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Algorithm development for soft and hard iron calibration of magnetic compass

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Abstract - *More navigation systems today use some type of compass to determine heading. Using the earth's magnetic field, electronic compasses based on magneto resistive (MR) sensors can electrically resolve better accuracy. In this paper the core error of magnetic sensor hard and soft iron errors are discussed. Calibration algorithm is developed for the same from linear square optimization method to get accurate heading.*

***Key Words*: Calibration, hard and soft iron error, heading.**

1. INTRODUCTION *(Size 11 , cambria font)*

The magnetic compass has been used in navigation for centuries. The inventor of the compass is not known, though evidence suggests that the Chinese were using lodestone (a magnetic iron ore) over 2000 years ago to indicate horizontal directions. It appears that Mediterranean seamen of the 12th century were the first to use a magnetic compass at sea [1].

Currently to get the positions GPS are used but if GPS service fails for some reason, low cost MEMS based navigation solution is used to get seamless positioning information. MEMS navigation is based on the data fusion of MEMS navigational sensors i.e. accelerometer, gyroscope with magnetic compasses. Magnetic compasses are used to sense the earth's magnetic field and to get the north direction. These magnetic compasses should have high accuracy and it should be calibrated to fulfill the required application. Magnetic compass plays a vital role in many applications as mentioned above. In recent technology sensors play a vital role in all products like land navigation, airborne navigation and sea navigation. Electronic magnetic sensors are placed in moving plat forms for the heading application. This electronic magnetic sensor has many parameters which have to be calibrated to get the accurate or the required data from the sensor.

The aim of the project is to develop an algorithm for hard and soft iron error of magnetic compass.

CHR6DM Magnetic module is used in this project. Algorithm is developed using least square optimization mathematical model for hard and soft iron error. Heading accuracy is verified using AHRS (attitude heading reference system) tool.

2. HARD AND SOFT IRON ERROR

For A compass responds to the vector sum of the Earth's field plus with all disturbing fields. Depending on their strengths, these fields can significantly reduce the accuracy of a compass.

Induced magnetism in ferrous objects such as iron and steel ("soft iron") in the vicinity of the compass will distort the ambient magnetic field, as will objects that may have acquired permanent magnetism ("hard iron"). Even car speakers and the electronic discharge from nylon clothing's can affect a compass. Consequently, the direction in which the magnet of a compass actually points called compass north will in general be different from magnetic north.

If no distortion effects are present the rotating a magnetometer through a minimum of 3600 and plotting the resulting data as y-axis v/s x-axis will result in a circle centred Around (0, 0), Fig 1.

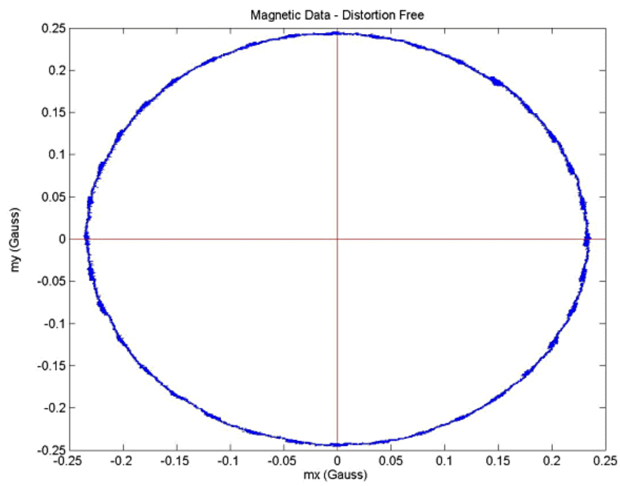

Fig. 1 Without distortion

This hard iron distortion is produced by materials that exhibit a constant additive field to the Earth's magnetic field, there by generating a constant additive value to the output of each of the magnetometer axes. Hard iron distortion is constant regardless of the orientation.

Hard iron distortion can be visibly identified by an offset of the origin of ideal circle from (0, 0) as shown in Fig. 2.

