Determining the Yaw Angle of a Moving Object Using Modern Electronic Devices

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Abstract **— The navigation of a moving object requires knowledge of its direction of movement—the course. This research investigates the determination of the northern direction using electronic devices. The course of movement is determined through the northern direction. In this study, there are no restrictions placed on the position of the moving object in space. When the plane of movement is horizontal, the northern direction is determined using two axes of the magnetometer located in the horizontal plane. When the object's movement is not horizontal, the projection of the vector that determines the northern direction onto the horizontal plane has been found. To solve the posed problem, a system consisting of an accelerometer and a magnetometer sensor has been created on the Arduino Uno microcontroller platform. The position of the object in space is determined using the accelerometer. Depending on the spatial position, the method for finding the northern direction using the magnetometer is provided.**

Keywords — North direction, course angle, horizontal plane, accelerometer, magnetometer.

I. Introduction

One of the main issues in the control and navigation of various moving objects is the accurate determination of the direction of movement. The problem of correctly identifying the direction of movement has been one of the main challenges not only in our time but also in ancient times. In ancient times, people primarily relied on natural landmarks, especially stars and celestial bodies, to find their direction. Stars, particularly the North Star and other star groups, were the most important tools for navigation in ancient times. Accurately determining the direction towards the North Star allowed for the correct identification of the direction of movement.

Over time, alongside the development of modern technologies, the tools used to determine direction have also changed. Starting from the Middle Ages, the compass began to be used. The compass, as is known, is a device that indicates the northern direction based on the characteristics of the Earth's magnetic field. The working principle of the compass is related to the influence of the Earth's magnetic field on the compass needle. This technological development has played a significant role in the expansion of geographical discoveries and trade relations around the world.

Currently, these historical methods are combined with more modern and precise solutions. There are various approaches to solving these problems, one of which is the use of sensor technologies. This article describes the working principle of a sensor system placed on the Arduino Uno microcontroller platform for finding the north direction. In this system, magnetometer and accelerometer sensors have been used to determine the north direction.

During the research, the HMC5883L magnetometer and MPU6050 accelerometer were used as three-axis sensors, measuring the intensity of the magnetic field and the loads experienced by the object due to the forces acting on it along each received coordinate axis, respectively. The data obtained from the magnetometer is used to determine the north direction, while the accelerometer is used to determine the orientation status of the object.

When both sensors are placed on a moving object, they work together to determine the direction of movement in real time relative to the geographical north direction in space. Whether the intensity of the magnetic field or the loads are vector quantities, they are measured with respect to the local coordinate system of the corresponding sensor. For the operation of this technology, the axes of the local coordinate systems of the magnetometer and accelerometer are aligned parallel to each other (Figure 1). This approach ensures the alignment of angular data across the sensors, allowing the direction of the object's movement to be determined based on the obtained results.

II. Problem Statement

The knowledge of the north direction allows for determining the direction of an object's movement relative to this direction. The main objective of this research is to determine the course angle of a moving object using accelerometer and magnetometer sensors, specifically the angle between the projection of the object's displacement vector onto the horizontal plane and the north direction.

