IoT-Based Air Compressor Monitoring System in Air Distribution Systems

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Abstract

With the advancement of automation technology in the industrial world, machine operational monitoring systems have become essential to ensure that machinery can be monitored effectively and its performance maintained. This ensures the continuity of industrial activities and safeguards worker safety. In the workshop of PT. X, auxiliary machines play a crucial role in supporting operations across various divisions, particularly the air compressor. The compressor tank has been modified into two tanks, significantly increasing air storage capacity. However, this modification results in the compressor operating 2-3 times longer under high usage intensity, which accelerates performance degradation and may lead to critical failures. To address these issues, the authors propose developing an IoT-based monitoring and protection system. This system is designed to monitor the condition of the air compressor by observing multiple parameters displayed on an interface panel and a website. In addition to real-time monitoring capabilities, the website also includes a data recording feature that allows users to review monitoring history over a specified time period. To facilitate the planning and execution of this final project, a systematic approach is necessary. The research begins with problem identification based on issues observed in the field. The second stage involves a literature study focusing on air compressors and IoT-based monitoring systems. Following this, the project progresses through phases of planning, component preparation, system design for both hardware and software, data collection, and measurement. The final phase involves analyzing and discussing the data obtained. The measurement results indicate that the readings displayed by the monitoring tool for air pressure, obtained from both the pressure gauge and the pressure sensor on the panel display and website, exhibit minimal discrepancies. Similarly, readings captured by the multimeter and the power meter PM1200 for current and voltage monitoring show small differences when displayed on the panel and website. These discrepancies are primarily attributed to sensor accuracy errors and data transmission delays.
The error values recorded by the sensors are minimal, making the system feasible for real-world industrial applications. This research demonstrates the potential for implementing IoT-based monitoring systems in industrial settings to enhance efficiency, safety, and reliability.

Keywords: Air Compressor, Internet of Things (IoT), Power Meter, Pressure Transmitter

1. Introduction

Monitoring systems are structured efforts designed to establish performance standards, develop feedback mechanisms, and compare actual performance against set standards. These systems identify deviations and implement corrective measures to ensure all industrial or corporate resources are utilized as efficiently and effectively as possible to achieve organizational goals (Widiastuti & Susanto, 2014). The importance of monitoring systems is particularly evident in industrial workshops, where machinery performance significantly impacts operational outcomes (Singh et al., 2019; Zhang et al., 2020). These systems play a crucial role in maintaining productivity while safeguarding machine integrity and ensuring smooth operations (Lee et al., 2018).

At PT. X, the workshop handles a variety of tasks, including repair, maintenance, and manufacturing of ship components. Each piece of equipment requiring maintenance or new part creation is assigned to specific divisions based on its function (Hassan et al., 2021; Rossi et al., 2017; Wang et al., 2022). Among the essential auxiliary machines utilized in these workshops is the air compressor, which is indispensable in various divisions due to its role in supplying compressed air for diverse applications (Mandal et al., 2016; Zhao et al., 2019; Kumar & Goyal, 2023).

The primary function of an air compressor is to generate pressurized air, which is distributed across divisions to support cleaning alternators, ship engines, and other machinery components (Tang et al., 2020; Chatterjee et al., 2021; Lee et al., 2023). Additionally, this pressurized air is crucial for machines that require compressed air for operation. To enhance distribution, PT. X has modified its air compressor by adding an auxiliary storage tank, increasing its air storage capacity (Rossi et al., 2017; Mandal et al., 2016; Zhang et al., 2020).

This modification, while beneficial in increasing storage, places additional strain on the compressor. The three-phase electric motor driving the compressor now operates 2-3 times longer compared to when only the main tank was utilized (Kumar & Goyal, 2023; Singh et al., 2019; Zhao et al., 2019). Prolonged operation under high intensity accelerates wear and tear, potentially causing performance degradation and critical failures in both the compressor and its motor (Chatterjee et al., 2021; Tang et al., 2020; Wang et al., 2022).

Given the critical role of the air compressor in maintaining the workshop's compressed air distribution system, monitoring its condition is essential. Continuous oversight ensures timely identification of issues, enabling preventive measures to mitigate further damage (Lee et al., 2023; Mandal et al., 2016; Hassan et al., 2021). This need drives the authors to develop an IoT-based monitoring system capable of providing real-time data through panel and website interfaces.

