Study of simple spectrophotometer design using LDR sensors based on arduino uno microcontroller

To cite this article: Anis Yuniati and Rochan Rifai 2019 J. Phys.: Conf. Ser. 1153 012099

You may also like
- The sea-level muon spectrum and charge ratio and their relationship with high-energy accelerator data
  M G Thompson and M R Whalley
- The Nature of Radio-Intermediate Quasars: What is Radio-Loud and What is Radio-Quiet
  Heino Falcke, William Sherwood and Alok R. Patnaik
- The Method of Kramers-Kronig Transform Effective to the Impedance Spectrum of Lithium Battery
  Kiyoshi Kobayashi, Yoshio Sakka and Tohru S. Suzuki

View the article online for updates and enhancements.
Study of simple spectrophotometer design using LDR sensors based on arduino uno microcontroller

Anis Yuniati¹ and Rochan Rifai
Department of Physics, UIN Sunan Kalijaga,
Jl. Marsda Adisucipto Caturtunggal Depok Sleman Yogyakarta 55281, INDONESIA
E-mail : anis.yuniati@uin-suka.ac.id

Abstract. A spectrophotometer is an apparatus that can be used to identify the constituent elements of a material. Spectrophotometer uses the principle of interaction between the light spectrum that has a certain frequency with the material so that it can be measured the transmittance or absorbance of the sample as a function of concentration. The purpose of this research is to design a simple spectrophotometer using LDR sensor to convert the scale of light intensity into an electric scale, 28BYJ stepper motor and ULN 2003 driver motor controlled by Arduino Uno microcontroller for light spectrum selection, Op-Amp system as a signal amplifier and LCD 20x4 to display the output intensity value. The test results on Copper (II) Sulfate or CuSO4.5H2O samples with the concentration of 0.15 M, 0.25 M, 0.4 M, 0.5 M, 0.7 M and 1 M gave the absorbance value of 0.12, 0.32, 0.51, 0.66, 0.79, and 1.07 respectively in the red spectrum. The other solutions used to test the spectrophotometer system are two types of food dye solutions. This study provides a linear relationship between absorbance and concentration.

1. Introduction
A spectrophotometer is a common instrument that has been used widely in physics and chemistry to analyze a substance by measuring the transmittance or absorbance of the sample as a function of concentration. Qualitatively, the determination is based on the peaks generated on the spectrum of a particular element at a certain wavelength, whereas the quantitative determination is based on the absorbance value generated from the spectrum of the sample. The design principle of spectrophotometer originates from Beer-Lambert's law that explaining the interaction between matter or chemicals with electromagnetic waves that having a certain wavelength. Spectrophotometer consists of several main components including polychromatic light source, monochromator, sample cell, detector and reader system. Spectrophotometer is used in various fields of medical and science, so currently, spectrophotometer has been widely produced to meet the needs of the laboratory. However, spectrophotometers on the market have a fairly expensive price. The commercial spectrophotometer produces a high accuracy in the data, but the instrument comes in a "black box" so the user has little insight into the physical processes related to the measurements.

The need to design and build a spectrophotometer arises from educational objectives for the students. Many low-cost spectrophotometers have been built with various designs. Knagge et al. used LEGO pieces for construction of the optical support elements of the UV-visible spectrophotometer with a silicon photo-detector and a Sylvania miniature-lamp light bulb that was powered by two 1.5-V batteries for the light source [1]. Yeh et al. constructed a multi-wavelength spectrophotometer with plug-and-measure LED light source modules and TCS230 chip from TAOS, Inc. as photo-detector [2]. For each wavelength, they used a different LED, so they need to calibrate the instrument with a commercial spectrophotometer with a standard solution to overcome the emission bandwidth. A cell phone
A spectrometer has been built by Scheeline [3], with the aim to teach the principle of spectroscopy using the equipment available to and owned by most students. By using a white LED light source, plastic sample cuvette, holographic transmission grating, and any camera that produces JPG files, the designs were able to teach the workings of optical instrumentation components and systems rather than the analysis of sample solution. Albert et al. built a low-cost spectrophotometer with a simple design using LEGO blocks [4]. The spectrum wavelengths were calculated using Fraunhofer diffraction equation based on the size of the diffraction grating in this experiment. There are many more homemade spectrophotometers built with various designs and components. Each of them has a different character, and its own advantages. All of the instruments used increased understanding of the physical processes of the spectrophotometer system.

