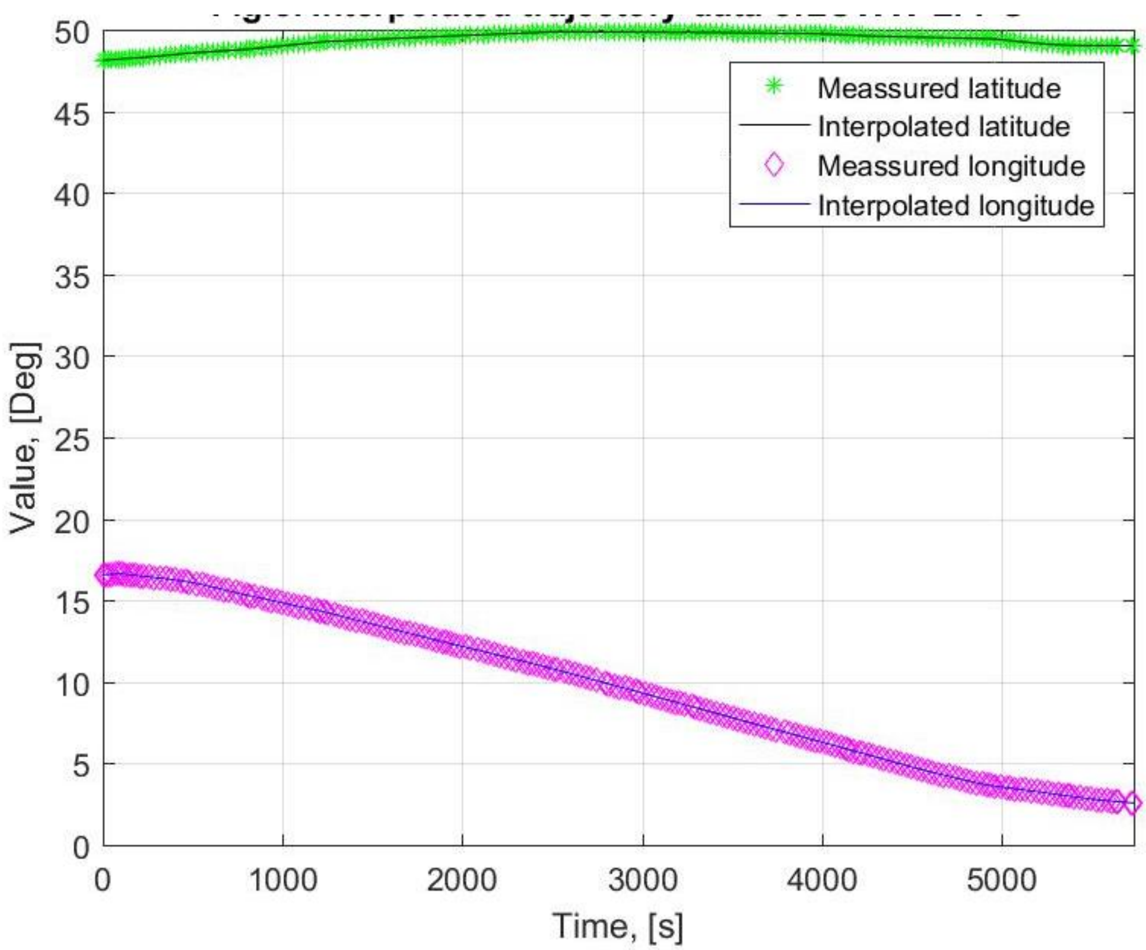


Figure 4.6 – Interpolated data for 1 Hz of AUA417 (20 September 2022)