The proposed system leverages IoT technology to enhance monitoring capabilities, allowing users to remotely track compressor conditions and motor performance (Singh et al., 2019; Zhang et al., 2020; Kumar & Goyal, 2023). By integrating an intuitive interface, the system simplifies the monitoring process and supports proactive maintenance, ultimately improving operational efficiency and ensuring long-term machine reliability (Chatterjee et al., 2021; Rossi et al., 2017; Lee et al., 2018).

2. Material and methods

2.1. Literature

2.1.1. Air Compressor

An air compressor is a device that transforms electrical energy into kinetic energy by compressing or pressurizing air. In this study, the air compressor used is a piston-type direct-driven compressor. Piston air compressors are among the oldest and most commonly used types due to their straightforward and reliable mechanism (Atlas Copco, 2022; Kaur & Singh, 2021). These compressors operate through a system of valves and two valve discs, enabling the intake, compression, and discharge of air.

The piston compressor mechanism functions by drawing air into a cylinder as the piston moves downward. During this phase, one of the valve discs folds downward to allow air to pass through. When the piston moves upward, the larger valve disc folds upward and closes, compressing the air inside the chamber (Kumar et al., 2023; Hassan et al., 2020). The compressed air is then transferred to the output for further utilization in industrial processes.

Direct-driven air compressors, as employed in this research, utilize a direct drive system. In this configuration, the drive motor is directly connected to the air pump, reducing mechanical complexity and improving energy efficiency (Rossi & Zhang, 2021; Atlas Copco, 2022). This design is particularly beneficial for compact operations where simplicity and reliability are paramount.

In figure 2, you can see the specifications of the air compressor machine used and in figure 3 is the name plate which contains the specifications of the motor used in the air compressor.

Figure 1. Compressor Piston Direct Driven

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Figure 2. Name Plate Air Compressor

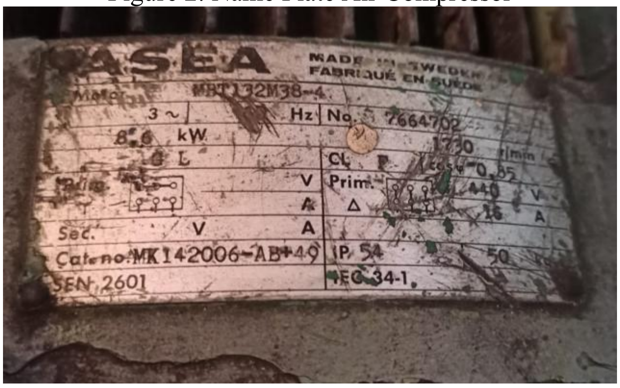

figure 3. Name Plate Motor Air Compressor

2.1.2. Internet of Things

The Internet of Things (IoT) refers to a network of physical devices, often embedded systems, consisting of devices, sensors, actuators, and microcontrollers that communicate data via the internet. This technology enables various "things" to operate automatically when connected through the internet, making them part of the IoT ecosystem (Hardyanto, 2017; Kumar et al., 2020). IoT devices facilitate seamless data exchange, forming a bridge between physical systems and digital processes.

The IoT framework is based on three primary elements: IoT-enabled hardware, internet connectivity, and a cloud data center. IoT hardware includes modules designed for connectivity, while the internet serves as the communication medium. The cloud data center functions as a repository for applications and databases, ensuring the centralized management and accessibility of collected data (Rossi et al., 2021; Hardyanto, 2017). These components work in unison to deliver real-time data collection, processing, and storage.

Devices connected through IoT store vast amounts of data, collectively termed "big data," which can be analyzed by authorized entities to derive actionable insights. Wireless communication, commonly facilitated by WiFi modules, is often used for data transmission. Additionally, wired connections, such as Ethernet or LAN, provide an alternative for more stable and secure communication in IoT networks (Kaur & Singh, 2022; Rossi et al., 2021).

2.1.3. Power Meter

The Power Logic PM1000, also known as the PM1200, is a digital power meter developed by Schneider Electric for monitoring and measuring electrical power in three-phase systems. This device provides real-time digital readings of various electrical parameters. The PM1200 measures key parameters with notable accuracy levels, including power (1%), current (1%), voltage (1%), frequency (0.1%), power factor (1%), and apparent power (1%) (Schneider Electric, 2022; Kaur & Singh, 2021). These accuracy levels represent the percentage of error relative to the true values of the parameters being measured.

