Magnetic Field Detection and Controlling

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Abstract

We tried to measure the geo-magnetic field, both magnitude and direction, in the horizontal plain. After measuring, through feedback from arduino we tried to control the ambient field and create a field free environment, which is an essential requirement of many physical experiments.

Introduction

Since the discovery of magnetic field, it has always been important for our understanding to detect and measure magnetic field, specially the geo-magnetic field. Today, we have reached a level where the modern day techniques are completely different on physics grounds than the device predominant in the earlier days.

Thus we categorize the magnetometric devices on two regimes. First, the classical magnetometers, which include devices based on Faraday effect, Hall effect, fluxgates, induction and mechanical. Second, the Quantum magnetometers, based on Josephson effect, SQUID, NMR, atomic vapor and optical pumping.

The objective of our project is to detect the geo-magnetic field which is of the range $25 - 65\mu T$, exploiting classical physics along with modern day electronics. We will finally create a field free space through counter field generation.

We have divided the project into three modules. First, the detection of the magnetic field along with the direction and its magnitude. In our case, to simplify the setup and complete the project in limited time we only considered the detection of the field in the horizontal plain. Second, the arduino setup which detects the deflection angle caused by the varying magnetic field generated by solenoid, using photodiodes. The intermediate setup is important in the context that it analyses the feedback and generated suitable signal to control the magnetic field of the solenoid for our required deflection from magnetic needle. The third module is the arduino generated signal to control the magnetic field due to second solenoid to generate a field free space. All this is to be done in real time.

The difference of our device form traditional mechanical magnetometers that detect field direction, is from the point that as in the mechanical case we need an observer to look at the deflection of the needle all the time. However in our case this is automated. Even the controlling module is automated by the electronic circuitry. Essential criteria for measuring is the sensitivity and accuracy of the magnetometric device.

Major components

The major components that we used for the project are solenoids (designed to generate field in the geo-magnetic range), photodiodes, freely suspended system of magnetic needle, LEDs along with suitable resistors, an Op-Amp and an Arduino Atmega 168.

In the following sections we are going to discuss about these modules in details, the mechanism followed, the components, the challenges faced and the limitations of our device and what

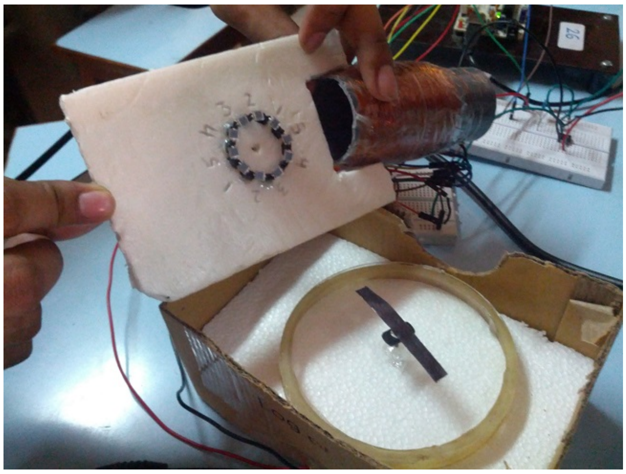


Figure 1: Left: The magnetic needle freely suspended horizontally, underneath it(not seen in the picture) is a LED. Right: The needle and the angle sensing array of photodiodes.

all could be done to tackle those problem to convert the prototype into a well finished product.

