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Development of a Remote Three-Phase Motor Wiring Practice Tool Using ESP32, LabVIEW, Wokwi, and Adafruit IO

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ABSTRACT

The practical application of three-phase induction motor wiring is an essential part of mechatronic engineering education. The integration of IoT-based tools and simulation software such as Wokwi, LabVIEW, and Adafruit IO enables remote monitoring and control of motor wiring practices. This article discusses the development of a remote three-phase induction motor wiring tool utilizing the ESP32 microcontroller, LabVIEW for real-time monitoring and control, Wokwi for circuit wiring simulation, and Adafruit IO for cloud-based data communication. Testing shows that the system effectively facilitates remote motor control and wiring simulation, providing a flexible and accessible learning environment.

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1. INTRODUCTION

Three-phase induction motors are widely used in various industrial applications due to their efficiency and robustness. For mechatronic engineering students, learning and practicing how to build circuits and control these motors is very important. The practice of wiring these motor circuits requires physical presence in the laboratory. However, the COVID-19 pandemic has brought to light the importance of distance learning solutions. In addition, the cost of maintaining multiple physical setups for individual practice can be very high for educational institutions, not to mention the safety risks for direct wiring of 3-phase electric motors are very high, as they deal with high currents and voltages. This study addresses the specific need for remote practice of wiring 3-phase induction motors. The integration of IoT technology with traditional motor control systems offers new possibilities for distance learning while maintaining the quality of practical learning and also providing safety for both users and equipment in the Laboratory.

Previous research on this remote wiring practice has been widely conducted, including the development of the Remote Wiring and Measurement Laboratory (RwmLAB) which allows students to build and measure electrical circuits remotely, allowing them to experience a real-world laboratory environment while accessing the laboratory remotely. The RwmLAB instrument enables remote wiring and real-time data acquisition of electrical and electronic circuits over the Internet, ensuring global access and flexibility for users [1]–[3].

Subsequent research has developed VISIR (Virtual Instrument Systems in Reality) remote lab, which allows remote wiring and measurement of electronic circuits on project boards, offering a unique solution for teaching electronics to students. The integration of VISIR into several classroom lessons has shown potential to improve collaboration and learning outcomes. VISIR technology enables remote electrical and electronic circuit experiments, allowing online wiring and measurement of electronic circuits, which promotes lifelong learning and distance education [4]–[7].

In relation to the field of Mechatronics, a training using an innovative remote laboratory has been developed. The training has been successfully implemented with 70 participants, and 90% of them gave positive feedback. From this it is known that the Remote Laboratory allows participants to gain practical skills by conducting experiments remotely, and allows for better understanding because it arouses greater curiosity in participants [8].

The next research developed a device that could provide remote access for students to test and verify their software designs on embedded systems and mechatronic hardware. The system provides real-time interaction, allowing students to experiment online with embedded systems and develop practical skills in mechatronic engineering [9], [10].

Several studies have developed remote laboratories with LabVIEW software. LabVIEW is widely used in this remote laboratory development research because of its ease of development of intuitive interfaces, easy hardware integration, real-time measurement and data processing capabilities, flexibility in network development and remote communication, scalability and monitoring of many instruments [11]–[17].

Several remote laboratory developments integrate internet of things-based technology, with the most widely used component being ESP32. ESP32 is widely used in IoT-based remote laboratory developments, such as those implemented in VMLab, due to its advantages in terms of wireless connectivity (Wi-Fi and Bluetooth), high performance, affordable price, and flexibility in using various types of sensors and other hardware [18].

With physical laboratories, collaboration across countries or between institutions is difficult, because equipment cannot be accessed remotely. This limits the opportunity to collaborate on global research or projects. The development of remote laboratories is an opportunity to produce better and more beneficial collaborative projects [19].

A study that reviewed practical learning between distance laboratories (Non-Traditional Laboratories) and physical laboratories (Traditional Laboratories) found that learning outcomes in NTL were the same or even higher than learning outcomes in TL. This was consistent across all aspects, both in knowledge, scientific inquiry and practical skills [20].

