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Research Article

IoT based Oxygen Availability Monitoring and Automatic Control System for Clinical Patients

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Abstract: Oxygen is essential for human survival, comprising 2% of total body weight yet the brain consumes approximately 20% of the body's oxygen. Oxygen deficiency in the brain causes hypoxia, potentially leading to irreversible damage, liver dysfunction, and even fatality. Ensuring stable oxygen delivery in healthcare facilities requires an efficient centralized oxygen system. According to Indonesia's Ministry of Health Regulation No. 4 of 2016, centralized systems must maintain an output pressure of 4-5 bar. This study addresses the challenge of ensuring uninterrupted oxygen supply by developing an automatic supply-switching system. Utilizing programmable logic controller (PLC) Outseal control and IoT-based monitoring, the system detects cylinder pressure levels, switches supply to cylinders with pressure > 4 bar, and provides real-time data on pressure, flow, and cylinder status via human machine interface (HMI) and the Haiwell Cloud smartphone application. Rigorous testing demonstrated high precision, with error rates of 0.18% for Pressure Sensor A, 0.079% for Pressure Sensor B, and 0.89% for the flow sensor. This innovation enhances reliability and safety in medical oxygen systems.

Keywords: Human Machine Interface, Internet of Things, Automatic, PLC Outseal, Hypoxia.

1. INTRODUCTION

Oxygen is vital for human survival, constituting 2% of body weight but sustaining critical organs, particularly the brain, which consumes 20% of the body's oxygen. Hall and Hall [1] found that hypoxia—oxygen deprivation—can cause irreversible brain damage, neurological disorders, or death within minutes. Healthcare facilities, including hospitals and school health units, play a crucial role in ensuring oxygen availability for emergencies, particularly respiratory conditions. In schools, sudden incidents, such as shortness of breath during physical activities, demand immediate access to oxygen. However, many health units rely on single-cylinder systems, posing risks during simultaneous emergencies due to supply limitations. A survey at Ponorogo Muslimat Hospital and SMKN 1 Jenangan's health unit identified significant differences in oxygen supply management. Hospitals use centralized oxygen systems with backup cylinders, while schools depend on single-cylinder approaches. In centralized systems, oxygen supply switches manually to a backup cylinder upon depletion, triggered by an alarm. Although effective, manual switching introduces risks, including delays and operator errors. Mulyanto *et al.* [2] referred to the Indonesian Ministry of Health Regulation No. 4 of 2016 mandates that centralized oxygen systems maintain a minimum pressure of 4-5 bar, incorporating pipelines, shut-off valves, and medical gas alarms. Compliance with these standards in resource-constrained settings like schools remains a challenge. The IoT offers transformative potential by enabling real-time communication between devices, sensors, and users. Yudhanto and Aziz [3] investigated IoT systems improve monitoring and control by providing continuous access to system data, facilitating proactive interventions and decision-making. This study addresses the challenge of reliable oxygen supply by developing

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an automatic control and monitoring system for oxygen supply in clinical settings based on internet of things (IoT). Utilizing a solenoid valve and programmable logic controller (PLC) out-seal, the system automates cylinder switching based on pressure sensor data. Integrated with a human machine interface (HMI) and cloud platform, it provides real-time monitoring and alerts via smartphones [4, 5]. By leveraging IoT, this solution minimizes manual intervention, ensures consistent oxygen availability, and enhances emergency preparedness, particularly in school health units.

2. MATERIALS AND METHODS

Numerous studies on the topic being discussed contribute to a more comprehensive understanding and offer insights into the background and main aspects being examined [6]. The study by Hendryani *et al.* [7] focused on monitoring oxygen cylinder pressure. The system successfully detected pressure levels below the standard threshold and, upon detection, automatically switched the primary gas cylinder to the secondary one. The system was developed using the Atmega328 microcontroller. While this study demonstrated a basic pressure-monitoring and switching mechanism, it lacked advanced features such as integrated flow monitoring or remote accessibility. Another study by Haryanto [8] employed the MPX 5700 sensor to detect medical gas pressure. An alarm was triggered when the pressure dropped below 150 kPa. Additionally, when the oxygen pressure in the main cylinder was depleted, the system automatically switched to a backup cylinder. The device interface, built using the Arduino WeMos D1 R1 WiFi UNO ESP8266 microcontroller, incorporated IoT-based monitoring via the telegram application. While the study effectively integrated internet of things (IoT), its scope was limited to pressure monitoring and lacked advanced control mechanisms. In a related work Nasrullah *et al.* [9] developed a system capable of real-time monitoring and displaying oxygen gas volume on a PC. A water flow sensor detected oxygen flow, while an ATMega32 microcontroller handled data processing and control. Although this study enabled central monitoring, it primarily focused on flow measurement without addressing automated switching or IoT integration. In the same way, Agustian *et el.* [10] has explored an IoT-enabled system for monitoring oxygen cylinder levels. The system used a Node MCU V3 microcontroller, with data displayed on a 2 × 16 LCD. When the system detected pressure levels below 10%, a buzzer was triggered, and the display alerted users about oxygen depletion. Data management and visualization were carried out using the IoT platform ThingSpeak; however, the system required extensive integration with HMI controls.

