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Tilt-Induced-Error Compensation for 2-Axis Magnetic Compass with 2-Axis Accelerometer

Li Xisheng, Kang Ruiqing, Shu Xiongying, Yu Guanghua
University of Science and Technology Beijing, Beijing 100083, China

Abstract

This paper presents an efficient tilt compensation algorithm for the low cost two-axis magnetic compass. The general magnetic compass module consists of a three-axis magnetic compass and a two-axis inclinometer to calculate tilt-compensated azimuth information. In the interest of reducing the cost, a two-axis magnetic compass with a two-axis accelerometer is developed in this paper. The third-axis data of the magnetic compass is estimated using earth magnetic field information. The tilt-induced-error is compensated using the estimated data and measurement data. Results of experiment show that this algorithm can be used to realize tilt-compensation for 2-axis magnetic compass.

1. Introduction

The Earth's magnetic field intensity is about 20 to 50 A/m and has a component parallel to the Earth's surface that always point toward magnetic north [1-4]. This is the basis for all magnetic compasses. Magnetic compass has been used in navigation for centuries. Today, advances in technology have led to the solid state electronic compass based on MR magnetic sensors and acceleration based tilt sensors. Electronic compasses offer many advantages over conventional "needle" type or gimbaled compasses such as: shock and vibration resistance, electronic compensation for stray field effects, and direct interface to electronic navigation systems.

Most often compasses are not confined to a flat and level plane. They are often hand held, attached to an aircraft, or on a vehicle in an uneven terrain. This makes it more difficult to determine the azimuth, or heading direction, since the compass is not always horizontal to the earth's surface. Error introduced by tilt angles can be quite large depending on the amount of the dip angle. A typical method for correcting the compass tilt is to use an inclinometer, or tilt sensor, to determine the roll and pitch angles. Generally, the magnetic compass module consists of three magnetic sensors and two inclinometer, all used to compensate the tilt error. However, the price of the magnetic sensor for the third axis component is high. This restricts the application of 3-axis magnetic compass.

In this paper, a tilt compensation algorithm for a 2-axis magnetic compass with a 2-axis accelerometer is proposed. The third-axis data of the magnetic compass is estimated using earth magnetic field information. The tilt-induced-error is compensated using the estimated data and measurement data.

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2. Anistropic Magnetoresistive Sensor and Its Application to Electronic Compass

The anisotropic magnetoresistive (AMR) sensor is one type that lends itself well to the earth's field sensing range. AMR sensors can sense DC static fields as well as the strength and direction of the field. This sensor is made of a nickel-iron (Permalloy) thin film deposited on a silicon wafer and is patterned as a resistive strap. The properties of the AMR thin film cause it to change resistance in the presence of a magnetic field. Typically, four of these resistors are connected in a Wheatstone bridge configuration so that both magnitude and direction of a field along a single axis can be measured. For typical AMR sensors, the

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bandwidth is in the 1-5 MHZ range. The reaction of the magnetoresistive effect is very fast and not limited by coils or oscillating frequencies.

The electrical output of AMR sensor is proportional to the magnetic field strength along its sensitive axis. When an AMR sensor is spun around a horizontal plane starting from magnetic north, the output is a cosine function of the heading angle. A minimum of two sensors that are arranged mutually perpendicular would eliminate the ambiguity in electrical output with respect to heading direction as seen in Figure 1.

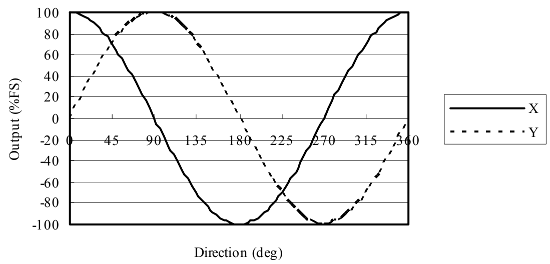

Figure 1. Output of two orthogonal magnetic sensors rotated horizontally in the earth's magnetic field showing Sine and Cosine functions

Figure 2 shows an electrical block diagram of electronic compass providing a numerical output of heading direction. Azimuth or the heading is calculated by the equations given below [1-8]

$$\alpha = \mathrm{arcTan}\left(\frac{Y}{X}\right) \tag{1}$$

The X sensor defines the forward direction and the Y sensor is to the right.

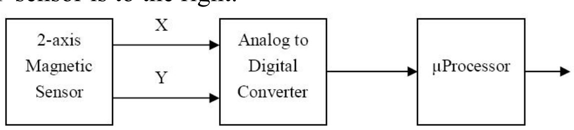

Figure 2. Functional block diagram of a two-axis compass without tilt compensation

This two-axis compass will perform well as long as it is kept horizontal and is useful in hand held applications. However, operation of the compass while it is not level can result in considerable amount of heading error.

