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Design and Realization of Temperature and Speed Control System of Meyer Rod Coating Based on Arduino for Silver Nanowires Thin Film Applications

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Abstract

The design and implementation of an Arduino-based temperature and speed control system for Meyer rod coating have been successfully accomplished. The tool is capable of automatically regulating the temperature and speed of the plate and Meyer rod. The components utilized in manufacturing the coating tool include Arduino Uno, stepper motor, thermocouple sensor, heating plate, relay, stepper motor driver (TB6560), and thermocouple sensor supported by the MAX-6675 module. The motivation behind developing this tool stems from the inconsistency in temperature and speed during manual Meyer rod coatings, where substrate transfer to the heater is done manually. Therefore, the purpose of this tool is to make the rod's pressure and speed stable, and the substrate does not need to move. The results of this study are that the stepper motor achieved a remarkable speed accuracy of 99%, and the thermocouple sensor exhibited an accuracy of 88.43%. Further, the time required for the heater to reach 100 °C was 09.45 minutes.
Keywords: *Nanowires, Meyer Rod Coating, Motor Stepper, Thermocouple.*

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INTRODUCTION

In the area of material technology, researchers worldwide are dedicated to developing innovative materials tailored to meet specific needs and requirements. Among the diverse array of materials under investigation, thin film layers have emerged as a critical area of focus [1].

Nanotechnology is a significant priority in science and technology. Within this field, thin film is one of the products of nanotechnology. The layers are composed of very thin organic, inorganic, metal, or metal-organic mixtures, meticulously deposited onto a medium called a substrate at the nanometer to millimeter scale, and have conducting, semiconducting, or insulating properties [2-5].

Many methods for producing thin films utilize silver nanowires (AgNWs) and silver nanorods (AgNRs). These methods commonly include Meyer rod coating, spin coating, spray coating, dip coating, and electrospinning. The deposition process is typically performed on various substrates such as transparent glass, quartz glass, polyethylene terephthalate (PET), and indium tin oxide (ITO). In manufacturing thin films, the primary attention is focused on several important factors, such as conductivity, resistance, and transmission [6-13].

The Meyer rod coating method is a commercial method for coating paper, which can take advantage of paper printing technology [14]. This method is well known in the thin film industry for fabrication due to the flexibility and conductivity of the coating, the simplicity of its structure, and the ease of upgrading [15]. This method has advantages because the deposition is done with a process that can be measured, is simple and cheap, and can improve the performance of the transparent electrodes. This method works because the coating material flows through the grooves of the rod and coil of wire to form a thin layer. Control and decision on the coated layer's thickness depends on the diameter of the wire winding [16].

The Meyer rod coating method is still widely used manually. This method involves sliding the Meyer rod and subsequently moving the substrate to a heater for drying. However, this presents a challenge in the research as an inconsistent applied pressure throughout the flow can result in an inadequate thin layer. Furthermore, the user needs to manually remove the coating before drying the substrate. Therefore, an automated tool with a motion and heating system capable of controlling the thickness of the thin layer is required.

Based on the background described, this study focuses on the design and realization of the coating system using the Meyer rod coating method. The components used in the manufacture of this tool are Arduino Uno as a control system, a NEMA 17 stepper motor as a drive system, a TB6560 driver for the motor driver, a heating plate for drying chemicals, a thermocouple sensor to measure the temperature difference on the heating plate, a printed circuit board (PCB) serves to install all the components used, relays to turn on and off the electric current, a liquid crystal display (LCD) to output the process results, and a keyboard to enter input to the microcontroller. The development of this tool is based on Arduino technology, incorporating advancements in automating the movement of the Meyer rod and integrating built-in heaters. The implementation of a stepper motor in this tool is based on its numerous advantages, including consistent linear movement, speed control capability, and high resolution [17].

METHOD

Tool Design

The design of the thickness control system uses the Meyer rod coating technique, which is used as a coating leveler. The device in this design uses wood as the primary material. The upper part uses a stainless steel plate. At the front, an I2C LCD and a keyboard are placed. The design of this study tool is shown in Figure 1.

