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LOCAL MAGNETIC FIELD DATA PROCESSING

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Abstract. *The article represents the methodology for estimation of the Earth's magnetic field characteristics for a particular area. It is proposed to use a group of sensors inside of a tablet or a cell phone as a measurement device. We used typical sensors raw data like pitch, roll, yaw (from gyros); components of magnetic field intensity vectors (from magnetometers); latitude, longitude, altitude (from global positioning sensor). We represent the result of intensity vector components estimation for particular area. It is stated that the most important characteristics of magnetic field are horizontal and vertical components of intensity vector and inclination and declination angles. In addition, we compared the received results with magnetic field forecast, according to the world magnetic model.*

Keywords: accelerometers; approximation; gyroscopes; magnetic field; magnetometers; mobile phone interpolation; polynomial; tablet.

1. Introduction

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. For example, in inertial navigation systems global magnetic field is used for sensors calibration. Characteristics of magnetic field are also used for rotation detection and angular speed calculation. Typically total magnetic field in some point of atmosphere is the sum of thee different components: main magnetic field, which is a result of geomagnetic process inside of the Earth core; external magnetic field, which is a result of sun influence, depends on current solar activity and usually is less than 5 % of total magnetic field; anomalous – a result of influence of different ground anomalous areas, which contains some ore deposits with magnetic characteristics in the Earth crust. However, some of magnetic anomalies are can not be described by ore deposits, for example "Big Atlantic anomaly". 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. Definitely, 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. With human-based part we can also include different electrical devices which can result in magnetic injection.

2. Analysis of research and publications

Nowadays different international programs investigate and monitor characteristics of magnetic field. National oceanic and atmospheric administration (NOAA), U.S. Geological Survey (USGS) [1], Swarm earth explorers by European Space Agency (ESA) investigate this problem, but in common way all of them are focused on global scale of magnetic field.

3. Aim of the work

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. As a result, non accurate model produce errors, which will be in result of positioning or heading error. In some cases influence of human-based field is very valuable for navigation purposes. That is why the aim of this work is to describe methodology of local magnetic field parameters measurement through the use of typical users equipment.

4. Sensors

Usually magnetic field is characterized by intensity vector. Intensity vector "T" is the sum of the vectors strengths of several fields [2]. Typically, the vector T is estimated from its projections, on the some Cartesian coordinate system (Tx, Ty, Tz components). In addition, two angles are important: declination(D) and inclination(I), which indicate position of intensity vector in space, horizontal TH and vertical Tz 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.

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.

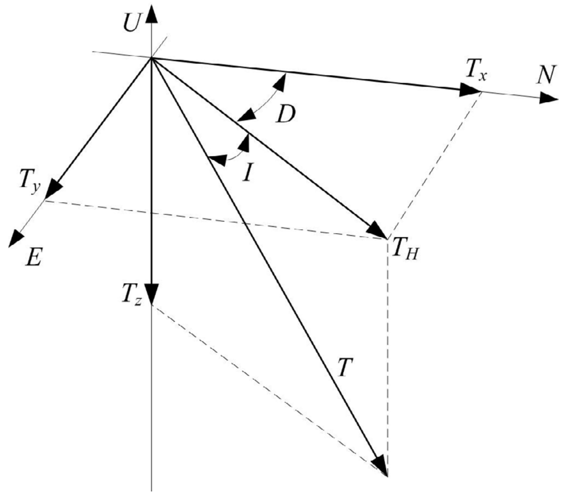

Fig. 1. Components of magnetic field intensity vector

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 Tx, Ty, Tz components of intensity vector), 3 gyroses (to detect angular position of tablet) and positioning sensor – GPS (Global Positioning System) 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 – Tx, Ty, Tz – components of magnetic field vector in nanotesla (nT), usually. With the help of Gyroscope – rotation angle data.

During an experiment were used a cell phone Samsung Galaxy I9300 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.

Trajectory of measurement and result of positioning is represented on fig. 2.

Fig. 2. Experimental trajectory by GPS data

5. Data transformation for the same time

Unfortunately different sensors inside 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 this time problem clear it is necessary to interpolate coordinates in order to unify sensors data time. The easiest way to do this is to use polynomial approximation. Let's use polynomial interpolation with mth order of the polynomial:

$$y = A_0 + A_1x + A_2x^2 + A_3x^3 + \ldots + A_mx^m,$$

where Ai are polynomial coefficients with i=0…m.

