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Improvement of Digital Compass Readings in Presence of Soft and Hard Iron

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Abstract: **The magnetic compass has been guiding travelers for thousand years or more. It is one of the oldest and easiest navigation instrument used to determine heading. Using earth's magnetic field, electronic compass based on Anisotropic Magnetoresistive (AMR) sensors can sense and electrically resolve the heading with enhanced accuracy. The core errors of magnetic sensor: hard and soft iron errors are determined and corrected. Magnetic field at two positions, direction between them based on two sensor values are found. Scaling factor is verified from the world magnetic field map. Calibration algorithm is developed for the same from least square optimization method to get accurate heading.**

Keywords: **Compass, Calibration, hard iron error, heading, Magnetoresistive, soft iron error.**

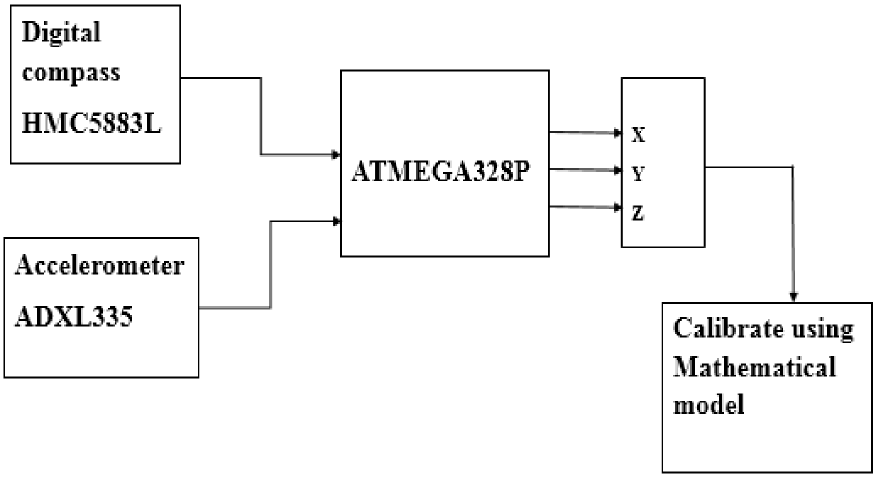
I. INTRODUCTION

More than centuries magnetic compass has been used in navigation. The inventor of the compass is unknown, though evidence suggests that the Chinese were using lodestone (a magnetic iron ore) over 2000 years ago to indicate horizontal directions. It was found that Mediterranean seamen of the 12^{th} century were the first to use a magnetic compass at sea [1].

Today Navigation is done by using GPS, there are some instances when GPS signals are not available: for example in tunnels or underground parking garages. In urban environment GPS signals can be also very weak or affected by multipath In this case the position accuracy derived from GPS receiver might be lower than required so low cost MEMS based navigation solution is used to get seamless positioning information. MEMS navigation is based on combination of MEMS navigational sensors i.e. accelerometer with magnetic compasses. Magnetic compasses are used to sense the both direction and magnitude of the earth's magnetic field 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 modern technology sensors play a vital role in all products like land navigation, airborne navigation and sea navigation. Electronic magnetic sensors are placed in moving stages for the heading application. This electronic magnetic sensor has several 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. HMC5883L Digital compass and accelerometer ADXL335 is used in this project. Algorithm is developed using least square optimization mathematical model for hard and soft iron error. Magnetic field between two positions are found out, direction between them are determined. Angle between two sensor values also found. Finally scaling factor is found out in order to correct the uncalibrated value.

II. BLOCK DIAGRAM



III. 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 well 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.

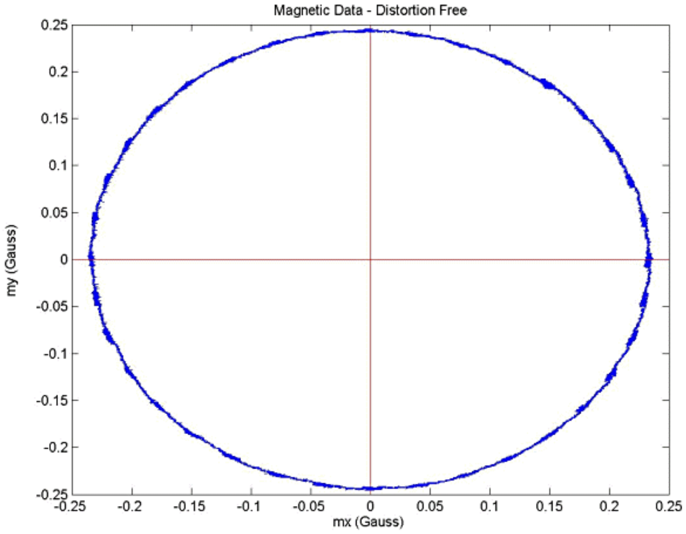


Fig. 1 Without distortion

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.

