

МІНІСТЕРСТВО ОСВІТИ І НАУКИ УКРАЇНИ
НАЦІОНАЛЬНИЙ АВІАЦІЙНИЙ УНІВЕРСИТЕТ

Кафедра аеронавігаційних систем

ДОПУСТИТИ ДО ЗАХИСТУ
Завідувач кафедри

_____ Ларін В.Ю.

«__» _____ 2017р.

ДИПЛОМНА РОБОТА
(ПОЯСНЮВАЛЬНА ЗАПИСКА)

Тема: «Методика обчислення параметрів магнітного поля
обмеженої території»

Виконавець:

Миронюк О.О.

Керівник:

Остроумов І.В.

Нормоконтролер:

Ларін В.Ю.

Київ 2017

НАЦІОНАЛЬНИЙ АВІАЦІЙНИЙ УНІВЕРСИТЕТ

Навчально-Науковий Інститут Аеронавігації

Кафедра Аеронавігаційних Систем

Спеціальність: 8.07010203 « Системи аеронавігаційного обслуговування»

ЗАТВЕРДЖУЮ

Завідувач кафедри

_____ Ларін В.Ю.

«__» _____ 2017р.

ЗАВДАННЯ

на виконання дипломної роботи

Миронюк Олени Олександрівни

1. Тема дипломної роботи «Методика обчислення параметрів магнітного поля обмеженої території» затверджена наказом ректора від 11 жовтня 2016р. № 2600/ст.
2. Термін виконання роботи: з 11.10.2016 по 20.01.2017.
3. Вихідні дані до роботи: документи Міжнародної організації моніторингу стану магнітного поля землі, NASA і технічна інформація .
4. Зміст пояснювальної записки: основи магнітного поля Землі, опис датчиків кишенькового пристрою, вимірювання та обробка даних магнітного поля локально.
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 «Основи магнітного поля»	11.10.16-26.10.16	виконано
2.	Підготовка та написання 2 розділу «Датчики кишенькового пристрою»	27.10.16-11.11.16	виконано
3.	Підготовка та написання 3 розділу «Обробка даних вимірювань магнітного поля Землі локально»	12.11.16-01.12.16	виконано
4.	Підготовка та написання 4 розділу «Експериментальне вимірювання магнітного поля Землі локально»	02.12.16-02.01.17	виконано
5.	Підготовка презентації та доповіді	03.01.17-20.01.17	виконано

7. Дата видачі завдання: « 11 » жовтня 2016 р.

Керівник дипломної роботи _____ Остроумов Іван Вікторович
(підпис керівника) (П.І.Б.)

Завдання прийняв до виконання _____ Миронюк Олена Олександрівна
(підпис студента) (П.І.Б.)

РЕФЕРАТ

Пояснювальна записка до дипломної роботи «Методика обчислення параметрів магнітного поля обмеженої території»: 104 сторінок, 54 рисунків, 1 таблиця, 40 використаних джерел, 2 додатка.

Об'єкт розробки – інтегрована система вимірювання параметрів магнітного поля.

Предмет розробки – оцінювання характеристик магнітного поля за даними сенсорів кишенькового пристрою.

Мета роботи – розробка методики оцінювання параметрів магнітного поля для обмеженої території за даними вимірювань кишенькового пристрою.

Метод дослідження – комп'ютерне моделювання та експериментальне випробування.

Магнітне поле Землі є одним з найважливіших речей планетарної структури. Також магнітне поле є одним з ключових елементів для цілей навігації. Його параметри надзвичайно важливі для виявлення напрямку, навігації та функціонування інших програм. Сучасні навігаційні прилади та датчики, засновані на характеристиках магнітного поля, використовують моделі магнітного поля, які не містять дані про людський фактор магнітного поля.

Всі датчики, які нам потрібні, ми можемо знайти всередині типового планшета або в сучасного мобільного телефону. Тому, потрібно три магнітометри, три гіроскопи (для виявлення кутового положення планшета) і датчик позиціонування – GNSS-приймач (у складі даних). Нажаль різні датчики всередині мобільного телефону мають різний час вимірювань. Щоб вирішити цю проблему, потрібно інтерполювати координати для того, щоб об'єднати датчики часу. Результати роботи відзначають, що датчики мобільного телефону можна використовувати в режимі реального часу оцінки характеристик магнітного поля.

МАГНІТНЕ ПОЛЕ, МОБІЛЬНИЙ ТЕЛЕФОН, ІНТЕРПОЛЯЦІЯ, ПОЛІНОМ, МАГНІТОМЕТРИ, АПРОКСИМАЦІЯ, DATA RECORDING, ДАТЧИКИ.

NOTES

MINISTRY OF EDUCATION AND SCIENCE, OF UKRAINE
NATIONAL AVIATION UNIVERSITY

Air Navigation System Department

PERMISSION TO DEFEND
GRANTED
Head of the Department

« _ » _____ 2017

MASTER'S DEGREE THESIS

Theme: « Method of parameters calculation of magnetic field
of restricted area»

Completed by:	Mironyuk O.O.
Supervisor:	Ostroumov I.V.
Standarts Inspector:	Larin V.Yu.

Kyiv 2017

NATIONAL AVIATION UNIVERSITY

Educational and Scientific Institute of Air Navigation

Air Navigation Systems Department

Specialty: 8.07010203 « Systems of Aeronavigation Service »

APPROVED BY

Head of the Department

_____ V.Yu. Larin

« _ » _____ 2017

Graduate Student's Degree Thesis Assignment

Mironyuk Olena

1. The Project topic: «Method of parameters calculation of magnetic field of restricted area » approved by the Rector's order of « 11 » October 2016 № 2600/st.
2. The Project to be completed between: 11.10.2016 – 20.01.2017.
3. Initial data to the project: documents of the international organizations monitoring the state of Earth's magnetic field, NASA and technical information.
4. The content of the explanatory note (the list of problems to be considered): basics of magnetic field, sensors of smartphone, local magnetic field data processing, sensing of local magnetic field.
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: « Basics of magnetic field »	11.10.16-26.10.16	completed
2	Preparation of chapter 2: « Sensors of smartphone »	27.10.16-11.11.16	completed
3	Preparation of chapter 3:« Local magnetic field data processing »	12.11.16-01.12.16	completed
4	Preparation of chapter 4: « Sensing of local magnetic field »	02.12.16-02.01.17	completed
5	Preparation of report and graphic materials	03.01.17-20.01.17	completed

7. Assignment accepted for completion «11» October 2016

Supervisor _____ I.V.Ostroumov

Assignment accepted for completion _____ O.O. Mironyuk

ABSTRACT

Explanatory note to the master's thesis, « Method of parameters calculation of magnetic field of restricted area »: 104 pages, 54 figures, 1 tables ,40 references, 2 appendixes.

Development object – integrated system for measuring parameters of magnetic field.

Development subject – estimation of characteristics of the magnetic field sensor according pocket devices.

Purpose of the work – the development of method for estimating parameters of the magnetic field for a restricted area according to the measurements of a pocket devices.

Investigation method – computer modeling and experimental testing.

Global Earth's Magnetic field is one of the most important things in planetary structure. Magnetic field is also one of the key elements for navigation purposes. Its parameters are extremely important for direction detection and other applications.

Modern navigation devices and sensors grounded on magnetic field characteristics use magnetic field models which do not contain data about human based part of magnetic field.

All sensors which we need can be found inside of typical tablet or in modern cell phone . That's way it is need 3 magnetometers, 3 gyroses (to detect angular position of tablet) and positioning sensor – GPS receiver (to data composition)

Unfortunately different sensors inside mobile phone have different time of measurements. To make this time problem clear it is necessary to interpolate coordinates in order to unify sensors data time. Results of work indicate that mobile phone sensors can be used for real time magnetic field characteristics estimation.

MAGNETIC FIELD, MOBILE PHONE INTERPOLATION,
POLYNOMIAL, MAGNETOMETERS, APPROXIMATION, DATA RECORDING,
SENSORS.

CONTENT

LIST OF ABBREVIATIONS AND EXPLANATION OF TERMS	ERROR!
	BOOKMARK NOT DEFINED.
INTRODUCTION.....	12
CHAPTER 1. BASICS OF MAGNETIC FIELD	14
1.1. Magnetic field.....	14
1.2. Structure of Earth's magnetic field.....	19
1.3. Vector of magnetic field intensity	23
1.4. Impotance of Magnetic Field.....	33
1.5. World Magnetic Model.....	37
CHAPTER 2. REQUIRENMENTS SPECIFICATION	49
2.1. Title of thesis.....	49
2.2. Basis for conducting thesis	49
2.3. Object and purpose	49
2.5. Expected scientific results and the procedure for their implementation	50
2.6. Requirements for the work	50
2.7. Stages of the work and terms of their implementation.....	51
CHAPTER 3. SENSORS OF SMARTPHONE.....	53
3.1 Structure of smartphone.....	53
3.2. Sensors of smart phone	53
3.2.1. GPS sensors	54
3.3. Software for data collection.....	66
CHAPTER 4. ALGORITHMS OF LOCAL MAGNETIC FIELD DATA	
PROCESSING.....	72
4.1. Methodic of magnetic field data processing.....	72
Structure scheme method of magnetic paratemers calculation	73
4.2.Data transformation for the same time	73
4.3. Coordinate systems	75
CHAPTER 5. SENSING OF LOCAL MAGNETIC FIELD.....	80
5.1. Description of experiment	80
5.2. Result of measurement.....	82
5.3. Inclination and Declination calculation	85
5.4 Local magnetic field data processing	86
CONCLUSIONS	ERROR! BOOKMARK NOT DEFINED.
REFERENCES.....	93
APPENDIX A.	97
PROGRAM CODE FOR MATLAB SOFTWARE	97

APPENDIX B.ERROR! BOOKMARK NOT DEFINED.