Detection module

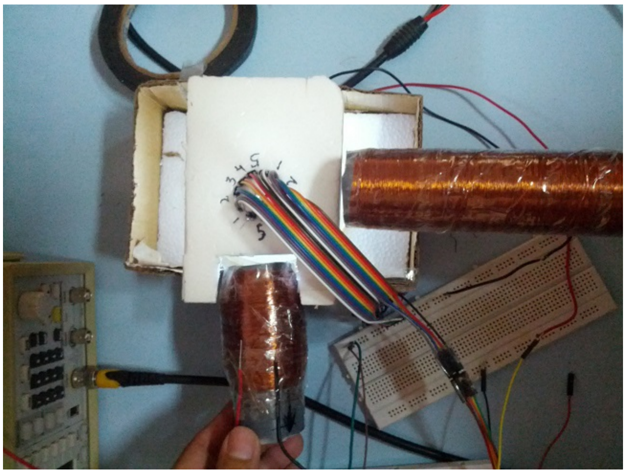
The major difference of our magnetometer from usual is by being automated. However the major challenge that we needed to tackle was to make the device automated, which requires the angle deflection of the needle (needed for strength and direction detection of earth field) and the solenoid field strength controlling to be automated.

For the detection of geomagnetic field, we need to find out both magnetic strength and the direction in the horizontal plain. We designed to place a magnetic needle in a dark closed box, to avoid ambient light, whose importance is discussed below. From below, of the needle we cast a light form a LED, which further produces a shadow on the screen placed above the magnetic needle. The screen above has a circular array of photodiodes (BPW34 Photodiode, 2NA, 900NM, Rectangular). This array, senses the intensity difference due to the shadow of the needle and the varying voltage output of the diodes are given as inputs to the arduino in the analog I/O pins. To avoid noise from ambient light into the system, we used a closed system.

Initially the needle is just kept in the geo-magnetic field, this gives us the direction of the field. To get the strength of the field we use a simple concept. We place a solenoid perpendicular to the initial direction of the needle which can have a varying current, which in turn generate variable magnetic field. From the production of magnetic field of equal strength to the geo-magnetic field by the solenoid, will deflect the needle 45° from its initial state. This variation will generate a variation in the intensity profile due to the shadow on the photodiode. This change in profile is detected by sophisticated arduino code to non-mechanically detect the deflection. The code also varies the current of the solenoid to produce an equal geo-magnetic strength to finally achieve a 45° deflection. We get to know the field strength by reverse calculation to get field from the given current that was used to generate field from solenoid.

Challenges faced

The limitation that we face at this stage of angle detection is from the limited and discrete numbers of photodiodes that we uses to sense the deflection. Therefore the system gives a



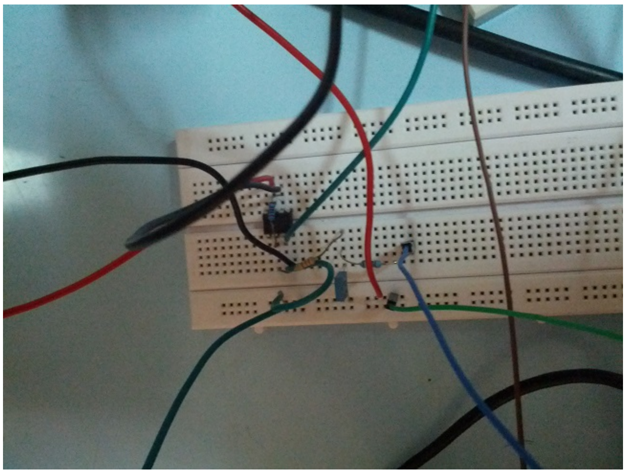


Figure 2: Left: The solenoids used to probe the canceling field and sensors from behind. Right: The OpAmp inverting amplifier circuit.

limitation of approximately 18° and minor variations in the position of needle in not feasible (may be caused by some additional noise field). One possible solution can be, by using a black and white color coded angular splits. And the position of the needle on a color profile may give the position of the needle. However, the solution, this way turns out to be more mechanical and affect the free suspension of the magnetic needle if not demanding a large number of sensors. Another possible solution is to use a continuously sensitive photodiode.

How the process of achieving a nearly half-quarter deflection is done will be discussed in the next sections.