From the studies that have been conducted, it can be seen that the development of remote laboratories is very important and useful. That is why this research was conducted, to develop interactive and effective remote laboratories, especially for mechatronics engineering education. With the remote laboratory that has been developed, students' practice hours will automatically increase, because students can practice independently from anywhere and anytime. These practice hours are important because the industry generally requires skilled technical personnel, who can be trained with many hours of practice in the laboratory.

The distance learning practice developed in this study is the practice of wiring 3-phase induction motors. Unlike previous studies, which used very complex and expensive equipment, such as that applied to the development of RwmLab and VISIR, in this study, the Wokwi application software was used, which can simulate wiring for free and can be run online and simultaneously. This Wokwi application software makes it possible to do wiring at many connection points, and send the connection data to the device via internet communication with the MQTT protocol. Because it can be run online, it makes it easy for students to access it, either with a cellphone or computer, from anywhere and anytime. The connection results will be known immediately, and if the connection is correct, the 3-phase induction motor in the Automation Laboratory of the Vocational Faculty of Sanata Dharma University can be run, following the connection made.

2. METHOD

To be able to produce this remote wiring application, several stages are required. There are 4 stages carried out, namely:

2.1 System Design

This system is designed based on the ESP32 microcontroller, which acts as a controller for a three-phase induction motor. LabVIEW provides a user interface for monitoring and control and data processing, while Wokwi simulates the motor wiring process. Adafruit IO serves as a cloud platform for remote data communication, as well as visualization of the connection results. The three devices are connected to the internet via the MQTT protocol. Figure 1 below shows the system design.

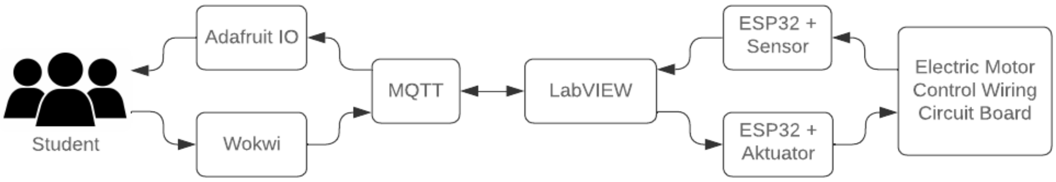

Figure 1. System Design for Remote Practice of 3-Phase Induction Motor Wiring

2.2 Hardware Implementation

The ESP32 microcontroller is connected to relays and sensors that control and monitor the three-phase motor. These components allow the motor status, such as voltage, current, and speed, to be communicated to the user via LabVIEW and Adafruit IO. Students can remotely observe and verify their wiring via Adafruit IO. Figure 2 below shows a 3-phase induction motor wiring board connected to traditional control devices, including MCBs, Contactors, Timers, Push Buttons, and Pilot Lights. Each connection point of the equipment is connected to a terminal, which is numbered sequentially. The traditional control devices are monitored and controlled by the ESP32 via sensors and relays.