LIST OF ABBREVIATION

ASM – Absolute Scalar Magnetometer

CG – Center of Gravity

CME – Coronal Mass Ejections

CMG – Control Moment Gyroscope

CNES – National Center for Space Studies

CSC – Compact Spherical Coil

ECEF – Earth-Centered Earth-Fixed Coordinate System

ENU – East-North-Up

ESA – European Space Agency

GPS – Global Positioning System

IAGA – International Association of Geomagnetism and Aeronomy

IGRF – International Geomagnetic Reference Field

IMF – Interplanetary Magnetic Field

NASA – National Aeronautics and Space Administration

NMR – Nuclear Magnetic Resonance

NOAA – National oceanic and atmospheric administration

OVH – Overhauser magnetometer

PWM – Pulse-Width Modulation

SV – Secular Variation

TSV – Tab-Separated Values

UPS – Universal Polar Stereographic

USGS – U.S. Geological Survey

UTM – Universal Transverse Mercator

VFM – Vector Field Magnetometer

WMM – World Magnetic Model

INTRODUCTION

Thesis actuality. Global Earth's Magnetic field is one of the most important things in planetary structure. Also magnetic field is one of the key elements for navigation purposes. Its parameters are extremely important for direction detection and other applications. For example in inertial navigation systems global magnetic field has been used for sensors calibration. Characteristics of magnetic field have been using for rotation detection and angular speed calculation too. Typically total magnetic field in some point of atmosphere has been sum of three different components: main magnetic field – is result of geomagnetic process inside of Earth core; external magnetic field – is result of sun influence, depends on current solar activity and usually less than 5% of total magnetic field; anomalous – is result of influence of different ground anomalous areas which contain some ore deposits with magnetic characteristics in earth crust. Nowadays it is possible to detect influence of different human – made structures to total magnetic field. This is the result of wide metal construction usage in city building. Of course this type of influence is a part of anomalous magnetic field, but it is directly connected with results of human changing. In this case we can access natural and human based components of anomalous field. Also for humane based part we can include different electrical devices which can result in magnetic injection.

Nowadays different international programs investigate and monitor characteristics of magnetic field. National oceanic and atmospheric administration (NOAA), U.S. Geological Survey (USGS), Swarm earth explorers by European Space Agency (ESA) investigate this problem, but in common way all of them are been oriented into global scale of magnetic field.

Modern navigation devices and sensors grounded on magnetic field characteristics have been using magnetic field models which don't contain data about humane-based part of magnetic field. In result non accurate model produce errors which will be in result of positioning or heading error. In some cases influence of human-based field will be very valuable for navigation purposes. That's why the aim

of this work to describe methodology of local magnetic field parameters measurement by typical users equipment.

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 Earth's magnetic field and NASA.

Investigation object - integrated system for measuring parameters of magnetic field.

Investigation subject - estimation of characteristics of the magnetic field sensor according pocket devices.

Purpose of the work - the development of method for estimating parameters of the magnetic field for a restricted area according to the measurements of a pocket devices.

Investigation method - computer modeling and experimental testing.

Science research novelty - results of work indicate that mobile phone sensors can be used for real time magnetic field characteristics estimation.

Practical results of science research. The results of scientific's work will be published in Proceeding of the NAU issue 1 in 2015, represented in the scientific conferences and the program will receive a patent.

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

CHAPTER 4. LOCAL MAGNETIC FIELD DATA PROCESSING

4.1. Method of magnetic field data processing

There are several sensors in the smartphone. Such as GNSS, gyroscopes, magnetic field sensors and accelerometers.

With the help of GPS receiver we measured: Height – a scalar value, in meters; Lat – scalar geodetic latitude, in degrees, where north latitude is positive and south latitude is negative; Lon – A scalar geodetic longitude, in degrees, where east longitude is positive, and west longitude is negative.

With the help of Magnetic Field sensors – T_x , T_y , T_z – components of magnetic field vector in nanotesla (nT), usually. With the help of Gyroscope– rotation angle data.

These data are recorded in the special program «Data Recording». They are saved and available for processing in Matlab. Then we interpolate to a unique time.

We transform the coordinates to the NED-coordinate system. Next we calculate inclination, declination, H and V (components of magnetic field vector).

Then we predict parameters of magnetic field for these coordinates and unique time[1].

Data interpolation in 3D space are for real and interpolate data. In the next we calculate difference between the obtained results and achieve the results visualization (Fig.4.1).

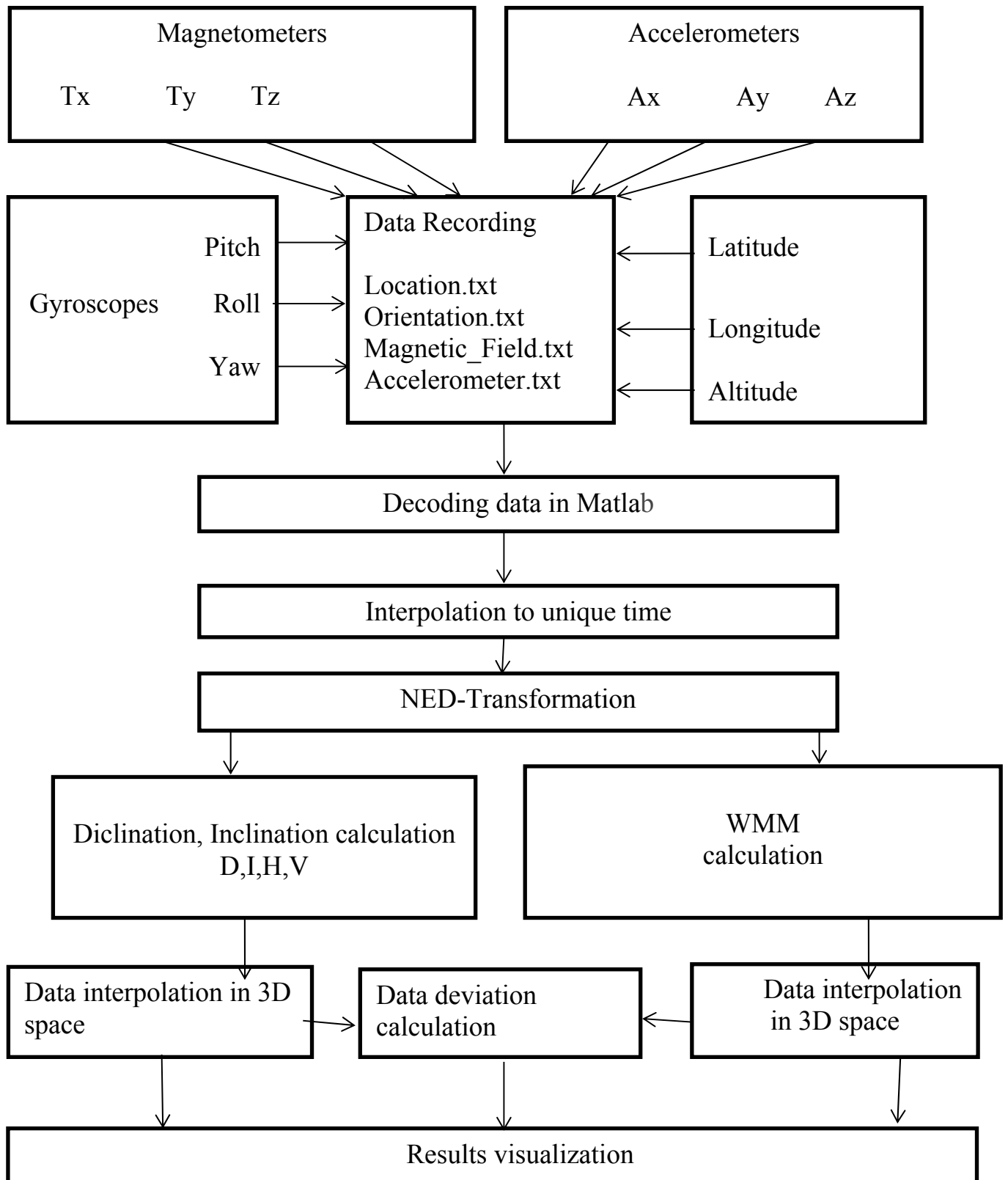


Figure 4.1 – Structure scheme method of magnetic parameters calculation

4.2. Data transformation for the same time

Unfortunately different sensors inside of mobile phone have different time of measurements [4]. It means that each sensor measures in some specific time scale. For example in experiment GPS module provides us 1 result per second and other sensors 10 times per second. To make clear this time problem it is necessary to interpolate coordinates to unify sensors data time. The easiest way to do it is the usage of polynomial approximation. Let's use polynomial interpolation with m^{th} order of the polynomial:

$$y = A_0 + A_1x + A_2x^2 + A_3x^3 + \dots + A_mx^m, \quad (4.1)$$

where A_i are polynomial coefficients with $i=0\dots m$.

By result of measurement polynomial coefficients will be calculated.

In this case the least square method will be used for calculation. But at first let's compose system of math equation which helps to calculate polynomial coefficients:

$$\begin{cases} A_0S_0 + A_1S_1 + A_2S_2 + \dots + A_mS_m = B_0 \\ A_0S_1 + A_1S_2 + A_2S_3 + \dots + A_mS_{m+1} = B_1 \\ A_0S_2 + A_1S_3 + A_2S_4 + \dots + A_mS_{m+2} = B_2 \\ \dots \\ A_0S_m + A_1S_{m+1} + A_2S_{m+2} + \dots + A_mS_{2m} = B_m \end{cases}, \quad (4.2)$$

where $S_k = \sum_{i=1}^n x_i^k$, $k=1\dots m$,

$S_0 = n + 1$, n -number of measurements,

$$B_k = \sum_{i=1}^n (y_i \cdot x_i^k).$$

Let's represent it in matrix form:

$$A \times S = B, \quad (4.3)$$

where

$$A = |A_0, A_1, \dots, A_m|, \quad (4.4)$$

$$S = \begin{vmatrix} S_0 & S_1 & S_2 & \dots & S_m \\ S_1 & S_2 & S_3 & \dots & S_{m+1} \\ S_2 & S_3 & S_4 & \dots & S_{m+2} \\ \dots & & & & \\ S_m & S_{m+1} & S_{m+2} & \dots & S_{2m} \end{vmatrix}, \quad B = \begin{vmatrix} B_0 \\ B_1 \\ B_2 \\ \dots \\ B_m \end{vmatrix} \quad (4.5)$$

Then, polynomial coefficients will be calculated by the next formula

$$A = B \times \text{inv}(S). \quad (4.6)$$

These coefficients will be inserted into the main formula of the polynomial to calculate position for required time. Result of interpolation for different coordinates has been represented on figure 3 and 4 for time closed to 1500 second.