Feedback and analysis module

So voltage variation occurred here was due to the projection of the needle on photodiodes. Here the effective covered by the shadow was approximately less than twice the area of photodiode (PD). Each pair of the diametrically opposite PDs gave a specific value of voltage whose initial values were stored as the reference value. Now any change in magnetic field in the vicinity would cause the voltage values of diametrically opposite pairs to vary. This variation in voltage is taken as input by arduino. Now the current feedback is given by the arduino to the solenoid which aims to compensate the change that was generated by the stray magnetic field. Here the connection to the solenoid are made such that the current can alter the direction which is an added feature of in the system. This feature limits the number of solenoids required to nullify the magnetic field to two, one along both the orthogonal directions. The solenoid takes feedback after every 15 second and adjusts its current value accordingly.

Controlling module

One of the important parameters that justifies the nullification of magnetic field, is the variation of the current value that generates opposing magnetic field. Here the magnetic field generation by solenoid depends on the number of turns and the current flowing through the coil, which is given by the formula

$$B = (\frac{\mu_o n I}{2}(sin(\theta_2) - sin(\theta_1)))$$

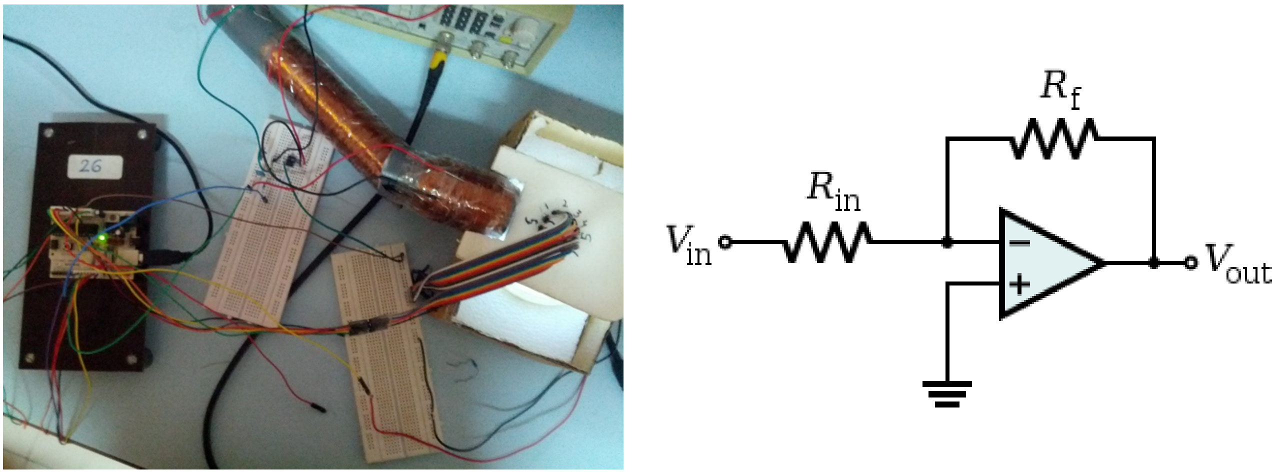


Figure 3: Left: The complete setup. Starting with the Arduino, OpAmp circuit, the Solenoids and the sensors. Right: The OpAmp inverting amplifier circuit.

where n and I are the number of turns and the currents, and θ_1 and θ_2 are the angles made by the solenoid's near and farther ends at the region where field is canceled. So after every 15 seconds the PDs note the corresponding voltage values and sends back to arduino and accordingly gives the feedback to the solenoid. To implement this for a wider range of field magnitudes, we included an inverting amplifier circuit (of Gain = 10) that supplies it's output to the solenoid. Link to Arduino Code

Conclusion and Future Perspectives

With the available resources and limited time constrains, we are able to detect the deflection of the needle using arduino. From the readings of the diodes, we are able to detect the strength as well as direction of the geo-magnetic field. Finally with suitable feedback and analysis we are able to cancel the magnetic field to create a field free space. In our project, we have been very restrictive in working with very specific range of magnetic field. The range can be widened by using more sophisticated solenoids.

The first hand learning experience through the project was very encouraging and enjoyable. We learned the deviation between experimental physics from theoretical considerations. There is a lot of scope to develop this very idea into a full fledged magnetometer with more added feature.

Acknowledgements

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