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The design and manufacture of a trapezoidal coil to produce a homogeneous magnetic field for use in medical applications

Abstract

Conventional treatments for cancer include surgery, chemotherapy and radiotherapy. These methods are not necessarily effective in all cancers and each has its own side effects, and researchers are now looking for other ways to fight cancer. According to studies in this field, new methods of cancer treatment include nano drug delivery and hyperthermia using magnetic nanoparticles. Studies show that using nano drug delivery knowledge, the drug works only in the affected area and does not cause complications in healthy areas of the body. By using these methods, drugs can be delivered accurately and quickly to target tissues. Also, in hyperthermia, a fluid containing magnetic nanoparticles is injected directly or through the vein system into the target tissue, and an alternating magnetic field generated by magnetic coil (such as Helmholtz Coil) is applied to the target area and the magnetic nanoparticles emit heat. The heat produced increases the temperature of the tissue and destroys the desired cells by increasing the temperature above 42°C. In this article, we survey the Helmholtz coil and designing and manufacturing a new coil to create a homogeneous magnetic field and build a magnetic field measuring sensor to measure the magnetic field flux produced by the new coil.

Keywords: magnetic coil, homogeneous, axis, hyperthermia, drug delivery, hyperthermia, magnetic field flux, sensor

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Introduction

The rapidly changing magnetic fields are used in many areas of science and engineering. In the field of medicine, the important topic in which the magnetic field is used is the area of nano-drug delivery and magnetic hyperthermia where alternating or rotating magnetic fields are used to generate heat in magnetic nanoparticles.[1,2] Magnetic nanoparticles are a subset of nanomaterials that have high magnetization and high biocompatibility so can be used in a variety of biomedical fields including targeted drug delivery and biosensing.[3–10] In general, magnetic nanoparticles can generate useful heat based on a few 100 W/g.[11] Produced heat is capable of destroying cancer tissue or releasing drug molecules from liposomes for targeted drug delivery. However, there are several challenges to this technology to its maximum. The concentration of nanoparticles required for effective removal of cancerous tissue should be in the order of several milligrams per milliliter to the required temperature of 42 to 45 °C.[12] In addition, magnetic hyperthermia treatments last for minutes and hours. Stimulation of biological systems is by magnetic fields, which require a homogeneous and controlled magnetic field. Systems typically used to generate a homogeneous magnetic field are based on permanent magnets and nuclear coils of simple geometric shapes (circles, squares, and rectangles) of two coils or more with different spacing. The Helmholtz pair is one of the most commonly used configurations in applications of electromagnetic excitation due to the very uniform magnetic field generation. In this article, we first give a brief overview of the Helmholtz Coil and then describe the new coil model that we designed.

The study of Helmholtz coil

The Helmholtz coil was invented in the mid-19th century by Hermann Von Helmholtz, which produces a nearly homogeneous magnetic field. The Helmholtz Coil is ideal for producing a large area of uniform magnetic field. It has two coils with equal diameter. The distance between two coils is equal to radius of the coil, and each coils having a N circumference is a wire.[13,14] As a current passes through a coil, the magnetic field is created in the space around it. Inside the coil is a homogeneous magnetic field. The direction of the magnetic field can be predicted using the right-hand rule and the magnetic field's intensity is calculated at the center using a derivation of the Biot-Savart law.[15] As in the equation 1, μ_0 is the permeability constant in vacuum, n is the number of turns of the wire, I is the current and R is the radius of the coils.[4]

$$B = \left(\frac{4}{5}\right)^{3/2} \frac{\mu_0 nI}{R} \quad (1)$$

As shown in the Figure 1, the Helmholtz coil magnetic field is much more homogeneous than the single-coil magnetic field.

The pre design of coil by simulation

In this project we used Comsol software to simulate. Design and simulation of electrical, mechanical, geosciences, chemistry, physics, astronomy and quantum engineering projects can be done with the use of Comsol software.[16] It also interacts with other engineering software such as MATLAB, Excel, and more. Comsol software is a complete set of simulations that can solve differential equations of nonlinear systems by partial derivatives using finite element method in one, two and three dimensional spaces. According to the Figure 2, we first had to implement the Helmholtz Coil in the simulation environment to design a new coil according to the magnetic flux diagram. After examining the Helmholtz Coil magnetic flux diagram, we simulate a new model of the coil. At this point, we have simulated a number of new models in the camcorder software environment, from which we have developed and tested a trapezoidal coil. In the final simulation, two trapezoidal coils with a large side 30cm, a small side 15cm and a height of 15cm are used. In each coil, 40 rounds of wire are wrapped. As shown in the Figure 3, the magnetic flux is homogeneous along all three coordinate axes. After simulating the 3D environment, we also changed the coil spacing and observed that the magnetic flux diagram of the coil varied at different distances and had the best homogeneous field at distances less than 10cm.