To increase computation time it is possible to use polynomial with less order, but in this case interpolation errors increase rapidly.

4.3. Coordinate systems

4.3.1. ECEF

The ECEF (Earth-Centered Earth-Fixed Coordinate System) coordinate system rotates with the earth around its spin axis. As such, a fixed point on the earth surface has a fixed set of coordinates. The origin and axes of the ECEF coordinate system (see Fig.4.2) are defined as follows:

1. The origin (denoted by O_e) is located at the center of the earth.
2. The Z-axis (denoted by Z_e) is along the spin axis of the earth, pointing to the north pole.
3. The X-axis (denoted by X_e) intersects the sphere of the earth at 0° latitude and 0° longitude.
4. The Y-axis (denoted by Y_e) is orthogonal to the Z- and X-axes with the usual right-hand rule. Coordinate vectors expressed in the ECEF frame are denoted with a subscript e.

Similar to the geodetic system, the position vector in the ECEF frame is denoted by

$$P_e = \begin{pmatrix} x_e \\ y_e \\ z_e \end{pmatrix} \quad (4.7)$$

CHAPTER 5. SENSING OF LOCAL MAGNETIC FIELD

5.1. Description of experiment

Magnetic field is characterized by intensity vector, usually. Intensity vector “ T ” is the sum of the vectors strengths of several fields [1]. Typically, the vector T is estimated from its projections, on the some Cartesian coordinate system (T_x , T_y , T_z components). Also two angles are important: declination (D) and inclination (I), which indicate position of intensity vector in space, horizontal T_H and vertical T_z components of T .

Declination is positive for an eastward deviation of the field relative to true north. It can be estimated by comparing the magnetic north/south heading on a compass with the direction of a celestial pole.

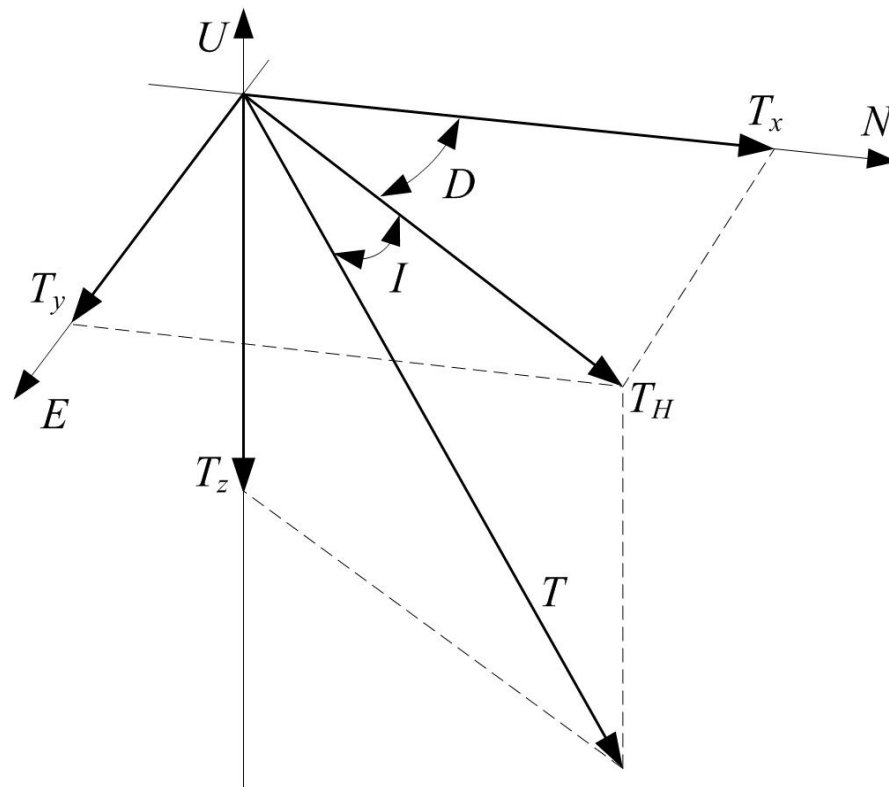


Figure 5.1 – Components of magnetic field intensity vector

The inclination is given by an angle that can assume values between -90° (up) to 90° (down). In the northern hemisphere, the field points downwards. It is straight

down at the North Magnetic Pole and rotates upwards as the latitude decreases until it is horizontal (0°) at the magnetic equator.

All sensors which we need can be found inside of typical tablet or in modern cell phone [3]. That's way it is need 3 magnetometers (they will sense T_x , T_y , T_z components of intensity vector), 3 gyroses (to detect angular position of tablet) and positioning sensor – GPS receiver (to data composition).

With the help of GPS receiver we measured: Height - a scalar value, in meters; Lat - scalar geodetic latitude, in degrees, where north latitude is positive and south latitude is negative; Lon - A scalar geodetic longitude, in degrees, where east longitude is positive, and west longitude is negative. With the help of Magnetic Field sensors – T_x , T_y , T_z – components of magnetic field vector in nanotesla (nT), usually. With the help of Gyroscope – rotation angle data.

During an experiment cell phone Samsung Galaxy I9300 was used, and free Android application "Data Recording" for data collecting and storing.

As a result of software measurement we obtained text files with measured data. Pitch, roll and azimuth - these variables determine the position of device in the space. Azimuth serves as a compass, returning a value from 0 to 360 degrees, where 0 is north. Roll, which defines the "looks" screen phone in the ground or in the sky returns a value from 0 to 180 degrees, as you turn the phone to the right (180 degrees when the screen looks down), and from 0 to -180 as you turn your phone left. Pitch determines the angle of the phone in an upright position, returns a value from 0 to 180 (when tilted to the right) and from 0 to -180 when tilted to the left[3].

Trajectory of measurement and result of positioning is represented on fig.5.2.

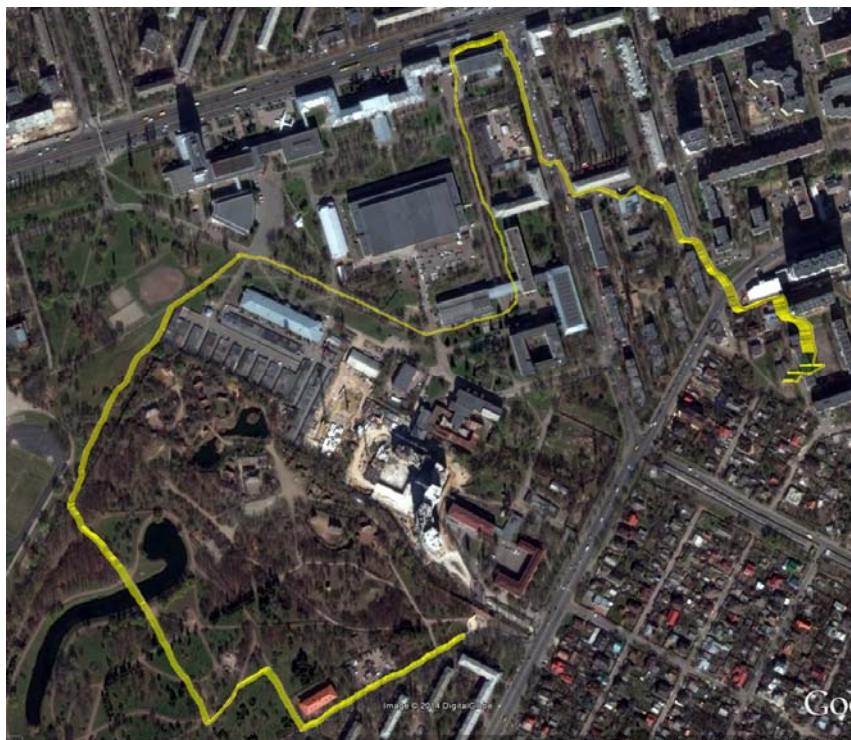


Figure 5.2 – Experimental trajectory by GPS data

5.2. Result of measurement

The results of measurements of sensors are shown in the graphs. (Latitude,longitude,altitude and magnetic field).

