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IoT-based viscometer fabrication using the falling ball method for laboratory applications

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ABSTRACT

This study outlines the production procedure of internet of things (IoT)-enabled viscometers designed for laboratory use. These viscometers utilize photodiode sensors, lasers, and falling ball techniques. The system is equipped with a temperature sensor that is utilized to quantify the impact of temperature on viscosity. The temperature sensor's characterization yielded a R-square value of 0.999. The photodiode and laser sensors are utilized to operate a timer within the system, ensuring precise time measurement. The R-square value for the sensor characterization is 0.996. A viscometer equipped with an integrated IoT module for seamless wireless transmission of data. The photodiode timer sensor has an accuracy of 95.76% and a precision of 99.96%, while the temperature sensor has an accuracy of 99.43% and a precision of 99.93%. The viscometer transmits the measured viscosity data to the server using wireless technology. This IoT viscometer has the potential to enhance the efficiency and precision of liquid viscosity measurement in laboratory settings. Additionally, it enables real-time monitoring and data collection for subsequent analysis and research purposes.

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1. INTRODUCTION

Viscosity is a critical characteristic in many laboratory applications, including physics, chemistry, and others [1], [2]. Understanding fluid behavior, improving process parameters, and ensuring product quality all rely on accurate viscosity measurement [3]. Traditional viscometers, on the other hand, frequently need manual operation and lack real-time data monitoring capabilities, which might limit their efficiency and comfort in a laboratory setting [4], [5]. To address these constraints, the integration of internet of things (IoT) technologies with viscosity measuring devices has received considerable interest. IoT-based viscometers provide remote access and automated data collection, revolutionizing how viscosity measurements are conducted in the laboratory [6], [7].

In this study, we concentrated on creating IoT-based viscometers using photodiode and laser sensors designed primarily for laboratory applications. This photodiode sensor and laser technology combo offers a number of benefits, including high sensitivity, rapid reaction times, and non-invasive testing capabilities [8]. Previous studies have focused on manufacturing a fluid viscosity measuring instrument using an Arduino microcontroller with a photodiode sensor, but the data analysis and reading still relied on a serial monitor or LCD. Furthermore, a viscometer system based on a hall effect magnetic sensor was also made, but data readings still used a serial monitor or LCD [9]–[11].

The system is also equipped with a temperature sensor to see the fluid's viscosity behavior which is affected by temperature. The primary goal of this project is to create a viscometer that uses IoT principles, allowing for smooth data transmission, real-time monitoring, and improved measurement accuracy. We want to accomplish exact viscosity measurements with low interference and dependable findings by using photodiode sensors as light detectors and lasers as light sources. Characterizing and calibrating photodiode sensors to test their reactivity to variations in light intensity will be part of this study. Furthermore, the incorporation of IoT modules will enable wireless data transfer to a central server, allowing researchers to access and evaluate viscosity data remotely. The findings of this study will help to enhance IoT-based viscosymmetry technologies for laboratory applications. The suggested viscometer will improve efficiency, accuracy, and comfort by allowing laboratory employees to do real-time viscosity measurements. Furthermore, IoT integration will encourage data-driven research, make process optimization easier, and improve quality control in the laboratory.

2. METHOD

The research was conducted in the physics laboratory of Universitas Negeri Padang by conducting tests on a laboratory scale. In this study, engineering research procedures were used. The important points made in this research are product design related to hardware design and software design, as well as its relation to the physical theory used in the system.

2.1. Hardware design

Hardware design relates to components, sensors, microcontrollers, and devices used in the preparation of the system. To describe the hardware design that was built briefly, it can be seen in Figure 1. The system block diagram shown in Figure 1 illustrates the hardware design that is made.