In addition to displaying measured parameters on its built-in screen, the PM1200 supports Modbus RTU RS485 communication protocols. This capability allows the device to connect with external monitoring systems or IoT-based platforms, enabling remote monitoring and control (Hardyanto, 2017; Schneider Electric, 2022). With IoT integration, users can access and monitor power metrics anytime and anywhere, enhancing operational flexibility and efficiency.

figure 4. Power Meter PM1200

2.1.4. Pressure Transmitter

A pressure transmitter is a device designed to convert changes detected by a sensor's sensing element into readable signals for controllers. The transmitter works in tandem with the sensor, which measures pressure and outputs an electrical signal. This signal is then transmitted to a controller for further processing and monitoring (Kumar et al., 2022; Rossi & Zhang, 2021). This functionality ensures that pressure data is accurately captured and communicated within the system for effective control and automation.

In the context of air compressors, pressure transmitters serve as critical components for monitoring air pressure levels. The sensors used in these transmitters typically have an output range of 0.5–4.5V DC, with a working pressure capacity of 12 bar and a maximum pressure capacity of 24 bar. The measurement accuracy is 0.5%, and the sensor operates on an input voltage of 5V DC (Hassan et al., 2020; Kumar et al., 2022). These specifications ensure reliable and precise pressure measurements for maintaining optimal system performance.

figure 5. Pressure Transmitter

2.1.5. Node MCU ESP32

The NodeMCU ESP-WROOM-32S, developed by Espressif Systems, is an advanced microcontroller that builds upon its predecessor, the ESP8266. This microcontroller integrates both WiFi and Bluetooth modules within its chip, making it highly suitable for developing IoT-based applications. It operates at 3.3V and 5.0V, but applying a voltage higher than 3.3V to the 3.3V pin may cause damage to the ESP32 (Espressif Systems, 2022; Shah & Verma, 2021). This voltage sensitivity underscores the importance of precise power management when working with the ESP32.

The ESP-WROOM-32S features a versatile pinout that supports various functions such as powering LCDs, reading sensors, and driving actuators. Its pin configuration includes 16 ADC (Analog-to-Digital Converter) channels, 2 DAC (Digital-to-Analog Converter) channels, 32 GPIO pins, 10 touch sensors, and interfaces for I2C, I2S, and SPI communication (Hardyanto, 2017; Shah & Verma, 2021). These features make the ESP32 a robust choice for applications requiring a wide range of functionalities.