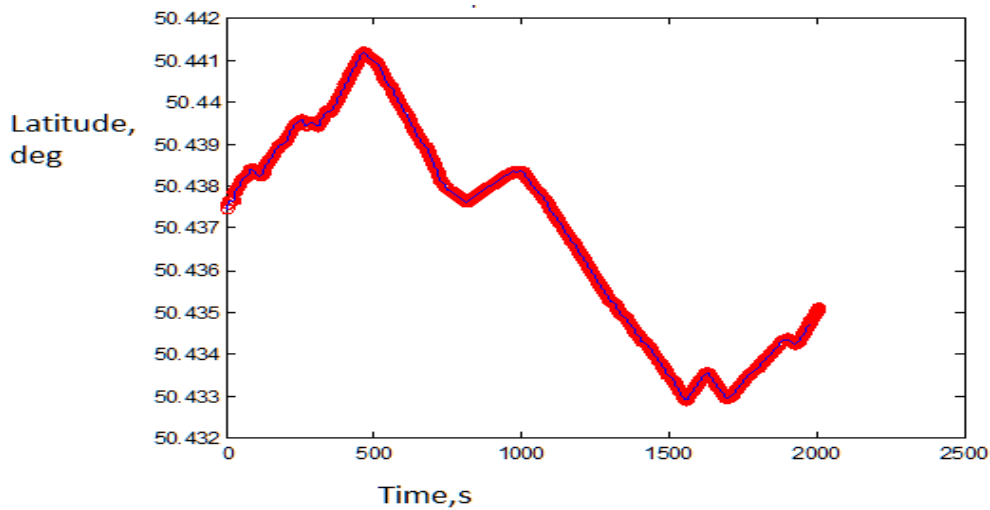


Figure 5.3 – Dependence latitude from time

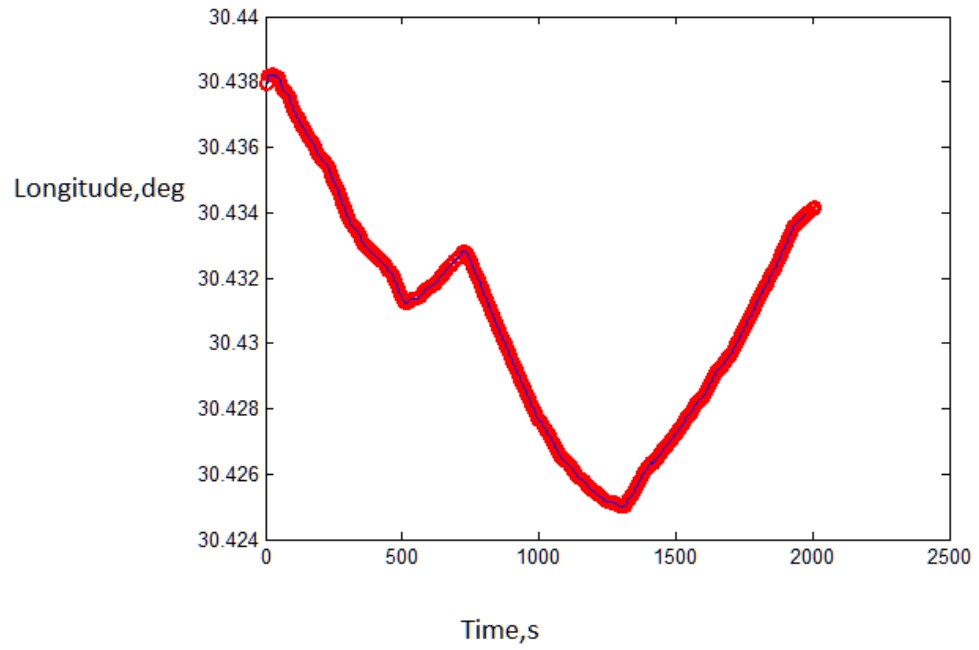


Figure 5.4 – Dependence longitude from time

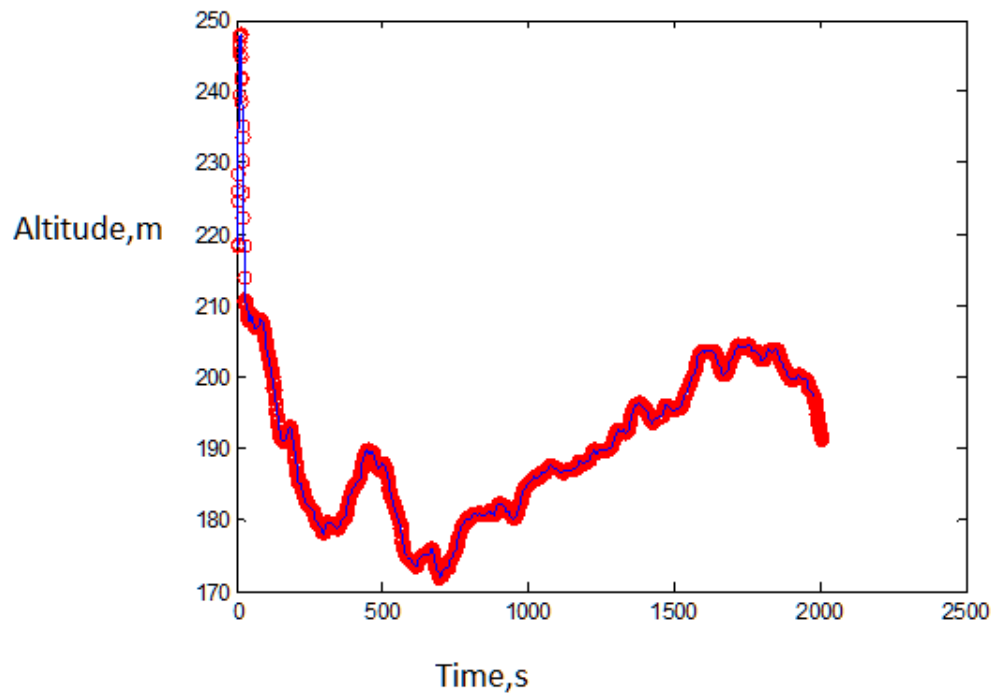
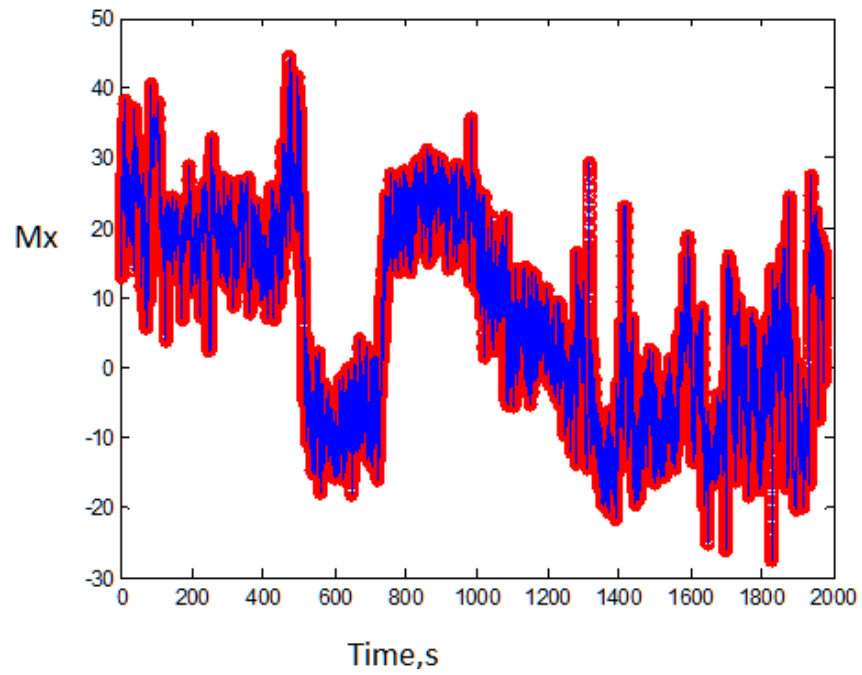
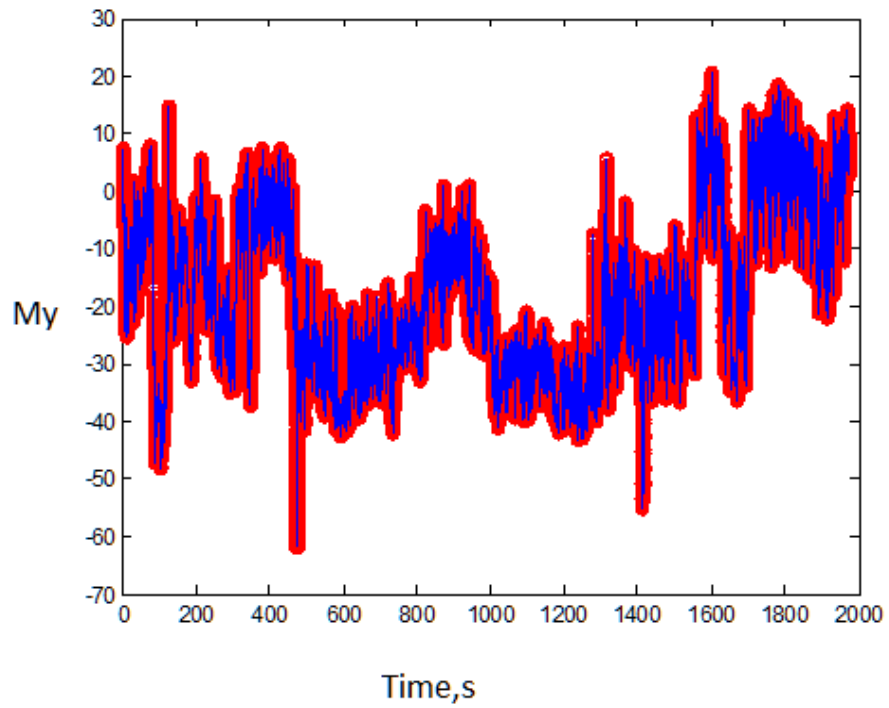