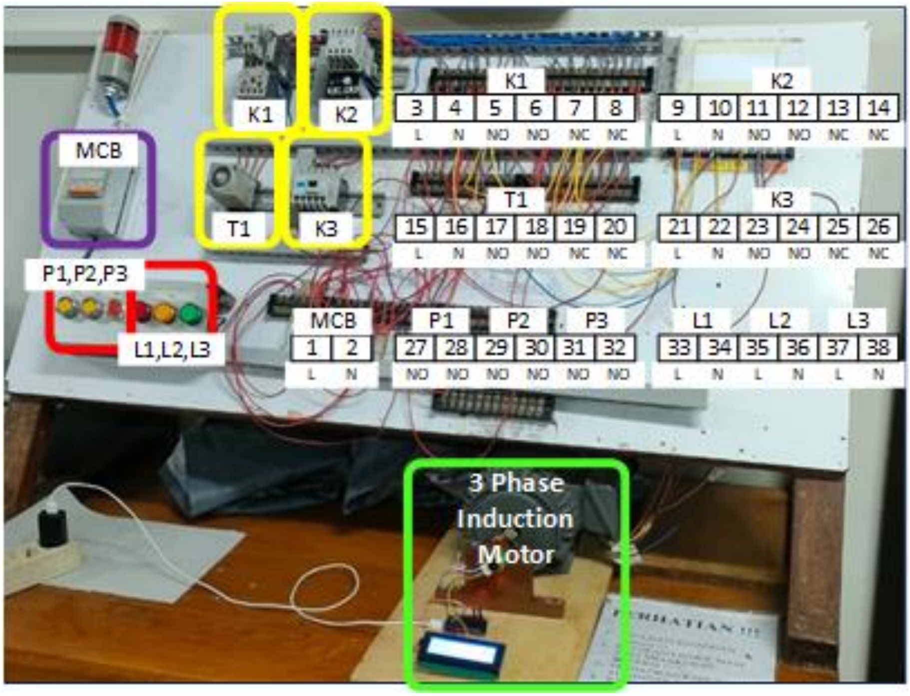

Figure 2. The Wiring Board of a 3-Phase Induction Electric Motor Connected to Traditional Control Devices, Including MCB, Contactor, Timer, Button, and Pilot Lamp, Which Are Numbered Sequentially, and All Are Monitored and Controlled by ESP32

2.3 LabVIEW and Wokwi Interface

The LabVIEW interface was developed to forward the wiring created in Wokwi to the control equipment via ESP32. LabVIEW will check whether the connection sent is correct or not. If the connection is correct, then ESP32 will apply control according to the connection pattern. To ensure security, the connection data sent by Wokwi is accompanied by the student name code, NIM code and type of question. LabVIEW will check the three codes, if the data for the three codes is in the list, then the connection check and the next process will be carried out.

So that Wokwi can be used to simulate wiring, an offline experiment was first carried out using the Proteus simulation software. The Arduino Mega component was chosen because it has quite a lot of IO legs, up to 70 IO legs. The first two IO legs (D0 and D1) are used for serial communication, while the other 68 IO legs are connected to 68 terminals, imitating the terminals on the wiring board. Serial communication is needed here to display the connection reading data. To find out which legs are connected, it is done by giving a Low value sequentially starting from legs D3 to D53, followed by A0 to A16. While the Low value is given to a particular leg, the reading is done for all legs. If there is a pin that has a Low value, then the pin is marked by making the ASCII character for that leg the same as the ASCII for the leg that is made Low. As seen in Figure

3 below, in the Virtual Terminal box, the ASCII character number 2 is in the 2nd and 16th positions, while the circuit image in Proteus also shows terminal 2 connected to terminal 16. Likewise, the ASCII character number 3 is in positions 3, 6, 26, 30, 50 and 54, which corresponds to the circuit image in Proteus.

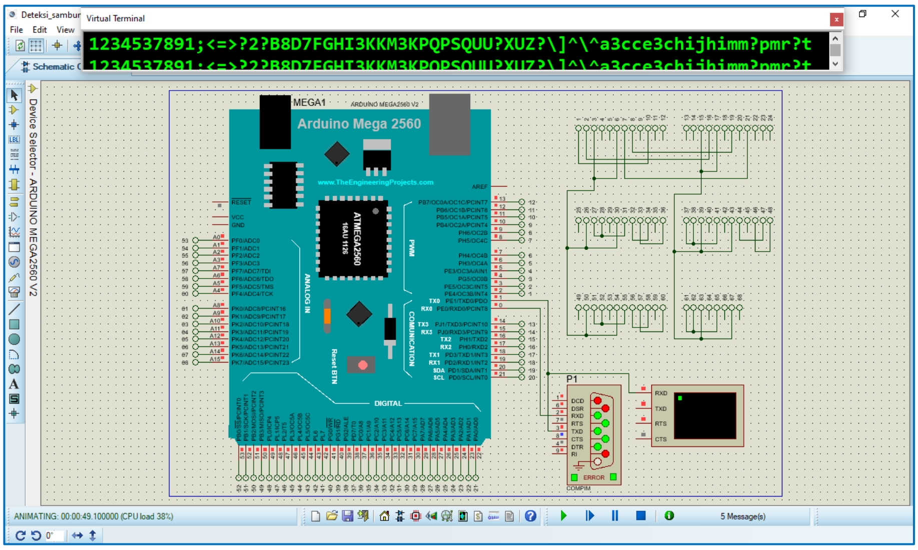

Figure 3. Connection Data Is Generated by Reading Which Pins Have a Low Value When One of the Legs Is Made Low. If a Pin Is Found to Have a Low Value, Then the ASCII Character on That Leg Is Made the Same as the ASCII Character on the Leg That Is Made Low, and Then the 68 ASCII Characters Are Sent via Serial Communication