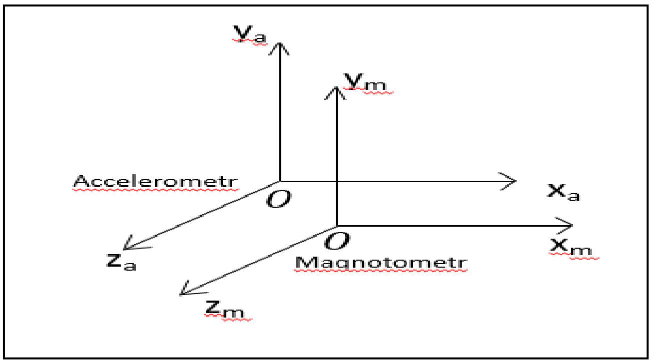

Fig. 1. Placement of the coordinate axes of the accelerometer and magnetometer

The data obtained from the accelerometer represent the components of the loading force acting on the object along x_a, y_a, and z_a axes in relation to the local coordinate system of the accelerometer, while the data obtained from the magnetometer express the components of the Earth's magnetic induction vector along x_m, y_m, and z_m axes in relation to the local coordinate system of the magnetometer. This data is analyzed together in a structure where the coordinate axes of both sensors are arranged in parallel and established in a Descartes coordinate system. The Descartes coordinate system is a fundamental mathematical framework consisting of three main axes (X, Y, Z) that describes the position of objects. In this system, the Y axis is defined towards the front of the object moving from the coordinate center, the Z axis is directed upwards from the coordinate center, and the X axis is oriented to the right from the coordinate center. The coordinate axes are arranged perpendicularly to each other. Let's define the global coordinate system as follows. The global coordinate system is a three-axis coordinate system where each axis is arranged perpendicularly to the others, forming a Descartes coordinate system. The Y_g axis of the global coordinate system is directed from the defined coordinate center towards the North Pole, the Z_g axis is directed upwards from the Earth's surface, and the X_g axis is oriented along the East direction from the coordinate center. The global coordinate system is illustrated in Figure 2.

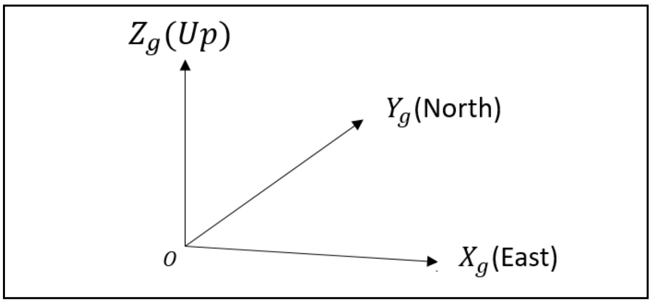

Fig. 2. Description of the global coordinate system

As a result, it becomes possible to determine on which plane the object's movement direction vector lies, whether it is on the $x_a y_a$, $Ox_a z_a$ or $Oy_a z_a$ plane, and to calculate the course angle. The course angle is calculated based on the values of the magnetic induction vector obtained from the magnetometer along the x_m, y_m and z_m axes. Both the north direction and the movement direction are defined with respect to the global coordinate system.

In addition to the northern direction and the direction of movement, the Krılov angles are also calculated with respect to the global coordinate system.

The Krilov angles consist of three main angles that describe the orientation of objects—pitch, yaw, and roll. Pitch is the rotation around the X-axis, meaning the upward or downward rotation of the object's front part around its center of gravity; yaw is the rotation around the Y-axis, meaning the upward and downward movement of the wings; and roll is the rotation around the Z-axis, meaning the rotation of the object's front part in the clockwise or counterclockwise direction. Figure 3 depicts the Krlov angles. These angles determine the spatial position of objects. When using the Krilov angles, the sequence must be followed. Specifically, the sequence should be first the rotation around the Z-axis, yaw; then the rotation around the Y-axis, pitch; and finally, the rotation around the X-axis, roll.

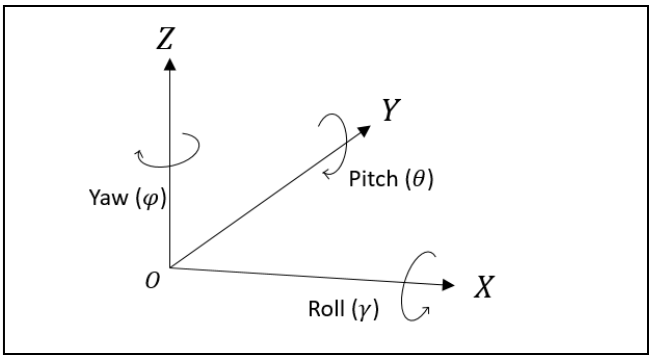

Fig. 3. Example of Krılov angles

The analysis of accelerometer and magnetometer data plays a key role in determining the object's position in which plane and its course angle. This methodology allows for the determination of the object's orientation by analyzing the data.

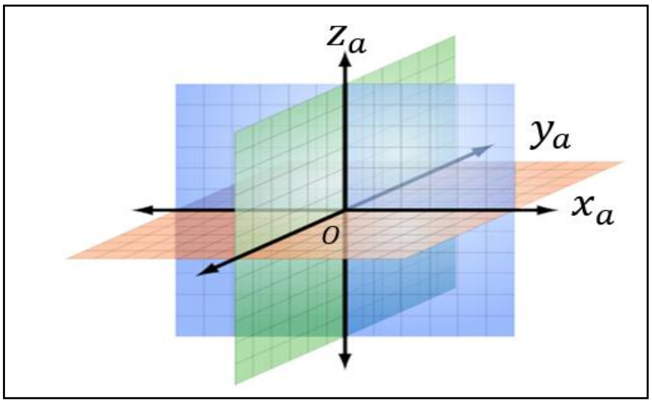

Fig. 4. The planes created by the coordinate system of the accelerometer.

