Paper

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Arduino and LabVIEW-based remote data acquisition system for magnetic field of coils experiments

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Abstract

The topic of electric and magnetic fields is fundamental to the physics curriculum in both high school and college. The applied aspect of this topic has triggered the rapid development of modern technology in this era. This paper reported a remote data acquisition system developed for experiments with magnetic fields by coils to support experimental physics learning remotely. The system used magnetic sensors, Arduino interfaces, and NI-Vernier Sensor-DAQ and LabVIEW as a data acquisition software. It was successful in testing for and measuring the distribution of magnetic fields along the axis of a circular coil. The measurement results showed experimental values in line with Biot–Savart law. The system developed is therefore useful as a learning tool that provides students with the opportunity to control instruments and conduct experiments in real-time remotely via the web. This system is also useful for overcoming the limited access to experimental devices.

1. Introduction

Electromagnetism is one of the four fundamental forces of nature studies that support the field of modern physics, combining electrical and magnetic studies. Electricity combines the study of charged particles, electric fields, electric potential, and electric currents, while magnetic studies involve, magnetic fields, magnetic force, and magnetic dipoles [1, 2]. Electrical and magnetic laws play a central role in the development of devices such as smartphones, electric motors, high-energy accelerators, bio-magnetic measurements [3, 4], and transcranial magnetic stimulation [5]. Meanwhile interatomic and intermolecular forces play a fundamental role in the formation of solids and liquids [6]. Today's modern technology relies heavily on the application of electricity and magnetism.

Therefore, the topics of electricity and magnetism associated with electric and magnetic fields are fundamental in the physics curriculum for high school and tertiary education. A magnetic field is produced not only by permanent magnets but also by electric currents. The magnetic field around an electric current has a different profile from the magnetic field produced by a permanent magnet, depending on the electric current circuit, such as wire or geometry [7]. Therefore, mathematical formulas for magnetic fields around current sources differ for each form, and it presents