Although, previous studies have addressed oxygen cylinder pressure monitoring, automated switching, and partial IoT integration, a significant research gap remains in developing a unified system that combines these features with flow monitoring, advanced automation, and a user-friendly IoT-connected HMI interface. Current solutions focus on isolated aspects-pressure detection, IoT-based alerts, or flow measurement, but fail to provide a holistic approach for monitoring both pressure and flow simultaneously or enabling remote access and control through an integrated HMI. To address these gaps, the aims of the present research are:

- Integrate a pressure sensor for monitoring cylinder and automating valve switching between two cylinders.
- Incorporate a flow sensor to monitor the volume of distributed oxygen in real time.
- Develop a comprehensive HMI for seamless control and visualization of cylinder pressure and oxygen flow.
- Leverage IoT connectivity for remote monitoring and control via smartphones or computers, enhancing accessibility and operational efficiency.

In contrast to previous studies, our approach integrates pressure and flow monitoring within a unified system, incorporates PLC Outseal for enhanced control, and leverages IoT-enabled HMI for real-time visualization and remote accessibility. This combination provides a more comprehensive and reliable solution for oxygen monitoring. The system is designed under the assumption that merging flow and pressure monitoring with IoT and HMI technologies will improve both reliability and user interaction; this will eliminate the shortcomings of earlier models, which lacked such integration. The proposed design ensures continuous monitoring of critical parameters, including pressure thresholds and flow rates, while enabling automated responses to minimize the risk of oxygen depletion. IoT connectivity and HMI functionality further enable remote access and control, directly addressing existing limitations in hospital oxygen management systems. By addressing these gaps, our research seeks to make a substantial contribution to the field of medical gas monitoring systems. The following theories are presented as the foundation for conducting this research, with the aim of detailing conceptual framework and theoretical foundation that will guide development and implementation of this study [11].

The IoT offers innovative solutions to current challenges by integrating physical and virtual systems via advanced ICT [12]. Defined by Kevin Ashton in Making Sense of IoT, it connects sensors to the internet, enabling seamless data sharing and applications [13]. IoT allows devices to sense their environment and integrate into daily life. In healthcare, IoT connects medical devices for remote monitoring, reducing the need for physical visits and associated costs. Centralized monitoring systems enable real-time data tracking, improving patient care and reducing expenses, aligning with modern healthcare advancements and enhancing efficiency.

Programmable Logic Controller (PLC) is a digital device designed for industrial automation, managing inputs, processing data, and controlling outputs to operate machines efficiently. PLCs execute functions like logic, timing, and sequencing through programmable memory, offering reliability and flexibility in automation systems [14]. This study employs the Outseal Nano v5 PLC, an open-source automation solution developed by Indonesian engineers using Arduino-based technology. Its affordability and customizable hardware make it a practical choice for cost-sensitive applications [15]. The Outseal PLC is programmed using ladder diagrams via Outseal Studio, a visual platform with an intuitive interface in Indonesian language [16]. Once programming is transferred, the PLC operates autonomously without needing a continuous connection. Additionally, the Modbus protocol, a widely adopted standard for reliable data exchange, facilitates communication between the Outseal PLC and other devices, ensuring seamless integration in automated systems [17].

HMI connects users with machines, enabling intuitive system interaction. It provides real-time visualizations of operations, including sensor data, alarms, and graphical trends, ensuring effective supervision and control. Communication between HMI and controllers uses RS232, RS485, USB, or Ethernet ports [18]. Input data from sensors or actuators is processed by a PLC and visualized on HMI screens. In manufacturing, HMI typically functions as a Graphical User Interface (GUI), offering user-friendly displays of machine conditions, control elements, alarms, and performance data via graphs or tables [19]. This facilitates efficient decision-making and enhances operator-machine interactions.

