Robot Navigation With Anisotropic Magneto-Resistive (AMR) Sensors

S. B. A. Kumara

Abstract: This is a study on the use of anisotropic magneto-resistive (AMR) sensors for robot navigation. The geomagnetic field was measured using AMR sensors within a building. Then, that magnetic field information was mapped using the Surfer 9 software to identify special locations such as concert columns, stair case which could be used as landmarks for robot navigation and an algorithm was developed to navigate the mobile robot using mapped information. In order to measure the magnetic field at each location, a microcontroller based portable magnetometer was developed. Finally, a simple robot vehicle was navigated successfully throughout the mapped area using the magnetic field information. Data were collected at 397 different locations in two rooms in a house with concrete columns and slabs. In addition, data were collected continuously at three selected points in order to analyze variations of magnetic fields during both day and night time. The moving average filtering was applied to remove noise and fluctuations of the data from the sensor. The diurnal magnetic field variations were monitored from 6.00AM to 10.00PM. The field variations were stable at night time. During day time fluctuations were observed owing to the sunlight and the range of variation was around 10^{-2} µT. The uncertainty of the measurements was around 10^{-4} µT level. Consequently, the diurnal variations were found not to affect the magnetic field measurements significantly.

Index Terms: AMR sensors, Geomagnetic field, Moving average filter.

1 INTRODUCTION

For a mobile robot, it is very important to have the ability of navigating in its environment. Main purpose of the mobile robot navigation is to find its way while avoiding undesirable situations such as collisions and unsafe conditions. Various sensors such as cameras, ultrasonic sensors, proximity and passive IR sensors are used to sense the environment for successful navigation [6]. Earth magnetic field, which is always pointed towards the north, has been used by humans from the ancient times as a navigation aid. Within buildings, the earth magnetic field is modified due to the presence of ferromagnetic materials and therefore it may not always point towards the north. However, if the magnitude and direction of the magnetic field is measured beforehand, and a map is prepared, a mobile robot, equipped with a suitable magnetometer should be able to sense the magnetic field and determine its path with the help of the map. As the direction and magnitude of the magnetic field does not uniquely specify the location within a building, a suitable algorithm will have to be developed for the robot to find its way, by starting from a known location. The main objective is to map the magnetic field within a building by using anisotropic magneto-resistive sensors (AMR) and develop an algorithm to navigate using mapped information. A simple robot vehicle was constructed for testing this system.

1.1 Sensor overview

A three-axis magnetometer sensor module was used to measure the direction and magnitude of the magnetic field within a building. Especially, HMC5883L magnetic sensors module [1] can be used to measure the three - axis components of the magnetic field in selected location. It is based on Anisotropic Magneto-resistive (ARM) technology with a small size chip and digital interface which is designed to measure both direction and magnitude of the geomagnetic field from milli-gauss to 8 gausses [2, 3]. As well as this chip includes integrated 12-bit ADC, 160Hz maximum data rate, I2C digital interface and 1-2 degree heading accuracy.

1.2 Magnetic field measurement system

The three-axis AMR sensor module can detect magnetic field components in the X, Y, and Z directions of a selected point. The AMR sensor module has I2C digital interface and it sends digitalized X, Y and Z magnetic field data through this interface to the mother board, The ATmega32 microcontroller-based system performs calculations to convert the received digital values to magnetic field values in Gauss, the results save in SD card and displays the LCD display. In addition, it can transmit data through a serial port to a computer. The magnetic fields variations inside a building are found in Ferro magnetic materials (ex: iron, cobalt and nickel) and also man-made sources such as power electrical systems, electronic appliances and stationary structures, such as concrete columns, pillars, railings, walls, doorways, and steel structures. Magnetic variations or anomalies can be generated due to all these objects. Analyzing that information will be useful for future mobile robot navigation.

1.3 Mapping the measured magnetic field

Once data were sent from the portable magnetometer to the PC serial port, the magnetic field data were arranged as a table in a Microsoft Excel sheet created by a software tool which was developed for this purpose using .net frame work. This software was developed using C# programming language [4]. Further data was analysis and mapping was performed by using Surfer 9 software [5]. Surfer 9 is a scientific data analysis and graphing software package that runs under the Microsoft Windows operating system. Contour maps can easily be generated by this software using collected and calculated data set of total magnetic field and directions of the relevant locations. That information can be used for developing an algorithms and navigation in robotic system of selected pathway.