3. Tilt-induced-error compensation for electronic compass

Most often compasses are not confined to a flat and level. If the compass were tilted, the tilt angles (pitch and roll) and three magnetic field components must be used to calculate heading [1-8]. An inclinometer, or tilt sensor, should be used to determine the roll and pitch angles. The terms roll and pitch are commonly used: ROLL refers to the rotation around the X-axis, or forward direction, and PITCH refers to the rotation around the Y-axis, or left-right direction.

The general magnetic compass module with tilt-induced-error compensation consists of a three-axis magnetic compass and a two-axis inclinometer to calculate tilt-compensated azimuth information [1-8]. However, the price of the magnetic sensor for the third axis component is high. This restricts the application of 3-axis magnetic compass. In this paper, the tilt-induced-error compensation of a two-axis magnetic compass with a two-axis accelerometer is realized. The Functional block diagram of proposed electronic compass is illustrated in figure 3. The two-axis magnetic compass is used to measure X and Y components of magnetic compass. The two-axis accelerometer is used to measure pitch and roll angle. The third-axis data of the magnetic compass is estimated using earth magnetic field information.

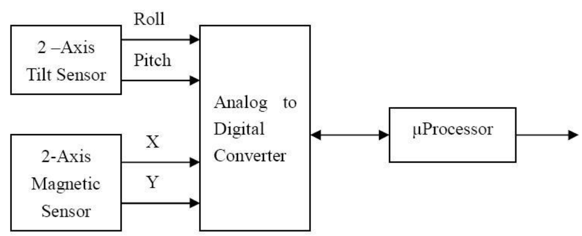

Figure 3. Function block diagram of proposed electronic compass

The procedure of tilt compensation is summarized as follows:

1) Z component calculation.

In this paper, only two magnetic sensor are used. In other word, only the X and Y components of the earth's magnetic field can be measured by using X and Y sensor. The Z component of the earth's magnetic field should be calculated by applying the following equation.

$$Z = \sqrt{H_{\mathrm{earth}}^2 - \left(X^2 + Y^2\right)} \tag{2}$$

where the initial value of H_{earth} is provide by the longitude and latitude, the value of H_{earth} is updated in step 5.

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$$Z = \sqrt{H_{\text{earth}}^2 - \left(X^2 + Y^2\right)} \qquad (3)$$

where the initial value of H_{earth} is provide by the longitude and latitude, the value of H_{earth} is updated in step 5.

3) Roll compensation.

According to the roll angle, roll compensation is done by applying the rotational equations shown below.

$$\begin{cases} X_{\text{rc}} = X \\ Y_{\text{rc}} = Y\cos(\theta) + Z\sin(\theta) \\ Z_{\text{rc}} = -Y\sin(\theta) + Z\cos(\theta) \end{cases} \qquad (4)$$

where θ is roll angle.

4) Horizontal and vertical magnetic components calculation.

After roll compensation, according to the pitch angle, the X, Y and Z magnetic components can be transformed back to the horizontal plane and vertical direction by applying the rotational equations shown below.

$$\begin{cases} X_{\text{h}} = X_{\text{rc}}\cos(\varphi) - Z_{\text{rc}}\sin(\varphi) \\ Y_{\text{h}} = Y_{\text{rc}} \\ Z_{\text{v}} = X_{\text{rc}}\sin(\varphi) + Z_{\text{rc}}\cos(\varphi) \end{cases} \qquad (5)$$

where φ is pitch angle. Horizontal and vertical magnetic components are gotten.

5) Azimuth calculation.

Once the X and Y magnetic components are in horizontal plane, the azimuth can be calculated by using the following equation.

$$\alpha = \text{arcTan}\left(\frac{Y_{\text{h}}}{X_{\text{h}}}\right) \qquad (6)$$

Therefore we can see that the tilt compensated azimuth can be computed using the sensor output of 2-axis magnetic compass with two-axis accelerometer.

4. Experimental results analysis

An experiment was carried out to verify the performance of proposed algorithm. Before doing this experiment, H_{earth} was calculated according to another 3-axis magnetometer. In order to cancel the influence of the sensitivity temperature coefficient, the sensitivity of AMR sensor is calibrated according to the sensitivity of the 3-axis magnetometer. In this experiment, Azimuth is set to 45°. Figure 4 and 5 show the experiment results. For figure 4, the roll angle was set to 10° and the pitch angle was changed. The range of the pitch angle is from -10° to 10°. For figure 5, the pitch angle was set to 10° and the roll angle was changed. The range of the roll angle is from -10° to 10°. The results show that the measurement error with compensation becomes smaller than that without compensation. In figure 4, the maximum measurement error without compensation (absolute value) is about 22°, that with compensation is about 0.5°.In figure 5, the maximum measurement error (absolute value) without compensation is about 22°, that with compensation is about 0.5°. Experimental results show that the azimuth error with compensation becomes rarely affected by the tilt angles. For magnetic compass not confined to a level, tilt-induced-error compensation must be done, otherwise the result of azimuth measurement will be unusable. The maximum azimuth error without tilt compensation may be greater than the sum of absolute values of pitch and roll angle, for example, in figure 4 the maximum azimuth error is about 22° and the maximum value of the sum of pitch and roll angle is 20°. The tilt angles will contribute the largest percentage of error to the azimuth measurement.