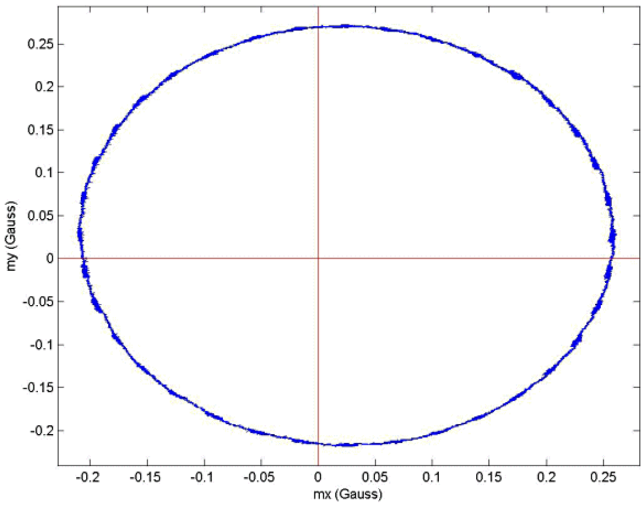

Fig. 2 Hard iron distortion

This soft iron distortion is the result of material that influences or distorts a magnetic field but does not necessarily generate a magnetic field itself, and is therefore not additive Ex: Iron and nickel

Soft iron distortion is not constant regardless of the orientation. Soft iron distortion is dependent upon the orientation of material relative to the sensor and the magnetic field. Soft iron distortion cannot be compensated with a simple constant; instead a more complicated procedure is required. Soft iron distortion is typically exhibited as perturbation of the ideal circle into an ellipse.

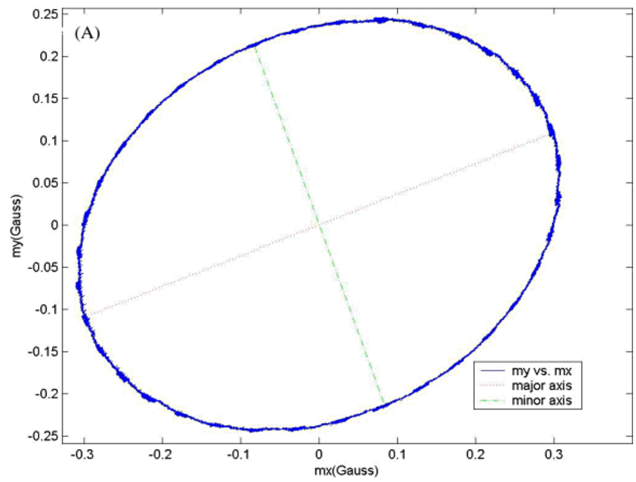

Fig 3 soft iron distortion

3. MATHEMATICAL MODEL

We have considered the method of Least Square which is a standard approach to get the approximate solution of sets of equation in which more number of equations than the unknowns.

"Least squares" means that the overall solution minimizes the sum of the squares of the errors made in the results of every single equation.

The general linear model relating independent variable Xj[i] to dependent variable y[i] at measurement i via fitted model parameters βj is:

Y[i] = β0X0[i] + β1X1[i] + + βN-1XN-1[i]

The fit to the model will, in general, not be perfectly accurate and will result in an error term r[i] defined as:

r[i] = Y[i] - β0X0[i] - β1X1[i] - - βN-1XN-1[i]

For a series on M measurements, equation can be written in the form:

$$\begin{pmatrix} r[0] \\ \vdots \\ r[M-1] \end{pmatrix} = \begin{pmatrix} Y[0] \\ \vdots \\ r[M-1] \end{pmatrix} - \begin{pmatrix} \mathrm{X0}[0] & \dots & \mathrm{XN}-1[0] \\ \vdots & \ddots & \vdots \\ X0[M-1] & \dots & XN-1[M-1] \end{pmatrix} \begin{pmatrix} \beta0[0] \\ \vdots \\ \beta\mathrm{N}-1[M-1] \end{pmatrix}$$

With the definitions that r is the column vector of residuals:

Y is the M by 1 column vector of M measurements on the dependent variable.

X is the M by N matrix of M measurements of the independent variable:

β is the N by 1 column vector of unknown model coefficients β0 to βN-1 to be determined:

Therefore the general equation becomes as given below

r = Y – Xβ

solving the above equation for homogenous or non homogenous according to the required solution the beta factor will give the calibration matrix for the respective magnetic sensor at that position.

For non homogeneous case: β = (XTX)-1XTY

For homogenous case: XTXβ = λβ, the solution vector beta is the eigenvector of the product XTX associated with Eigen values λ.

