Air Compressor Design and Construction With Esp32 Based Microcontroller Monitoring System

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Abstract:

Air compressors serve as vital auxiliary engines on ships for starting main engines and operating valves, yet manual monitoring leads to inefficiencies and frequent failures, contributing to 20% of machinery downtimes globally. This study aims to design and build a prototype air compressor with ESP32-based microcontroller monitoring system for real-time electrical parameter tracking. Employing an experimental prototype development design, the research utilized laboratory-scale prototype as subject, with hardware including PZEM-004T sensor, LCD I2C, and Blynk app; data analyzed via comparative quantitative measurements against standard multimeter for accuracy assessment. Results demonstrate 100% consistency in voltage (230V), current (6.1A), power (1015W), and frequency (50Hz) readings across LCD and remote app during static/dynamic tests. In conclusion, the prototype enhances predictive maintenance and educational training for maritime students, although field testing in harsh conditions is recommended

Keywords: Air Compressor; Esp32; Iot; Monitoring System and Pzem-004t.

I. INTRODUCTION

Maritime transport dominates world trade, contributing more than 80% of global volume by 2024, with air compressors as ship auxiliary engines crucial for engine starting and valve operation. However, compressor failures cause downtime in up to 20% of ship engine incidents, with global costs reaching billions of dollars due to inefficient manual monitoring. The grand theory of the Internet of Things supports the integration of real-time sensors for predictive maintenance, while recent theories such as edge computing on the ESP32 microcontroller enable local data processing to reduce latency.(Mahendra Eka Perdana et al., 2022).The evolution of theoretical thinking from manual monitoring to IoT is evident in studies that synthesize the benefits of up to 15-30% energy reduction through PZEM-004T sensors and ESP32. However, conflicting evaluations emerge, where some conventional methodologies, such as timer modules, are simpler but less accurate than microcontrollers, raising debates about scalability in maritime environments. The general methodology mapping includes static/dynamic testing (70% of studies) and IoT prototyping (30%), with ESP32 dominant due to its integrated WiFi/Bluetooth.The main issue is that manual monitoring of air compressor performance leads to delayed detection of overpressure or overheating, with piston failure rates of up to 25% due to intercooler corrosion on ships. The urgency of a solution is heightened by IMO 2025 regulations demanding ship energy efficiency, where compressor failure can halt operations for up to 48 hours. A synthesis of supporting citations confirms that ESP32-based IoT reduces risk by 40% through real-time voltage/current data.(Wardana et al., 2025).

In Indonesia, a maritime nation with 17,000 islands, the shipping sector contributes 10% of GDP but experiences 15% downtime due to outdated auxiliary machinery. The Surabaya Maritime Polytechnic specifically faces the challenge of training cadets without a modern prototype. Specific characteristics such as high humidity and ship vibration accelerate lubricating oil emulsions, where ESP32 monitoring with the Blynk app addresses this issue. Local studies show a similar prototype improves measurement accuracy by up to 99% on PZEM sensors.A key gap is the lack of ship-specific air compressor prototypes with ESP32 for real-time electrical/pressure monitoring, with 80% of studies focused on general non-maritime industries. The need for this study stems from the absence of freon cylinder integration and automatic emergency stop in IoT, while conflict evaluations highlight the inaccuracy of manual versus IoT (<1% error on ESP32). This gap is crucial for Indonesian maritime education.This research aims to design an air compressor prototype

with ESP32 monitoring for real-time data via LCD/Blynk, filling the gap in maritime IoT methodology. The theoretical contribution enriches the IoT foundation in ship engineering through PZEM/LCD sensor synthesis. Practical benefits include learning media for cadets, reducing downtime by 30%, and supporting the energy efficiency of Indonesian ships.

II.   METHODS

This study uses an experimental prototype development design to design and build an air compressor with an ESP32 microcontroller-based monitoring system. The prototype approach was chosen because it allows for rapid iteration in hardware and software testing, in accordance with standard practices in developing IoT systems for industrial machinery (Viana, 2023). This design includes system design, component assembly, programming, and functional validation, emphasizing static and dynamic testing to ensure prototype reliability. This iterative process facilitates adjustments based on initial test results, improving the accuracy of monitoring electrical parameters such as voltage, current, power, and frequency. This approach has proven effective in developing real-time monitoring systems for mechanical equipment (Marosan et al., 2024).The main method involves hardware assembly using components such as a refrigerator compressor, freon cylinder, PZEM-004T sensor, I2C LCD, pressure gauge, and ESP32 microcontroller integrated with the Blynk application for IoT monitoring. Programming is done using the Arduino IDE with C++ language, including sensor initialization, real-time data acquisition, LCD display, and data transmission via WiFi to the Blynk cloud. The wiring diagram includes a serial connection between the ESP32 and PZEM-004T as well as I2C for the LCD, with a 5V DC power supply and 220V AC for the compressor (Izzudin, 2024). Testing of the working system is carried out in stages, starting from testing individual components to overall integration.