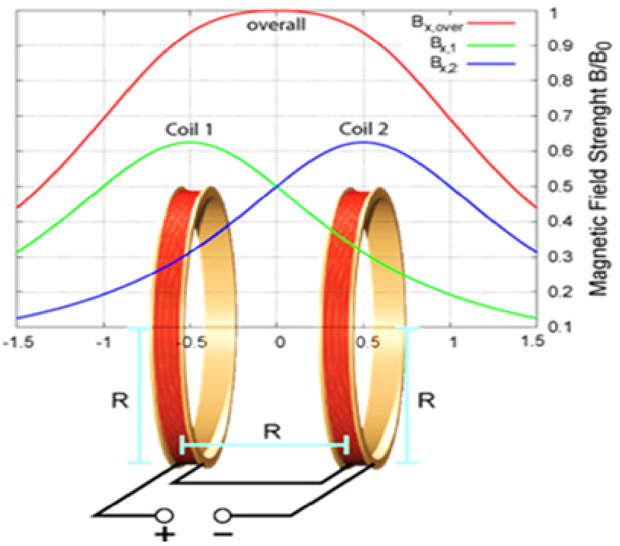

Figure 1 The schematic of Helmholtz coil and the magnetic field curves.[14]

The manufacture process of a new coil

We cut the designed trapezoidal coils with dimensions, a large side 30cm, a small side 15cm and a height of 15cm, according to the Figure 4, on the wood by CNC machine. The coils are designed to be movable so that we can measure the field at different distances. To select the proper wire for this coil model, it is necessary to calculate the maximum tolerable current. This current is calculated by equation 2:[17]

$$I = \frac{\pi . d^2}{4} . \sqrt{\frac{\frac{\Delta T}{t} . c . \rho m}{\rho r}} \quad (2)$$

Where in, I is the current that passes through each coil, d is the diameter of the wire, $\frac{\Delta T}{t}$ shows the increase in temperature over time, c is the specific heat capacity of the wire, ρ_m is the capacity of the wire and ρr is the resistance of the wire. We chose the right wire according to the process we had. Wire used for coiling coils, sieve coated copper wire with 1.25 mm thick, 1kg approximate total weight of wire and in 40 rounds of wrapped wire, 36m of wire is used. This wire model was chosen because of its light weight and suitable thickness for hand coiling and tolerating voltage and current. We coiled the coils and connected them in series to the voltage source (Figure 5).

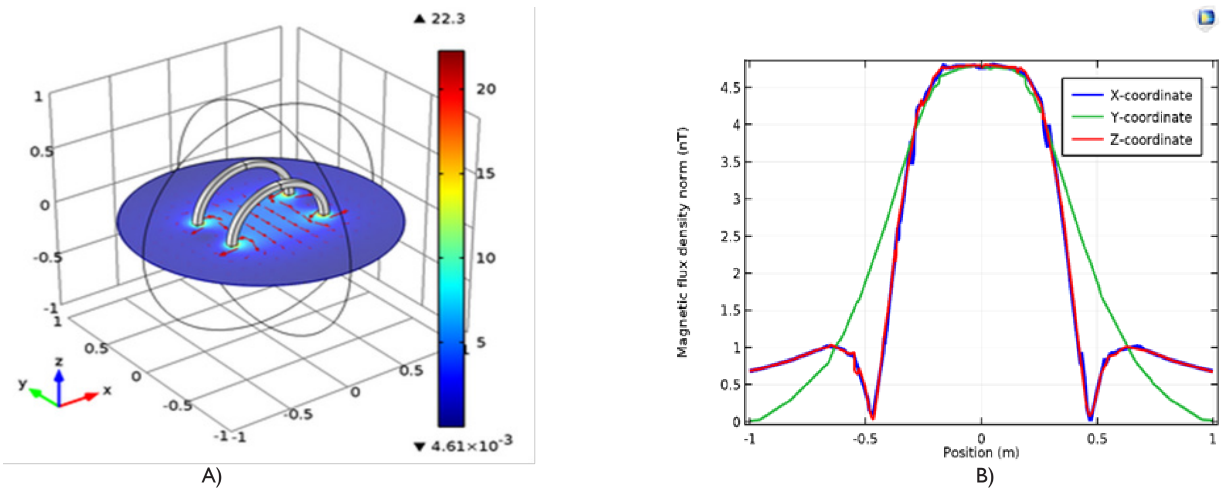

Figure 2 The simulation of Helmholtz Coil, A) the schematic of Helmholtz coil created by COMSOL. B) The Magnetic flux density (T) result in different coordinates obtained from FEM simulation.