Figure 5.5 – Dependence longitude from time

Figure 5.6 – Dependence M_x from timeFigure 5.7 – Dependence M_y from time

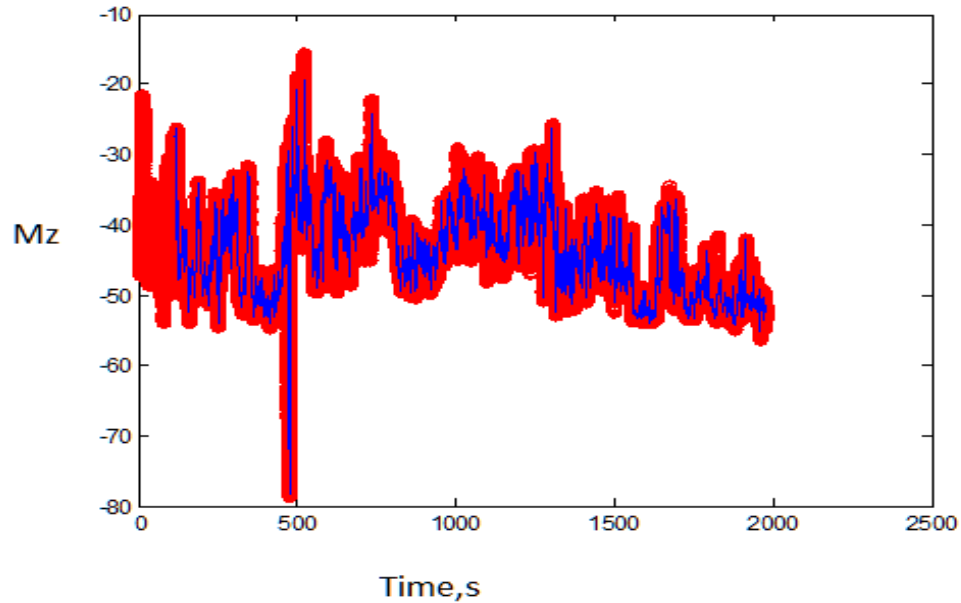


Figure 5.8 – Dependence Mz from time

5.3. Inclination and Declination calculation

At any location, the Earth's magnetic field can be represented by a three-dimensional vector. A typical procedure for measuring its direction is to use a compass to determine the direction of magnetic North. The intensity (T) of the field is proportional to the force it exerts on a magnet. Its angle relative to true North is the declination (D) or variation:

$$D = \arccos\left(\frac{T_{xENU}}{T_{HENU}}\right). \quad (5.1)$$

Facing magnetic North, the angle the field makes with the horizontal is the inclination (I) or dip:

$$I = \arctg\left(\frac{T_{zENU}}{T_{HENU}}\right). \quad (5.2)$$

Horizontal component of intensity vector of magnetic field:

$$T_{HENU} = \sqrt{T_{xENU}^2 + T_{yENU}^2}. \quad (5.3)$$

All of these parameters are important for navigation and other magnetic field applications. That's why let's calculate declination, inclination and intensity for all input data. After that we will have these data across trajectory of mobile phone movement (fig.5.9 – 5.12).

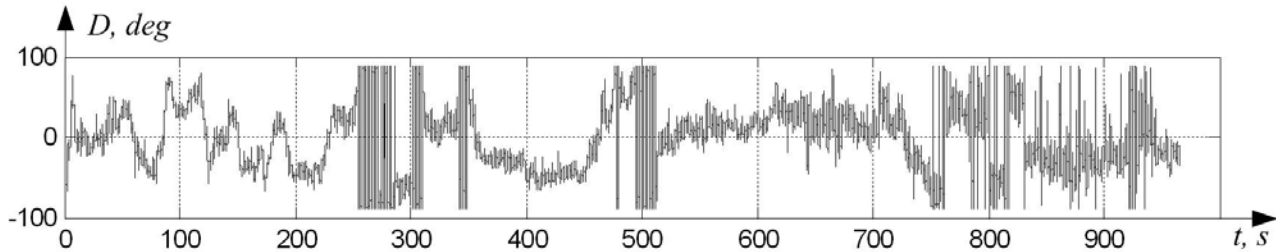


Figure 5.9 – Declination during movement

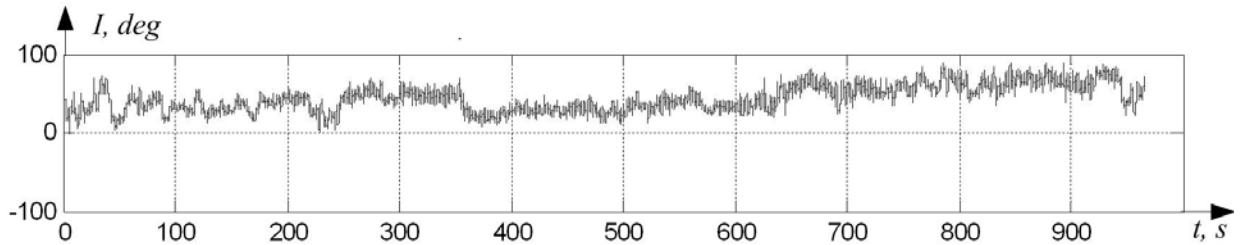


Figure 5.10 – Inclination during movement

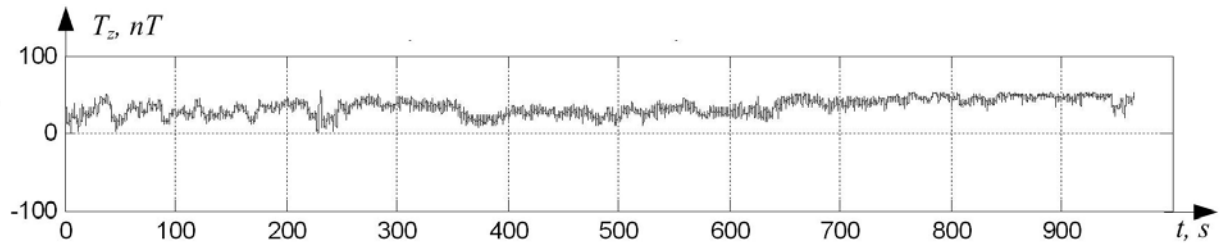


Figure 5.11 – Vertical component of intensity of Magnetic field vector

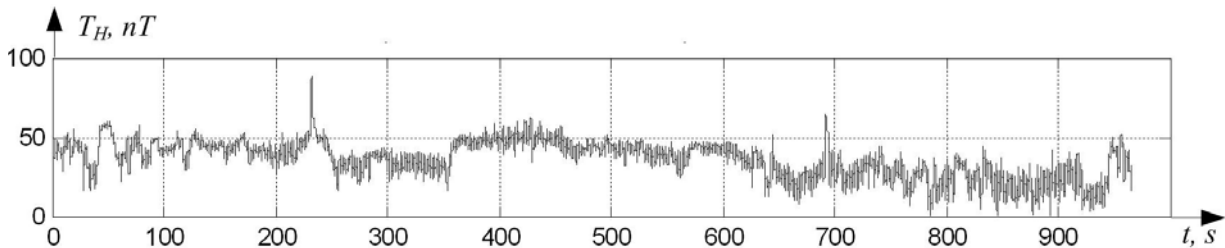


Figure 5.12. – Horizontal component of intensity of Magnetic field vector

5.4. Local magnetic field data processing

The “V4” method has been used to interpolate values of declination, inclination and intensity for area which is close to movement trajectory.

The “V4” method is much like a radial basis function interpolate. These methods are distance based methods, so we will have a single radially symmetric basis function around every data point. The “V4” method will form a linear combination of these basis functions, so it must formulate and solve a linear system of equations, of size the number of data points. It is apparently a Greens' function approach. It uses a full matrix composed of all of the interpoint distances. This will be slow for many points, and extremely memory intensive. In result surface which fit to the data has been calculated (figures from 5.15 to 5.16).

For data verification international world magnetic model has been used. The predicted state of intensity vector of magnetic field for local area of investigation has been calculated by NOAA data with the help of MATLAB specific software on the same date and time of real data measurement. Result of Intensity vector forecast in terms of declination, inclination and intensity are represented on fig.5.17-5.20.