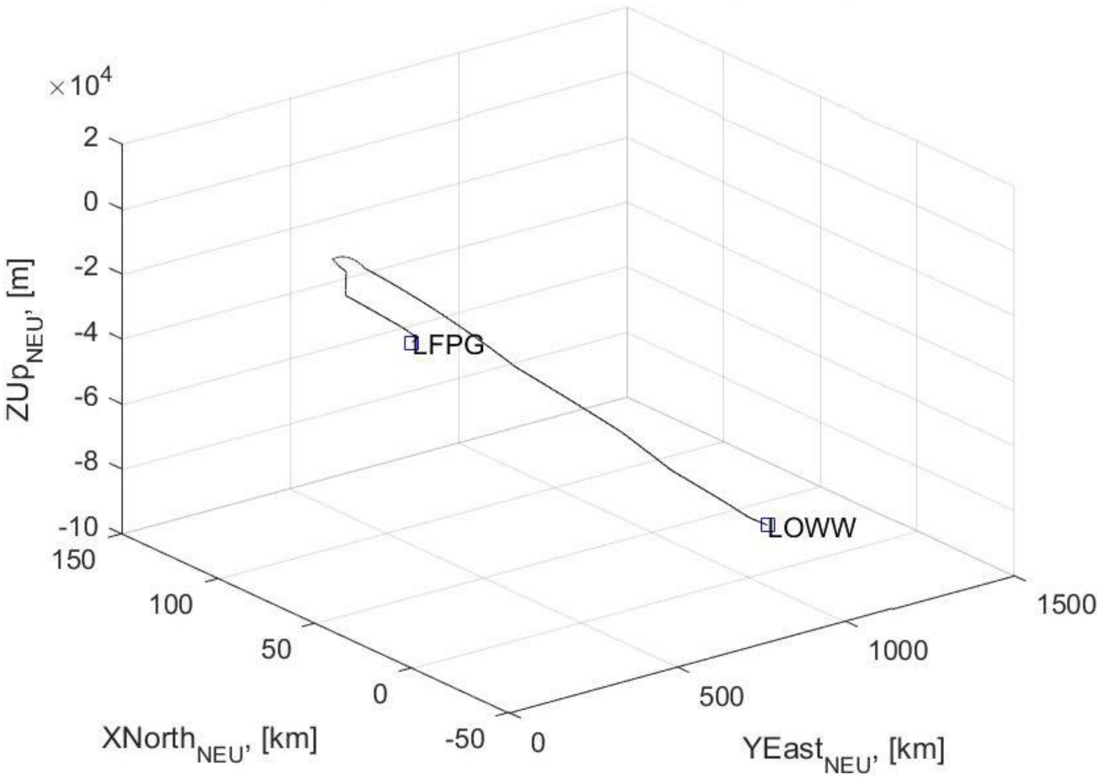


Figure 4.7 – 3D trajectory of AUA417 in NED reference frame

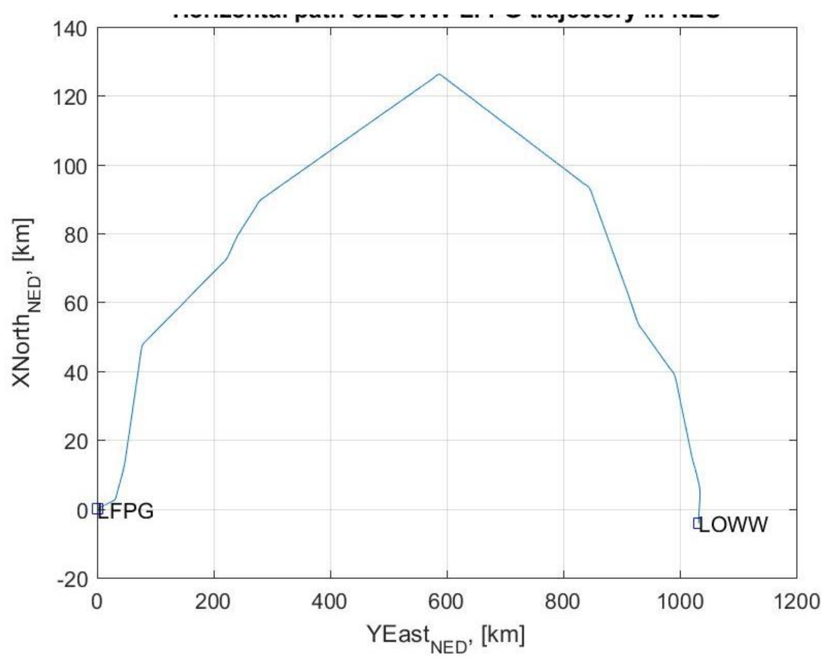


Figure 4.8 – Flight path of AUA417 in local NED

4.1.4. Trajectory data calculation

Based on the data set of the three-dimensional movement trajectory, we will calculate the speed components. In particular, I calculate the full speed of an airplane, vertical, and horizontal components. The results of the speed calculation are shown in Fig. 4.9, and the estimated course of the plane in Fig. 4.10. Also, I calculate the total flight time and the length of the route and trajectory.

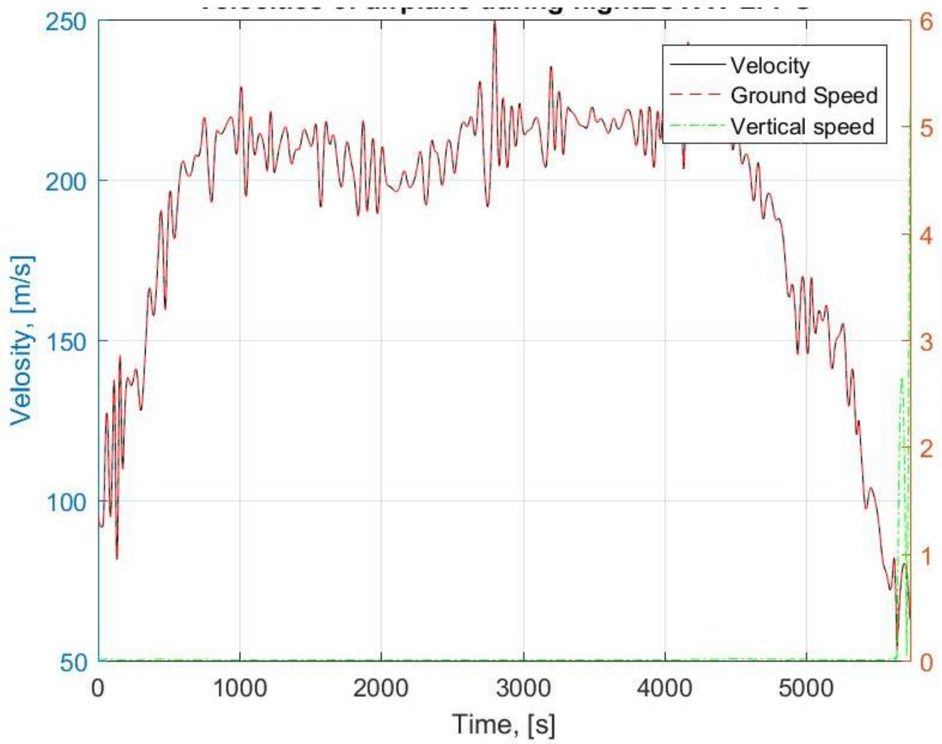


Figure 4.9 – Results of velocity estimation of AUA417 (20 September 2022)

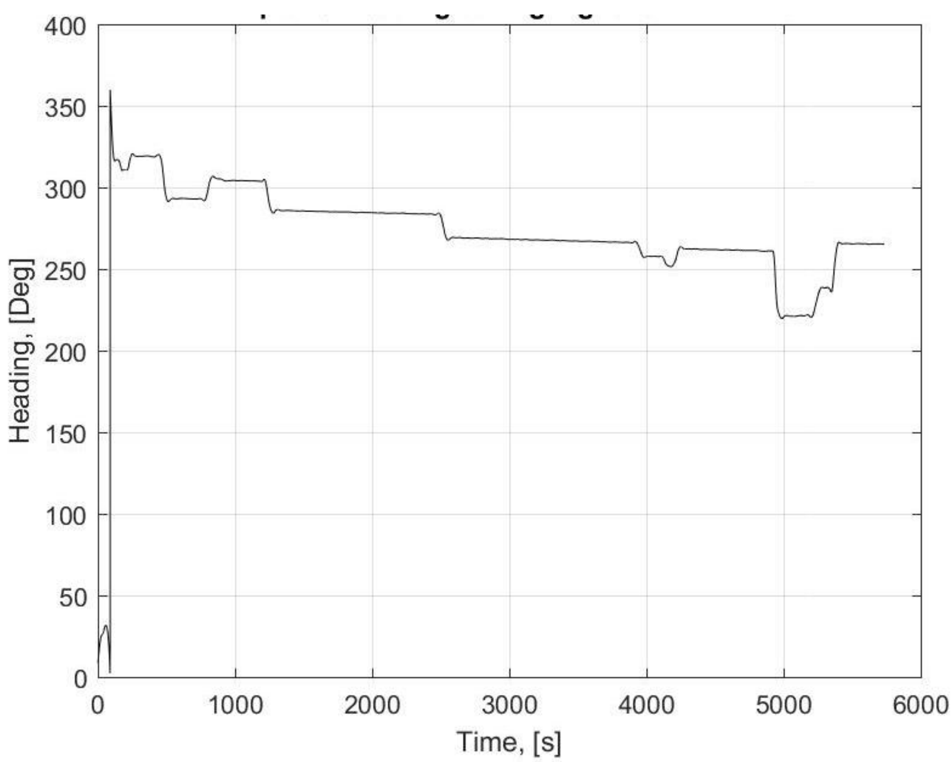


Figure 4.10 – Results of heading angle calculation of AUA417 (20 September 2022)

The total flight time of AUA417 on September 20, 2022, was 1 hour 35 minutes 35 seconds. The length of the trajectory is 1098.6 km, and the length of the flight path (horizontal component) is 1098.5 km.