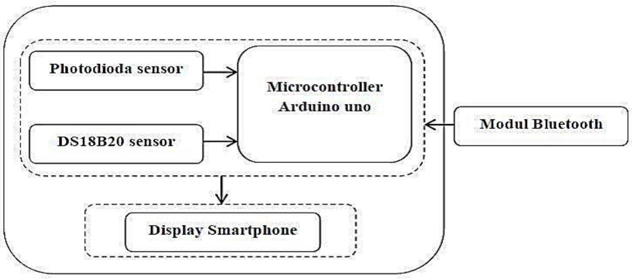

Figure 1. Block diagram system

There are three important parts that make up this viscometer system: the sensor section to read the desired physical quantities, the microcontroller section to process the readings from the sensor, and the data display section to display data that has been processed by the microcontroller. The three important parts are integrated into this system. The working principle of the IR infrared sensor is infrared light-emitting diodes (LEDs) serve as sources of infrared radiation, which is imperceptible to the human visual system. When powered by a 5V source, they draw around 3 to 5 milliamperes of current. These devices are specifically photodiodes and phototransistors, and their distinction lies in their exclusive ability to detect infrared light. Modulating infrared emitters enables the generation of precise infrared light frequencies. Displayed below is an image of a photodiode, often known as an IR receiver. When using them in conjunction, it is important to verify that the characteristics of the recipient and sender are compatible. The system comprises a MOSFET that permits the passage of electric current alone when the phototransistor detects infrared light. Consequently, the MOSFET is activated, causing the LED to illuminate, thus serving as a load for the MOSFET. The detection distance may be altered by manipulating the potentiometer on phototransistor [12].

The working principle of the DS18B20 sensor is a waterproof device used for detecting an individual's body temperature. The DS18B20 sensor produces digital data as its output. This sensor operates within a voltage range of 3-5V. It has an error accuracy level of ±0.5 °C and can measure temperatures ranging from -10 °C to 85 °C. The red cable on the DS18B20 sensor is used for VCC, the black cable is for GND, and the yellow cable is for data. The cable has a diameter of 4 mm and a length of 90 cm [13]–[15]. Next, the microcontroller used Arduino, a physical computing platform that is open source and operates using basic input/output (I/O) circuits. It also includes a programming environment that utilizes a processing language. Arduino may be used for the creation of independent interactive entities or can be linked to computer software (e.g., Flash, Processing, VVVV, or Max/MSP) [16]. The HC-05 module is a user-friendly Bluetooth serial port protocol (SPP) module designed for wireless serial communication. It enables the conversion of a serial port into Bluetooth connectivity. components that are no less important in this hardware are the HC-05 module employs Bluetooth V2.0 + enhanced data rate (EDR) technology, which enables data transmission at a rate of 3 Mbps. This is achieved via the use of 2.4 GHz frequency radio waves [17], [18].

2.2. Software design

In software design, it is related to making programs that can integrate reading, processing, and output in the form of data that can be analyzed. Can be seen in Figure 2 for the program flowchart used in the system. In the flowchart, there is an initiation of a photodiode sensor as a timer and a DS18B20 sensor as a reader of temperature changes (input), an Arduino Uno as a processing center (process), and a smartphone as a data viewer (output). The flowchart in Figure 2(a) is made into a program using C++ language using the Arduino IDE platform, the Arduino IDE is a versatile software tool that is developed using features derived from the C and C++ programming languages. It is used for the purpose of composing and transferring programs to Arduino boards that are compatible, and may also be employed, with the assistance of third-party cores, for other manufacturers' development boards [19]. After the programmed on the Arduino is complete, enter flowchart stage 2(b) to display the data on the smartphone. The flowchart in Figure 2(b) after the program is input to the Arduino board, the data is then displayed on the MIT App Inventor, App Inventor this software is specifically tailored for novice programmers who want to develop personalized apps for the Android operating system. App Inventor has a code block that enables users to effortlessly construct apps for the Android operating system by simply dragging and dropping code blocks [20].