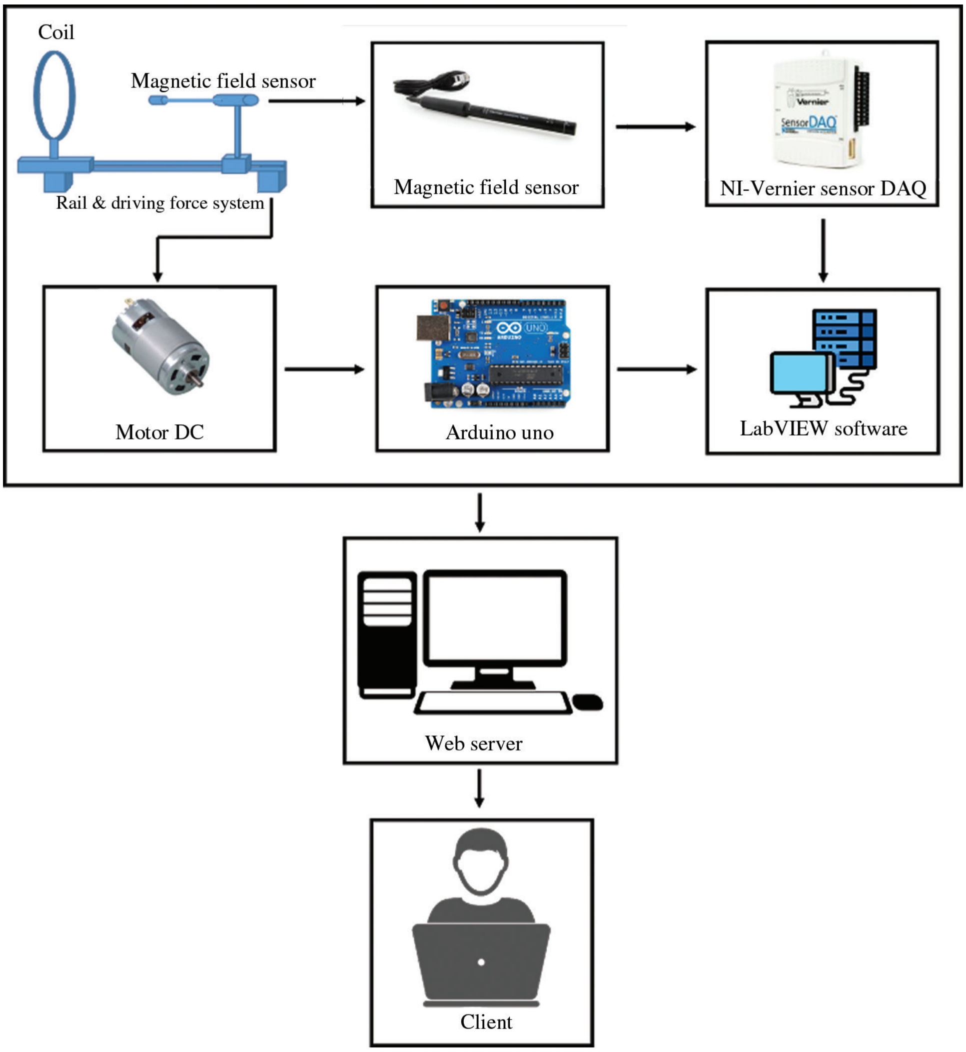

Figure 1. Pattern control of the magnetic field of coils experiment apparatus.

difficulty for students to imagine magnetic fields [8]. Another difference is that magnetic fields induced by electric currents are relatively smaller compared to magnetic fields made by permanent magnets. It is challenging to observe magnetic phenomena [9]. Electricity and magnetism should be studied not only through theoretical studies but also experimentally. Experimental studies in the laboratory are usually hands-on, but such a method is still constrained by limited access due to the limited equipment, a certain amount of time to prepare, and the requirement to attend the laboratory.

From the pedagogical perspective, learning physics, including electricity and magnetism, can be done by adopting theoretical, experimental, and computational approaches. Driven by the development of ICT, especially Internet technology, laboratory devices for science experiments are increasingly diverse. For instance, experiments are conducted in real laboratories, virtual labs, and remote labs [10, 11]. Authentic experiences can be accomplished directly (hands-on) and remotely with experiments carried out by accessing and controlling real equipment through the web [12–14]. A remote laboratory allows users to collect, analyze, and display data efficiently and online during experiments. Therefore, the learning is more focused on understanding the physics concepts