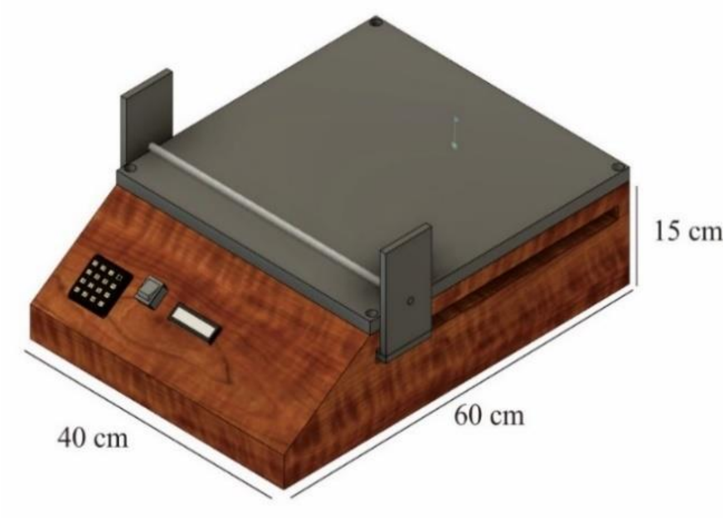

Figure 1. Design of Tools

System Project
Figure 2 shows the system used in this research**.**

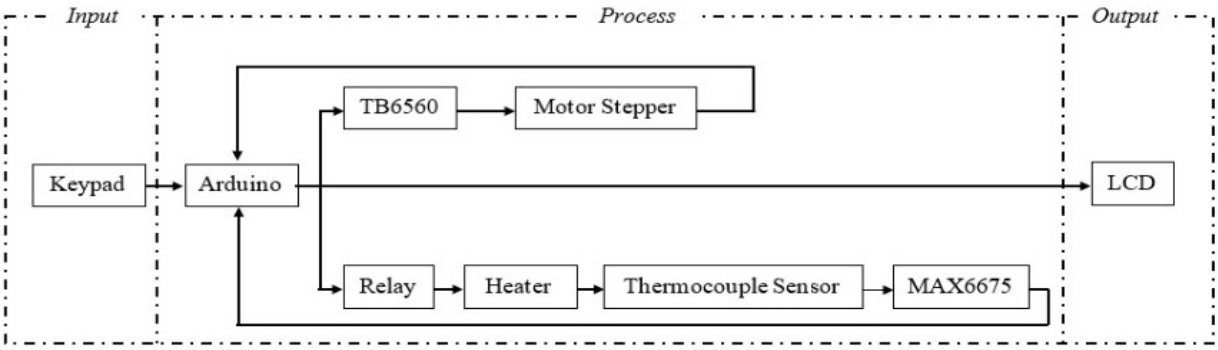

Figure 2. System Project

The system operates by receiving user input value through the keyboard. The microcontroller receives and processes this current value and continues to display the value to the LCD screen [18-20]. At the same time, the microcontroller outputs a signal sent to the control circuit depending on whether the user wants to run a Meyer rod or initiates the substrate drying process with a heater. Based on this user selection, the microcontroller sends a control signal to the driver (TB6560) and the relay. These components act as a temperature and speed controller, adjusting the system according to the user's input. As the system operates, the microcontroller provides real-time monitoring, displaying speed and temperature values on the LCD screen. The temperature value is displayed in real-time, from the lowest position to the desired position.

A thermocouple sensor is used to determine the temperature change value directly. The thermocouple works as feedback to the heater controller. In the control circuit, the value changes to the voltage [21]. The sensor is then processed by the MAX6675 module, which then will be sent to the microcontroller for direct display on the LCD screen. The implementation procedure of this research follows the flow chart shown in Figure 3.