As a 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:

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

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

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

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

Let's represent it in matrix form:

$$A \times S = B ,$$

where

$$A = |A_0, A_1, \ldots A_m| ,$$

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

Then, polynomial coefficients will be calculated by the next formula

$$A = B \times inv(S) .$$

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.

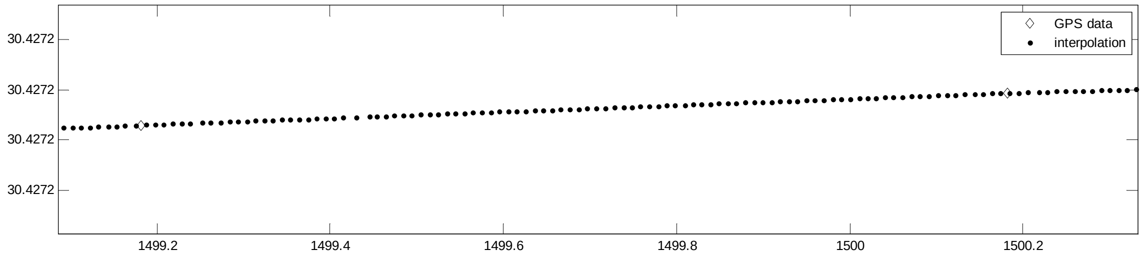

Fig. 3. Longitude Interpolation of GPS data

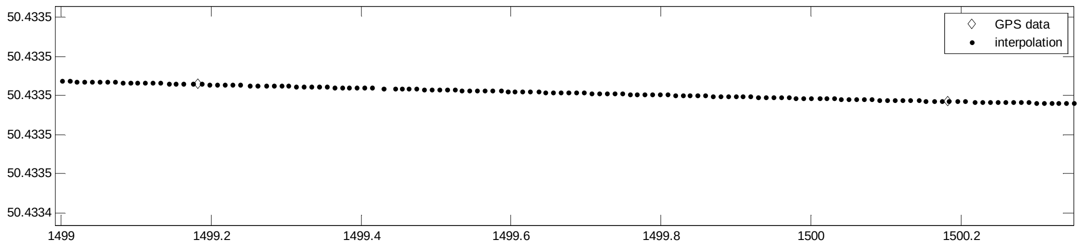

Fig. 4. Langitude Interpolation of GPS data

6. Transformation of coordinate systems

The input data are the result of measurement of sensors that located in the device. All measurements are performed in "Body" coordinate systems. Body coordinate system refers to the body of cell phone frame.

Center of Body coordinate system is usually located in the center of mobile phone. Axis *X* directed in front, *Y*- go to the right and *Z*- up by normal.

In result let's represent measurements in East-North-Up (ENU) coordinate system. The ENU coordinate system is a local system specific to any point on the Earth. It is formed from a plane tangent to the ellipsoid model surface at this point. The axis E is directed to the east, N to the north and U - up orthogonal to the tangent plane.

The coordinates transformation between Body and ENU is realized with the help of angular coordinates of device: pitch (θ), roll (φ) and yaw (ψ). Roll is the rotation around the front-to-back axis. Pitch is the rotation around the side-to-side axis. Yaw is the rotation around the vertical axis. Coordinates in ENU frame will process with transformation matrix by following equation [5, 475 p.

$$T_{ENU} = \begin{bmatrix} \sin(\psi)\cos(\theta) & \cos(\phi)\cos(\psi)+\sin(\phi)\sin(\psi)\sin(\theta) & -\sin(\phi)\cos(\psi)+\cos(\phi)\sin(\psi)\sin(\theta) \\ \cos(\psi)\cos(\theta) & -\cos(\phi)\sin(\psi)+\sin(\phi)\cos(\psi)\sin(\theta) & \sin(\phi)\cos(\psi)+\cos(\phi)\cos(\psi)\sin(\theta) \\ \sin(\theta) & -\sin(\phi)\cos(\theta) & -\cos(\phi)\cos(\theta) \end{bmatrix} \times T_b$$

where $T_b = \begin{bmatrix} T_{xb} \\ T_{yb} \\ T_{zb} \end{bmatrix}$ – matrix of magnetic field components in body coordinate system;

$T_{ENU} = \begin{bmatrix} T_{xENU} \\ T_{yENU} \\ T_{zENU} \end{bmatrix}$ – matrix of magnetic field components in ENU coordinate system.