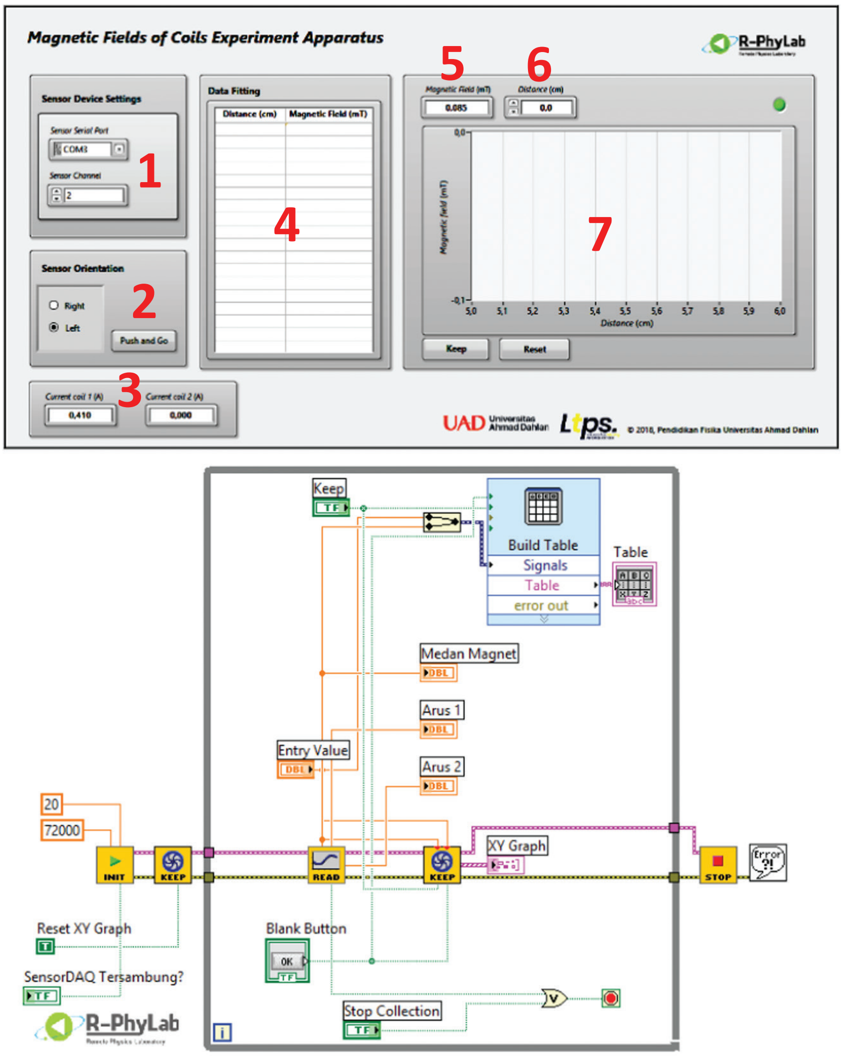

Figure 2. Front panel display and block diagram of the apparatus.

[11, 15]. Remote laboratory equipment can overcome the obstacles to learning in the laboratory. Laboratory activities are no longer constrained by space, time, and equipment. As a result, the teacher can improve physics learning in terms of access and quality. This study aims to develop a system of remote data acquisition to experiment with magnetic fields by coils in order to support physics learning experimentally through remote laboratories. The system developed in this paper has a novelty and extravagance. It is a magnetic field sensor' moving forward or backward that can be controlled close to or far from the coil via the website.

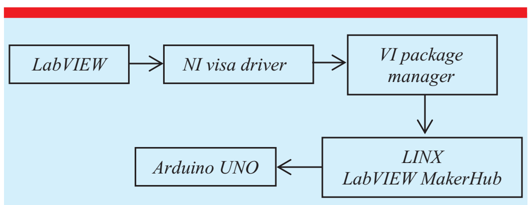

Figure 3. Connection path between LabVIEW and Arduino UNO.

2. Materials and methods

The magnetic field of coils experiment apparatus is a data acquisition system consisting of a sensor drive systems, magnetic field sensors,

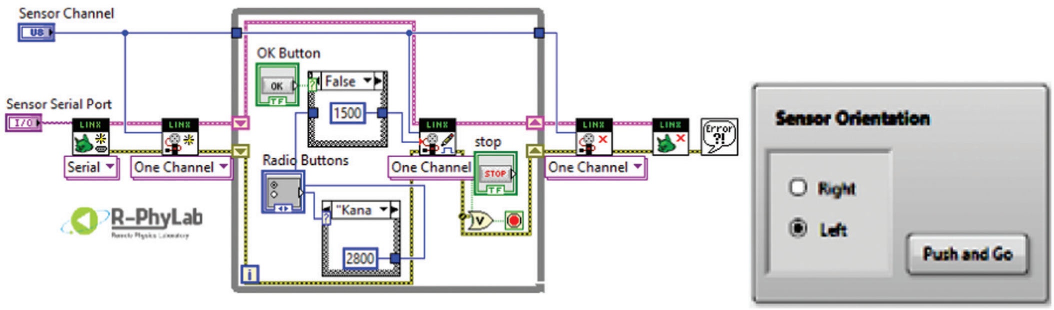

Figure 4. Sections from the front panel and a block diagram of the sensor drive system.

interfaces, and coils. The sensor drive system in this device uses a DC motor, which is controlled by the Arduino Uno microcontroller through a digital pin connection. Arduino Uno is a microcontroller that can provide control systems in real-time with analog or digital connections [16, 17].

The drive system in this tool will move the magnetic field sensor closer to and away from the coil. Magnetic field sensors are used to capture magnetic field data generated by electrified coils. LabVIEW controls such sensors through the NI-Vernier SensorDAQ connection. In summary, figure 1 shows the magnetic field of coils experiment system.

The user can have control of the sensor drive system and the data sampling process through the front panel. It is built using LabVIEW software, a block diagram-based programming language from the National Instrument, which has a connection facility with Arduino Uno [18, 19]. This front panel was developed to make it easier for users to use the system.