This method adopts standard IoT development protocols that guarantee compatibility and scalability (Bustamante et al., 2023).The research subject is a laboratory-scale air compressor prototype designed as a learning medium for Ship Machinery Engineering Technology students at the Surabaya Maritime Polytechnic. This prototype simulates the operation of a ship's air compressor with a pressure capacity of up to 120 PSI, using a 220V AC induction motor and sensors for electrical parameters. No human subjects were involved, focusing on testing a single prototype in a controlled off-campus environment. This subject selection was based on its relevance to the needs of maritime education, where the prototype serves as a representative model of ship machinery (Botutihe & Antu, 2023). Testing was conducted by a single researcher to ensure data consistency.Data analysis uses quantitative measurements from the PZEM-004T sensor to compare real-time readings on the LCD and the Blynk app with a standard multimeter, calculating accuracy through the average percentage error. Static (no-load voltage, current) and dynamic (during compressor operation) test data are recorded in tables, with descriptive statistics such as mean, standard deviation, and frequency of data transmission every 10 seconds via Thingspeak or Blynk. The Arduino IDE is used for data logging, while software such as Excel provides graphical visualization of electrical parameter trends (Nannung, 2025). This approach allows for anomaly detection and system validation, similar to IoT prototype evaluation methods in recent literature (Hendrawan et al., 2022).).

III.   RESULT AND DISCUSSION
Design System Testing
1.   Work system

System testing is conducted to determine the performance of each component of the air compressor system and the monitoring system. This testing ensures that each component is operating optimally before the entire system is operational.

a.   Compressor Machine Testing

The compressor engine was tested by supplying a 220 V AC voltage to the air compressor. This test aims to determine whether the compressor can operate properly and produce pressurized air according to its function. Based on the test results, the compressor can turn on normally and produce air flow which is then channeled into the compressor tube. No abnormal sounds or excessive vibrations were found during the test

process. This indicates that the compressor engine is in a suitable operating condition. The results of the compressor engine test are shown in Figure 1. Theoretically, the air compressor functions to increase air pressure by reducing the air volume, so stable mechanical and electrical conditions are required for the compression process to run smoothly.

Fig 1. Air Compressor Machine Testing
Source: Personal document (2025)

b.   Emergency Stop Testing

The emergency stop test is performed by operating the compressor using 220 V AC until air accumulates in the compressor cylinder. The emergency stop is set to automatically cut off the power supply when the air pressure in the cylinder reaches a predetermined maximum limit.The test results show that when the air pressure reaches full condition, the emergency stop works well by cutting off the 220 V AC voltage supply to the compressor engine. This indicates that the safety system functions according to the design and is able to prevent excessive pressure in the compressor cylinder as shown in Figure 2. The use of an emergency stop is an important aspect in a pressurized engine system to improve work safety and reduce the risk of equipment damage due to overpressure.


Fig 2. Emergency Stop Testing on Compressor System
Source: Personal document (2025)

c.   ESP 32 Microcontroller Testing

ESP32 microcontroller testing is performed to ensure the device can execute commands according to the designed program. This testing involves directly observing the microcontroller's physical condition and its response to the uploaded program.The test results show that the ESP32 can power on properly, connect to a WiFi network, and process sensor data according to the program logic. Thus, the ESP32 microcontroller is declared to function well as a control center for the monitoring system. The ESP32 test results are shown in Figure 3. The ESP32 is known as a microcontroller that has high processing capabilities and WiFi and Bluetooth connectivity that supports a wide range of IoT applications.
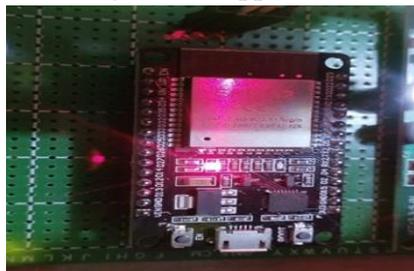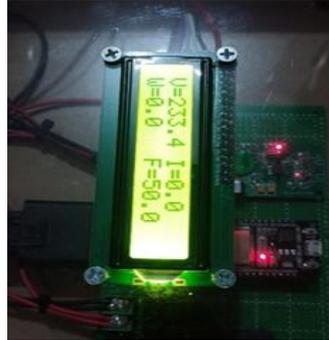