7. Evaluation of the magnetic field

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:

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

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

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

Horizontal component of intensity vector of magnetic field:

$$T_{HENU} = \sqrt{T_{xENU}^{\ 2} + T_{yENU}^{\ 2}}\ .$$

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. 5-8).

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 9 to 12).

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.13-16.

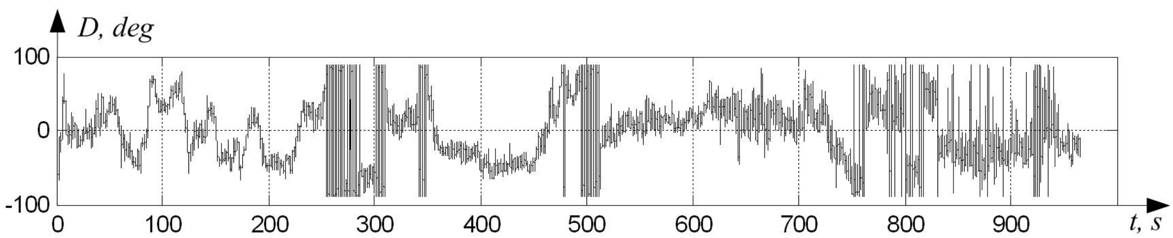

Fig. 5. Declination during movement

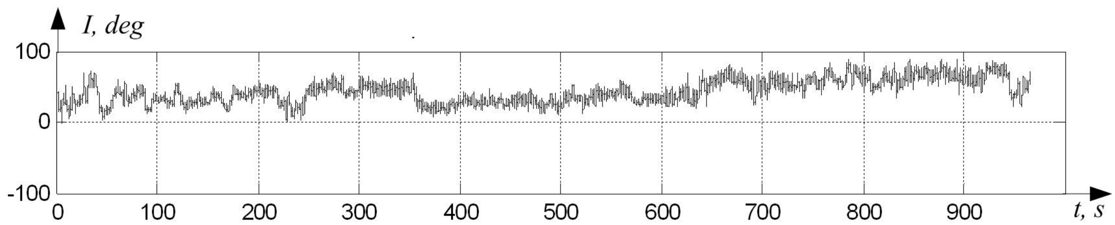