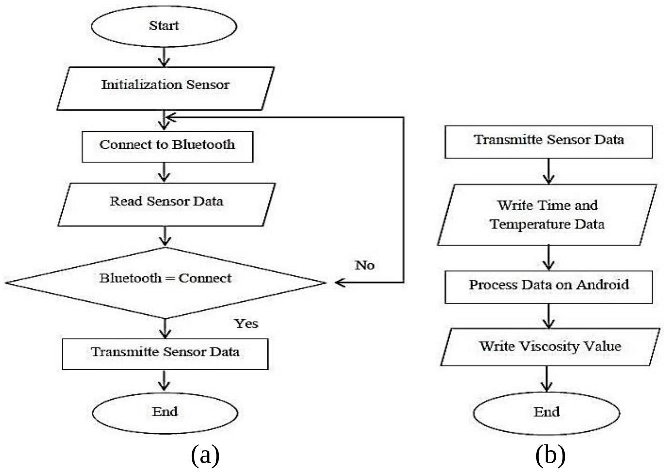

Figure 2. Flowchart microcontroller program (a) Arduino IDE and (b) flowchart to display the data on the smartphone

2.3. The theory of falling ball method

The viscosity of a falling ball is explained by stokes theory, which was first developed by the English mathematician and physicist Sir George Gabriel Stokes. This theory describes the movement of a ball falling through a liquid medium due to the force of gravity and fluid viscosity resistance. The formula used in the falling ball viscosity theory is as in (1):

$$F = 6.\pi.\eta.\upsilon.r \tag{1}$$

Where:
F is the resistance force experienced by the ball (N).
η is the viscosity of the liquid (Pa.s or N.s/m^2).
r is the radius of the ball (m).
υ is the velocity of the ball relative to the liquid (m/s).
π is the pi constant (approx. 3.14159...).

The drag force F acts up and in the opposite direction to the ball's motion. When the ball begins to move, this drags force will cause it to decelerate and eventually reach terminal velocity. Terminal velocity is the constant speed at which the viscous drag force is balanced by the gravitational force exerted on the ball. The terminal speed υ can be calculated using in (2):

$$\upsilon = 2.g.r2/9.\eta \quad (2)$$

Where:
g is the acceleration due to gravity (m/s²).
In practice, the theory of falling ball viscosity can provide a good initial estimate of the behavior of a falling ball through a liquid medium, but other factors such as turbulence and more complex ball geometries must be considered for more accurate situations [21]–[24].

3. RESULTS AND DISCUSSION

3.1. Electronic circuit

An electronic circuit is a combination of various electronic components that are interconnected and work together to perform a specific function or task. Figure 3 shows the shape of the circuit and wiring of all the electronic components used in this system. The laser diode will influence the photodiode sensor, based on its working principle explained in the hardware section. This will allow you to engineer a sensor that initially functions under the influence of light and can calculate time using two sensors in the system. Utilizing the laser diode will accomplish this. The system shown in Figure 3 operates using two photodiode sensors that function as on/off timing points. When the spherical item prevents light from reaching the photodiode 1 sensor, the timer will activate and begin counting the amount of time that has passed at that moment. Additionally, the timer will be in the off state when the ball object hits the photodiode 2 sensor throughout the course of the experiment. For the purpose of ensuring that the reading data from the timer and temperature sensor will be shown on the display of the smartphone instantly, with the assistance of the Bluetooth module that is coupled to the microcontroller. The reset button restarts the gadget from its initial state.