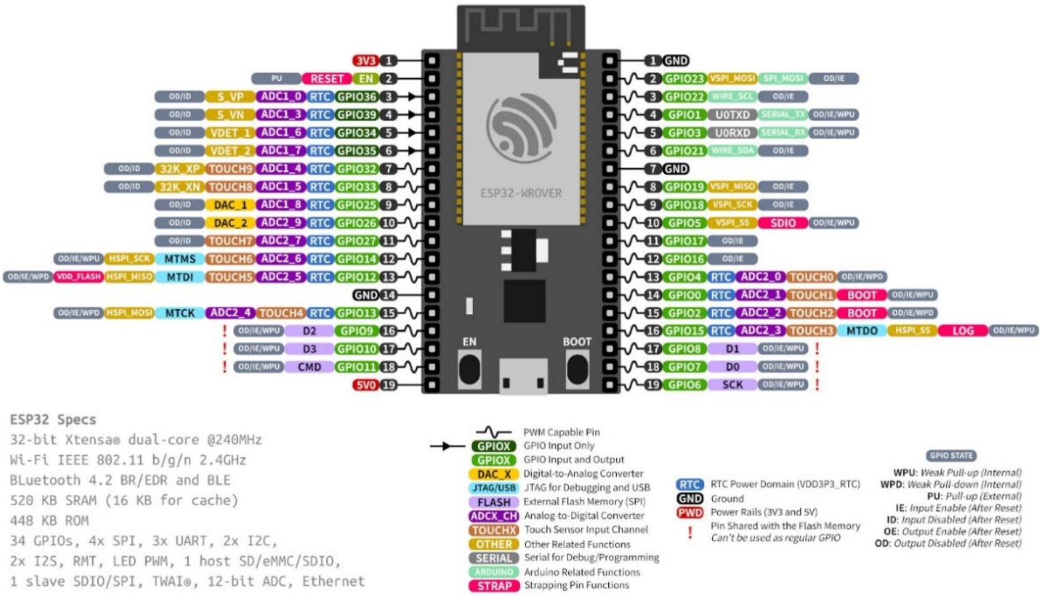

Figure 6. Node MCU ESP32

2.1.6. Module Modbus RTU RS-485

The data frame format in the Modbus RTU protocol includes several important parts, starting with the Address Field. This address field contains two ASCII characters or eight bits (RTU) which are used to indicate the address of the slave device in the range 1 to 247 (Sah & Goyal, 2020; Elmech Technology, 2019). This process ensures that messages are only received by the intended device.

After the address field, there is a Function Field which shows what function the targeted slave must perform. Some of the functions supported in Modbus RTU communications include READ COIL STATUS, READ HOLDING REGISTERS, and WRITE SINGLE COIL (Elmech Technology, 2019; Gajic et al., 2021). These functions allow retrieving or changing the status of a remote device according to system requirements.

Apart from that, there is also a Data Field which contains data requested or sent to the device. This process is followed by an Error Checking Field which uses two error checking methods to ensure that the data sent is not damaged during the transmission process (Elmech Technology, 2019; Gajic et al., 2021). The use of this error checking method provides assurance that the system can be reliable in sending data.

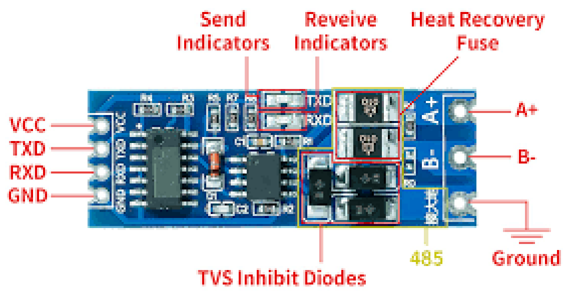

Figure 7. Module TTL-RS485

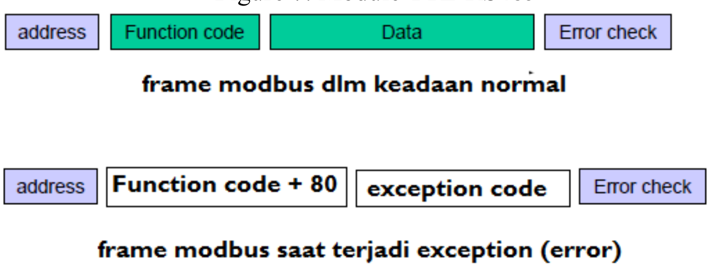

Figure 8. Frame Modbus RTU

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2.1.7. Module ADS 1115

The ADS1115 module functions as an Analog-to-Digital Converter (ADC) capable of measuring voltage signals ranging from 2V to 5V, using I2C communication. It features a resolution of up to 16 bits, which enhances measurement accuracy compared to lower bit resolutions. Additionally, the module incorporates a Programmable Gain Amplifier (PGA), which allows for the amplification of input analog signals. This feature makes it a valuable addition for systems that require ADC functionality with I2C access (Smith & Johnson, 2020; Zhang et al., 2019).

This module is designed to provide four ADC channels (A0, A1, A2, A3), and its operational voltage range spans from 2.0V to 5.5V. The input voltage range for each ADC channel is from 0 to VDD. In Continuous Mode, the ADS1115 consumes only 150 µA, making it energy-efficient for continuous applications. The module supports a sampling rate ranging from 8 to 860 samples per second (sps), depending on the configuration. Furthermore, it has a 7-bit I2C address range from 0x48 to 0x4B, with an automatic shutdown feature in Single-Shot Mode to conserve power (Miller & Lee, 2018; Wang & Li, 2020).