Fig. 6. Inclination during movement

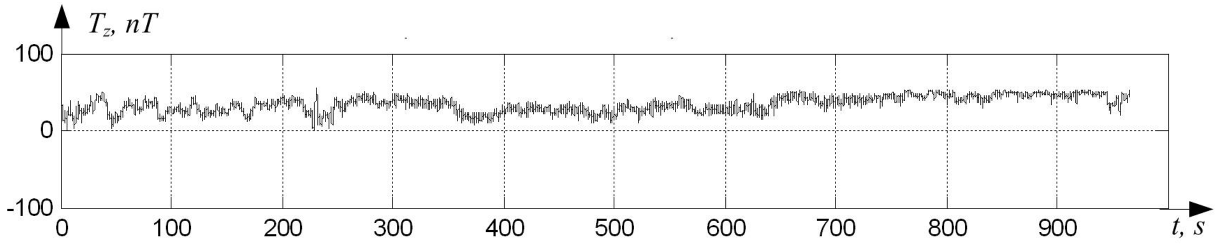

Fig. 7. Vertical component of intensity of Magnetic field vector

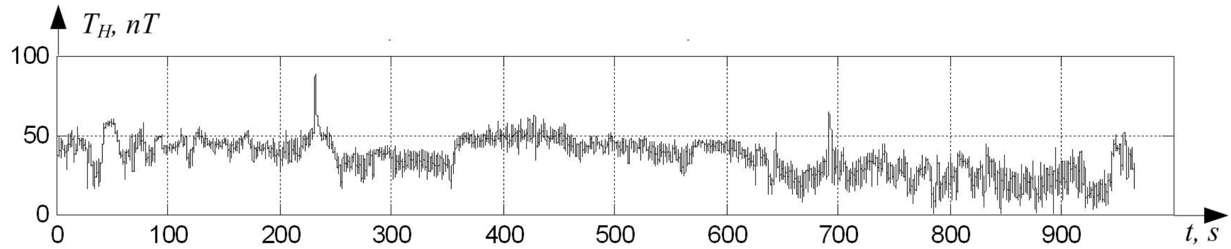

Fig. 8. Horizontal component of intensity of Magnetic field vector

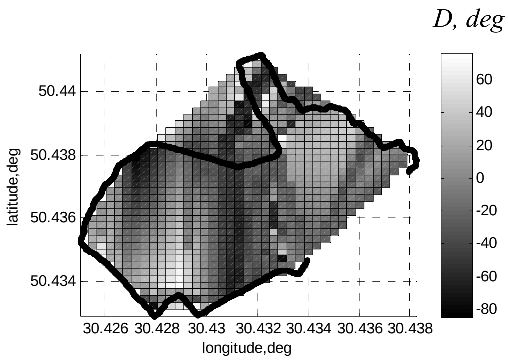

Fig. 9. Declination surface interpolation

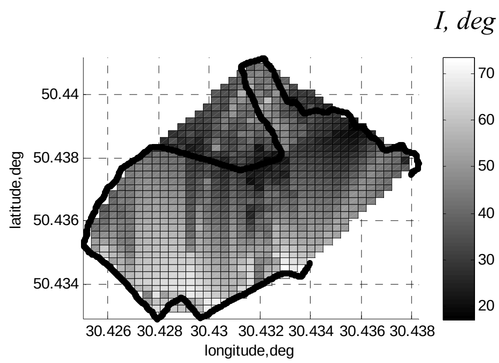

Fig. 10. Inclination surface interpolation

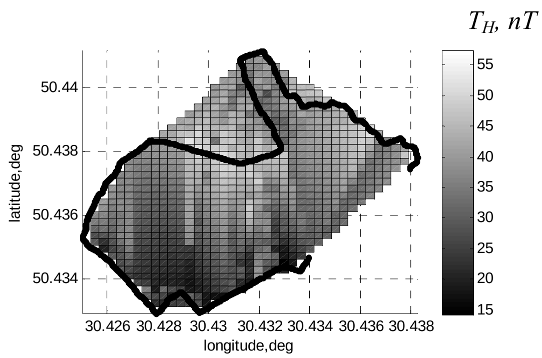

Fig. 11. Horizontal component of intensity of Magnetic field vector surface interpolation

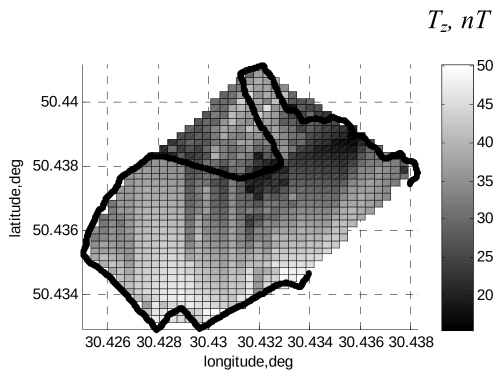

Fig. 12. Vertical component of intensity of Magnetic field vector surface interpolation