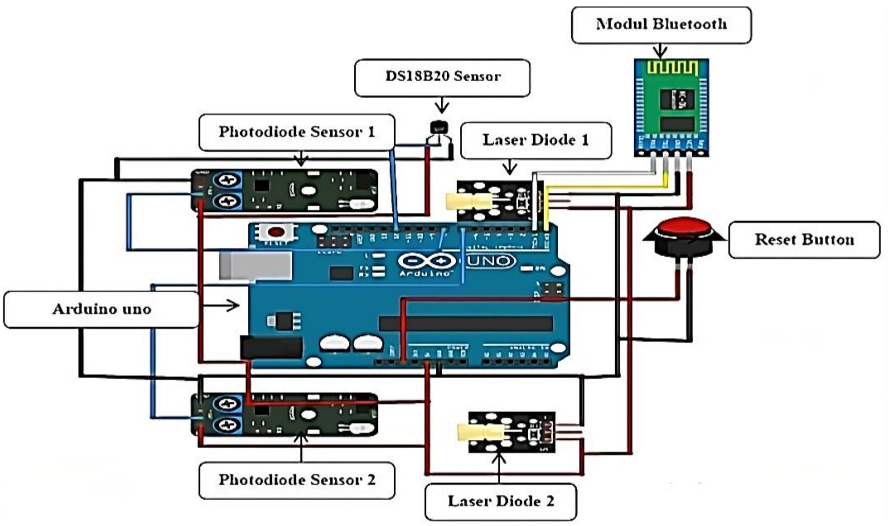

Figure 3. Electronic circuit

3.2. Mechanical system

In Figure 4, you can see the results of the design of the IoT viscometer tool. This IoT viscometer is composed of a photodiode sensor as a light receiver, a temperature sensor as a temperature gauge in the fluid, and a diode laser as a light emitter. The Bluetooth module in the system supports the IoT system and communicates data to the display of the smartphone. Push buttons, LEDs, resistors, and a 9-volt adaptor that serves as a power source are some of the other components that comprise this configuration. In the mechanical construction of the system, pipes with four containers are used to position the photodiode and laser sensors in parallel. The component box utilizes acrylic material. The observation container is a 0.5-liter glass tube. To ensure unobstructed light from the laser diode, a clear glass tube is used.

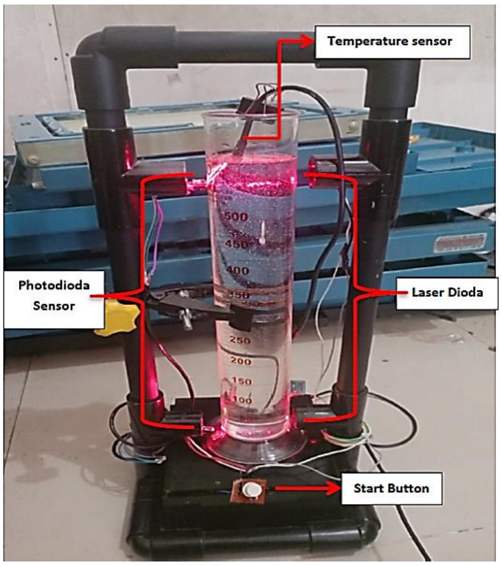

Figure 4. Hardware system viscometer IoT

3.3. Software system

In Figure 5, you can see the results of the design of the IoT viscometer smartphone display software. This data display is the result of a design using the MIT App inventor with a communication base using Bluetooth [25], [26]. The software design consists of several input parameters that can be adjusted according to system specifications. two input sensors in the form of a timer and temperature. Furthermore, all the data collected will be calculated using the empirical exchange used in the adopted falling ball method. The software above can only work on the Android system. There are several additional parameters that can be input according to the parameters used, such as the density of the ball used and the density of the fluid. On the display, there are also 2 buttons, namely the Bluetooth select button and the calculate button. These two buttons have different functions. The Bluetooth select button functions to connect Bluetooth to the Android used with the HC-05 Bluetooth module used in the system; the calculate button functions to calculate all parameter values that have been input into the software; and the calculations from the software are based on the empirical falling ball equation used. This software also functions as a calculator for the system in addition to displaying data.

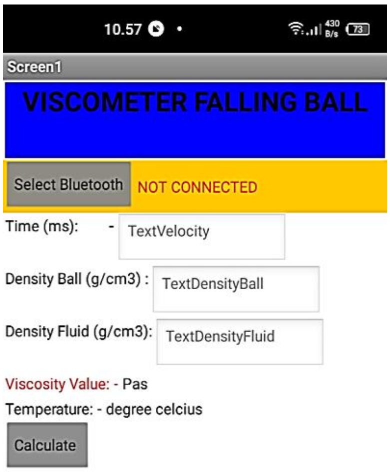

Figure 5. Display smartphone

3.4. Validity test for the sensor

To ensure the use of sensors in this system is in accordance with the application goals, a characterization test is carried out by looking at the linearity of the sensor against standard tools used in conventional viscometer devices. Travel time is an important parameter that is measured in the viscosity measurement in this falling ball method. The linearity test data of the photodiode sensor as a timer and temperature sensor can be seen in Figure 6.