4.2. Effectiveness of moving object positioning in air space by data from pocket device sensor

For the aviation industry, the year 2022 is characterized by the continuation of the trends of the end of last year 2021, which were formed under the influence of global economic and political processes (crisis, COVID, military situation in Ukraine, etc) [51, 56]. The current general state of the economic conjuncture, the negative dynamics of the main macroeconomic indicators, the instability of the economy, difficult meteorological conditions and the tense epidemiological situation at the end of the year - these factors had the greatest impact on the air transportation market, where there is a decrease in all the main production indicators compared to the previous 2021 year [5].

Statistical data of investment from 2016 to 2022 years are presented in Table 4.2.

Table 4.2 – Statistical data of investments in aviation field.

Years	**x**	**Statistical data (investments)**
2016	16	550
2017	17	600
2018	18	530
2019	19	580
2020	20	520
2021	21	510
2022	22	490

With the help of the method of correlation-regression analysis, an analysis of air transportation and forecasting of transportation for the following years was made.

4.2.1. Correlation-regression analysis.

The method of correlation-regression analysis is used to make decisions about forecasting phenomena and in the case of determining interdependencies between multidimensional measurements. When conducting multidimensional measurements, it is very important to determine the interdependencies between the measured characteristics.

The main characteristics of the correlation-regression analysis are the correlation coefficient r and the regression line. The correlation coefficient r lies within $-1 \le r \le 1$. If $r = 0$, then there is no connection between the characteristics of the object (phenomenon) being studied. If $r = 1$, then the connection is strong and direct. If $r = 0.7...0.8$, the connection is good. If $r = -1$, then this is an inverse strong relationship.

The regression line determines the type of dependence and connects the average value of the response function f (x) with the values of the factor x.

Stages of correlation-regression analysis:

1. Collection of statistical data (conducting an experiment).

2. Correlation analysis. Using the correlation coefficient r, we determine the closeness of the relationship (strong, weak, etc.) and the nature of the relationship (direct, reverse).

3. Regression analysis. Definition of the type of dependence. The results of the experiment (statistical data) are applied to the correlation field and the type of dependence is visually determined. For example, for a straight line, we write down the analytical type of dependence y = b0 + b1x, where b0, b1 are regression coefficients.

4. Determination of values of regression coefficients.

5. Determining the significance of the obtained values of correlation and regression coefficients using Student's and Fisher's tests.

6. Construction of the regression line.

7. Forecasting (extrapolation and interpolation).

Calculation of regression coefficients according to the formulas 4.1 and 4.2:

$$b_0 = (\sum y \sum x^2 - \sum xy \sum x)/(n\sum x^2 - (\sum x)^2);$$

$$b_1 = (n\sum xy - \sum x \sum y)/(n\sum x^2 - (\sum x)^2), \qquad (4.1)$$

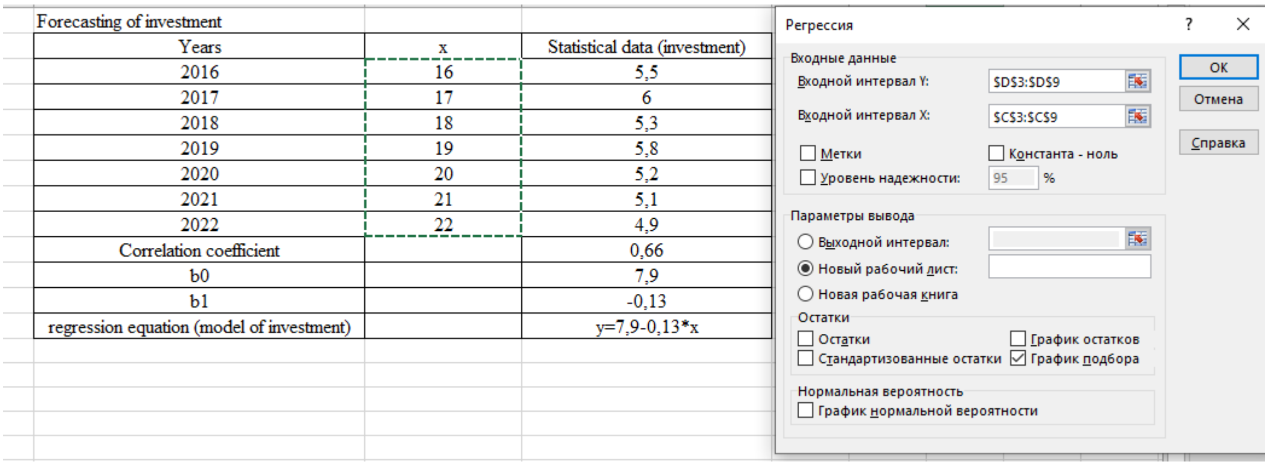
where n is the number of data.

Calculation of the correlation coefficient according to the formula:

$$r = \frac{\sum xy - (1/n)(\sum x)(\sum y)}{\sqrt{\left[\sum x^2 - (1/n)(\sum x)^2\right]\left[\sum y^2 - (1/n)(\sum y)^2\right]}}. \qquad (4.2)$$

$$-1 \le r \le 1$$

The value of the correlation coefficient shows how the variables x and y are related (inverse (as the value of r is negative) weak (as the value of r is closer to 0 than to -1) relationship). That is, over time, the number of transported passengers’ decreases. A statistical analysis of investments was made and, with the help of correlation-regression analysis, a forecast of transportation until 2026 was made (Fig. 4.11) using MS Excel.