4. MAGNETIC MODEL

The calibrated magnetometer reading Bc(where 'calibrated' means that hard and soft iron distortions have been removed) is simply the local geomagnetic field Br rotated by the orientation matrix R describing the orientation of the magnetometer. The geomagnetic vector Br is a fixed vector in the global reference frame and the multiplication by the circuit board orientation matrix R is an example of a vector transformation from the global coordinate frame to the sensor coordinate frame.

Bc= RBr

The most general linear model for the distortion of Bc into the measurement magnetometer reading Bp by hard and soft iron distortion is:

Bp = WBc + V = WRBr + V

V is a 3x1 vector and W is a 3x3 matrix. The vector V is termed the hard iron offset and the matrix W is termed the soft iron matrix. Simplifying a complicated subject somewhat, the hard iron offset models the sensor's intrinsic zero field offset plus the effects of permanently magnetized components on the circuit board and the soft iron matrix models the directional effect of induced magnetic fields and differing sensitivities in the three axes of the magnetometer sensor.

The above proves to be an excellent model for the magnetometer measurements but obviously becomes less accurate when the linearity assumption starts to break down. The most common reason for deviations from equation is the presence of magnetic hysteresis which is, by definition, a non-linear path dependent magnetic distortion.

The calibration algorithms derived here estimate the hard iron offset V and the soft iron matrix W from magnetometer measurements stored in the magnetometer buffer and then invert equation to give the calibrated magnetometer measurement as:

Bc = W-1(Bp – V)

The above equation similar to the equation: $r = Y - X\beta$. Therefore the solution vector V (hard iron error) and W (soft iron error) can be calculated through homogenous and non homogenous solutions.

5. IMPLEMENTATION

CHR6DM tilt compensated (accelerometer and gyroscope calibrated) module is considered in this calibration implementation.

Code for the stated algorithm is written in C in visual studio software.

Step1: The magnetometer reading in all possible direction and orientation measurements are taken (around 1000 measurements).

Step2: The code in the visual studio is executed to get the hard and soft iron error matrix of the magnetic sensor.

Step3: The matrix is noted down.

Step4: Run the AHRS tool to get the estimated heading angle of the compass without calibration and note down the angle.

Step5: Enter the calculated calibration matrix in the AHRS tool and note down accuracy of the heading angle because of the calibration matrix.

Step6: Each time when the module turned on it should be calibrated.

6. RESULTS AND CONCLUSION

The compass reading values are set for the north direction. That is Y axis must be zero and X axis must be positive so that the compass is pointing to north direction. At this point the accelerometer and gyroscope bias point are set.

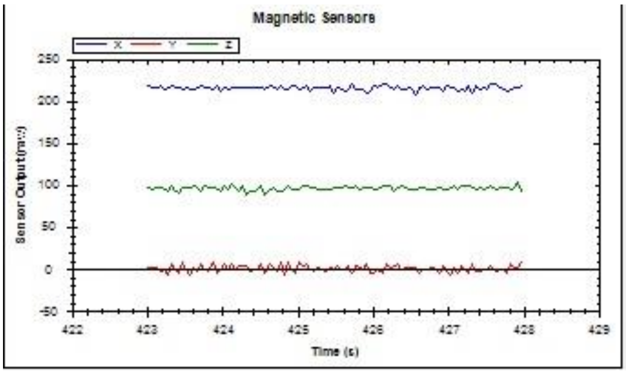

Fig 4. Setting compass towards north by making 'y' zero and 'x' positive

At the above mentioned scenario the compass heading must be zero, but without compass calibration the heading value by the system is 15 degree.