The real time measurement of the magnetic flux density

To test the device, need a sensor that measures the field intensity produced by the device. In this project, we use the principle of analogue to digital signal conversion in Arduino. The Arduino is a single-board microcontroller designed to make it easier to create applications that interact with objects or environments. The Arduino board is built on the microcontroller at mega 328p. The Arduino has six analogue-to-digital channels. The UNO ADC has 10 bits of resolution that will have values of 0 to 1023. This means that it converts the voltage between 0 to 5 volts into 0 to 1023units, So each unit is equal to 4.9mV. Arduino comes with an integrated IDE software development environment that runs on ordinary computers that allow Arduino to use C or C++ programming.[18] In this project, the code used to program the microcontroller is shown (Figure 6).

```
#include <LiquidCrystal.h>

//initialize the library with the numbers of the interface pins
```

LiquidCrystal lcd(8, 9, 10, 11, 12, 13);/// REGISTER SELECT PIN , ENABLE PIN , D4 PIN , D5 PIN , D6 PIN , D7 PIN

char ADCSHOW[5] ; //initializing a character of size 5 for showing the ADC result

void setup()

{

// set up the LCD's number of columns and rows:

lcd.being(16,2);

}

void loop()

{

lcd.print("FluxDensity");//showing name

lcd.setCursor(0, 1);//move to second line

lcd.print("(in Gauss):");//showing units

String ADCVALUE =

String((analogRead(A0)-515)/3.76);

/* Now since the default reference if 5V and resolution is 10bit so for every 5/1024 = 5Mv , we get one increment is count , The sensor provides increment voltage of 1.3V for every 1Gauss increment if field.

So we need to divide ADC value by 3.76 for getting the gauss value , now the 0 gauss output of sensor is 2.5V so we need to subtract that first. To hold a read at 0Gauss field. */

// Convert the reading to a char array ADCVALUE. ToCharArray(ADCSHOW, 5);

lcd.print(ADCSHOW) ; //showing the field

strength value

lcd.print("G ");