The pressure sensor operates by converting mechanical strain into electrical signals, enabling the measurement of pressure from both liquids and gases. The principle behind its function is based on the change in the electrical resistance of the conductor material, which occurs as the length and cross-sectional area of the material change. When pressure is applied to the sensor, it induces deformation or bending of the wire, leading to a change in its resistance. The pressure transmitter, a type of pressure sensor used in this system, is highly effective for measuring pressure in industrial processing systems [20]. A flow sensor is a device used to measure the flow rate of gases or vapors. Flow measurement typically involves a transducer and a transmitter. The flow sensor, as a key component, is commonly integrated into flow meters [21].

A solenoid valve, features a coil that drives a piston, which can be activated by alternating current (AC) or direct current (DC) passing through the coil/solenoid. The solenoid valve typically has three main ports: the inlet, outlet, and exhaust. The inlet port is where pressurized air enters the valve, while the outlet port is where pressurized air exits once the valve is opened. When the solenoid coil is supplied with voltage, it generates a magnetic field that moves the piston within the valve. The piston's movement alters the valve's position, enabling the flow of air from the valve to the connected system [22]. The method is a systematic approach employed by researchers to collect the necessary data in the process of designing and constructing a device [23, 24].

2.1. Device Planning Method

Device planning method is designed to facilitate the planning, design and evaluation processes in preparation for the development and construction of the device, including observation, interview and discussion methods [25]. In this method there are four parts, namely component planning, system design, control design, and hardware planning, and software planning. Here is an explanation of these parts:

2.1.1. Component planning

The development of this system requires meticulous planning for component selection. Proper identification of each component is crucial to streamline the design process, enabling the creation of both electrical and mechanical designs [26]. This structured approach ensures that all necessary elements are effectively integrated into the system, optimizing performance and functionality; power supply (switching 24Vdc 2A), outseal PLC (nano v5.1), HMI (haiwell c7s-w), pressure sensor (transmitter sensor), flow sensor (SFAB-200U), solenoid valve (valve 3/2 pneumatic), tower lamp (red, yellow, and green), buzzer (24vdc 22mm), relay (my2n 24vdc), MCB (4A), box panel (30 × 40 cm), duct cable (25 × 40 mm), and block terminal.

2.1.2. System design

The key components of the design are described as follows:
- Tabung A and Tabung B, these are 2 medical-grade oxygen cylinders designated for A and B.
- Regulator A and Regulator B, each oxygen cylinder is equipped with a dedicated pressure regulator to control the oxygen flow.
- Sensor tekanan A and sensor tekanan B, these pressure sensors are installed at the outlet of each regulator on the flow paths of Cylinder A and Cylinder B to monitor oxygen pressure.
- Solenoid valves (SVA and SVB), are installed downstream of the pressure sensors on each flow path from Cylinder A and Cylinder B, respectively.
- Shuttle valve (or gate), positioned where the flow paths of Cylinder A and B converge, ensuring a seamless transition between oxygen supplies.
- Flow sensor, located downstream of the shuttle valve. It measures the volume of oxygen flowing out of the system.
- Sistem kontrol (control system), installed adjacent to the medical oxygen flow installation and serves as the central control hub for all actuators. Sensors and actuators are connected to the control panel, indicated by orange lines in the system design. Figure 1 highlights the placement of sensors and actuators [27]. This configuration ensures the system's ability to monitor and control oxygen supply, supporting real-time adjustments and operational reliability.

2.1.3. Control design

Encompasses 2 primary components: the system block diagram and the wiring diagram. The system block diagram, this provides a comprehensive overview of the system architecture, illustrating the interaction between various inputs, the PLC control unit, outputs, and the Human-Machine Interface (HMI) [28]. Figure 2 shows the system workflow, comprising input, process, output, and monitoring components. Two pressure sensors and an SFAB flow sensor measure oxygen pressure in Cylinders A and B and flow volume. Data is processed by

