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Development of light polarization experimental apparatus for remote laboratory in physics education

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Abstract

This paper describes the development of a light polarization experimental apparatus for a remote laboratory. The apparatus had been developed by controlling the analyzer rotation using a stepper motor controlled via the Arduino. Device control and data acquisition applications were developed with LabVIEW which provides remote control panel facilities and web publishing tools. With the developed apparatus, light polarization experiments about Malus's law in physics teaching can be carried out remotely via the web. The results of the remote experiment show a good agreement with the theoretical predictions. It is concluded that the apparatus for remote laboratories is suitable for use in online experiment-based physics teaching

Keywords: light polarization, remote laboratory, physics teaching

1. Introduction

The phenomenon of light polarization is strong evidence of the transverse nature of electromagnetic waves. This phenomenon is very important to understand, from its conceptual and applied aspects, because it has many contributions to the development of science and technology. However, behind the importance of understanding this phenomenon of light, learning in secondary schools and universities is often neglected. This is unfortunate, because polarization makes it possible to conduct many amazing experiments using low-cost materials. In addition, the discussion of the phenomenon of polarization is very suitable to use an interdisciplinary approach between science, technology, and art, which usually makes things more attractive to students [1, 2]. It is well known in biology that sensitivity to polarized light is widespread among marine animals. They use this ability to direct and find prey [3].

The phenomenon of polarization is also applied in spectroscopy for the analysis of samples regarding molecular orientation and measuring the surface reflective properties of thin films [4]. Other applications of the polarization phenomenon are found in food technology, such as the analysis of the effects of impurity in a mixture of olive oil and palm oil characterized by the polarized absorption method. Polarized absorption is based on the absorption of light that vibrates in a certain plane when it passes through the sample [5]. On this basis, it is necessary to develop experimental devices on light polarization for middle school and college students, in order to gain a deep understanding of the theoretical and experimental aspects of the phenomenon of light polarization.

Traditionally, the experimental approach to learning physics is done hands-on in the laboratory room. The development of apparatus and data acquisition systems for polarization experiments has been conducted by several researchers, including a computer-controlled data acquisition system for measuring the intensity of light transmitted through two polarizers and measuring the angle of the polarizer axis [6]. Basic studies related to polarization, which are Malus's law, elliptical and circular polarization, have used computerized rotational motion of polarizers and light sensors. This computer-based laboratory allows online students to collect, analyse, and display data during experiments. It has led to a better understanding of the concept of polarization which is very difficult [7]. A new technique for adjusting and measuring the angle of rotation of the polarizer/analyzer has been conducted with a multi-purified potentiometer and light sensor connected to the Arduino board. This technique allows measurement of light intensity as a function of the analyzer rotation angle simultaneously [8]. From the apparatus that has been developed there is still no software control on the analyzer rotation, which allows complete control of the data acquisition process to support the implementation of online or remote experiments.

Referring to what has been and has not been done in the development and use of polarization experimental apparatus, this paper discusses the development of light polarization experimental apparatus about Malus's law for remote laboratories. The novelty of this apparatus lies in the computerization of the analyzer device control process and data acquisition. Device control and acquisition is conducted by the user through a graphical user interface (GUI) developed with LabVIEW. Apparatus for remote laboratories can be used in online experiment-based physics teaching.

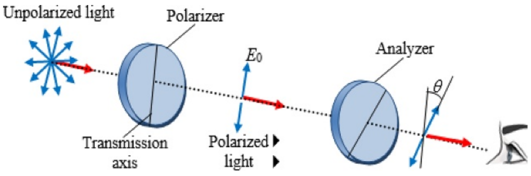

Figure 1. Physical diagram of the light polarization process.

2. Materials and methods

The development of the light polarization experimental apparatus for remote laboratory-based physics teaching was performed in three stages consisting of conducting theoretical studies on the physics concept of light polarization, designing apparatus hardware, and making software to control the system and data acquisition.