The front panel consists of several parts, including (1) sensor service settings, to manage communication between software and hardware, (2) sensor orientation, to adjust the direction of motion and to move the sensor, (3) current coil monitor, to display the flowing electric current on the coil, (4) data fitting table, to display the data that has been copied, (5) magnetic field monitor, to display the magnitude of the magnetic field read by the sensor, (6) distance monitor, to display the sensor distance to the coil, and (7) figure, to display graphs of data on the relationship between sensor distance and magnetic field strength successfully captured. Figure 2 shows the front panel display.

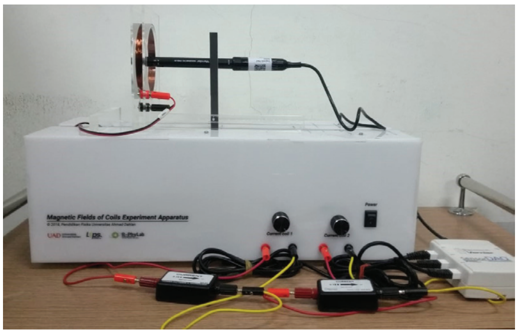

Figure 5. Experimental equipment.

In this research, the Arduino was controlled by LabVIEW with the help of LINX as the connecting gateway. LINX is a device developed as a freeware toolkit for implementing program control systems from platforms designed with input–output systems from Arduino microcontrollers [20]. In addition, NI-VISA drivers became the USB serial communication on computers with the Arduino. Figure 3 shows a connection path between LabVIEW and Arduino.

A magnetic field sensor executed the process of sampling magnetic field data through the NI-Vernier SensorDAQ analog 1 pin connection. Then, the data was stored and approved on the front panel system.

Meanwhile, the sensor drive system executed by the DC motor was programmed through the diagram block as shown in figure 4.

3. Results and discussion

The magnetostatic experimental apparatus for the Biot–Savart law uses coils with 150 turns, a wire diameter of 0.50 ± 0.05 mm, and a coil diameter R of 8.900 ± 0.005 cm. In the experimental activity, the coil flows at 0.408 Ampere. The magnetic

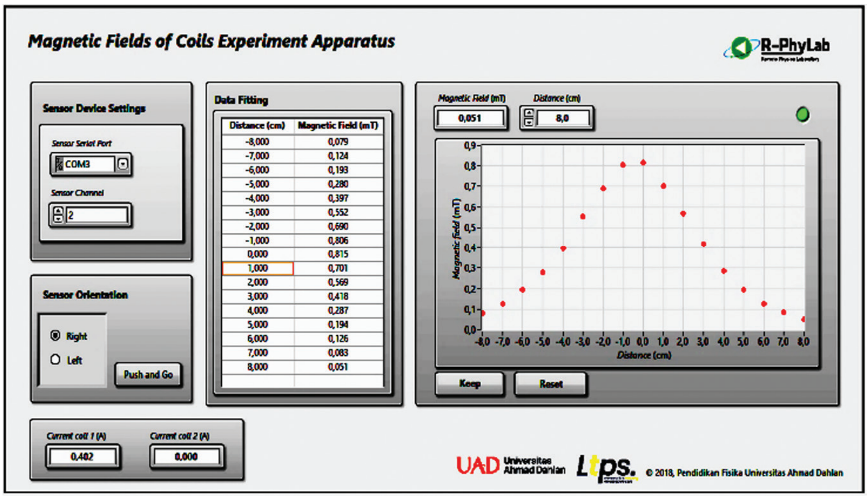

Figure 6. Results of experimental data sampling.

Table 1. Experimental data results.