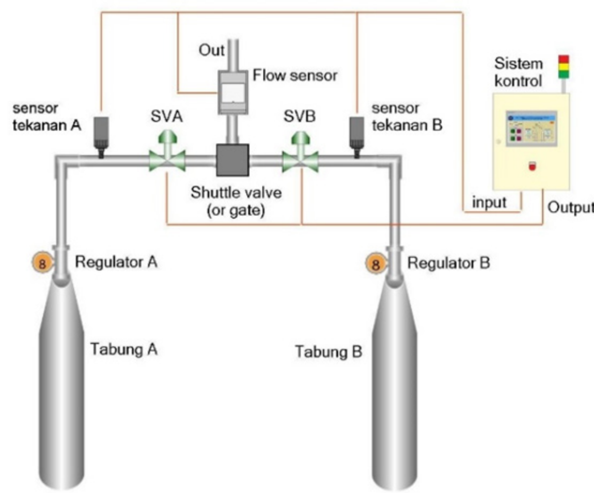

Fig. 1. Device system design.

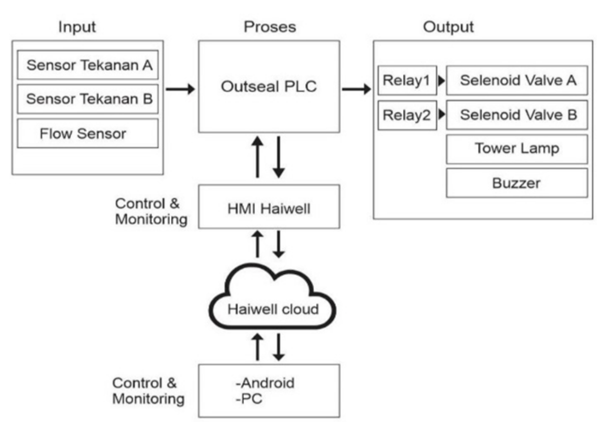

Fig. 2. System block diagram.

Outseal PLC, controlling solenoid valves for oxygen flow, a tower lamp for signals, and a buzzer for alerts. Monitoring is done through Haiwell HMI with IoT features, providing real-time visualization of oxygen pressure, flow, and system control.

The wiring diagram was created as a reference for connecting cables between the various components. The wiring design was developed using AutoCAD software. The wiring as illustrated in Figure 3 shows the relay contact outputs connected to the actuators and indicators, where the solenoid valve, buzzer, and indicator lights are connected through their respective relay contacts, with the following specifications:

(a) Contact no. K1 is connected to solenoid valve A (SVA).
(b) Contact no. K2 is connected to solenoid valve B (SVB).
(c) Contact no. K3 is connected to the buzzer LED (2H1).
(d) Contact no. K4 is connected to the green tower lamp (53H2).
(e) Contact no. K5 is connected to the yellow tower lamp (53H3).
(f) Contact no. K6 is connected to the red tower lamp (53H4).

2.1.4. Hardware planning

Hardware planning involves two main aspects: the control panel design and the medical oxygen flow system installation. These aspects details are given below:

(1) Control panel design: The control panel is housed in a 30 × 40 cm enclosure. Figure 4 illustrates the layout of both the front and internal components of the control panel. The front panel includes the HMI, a tower lamp, and a buzzer, with each component installed through appropriately sized cutouts on the enclosure. The layout shown in Figure 4 is designed for efficient wiring and a neat appearance. Key components are strategically placed for ease of installation and maintenance. The top section houses the MCB, power supply, and Outseal controller. The middle section contains relays, and the bottom row features terminal connectors for external interfaces. This arrangement ensures reliable operation and facilitates troubleshooting.

(2) Medical oxygen flow system installation: Figure 5 depicts the installation of the medical oxygen flow system. The configuration starts with oxygen cylinders A and B.

- For Cylinder A:

- Oxygen exits the cylinder and passes through Solenoid Valve A (SVA).
- A pressure sensor is installed between SVA and the cylinder to monitor pressure.

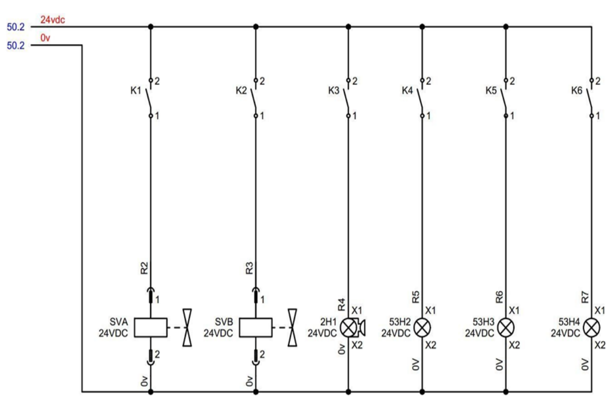

Fig. 3. Wiring diagram of the component output.