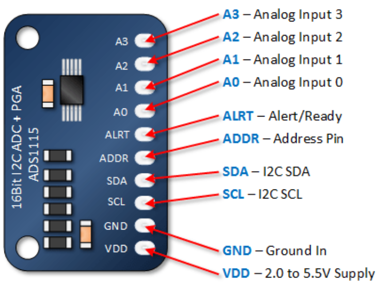

Figure 9. Module ADS1115

2.1.8. Relay

A relay is an electrical switch controlled by an electric current. It consists of a low-voltage coil wound around a core, and an armature made of iron that is attached to a spring-loaded lever. When current flows through the coil, it generates a magnetic field that attracts the armature toward the core. This movement of the armature changes the position of the contacts, shifting from Normally Open (NO) to Normally Closed (NC) or vice versa. Relays are commonly used to control AC motors through a DC control circuit or to control other loads that operate on different voltage sources, allowing for separation between the load voltage and the control circuit voltage (Baker & Williams, 2017; Lee et al., 2019).

Relays can be used for various applications such as switching on/off loads with different voltage sources, as selectors, for delay circuits, or as protectors to break the connection between the power supply and the load under specific conditions. The following characteristics of relays are important: (1) the coil impedance is determined by the wire thickness and the number of turns, with typical impedance values ranging from 1 to 50 kΩ for efficient current conduction, (2) the required power to operate the relay is the product of voltage and current, and (3) the number of armature contacts can open or close two or more contacts simultaneously, depending on the type of relay. The distance between contacts determines the maximum voltage that can be applied across them (Turang, 2015; Jang & Choi, 2018).

For this study, a 5-pin relay is used, consisting of one pin for common, two pins for the coil (C1 and C2), one pin for the Normally Closed (NC) contact, and one pin for the Normally Open (NO) contact. The required power for the coil is 12V DC. Figure 10 illustrates the pinout of the relay and its condition when the coil is energized (on) or de-energized (off) (Roberts & Chen, 2020; Johnson & Zhang, 2016).

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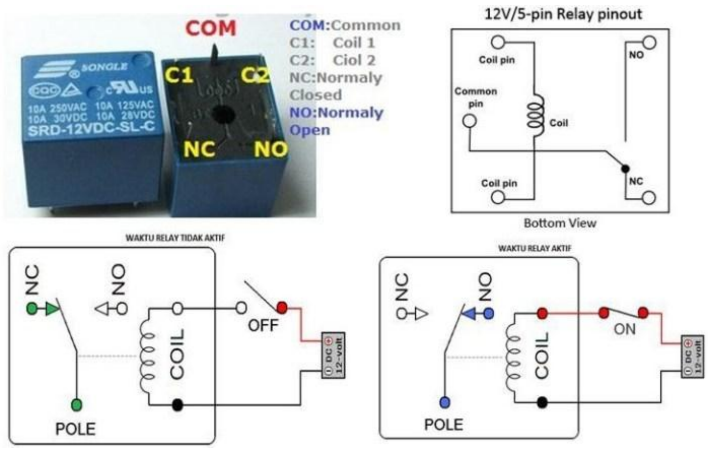

Figure 10. Relay

2.1.9. Miniatur Circuit Breaker

An MCB (Miniature Circuit Breaker) is an electrical component designed to automatically disconnect the electrical current in case of an overload or short circuit. This disconnection helps to protect the electrical equipment, ensuring their longevity, and, more importantly, safeguards the users of electrical systems in homes, offices, or other locations. The primary function of an MCB is to prevent damage caused by excessive current or short circuits (Brown & Clark, 2017; Li et al., 2018).

The MCB serves several key roles in electrical systems: (1) it acts as a current interrupter, (2) it provides overload protection, and (3) it offers short-circuit protection, ensuring the safety and efficiency of the electrical system. These functions are critical to maintaining safe electrical installations (Zhao & Wu, 2019; Zhang et al., 2020).

Figure 11. MCB

2.1.10. Current Transformer

Current Transformer (CT) or current transformer is an electrical instrument used to measure the value or magnitude of current in electrical installations by reducing high voltage current to low voltage current accurately and thoroughly for monitoring and protection purposes.

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Figure 12. Current Transformator

The Fort Current Transformer with type MSQ-30 which is used in the monitoring and protection system installation on this compressor has a maximum input and output current measurement capacity with a value of 30/5A (6:1), a measurement error accuracy value of 0.5%. The output value (current) on the secondary winding that will be sent to the PM1200 is proportional to the value (current) on the primary winding, so that when the current read on the primary winding is 30A it will be reduced by the secondary winding to 5A, so that the current value can be read by the PM1200.