2.1. Theoretical review

The most technique for producing polarized light is to use a material that transmits waves whose electric field vectors oscillate in a parallel plane in a particular direction and absorbs waves whose electric field vectors oscillate in any other direction.

Figure 1 shows the non-polarized beam coming on the first polarizing sheet, which is called the polarizer. Because the transmission axis is vertically oriented, the light transmitted by this sheet will be vertically polarized. The second polarizing sheet, called the analyzer, which transmission axis angles q to the polarizer cuts the beam. By calling the electric field vector of the first transmission line as $\mathbf{E}_0$, the component E_0 which is perpendicular to the analyzer axis is totally absorbed. The E_0 component is parallel to the axis of the analyzer that is passed:

$$E = E_0 \cos\theta \tag{1}$$

Since the light intensity varies with the square of the electric field, the intensity of the light transmitted through the analyzer is:

$$I = I_0 \cos^2\theta \tag{2}$$

where I_0 is the intensity of the polarized light coming to the analyzer. This statement is known as Malus's law, which applies to two polarizing materials [9]

2.2. Hardware development

The materials used for the development of apparatus hardware consist of: (1) Fix Polarizer, (2) Adjustable Analyzer with Rotary Motion Sensor, (3) Light source, (4) Light sensor, (5) Stepper Motor, (6) SensorDAQ interface, and (7) Arduino Uno board. For ingredients/points 1–6, it used products from Vernier. The adjustable analyzer has a scale in degrees, with the vertical position as the zero angle. In this position, the polarizer passes vertically polarized light and the angle of rotation of the analyzer is measured by the Rotary Motion Sensor. The light source uses an LED with white light which acts as a point source. Light sensors are used for intensity measurement in various situations, with a choice of 0.2 lux resolution for the light intensity range (0–600 lux), and the wavelength range of light (400–800 nm). Rotary Motion Sensor is able to detect angular motion precisely and easily, with a choice of resolution: 1° or 0.25° [10].

SensorDAQ is a USB data acquisition interface from National Instruments and Vernier that is suitable for building control and data acquisition systems using LabVIEW software. The SensorDAQ maximum sampling rate reaches 48 000 samples per second [11]. The Arduino Uno is a microcontroller board based on the ATmega328P which has 14 digital input/output pins (6 pins as PWM outputs, 6 pins as analog inputs), a 16 MHz ceramic resonator, with a USB connection [12]. A stepper motor is a DC electric motor which divides the full rotation into a number of equal steps. The position of the motor can be commanded to move and stop at any of these steps without a position sensor as feedback [13].

Referring to the theoretical study of light polarization, in particular Malus's Law, and the support of laboratory component materials, a light polarization experimental apparatus can be designed for remote laboratories as shown in figure 2. The movement of a stepper motor controlled via Arduino is used to rotate the Analyzer. The analyzer rotation angle value is measured by the Rotary Motion Detector which is connected to the digital channel SensorDAQ. The Light Sensor connected to the analog channel SensorDAQ measures the intensity of polarized light passing through the Analyzer.

The main component of the hardware apparatus being developed is the addition of a stepper motor to the Adjustable Analyzer (figure 3(a)). The stepper motor rotates the analyzer and the rotary motion sensor will detect the angle of rotation of the analyzer. This addition makes it possible to control/adjust the analyzer rotation angle via instrument control and data acquisition software. The rotation of the stepper motor is controlled via the Arduino by software, with a series of tools as shown in figure 4.

The DIR (Direction) pin is used to determine the direction of rotation of the stepper motor, clockwise or counterclockwise. The STEP pin is used to send the number of steps from the Arduino le stepper motor driver module. The number of steps is determined by the number of square signals sent by Arduino. The SLEEP pin is used to stop/turn on the current flow to the stepper when it is operating or function as an on/off switch. The Stepping mode on the EasyDriver module (figure 5) is regulated by the MS1 and MS2 parameters as shown in table 1 [14].

Table 1. Stepping mode on EasyDriver.