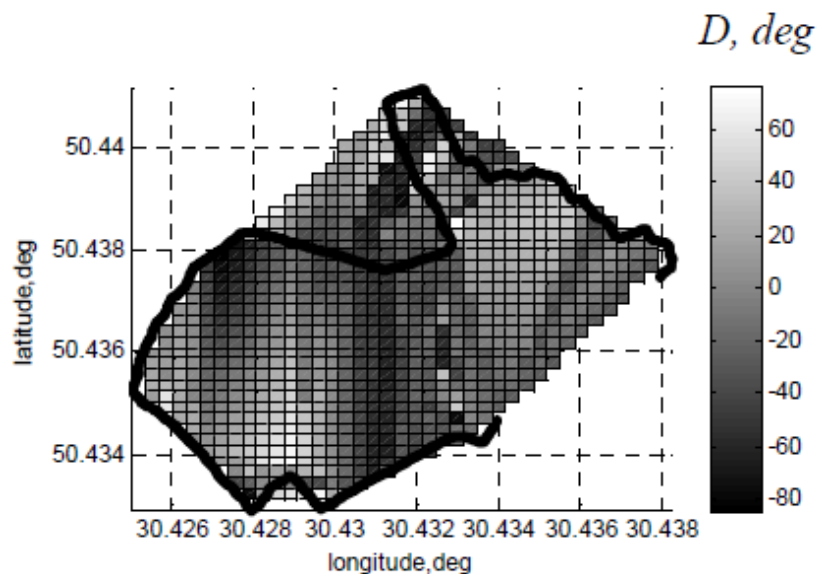


Figure 5.13 – Declination surface interpolation

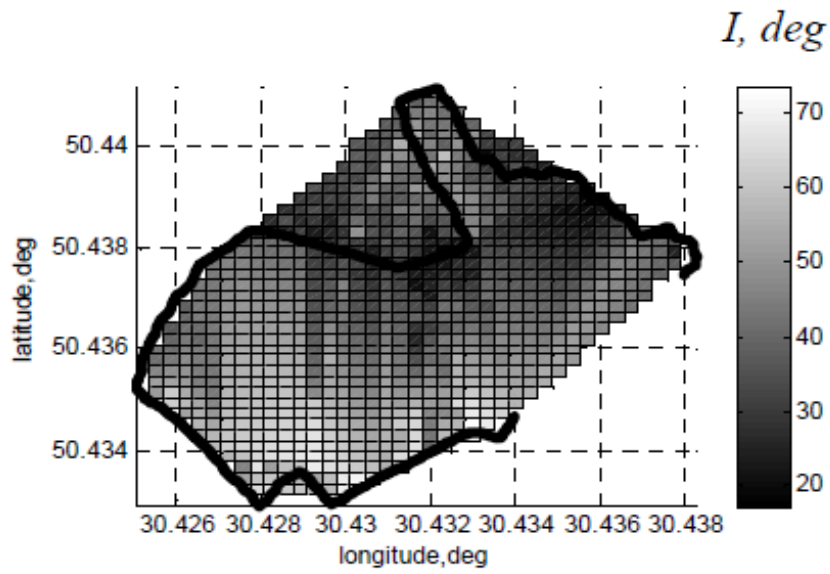


Figure 5.14 – Inclination surface interpolation

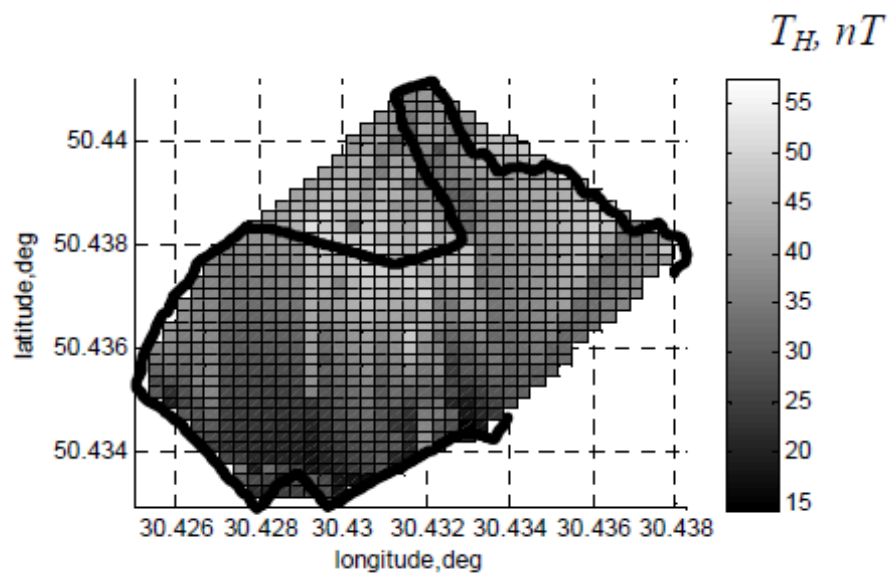


Figure 5.15 – Horizontal component of intensity of Magnetic field vector surface interpolation

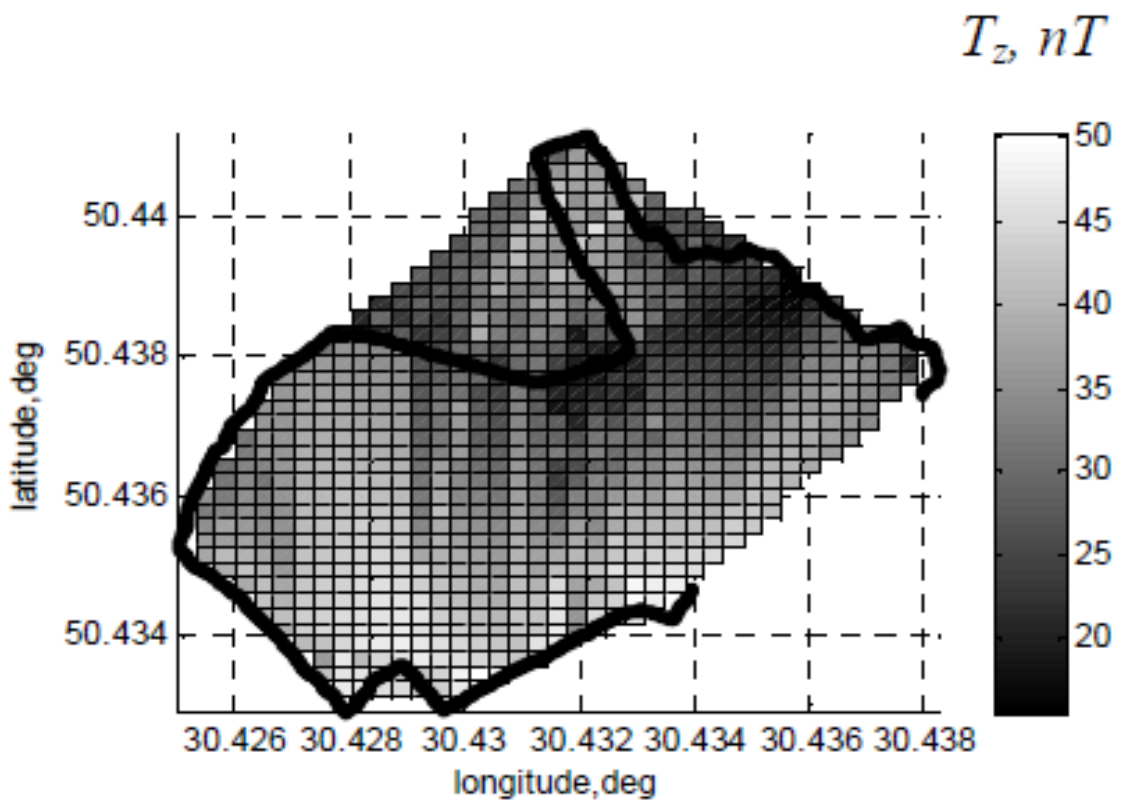


Figure 5.16 – Vertical component of intensity of Magnetic field vector surface interpolation