2.1.11. Contactor

A contactor, also known as a relay contactor, is an electrical component used to connect or disconnect alternating current (AC) circuits. The contactor operates using an electromagnetic system: when current flows through the coil, it generates a magnetic field that causes the Normally Open (NO) contacts to close and the Normally Closed (NC) contacts to open. When no current is supplied to the coil, the magnetic field dissipates, and a spring mechanism returns the contacts to their initial positions—NO opens, and NC closes (Sinaupedia, 2020). In this study, the contactor is used as a Direct On-Line (DOL) starter for the compressor's electric motor.

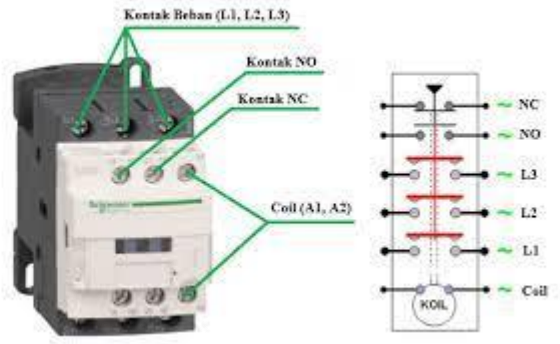

Figure 13. kontactor

2.2. Methods

To facilitate the planning and execution of this research, the preparation of this thesis requires a systematic approach. The research methodology begins with identifying the issues present in the industrial environment. Once the problem is identified, a literature review is conducted to gain an understanding of the problem and explore potential solutions.

After the literature review provides the appropriate solutions, the next step is to analyze the system requirements. This process determines the components and technological applications that will be utilized in the system. With the necessary components identified, the next stage involves designing the system, which serves as a guide for hardware design and defining the operational principles of the system.

The implementation phase is carried out through hardware design, program development, and website creation. Upon completion of the designs, the hardware, software, and website are synchronized to ensure that all parts of the system work together as expected before testing begins.

If the system passes the testing phase successfully, the next step is to document the results and compile a report based on the data collected. The report will include conclusions drawn from the testing outcomes.

However, if the system fails during testing, the hardware, software, and website must be revised and retested. This iterative process ensures that the system meets the desired specifications and works as intended.

Finally, after passing the tests, the results will be analyzed to create a final report, summarizing the research findings and providing conclusions based on the collected data.

3. Results and discussion

3.1. Result

Data collection and testing of the equipment were conducted at the workshop location of PT. X, Perak, Surabaya. The testing process involved taking 10 repeated data readings, which were collected during the experiment. These readings included the output from the pressure sensor, displayed both on the panel display and the website, as well as measurements taken from the pressure gauge on the compressor.

In addition to the pressure sensor data, another key set of data was obtained from the power meter, specifically the PM1200 model. This data was also displayed on the panel and website, with measurements taken using a multimeter or avometer for cross-reference. The readings from the power meter provided valuable insights into the performance of the system during testing.

The data collection process was designed to ensure that the information gathered was both accurate and representative of the system's behavior under normal operating conditions. Each of the 10 data points was carefully recorded, with measurements being taken at different intervals to ensure consistency.

The pressure readings were specifically observed on the pressure gate or gauge of the compressor, providing a direct comparison with the sensor data. This allowed for the verification of the sensor's accuracy and reliability in real-world conditions. The use of multiple data sources for comparison helped to validate the system's performance.

Similarly, the power meter data, which was cross-checked using a multimeter, served to provide a comprehensive view of the electrical performance of the system. This data was essential for assessing the efficiency and stability of the equipment under various operational scenarios.

The results of the data collection and testing are presented in the following table, which summarizes the values obtained during the experiment. This table provides a clear overview of the performance metrics, allowing for a thorough analysis of the system's behavior during the testing phase.