MS1	MS2	Resolution
Low	Low	Full step (2 phase)
High	Low	Half step
Low	High	Quarter step
High	High	Eight step

The stepper motor specification used is NEMA 17 which has 200 steps per rotation in

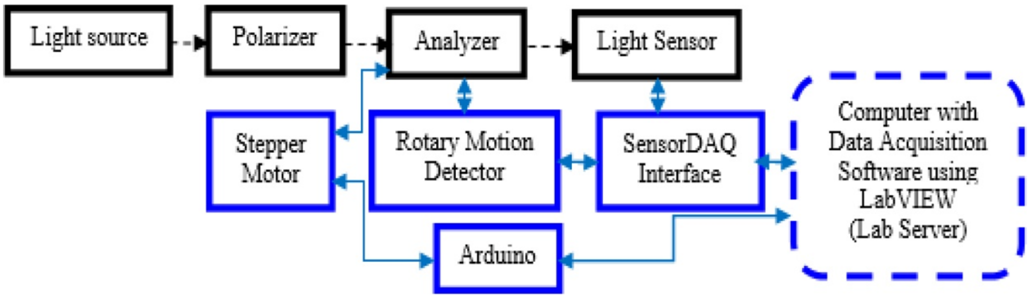

Figure 2. Block diagram of the hardware of the light polarizing apparatus.

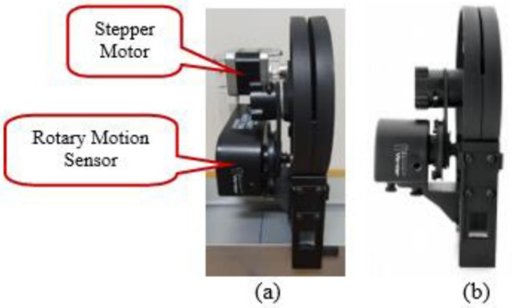

Figure 3. (a) Adjustable analyzer with the addition of a stepper motor, (b) adjustable analyzer before modification.

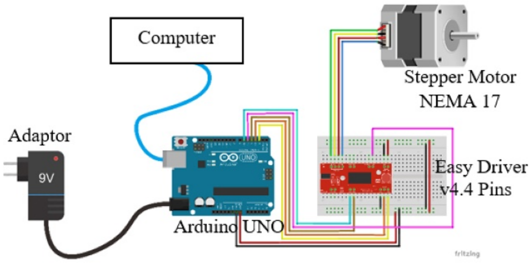

Figure 4. Circuit of components for control of stepper motor movements.

full step mode. This stepper motor when operated using the EasyDriver driver module will have the following criteria: Full Step = 200 steps/turn (1.8°/step), Half Step = 400 steps/turn (0.9°/step), Quarter Step = 800 steps/turn (0.45°/step), and Eight Step = 1600 steps/turn (0.225°/step).

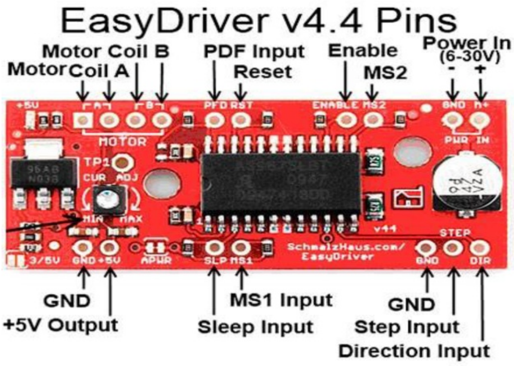

Figure 5. Stepper motor driver.

2.3. Software development

The programming language used for the development of data acquisition software is LabVIEW from National Instruments. LabVIEW is a graphical programming language aimed at virtual instrumentation. The LabVIEW program is known as a virtual instrument (VI), which consists of three components: Front Panel (to interact with users), Block Diagram (as program code), and Icon/Connector used to connect inter-VI. LabVIEW was chosen because it has the Web Publishing Tools feature where the resulting VI program can be converted to HTML so that it can be run by a web browser [15, 16]. Thus, lab equipment can be accessed and operated remotely via the web. The GUI design which is the LabVIEW front panel in the light polarization experiment software is shown in figure 6. The block diagram of the GUI section for device settings is in figure 7, and the block diagram of the GUI section for data acquisition is in figure 8.