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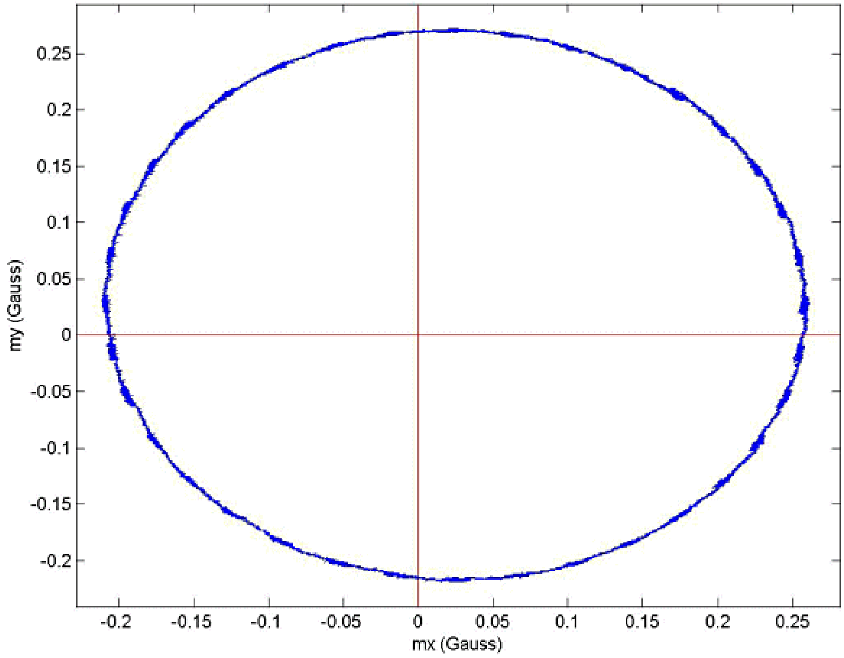

Fig. 2 Hard iron distortion

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.

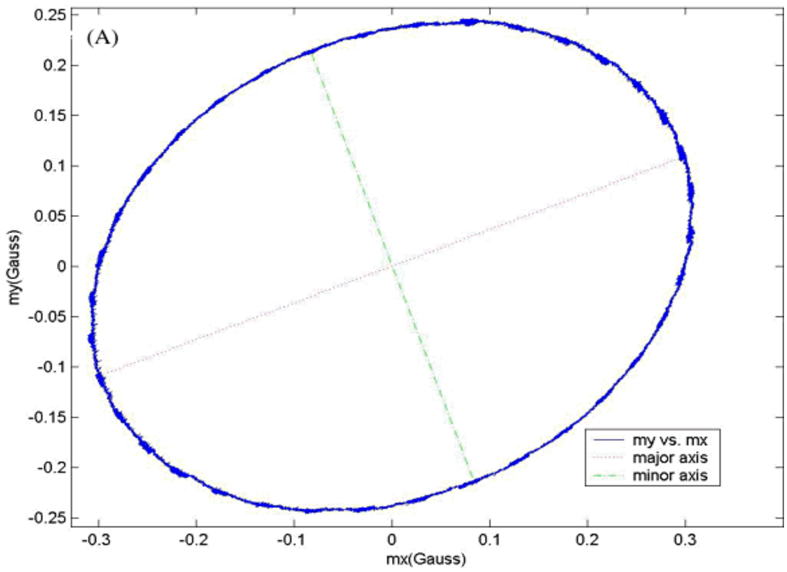

Fig 3 soft iron distortion

IV. 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.

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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:

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

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: $\beta = (X^TX)^{-1}X^TY$

For homogenous case: $X^TX\beta = \lambda\beta$, the solution vector beta is the eigenvector of the product X^TX associated with Eigen values λ.

V. 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:

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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.

VI. IMPLEMENTATION

HMC5883L and ADXL335 (Digital compass and accelerometer) is considered in this calibration implementation.

Code for the stated algorithm is written in Embedded C in Arduino IDE.

Step1: The magnetometer and accelerometer reading in all possible direction and orientation measurements are taken.