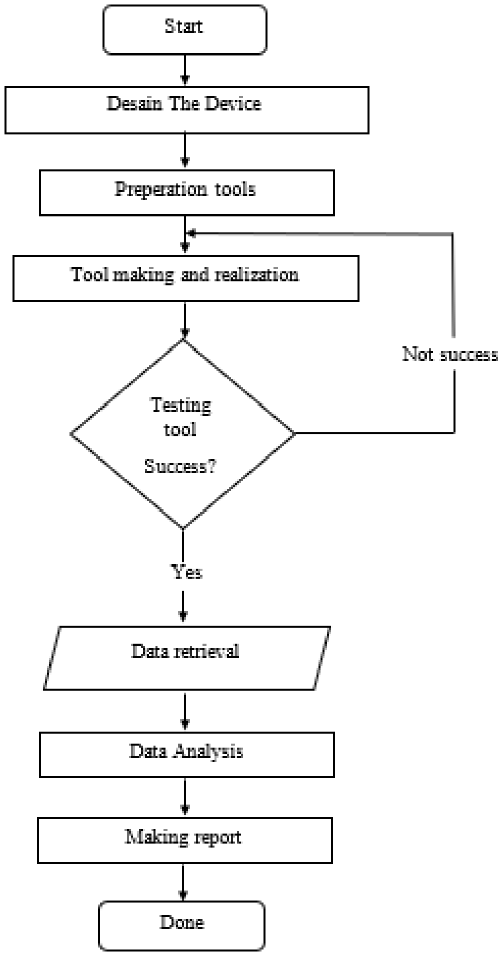

Figure 3. The Research Flowchart

Figure 3 illustrates the sequential stages involved in creating a temperature and speed control system for a Meyer rod coating tool. The process begins with the design phase. Subsequently, the necessary tools and materials are prepared. The manufacturing and realization phase follows. After this, the system is rigorously tested to obtain optimal measurement results, ultimately determining the best operating conditions for the tool's performance.

In conclusion, a control system for a Meyer rod coating tool using an Arduino Uno microcontroller was created. It involved the development of a dedicated control program for the Meyer rod coating tool using the Arduino IDE programming application, which was specifically designed to run on the Arduino [22]. Subsequently, instrument control system testing was conducted by entering values on the keyboard, with the inputs taking the form of motor speed values or temperature setpoint values.

RESULTS AND DISCUSSION

Speed Control system

In manufacturing Meyer rod coating tools, a drive system must move the Meyer rod. In this drive system, the main component is an Arduino-based NEMA-17 stepper motor that will be controlled by a microcontroller depending on the input from the keyboard [23]. The motor is a driving component assisted by a TB6560 drive and a 12 V power supply. The keyboard works to enter the RPM value, and subsequently the value will display on the LCD. The speed control system is shown in Figure 4.

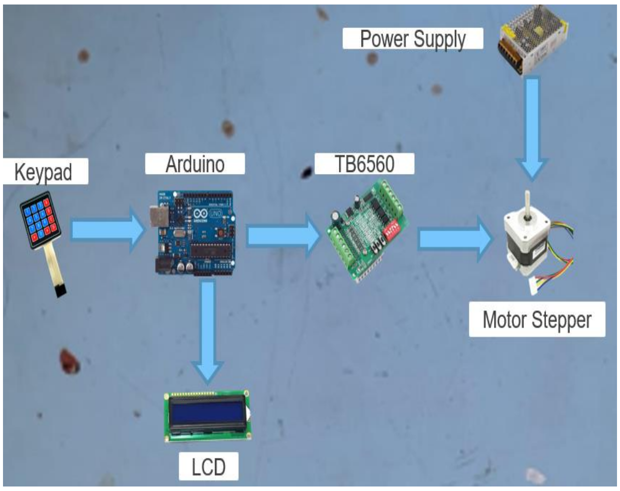

Figure 4. Speed Control System

Temperature Control System

In the Meyer rod coating apparatus, an integral heater has been incorporated, designed for the purpose of drying the thin layer on the substrate. The heating plate measures 7×7 cm and comprises three individual heating elements within the system. To monitor the heat generated by this heating plate, a thermocouple sensor assisted by the MAX-6675 module for communication to the microcontroller [24]. Control over the heater is achieved through the utilization of a relay, which manages the supply of electric current to the heater based on the input value provided via the keyboard [25]. Figure 5 illustrates the internal temperature control mechanism.