lcd.setCursor(0, 0); // set the cursor to

column 0, line 0

}

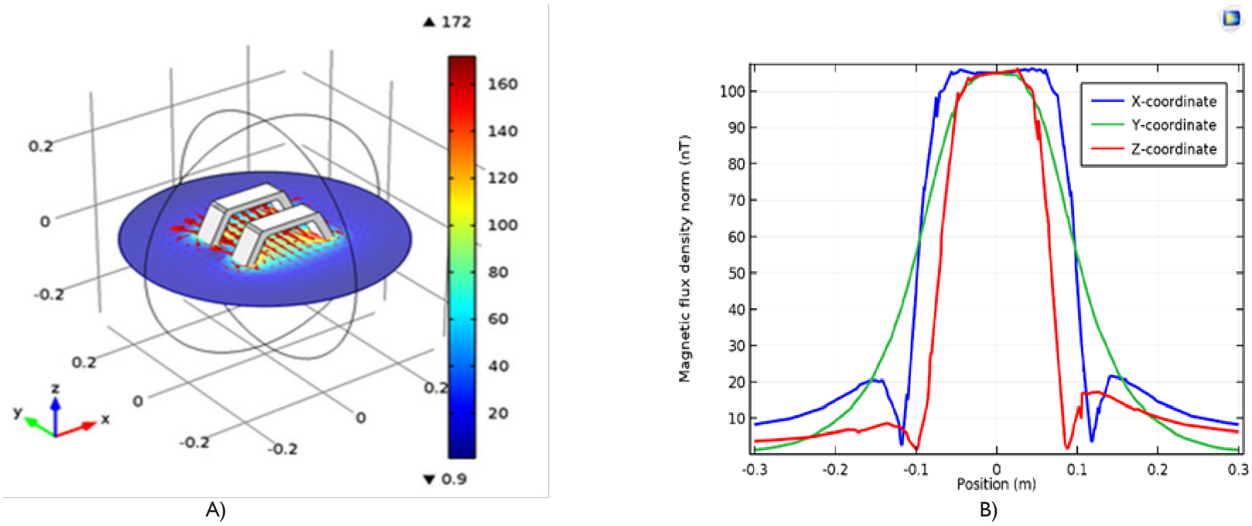

Figure 3 The simulation results of trapezoidal coil by COMSOL. A) The schematic of a new coil. B) The Magnetic flux density result in different coordinates obtained from simulation.

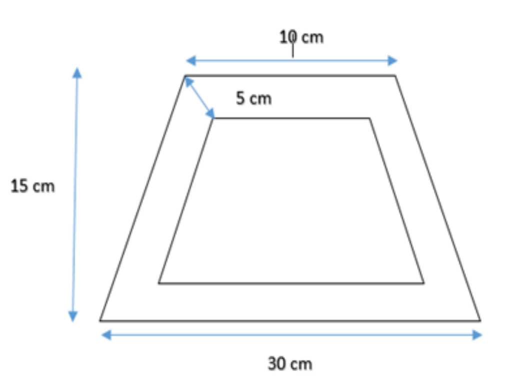

Figure 4 The dimensions of the proposed trapezoidal coil.

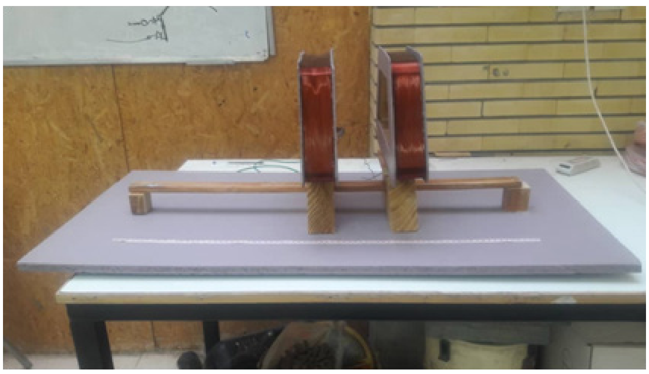

Figure 5 The real image from trapezpidal coil.

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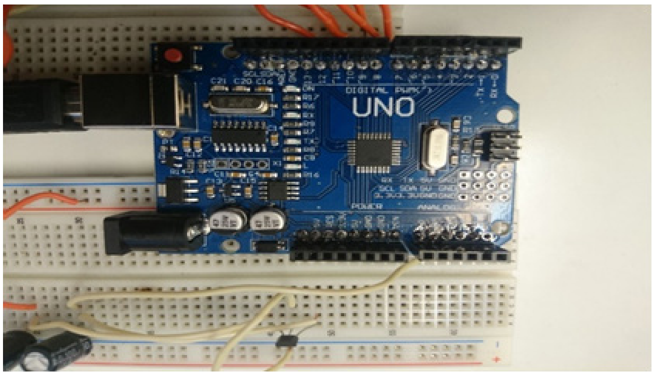
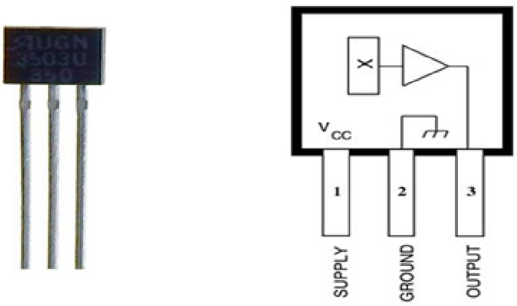


Figure 6 The Arduino board, UNO ADC type.

