Information system for positioning and orienting antenna system

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Abstract

A microprocessor-based computer system using triaxial accelerometers and magnetometers mounted on the moving part of the antenna has been proposed, along with a methodology for determining the position of the antenna installation axis in space, with magnetic azimuth correction via the Internet. A mathematical model has been used, which includes matrix transformations of the coordinates of the Earth's acceleration and magnetic field vectors. A prototype of the system was created using inexpensive components, and its operation was tested.

Keywords

accelerometer, magnetometer, antenna system, spatial orientation, matrix transformations.

1. Introduction

Nowadays, various navigation systems for stationary and mobile devices (land, air, and surface) have been developed significantly, enabling the determination of an object's position, direction, and speed, as well as its displacement from the horizontal plane (lateral and longitudinal tilts). An important task for certain positioning systems, such as antenna posts, is to determine the true azimuth and elevation angle of the antenna system's radio-technical axis, given an arbitrary placement of the base and its potential movement in space and longitudinal and transverse oscillations. The conventional existing systems are generally based on the outdated methods using gyroscopes, stabilizing platforms, and single-axis inclinometers. More modern systems are equipped with electronic triaxial magnetometers (compasses) and accelerometers, positioning systems like GPS (or similar), and are controlled via microcontrollers. They have the capability to network or transmit data to external PCs or the cloud. Based on this, the development of a structural-functional scheme and algorithm for a modern positioning and aiming system, applicable in antenna technology, is an urgent issue. However, such a system can also be used for low-speed moving objects in field conditions (pedestrians, vehicles, aerial drones, boats, etc.). The main requirements are to ensure accurate movement and positioning amid various disturbances—such as uneven ground, wind loads, and water surface waves.

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2. Objective of the Paper

The creation of a computer-based microprocessor system that can operate in field conditions and provide the necessary accuracy in determining specified directions in space for an antenna system. This system should not require additional sensors for the axes positions of the antenna's support-turning device. Additionally, the work aims to establish dependencies for determining these positions through the indicators of magnetic field sensors and gravitational force in three-dimensional space.

3. Main part

The proposed system consists of the following main components: a rigid non-magnetic platform on which triaxial accelerometers and magnetometers are mounted and rigidly fixed, ensuring their spatial alignment, a GPS navigation system, a microcontroller for processing data from all systems, and an interface part designed for communication with an external computer (RS232, LAN, Wi-Fi, Bluetooth) or a mobile communication transmitter (LTE, 4G). The structural diagram is shown in Figure 1.

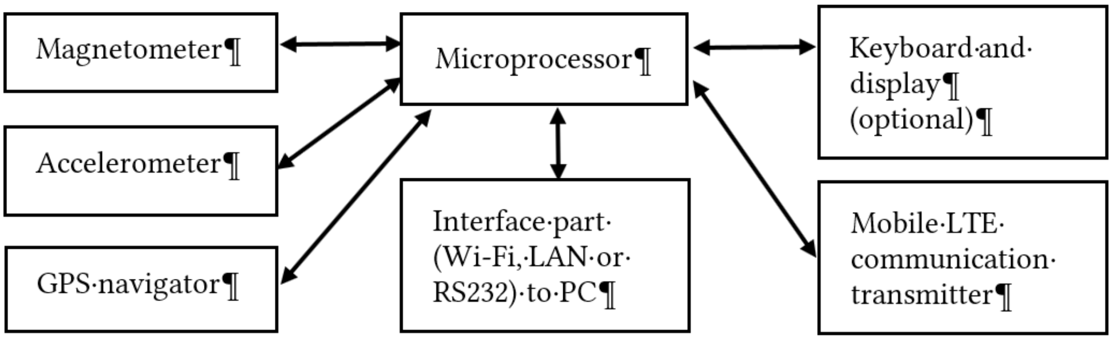

Figure 1: The structural diagram of the proposed system.

We assume that the sensors (accelerometer and magnetometer) are calibrated for sensitivity and measurement direction using methods described in the literature [1 - 3], and the correction parameters are stored in the microcontroller's memory. The rigid platform is fixedly mounted on the antenna installation so that its *X*-axis aligns with the antenna axis direction.

Let us consider the mutual arrangement of the coordinate system of the displaced sensor and the stationary coordinate system, where the horizontal plane *XOY* is parallel to the Earth's surface. The *X*-axis is directed along the antenna axis, as shown in Figure 2.

It is known that the direction of Earth's gravitational acceleration is always downward, perpendicular to the Earth's surface, and the direction of the projection of the Earth's magnetic field vector is directed with a certain error towards the north. The above-mentioned error can be compensated using magnetic declination tables, which should be stored in the microcontroller's memory, depending on the coordinates of the observation point, or transmitted over the Internet from an appropriate database. For this purpose, data from the GPS positioning system are used.

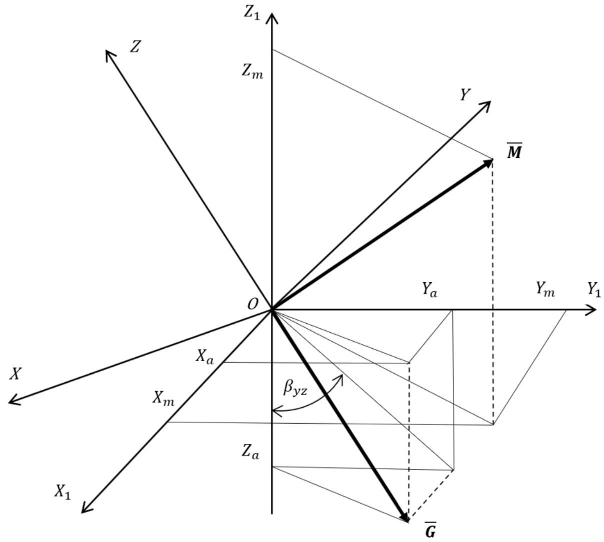

Figure 2: The coordinate system of the displaced sensor.