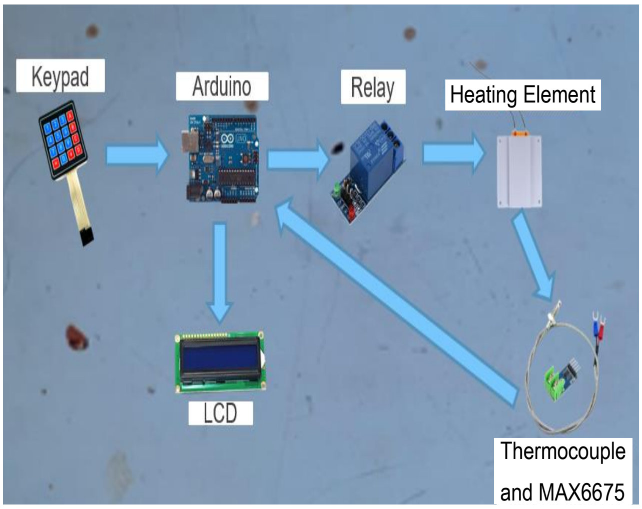

Figure 5. Temperature Control System

Meyer rod coating Devices

The manufacturer of this Meyer rod coating tool uses an Arduino Uno microcontroller. At the top is a stainless steel plate (C). At the front, there is a keyboard (B) and an I2C LCD at the front (A). This microcontroller works as a processor of values given by the keyboard, which will then be displayed on the LCD screen. Meyer rod coating tool can be seen in Figure 6.

Figure 6. The Device of Meyer Rod Coating

Calibration of Speed Control

One of the components used in the coating tool is the NEMA-17 stepper motor, boasting a specification of 200 rotations/revolutions. The step used in designing this coating tool is to test the speed of the stepper motor with a tachometer for calibration tool [26]. This test compares the setpoint value entered through the keyboard and the speed value read on the calibration tool. The values obtained from the calibration results can be seen in Figure 7.

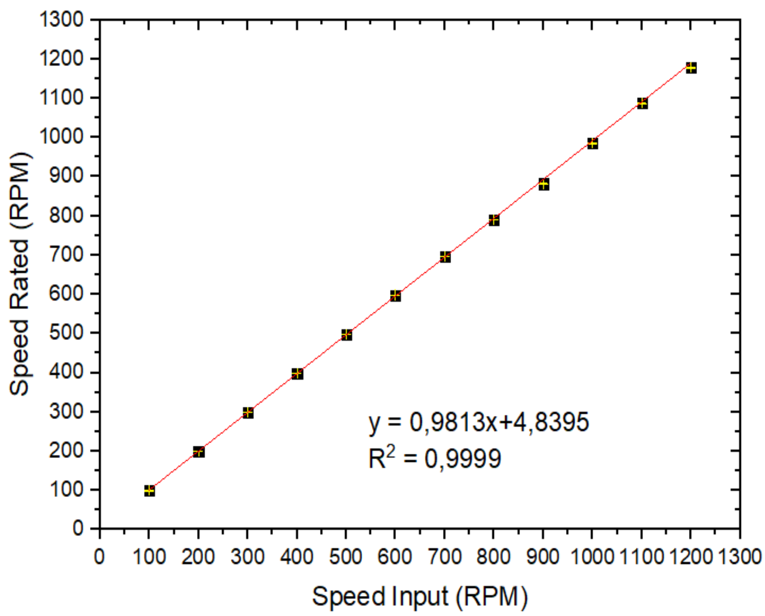

Figure 7. Calibration of Speed Control

Figure 7 visually represents the setpoint data acquisition test for three repetitions with a speed range from 100 RPM to 1200 RPM. The average accuracy level is 99.09%, and the error level is 0.91%. In addition, the accuracy value obtained of as much as 99.76% proves that the stepper motor has a good accuracy value in its application [27-28].