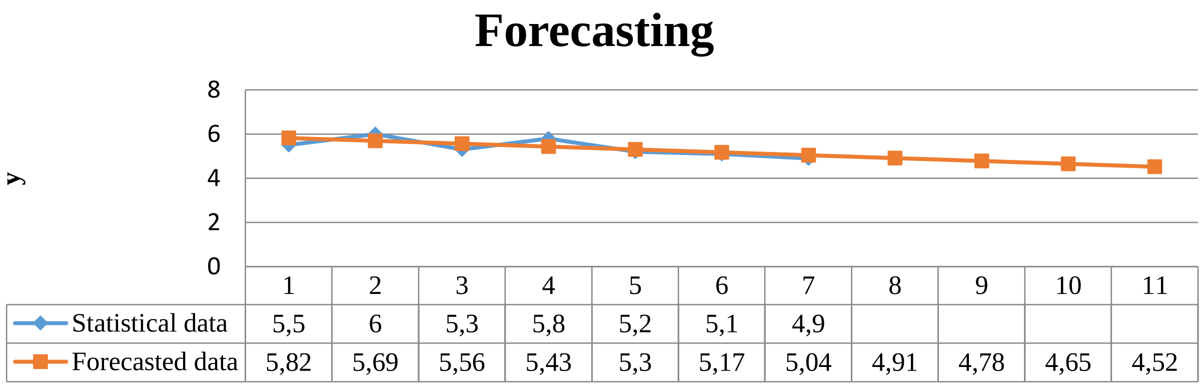


Forecasting of investment		
Years	x	Statistical data (investment)
2016	16	5,5
2017	17	6
2018	18	5,3
2019	19	5,8
2020	20	5,2
2021	21	5,1
2022	22	4,9
Correlation coefficient		0,66
b0		7,9
b1		-0,13
regression equation (model of investment)		y=7,9-0,13*x

Figure 4.11 – Calculation of correlation and regression coefficients.

A forecast was made for passenger transportation (Fig. 4.12). We received a transportation model for demand forecasting (4.3):

$$y=b0+b1x=7,9\text{-}0,13x, \qquad (4.3)$$



	1	2	3	4	5	6	7	8	9	10	11
Statistical data	5,5	6	5,3	5,8	5,2	5,1	4,9				
Forecasted data	5,82	5,69	5,56	5,43	5,3	5,17	5,04	4,91	4,78	4,65	4,52

Figure 4.12 – Investment forecasting

Thus, according to statistical data, 550 millions of investments in aviation field were carried out in 2016 year, and 452 millions of investments are expected in 2026.

4.2.2. Economic efficiency.

Efficiency is the expected and actual result. A synergistic result due to the system integration of the following types of efficiency:

– Economical
– Technical
– Informational
– Mathematical modeling and decision-making

- Psychological
- Technological
- Social
- Cultural
- Ecological
- Ergonomic
- Mathematical modeling and decision-making

Calculation of the economic efficiency of the project.

The computer program must be cost-effective, while at the same time satisfying the diverse interests of the ATM community. The cost of services to airspace users should always be considered when evaluating any proposal to improve the quality or performance of ATM services. ICAO policies and principles must be followed by user fees.

Efficiency.

Efficiency is considered as the operational and economic efficiency of operations during flights from the starting point of the flight to the final point of the flight. At all stages of the flight, airspace users want to be able to choose the time of departure and arrival, as well as the optimal route [68]. Shown in Fig. 4.13 and Fig. 4.14.

Algorithm for calculating project profitability:

1. Costs for the main option (4.4):

a. $З_{прб} = С_б + Е_н \cdot К_б,$ (4.4)

2. Costs for an alternative (new) option (4.5):

a. $З_{пра} = С_а + Е_н \cdot К_а,$ (4.5)

Сб - basic costs;

Кб – investment;

Ен - investment efficiency ratio standard, Ен = 0,15.

1. Payback period of additional capital investments (4.6):

$$Т_{ок} = \frac{К_а - К_б}{С_б - С_а} \quad (4.6)$$

2. Annual economic effect from the introduction of the new system (4.7):

$$Е_г = З_{прб} - З_{пра} = (С_б + Е_н \cdot К_б) - (С_а + Е_н \cdot К_а) \quad (4.7)$$

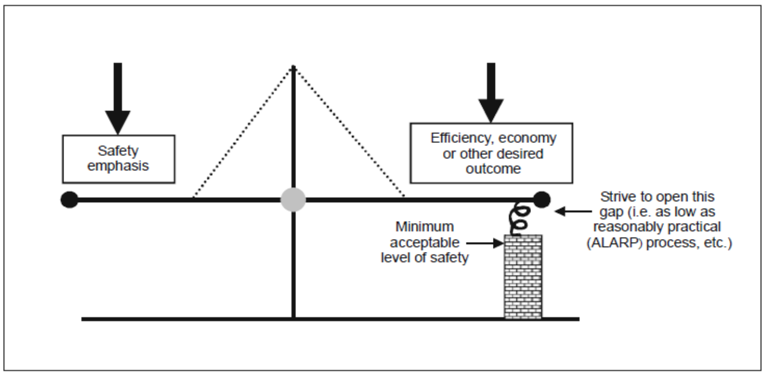


Figure 4.13 – Safety balance model

2					
3				Basic	New (alternative)
4	Number AWP			10	7
5	Cost PC			25000	20000
6	Зпт			20000	30000
7					
8					
9					
10					
11				Basic	New (alternative)
12	Basic costs		C	250000	140000
13	Капіталовкладення		К	200000	210000
14	Costs		Зпр	280000	171500
15	Payback period			0,09216589862	
16	Annual effect			108500	
17					

Figure 4.14 – Efficiency calculation

The efficiency calculation shows us how does our program can reveal in aviation industry and how can it pay off.

Conclusions to chapter 4

In this chapter I investigated the trajectory of aircraft AUA417, used the flightaware.com website. I simulated the flight data and plotted 9 graphs of time of ADS-B data, velocity of airplane and range at each iteration using Matlab application.

Tis Matlab modelling gives us an opportunity to see how the trajectory may vary from different flight parameters like time, latitude, longitude, heading angle, ground speed and barometric altitude. The change of these parameters may give us a figure results with another flight path and we can see how it influences in each stage of flight.

Also, in this chapter were commenced a statistical analysis, correlation-regression analysis, forecasting the efficiency of investment and economic efficiency using MS Excel. The results of research were obtained by graphs and tables. I used the statistical data from Eurocontrol Seven-Year Forecast February 2015 from 2016 till 2022 years and made a calculations of forecasted data and received a transportation model for demand forecasting. The results were similar to the original forecasted data.

CHAPTER 5. ENVIRONMENT SAFETY

According to the “Law of environment protection” the environmental safety is the state of the natural environment, that ensure to prevent the deterioration of the environmental.