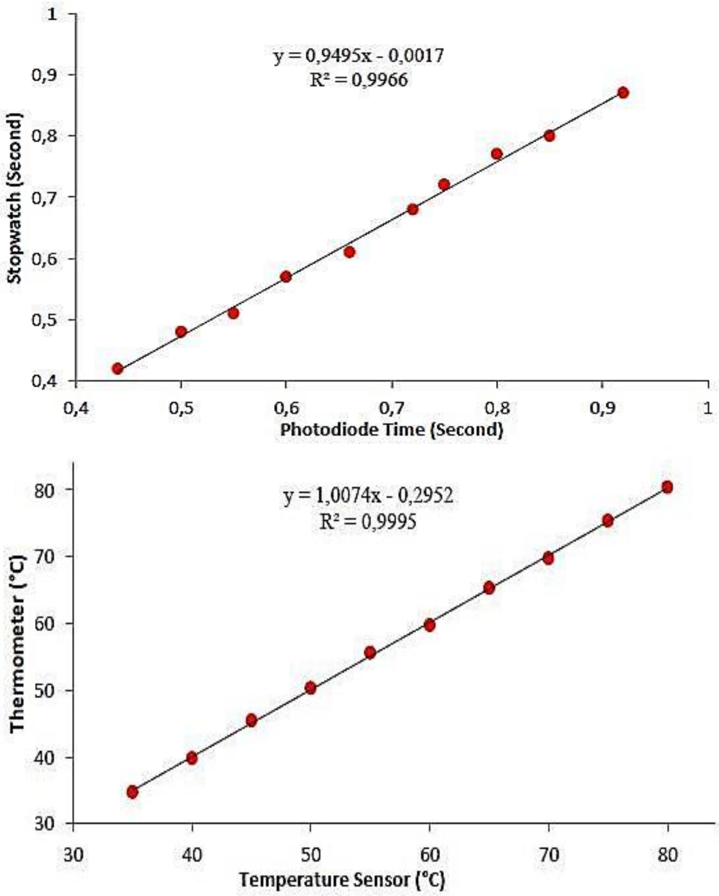

Figure 6. Characterization of the IoT viscometer system with a conventional system

The data shown graphically in Figure 6 is the linearity test data of the photodiode sensor, which is set as a timer in this system. In testing the linearity of the timer, a test is carried out using a stopwatch used on a conventional viscometer. The linearity value obtained from this timer test is 0.9966. From these values, it can be concluded that the use of the photodiode sensor as a timer on this digital viscometer is very good. Then we added a temperature sensor to see the effect of increasing temperature on fluid behavior. The temperature sensor used in this system is the DS18B20 sensor, and its linearity is tested using a conventional thermometer. The data shown graphically in Figure 6 is the linearity test data for the DS18B20 temperature sensor, which is set as a fluid temperature gauge in this system. In testing the temperature linearity, the test is carried out using a conventional thermometer. The linearity value obtained from testing this temperature sensor is 0.9995. From these values, it can be concluded that the use of the DS18B20 sensor as a fluid temperature gauge on this digital viscometer is very good**.**

3.5. Sensor accuracy and precision testing

In testing the accuracy of the sensor, a comparison measurement is made between the sensor and the standard tool to see the accuracy of the sensor. In this system, 2 main sensors are used, namely a photodiode as a timer to measure the length of time the ball moves when dropped from the test tube, and a temperature sensor to see the effect of temperature values on the measured viscosity level. The accuracy data of the photodiode timer sensor and temperature sensor can be seen in Figure 7.