Step2: the obtained measurements are raw data i.e. uncalibrated value

Step3: The X and Y matrix are calculated from the magnetometer reading and the B(magnetic field) is calculated as per the least square optimization method by using MATLAB. Tilt Angle between two positions are also taken by Accelerometer. This gives the calibrated value.

Step4: The above steps are done at two different positions in order to find the Direction and distance between two positions.

Step5: The uncalibrated value is compared with the calibrated value in order to find the heading accuracy.

Step6: Scaling factor is found out in order to correct the uncalibrated.

Step7: Each time when the module turned on it should be calibrated.

VII. RESULTS

The readings from the magnetometer at two positions are taken.

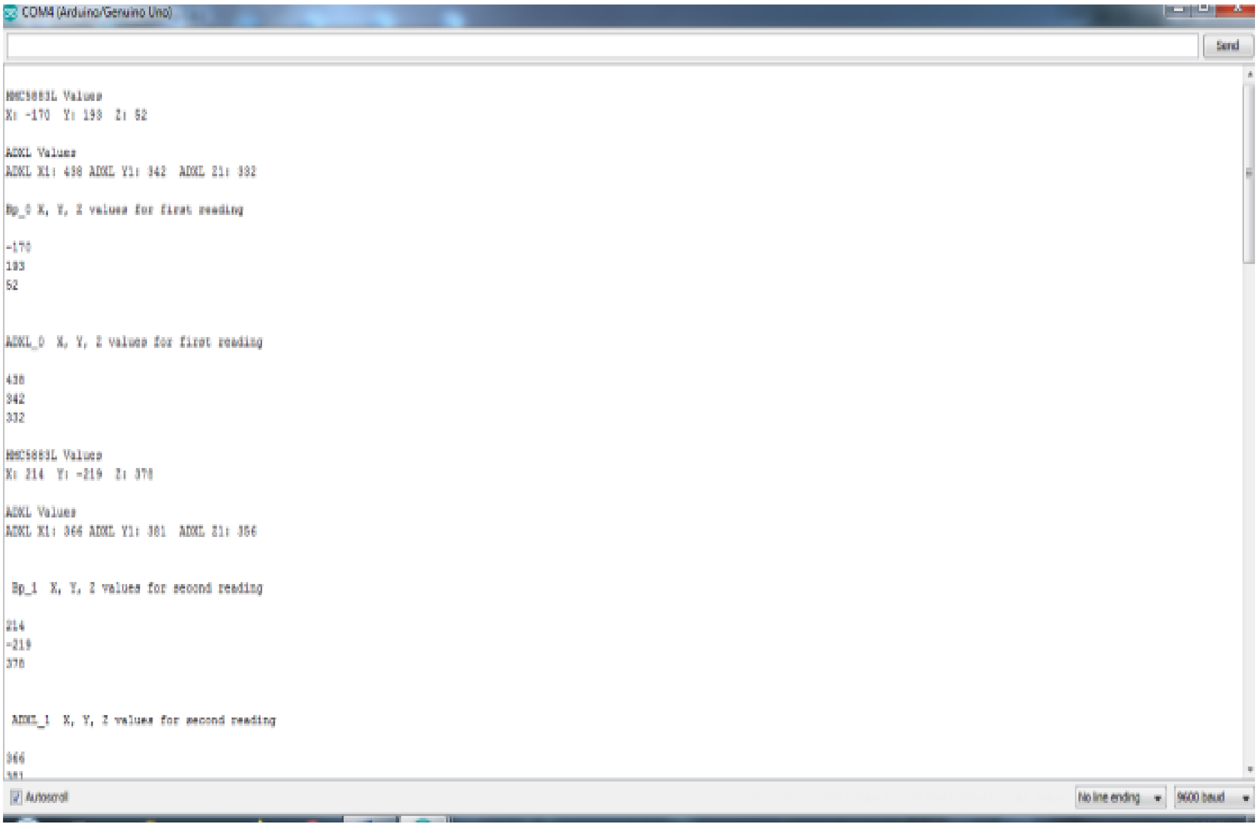

Fig 4. Digital compass readings at one position

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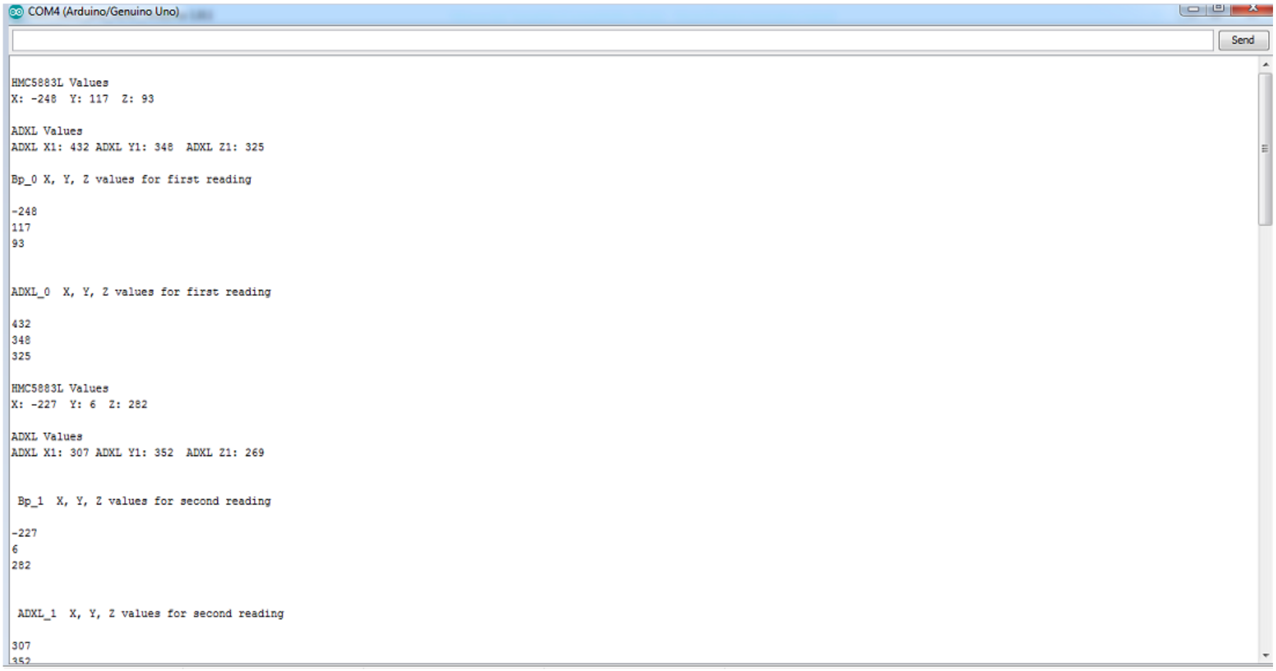

