Design of magneto-optic characterization properties of vegetable oil using Faraday rotation method based on microcontroller

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Abstract. The research aimed to design and create Faraday’s rotation system as a tool to characterize the magneto-optic properties of vegetable oil. The measured magnitude were the intensity of light, the magnitude of the magnetic field, and the change in the rotation angle of polarization. Measurement of light intensity was carried out using BH1750 as a light sensor, magnetic field measurement was carried out using Gauss meter. Changes in the rotation angle of polarization were made by the stepper motor which drove the lens of the analyzer which had been geared. The light source used was an RGB laser with a power 300mW. Data were collected by the initial condition of the angle between polarizer and analyzer lens at 45°. It can be concluded that Faraday rotation experiment is affected by heat produced by the solenoid and olive oil has magneto-optic property.

Keywords: design, magneto-optic, vegetable oil

1. Introduction
In 1845 Michael Faraday was the first person who discovered physical phenomena that connecting light and magnetism. He was able to rotate the polarization of light when he induced a magnetic field in the same direction of light.

The phenomenon of Faraday rotation is also commonly called magneto-optic phenomenon. Faraday rotation only occurs when light passes through transparent dielectric materials [1]. Faraday rotation is the result of magnetic resonance which causes light or waves to break down into two circularly polarized rays that travel at different speeds. This known as Circular Birefringence. The two rays will rejoin after passes the sample induced by the magnetic field. Faraday rotation satisfy the equation

\[ \theta = VBd \]  

Theta is the magnitude of rotation angle in plane of polarization, B is the magnitude of magnetic induction, d is sample length. V is known as Verdet constant that gives a quantitative measure of the Faraday rotation ability of the material.

There are many applications of Faraday rotation such as current and magnetic field sensors [2], optical circulators [3], and optical isolators [4]. Optical isolator is an optical device used to prevent unwanted back reflections [5]. Moreover, semiconductor and magnetic materials can be characterized
by Faraday rotation method [6]. In the case of vegetable oil use, if the oil has magneto-optical properties, the Faraday rotation method can be used to determine the quality of vegetable oil. By looking at the value of Verdet constant before oil is used and after oil is used, it is expected that we can determine the quality of vegetable oil that we use (see Figure 1).

Faraday rotation is very closely related to polarization of light. If the light produced by the light source has not been polarized, the instrumentation system for characterizing magneto-optic properties need a polarizing filter, so that changes in the angle in plane of polarization can be seen. The purpose is light that passing through the sample is polarized and only has one vibrating plane. A polarizing filter can pass light that initially have many areas of vibration become to light that has only one area of vibration. Figure 2 shows some examples of polarized light.

Research on Faraday rotation has been widely carried out. There are many types of sample are used in the experiment, such as magneto-optical glass [6], SF-59 glass [1], fibers’ [7], ethyl alcohol, methyl alcohol, BK7 glass [5], and coconut oil [8]. As one example of the Faraday rotation experiment, Muhammad Rizki Nurriansyah, Arief Sudarmaji, Luthfi Azmaiza Hadsyah, and Arnold Fedriko [8] designed a data acquisition system for the Faraday rotation phenomenon. The samples used are distilled water and coconut oil. Magnetic field generator used was 2 coils. From these studies it can be concluded that Faraday rotation can characterize magneto-optic properties and that coconut oil has a magneto-optic property.

The research uses olive oil as a sample. Meanwhile, the magnetic field generator that we used is solenoid. By drawing conclusions from several previous researches, the research tries to design a microcontroller-based Faraday rotation instrumentation system as a tool for characterizing the magneto optic property of vegetable oil as the final goal. It is expected that the research can determine the quality of vegetable oil sold in the market by using the Faraday rotation method.

2. Experimental setup
The optical system is designed and made to be used as a tool to characterize the magneto-optic properties of vegetable oils. Instrumentation system is created based on previous researches.

The light source used is an RGB laser with a power of 300mW. The red light source has a wavelength of 625 nm, the green light source has a wavelength of 520 nm, and the wavelength for a blue light source is the wave for a blue light source is 475 nm. The choice of the light source used can be chosen through a PC integrated with a microcontroller.