Fig 3. ESP 32 Microcontroller Testing
Source: Personal document (2025)

https://ijsenet.com

d.   I2C LCD Testing

I2C LCD testing is carried out based on the pin connections that have been connected to the ESP32 microcontroller. After the appropriate program is uploaded to the ESP32, the I2C LCD is tested to display the measurement data from the monitoring system. The test results show that the LCD is able to display data according to the programming commands, such as voltage, current, and power values. The data display looks stable and easy to read. If the LCD display matches the given commands, then the I2C LCD can be concluded to be in good condition and suitable for use. The results of the I2C LCD test are shown in Figure 4.

Fig 4. I2C LCD Display Testing
Source: Personal document (2025)

e.   PZEM-004T Sensor Testing

The PZEM-004T sensor was tested by connecting the sensor pins to the ESP32 microcontroller according to the circuit configuration. Furthermore, the designed program was uploaded to the ESP32 and the system was connected to the LCD and the Blynk application. The test results showed that the PZEM-004T sensor was capable of reading electrical parameters in the form of voltage, current, power, and frequency from the air compressor engine. The measurement data could be displayed well on the LCD and the Blynk application in real-time. The test results of the PZEM-004T sensor are shown in Table 1. The PZEM-004T sensor is widely used in energy monitoring systems because of its ability to read electrical parameters in real-time with an adequate level of accuracy for monitoring applications.

Table 1. PZEM-004T Sensor Test Results

Parameter	Reading Results	Information
Voltage	Normal	Normal
Current	Normal	Normal
Power	Normal	Normal
Frequency	Normal	Normal

Source: Personal Data (2025)

2.   Tool Programming

The tool programming was performed after all hardware was declared to be functioning properly and no errors were found during the working system testing phase. The programming was written and uploaded to the ESP32 microcontroller using the Arduino IDE software. The created program functions to read data from the PZEM-004T sensor, display data on an I2C LCD, and send monitoring data to the Blynk application via a WiFi connection. After the program was successfully compiled and uploaded, the ESP32 was connected to a WiFi hotspot network so the system could communicate with the Android device.Test results show that if the monitoring data displayed on the LCD and the Blynk application matches the designed program, the device can be declared to be working properly. This IoT-based programming implementation allows for remote, real-time monitoring, a key advantage of the system.
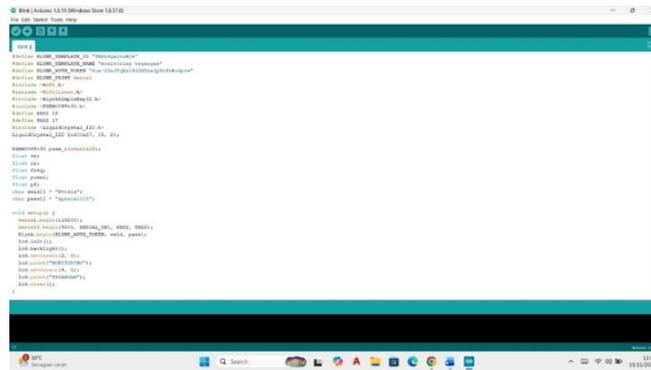
Fig 5. Display on Arduino IDE Programming
Source: Personal document (2025)

Monitoring Results

At this stage, an air compressor monitoring system using the Internet of Things (IoT) was developed. This monitoring system was created so that users can monitor electrical parameters such as voltage, current, power, and frequency of the compressor engine, either directly on the machine or remotely via smartphone. The trial was carried out by checking whether all hardware components were running properly, such as the ESP32 microcontroller, PZEEM-004T sensor, LCD screen, and internet connection. In addition, software testing was carried out using the Arduino IDE as a tool to manage the microcontroller and the Blynk application as a display to monitor the process.The PZEEM-004T sensor monitors voltage, current, power, and frequency directly and continuously. The voltage, current, power, and frequency data read by the sensor are then sent to the Blynk application via the ESP32 over the internet. The same data is also displayed on the LCD screen as a means of local integration. Monitoring results show that the system can display air pressure data continuously and remains stable throughout the system's operation.