III. Metod Method for Determining the Course Angle of an Object

In the research work examined, two cases have been considered for calculating the direction of the object's movement.

In the simple case, the process of calculating the north direction has been carried out based on the specified conditions. In the simple case, the local coordinate system has been parallelized to the global coordinate system. In this case, the plane in which the object is located is defined. That plane is determined to be parallel to the horizontal plane. The horizontal plane is understood to be the plane parallel to the global coordinate system. According to the global coordinate system, the plane parallel to the ground is the OX_gY_gplane. Therefore, in the simple case, the direction of movement is calculated in the OX_gY_g plane. In this case, the tangent and crane angles are considered to be equal to zero, as the object can only rotate around the Z_g axis. Based on the above conditions, a magnetometer sensor has been used to find the direction of movement. As noted, the magnetometer sensor is a 3-axis sensor that measures the values of the components of the magnetic induction vector along the local coordinate system's y_m , x_m , z_m axes. Based on the obtained data, the north direction is calculated according to the formula (1):

$$\varphi = \frac{180^\circ}{\pi} arctan\frac{x}{y} \tag{1}$$

In equation (1), the angle φ is the angle between the projection of the displacement vector onto the horizontal plane and the north direction. x_m and y_m are the components of the magnetic induction vector obtained from the magnetometer along those axes. In this case, the displacement vector is directed along the y_m axis. In equation (1), the result is converted from radians to degrees.

IV. Determination of the Horizontal Plane While the Object is in a Rotational State

In a complex case, the issue of determining the north direction in any position of the object must be resolved. The calculation of the north direction in a complex case can be carried out in two stages. The first stage involves selecting the plane with the least inclination relative to the horizontal plane. Since the magnetometer sensor is a 3-axis sensor and each axis is positioned perpendicular to the others, the coordinate axis pairs create three mutually perpendicular planes. Among these planes, the one with the least inclination relative to the horizontal plane is selected. To choose the plane with the least inclination relative to the horizontal plane from these three planes, the accelerometer sensor is used. Based on the accelerations obtained from the accelerometer sensor along each axis, the axis associated with the maximum magnitude of acceleration is considered the axis with the least inclination in the direction of free fall acceleration. The plane formed by the two axes perpendicular to this axis is considered the plane with the least inclination relative to the horizontal plane. When using this principle, the length of the acceleration vector is approximately taken to be 1.

$$|a| = \sqrt{a_x^2 + a_y^2 + a_z^2} \cong 1.$$

Here, a_x, a_y, a_z are the components of acceleration along the axes Ox_a, Oy_a və Oz_a, respectively, |a| is the length of the acceleration vector. After selecting the plane, the next stage involves determining the course angle. In this stage, the corresponding axes of the plane, determined based on the accelerometer, are selected, and the course angle is calculated based on the data obtained from the magnetometer sensor along those axes. The course angle is calculated based on formula (2).

$$\varphi = \frac{180^\circ}{\pi} arctan\frac{a}{b} \tag{2}$$

In formula (3), the variables a and b depend on which of the accelerometer coordinate planes of the magnetometer is projected onto the OX_gY_g plane.

The choices of the projections are as follows:

- If the plane Ox_my_m is projected onto the global coordinate system OX_gY_g, then: a = x, b = y;
- If the plane Oy_mz_m is projected onto the plane OX_gY_g: a = z, b = y;
- If the plane Ox_mz_m is projected onto the plane OX_gY_g: $a = z, b = x$.

Thus, the values of a and b are determined according to the plane selection, and the course angles are calculated based on those values.

V. Conculision

Thus, the research work proposes a system that allows for the determination of the north direction through sensors placed on the board of the flying object, regardless of its position in space. For this purpose, accelerometer and magnetometer sensors installed on the Arduino Uno microcontroller platform have been used. The accelerometer sensor is used to determine the spatial orientation state of the object. The magnetometer sensor is used to determine the north direction concerning the defined position of the object. The proposed technology is sufficiently simple and can be applied to determine the direction during the navigation of moving objects.

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