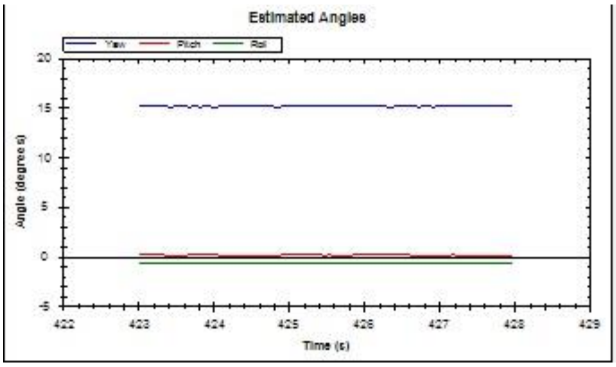

Fig 5. Heading angle without calibration

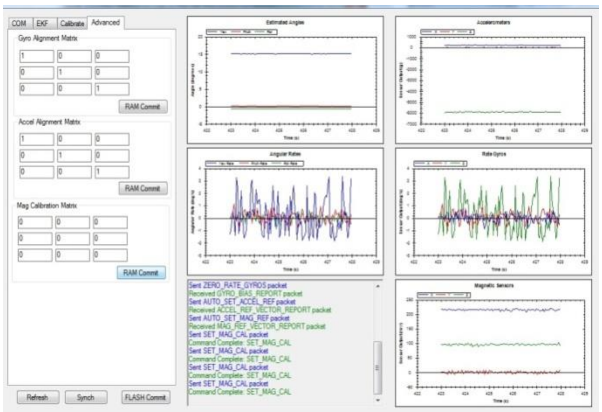

Fig 6. Without calibration AHRS output

The magnetic compass calibration matrix is generated by executing the code in visual studio.

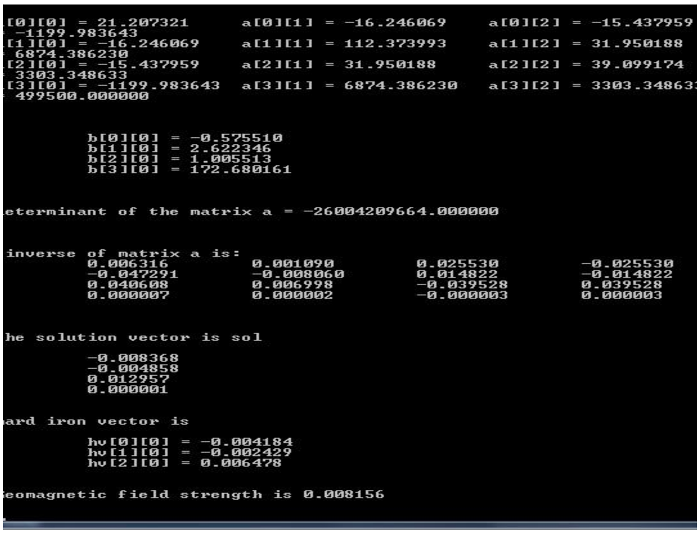

Fig 7. Hard iron vector values in visual studio

The calculated calibration values are inserted in the magnetic calibration matrix in AHRS tool. By this calibration matrix the compass estimated angle is almost zero as shown below.

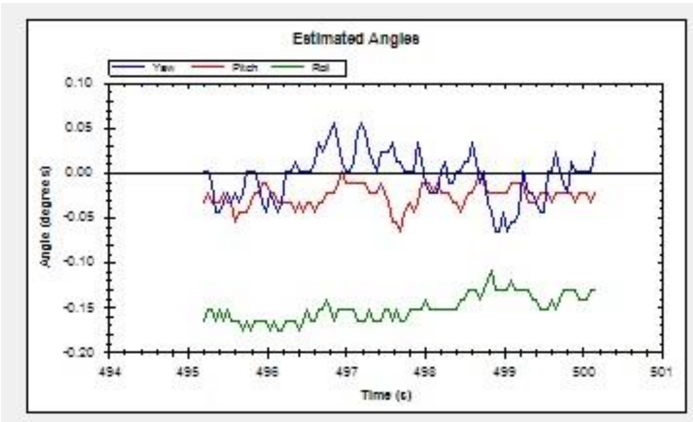

Fig 8. Heading angle with calibration

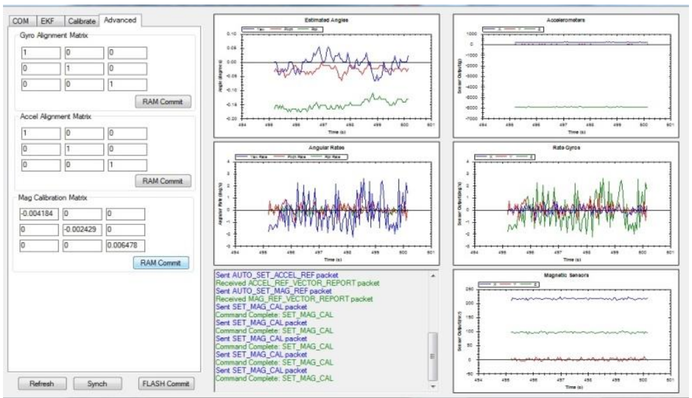

Fig 9. With calibration AHRS output

The tilt compensated compass heading was 15 degree to north without calibration but by our calibration method the compass heading is 0.05 degree to north.

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