We used a Hall effect sensor to measure the magnetic field flux. The name of the sensor we used is UGN3503U. The sensor is a transducer Hall effect sensor, which shows voltage in response to changes in the output magnetic field. By applying a large magnetic field, the voltage is in the range of a few microvolts. If it is not adjacent to the magnetic field, the sensor has a constant output voltage of about 2.5volts (about half the supply voltage) at the sensor output. The operating voltage range of the sensor is between 4.5 and 6V and the operating current of the sensor is between 9 and 13 mA.[19] The Figure 7 shows a schematic of a UNG3503U sensor with tripod.[20,21] When the magnetic field flux is measured by the sensor, its value is displayed on the LCD. LCDs include a variety of characters and graphics. Here's the type of character we used. Character displays are also divided into parallel and serial categories in terms of information exchange. One type of serial is less use of microcontroller pins. In terms of size, these have different variations, including 16×2, 32×2, 40×2, 16×4 and so on, which means these numbers, the number of characters displayed in a row and Its rows.[22] For example, type 16×2 has 2 rows and represents 16 characters per row. In this project, we have used type 16×2 which is very useful (Figure 8). Schematic of the overall circuit of the magnetic field flux measuring sensor, designed by the elements mentioned above and shows in the Figure 11 & Figure 9. This sensor is located between the coils, and when applied to the magnetic field, it displays the magnitude of the magnetic field at different distances between the coils in Gauss. Finally, we connected the dc source (5Volts) to the coils and the magnetic field measuring circuit and adjusted the distance between the coils to 4cm. The field generated by the new trapezoidal coil was measured with a sensor. We plot the results in Figure 10. From the measurement of the magnetic field intensity with the voltage change, it was concluded that the field changes in terms of voltage changes are almost linear (Figure 11).



A) B)

Figure 7 A) UGN3503U Hall effect sensor.[20] B) the schematic of Hall effect sensor.[21]

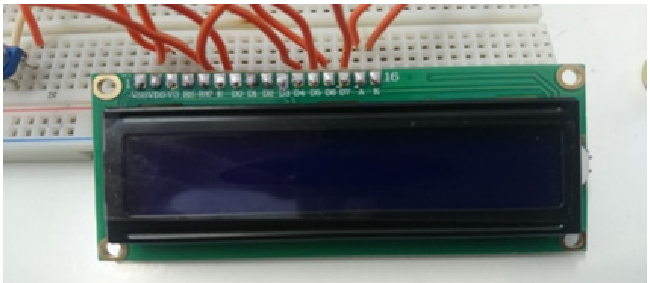


Figure 8 LCD used in this project is 16×2 type.

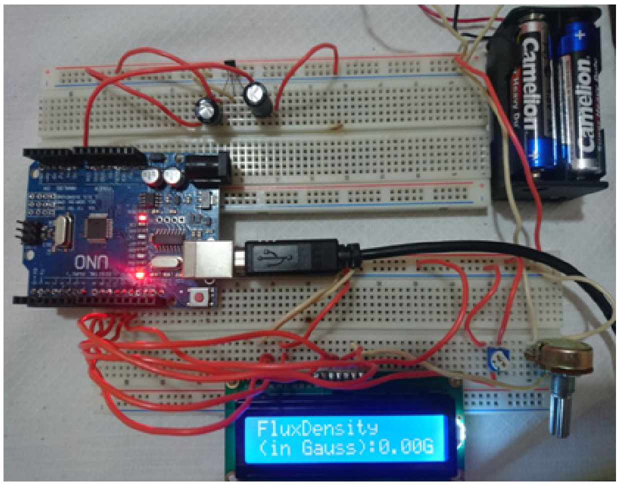


Figure 9 Electronic circuit of magnetic field flux measuring sensor.

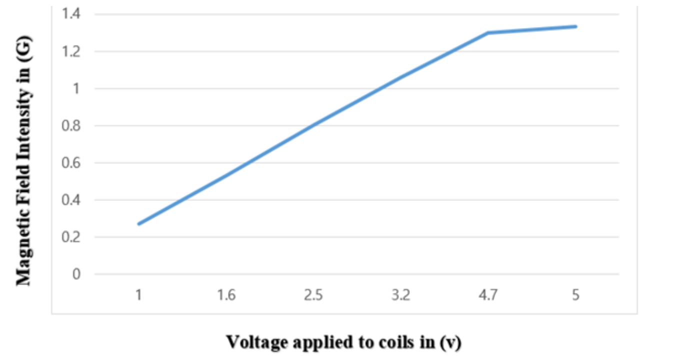


Figure 10 The experimental result of the magnetic field flux measured by the sensor in terms of voltage applied to the coils.

Conclusion

We know that smart drug delivery has a remarkable role in the treatment of cancers because with the use of nano-drug knowledge, the drug works only in the affected area and does not cause complications in healthy areas of the body. The purpose of this project was to design a new magnetic coil that is different from the conventional circular coils used in medical applications. The trapezoidal coil that designed is proposed in biomedical domain because of its geometrical shape. This specific design permits us to use it in several investigations. This geometry has many advantages compared to the cylinder coil. For example, in MRI diagnostic the patient has a more open space and is useful for technician or physician freedom and the patient will feel more comfortable and these properties and the geometrical shape of the trapezoidal coil have not eliminated the homogeneous property of the field.