Calibration of Temperature Sensor

A thermocouple sensor is one of the components used by coating tools. The stage used in designing this coating tool is calibrating the thermocouple sensor. The calibration tool uses a digital thermometer. This test compares the input value entered through the keyboard and the temperature read on the calibration tool. The obtained values can be seen in Figure 8.

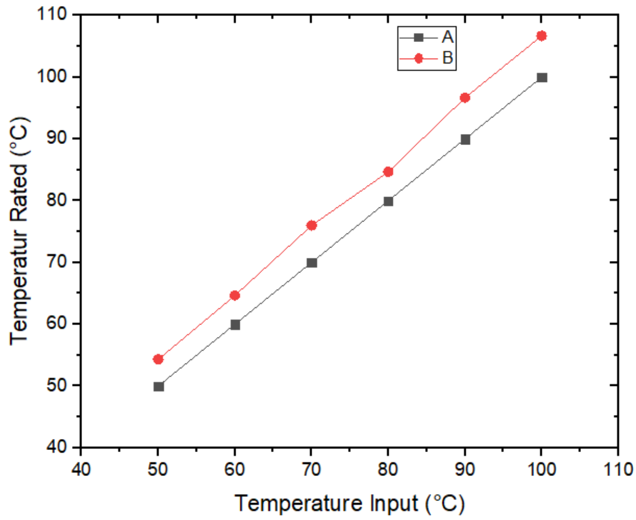

Figure 8. Calibration of Temperature Sensor

According to Figure 8, line A is the value of the thermocouple sensor, and line B is the value of the digital thermometer. The graph shows many setpoint data with a temperature range from 50 °C to 100 °C. The average level of accuracy is 88.43%, and the error is 11.57%. Meanwhile, the accuracy value is 98.91%. The graph above proves that there is still a difference between a digital thermometer and a thermocouple sensor [29-30].

Comparison of Speed and Time

The stage used in designing this coating tool is to test the time available in the Arduino IDE program. This test uses a stopwatch calibration tool that compares the time obtained in the program (i.e., by dividing the distance divided by the speed contained in the program) with the time found on the stopwatch. This is illustrated in Figure 9.

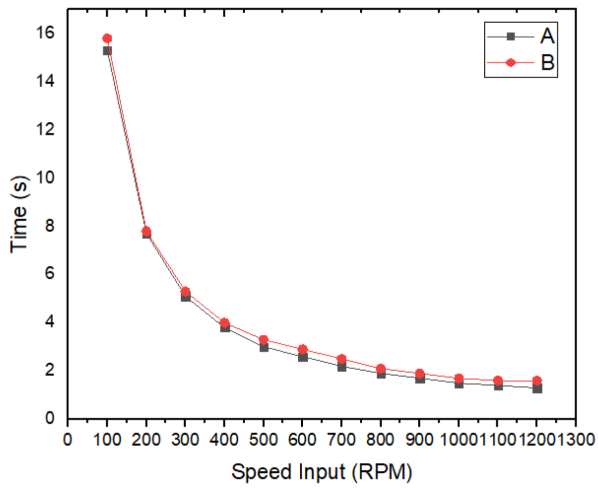

Figure 9. Comparison of Temperature and Time

Based on Figure 9, line A is the time in the program, and line B is the stopwatch for the calibration tool. The graph shows the data collection setpoint three times with a speed range from 100 RPM to 1200 RPM. The average level of accuracy is 89.84%, and the error is 10.16%.

Comparison of Temperature and Time

In the designing phase of this coating tool, a critical assessment was conducted to determine the ratio of temperature rise over time. The calibration tools used are stopwatches and thermocouple sensors. This test compares the temperature set point value entered via the keyboard with the time and temperature read on the calibration tool. This measurement data acquisition starts with the temperature recorded on the digital thermometer, which is 33 °C. A comparison chart can be seen in Figure 10.