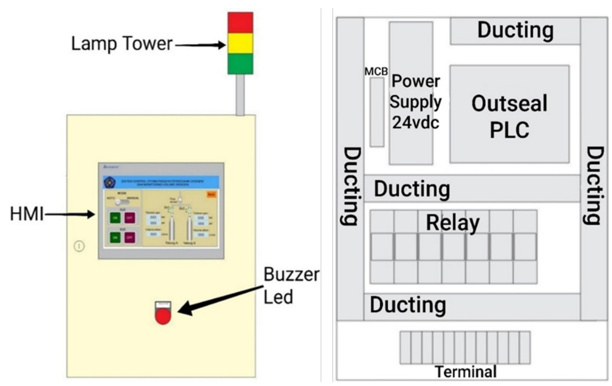

Fig. 4. Control system design, where the left side represents the external form, and the right side represents the internal form.

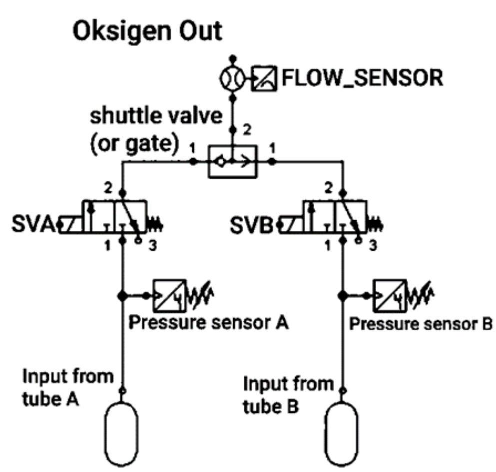

Fig. 5. Medical oxygen flow installation design.

- The output of SVA is routed to an OR gate, which then directs the flow to the flow sensor.
- After the flow sensor, the oxygen is distributed to the intended application.

- For Cylinder B:

- Oxygen exits the cylinder and passes through Solenoid Valve B (SVB).
- A pressure sensor is installed between SVB and the cylinder to monitor pressure.
- The output of SVB is also routed to the OR gate, then to the flow sensor for distribution.

The oxygen flow system is connected using 4 mm pneumatic tubing, ensuring secure and efficient linkage between components. This design provides a seamless transition between oxygen sources, supporting consistent medical oxygen delivery.

2.1.5. Software planning

Process comprises two main components: PLC and HMI programming planning. Each component is described as follow:
(1) PLC Programming Planning: The first step in PLC programming planning is identifying PLC address allocation based on the wiring diagram. This step ensures that sensors and actuators are properly mapped to their respective addresses before programming the PLC.
(2) HMI Programming Planning: The HMI design serves as the interface for control and monitoring, and it is developed to provide detailed insights into the condition of each oxygen cylinder.

2.2. Device Design

Device design is a systematic approach that integrates various engineering principles to create efficient and effective devices tailored to meet specific user needs and requirements [29]. There are two parts that will be explained, namely hardware design and software design.

2.2.1. Hardware design

The system design comprises two main stages: the design of the equipment box and component layout, and the wiring installation design. Each stage is detailed below:
(1) Equipment Box and Component Layout Design: This design uses a 30×40cm panel box. The front panel features cutouts for components such as the HMI and buzzer, while a tower lamp is mounted on top as an indicator. Inside the box, space is organized to accommodate all components, ensuring efficient wiring connections. This layout promotes a neat and organized control system for optimal functionality.
(2) Wiring Installation Design: Following the component layout design, the next stage involves wiring installation. The wiring design adheres to the circuit diagram developed during the planning phase. Components are interconnected using appropriate wires, with each wire end fitted with cable lugs that match the wire gauge. The wiring process is carried out using basic hand tools such as screwdrivers, wire cutters, and crimping pliers. These tools ensure secure and reliable connections between components, contributing to the system's operational integrity.