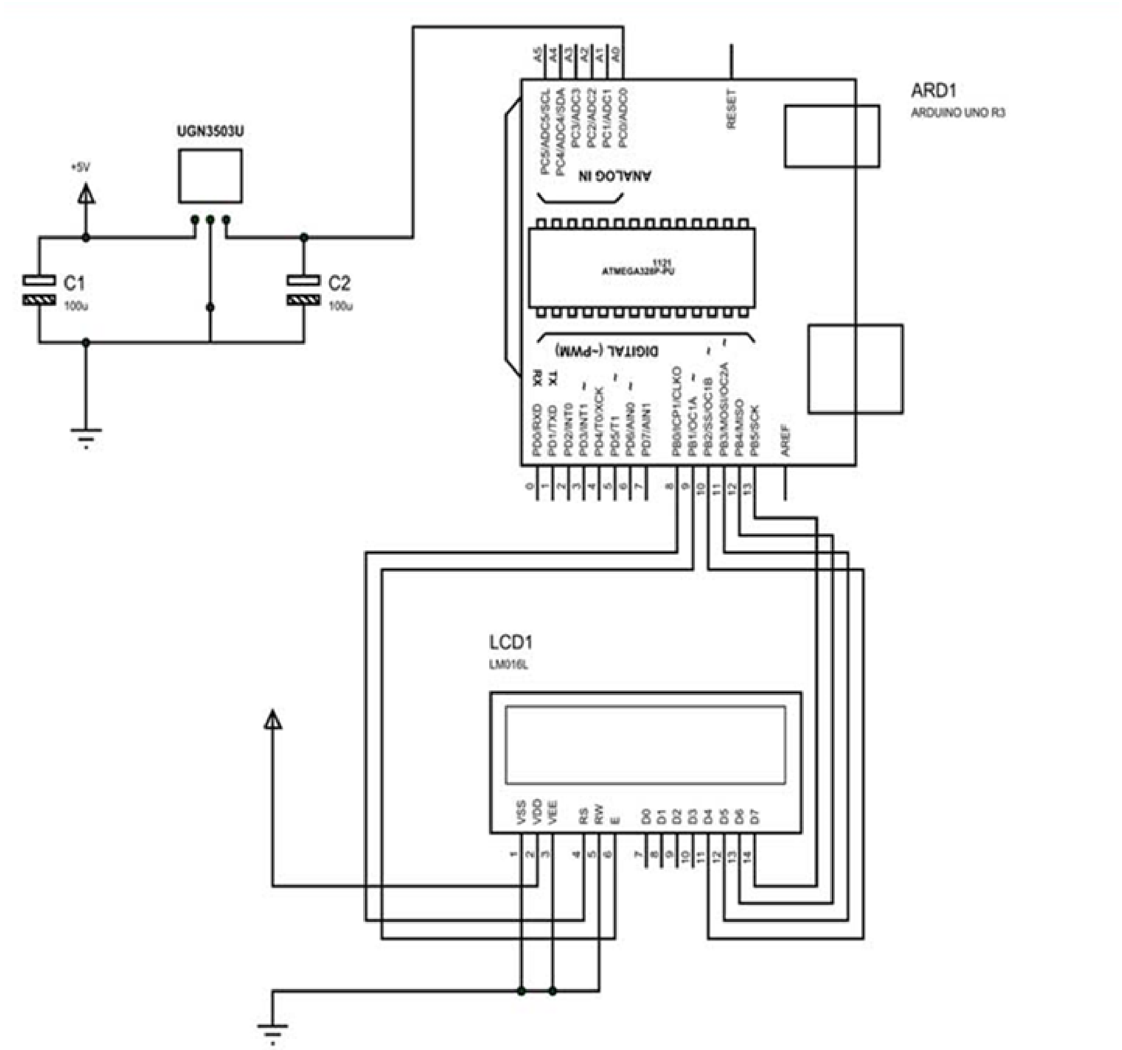


Figure 11 The diagram of the overall circuit of the magnetic field flux measuring sensor.

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None.

Conflicts of interest

Authors declare that there is no conflict of interest.

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