The activities of natural and legal persons, which causes damage to the natural environment, may be suspended by a decision of the court. Article 54 in redaction to “Law of Ukraine” from (14.12.2011 N 1288-XIV) Protection of the natural environment from acoustic, electromagnetic, ionizing and other harmful effects of physical factors and radiation pollution. Local councils, enterprises, institutions, organizations and citizens in the implementation of their activity are obliged to take the necessary measures to prevent and eliminate excess of the established levels of acoustic, electromagnetic, ionizing and other harmful physical impacts on the environment and human health in the settlements, recreational and protected areas, and also in places of a mass congestion of and breeding of wild animals.

Enterprises, establishments and organizations carrying out economic or other activity involving the use of radioactive substances in various forms and with whom-what purpose, are obliged to provide environmental safety of this activity, which would exclude the possibility of radioactive contamination of environment and negative impact on the health of the people in the process of the production, enrichment, transportation, processing, use and disposal of radioactive substances.

5.1. Analysis of the safety environment

The Ukrainian “Law of the environment protection” provided means for prevention and elimination of harmful physical impacts, including electromagnetic field. One of the most important harmful factors which influence to the environment is electromagnetic radiation (electric field, magnetic field, electro-static field).

During millions of years the earth's magnetic field, have been the periodic ecological factor is constantly affected on the state of ecosystems.

During the evolutionary development of the structural-functional organization of ecosystems adapted to the natural background.

Harmful influence on the human organism is invisible but very harmful electromagnetic pollution of the environment to much more fast than the progress in electronics.

The proposed Flight Data Vision System is intended to significantly improve the safety of the flight, it is more effective in comparison with the existing systems, because it uses information from many onboard systems and integrate it in one display. From year to year is growing pollution of the environment of physical hazards, which include electromagnetic and ionizing and thermal radiation, transport and industrial noise, and also acoustic pollution of the environment. Today the permanent monitoring of the parameters of physical factors in many cities and towns practically is not carried out. Dangerous factor such as electromagnetic radiation is very dangerous effect on human health. Its sources are television and radio stations, power lines, production facilities and numerous appliances, surrounded by livelihoods of people.

Flight Data Vision System consists from display monitors which such as computers displays radiate the electromagnetic radiation. And also pollute the environment and surrounding living organisms. But this information not confirmed.

Investigation system is integrated and give information from different sources from ground and in fly. Such as proposed system located onboard, was considered the systems in airports also. Any technological process influence on the environment and sometimes contaminate it. In any case suffer the man himself. Thus need to prevent the harmful effects of human activities on the environment or minimize it.

5.2 Protection and prevention from electromagnetic radiation

According to the Law of Ukraine “Protection of atmospheric air” in the area of protection of atmospheric air are established standards of maximum permissible impact of physical factors of the stationary and mobile sources. Standards of maximum permissible levels of impact on atmospheric air are established for each stationary source and for each type of mobile sources, taking into account modern technical solutions to reduce levels of influence in physical factors.

The implementation of organizational and technical activities are vested primarily in the bodies of sanitary supervision. Enterprises and institutions that use sources of EMF, should conduct current sanitary surveillance, carry out the organizational work from preparation of specialists and engineering-technical supervision. In the design stage must be ensured the mutual arrangement radiated and irradiated objects, which would minimize the intensity of radiation. The need to reduce the probability of penetration of people in areas with high intensity EMF, reduce the spent time in radiation. Power of radiation sources should be the minimum necessary.

Important engineering-technical methods of protection: collective, local and individual. Collective defense is based on the calculation of the propagation of radio waves in the conditions of a specific terrain. Economically more rational use of the natural screens - terrain, forests, non-residential buildings.

By installing the antenna above, can reduce the intensity of the field, which radiate the settlement in many times.

With protection from radiation of the screen should be taken into account attenuation of the waves passing through a screen (for example, through a forested strip). For screening can use the vegetation. Special screens in the form of reflective shields is expensive and are used very seldom. Local protection is very effective and used frequently. It is based on the use of radiation protection materials, which provide high absorption of radiation energy in the material and reflected from its surface.

For screening by the reflection, using metal sheets and a grids with conductivity. Protection of premises against external radiation can be done by pasting of walls metallized paper, protection of window by grids, metal blinds. Irradiation in such room is reduced to a minimum, but reflected from the screens of radiation interspreading in the space and attaches to other objects.

Engineering-technical means of protection include:

– constructive opportunity to work with the lower power is in the process of debugging and prevention;
– work in equivalent loads;
– remote control.

For personnel in aviation who serving radio means and located in a short distance, need to ensure reliable protection by screening equipment. Widespread the screens of materials that absorb infrared radiation. There are a large number of radio-absorbed materials of homogeneous composition, and composite, which consist of heterogeneous dielectric and magnetic substances.

With the purpose the increase of efficiency of the absorber screen surface is rough, ribbed or in the form of spikes. Radio-absorbed materials can be used for protection of the environment from the EMF generated by the source, which is located in screened object.

5.3. Means of individual protection

Individual protection means are used in cases, when other means are not effective: when passing through the zone of increased radiation intensity, repair and commissioning operations in emergency situations, during a short-term control and for changing the intensity of the radiation. Individual protection means is used when the work safety cannot be ensured by design and placement of equipment, organization of production processes, architectural-planning decisions and means of collective protection.

According to the Law of Ukraine “About protection of labor” in works with harmful and dangerous working conditions employees issued the charge clothing, footwear and other means of individual protection. For protection of the body is used clothing from metallized fabrics and radio-absorbed materials.

So electric closure seams by conductive solutions or adhesives, which provide galvanic connection or increases the capacitance of the connection wires, which are not in direct contact. Eyes protect the special glasses from glass, applied to the inside of the leading film the dioxide tin. Rubber rim glasses has pressed metal mesh or papered by metallic cloth. These glasses UHF radiation is attenuated by 20-30dB. Previously used gloves and boot covers, now consider useless, because the permissible value of the density of energy flow for hands and feet to many times higher than for the body.

Conclusions to chapter 5

In this chapter I realized the analysis of the environmental hazard of projected object, also has been considered the effect of electromagnetic radiation (VHF, UHF, SHF) on the environment and on the personnel and also considered a number of measures of individual protection. For reduce the impact of EMF on the personnel and population, which is located in the zone of radio-electronic means, should take the protective measures.

These include organizational, engineering-technical and medical-preventive. Individual protection means are used in cases, when other means are not effective. Individual protection means is used when the work safety cannot be ensured by design and placement of equipment, organization of production processes, architectural-planning decisions and means of collective protection.