The magnetic field generator used is aluminium-based solenoid. The number of turns of the solenoid used is 2700 turns. Total length of solenoid is 20 cm, but we placed the sample in the center of the solenoid (at 10 cm point). Solenoid were chosen as the source of the magnetic field because the solenoids can produce more homogeneous magnetic fields for each direction (x-axis, y-axis, z-axis).
Fig. 3 is the block diagram of the system that has been made. The light produced by the laser is assumed to be unpolarized light. The light will pass through the polarizer to become polarized light. Polarized light is needed so that changes in the vibrational plane of light can be seen. After passing through the polarizer, the light will pass through the sample which is placed in the center of the solenoid.

As known together, the greatest magnetic field of the solenoid is in the center of the solenoid. After the light passes through the sample, the light will pass through the analyzer. The analyzer will rotate if there is a change in the vibrational plane of the light. CPL lenses are used as polarizer and analyzer. CPL stands for Circular Polarizer / Linear. In accordance with its name, CPL lenses can be used to polarize light.

Stepper motor are used to drive the analyzer. The type of stepper motor used in this system is NEMA 17. The stepper motor used is a 2-phase stepper motor and has a step angle of 1.8 degree / step. The accuracy of this stepper motor is relatively good, that is ± 5%. Because the system requires a step resolution of 1 degree, additional driver is used to increase the resolution and smooth the movement of the stepper motor. The driver used is A4988. A4988 driver is used to help regulate motor movement with microstep capability. Microstep is the ability to divide steps from stepper motors into smaller ones.

The light sensor used in the system is IC BH1750. The reason for choosing BH1750 as a light sensor, first, BH1750 is an IC that can automatically measure changes in light intensity. Second, the output value of BH1750 is in Lux units, so we don't have to do any more conversions. Third, the measurement range of BH1750 is quite wide, 0-65525 Lux. The measurement range is considered enough for the system specifications made.

3. Component testing
After the system is made into a single unit, there are things that need to be considered, namely testing some of the used components. Component testing needs to be done to ensure every part of the system can work in accordance with its function. System testing is also done to reduce errors when the process of retrieving data. System testing includes testing BH1750 as a light sensor, testing the solenoid as a magnetic field generator, and angle calibration on the analyzer lens that is driven by a stepper motor.

BH1750 testing is done by comparing the value of the light intensity read on BH1750 with other light sensors used as comparison. In this study, the light sensor used as a comparison is TASI-8721. Figure 4 presents the test results of BH1750 as a light sensor.
The data taken were 251 data. Measured light intensity values range from 0 Lux to 31211 Lux. Figure 4 shows the linearity between BH1750 and TASI-8721. When the light intensity reads on TASI-8721 as a comparison sensor increases, the light intensity reads on BH1750 also increases. From the results of the BH1750 test, it can be concluded that the BH1750 can be used as a good light sensor in the instrumentation system that has been made.

The next component test is the analyzer to calibrate the angle. Angle calibration is done to ensure there is no difference in rotation between analyzer and the stepper motor. The analyzer and stepper motor are fitted with gear so that when stepper motor is rotating, the analyzer also rotates. The gear is used is result of its own design which is made using 3D printer. The material of gear is plastic. Angle calibration is done by converting the pulse given to the stepper motor to a rotation angle value of analyzer. The stepper motor is programmed to rotate until the analyzer rotates 360 degrees. This test is carried out for 10 times. Table 1 shows the relationship between rotation angle of analyzer and the number of stepper motor’s pulse. The number of stepper motor’s pulse is increase linearly to the rotation angle of analyzer. The gradient value obtained is 33.75. The gradient value obtained is a multiplier constant that is used to determine the rotation angle of analyser, as presented in Figure 5.

**Table 1. Stepper Motor Test Data**

| Angle of Rotation (Degrees) | Number of Clock Pulse |
|-----------------------------|-----------------------|
| 360                         | 13478                 |
| 720                         | 26959                 |
| 1080                        | 40443                 |
| 1440                        | 53780                 |
| 1800                        | 67262                 |
| 2160                        | 80742                 |
| 2520                        | 94083                 |
| 2880                        | 107615                |
| 3240                        | 121078                |
| 3600                        | 134537                |
The next test is testing the solenoid as a source of the magnetic field. The test purpose is carried out to see the performance of the solenoids used in Faraday rotation instrumentation system. The performance of concern is the amount of magnetic field that can be induced in the sample used.