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1.4 Mobile robot and embedded system

According to the mapped magnetic field information, the magnetic field variation was identified in as elected area in a building. That information was saved in the memory of the microcontroller-based system as a small data base. When the robotic system is moving inside the same area in the building, it can measure the magnetic field and identify special landmarks such as concrete columns, steel structures, etc. using the stored information of system data base. With the support of such landmarks, it can navigate along a specified pathway.

2 EXPERIMENTAL PROCEDURE

The experimental processes of those are Construction of Portable magnetometer, embedded system programming, Data collection methodology, Data analyzing and mapping [17], Mobile robot circuit design and construction [6]. The magnetic field was measured in the Z, Y, Z directions and the magnitude was calculated by using constructed portable magnetometer. These magnetic fields are formed by stationary objects such as walls, concrete columns, steel railing, stair case, doorways and electrical equipment inside of a building [16]. All these results of magnetic field measurements within a building are analyzed for further navigation of the mobile robot.

2.1 Construction of portable magnetometer

The portable magnetometer system was developed to success for the measured and mapped the magnetic field within a building. This portable magnetometer mainly consists of the HMC5883 anisotropic magneto-resistive sensor module, microcontroller base data processing board and display (LCD) unit. The block diagram of developed magnetometer is shown in Figure 1. Description of this system as follows,

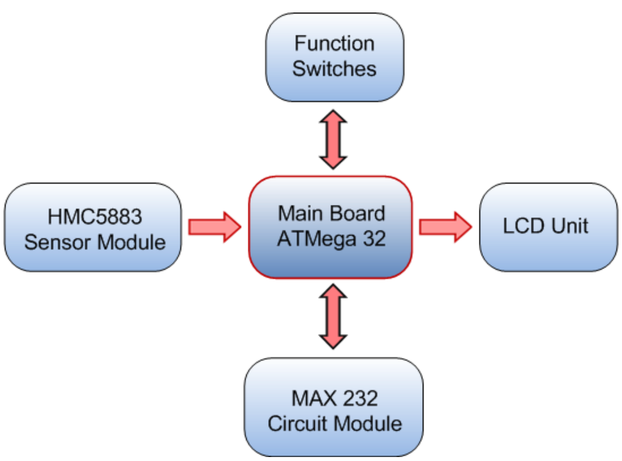

Figure 1. Block Diagram of Portable Magnetometer

2.1.1 Sensor Module

The sensor interfacing board was constructed to interface with the main board via two-wire data communication method (I2C or TWI) [7]. This board is surface mounted board and HMC5883 sensor module can be connected as well as removed easily. Sensor board and its PCB design are shown Figure 2.

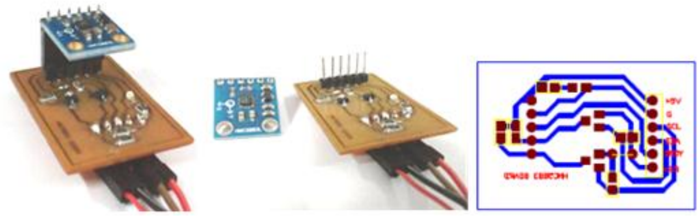

Figure 2. Sensor interface board and PCB design

2.1.2 Main processing Board

The main processing board was designed to collect the raw output data from the sensor board as well as to process that data set accurately. Main board mainly consists of ATMega32 AVR microcontroller, 5V and 3.3V regulator power supply and it has several types of connectors such as USBasp Connector, LCD connector, Main power supply connector, I2C connector, Serial communication module Connector and Programmed power or external power jumper. External crystal oscillators can be connected to this board and also it works with 8MHz internal oscillator of the ATMega32. The main board of the portable magneto meter is shown in Figure 3.