CHAPTER 6. LABOR PRECAUTION

The important point in the complex of measures, aimed in improvement of the conditions of labor are the measures from labor precaution. This questions every year has been growing attention, because care about the health of the person has become not only a matter of state importance, but also the element of competition employers in the question of recruitment of the personnel. For the successful realization of all activities of labor precaution, need the knowledge in the field of physiology of labor, which allow to organize the process of labor activity of the person.

In this chapter we consider the main questions of safety and ecology of labor. Such as example of the optimal workplace engineer- programmer provides the analysis of the characteristics of the premises and the calculation of natural lighting on the example of information technologies department. In this chapter we considered the labor protection at the working place of the engineer-programmer on ACFT in the laboratory of operation the aviation radio-electronic equipment.

6.1. List of dangerous and harmful factors which arising during the operation of the computer.

Dangerous factor is called the factor of production, the impact of which on working in certain conditions leads to injury or other deterioration of health. If the factor of production leads to the disease or lower efficiency, then it’s considered harmful (ГОСТ 12.0.002-80).

Scientific and technical progress has made major changes in the conditions of production activity of non-manual workers. Their work has become more intense, requiring significant costs of mental, emotional and physical energy. At the present time the computer equipment is widely used in all fields of human activity. When working with a computer, person is exposed with many dangerous and harmful production factors: electromagnetic fields (the range of frequencies: VHF, UHF and HF), infrared and ionizing radiation, noise and vibration, static electricity, etc.

Work with computer is characterized by a significant mental stress and nervous-emotional activity operators, high tension visual work and large enough load on the muscles of the hand when working with the keyboard of the computer.

In the process of work with the computer it is necessary to observe the correct mode of work and rest. The classification of hazardous and harmful production factors is given in ГОСТ 12.0.005-80. They are: chemical, biological, psychophysical and physical factors.

The state of working conditions of employees and its security, today has not satisfy the modern requirements. Employees are facing to the impact of such physically dangerous and harmful production factors as:

– The parameters of the microclimate;
– The color and reflection coefficients;
– Noise and vibration;
– Electromagnetic and ionizing radiation;
– Lighting of the working area;
– Electric current;
– Static electricity.

After research the hazardous and harmful production factors were considered: The color and reflection coefficients. The color of the premises and furniture should promote the creation of favorable conditions for the visual perception and good mood. Light sources, such as lamps and windows, which provide the reflection from the surface of the screen, significantly affect the accuracy of the perception of the characters on the screen of the monitor or keyboard and entail the obstacles physiological character, which may result in significant tension, especially at long work. Reflection, including reflection from the secondary sources of light must be kept to a minimum. For protection against excessive brightness of the window can be applied blinds and screens. In the premises, where the computer resides, can be the following values of the reflection coefficient for the ceiling: 60.70%, for walls: 40.50%, for the floor: about 30%. For other surfaces and workers of furniture: 30.40%.

The parameters of the microclimate. The parameters of the microclimate can be with wide limits, then as a necessary condition of human life is to maintain a constant temperature of the body, owing to the thermoregulation, the ability of the body to regulate the impact of heat into the environment. The principle of regulation of the microclimate - creation of optimal conditions for the heat transfer of the human body. Computer engineering is a significant source of heat, which may lead to an increase in temperature and decrease of the relative humidity in the room. In the premises, there are computers, it should meet certain parameters of the microclimate. In the sanitary norms established by the values of the parameters of the microclimate, which create comfortable conditions. These standards are set depending of the year time, nature of labor process and the nature of the industrial premises (Table 6.1).

The volume of the premises in which the posted workers computing centers must not be less than 19,5 /man, taking into account the maximum number of simultaneously working in the shift. Rules of submission of fresh air in the premises, where the computers installed, are given in the Table 6.2.

Table 6.1 – Parameters of the microclimate in the premises where the computers installed

Year	**Parameters of microclimate**	**Values**
Cold	Air temperature in premise Relative humidity Air speed	21.23°C 39.59% to 0,2m/s
Warm	Air temperature in premise Relative humidity Air speed	24.26°C 39.59% 0,2.0,3m/s

Table 6.2 – Rules of fresh air submission in the premises, where the computers installed

Characteristics of premises	**Volume using of air fresh in premise m^3 /for one person in hour**
Volume to 20m^3 for person 20.40m^3 for person More than 40m^3 for person	No less 31 No less 21 Nature ventilation

For ensure comfortable conditions are used organizational methods (rational organization of work depending of the year time and day, the alternation of work and rest) and technical equipment (ventilation, air-conditioning, heating system).

Noise and vibration. Noise degrades the working conditions of carrying out of the harmful effect on the human body. Working in conditions of prolonged exposure noise experience irritability, headaches, dizziness, memory loss, fatigue, loss of appetite, pain in the ears, etc. Such violations in the work of organs and systems of human organism can cause negative changes in the emotional state of the person and go to stressful situations. Under the influence of noise, reduced the concentration of attention, also violated physiological functions, appears fatigue due to higher energy costs and nerve-strain, worsens the language switching. All this reduces the efficiency of human and its performance, quality and safety. Prolonged exposure to intense noise (more 80 dB) for human ears can lead to partial or complete loss. In Table 6.3 defined the maximum levels of sound depending of the category of severity and intensity of work that are safe according health and efficiency.

The level of noise in the workplace of mathematician programmers and video operators should not exceed 50dB, and in the halls of the processing of information on computers - 65dB.

To reduce the level of noise walls and ceiling of the premises where are computers, can be lined with absorbent material. The vibration level in the premises of the computing centers can be reduced by the installation of the equipment for special vibration isolators.

Table 6.3 – Maximum sound levels dB, at the workplaces

Category Intensity of work	**Category Intensity of work**			
	I. Light	**II. Medium**	**III. Heavy**	**IV. More heavy**
I. Less intensive	70	70	65	65
II. Slow intensive	60	60	55	55
III. Intensive	50	50	-	-
IV. More intensive	40	40	-	-

Electromagnetic and ionizing radiation. The majority of scientists believe that as a short-term and long operation of all types of radiation from the screen of the monitor is not dangerous to the health of service personnel or computers. However, comprehensive data about the dangers of radiation exposure from the monitors at working with computers, there is no research in this area is continued.