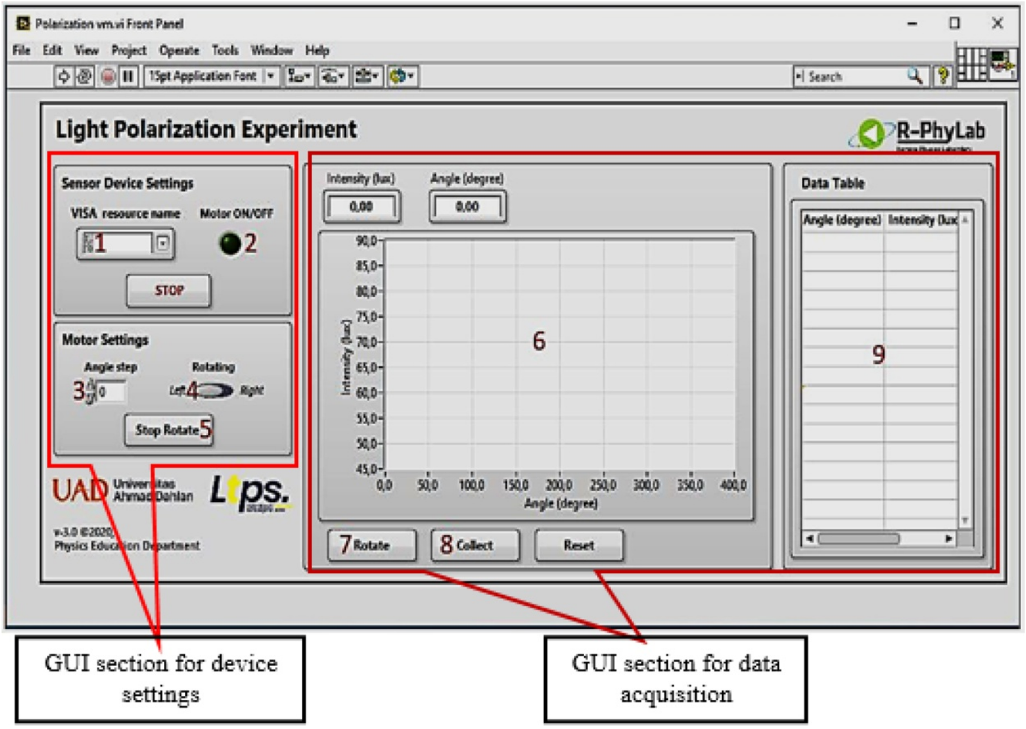

Figure 6. Front panel view for light polarization experiment GUI.

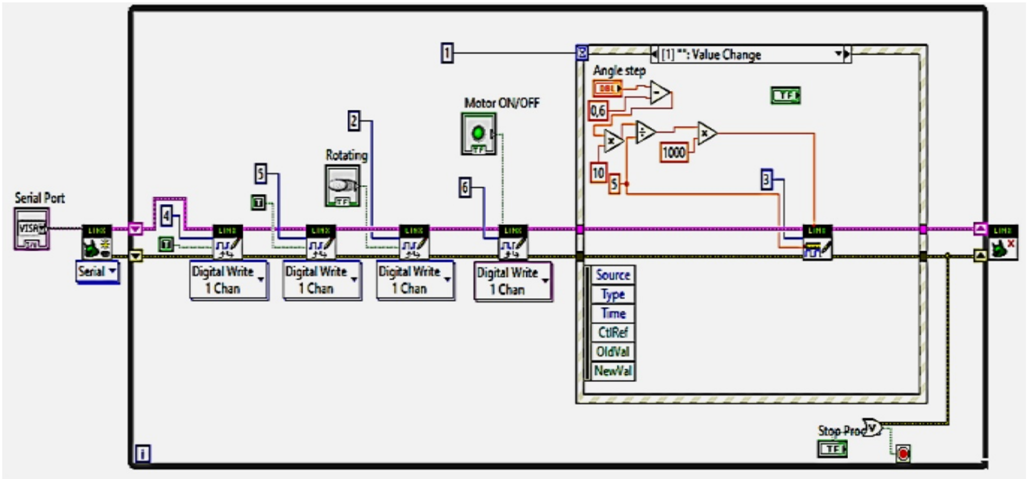

Figure 7. Block diagram of the GUI section for device settings.