After the offline simulation with Proteus software is successful, the next step is to apply the same simulation to the Wokwi circuit. The advantage of this Wokwi simulator is the availability of ESP32 components that can be used to forward connection data to remote devices via the internet with the MQTT protocol. In Wokwi, even though the Arduino Mega component is available and the ESP32 component is also available, both cannot be displayed on one page. To be able to use both, 2 Wokwi pages are needed, where later the Arduino Mega component and the ESP32 component are connected via serial communication. Figure 4 below shows a simulation in Wokwi that is the same as the simulation in Proteus, only here an I2C LCD component is added to display information and 3 buttons for data sending and testing purposes. For checking purposes in LabVIEW, the data sent is not only connection data, but also equipped with a username, 3 digit user ID and question code. The three codes will be checked whether they match the list stored in LabVIEW. If they do not match, the connection data will not be processed.

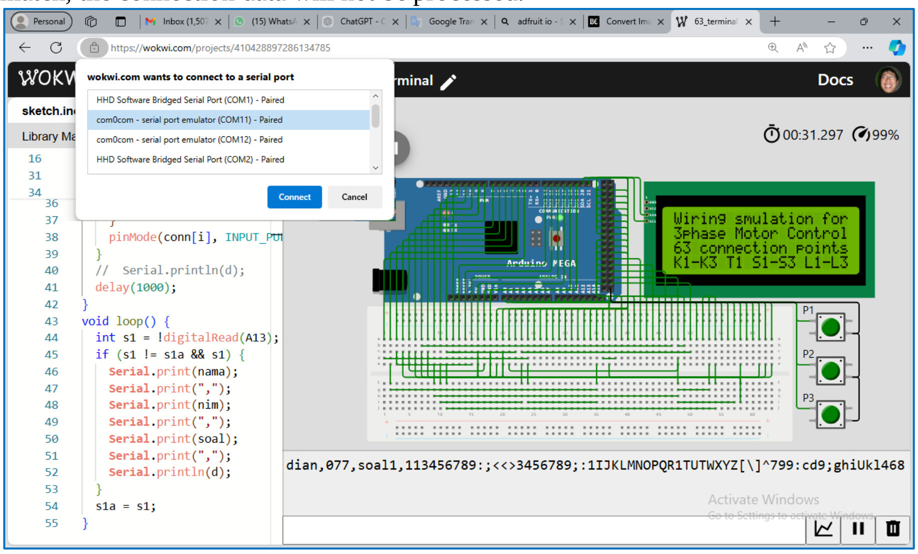

Figure 4. The Wokwi Circuit Above Runs the Same Simulation as the Simulation in Proteus, the Connection Data Is Shown in the Serial Monitor, Where in Addition to the Connection Data, There Is Additional Data in

the Form of the User Name, 3-Digit User ID Number, and Question Code Placed at the Beginning of the Data

After the Arduino Mega circuit in Wokwi can display the connection data created on the project board, and send the data via serial communication, the next step is to add an ESP32 component so that it can forward the data received via serial communication to LabVIEW via the MQTT protocol. For testing, the Hive-MQ Websocket application is used here which can display data sent via the MQTT protocol by subscribing to the topic sent by the ESP32. As seen in Figure 5 below, the data in the Serial Monitor box of the first Wokwi circuit also appears in the Serial Monitor box of the second Wokwi circuit, and is also displayed in the Hive-MQ Websocket Message box.