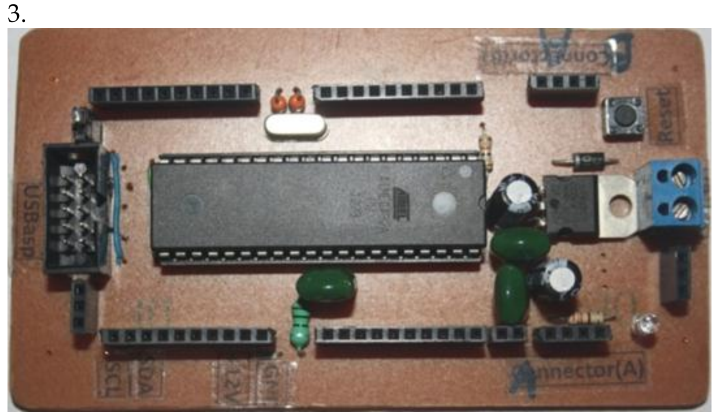

Figure 3. Main Board (ATMega32)

2.1.3 LCD Unit and Functional Switches

The 16x2 Liquid Crystal Display (LCD) [8] was used for this portable magnetometer and it displays the x, y and z magnetic field components and total magnetic field at the relevant position in units of micro Tesla (μT). Functional switches were used for the master reset of the processor, to operate the display functions (to separately display the angle and total field) and, as the data save button.

2.1.4 RS232 Serial Data Communication [9] with PC

Specially, the portable magnetometer can be connected to the serial port of the PC. MAX232 [10] level converter IC was used to communicate the data from main board to PC and support Baud rate of the serial port is 19200.The serial communication module and its PCB Layout are shown in Figure 4 and 5 respectively.

Figure 4. Serial Communications Module

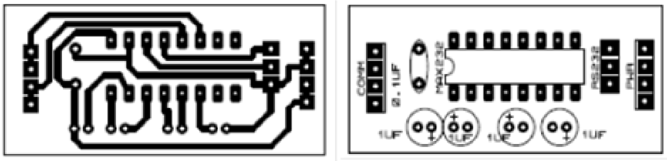

Figure 5. PCB Layout of the Serial Communication Module

2.2 Embedded system programming

AVR ATMega32 Microcontroller has been programmed by using USBasp programmer [11] and it supports AVR dude open source programming Software. The source codes have been created using GCC compiler [12] and WinAVR -20100110 software (used C Programming language [13]). Embedded system programming [15] was used for following task.

- ATMega32 programming method for I2C data communication with the sensor module.
- LCD module interfacing.
- Serial Data Communication Method Programming of ATMega32.

2.2.1 I2C Programming of ATMega32

SDA (PC1) and SCL (PC0) pins of microcontroller were connected to the sensor module with two pull up resistors. TWI Bit Rate Register (TWBR), TWI Status Register (TWSR), TWI Data Register (TWDR), TWI Control Register (TWCR) and TWI Address Register (TWAR) should be setup for the data communicating from the magnetic sensor module.

2.2.2 LCD interfacing of ATMega32

Port B, PB4 - PB7 pins of ATMega32 were connected to the LCD data pins D4-D7 as well as PB0, PB1, PB2 pins were connected to the RS input (Register select), RW (Read/Write) and EN pins of the microcontroller respectively.

2.2.3 Serial communication of ATMega32

RXD and TXD pins of Microcontroller were connected to the serial port of the computer via the MAX 232 IC. The USART Control and Status Register A (UCSRA), USART Control and Status Register B (UCSRB), USART Control and Status Register C (UCSRC) and USART Baud Rate Registers (UBRRL and UBRRH) should set up for the data transmitting and receive from microcontroller to computer.

2.3 Data collection methodology

The developed portable magnetometer was used for the colleting magnetic field data at relevant locations. Data have been collected in two ways. There are measures for the magnetic field at one time and continuous data measuring in the selected point. The experiments were performed at the two rooms at a home. This two rooms have 9 concrete columns, stair case and roof of the two rooms are covered the concrete slab. Measuring data points and rooms plane are shown in Figure 6.

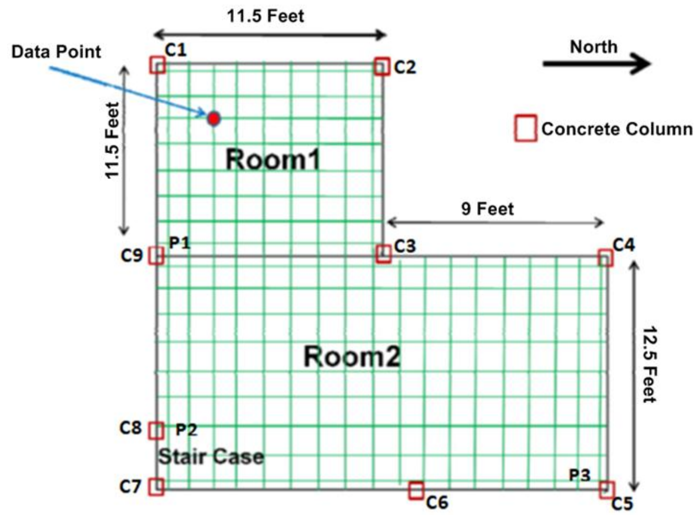

Figure 6. Floor Plane of data collecting area (two rooms in a house)