Front panel elements for GUI consist of: (1) Identification and determination of communication channels with input/output (I/O) devices, (2) Buttons to turn off and on stepper motors, (3) Scroll bar to adjust the interval of the analyzer rotation angle, (4) Switch to adjust the direction of rotation of the polarizer (left: counterclockwise. Right: clockwise), (5) Button to stop the rotation of the stepper motor, (6) Graph page of light intensity data as a function of the analyzer

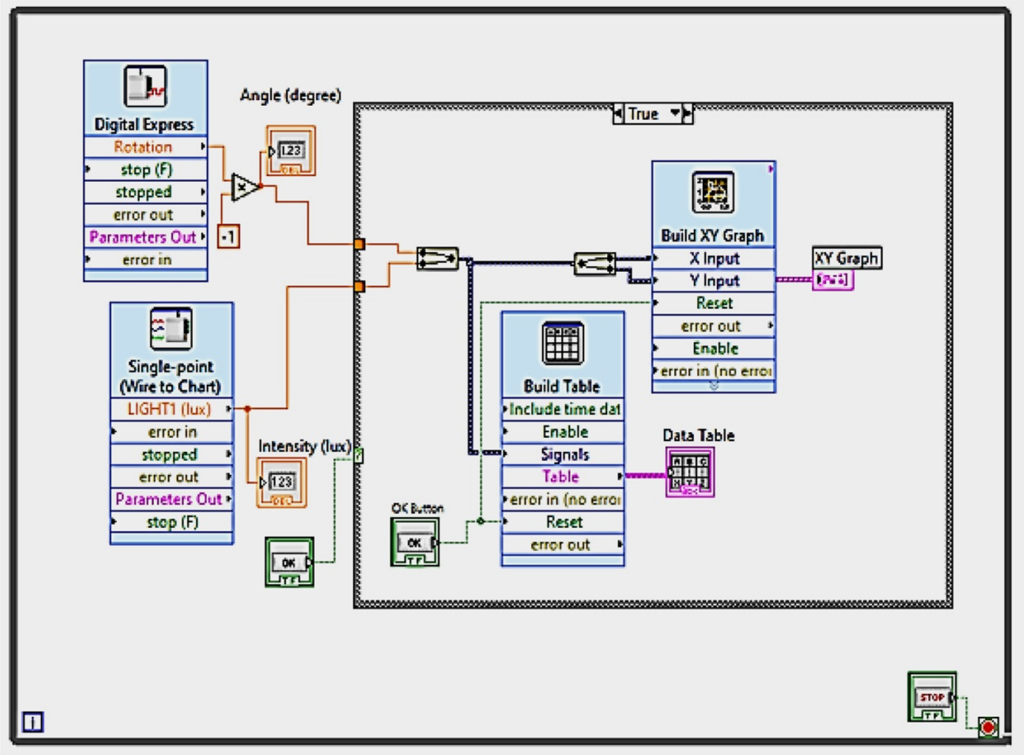

Figure 8. Block diagram of the GUI section for data acquisition.

rotation angle, (7) Button to rotate the polarizator, (8) Button for data collection of light intensity and analyzer angle position, and (9) Table page of light intensity data and analyzer angle position.