Fig 5. Digital compass readings at another position

The values are given as input to MATLAB then magnetic field and angle for two different positions are taken.

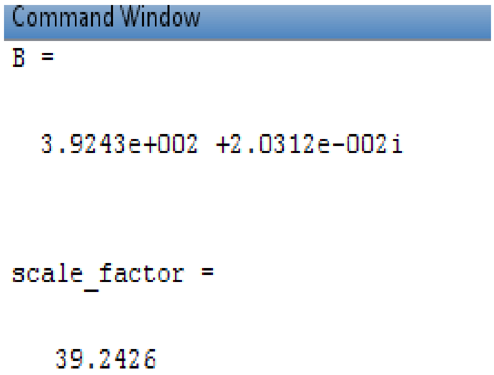

Fig 6. Magnetic field value at one position

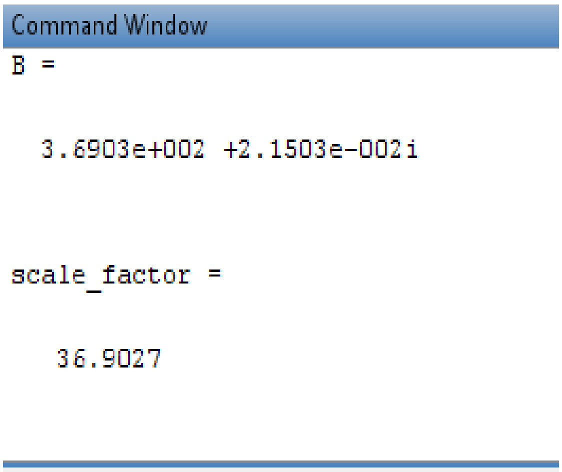

Fig 7. Magnetic field value at another position

The magnetic field value obtained is in μT compared with the world magnetic chart so there is difference of 0.242 μT

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VIII. CONCLUSION

Hard and soft iron distortions in magnetic compass are studied. Algorithm is developed and coding is written in Embedded C language. Direction between two positions is calculated.

The compass and accelerometer are calibrated each time when it is restarted. This low cost calibration method is very accurate and very much suitable for all application.

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