On the cathode-ray tube there is a potential of about 20 000 volts (100 times higher voltage in the network). This potential is created between display screen and the face of the operator, and scattered the dust that settled on the screen, to the huge velocities. And these dust particles, like bullets cut into the skin of the one who sits in front of the screen. The following methods for combating this phenomenon: reducing the amount of dust in the room. In particular, in computer classes it is extremely desirable to use chalk, because the chalk is gradually moving from the board on the faces of the children by means of dispersal of the static fields. Note - good computer class is equipped with a marker board, air conditioning, and sometimes "Chandelier Chizhevskogo". These devices reduce the amount of dust in the room, as "Chizhevskiy's Chandelier" also suppresses the static fields.

6.2. Development of technical means for reducing the negative impact on the technical staff

The lighting. Properly designed and executed industrial lighting improves visual work, reduces fatigue, productivity, a beneficial effect on the working environment, providing a positive psychological impact on working, improves safety and reduces injuries.

The lack of lighting leads to the voltage of view, weakens attention, leads to occurrence of premature fatigue. To bright light causes blindness, irritation and pain in the eyes, wrong direction of the light at the workplace can create harsh shadows, reflections, disorient the working people. All of these factors may result in an accident or occupational illness, so it is important the correct calculation of illumination.

There are three types of lighting – natural, artificial and mixed (natural and artificial together). According to ГОСТ-4-79 in apartments need to apply a system of mixed lighting. For performance of works the category of high visual accuracy (the smallest size of the object distinction 0,3 - 0,5mm) the value of the coefficient of natural light (KEO) must not more 1.5%, and when the visual work of average accuracy (minimum object size discernment of 0.5 - 1.0 mm) KEO shall be not less than 1.0%. As a source of artificial light are usually used fluorescent lamps type b, or DRL, which pairs are combined in the lamps, which must be placed evenly on the working surfaces. Requirements for lighting in the premises in which computers installed, the following: the visual work of the high accuracy of the overall lighting should be 300lk, and combined – 750lk.

The relative area of the sky lights α – the ratio of the windows area to the area of the apartment floor, (expressed in percentage):

$$\alpha = \frac{Swindows}{Sfloor} \times 100\% \qquad (6.1)$$

where $S_{windows}$ – sum area of windows in apartment, m^2; S_{floor} – area of the floor in apartment, m^2.

Checking calculation of natural illumination of premises is made in the following sequence:

1.Measuring the total area of the windows (skylights) $S_{windows}$.

2.Measuring the total area of the floor (skylights) S_{floor}.

According to the formula 6.4. determine the relative area of sky lights and compare it with the recommended value (Table 6.4).

Table 6.4 – The recommended values for the relative area of sky lights for industrial premises

Category of good job	**Form of job for degree of accuracy**	α,%
I	Jobs of very split-hair accuracy	17…21
III	Jobs of split-hair accuracy	15…17
IV	Jobs of medium accuracy	13…15
V	Jobs of small accuracy	9…11
VI	Rough jobs	7…9

Giving work was made in premise, area of which 190 square meters, it has 6 windows, every window with size 2.6 x 2meters.

Calculated the total area of windows (sky lights):

$$Swindows = 6 \times 2.6 \times 2 = 31.2\ m^2, \qquad (6.2)$$

Area of the floor in this premise $S_{floor} = 190m^2$

3. According to the formula 5.3 calculate the relative area of sky lights:

$$\alpha = \frac{Swindows}{Sfloor} \times 100\% = \frac{31.2}{190} \times 100 = 16\% \qquad (6.3)$$

In Table 6.5 define in this room you can schedule visual work of high accuracy that corresponds to the second(II) category of very high visual accuracy work. In table 7.1 establish that the smallest size of the object of discernment for this discharge is 0,3...0,5 mm.

Define the normalized value of the natural lighting coefficient. The apartment is located in Kyiv. The windows are located on the South.

1. In the Table 7.6 to industrial apartment for II category of visual work, define the normalized value of the natural light coefficient : (КПО) =2.5%

2. For V belt of climate lighting (Kyiv) and for the windows orientation to the South in Table 7.6 we find that the coefficient of luminous climate =0,75.

3. The normalized value КПО by the formula 5.4 is equal to:

$$(КПО)_{\text{norm}} = (КПО)_{\text{standarts}} \times m_n = 2{,}5 \times 0{,}75 = 1{,}87\% \qquad (6.4)$$

Table 6.5 – Value of lighting climate coefficient (for side lighting)

Orientation of lighting in horizon sides	Coefficient of lighting climate, m_n	Zone of lighting climate
	IV	**V**
North	0,9	0,8
Northern east,Norhern west	0,9	0,8
East,West	0,9	0,8
Southern east,Soursen west	0,85	0,8
South	0,85	0,75

Table 6.6 – Normalized values of the КПО for side natural lighting in manufacture apartments

Characteristics of visual work	**Class of visual work**	**КПО with natural side lighting(КПО)norm,%**
Highest accuracy	I	3,5*
Very high accuracy	II	2,5*
High accuracy	III	2,0*
Medium accuracy	IV	1,5
Small accuracy	V	1
Very small accuracy	VI	1
Work with materials and goods which lighting in hot shops	VII	1

6.3. Fire and Explosion Safety

Fire safety according ГОСТ 12.1.004-91 ensured the next norms:

– system of fire prevention

– system of fire protection

– organization-technical means of fire safety

In the apartment is chilly, relative humidity is 48-55%, air temperature does not exceed 26 C. By the category of explosive and fire hazard this room belongs to the category B of fire hazard because the presence of solid combustible materials, such

as desktops, isolation, paper, etc. According to the categories of fire risk and number of stores of a house the degree of refractoriness of the building is II.

System of fire safety:

– Emergency switching and switching-off the equipment;

– Existence of the primary means of firefighting, four portable fire extinguishers BBK-5, because carbon dioxide has a bad electrical conductivity.

– In apartment there are the system of fire signaling, warning system, light and sound alarm; protection of flammable parts of the equipment, designs of protective materials;

– Such as office apartment is located in the first floor of living quarters that’s mean evacuation in case of fire will be through doorway and another case through the windows of apartment.

Conclusions to chapter 6

In this chapter are considered and listed hazardous and harmful factors arising during the operation in the computer. In this chapter discussed the questions connected with computers: computer operators, operators in the preparation of the data, programmers, as well as before are exposed to physically dangerous and harmful production factors.

The main of which are the color and reflection coefficients, lighting, the parameters of the microclimate, noise, vibration, etc. Proposed technical measures that reduce the impact of dangerous and harmful factors on the technical staff. Also produced detailed instructions from fire and explosion safety, working with personal computer.