The VI program of this GUI by the LabVIEW web publishing tool is converted into the necessary html code to display the front panel VI which will appear in the browser when the generated http URL is given as the address for the browser. This URL also contains IP information for the system on a local area network (LAN). This browser page will display a front panel VI that is running on a computer device as a Lab Server (figure 2) where VI is created and stored and can be accessed by the device locally on the same LAN. Hence, front panel VI can be accessed and controlled remotely, the Lab Server computer device is given a public IP so that it becomes a server that can be accessed by other devices, both local and non-local [17]. The architecture of the remote laboratory system used is as shown in figure 9. Computer devices that will access VI remotely via the internet need to be equipped with supporting software (plugins) compatible with the browser platform and the LabVIEW run time engine used. In this case, the browser that supports displaying the front panel VI is UC Browser.

3. Results and discussion

3.1. Results

The physical form of the development results of the experimental light polarization apparatus hardware is shown in figure 10. The novelty of this apparatus lies in the computerized process of device control and data acquisition, which are the motion and angle measurement of the analyzer.

Apparatus can be used in teaching physics through online experimentation based on remote laboratory. By installing a webcam on a

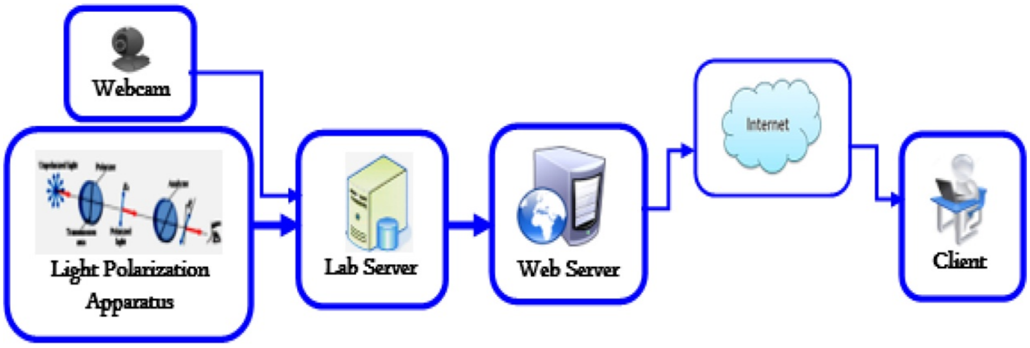

Figure 9. Block diagram of remote laboratory architecture.

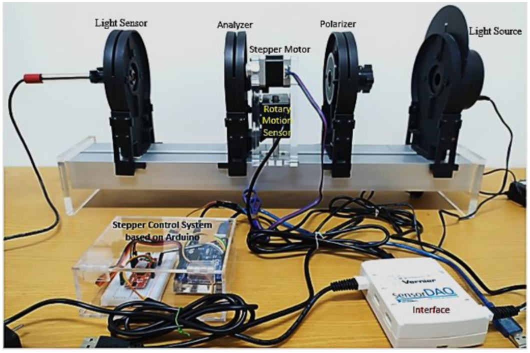

Figure 10. Photograph of light polarization apparatus for remote laboratory.

remote laboratory system (figure 9), live streaming video can be performed which allows students to directly observe experimental devices, control equipment, and the data acquisition process. With a remote laboratory system, this apparatus can be accessed for online/remote experiments at the web portal address http://rphylab.pf.uad.acid/sistem by asking for a username and password to the administrator. The results of the remote light polarization experiment via the web are shown in figure 11. Experiments were conducted from the analyzer angle of 0.5°–364° with an average interval of change in angle of 9.1°. The measured maximum light intensity is 92.625 lux and the minimum light intensity is 50.722 lux. On the user's computer monitor, the analyzer movement during the data capture process can be observed via streaming video by a webcam.