2.2.2. Software design

The oxygen monitoring and control system requires specific software tools for design and implementation:
(1) Outseal Studio: Essential for PLC programming, Outseal Studio creates programs based on predefined flowcharts, processes sensor data, displays information on the HMI, and controls system output. After validation ensures compliance with design specifications. Debugging is performed if discrepancies arise before uploading the final program to Outseal Nano V5.1.
(2) Haiwell Cloud SCADA Designer: Used for HMI interface design, this software displays sensor data and system status. Validation ensures accuracy, and any errors are corrected before uploading the interface to the Haiwell HMI device.
(3) Haiwell Cloud Application: Installed on a smartphone, this app enables real-time monitoring of oxygen pressure and availability via the internet. Users can access system data remotely, ensuring continuous oversight of oxygen supply conditions, enhancing system efficiency and reliability.

2.3. Device Testing Method

The device testing method involves processes aimed at identifying and addressing potential software errors [30]. The first step is a thorough review of the developed program, where the author evaluates and corrects any errors or bugs. This step ensures the optimal functioning of the device components

[31-33]. Testing the automatic control and monitoring system for oxygen availability assesses overall system performance, ensuring it aligns with expected principles and functions without errors. This stage helps verify the device's reliability and confirms its readiness for practical application.

3. RESULTS AND DISCUSSION

The design results, illustrated in Figure 6, shows the complete internal arrangement of components within the enclosure, including proper wiring and layout. Visible in the upper section is the Outseal PLC module mounted on the DIN rail, responsible for system logic control. Below it are multiple relays and contactors used to manage connected actuators and indicators. The power supply unit is located on the upper left side. A tower signal light is mounted on the top of the cabinet to provide operational status feedback (green for normal, yellow for warning, red for error). The right-side door contains wiring routed through protective flexible spirals, ensuring cable safety and flexibility when the door is opened or closed. The black component with a red, yellow, and green wire is the emergency switch, yet to be mounted, which serves as the primary user interface for safety shutdown. This design ensures clear signal communication, structural durability, and operational reliability in demanding environments.

The result of the oxygen flow installation design is illustrated in Figure 7. This was constructed using an acrylic board, adhering closely to the planned design specifications for the medical oxygen flow system. Precision in the design process is critical to prevent potential leakage in the system. Connections involving threaded joints were sealed with insulating tape to ensure airtight and secure connections. This approach minimizes risks and ensures the system meets the necessary safety and performance standards for medical applications.

The software design for the PLC program was developed using Outseal Studio, with the hardware configured to Nano V5. The design process began with the creation of PLC tag variables, defining the input and output parameters required for the Outseal system. A ladder diagram was then constructed, guided by the program's flowchart. To ensure that the system meet operational requirements, the program underwent thorough functionality testing. The HMI was designed and implemented using Haiwell Cloud SCADA Designer. The process started with the creation of a new project, selecting the Haiwell C7S HMI type, and configuring the interface to connect the HMI with the Outseal PLC. This configuration adhered to the specifications of both interfaces. Input and output variable tags were created to address elements in the HMI visualization. After completing the visualization design, the project was downloaded to the Haiwell HMI device for testing. Once verified, network settings were configured to connect the HMI to Haiwell Cloud, enabling remote monitoring and control through an internet connection. Wi-Fi connectivity was established to ensure seamless integration with Haiwell Cloud for real-time data access. The Haiwell Cloud application, installed on smartphones, provides remote access to the HMI device. Synchronization is facilitated by scanning the device's barcode, which connects the smartphone to the Haiwell Cloud app. This setup enables users to remotely monitor and control the system from any location with internet connectivity. This feature enhances system accessibility and operational

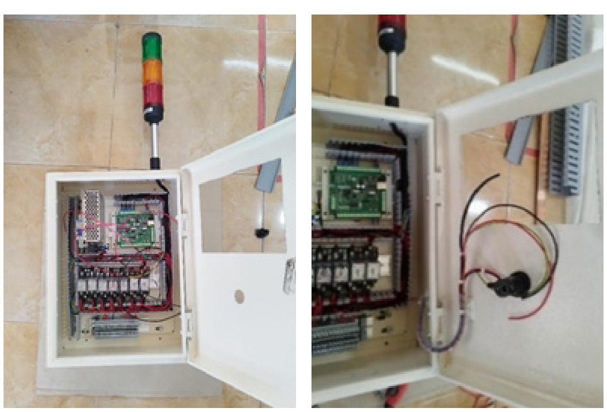

Fig. 6. Hardware of the electrical control panel.