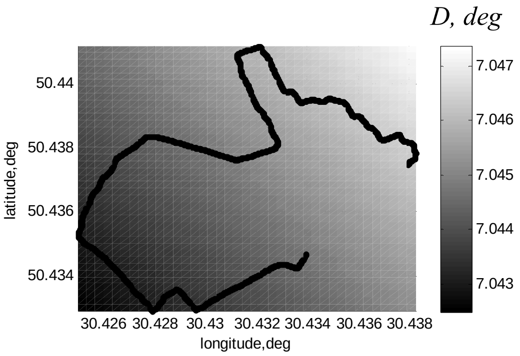

Fig. 13. Declination surface interpolation

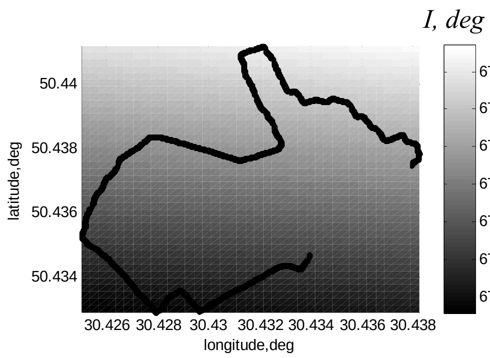

Fig. 14. Inclination surface interpolation

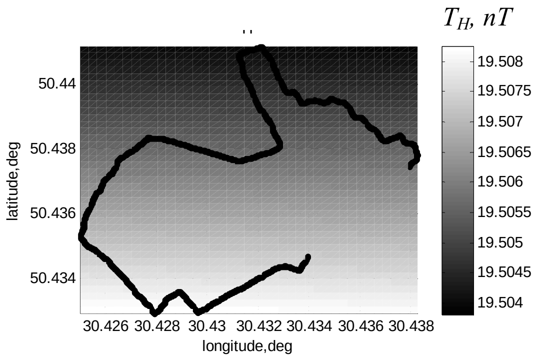

Fig. 15. Horizontal component of intensity of Magnetic field vector surface interpolation

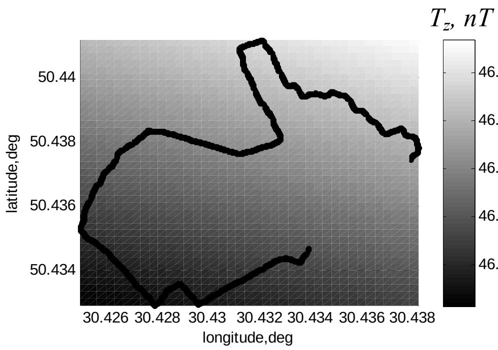

Fig. 16. Vertical component of intensity of Magnetic field vector surface interpolation

8. Conclusions

Results of work indicate that mobile phone sensors can be used for real time magnetic field characteristics estimation. Parameters of Earth's magnetic field: declination (fig. 9), inclination (fig. 10), intensity, horizontal (fig. 11) and vertical (fig. 12) components are extremely important for navigation purposes. Represented methodic of these parameters evaluation shows the cheapest way to improve navigation equipment functionality. Result of interpolation has been verified with forecasts by international world magnetic model.

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І. В. Остроумов[1], О. О. Миронюк[2], М. В. Ничак[3]. Обробка даних локальних вимірювань магнітного поля
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Статтю присвячено розробці методології оцінювання характеристик магнітного поля Землі для певного регіону. У якості вимірювального пристрою запропоновано використовувати групу датчиків розміщених усередині планшетного комп'ютера або мобільного телефону. У роботі було використано типові датчики, які вимірюють кути тангажу, крену, рискання (гіроскопи); компоненти векторів напруженості магнітного поля (отримуються від магнітометрів); широту, довготу, висоту над рівнем моря (від глобальної системи супутникового позиціонування). Наведено результати оцінювання компонентів вектора інтенсивності магнітного поля для певної території. Найважливішими характеристиками магнітного поля є горизонтальні й вертикальні компоненти вектора напруженості, а також кути магнітного нахилу та схилення. Отримані результати були порівнянні з прогнозом характеристик магнітного поля за моделлю магнітного поля.

Ключові слова: акселерометр; апроксимація; гіроскоп; інтерполяція; магнітне поле; магнітометр; мобільний телефон; планшет; поліном.

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Статья посвящена разработке методологии оценки характеристик магнитного поля Земли для определенного региона. В качестве измерительного устройства предложено использовать группу датчиков расположенных в середине планшетного компьютера или мобильного телефона. В работе использовались типовые датчики, измеряющие углы тангажа, крена, рыскания (гироскопы); компоненты векторов напряженности магнитного поля (получаемые от магнитометров); широта, долгота, высота над уровнем моря (от глобальной системы спутникового позиционирования). Представлены результаты оценивания компонентов вектора интенсивности магнитного поля для определенной территории. Наиболее важные характеристики магнитного поля: горизонтальные и вертикальные компоненты вектора напряженности, а также углы магнитного наклонения и склонения. Полученные результаты были сопоставимы с прогнозом характеристик магнитного поля по модели магнитного поля.

Ключевые слова: аппроксимация; акселерометр; гироскоп; интерполяция; магнитное поле; магнітометр; мобильный телефон; планшет; полином.

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