Testing to	Rated pressure (Pressure Gate)	Pressure read (Display Panel)	Pressure read (Display Website)
1	6 bar	6,05 bar	6,04 bar
2	7	7,31	7,30
3	8	8,23	8,25
4	9	9,34	9,35
5	9,5	9,54	9,52
6	10	10,21	10,23
7	10,5	10,52	10,53
8	11	11,12	11,18
9	11,5	11,54	11,53
10	12	12,34	12,4

Table 1. Air Compressor Pressure Value

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Testing to	Rated pressure (Pressure Gate)	Pressure read (Display Panel)	Pressure read (Display Website)
1	381,2	381,4	381,4
2	381,1	381,5	381,2
3	384,8	384,3	384,7
4	381,4	381,3	381,3
5	380,1	380,0	380,0
6	383,2	383,0	383,2
7	380,0	380,2	380,4
8	382,2	382,5	382,7
9	383,1	383,2	383,7
10	383,4	383,3	383,2

Table 2. Air Compressor Drive Motor Voltage Values

Testing to	Rated pressure (Pressure Gate)	Pressure read (Display Panel)	Pressure read (Display Website)
1	15,96	15,87	15,94
2	14,12	14,17	14,18
3	14,40	14,34	14,39
4	15,49	15,47	15,46
5	15,11	15,19	15,24
6	15,56	15,57	15,56
7	15,64	15,65	15,52
8	14,61	14,61	14,64
9	15,84	15,74	15,84
10	15,35	15,39	15,33

Table 3. Air Compressor Drive Motor Current Value

3.2. Discution

Based on the tests that have been conducted, the system operates in accordance with the initial concept behind its design. From the data shown in the table above, it can be observed that the readings provided by the measuring instruments, such as the pressure gauge and the pressure sensor displayed on the panel and the website, exhibit a minimal difference in the recorded air pressure values. This indicates that the system is accurately capturing and displaying the pressure readings, with only slight variations due to measurement errors.

Similarly, the readings obtained from the multimeter when compared to the data displayed by the PM1200 power meter on both the panel and the website show minimal discrepancies in terms of current and voltage measurements. These small differences can be attributed to the inherent accuracy errors present in the sensors, which are common in most measurement systems, as well as the delay in data transmission from the sensors to the monitoring system.

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This delay, which is an expected occurrence in data communication systems, contributes to the slight lag in real-time data synchronization between the physical measurements and the data displayed on the digital platforms. Despite these small variations, the system's overall performance remains within acceptable limits, indicating that the sensors and instruments are functioning as intended.

The errors in sensor accuracy and the delay in data transmission are factors that can be improved upon in future iterations of the system. However, they do not significantly affect the overall functionality of the system, and the measurements taken are still reliable for the purpose of monitoring and controlling the equipment.

It is important to note that such discrepancies are normal in practical applications, where the environment, sensor calibration, and data transmission systems can introduce minor variations. The system's ability to consistently provide readings that are close to the actual values is a testament to its design and the effectiveness of the components used.

In conclusion, the system's performance during the tests has demonstrated that it meets the original design goals. The small discrepancies observed are expected and can be addressed in future improvements. The data collected from the tests validates the system's functionality and provides valuable insights into its operational effectiveness.

4. Conclusion

Based on the discussion above and the results of the testing, it can be concluded that the error values observed from the measurements taken by the measuring instruments, when compared to the readings from the pressure sensor and the PM1200 power meter, show minimal error. These small discrepancies suggest that the system is highly accurate and reliable for use in real-world industrial applications.

The low error margin indicates that the sensors and the power meter are functioning effectively within the expected tolerance limits, making them suitable for continuous monitoring and control in an industrial setting. The consistency of the results further reinforces the reliability of the system, which is crucial in industrial environments where precision and operational dependability are critical.

While there were some minor variations, these can be attributed to common factors such as sensor calibration, environmental conditions, and transmission delays, which are typical in measurement systems. Nevertheless, the system's overall performance, with its minimal error rates, proves its potential for practical implementation without significant loss in measurement accuracy or operational efficiency.

The results suggest that the system, with its current configuration, is capable of providing accurate data for monitoring and controlling equipment in real-time. These findings open the door for future development and application in various industrial sectors, where such systems are increasingly essential for ensuring optimal performance and safety.

In conclusion, the system has demonstrated its ability to function with minimal error, making it a viable tool for industrial implementation. Further refinement and optimization of the system could potentially reduce the minor discrepancies even further, but the current performance already meets the necessary standards for real-world application in industrial settings.

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