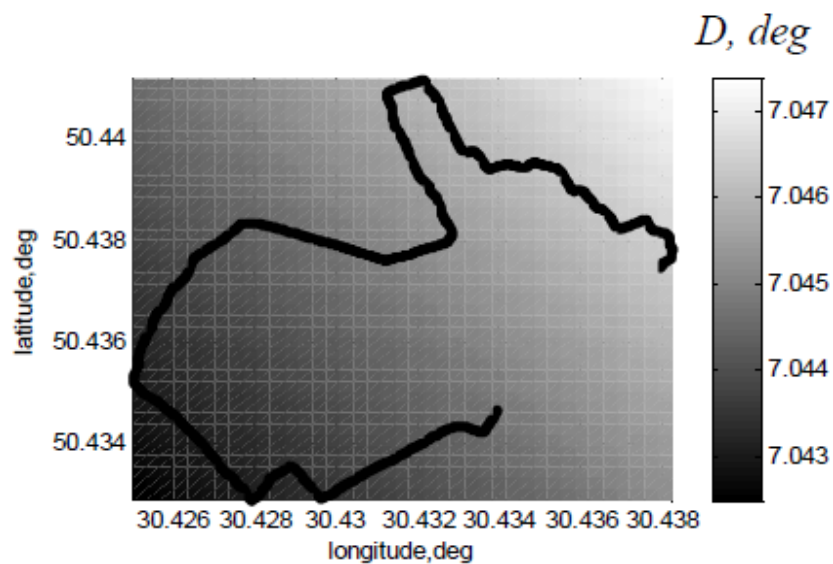


Figure 5.17 – Declination surface interpolation

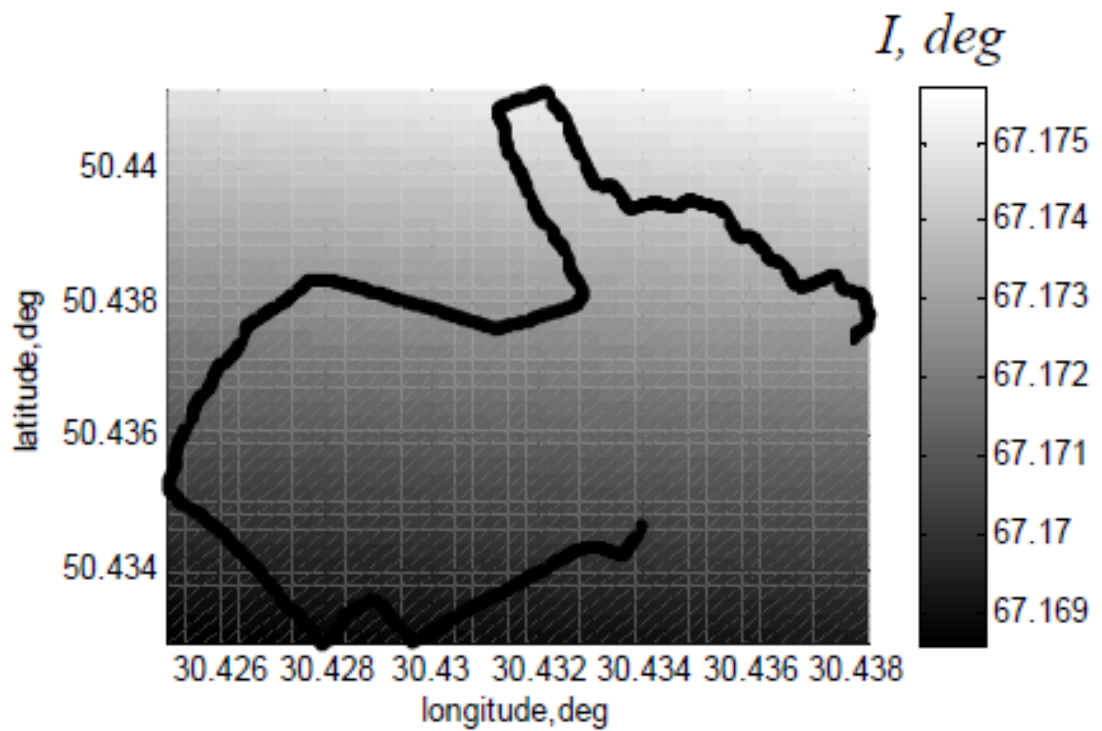


Figure 5.18 – Inclination surface interpolation

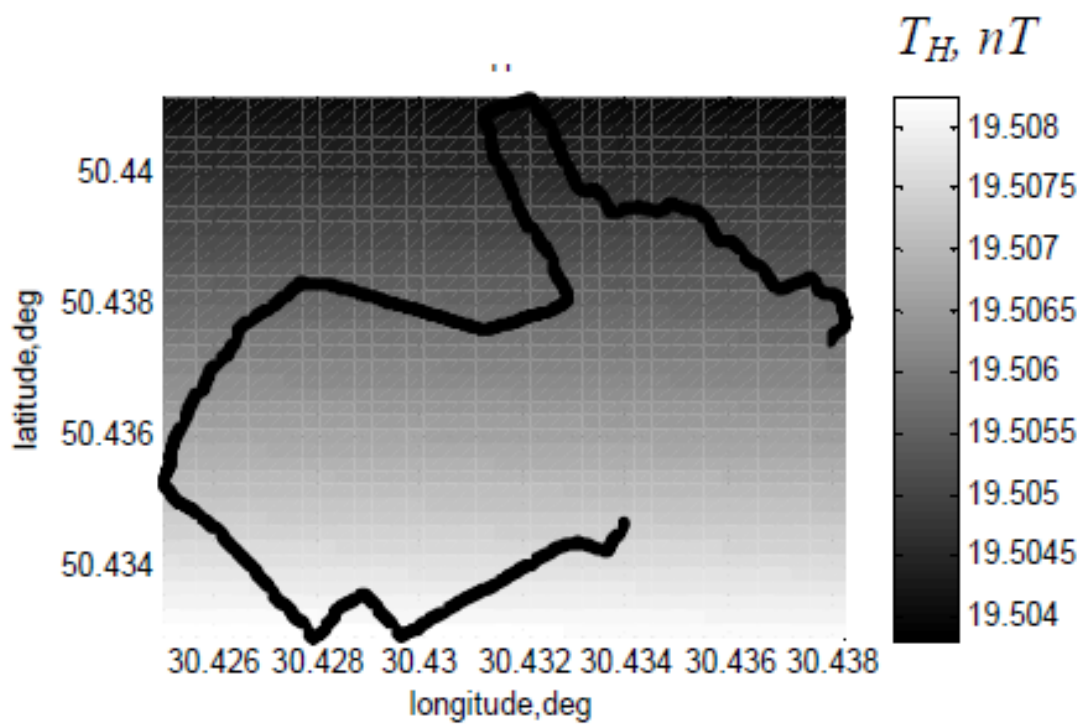


Figure 5.19 – Horizontal component of intensity of Magnetic field vector surface interpolation

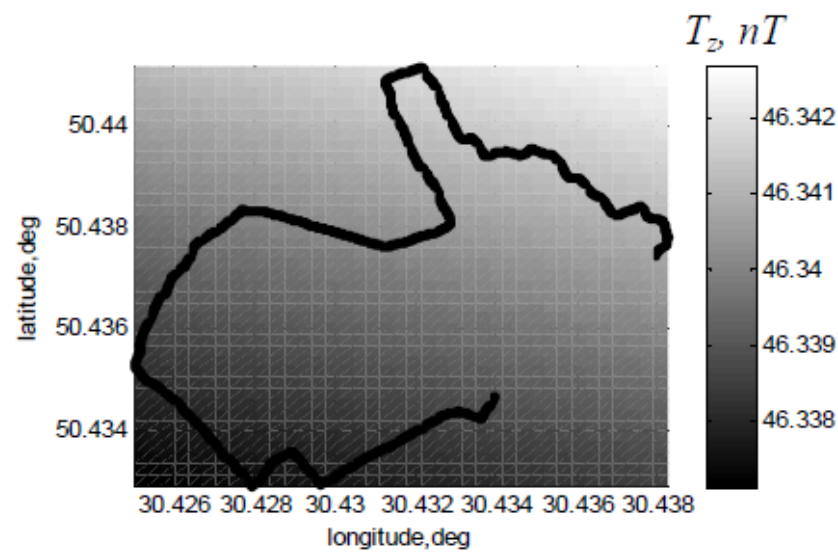


Figure 5.20 – Vertical component of intensity of Magnetic field vector surface interpolation

Conclusions to the chapter 5

This chapter includes results of the experiment. The results represented in figures. All of these parameters are important for navigation and other magnetic field applications. That's why let's calculate declination, inclination and intensity for all input data. After that we will have these data across trajectory of mobile phone movement .

The “V4” method has been used to interpolate values of declination, inclination and intensity for area which is close to movement trajectory.

That's why the aim of this work to describe methodology of local magnetic field parameters measurement by typical users equipment.

CONCLUSIONS

Researches of theoretical bases and the practical organization have allowed making the following conclusions.

Global Earth's Magnetic field is one of the most important things in planetary structure. Magnetic field is also one of the key elements for navigation purposes. Its parameters are extremely important for direction detection and other applications.

Modern navigation devices and sensors grounded on magnetic field characteristics use magnetic field models which do not contain data about human based part of magnetic field.

During an experiment were used a cell phone Samsung Galaxy I9300 and free Android application "Data Recording" for data collecting and storing.

The main purpose of the work is the development of method for estimating parameters of the magnetic field for a restricted area according to the measurements of a pocket devices.

Results of work indicate that mobile phone sensors are possible to use for real time magnetic field characteristics estimation. Parameters of Earth's magnetic field: declination (fig.5.7), inclination (fig.5.8), intensity, horizontal (fig.5.9) and vertical (fig.5.10) components are extremely important for navigation purposes. Represented methodic of theses parameters evaluation shows the cheapest way to improve navigation equipment functionality. Result of interpolation has been verified with forecasts by international World Magnetic Model.

Represented methodic of theses parameters evaluation shows the cheapest way to improve navigation equipment functionality.

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

REFERENCES

1. Mironyuk O.O. Interpolation of magnetic field characteristics by spline functions / O.O. Mironyuk, I.V. Ostroumov, M.V. Nychak // IV National Scientific Conference of young scientists and students «Problems and prospects of Aeronautics and Astronautics» 28 – 29 October 2015 y. — 2015. — 5 p.
2. Mironyuk O.O. Tablet location tracking by inertial sensors / O.O. Mironyuk, M.V. Nychak, V.I. Zaporozhets, I.V. Ostroumov // III National Scientific Conference of young scientists and students «Problems and prospects of Aeronautics and Astronautics» 23 – 24 October 2014 y – Kyiv,. — 2014. — 13 p.
3. Nychak M.V. Investigation of magnetic field / M.V. Nychak, O.O. Mironyuk, I.V. Ostroumov // Polit. Challenges of science today: XIV International Scientific and Practical Conference of Young Researchers and Students, April 2–3, 2014 : theses. – K.. — 2014. — 34 p.
4. Ostroumov I. Local magnetic field data processing / I. Ostroumov, O.Mironyuk, M. Nychak // Proceeding of the NAU. — 2015. — Is. 1. — P. 23-28.
5. А. с. 53899 Ukraine. Комп'ютерна програма «Оцінювання характеристик магнітного поля Землі» / І.В. Остроумов, О.О. Миронюк, М.В. Ничак. — заявл. 2014-10-07; опубл. 2015-03-01.
6. Kharchenko V. P. Avionics / V. P. Kharchenko, I. V. Ostroumov – K. : NAU. – 2012–281 p.
7. National Geomagnetism Program. USGS. Official web site: – <http://geomag.usgs.gov>
8. *Mohinder S. G.* Global Positioning Systems, Inertial Navigation, and Integration / Mohinder S. Grewal, Lawrence R. Weill, Angus P. Andrews. – John Wiley & Sons, 2007. – 416 p.

9. Parkinson W.D. *Introduction to Geomagnetism*, Edinburgh, UK: Scottish Academic Press., 1983.- 433 p.
10. Campbell W.H. *Introduction to Geomagnetic Fields*, Cambridge, UK: Cambridge University, 1997.- 290 p.
11. Jankowski J. and Sucksdorff C. *IAGA Guide for Magnetic Measurements and Observatory Practice*. Boulder, CO: International Association of Geomagnetism and Aeronomy Press, 1996.- 235 p.
12. Jacobs J.A. *Geomagnetism Volumes* respectively. London: Academic Press, 1987.- 1, 2, and 3, 627, 579, and 533 p.,
13. Jacobs J.A. *Geomagnetism Volume 4*. London: Academic Press, 1991.- 806 p.
14. Merrill R.T., McElhinny M.W., and McFadden P.L. *The Magnetic Field of the Earth*. London: Academic Press, 1996.- 531 p
15. NASA-Image Education and Public Outreach[Электронный ресурс]/ NASA Imager for Magnetopause-to-Auroral Global Exploration (IMAGE) . – Режим доступа: <http://image.gsfc.nasa.gov/poetry/> -доступ:20.10.2016.
16. Chulliat, A., S. Macmillan, P. Alken, C. Beggan, M. Nair, B. Hamilton, A. Woods, V. Ridley, S. Maus and A. Thomson, 2015, *The US/UK World Magnetic Model for 2015-2020: Technical Report*, National Geophysical Data Center, NOAA.
17. Clarke, E., O. Baillie, S.J. Reay, and C.W. Turbitt. A method for the near real-time production of quasi-definitive magnetic observatory data. *Earth Planets Space*, 2013.-65, 1363-1374p.
18. Kan, J.R. and L.C. Lee. Energy coupling function and solar wind magnetosphere dynamo. *Geophys. Res. Lett.*, 1979.- 6, 577–580p.
19. Langel, R.A. The main field. In *Geomagnetism*, edited by J.A. Jacobs, Academic Press, 1987.-249-512p.
20. Lühr, H. and S. Maus. Solar cycle dependence of quiet-time magnetospheric currents and a model of their near-Earth magnetic fields. *Earth Planets Space*, 2010.-62, 843-848p

21. Friis-Christensen, E., H. Lühr and G. Hulot, 2006. Swarm: A constellation to study the Earth's magnetic field. *Earth Planets Space*, 58, 351-358.
22. Olsen, N., L. Toffner-Clausen, T.J. Sabaka, P. Brauer, J.M.G. Merayo, J.L. Jørgensen, J.-M. L ger, O.V. Nielsen, F. Primdahl and T. Risbo. Calibration of the Orsted vector magnetometer. *Earth Planets and Space*, 2003.-55, 11-18p.
23. Peltier, A. and A. Chulliat. On the feasibility of promptly producing quasi-definitive magnetic observatory data. *Earth Planets Space*, 2010.-62p.
24. Thomson, A.W.P. and V. Lesur. An improved geomagnetic data selection algorithm for global geomagnetic field modelling. *Geophys. J. Int.*, 2007.-169, 951-963p.
25. Thomson, A.W.P., B. Hamilton, S. Macmillan and S.J. Reay. A novel weighting method for satellite magnetic data and a new global magnetic field model. *Geophys. J. Int.*, 2010.-181, 250-260p.
26. Macmillan, S. Observatories, Overview. In *Encyclopedia of geomagnetism and paleomagnetism*, edited by D. Gubbins and E. Herrero-Bervera, Springer, 2007.-708-711p.
27. Macmillan, S. and N. Olsen. Observatory data and the Swarm mission. *Earth Planets Space*, 2013.-65, 1355-1362p.
28. Maus, S. and P. Weidelt. Separating magnetospheric disturbance magnetic field into external and transient internal contributions using 1D conductivity model of the Earth. *Geophys. Res. Lett.*, 2004.-31p.
29. Maus, S. and H. L hr. Signature of the quiet-time magnetospheric magnetic field and its electromagnetic induction in the rotating Earth. *Geophys. J. Int.*, 2005.-162, 755-763p.
30. Maus, S., F. Yin, H. L hr, C. Manoj, M. Rother, J. Rauberg, I. Michaelis, C. Stolle and R. D. M ller. Resolution of direction of oceanic magnetic lineations by the sixth-generation lithospheric magnetic field model from CHAMP satellite magnetic measurements. *Geochem. Geophys. Geosyst.*, 2008.-9p.