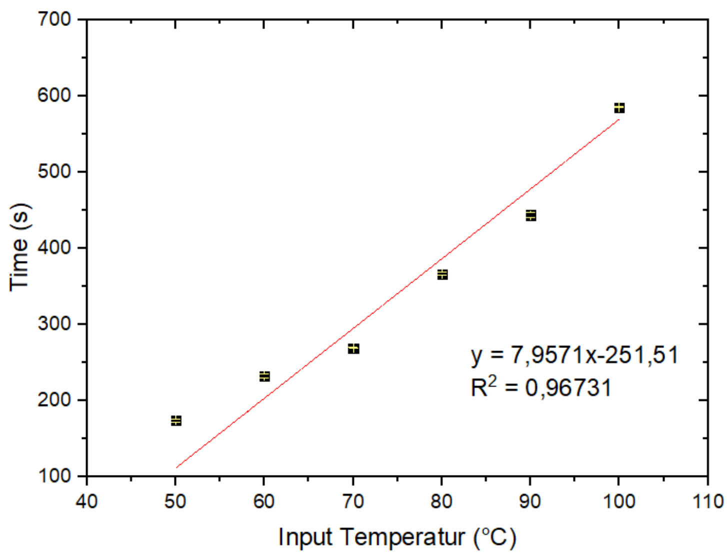

Figure 10. Comparison of Temperature and Time

Figure 10 shows the time the heating plate takes to heat the stainless plate from 50 °C to 100 °C. the incremental temperature milestones are as follows: 50°C in 172 seconds, 60°C in 230 seconds, 70°C for 270 seconds, 80°C for 368 seconds, 90 °C for 443 seconds, and 100 °C for 595 seconds.

This research primarily focuses on the development of instrumentation of instrumentation for producing thin films using the Meyer rod coating method. Arduino serves as a core control system for regulating the Meyer rod's speed, seamlessly integrated with a Nema-17 stepper motor. Additionally, Arduino controls plate temperature which is integrated with a thermocouple sensor and the MAX6675 module. The significance of this research extends to the advancement of nanomaterials and nanofibers. This tool developed here offers a valuable means of streamlining the production of thin films. In the future, this tool holds the potential for widespread application in the manufacture of thin layers, particularly in the creation of silver nanowire-based transparent conductive electrodes.

CONCLUSION

This research has successfully developed an instrument tailored for thin film manufacturing applications. The instrument was developed using an Arduino-type microcontroller combined with a temperature sensor, stepper motor, and display. Calibration assessments of the instrument have demonstrated exceptional precision, with the stepper motor displaying an impressive accuracy rate of 99.09%, with an error of 0.91%. in parallel, the thermocouple sensor, when evaluated against a measuring instrument, yielded an accuracy rate of 88.43%, with an error of 11.57%. notably, the heating plate takes approximately 9.45 minutes to reach a temperature of 100 °C. This tool can be utilized to create thin layers of AgNWs using the Meyer rod technique. The development of this tool for thin film manufacturing has a significant scientific impact in the field of physics. It offers an innovative and automated solution using an Arduino-based microcontroller, temperature sensor, stepper motor, and display. This instrumentation provides a reliable and controlled approach for producing thin layers of AgNWs using the Meyer rod technique. By incorporating precise motor control, temperature sensing, and automation, this tool enhances the efficiency and accuracy of thin film manufacturing processes. The research contributes to the advancement of nanomaterial synthesis and deposition methods, facilitating the production of high-quality thin films for various applications such as electronics, optoelectronics, and sensors. Furthermore, the insights gained from this research can inspire further studies and innovations in the field of physics, driving progress in materials science and technology.

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AUTHOR CONTRIBUTIONS

Junaidi: Investigation, Conceptualization, Validation, Review and Editing; Raihan Irvana and Humairoh Ratu Ayu: Original Draft, Methodology, and Writing and editing; Suotpo Hadi and Pulung Karo Karo: Investigation and Review; Arif Surtono, Roniyus Marjunus: Investigation and Formal Analysis.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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