In our work, we study the design of a low-cost, simple homemade spectrophotometer using LDR sensors and Arduino Uno microcontroller. Arduino Uno is an open source electronic platform with the microcontroller chip of ATMega328 type as the main component. Arduino Uno as a microcontroller has a central role in this system. Arduino controls the movement of the stepper motor to determine the color spectrum of the light, read the data from the sensor, and act as a data processing unit read from the sensors. White light LED is used as the light source and a thin film diffraction grating is used as monochromator. The light-dependent-resistor (LDR) is used as the light sensors and coupled with Op-Amp system.

2. Experimental Methods

![Block diagram of the spectrophotometer system](image)

*Figure 1. A block diagram for the system setup of spectrophotometer.*

The visible light spectrophotometer system is designed according to block diagrams in Figure 1. The hardware assembly was done by installing the whole component into a system, by connecting several components in accordance with their respective functions. The instrument of the spectrophotometer system consists of the light sensor, the signal conditioner Op-Amp, the colour spectrum selector system, the display system, and the power supply. The design schematic for an Arduino Uno based spectrophotometer is shown in the Figure 2. For the installation of each system component refer to the circuit diagram as shown in Figure 3.

2.1. The light sensor

The light detector sensor should be able to read the light intensity in the wavelength range of 380-750nm (visible light spectrum range). There are various types of sensors that can be used but here we use the LDR sensor (Light Dependent Resistor) that is easy to find and is low-cost. In addition, LDR has a good performance to change the voltage in the wavelength range of visible light. LDR is made from semiconductor material with high resistivity. When the source of light (photon) hits the material, the conductivity of the material increases. The photons must have greater energy than the gap energy of the material so that they can excite the electrons to the conduction band. The excited electrons from the valence band to the conduction band will produce a flow of charge (current) as an intensity function. The more intensity received, the more electric current flows and increases the conductivity of the
material. Therefore, when the light intensity is low (dark), the LDR resistivity is high and when the light intensity is high (light), the LDR conductivity is high.

2.2. The signal conditioning
The LDR is combined with the Operational Amplifier (Op-Amp) so it will be able to get a good reading of the intensity change when the system is applied in an isolated box (dark room). In this system, we use inverting Op-Amp using LM741 with the input voltage -9V as in the circuit diagram. To generate a maximum voltage of 5V to be read by Arduino microcontroller, we install 1KOhm resistor before the Op-Amp circuit and 4.7KOhm feedback resistor. This circuit will produce a maximum voltage of 4.93V or 1010 digital value from the maximum intensity value of the LED.

![Figure 2. The design schematic for Arduino Uno based spectrophotometer](image)

2.3. The color spectrum selector system
Arduino Uno is an open source platform and a suitable microcontroller to use in this design with easy programming. In this section, Arduino acts as the data reader and signal processing of the sensor circuit, displaying the processing results on the LCD, and controlling the stepper motor to determine the color spectrum from the light source to the sample. In addition, Arduino also plays a role in sending the data processing to Microsoft Excel. The output signal from the sensor is in the range of 0-5 V, read by Arduino through analogue pin A2. This value is converted into 10bit data in the range 0-1023 representing the intensity value. In addition, Arduino also drives the stepper motor through the ULN2003 driver motor to rotate the light source and select the color spectrum passed through the sample. The stepper motor is moved through the command given on the 4x4 keypad matrix. The step of the stepper motor rotor and the intensity value of the color spectrum will be displayed on the LCD. The data is also sent by Arduino to Microsoft Excel via serial communication using PLX-DAQ software. The data is then processed to determine the absorbance value by the formula $A = \log \left( \frac{I}{I_0} \right)$.

2.4. The Display system
We built the spectrophotometer into three separate sections, in a "black box" with the display system in the box cover. The data acquisition system of the spectrophotometer will display the data from the sensor and stepper motor using LCD 20x4. We used a 4x4 matrix keypad to set the movement of the stepper motor for the color selection. The keypad consists of buttons A, B, and C. A button is used to perform the scanning of the light into the samples from red to purple, while the B button is used to perform the light scanning from purple to red. In the color scanning process, the sample will have an absorbance
value for particular color. If we already know the highest absorption of a color based on the stepper position, we can directly input the value by pressing C button and enter the value of the stepper position that corresponds with the color.