31. Maus, S. et al. EMAG2: A 2-arc min resolution Earth Magnetic Anomaly Grid compiled from satellite, airborne, and marine magnetic measurements. *Geochem. Geophys. Geosyst.*, 2009.-10p.
32. Brand T. et. al, *Foot-to-Foot Range Measurement as an Aid to Personal Navigation*, Proc. ION 59th AM. Albuquerque, NM, 2003.- 113-125p.
33. Seo J. et al, *Bias Suppression of GPS Measurement in Inertial Navigation System Vertical Channel*, Proc. of IEEE/ION PLANS, 2006.-143-147p.
34. Kaser, J. and C. Hutchinson, "The OMEGA Navigation System—An Overview," *IEEE Communication Society Magazine*, 1978.-23-35p.
35. Pachter, M. and Porter, A., Bearings-only Measurements for INS Aiding: The Three-Dimensional Case, In Proceedings of the 2003 AIAA Guidance, Navigation and Control Conference, 2003, AIAA 2003.--5354p.
36. Barbour, N. and Schmidt, G., "Inertial Sensor Technology Trends," *IEEE Sensors Journal*, Vol. 1, No.4, 2001.- 332-339p.
37. Fontana, R. and Latterman, D., "GPS Modernization and the Future," *ION 56th Annual Meeting*, San Diego, CA, June 2000. Also see *Aviation Week & Space Technology*, September 23, 2002.- 56-58p.
38. Draper, C. S., "Origins of Inertial Navigation," *Journal of Guidance and Control*, Vol. 4, No. 5, 1981.- 449-463p.
39. Parkinson, B., "Origins, Evolution, and Future of Satellite Navigation," *Journal of Guidance, Control and Dynamics*, Vol. 20, No. 1, 1997.-11-25p.
40. Gustavson, T. et al., "Rotation Measurements with an Atom Interferometric Gyroscope," *Physical Review Letters*, Vol. 78, No. 11, 17 March 1997.-2046-2049p.

APPENDIX A

Program code for matlab software

```

clc
clear all
close all
tic
load travel_nau_02.mat;

time_ori=ori(:,1);
azimut=ori(:,2);
pith=ori(:,3);
v=find(pith<0);
pith(v)=360+pith(v);
roll=ori(:,4);
b=find(roll<0);
roll(b)=360+roll(b);

time_m=magnetic_xyz(:,1);
mx=magnetic_xyz(:,2);
my=magnetic_xyz(:,3);
mz=magnetic_xyz(:,4);

time_loc=location(:,1);
lon=location(:,3);
lat=location(:,4);
alt=location(:,5);

%coordinat interpolation for sensors data

start_tim=min(time_loc);
m=find(time_m>start_tim);
start_time=time_m(m(1));
figure('Color','white','Name','coordinats interpolation');
lon_s=interp1(time_loc,lon,time_m(m(1):length(time_m)));
subplot(2,1,1)
plot(time_loc,lon,'or',time_m(m(1):length(time_m)),lon_s,'>g')
legend('GPS data','interpolation')
title('longitude interpolation')
subplot(2,1,2)
lat_s=interp1(time_loc,lat,time_m(m(1):length(time_m)));
plot(time_loc,lat,'or',time_m(m(1):length(time_m)),lat_s,'>g')
legend('GPS data','interpolation')
title('latitude interpolation')

%body to ned transformation
poin=length(lon_s)-100;
for i=1:poin

    C=[sind(azimut(i)).*cosd(pith(i)), cosd(roll(i))*cosd(azimut(i))+sind(roll(i))*sind(azimut(i))*sind(pith(i)),-
sind(roll(i))*cosd(azimut(i))+cosd(roll(i))*sind(azimut(i))*sind(pith(i)); cosd(azimut(i)).*cosd(pith(i)), -
cosd(roll(i))*sind(azimut(i))+sind(roll(i))*cosd(azimut(i))*sind(pith(i)),
sind(roll(i))*cosd(azimut(i))+cosd(roll(i))*cosd(azimut(i))*sind(pith(i)); sind(pith(i)), -sind(roll(i))*cosd(pith(i)), -
cosd(roll(i)).*cosd(pith(i))];
    NED=C*[mx(i),my(i),mz(i)];
    xn(i)=NED(1);
    yn(i)=NED(2);

```

```

    zn(i)=NED(3);
end

d=atand(yn./xn);
h=sqrt(xn.^2+yn.^2);
inc=atand(zn./h);

figure('Color','white','Name','Magnetic field parameters');
subplot(4,1,1);
plot(time_ori(1:poin)',d);
grid on;
xlabel('time,s');
ylabel('declination');
title('dependence of declination form time');

subplot(4,1,2);
plot(time_ori(1:poin)',inc);
grid on;
xlabel('time,s');
ylabel('inclination');
title('dependence of inclination from time');

subplot(4,1,3);
plot(time_ori(1:poin)',zn(1:poin));
grid on;
xlabel('time,s');
ylabel('vertical component');
title('dependence of vertical component form time');

subplot(4,1,4);
plot(time_ori(1:poin)',h);
grid on;
xlabel('time,s');
ylabel('horizontal component');
title('dependence of horizontal component form time');

acur=10;
x=lat_s(1:acur:poin);
y=lon_s(1:acur:poin);
z=d(1:acur:poin)';

[xx, yy] = meshgrid(linspace(min(x),max(x),40), linspace(min(y),max(y),40));
zz = griddata(x,y,z,xx,yy);

zi=inc(1:acur:poin)';
zzi = griddata(x,y,zi,xx,yy);

zh=h(1:acur:poin)';
zzh = griddata(x,y,zh,xx,yy);

zn=zn(1:acur:poin)';
zzn = griddata(x,y,zn,xx,yy);

figure('Color','white','Name','Sensors data');
subplot(2,2,1);
surf(xx,yy,zz);
axis([min(x),max(x) min(y),max(y)])
xlabel('latitude,deg');
ylabel('longitude,deg');
zlabel('declination,deg');
title('DECLINATION');

```

УКРАЇНА



ДЕРЖАВНА СЛУЖБА **ВЛАСНОСТІ УКРАЇНИ**

ІНТЕЛЕКТУАЛЬНОЇ

СВІДОЦТВО
про реєстрацію авторського права на твір

№ 56816

Комп'ютерна програма "Оцінювання характеристик магнітного поля Землі"
("LocalMag")

(вид, назва службового твору)

Автор(и) Остроумов Іван Вікторович, Миронюк Олена Олександрівна, Ничак Михайло Васильович

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

Авторські майнові права належать Національний авіаційний університет, пр-т Космонавта Комарова, 1, м. Київ, 03680

(повне ім'я фізичної та/або повне офіційне найменування юридичної особи, адреса)

09.10.2014

Дата реєстрації



M. V. Kovina

**Голова Державної служби
інтелектуальної
власності України
М.В. Ковіня**

ДЕРЖАВНА СЛУЖБА
ІНТЕЛЕКТУАЛЬНОЇ
ВЛАСНОСТІ УКРАЇНИ
Україна, 03680, МСП, м. Київ-35,
вул. Урицького, 45
Тел. (044) 494-06-06
Факс (044) 494-06-67
E-mail: post@sips.gov.ua



STATE INTELLECTUAL
PROPERTY SERVICE
OF UKRAINE
Ukraine, 03680, MSP, Kyiv-35,
45, Urytskogo str.
Tel. (044) 494-06-06
Fax (044) 494-06-67
E-mail: post@sips.gov.ua

РІШЕННЯ

ПРО РЕЄСТРАЦІЮ АВТОРСЬКОГО ПРАВА НА ТВІР

Державна служба інтелектуальної власності розглянула заяву
Національний авіаційний університет, пр-т Космонавта Комарова, 1, м. Київ, 03058
(повне ім'я фізичної або повне офіційне найменування юридичної особи, адреса)

заявка від 12.08.2014¹ № 57160

про реєстрацію авторського права на твір і прийняла рішення зареєструвати авторське право на службовий твір Комп'ютерна програма "Оцінювання характеристик магнітного поля Землі" ("LocalMag"); Остроумов Іван Вікторович, Миронюк Олена Олександрівна, Нічак Михайло Васильович; Національний авіаційний університет
(вид, повна, скорочена (за наявності) назва твору, повне ім'я, псевдонім (за наявності) автора (ів), повна офіційна назва роботодавця)

Внесення відомостей до Державного реєстру свідоцтв про реєстрацію авторського права на твір та видачу 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 на твір".

Якщо протягом трьох місяців від дати одержання заявником рішення про реєстрацію авторського права на твір Державна служба не одержала 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 Державною службою не проводиться.

Голова Державної служби
інтелектуальної власності



M. B. Kovinia

М.В. Ковіня