No	Sensor distance (cm)	Magnetic field (mT)
1	−8.0	0.118
2	−7.0	0.154
3	−6.0	0.214
4	−5.0	0.298
5	−4.0	0.413
6	−3.0	0.557
7	−2.0	0.709
8	−1.0	0.832
9	0	0.860
10	1.0	0.780
11	2.0	0.645
12	3.0	0.492
13	4.0	0.366
14	5.0	0.264
15	6.0	0.192
16	7.0	0.137
17	8.0	0.102

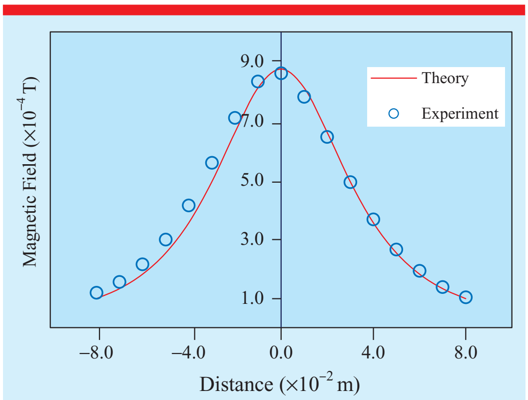

Figure 7. Experimental results compared with calculation results.

field sensor is moved as far as −8.0 cm to +8.0 cm from the coil. The minus sign means the sensor is to the left of the coil, and the plus sign means the sensor is to the right of the coil, while the zero point means the sensor is at the center of the coil circle. Explicitly, the experimental toolset is shown in figure 5.

When the sensor is at a distance x of −8.0 cm from coils, the magnetic field data read from the sensor is copied and stored in the table in the user interface. Then the sensor is moved back as far as 1.0 cm; at this distance (−7.0 cm) the magnetic field data is retaken and so on until the position of the sensor is at a distance of 8.0 cm. The user interface automatically saves and displays snippet data as shown in figure 6.

Table 1 displays the experimental results comprehensively.

Figure 7 shows a graph of the correlation between the sensor distance and the magnetic field strength B_x of the experimental results compared to the results of calculation based on equations (1) and (2) [21].

$$B_x = \frac{\mu_0 I}{4\pi} \oint \frac{\mathrm{d}s \cos\theta}{x^2 + R^2} \tag{1}$$

$$B_x = \frac{\mu_0 I R^2}{2(x^2 + R^2)^{3/2}}. \tag{2}$$

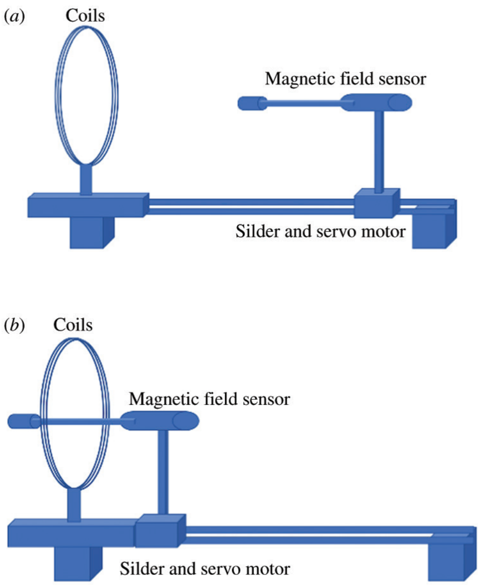

Figure 8. (a) The sensor is to the left of the coil, (b) the sensor is to the right of the coil, and the sensor body is inside the coil.

There are differences in the experimental results obtained when the sensor is to the left of the coil and the right of the coil when compared to the results of the theoretical calculation using the permeability of vacuum μ_0. When the sensor is to the right of the coil, the sampling data is relatively different from the calculated data. Meanwhile, when the sensor is on the left (see figure 8(a)), the data coil tends to be stable and follow the results of calculation. This is because when the sensor is to the right of the coil body rod, the magnetic field sensor itself enters the center of the coil (see figure 8(b)). The presence of a sensor bar in the center of the coil makes the permeability value higher than μ_0, causing a difference in the magnetic field values on the left and right of the coil.

For physics learning, remote data acquisition systems for a magnetic fields of coils experiment can be accessed at the web address http://rphylab.pf.uad.ac.id/sistem/ by requesting a username and password for the administrator via rphylab@gmail.com.

4. Conclusions

The developed product is an Arduino and LabVIEW-based remote data acquisition system for a magnetic fields of coils experiment. This system is successful in measuring the distribution of magnetic fields along a circular coil axis. It is useful as a learning tool allowing students to control instruments and conduct experiments in real-time remotely via the web.

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