Adoptable data reading points are represented in cross point of the mesh and it is shown in Figure 6. Two rooms have 397 no of data points and Small Square of the mesh is 1 by 1 feet distance. The x, y, z magnetic field strength was measured at the all data points in this two rooms. Specially, Data have been collected continuously at only three data measuring point at point P1, P2 and P3 in the room1 and room2. This is, to analyze variations of magnetic fields both day and night time. All magnetic field measurement have some errors and uncertainly. This research was carried out to find the uncertainty measurement values nearby points of selected concrete columns such as C1, C3 and C9 in the room1 and C3, C4 and C8 in the room2. This method was used to collect 60 measurements within one-hour time duration for calculating uncertainty measurements of these selected columns. The magnetic field data sent from the microcontroller were read by using Graphical user interface (GUI) software. Then the data was arranged and saved in Microsoft excel sheet using this GUI software tool which was developed using .net frame work and C# high level programming language.

2.4 Data analyzing and mapping

The collected data set were analyzed and mapped using MINITAB [14] and Surfer 9 software. MINITAB and Surfer 9 [5] software was used for statistical data analysis and scientific graphing as well as Surfer 9 software package can easily generate a contour map.

2.5 Mobile robot circuit design and construction [6]

The major characteristic of this mobile robot vehicle is properly moved through selected road map which is developed algorithm using suitable magnetic field data set. This mobile Robot was mainly controlled according to the presence magnetic field sensing of the HMC5883 sensor module. The mobile robot consists of main processing board (ATMega32), magnetic field sensor module (HMC5883), Two DC gear motor with motor controlling circuit, small size rechargeable power supply. The block diagram of mobile robot is shown in Figure 7.

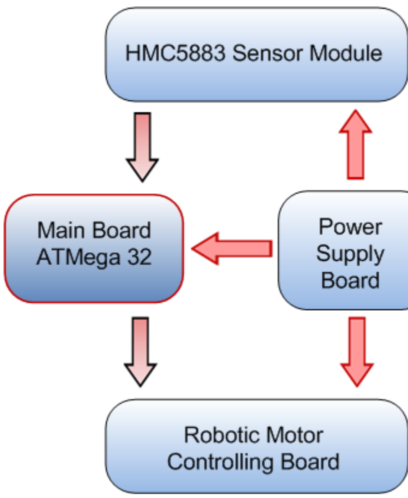

Figure 7. Block Diagram of Mobile Robot

L293D H-Bridge DC motor control IC was used for controlling the two wheels of robot vehicle in to forward and backward directions. Rechargeable battery with power supply boards is generated 3.3V, 4.2V and 5V regulate voltages. The rechargeable battery is 12V and 1.8Ahr. It can be used to drive robot vehicle continuously around time period of 4 or 5 hours. The fully competed mobile robot vehicle is shown Figure 8.

2.5.1 HMC5883 Sensor module Mounting

Sensor mounting is a very important thing for this robotic system. The DC motors have permanent magnets, when motor is running, it generates the magnetic fluctuation. Generally, electronic circuits generate the few magnetic fields near the circuit boards. Therefore, the sensor readings cannot be accurate due to above reasons. The robot vehicle includes about 1feet adjustable sensor mount stand and sensor is mounted top of this stand to get an accurate reading. This mounting system is shown in Figure 8.