To align the displaced coordinate system with the stationary one, it is necessary to rotate the $X_1Y_1Z_1$ coordinate system relative to each axis so that the gravitational acceleration vector, recorded in the moving coordinate system

$$G = \begin{vmatrix} X_a \\ Y_a \\ Z_a \end{vmatrix} \tag{1}$$

co-linearly aligned with the Z-axis of the stationary coordinate system. Rotating by the specified angles will align the shifted system with the stationary one, and the corresponding components of the magnetic field vector in the XOY plane of the stationary coordinate system will allow for the calculation of the true magnetic azimuth of the antenna system direction.

From Figure 2, it is evident that the first rotation needs to be performed around the OX_1 axis to align the projection of vector $\boldsymbol{G}$ (1) with the Z_1 axis by an angle β_{yz}. After this rotation, vector $\boldsymbol{G}$ will lie in the XOZ plane. The second rotation needs to be performed in this plane around the Y_1 axis to align vector $\boldsymbol{G}$ with the Z_1 axis by an angle β_{xz}.

The specified rotation angles are calculated using the formulae

$$\beta_{yz} = \arctan\left(\frac{Y_a}{Z_a}\right)$$

$$\beta_{xz} = \arcsin\left(\frac{X_a}{|G|}\right) \tag{2}$$

where the magnitude of vector $\boldsymbol{G}$ is calculated using the formula

$$|G| = \sqrt{X_a^2 + Y_a^2 + Z_a^2}$$

To determine the components of the magnetic field vector in a stationary coordinate system, we will rotate this vector by the calculated angles using a matrix transformation [4] of the form

$$M_R = T_2 \times T_1 \times M \tag{3}$$

where T_2 and T_1 are respectively, rotation matrices by angles β_{xz} and β_{yz} (2).

These rotation matrices take the following form

$$T_1 = \begin{vmatrix} 1 & 0 & 0 \\ 0 & \cos(\beta_{yz}) & \sin(\beta_{yz}) \\ 0 & -\sin(\beta_{yz}) & \cos(\beta_{yz}) \end{vmatrix}$$

$$T_2 = \begin{vmatrix} \cos(\beta_{xz}) & 0 & \sin(\beta_{xz}) \\ 0 & 1 & 0 \\ -\sin(\beta_{xz}) & 0 & \cos(\beta_{xz}) \end{vmatrix}$$

The column vector of the magnetic field components in the shifted coordinate system can be written as follows

$$M = \begin{vmatrix} X_m \\ Y_m \\ Z_m \end{vmatrix} \tag{4}$$

where X_m, Y_m and Z_m are measured magnetic axial values.

$$M_R = \begin{vmatrix} X_{mR} \\ Y_{mR} \\ Z_{mR} \end{vmatrix}$$

The vector-column M_R (3) obtained as a result of matrix multiplication of vector ***M*** (4) will have known components, oriented in the stationary coordinate system

$$Az = \arctan\left(\frac{Y_{mR}}{X_{mR}}\right)$$

Since the specified components of the magnetic field X_{mR} and Y_{mR} lie in the horizontal plane, the azimuth angle of the antenna axis, directed along the *OX* axis, is determined by the formula:

The azimuth value should be corrected for a full circle, taking into account the signs of the numerator and denominator in different angular quadrants.

$$El = \arcsin\left(\frac{X_a}{|G|}\right)$$

The elevation angle of the antenna axis direction is determined as the ratio of the component X_a of the gravitational acceleration vector in the shifted coordinate system to its magnitude taking into account that, the elevation angle of the antenna installation should not exceed the range of (-90 ...+90) degrees.

4. Discussion

A distinctive feature of the proposed antenna positioning system is the connection with an external computer or network database. This database, using known GPS coordinates, determines the shift of the magnetic field vector Az_m , which changes over time and is constantly updated in the corresponding databases. Therefore, the true azimuth is corrected accordingly

$$Az_R = Az + Az_m$$

Correction of the magnetic field vector can be performed in the field using other methods, recording the obtained result into the microcontroller's memory via an external computer.

To improve measurement accuracy and result stability, the well-known digital noise filtering methods should be applied. These range from the simplest, such as averaging or using a specific window function, to more complex methods like the Kalman filter.

Based on the proposed antenna system positioning methodology, a device has been developed that consists of an **ADXL345** accelerometer [6], a **HMC5883** magnetometer [7], a **u-blox M10** GPS signal receiver {8], and a **Quectel M66** mobile communication modem [9], all integrated on a **NUCLEO** microprocessor board based on the **STM32F042K6T6** chip. An RS485 interface has been used for data transmission to the computer, demonstrating high reliability in field conditions.

Verification of the specified device after calibrating the magnetometer and accelerometer using digital signal filtering methods demonstrated sufficient accuracy for practical applications in decimeter-wave antenna technology, with target indications within 2 degrees.

5. Conclusions

The developed microprocessor computer system has demonstrated sufficient accuracy in measuring the position of the object and can be applied in field conditions both for orienting the support-turning device of the antenna system and for other similar systems, such as spotlight lighting, mobile device direction control, recording the trajectory of object movement, and others.

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