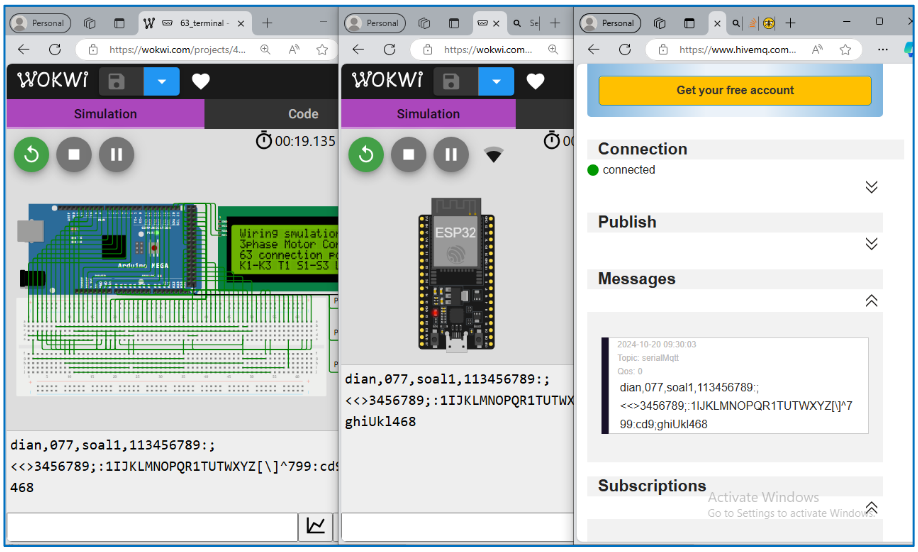

Figure 5. It Can Be Seen That the Connection Data Created on the Project Board Can Be Forwarded to the Hive-MQ Websocket With the Help of the ESP32 Component and the MQTT Protocol

After the data transmission from Wokwi to MQTT is successful, the next step is to make LabVIEW able to receive the data sent by Wokwi via the MQTT protocol. The data received by LabVIEW is then displayed in the form of a wiring image. Before implementing the MQTT communication, Figure 6 below shows the results of the wiring image generated by LabVIEW, where here for testing, the data received is not via the MQTT protocol, but via serial communication with Arduino Mega in the Proteus software. It can be seen that the connection data has been successfully mapped in the form of a wiring image.

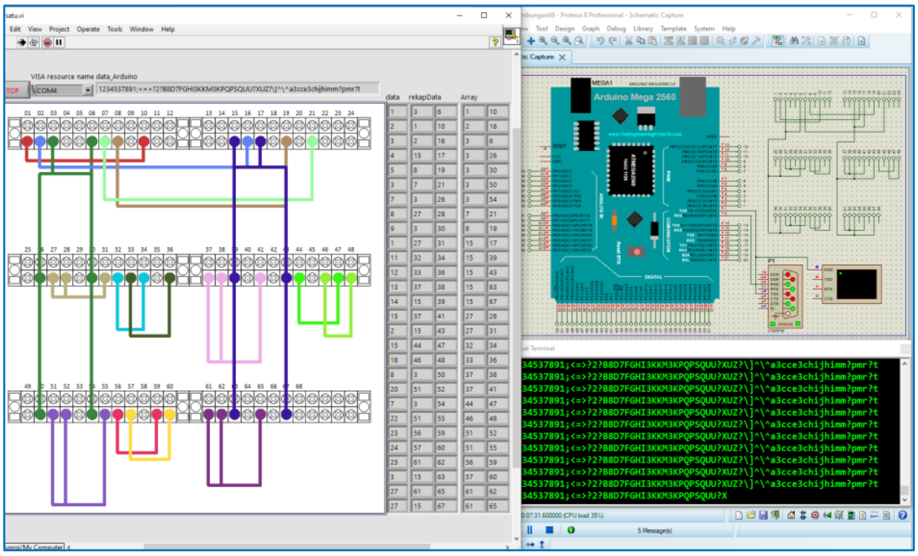

Figure 6. Testing the Wiring Image Display With Connection Data Obtained From the Arduino Mega via Serial Communicatio

The creation of the wiring image display above uses the LabVIEW program whose program code is in the form of a Block Diagram, as shown in Figure 7. It can be seen that the LabVIEW program code is quite interesting and simple, because it is in the form of an icon with data lines that create input output paths that make it easier to read the program flow or algorithm. Each complex program but has the same and specific function, can be combined into an icon, thus simplifying the overall program.