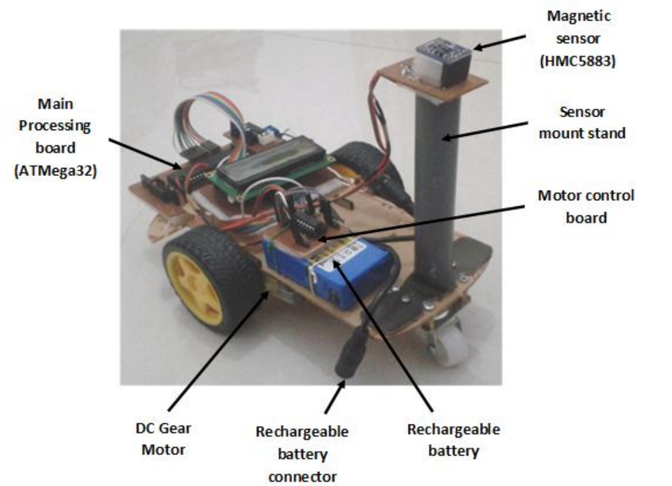

Figure 8. Completed Mobile Robot Vehicle

3 Result and Data Analysis

3.1 Magnetic field data mapping

Data were collected by using portable magnetometer in room1 and room2 and those magnetic field data were mapped using contour mapping technique. The Figure 9 and 10 illustrate the magnetic field variation in room1 and room2 respectively.