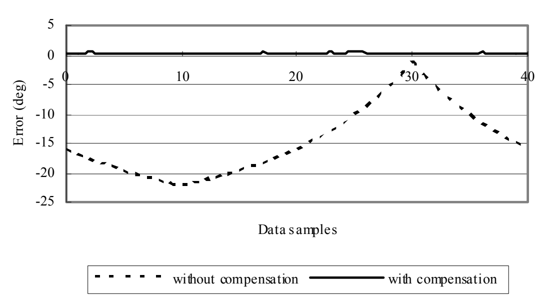

Figure 4. Azimuth error with and without tilt compensation (Roll angle: 10°)

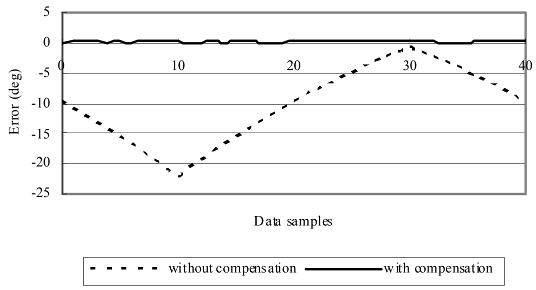

Figure 5. Azimuth error with and without tilt compensation (Pitch angle: 10º)

In this experiment, H_{earth} was calculated according to another 3-axis magnetometer. In fact, if the magnetic compass is being used, H_{earth} should be estimated according to the geographical location. Let's estimate the azimuth error caused by Z component estimation of earth magnetic field according to the geographical location. Assumed that the error of Z component estimation of earth magnetic field is less than 2 milliGauss, and horizontal component of earth magnetic field is about 200 milliGauss. Then the error of X_h and Y_h caused by Z component estimation will be less than 2 milliGauss. The maximum azimuth error caused by Z component estimation will be about 0.8°. This value is much less than the azimuth error without tilt compensation. This shows that this algorithm is feasible for magnetic compass.

5. Conclusion

In this paper, an efficient tilt compensation algorithm for the low cost two-axis magnetic compass is proposed. The third-axis data of the magnetic compass is estimated using earth magnetic field information firstly. And then the third-axis data of the magnetic compass is used for realizing tilt-compensation. The experiment results show that the azimuth error becomes rarely affected by the tilt angles. In other words, this algorithm can be used to realize tilt-compensation for 2-axis magnetic compass.

6. Acknowledgment

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7. References

[1] M. J.Caruso, "Application of magnetoresistive sensors in navigation systems", *Sensors and Actuators*, SAE SP-1220, 1997, pp. 15-21.

[2] M. J. Caruso, T. Bratland, C. H. Smith, R.Schneider, "A new perspective on magnetic sensing", *Sensors (USA)*, 15(12), 1998, pp. 34-46.

[3] M. J. Caruso, L. S. Withanawasam, "Vehicle detection and compass applications using AMR magnetic sensors", *Sensors Expo Proceedings*, 1999, pp. 477-489.

[4] M. J. Caruso, "Applications of magnetic sensors for low cost compass systems", *IEEE 2000. Position Location and Navigation Symposium* (Cat. No.00CH37062), 2000, pp. 177-184.

[5] A. Platil, J. Kubik, M. Vopalensky, P. Ripka, "Precise AMR magnetometer for compass", *Proceedings of IEEE Sensors 2003* (IEEE Cat. No.03CH37498), Vol.1, 2003, pp. 472-476.

[6] S. Robert, F. Andy, P. Penny, "Aspects of heading determination via fusion of inclinometer and magnetometer data", *ICAR'97*, 1997, pp. 739-744.

[7] G. Basile, M. Pierantoni, S. Pirani, M. Ranaldi, S. Varosi, "Attitude compensated electronic compass for aircraft navigation", *Proceedings of the 1994 Southcon Conference*, 1994, pp. 126-131.

[8] X. Li, J. Wang, C. Tang, L. Wang, S. Wang, "Development of High Accuracy Electronic Compass", *Chinese Journal of Sensors and Actuators*, 19(6), 2006, pp. 2441-2444.