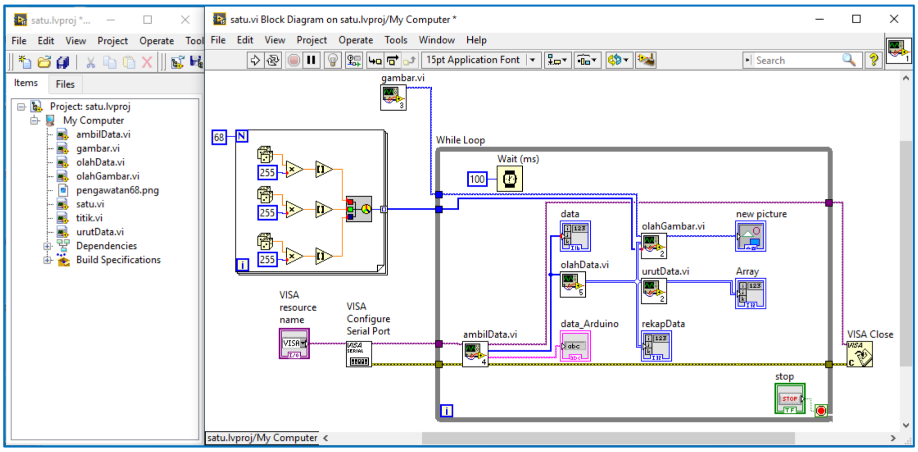

Figure 7. LabVIEW Program Code to Display a Wiring Image From the Connection Data Received

The LabVIEW program above can be written in a simple flowchart, as shown in Figure 8 below. First, LabVIEW will receive the connection data, then the connection data is checked, whether the 3 codes that start are correct and registered, if yes, then the check is continued, whether the connection data is exactly 100% the same as the answer, if yes, then the connection data is forwarded to ESP32 to run the electric motor control remotely, but if the connection data is not correct, then LabVIEW only sends the correct connection value.

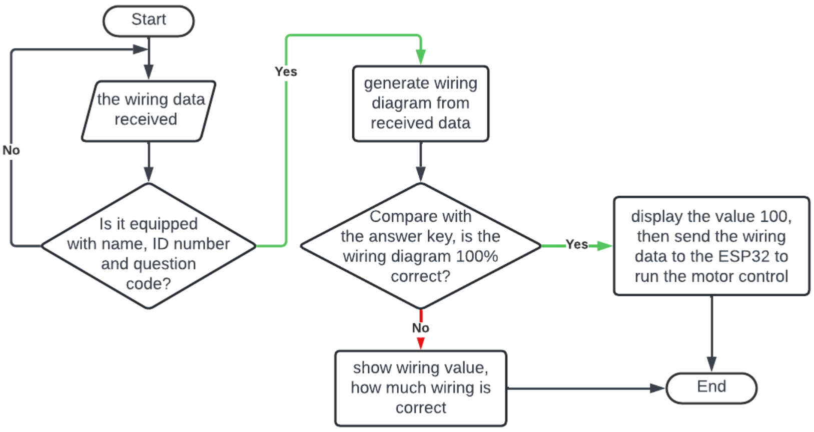

Figure 8. Flowchart for the LabVIEW Block Diagram in Figure 7

2.4 Adafruit IO Integration

Adafruit IO is integrated to facilitate cloud-based communication, allowing remote access and control, as well as visualization of the connection results. Users can log in to Adafruit IO to see if the connection is correct. If the connection value is 100% correct, users can view motor performance data and send control commands from any location to turn the motor on or off, reverse the motor rotation or add a Timer, depending on the type of problem given. As a first step, here is shown the reading of the PZEM-004T sensor and the encoder sensor by the ESP32, where the data is sent to the Adafruit IO Dashboard via the MQTT protocol, as shown in Figure 9 below.