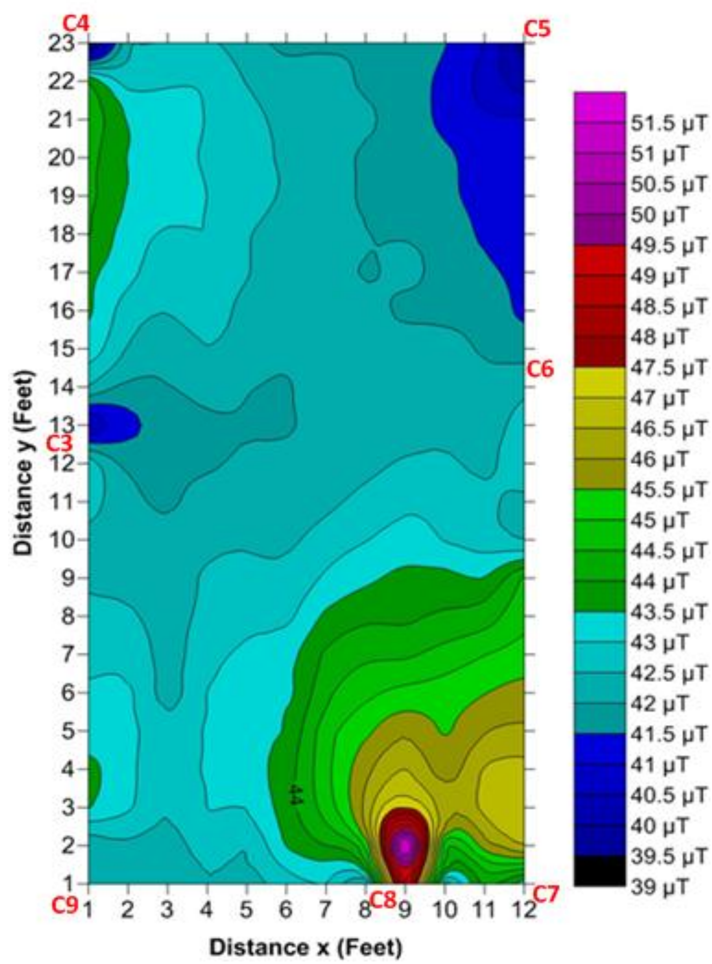

Figure 9. Magnetic field variations in Room1

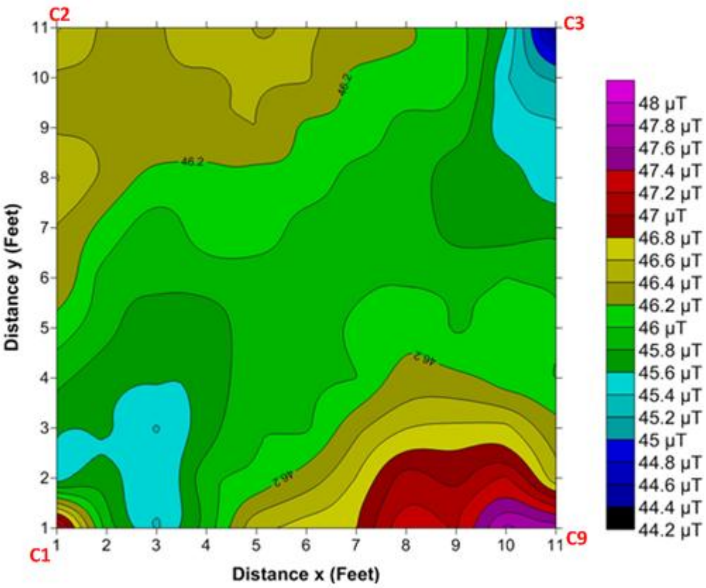

Figure 10. Magnetic field variations in Room2

3.2 Identification of the landmarks inside the rooms

Identification of the Concrete Columns inside the room1 and room2

There were several invisible landmarks inside the rooms that could be identified by looking at the contour maps. They include concrete columns, a staircase that could be identified from the behavior of the magnetic field variations. It was found that at some of the columns the magnetic field was high, while near some other columns the magnetic fields were low. In the contour maps, these locations can be identified as specific landmarks for the purpose of navigation. Figure 11 shows the variation of magnetic field. This was observed by the robot vehicle while travelling past the columns C1, C2, C3 and C9 in room 1. Similarly, Figure 12 shows the magnetic field variations when travelling pass the columns C9, C3, C4, C5, C6, C7, and C8 in room 2. The locations of the columns in these rooms are shown in Figure 6 above.

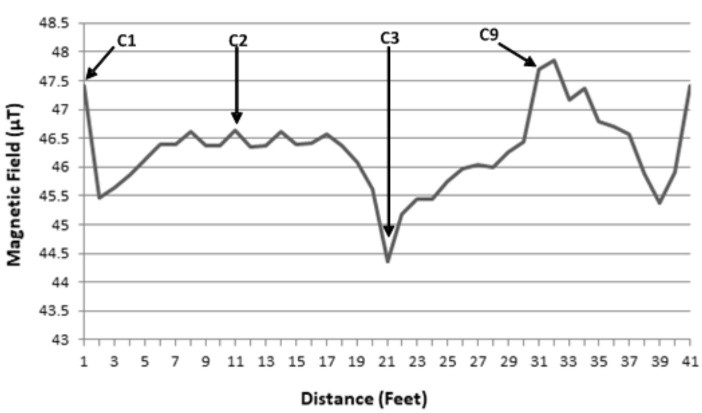

Figure 11. Magnetic field variation while passing each column in room1

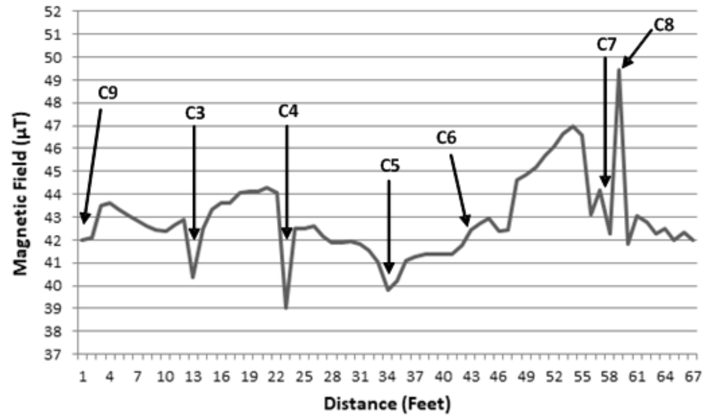

Figure 12. Magnetic field variation while passing each column in room2

Figure 11 illustrates that the locations of columns C1, C3 and C9 in the room1 can be easily identified because they have different fluctuations. Figure 12 shows that at column C8 there is a large magnetic field peak owing to the staircase near it and two concrete columns in the room2. Furthermore, columns C3, C4 and C5 can be identified as the unique points due to their low magnetic fields.

3.3 Uncertainty of the magnetic field measurements

All magnetic field measurements have some errors and uncertainly owing to such device errors, measurement error and human errors, etc. Under this research, an attempt was made to estimate the uncertainty of the measurements of selected concrete columns such as C1, C3 and C9 in the room1 and C3, C4 and C8 in the room2. The procedure was taken by 60 measurements within a one-hour time duration at each location for calculating the uncertainty of measurements at these selected columns. Using MINITAB statistical software, the values of the descriptive statistics (i.e. Mean, standard deviations) were calculated. When considering the standard deviation (s) and number of the measurements (n) and the uncertainty measurement (σ) the magnetic field variation between Mean (μ) + 2 σ and μ-2σ range is at 95% confidence interval.

$$\sigma = s/\sqrt{n}$$

Table 1 and Table 2 list the Mean, standard deviations and uncertainty measurement each of the above concrete columns in room1 and room2.