3.2. Discussion

From figure 11, it is found that the light intensity graph transmitted by the analyzer as a function of the change in the analyzer angle shows a pattern that is in accordance with the prediction of Malus's law, which follows the cosinusoidal periodic function (equation (2)). Figure 12 is the result of the analysis of the fitting data to the linear equation $y = ax + b$, by setting the light intensity as the dependent variable y and $\cos^2(q)$ as the independent variable x. The analysis results were obtained from the Trendline feature with the Linear function in Microsoft Excel. Analysis of fitting data is needed to determine the level of compatibility of experimental results with theoretical predictions. The coefficient of determination $R^2 = 0.9938$ in the linear equation of the relationship between the intensity of the polarized light that is transmitted by the analyzer with the cosine square value of the analyzer rotation angle shows a very good level of linearity. It shows that the results of the online light polarization experiment with the developed apparatus perfectly match the theoretical predictions of Malus's law. The results of this experiment are as good as the results of similar experiments conducted by Amrani & Paradis [6], Freitas *et al* [8], Garg *et al* [7], and Rosi & Onorato [18]. Thus, the apparatus developed in this research is stated to be able to verify Malus's law with satisfactory results.

The GUI of the data acquisition application developed in this study does not yet have a feature to display images or video of the apparatus. The view of the video analyzer and the apparatus as a whole in figure 11 is obtained from the Webcam

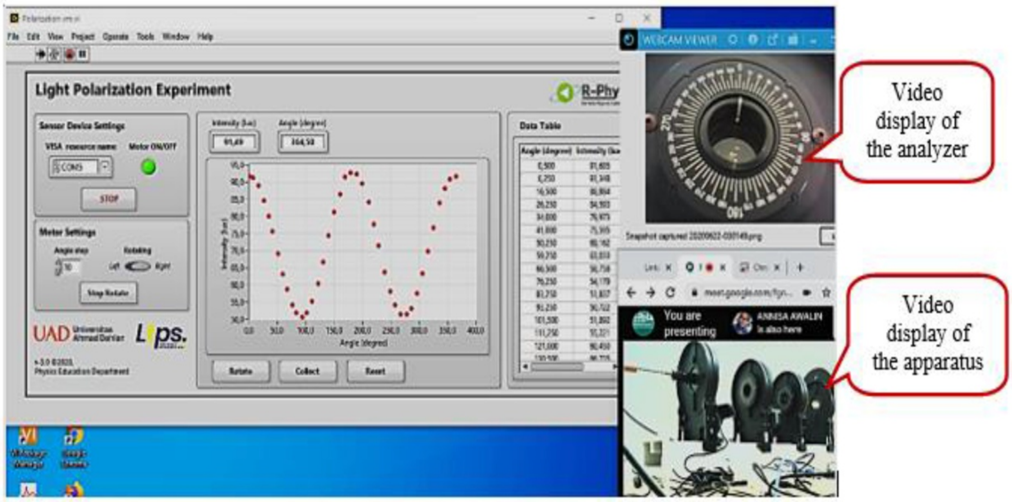

Figure 11. Results of an online light polarization experiment with a remote laboratory.

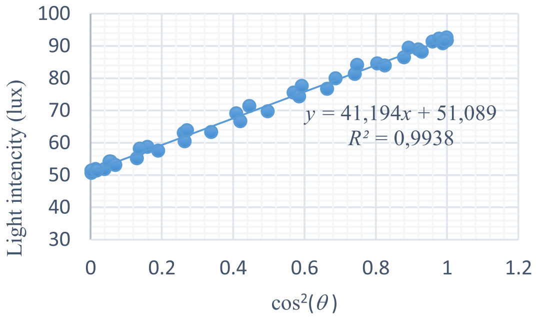

Figure 12. Relation of polarized light intensity to $\cos^2(q)$.

Viewer and Google Meet applications. Thus, that the video display on the computer monitor still needs to be adjusted in size and position manually. This can make users uncomfortable and become a weakness of the results of this development research. In terms of the level of accuracy of the experimental results, the light polarization experimental apparatus for remote laboratories can be used in physics learning through online experiments. Behind the weaknesses that still exist, the developed apparatus contributes to the expansion of student access to physics learning laboratory facilities and supports the demands of organizing E-Learning.

4. Conclusion

Light polarization experimental apparatus for remote laboratories in physics teaching has been successfully developed and tested for its measurement accuracy performance. The results of the polarized light intensity measurement through the analyzer have a good level of accuracy. It is concluded that the apparatus developed for remote laboratories is suitable to be used to verify Malus's law in online experiment-based physics teaching.

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