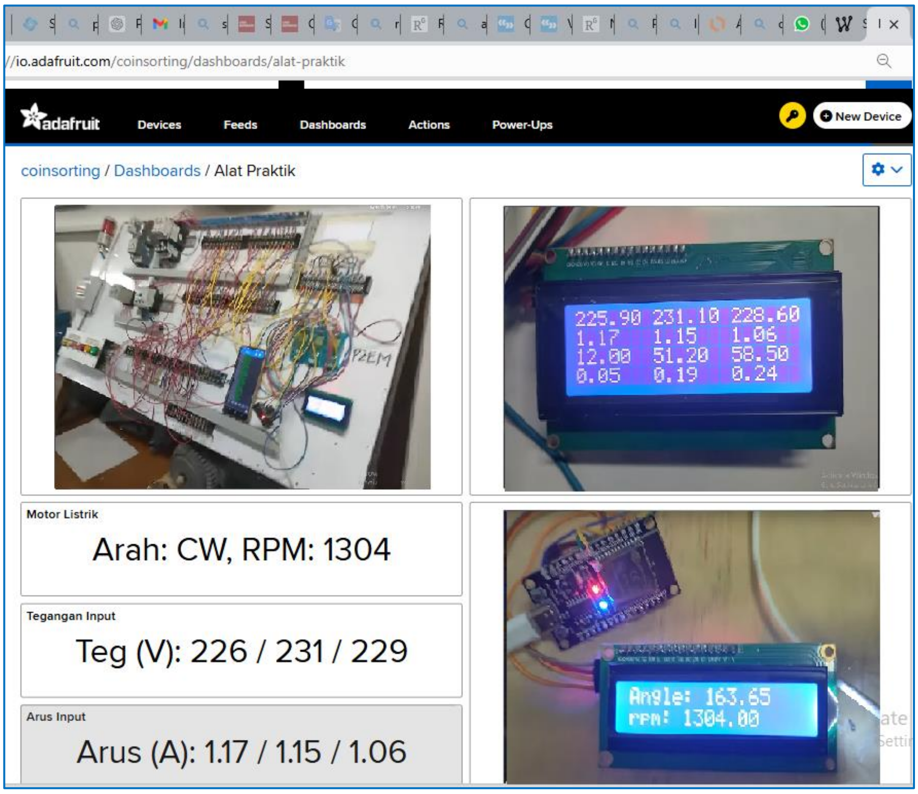

Figure 9. Taking Readings From Sensors Mounted on the Wiring Board, Including the PZEM-004T Sensor for Measuring Voltage, Current, and Power, and Encoder Sensors for Measuring Speed and Direction of Rotation, and Displaying Them on the Adafruit IO Dashboard

The next step is to display the results of the LabVIEW wiring diagram and also the connection assessment on the Adafruit IO Dashboard. Figure 10 below shows the Adafruit IO Dashboard display that displays the results and wiring diagrams and motor performance when the connections are correct and the motor can be run. The S1, S2 and S3 buttons on the Dashboard display can replace the S1, S2 and S3 buttons on the wiring board. The voltage, current, power display is also visible. The speed and direction of the motor rotation can be displayed on the Adafruit IO Dashboard, to show the condition of the 3-phase induction motor.