TABLE 1 Uncertainty measurements in room 1

Concrete Column	Mean(μT)	Uncertainty(σ) (μT)	μ+2σ (μT)	μ-2σ (μT)
C1	47.406	0.000515	47.40703	47.40497
C3	44.355	0.000406	44.35581	44.35419
C9	47.701	0.000804	47.70261	47.69939

TABLE 2 UNCERTAINTY MEASUREMENTS IN ROOM 2

Concrete Column	Mean(μT)	Uncertainty(σ) (μT)	μ+2σ (μT)	μ-2σ (μT)
C3	40.390	0.000245	40.390490	40.38951
C4	39.034	0.000703	39.035406	39.03259
C8	49.431	0.000559	49.432118	49.42988

When considering the above all uncertainty measurements are around 10^{-4} μT level. The variations of magnetic fields were observed inside the two rooms are much greater than these uncertainty values. Therefore, the fluctuations was observed in the rooms are real magnetic field variation.

3.4 Continuous magnetic field variation

In using these contour maps for navigation, one should also consider the earth magnetic field variations that occur as a function time during a day. In order to estimate how these variations can affect navigation, continuous magnetic field measurements at day and night time were made in two selected point of room1 (near the column C9) and room2 (near the column C8). Figures 13 and 14 illustrate the continuous magnetic field variations in the point of C8 (room2) and C9 (room1) respectively at this day and night time.

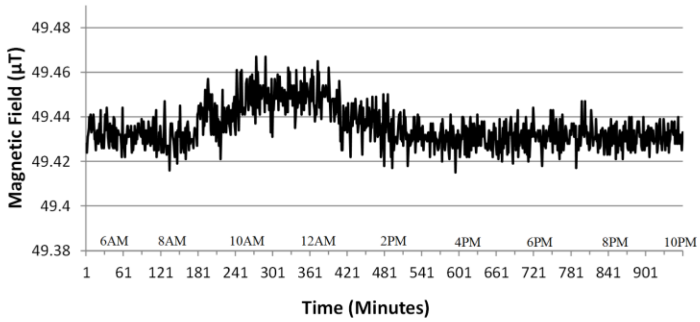

Figure 13. The diurnal magnetic field variation in room2 (nearby column C8) from 6.00 AM to 10.00 PM

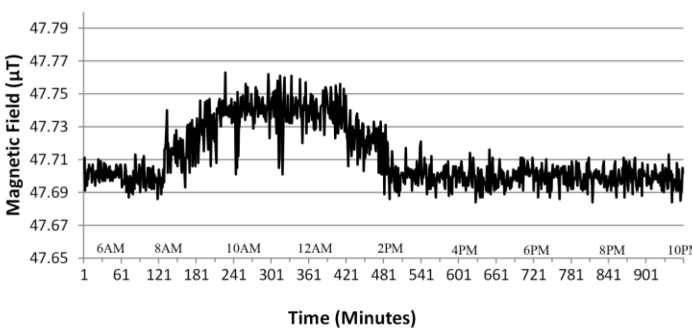

Figure 14. The diurnal magnetic field variation in room1 (nearby column C9) from 6.00 AM to 10.00 PM

Figures 13 and 14 show the diurnal magnetic field variations form 6.00 AM to 10.00 PM in room2 (nearby column C8) and room1 (nearby column C9) respectively. The magnetic field has slightly increased from 9.00 AM to 2 PM at day time in addition some very small fluctuations can be seen during the rest of the day (Morning 6.00 AM to 9.00 AM and evening 2.00 PM to 10.00 PM) owing to the sun light. Minimum and maximum values are seen in Figure 14 are 47.684 μT and 47.763 μT respectively. Its data range is 0.079 μT. In Figure 13, the minimum and maximum values are 49.415μT, 49.467 μT respectively and the data range is 0.052 μT. Again, these variations are significantly smaller than the field variations observed in the contour maps, as a function of location. Therefore, the diurnal variations are not expected to affect the robot navigation based on the contour maps.