Fig. 7. The oxygen flow installation.

efficiency. Sensor testing is essential to calibrate and verify the accuracy of the sensor in detecting the target object. The testing process involves comparing the sensor's output values with the actual reference values, ensuring that the difference is either zero or as close to zero as possible. Once the test data is obtained, the sensor measurement error is calculated using the Equation (1):

$$Error(\%) = \left(\frac{Sensor\ Value - Actual\ Value}{Actual\ Value}\right) \times 100\% \quad (1)$$

Tables 1, 2, and 3 present the results of sensor accuracy testing and error analysis for the system's core sensing components. Specifically, Tables 1 and 2 evaluate the pressure sensors installed on Oxygen Cylinder A and Cylinder B, respectively. In these tests, sensor readings (in bar) were compared against reference values obtained from a calibrated analog manometer gauge. The percentage error was then calculated to assess the precision and consistency of each pressure sensor under varying pressure levels. Table 3 displays the flow rate sensor testing, in which sensor outputs (in liters per minute) were validated using a manual flowmeter as the reference. Similar to the pressure tests, the percentage error between the sensor and the flowmeter readings was computed to evaluate accuracy. The combined results from all three tables serve to validate the reliability of the system's sensing components. Low error percentages across a range of operating conditions indicate that the sensors provide accurate and dependable readings, supporting their use in critical healthcare environments. This testing procedure is essential to ensure the system's suitability for real-time monitoring of oxygen supply and patient safety, especially in clinics or hospitals relying on automated control and alert systems.

Figure 8 shows the synchronized graphical user interface displayed on both the Human-Machine Interface (HMI) screen and a smartphone, demonstrating the system's remote accessibility via IoT. The interface displays real-time oxygen tank pressure levels (measured in psi), sensor statuses (green indicators for normal conditions), and flow direction to the patient. The charted areas reflect digital readings from the pressure sensors installed on both oxygen cylinders (Tabung A and Tabung B), with switching valve indicators (SV1 and SV2) positioned centrally to represent automatic control of oxygen flow. The matching displays confirm that

Table 1. Pressure sensor testing for Cylinder A.

Sr. No.	Manometer gauge (bar)	Pressure sensor (bar)	*Error (%)*
1	2	1.99	-0.5%
2	3	2.98	-0.66%
3	4	3.95	-1.25%
4	5	5	0%
5	6	6.07	1.16%
6	7	7.07	1%
7	8	8.10	1.25%
8	9	9.13	1.4%

Table 2. Pressure sensor testing for Cylinder B.

Sr. No.	Manometer gauge (bar)	Pressure sensor (bar)	*Error (%)*
1	2	1.99	-0.5%
2	3	2.98	-0.66%
3	4	3.93	-1.75%
4	5	4.99	-0.2%
5	6	6.04	0.66%
6	7	7.04	0.57%
7	8	8.13	1.62%
8	9	9.08	0.88%

Table 3. Flow sensor testing.

Sr. No.	Flowmeter manual (L/min)	*Flow sensor* (L/min)	*Error (%)*
1	2	2.0	0 %
2	4	4.0	0 %
3	6	6.1	1.6 %
4	8	8.1	1.25 %
5	10	10.0	0 %
6	12	12.2	1.6 %
7	14	14.1	0.71 %
8	16	16.3	1.87 %

Fig. 8. IoT-Based Monitoring Interface on HMI and Smartphone.

the data captured by the microcontroller is accurately transmitted via the internet to the smartphone interface. This ensures real-time monitoring and fault detection, such as alarm triggers in case of pressure drops or flow failures, thereby enhancing operational safety and enabling remote supervision.

4. CONCLUSIONS

The automatic control and monitoring system for medical oxygen supply demonstrated effective performance. It measures oxygen pressure up to 10 bar (10.19 kg/cm²) and processes sensor data using a PLC Outseal to control solenoid valves and read flow sensor data. Pressure sensors exhibited high accuracy, with average errors of 0.18% (Sensor A) and 0.079% (Sensor B), while the flow sensor achieved an average error of 0.89%. The system automatically switches cylinders when pressure drops below 4 bar, activating alarms and solenoid valves to ensure continuous supply. An emergency alarm is triggered if both cylinders fall below 4 bar. The Human Machine Interface (HMI) visualizes real-time oxygen pressure, flow volume, and system status. Remote monitoring via the IoT-enabled Haiwell Cloud app allows users to track oxygen availability anytime, anywhere. Future improvements include adding analog input modules, adopting higher-capacity pressure sensors, and enhancing measurement precision to 0.01 bar.

5. CONFLICT OF INTEREST

The authors declare no conflict of interest.

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