CONCLUSIONS

Researches of theoretical bases and the practical organization have allowed making the following 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 of acceleration and orientation measurements in order to localize an object in air space.

In my research, I analyze possibility to implement PPD in UAV application. In common way, PPD is equipped with various sensors. Moreover, at software level it is easy to get sensor data to provide positioning in airspace. Coordinates of UAV are estimated in ENU reference frame by inertial navigation relations. Unfortunately, errors of measurements degrade positioning accuracy progressively in time. Therefore, usage of inertial navigation is limited in time according to required performance level. Thus, considered approach may be implemented as a stand-by technique in case of GNSS lock. At upper level of trajectory data processing we use α-β-γ filter in the form of linear Kalman filter to reduce noise. Implementation of α-β-γ filter indicates optimal noice filtering for UAV with dynamic characteristics. In our future research we are going to consider group UAVs navigation with a set of various PPDs.

As a result we processed our data and get appropriate graphs and results.

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APPENDIX A

Program code for Matlab software

```
clc
clear all
close all
m=mobiledev;
m.AccelerationSensorEnabled=1;
m.OrientationSensorEnabled=1;
m.Logging=1;
pause(10);

m.Logging=0;
[a,t]=accellog(m);
[o,t]=orientlog(m);
m.AccelerationSensorEnabled=0;
m.OrientationSensorEnabled=0;

psi=o(:,1); %yaw
theta=o(:,2);%pitch
phi=o(:,3);%roll
%%
a(:,3)=a(:,3)-9.8;
n=length(psi);
X=[0,0,0];
for i=2:n
T=[sind(psi(i)).*cosd(theta(i)), cosd(phi(i)).*cosd(psi(i))+sind(phi(i)).*sind(psi(i)).*sind(theta(i)),  -
sind(phi(i)).*cosd(psi(i))+cosd(phi(i)).*sind(psi(i)).*sind(theta(i));
   cosd(psi(i)).*cosd(theta(i)),      -cosd(phi(i)).*sind(psi(i))+sind(phi(i)).*cosd(psi(i)).*sind(theta(i)),
sind(phi(i)).*cosd(psi(i))+cosd(phi(i)).*cosd(psi(i)).*sind(theta(i));
   sind(theta(i)),  -sind(phi(i)).*cosd(theta(i)),  -cosd(phi(i)).*cosd(theta(i))];
A(:,i)=T*a(i,:)';
X(i,:)=X(i-1,:)+ A(:,i)'*power(t(i)-t(i-1),2)+0.5*A(:,i)'*power(t(i)-t(i-1),2);
end
plot3(X(:,1),X(:,2),X(:,3))
grid on
xlabel('X,m');ylabel('Y,m');zlabel('Z,m');
figure
```

```
plot(t,a(:,1),t,a(:,2),t,a(:,3))
grid on
xlabel('Time,s');ylabel('Acceleration,m/s^2');legend('A_x','A_y','A_z');xlim([0,max(t)])
figure
plot(t,theta,t,psi,t,phi)
grid on
xlabel('Time,s');ylabel('Orientation,deg');legend('Pitch','Yaw','Roll');xlim([0,max(t)])
figure
plot(t,S(:,1),t,S(:,2),t,S(:,3))
grid on
xlabel('Time,s');ylabel('Path,m');legend('S_x','S_y','S_z');xlim([0,max(t)])
```

APPENDIX B

AUTHORSHIP LICENSE

УКРАЇНА

СВІДОЦТВО

про реєстрацію авторського права на твір

№ 96769

Комп'ютерна програма "Визначення координат безпілотного літального апарату за даними датчиків кишенькового пристрою" ("Pocket Positioning of UAV")

(вид, назва твору)

Автор(и) **Проценко Ейжена Костянтинівна, Руденко Микита Дмитрович, Остроумов Іван Вікторович**

(повне ім'я, псевдонім (за наявності))

Дата реєстрації 19.03.2020

Заступник Міністра розвитку економіки, торгівлі та сільського господарства України Д. О. Романович

М.П.

**МІНІСТЕРСТВО РОЗВИТКУ ЕКОНОМІКИ, ТОРГІВЛІ
ТА СІЛЬСЬКОГО ГОСПОДАРСТВА УКРАЇНИ
(Мінекономіки)**

вул. М. Грушевського, 12/2, м. Київ, 01008, Тел. (044) 200-47-53, факс (044)253-63-71
E-mail: meconomy@me.gov.ua, http://www.me.gov.ua, код ЄДРПОУ 37508596

РІШЕННЯ

ПРО РЕЄСТРАЦІЮ АВТОРСЬКОГО ПРАВА НА ТВІР

Міністерство розвитку економіки, торгівлі та сільського господарства України розглянуло заяву

Проценко Ейжена Костянтинівна, вул. Ватутіна, 73 Б, кв. 54, м. Бориспіль, 08301
(повне ім'я автора, адреса)

заявка від **12.03.2020** **№ 98299**

про реєстрацію авторського права на твір і прийняло рішення зареєструвати авторське право на твір **Комп'ютерна програма "Визначення координат безпілотного літального апарату за даними датчиків кишенькового пристрою"("Pocket Positioning of UAV"); Проценко Ейжена Костянтинівна, Руденко Микита Дмитрович, Остроумов Іван Вікторович**
(вид, повна, скорочена (за наявності) назва твору, повне ім'я, псевдонім (за наявності) автора (ів))

Внесення відомостей до Державного реєстру свідоцтв про реєстрацію авторського права на твір та видача свідоцтва будуть здійснені за умови сплати збору за оформлення і видачу свідоцтва про реєстрацію авторського права на твір відповідно до п.3 постанови Кабінету Міністрів України від 27 грудня 2001 року № 1756 "Про державну реєстрацію авторського права і договорів, які стосуються права автора на твір".

Якщо протягом трьох місяців від дати одержання заявником рішення про реєстрацію авторського права на твір Управління державних реєстрацій Департаменту інтелектуальної власності Міністерства розвитку економіки, торгівлі та сільського господарства України не одержало документ про сплату збору за оформлення і видачу свідоцтва у розмірі та порядку, визначених законодавством, або копію документа, що підтверджує право на звільнення від сплати зазначеного збору, заявка вважається відхиленою і реєстрація авторського права та публікація відомостей про реєстрацію Управлінням державних реєстрацій Департаменту інтелектуальної власності Міністерства розвитку економіки, торгівлі та сільського господарства України не проводиться.

**Заступник Міністра
розвитку економіки, торгівлі
та сільського господарства України** — **Д. О. Романович**

М.П.