3.5 Navigation process of the mobile Robot

At the starting point, the robot vehicle automatically faced the front side of the vehicle in to the predefined direction. The particular direction ($\theta = \tan^{-1}(y/x)$) was obtained by the x and y component of the geomagnetic field which is constantly captured by the AMR sensor. In this particular case the x axis of the considered area directed to the geomagnetic north ($\theta = 0$) and the algorithm was coded automatically facing the vehicle in to that direction. The path of the navigation was predefined according to the contour map of the magnetic field distribution which showed significant magnetic field variations near the concrete columns and the stair case. At any instant if the robot detected large magnetic field disturbance (by compare to the mapped data) the robot would wait at that location until the stable base line magnetic field is obtained.

4 CONCLUSION AND DISCUSSION

In this research, the possibility of using magnetic field anomalies for indoor mobile robot navigation has been investigated. According to the contour map, obtaining from the collected data significant magnetic anomalies were observed near the concrete columns and staircase. These anomalies were used as landmarks for the navigation purpose.

4.1 Identification of land marks

Locations with high magnetic fields due to concrete columns could be identified by mapping the magnetic field variations inside a building. The measurement uncertainty of the used magnetometer was to be found around 10^{-4} μT. The magnetic field variations that were measured inside the building were in the order of 10^{-2} μT and therefore, they were significantly greater than this measurement uncertainty. In addition, the diurnal magnetic field variations were to be found smaller than the field variations inside the building. Therefore, the field variation inside the building due to concrete columns and other fixed structures could be used as landmarks at any time of the day.

4.2 Experimental errors

This research, recorded that magnetic field data have been distorted by experimental errors from several sources. It can be affected to nearby magnetic fields generated by sources such as ringing of a mobile phone near the sensor, starting a motorbike, vehicle, refrigerator, motors, and other magnetic field generating instruments. Therefore, the baseline data should be collected carefully. In addition, when the ferromagnetic material objects were moving in the environment where the experiment was being carried out, magnetic field measurements can be changed unexpectedly. The performance of the portable magnetometer depends on mounting of the AMR sensor by using steel strip and nails. Therefore, a wood strip was used for mounting the magnetometer in this research. The moving average filtering was used to remove noise and fluctuations of the sensor information to compute average magnetic field measurements within a relevant time period which is expressed as the sum of the last N points data values divided by number of data points N. This method has been performed in this research by using computation techniques of the microcontroller.

4.3 Construction of mobile Robot

In Mechanical construction of the mobile robot should be done to minimize slipping and rolling over when it moves. To overcome these problems one should understand the nature of the wheels and their height, center of mass of the robot. Proper AMR sensor mounting is very essential for the mobile robot construction. Further, this sensor should be magnetic shielding owing to unpredictable electric current in a wire and large magnetic field disturbance from speakers, motors and permanent magnet in surrounding area. The mobile robot navigation path was predefined by considering the magnetic anomalies of the magnetic field contour map. All the inputs and outputs of the mobile robot were controlled by a microcontroller (ATMega 32) which was optimally programmed using C language. To power the mobile robot 12V rechargeable battery (small size) was used. One of the main advantages of this battery is the ability of on circuit rechargeable facility.

4.4 Further development

The developed mobile robot system will be used to collect the magnetic field information (x, y, z component) in the different types of indoors such as corridor in large size of buildings, engineering work shop, class rooms and laboratory, etc. Then it can find the land marks with respect to the magnetic anomalies. Finally, this system can be upgraded to navigate the mobile robot inside a large size of building complex even though the magnetic field disturbances occurred at real time due to several types of reasons. Mobile robot can be further developed to transmit magnetic field information data in to a personal computer from a remote location using wireless communication methods i.e. using RF transmitter and receiver, GSM network (sending a message using a mobile phone), Zigbee module (high frequency RF transmitting and receiving). This can be accomplished using the feature of SPI or I2C communication of the microcontroller based on the mobile robot. Then the data can be analyzed and mapped using PC after that special information can be feed to the mobile robot. Further this system can be upgraded by using ARM processing platform with open source software like Raspberry Pi small size single board computer. That processing platform performs for data collecting, analyzing, mapping and finally processing suitable algorithms together that implementation and algorithm in high fasting. Especially machine learning algorithm can be upgraded to identify the special land marks for continuous self-intelligent process of the mobile robot.

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