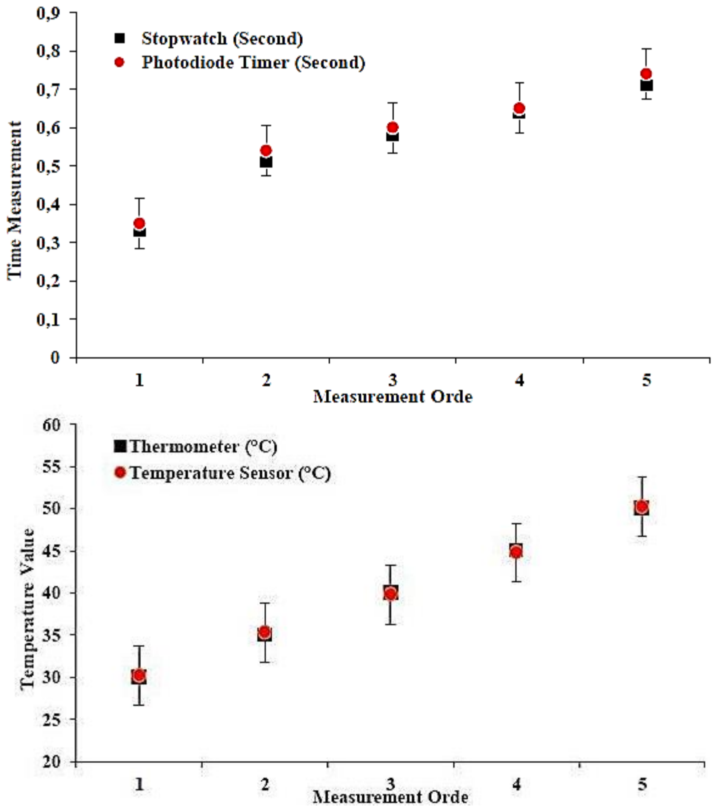

Figure 7. Sensor accuracy test result

From the results of the sensor accuracy test, Figure 7 is an accuracy test on the photodiode sensor which is engineered to calculate the time of the fall of the ball in the fluid. Testing is done by comparing the results of measurements made on a stopwatch with as much as 5 variation data so that the accuracy obtained on the photodiode timer sensor is 95.76%. Furthermore, Figure 7 also does the same thing, namely testing the accuracy of the temperature sensor. Tests are carried out by comparing the results of measurements taken on a thermometer with as much as 5 variation data so that the accuracy of the temperature sensor is 99.43%. Furthermore, precision testing is carried out on each sensor used. This precision is a repeated measurement of a parameter in the same situation to see the results of the closeness of the resulting value. The precision data from the photodiode timer sensor and temperature sensor can be seen in Table 1.

Table 1. System accuracy and precision data

Photodiode sensor	Average	Precision (%)	Δx	Temperature sensor	Average	Precision (%)	Δx
0.5	0.53	99.96	0.03	35.2	35.28	99.93	0.08
0.56			0.04	35.4			0.12
0.52			0.05	35.2			0.05
0.54			0.02	35.4			0.12
0.54			0.02	35.3			0.02
0.53			0.05	35.2			0.05
0.5			0.05	35.4			0.05
0.53			0.01	35.2			0.08
0.52			0.05	35,2			0.05
0.53			0.05	35.4			0.05
			0.035				0.067

Based on Table 1 is a test of the precision of the timer photodiode sensor, the test is carried out by repeated measurements under the same conditions to see the closeness of the data generated under the same conditions. Testing was carried out 10 times on the photodiode sensor so that the precision of the timer photodiode sensor was 99.96%. The same thing is also done, namely testing the precision of the temperature sensor, testing is carried out 10 times under the same conditions so that the resulting precision value of the temperature sensor is 99.93%.

4. CONCLUSION

In this research, an IoT-based viscometer has been successfully designed using the falling ball method. The hardware of the system consists of a system framework, photodiode sensors, laser diodes, temperature sensors, Bluetooth modules, and microcontrollers that interact with each other. Software from the system was compiled using the MIT App Inventor, consisting of several input parameters and two sensor reading inputs. The viscosity value can be calculated automatically after all parameters are obtained. The results of testing the sensor characterization for the timer and temperature obtained a very good response value. The sensor for the timer obtained an R-square value of 0.966, and the temperature sensor had an R-square value of 0.99. The accuracy of the photodiode timer sensor is 95.76% with a precision of 99.96%, then the accuracy of the temperature sensor is 99.43% with a precision of 99.93%. This value is an important indicator to see the system’s response when making related measurements.

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