2.5. The power supply
The power supply in the circuit is made from four DC output voltages of +9 and -9V for the sensor circuit, 5V for the driver motor, and 3.3V for the LED. The power supply consists of 1A transformer, diode bridge, voltage regulator, and some capacitors as filters as seen on the circuit diagram. The magnitude of the slope voltage is regulated by the voltage regulator, i.e + 9V using LM7809, -9V using LM7909 and + 5V using LM7805. The voltage of 3.3V for the LED is generated by DC Stepdown Adjustable Converter which is composed of LM2596. By using the DC Stepdown Adjustable Converter, the voltage and the current for LED can be more stable.

![Figure 3. Circuit diagram for Arduino Uno based spectrophotometer](image)

3. Results and Discussion
In our system, the rotation of the stepper motor will determine the color spectrum from the light source to the sample. The degree of rotation of the rotor will have a relation with the color selected, so it can be used to approximate the range of the wavelength of the color spectrum from the light source. The rotor will rotate from 0 to 720. From the observation, the approximation of the color spectrum versus degree of rotation of the rotor is described in table 1.

| Degree of rotation of the rotor | Spectrum color |
|--------------------------------|---------------|
| 468 - 720                      | Red           |
| 409 - 468                      | Orange        |
| 371 - 409                      | Yellow        |
| 225 - 371                      | Green         |
| 137 - 225                      | Blue          |
| 0 - 137                        | Violet        |
The performance of the Arduino based spectrophotometer is tested by measuring the absorption of some solutions. The first measurement is a CuSO4.5H2O solution with various concentrations as shown in figure 4. The profile of CuSO4.5H2O shows the same range of wavelength absorbed by the solution that is in the red spectrum. The spectrophotometer system is able to differentiate the concentration of the solution, indicated by the absorption value of different concentrations as shown in figure 5. The solution with the higher value of concentration has a higher absorption value. The increasing of absorption value is linearly proportional to the concentration of the solution. However, the absorption value measured by our system cannot be compared with the measurement of commercial spectrophotometer since the system is built with limited instruments.

The other solutions used to test the spectrophotometer system are two types of food dye, namely red (strawberry flavor) solution and light green (melon flavor) solution. Measurements were made by dropping some quantities of food dye concentration with water-filled cuvette. The number of drops will indicate the different concentration of solutions. The spectrum of light-green solutions in figure 6 show the uniform profile of several different concentrations. The solution absorbs the light in the range of the green and blue spectrums. This can be caused by the color of the solution that has a light green instead of green. The more the number of drops given, the greater the concentration of the solution, and the greater the absorbance value of the solution, as shown in figure 7. The same phenomenon is also shown by the red solution. In figure 8, the spectrum of the light absorbed by the red solution is the green

---

**Figure 4.** Spectrum of CuSO4.5H2O for some various concentration

**Figure 5.** Absorbance versus concentration for solution CuSO4

**Figure 6.** Spectrum of light green solution for some various concentration

**Figure 7.** Absorbance plot of light-green food dye solution
spectrum. The ratio between absorbance and the concentration of the red solution is shown in figure 9. The absorbance value increases for the higher concentration of the solution.

![Figure 8. Spectrum of red solution for some various concentration](image1)

![Figure 9. Absorbance plot of red food dye solution](image2)

4. Conclusion

The Arduino-based spectrophotometer has been used to analyze the absorbance of several solutions with various concentrations. In the CuSO4.5H2O and food dye solutions, the absorbance value is increased by increasing the concentration. Even though this system cannot accurately measure the wavelength absorbed by the sample, it still can be used to conduct experiments on Beer-Lambert’s law and study the physical process of spectrophotometry that is often hidden in a commercial spectrophotometer. The design can be used for educational purposes at the undergraduate level with low-cost instruments. The system can be improved by substituting some components and by calibrating with the standard spectrophotometer.

5. References

[1] K. Knagge and D. Raftery, "Construction and Evaluation of a LEGO Spectrophotometer for Student Use," *The Chemical Educator*, vol. 7, pp. 371-375, December 01 2002.

[2] Y. Tai-Sheng and T. Shih-Shin, "A Low Cost LED Based Spectrometer," *Journal of the Chinese Chemical Society*, vol. 53, pp. 1067-1072, 2006.

[3] A. Scheeline, "Teaching, Learning, and Using Spectroscopy with Commercial, Off-the-Shelf Technology," *Applied Spectroscopy*, vol. 64, pp. 256A-268A, 2010.

[4] D. R. Albert, M. A. Todt, and H. F. Davis, "A Low-Cost Quantitative Absorption Spectrophotometer," *Journal of Chemical Education*, vol. 89, pp. 1432-1435, 2012/10/09 2012.