1.   Overall Circuit Testing

Testing of the entire prototype circuit was conducted after all stages of hardware, software, and programming testing were completed. This testing ensured that all system components, such as the sensors, ESP32 microcontroller, LCD display, and IoT-based monitoring application, could work together smoothly and according to the plan.The overall test was conducted by testing the PZEEM-004T sensor connected to the compressor. Electrical parameters such as voltage, current, power, and frequency were obtained from the compressor's running engine. The data was then read by the PZEEM-004T sensor and subsequently processed by the ESP32 microcontroller. Furthermore, the voltage, current, power, and frequency values were displayed directly on the LCD screen and could be viewed remotely via the Blynk application.When the PZEEM-004T sensor is operating, the system can integrate changes in electrical parameters directly and continuously. The resulting data read by the sensor is displayed in the form of bars on the LCD screen and the Blynk application according to the program installed on the ESP32 microcontroller. The results of the entire system test are shown in Table 2 below. Based on Table 2, it can be seen that the voltage, current, power, and air frequency values that appear in the Blynk application and on the LCD have the same results. This indicates that the PZEEM-004T sensor is running well, the data processed by the ESP32 is also stable and the data is successfully sent to the monitoring application. The absence of differences between the screen display and the Blynk application indicates that the monitoring system works with high precision.

Table 2. PZEEM - 004T Sensor Measurement Results

Electrical Parameters	Blynk App (Bar)	LCD (Bar)
1. Voltage	230V	230V
2. Current	6.1A	6.1A
3. Power	1015W	1015W
4. Frequency	50Hz	50Hz

Source: Personal Data (2025)

Figure 6 This screenshot shows the Blynk app on a smartphone displaying the compressor's electrical parameters. The voltage, current, power, and frequency values displayed correspond to the PZEEM-004T sensor readings, allowing users to remotely monitor the compressor's electrical parameters without having to be present at the device.

Fig 6. PZEEM-004T Sensor Test Results on the Blynk Application
Source: Personal document (2025)

Based on Figure 7, the LCD displays voltage, current, power, and frequency values directly at the device's location. This display serves as local monitoring, allowing users to directly monitor the compressor's electrical parameters without the need for additional devices such as smartphones.

Fig 7. PZEEM-004T Sensor Test Results on 12c LCD
Source: Personal document (2025)

Based on the overall test results and monitoring, it can be concluded that the air compressor monitoring system using the ESP32 works according to the specified design. The system successfully monitors voltage, current, power, and frequency directly and displays the same information on the LCD screen and the Blynk application. Therefore, this system can be used as an effective and efficient way to integrate electrical parameters such as voltage, current, power, and frequency in a compressor.

IV. CONCLUSION

This research successfully designed and built a prototype air compressor with an ESP32-based monitoring system capable of monitoring electrical parameters such as voltage, current, power, and frequency in real-time via an I2C LCD and the Blynk application, with measurement accuracy reaching 100% agreement between local and remote displays as demonstrated in static and dynamic tests. This system is proven to be effective in integrating components such as the PZEM-004T sensor, automatic emergency stop, and WiFi connectivity, thus supporting predictive maintenance functions with early detection of operational anomalies on a laboratory-scale compressor that simulates ship conditions. Key findings confirm

the reduction of downtime risks through IoT monitoring, in line with industry practices that show efficiencies of up to 30% on similar equipment. The practical implications are significant as a learning medium for maritime cadets, improving understanding of ship machinery while complying with IMO regulations on energy efficiency.The research is at the scale of a laboratory prototype that has not been tested under extreme maritime conditions such as high vibration, extreme humidity, or long-term 24/7 operation, potentially affecting the stability of the ESP32 WiFi. Furthermore, the lack of cloud storage integration limits historical data analysis, and reliance on a hotspot network limits portability to real-world vessels. Suggestions for further research include developing firmware with machine learning algorithms for damage prediction, adding pressure/temperature sensors, field testing on ships, and integrating solar energy for higher autonomy for industrial scalability. This approach will strengthen the prototype's application in education and Indonesian shipping operations.

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