Tests carried out using Gaussmeter. Measurements are made at the center of the solenoid, which is at a distance of 10 cm. The current applied to the solenoid is a variation ranging from 0 A to 10 A with an increase in current 1 A. Figure 6 is the result of testing the magnetic field.

Based on figure 6, the increase in the magnetic field is proportional to the increase in current. The linearity between the current and magnetic field is quite linear with an $R^2$ of 0.9995. The multiplier constant represented in the gradient is 82.455. These constants can be used to convert current into magnetic fields

4. System calibration

Before data collection process, calibration between polarizer and analyzer is performed. Microcontroller which has been programmed to set the stepper motor to rotate the analyzer. The analyzer continues to rotate until the sensor gets the maximum light intensity value (0 degree). After getting the maximum light intensity, the lens rotates towards an angle -90 degrees and starts collecting light intensity data to an angle of 90 degrees. Light intensity data that have been collected then plotted to a graph that satisfy Malus’s law

$$I = Io \cos^2 \theta$$

(2)
I is the light intensity, Io is the maximum light intensity when there is no sample in system, and \(\theta\) is rotation angle of analyzer. Figure 7, 8, and 9 are the results of system calibration. System calibration is performed for each light source used, such as red, green, and blue. This is done to see the consistency of the system that has been made against the different light sources used. If the system is designed follow or comply with Malus’s law, it indicates that the system works well, and can be used to conduct Faraday rotation experiments.

Based on Figure 7 and Figure 9, the results of the malus law calibration for red and blue light sources are very close to the best condition. For the green source, the calibration results are slightly away from the best conditions as shown in Figure 8. This can be caused by external light entering the measurement system and affecting the reading of the light intensity on the light sensor.

From the calibration of the system that has been done, it can be concluded that the system has been made in accordance with the law of Malus. This is indicated by a calibration graph which is similar to the malus law graph. This indicates that the system made works well.

5. Results and discussion
The process of collecting data can be done after all components of the system are confirmed to work properly. Things that need to be considered include light passing through the polarizer already polarized, the system used has followed Malus’s law, and the light sensor used has been running well.
Olive oil is used as a sample. The magnetic field used is 920 Gauss (maximum) and -891 Gauss (minimum). If the system works well (there are no external influences) then the graph will have a shape like hysteresis graph. Figures 10, 11, and 12 present the test result.

Figure 10. Calibration Graph for Red Light Source

Figure 11. Calibration Graph for Green Light Source

Figure 12. Calibration Graph for Blue Light Source

Figure 10 shows the relationship between the magnetic field and the change in angle for the red light source. The maximum angle change that can be taken is 6 degrees. For green light source, the maximum angle change is also 6 degrees as shown in Figure 11. If we use blue light source, the maximum angle change is 5 degrees as shows in Figure 12. The angle obtained is the difference between the angle of 45 degrees and the angle formed when the system has been given a sample and a magnetic field.

The graph shows that there is something that affects the process of data collection so that the graph formed is not in the form of hysteresis. After several observation, it turns out that the solenoid which the higher the temperature affects the process of data collection.

The temperature of the solenoid will continue to increase as the current increases. The average temperature of solenoid when collecting data is 56 degrees Celsius. This is the main factor influencing the data obtained. Besides the factors that also affect, namely the presence of air particles in the sample chamber, external light entering the system, and the resolution of the stepper motor that has not been maximized.

Although the data collection process cannot be carried out to the maximum, experimental data shows that olive oil is a vegetable oil that has magneto-optic properties.
6. Conclusion

Based on the analysis, it can be concluded that Faraday rotation instrumentation system has been made based on the Malus’s law. However, there are several obstacles on the built system, one of which is the effect of heat on the solenoid used that affects the data collection process. The data obtained are not 100% representing magneto-optical properties, but it can be seen olive oil has magneto-optical property. Apart from that, system parts such as light sources, stepper motors, and light sensors used work well.

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