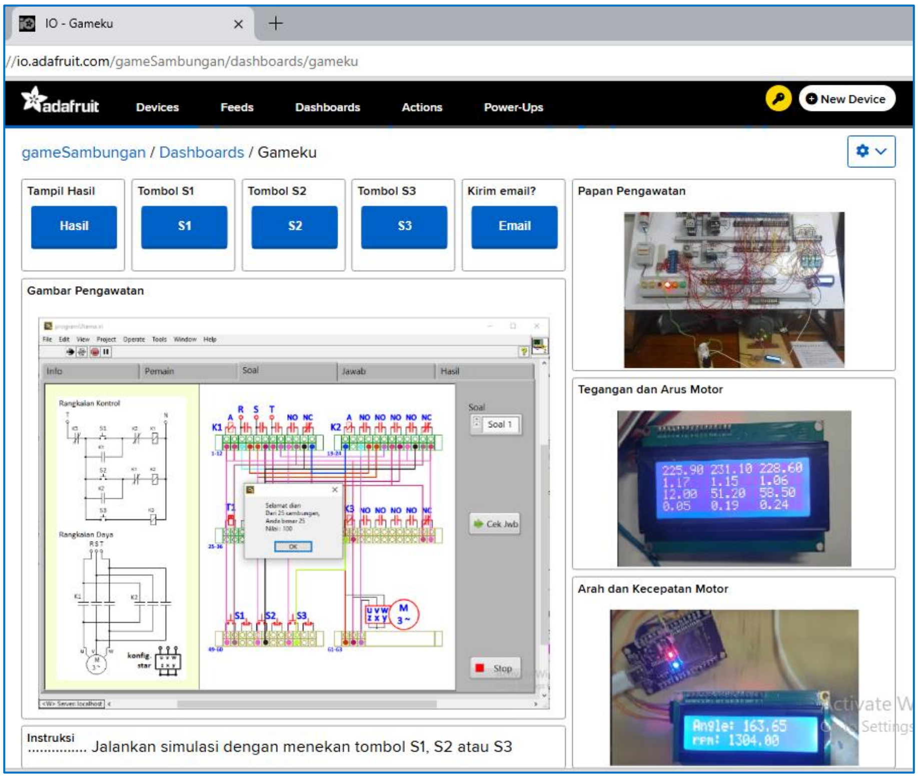

Figure 10. Adafruit IO Dashboard Display, Showing the Wiring Diagram According to the Connection Data, and the Connection Assessment. When the Connection Value Is 100% Correct, the Motor Control Can Be Run, Either Turned On or Off or Reversed. The LCD Display Shows Evidence That the Motor Is Working, With a Certain Voltage, Current, Power, Speed, and Direction of Rotation

3. RESULTS AND DISCUSSIONS

The remote laboratory testing showed positive results, where electrical equipment including contactors, timers, pilot lights and 3-phase induction motors could be monitored and controlled remotely in real time. The use of Wokwi as a simulation platform has proven effective in teaching programming and electronics concepts without the need for physical hardware. Students can understand how the ESP32 and related sensors work before applying them to real devices. In addition, integration with Adafruit IO allows students to monitor and analyze data generated by the device directly through an easy-to-use dashboard. This increases the interactivity and effectiveness of learning, because students can conduct experiments and see the results instantly.

In addition, the interesting thing about this remote laboratory is the safety of the equipment and users. Before using the remote laboratory for wiring this electric motor control, there were many errors in connecting the lines in the wiring circuit, which resulted in damage to the equipment due to the flow of large short-circuit currents in the equipment. Several students were also reported to be exposed to quite high electric voltage, because they forgot to open the MCB when wiring. With this remote laboratory, equipment damage can be avoided, because only the correct wiring circuit will be run, while the wrong wiring circuit will not be run. In addition, users will not be directly connected to the AC power source, so they are safe from the dangers of high voltage.

From the test results, the remote laboratory that was developed has a fairly high potential for sustainability, especially when viewed from the aspect of maintenance and technology integration. From the aspect of maintenance, hardware-based systems such as ESP32 and web-based software such as Wokwi and IoT platforms such as Adafruit IO are generally easy to maintain due to the large developer community and ongoing support from the IoT ecosystem. From the aspect of technology integration, ESP32, Wokwi and Adafruit IO support various communication protocols such as MQTT and HTTP, which allows integration with future technologies and other platforms that may emerge.

4. CONCLUSION

The development of a remote three-phase induction motor wiring or wiring practice tool using ESP32, LabVIEW, Wokwi, and Adafruit IO has successfully created an innovative solution for flexible and scalable learning in engineering education. By integrating real-time monitoring and control with virtual wiring simulation, the system allows students to develop practical motor wiring skills remotely. The ability to simulate wiring using Wokwi before applying it to physical wiring adds a valuable layer of security and reinforcement for learning. This tool represents a significant advancement in the way motor control and wiring practices are taught, offering a new model for distance learning and practical education in the digital age. Further research is recommended to evaluate the long-term impact of remote practice tools on engineering education.

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CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Author1: Conceptualization, Methodology, Software, Project administration. **Author2**: Software, Writting – original draft, Validation. **Author3**: Writing – review & editing, Supervision.

DECLARATION OF COMPETING INTERESTS

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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