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Oxygen Level System Development in WSN and IoT-Based Factory

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Abstract

The health of workers is essential to factory productivity. The lack of oxygen experienced by factory workers for a prolonged duration can disrupt the brain system. One solution to this problem is to build manufacturing facilities with well-maintained airflow, especially oxygen. The system can flow air from outside the factory into the factory based on the measurement of the oxygen level. In this research, an airflow system using the internet of things (IoT) and wireless sensor network (WSN) technology was developed to ensure no oxygen shortage in the factory space. The system comprises three main parts: an oxygen level sensor, a fan controller circuit, and a cloud-based communication system. The oxygen level sensor can measure the volume of oxygen in the factory room and is also connected to the fan controller to control the airflow to the radio-frequency (RF) communication factory room. Oxygen level monitoring data are also sent to the cloud server so that the condition of the factory space can be monitored remotely using internet computers and mobile devices. Performance tests that have been carried out show that the system can increase the oxygen level by 82% from its pre-installed condition. The system built is easy-to-install, low-power, and reliable, with a data loss value of only 1.67%. WSN implementation at the factory does not require a lot of wiring, thus making the system cheaper.

Keywords: factory space, IoT, lack of oxygen, system, WSN.

I. Introduction

The factory design must comply with the standards set by applicable laws and regulations. In Indonesia, work accidents are still relatively frequent [1], [2]. Unsafe behavior and unsafe conditions contribute to work accidents. Unsafe behavior is an action that causes work accidents committed by workers, such as by not using personal protective equipment (PPE) and by using non-standard equipment. Unsafe conditions are workplace conditions that do not support work per operating standards, such as darkness, heat, and lack of oxygen [3]–[5]. Repeated oxygen deficiency for a prolonged duration threatens the worker’s health.

The lack of oxygen in the factory area is often ignored by factory management and workers. The oxygen level in the factory must be properly maintained so that workers do not experience the negative impact of a lack of oxygen at work. The lack of oxygen in workers causes breathing problems, fatigue, muscle aches, and visual disturbances. If this condition continues, workers are at risk for anemia and disorders of the brain system [6]. Brain cells are very susceptible to changes in oxygen supply. If there is an interruption of oxygen supply to the brain for a prolonged duration, it can lead to coma or death.

One of the companies that complained about the decline in the quality of employee health is PT. XYZ. The company is one of Indonesia's leading manufacturers in the synthetic resin business. The company manufactures polymer emulsions, acrylic solutions, alkyd resins, and car care products. In an interview with the authors, the production manager of PT. XYZ complained that several employees, especially those over 45 years, experienced a decline in health. The average employee has worked for more than 20 years. High temperatures and stuffy environments are identified in the workspace in the production line. Some of the workers complained of fatigue, dizziness, and shortness of breath.

Building an automatic airflow system can provide a solution to the oxygen deficiency issue in the factory. The system can flow air from outside the factory into the factory based on the measurement of the oxygen level. Two studies discuss this system: first study, developing a temperature monitoring system based on WSN and a fan circulation system in a factory [7]. The system was implemented on two Boston lettuce cultivation plants, and a series of experimental performance evaluations were carried out. The results of this study showed that the fresh weight of the lettuce harvested increased by 61-109%. Other results show the system is efficient and significantly reduces temperature variations in the cultivation zone. The second study, the development of an airflow system for clean rooms using a real-time

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continuous particle sensor, has been investigated previously [8]. This system can provide the right amount of airflow into the cleanroom to prevent oversupply and save energy.

The internet of things (IoT) is a technology that is widely applied for remote monitoring, management, and engineering of a system [9], [10]. Most recently, the implementation of Smart City using IoT has been carried out in China [11], [12], and Germany [13], among others. Thus, all forms of activity of residents of a city can be appropriately monitored by a system with a large-scale database network. The scope of the IoT system can be expanded by integration with wireless sensor network (WSN). WSN is a system consisting of a collection of sensor nodes that can sense physical parameters and then exchange data with other nodes in a network. The application of WSN-integrated IoT technology has been developed and applied in agriculture [14], [15], and the health sector [16]–[18]. In addition, IoT and WSN systems have also been developed for digital water meter systems [19] and a street light control system [20].

In this research, an air control system in a WSN and IoT-based factory was developed. This system uses an oxygen sensor to measure the oxygen level in the factory room. In addition, this level value is used as the basis for controlling the fan as an oxygen supply from outside the factory. The oxygen sensor and fan control are connected to the network using the radio communication module in the WSN. Sensor data are sent to the internet as factory air monitoring data. The contribution of WSN and IoT in this research is a system that is easy to install, reliable, and energy efficient. WSN implementation at the factory does not require a lot of wiring, thus making the system cheaper. In addition, the data collected on the internet can be further processed for analysis and to prevent oxygen shortages in the factory.

II. Methodology and System Design

A. Methodology

The research method used in this study is a structured experimental method as shown in Figure 1.

This study started with field observations, namely in a manufacturing factory. This observation focused on the factory environment's state and the risks employees face while working. As explained in the introductory section, the condition considered more intensively is oxygen flow in the plant. Oxygen level measurements were carried out as initial observation data. This observation was also further analyzed with previous relevant works to find the core problem and then look for alternative solutions that can be applied to the actual situation. This observation and literature review identified the main problem in this study, namely the lack of oxygen supply that endangers the health of factory workers. Then set the research objectives.

This research focuses on developing a system that can monitor and ensure the supply of oxygen in accordance with the provisions of work safety in the factory. The designed system consists of a series of sensors, a series of controllers, network topology and WSN, and an IoT cloud server that can support access to monitoring data in real-time. The four parts of this design are related to each other so that it becomes an integrated system.

The system is measured to determine performance and as a reference for further system development. These measurements consist of WSN performance measurement, measuring the performance of sending data to Cloud server IoT, and measurement of oxygen quality before and after system installation. The system that has been measured and meets the needs of the field is then implemented in the actual situation.

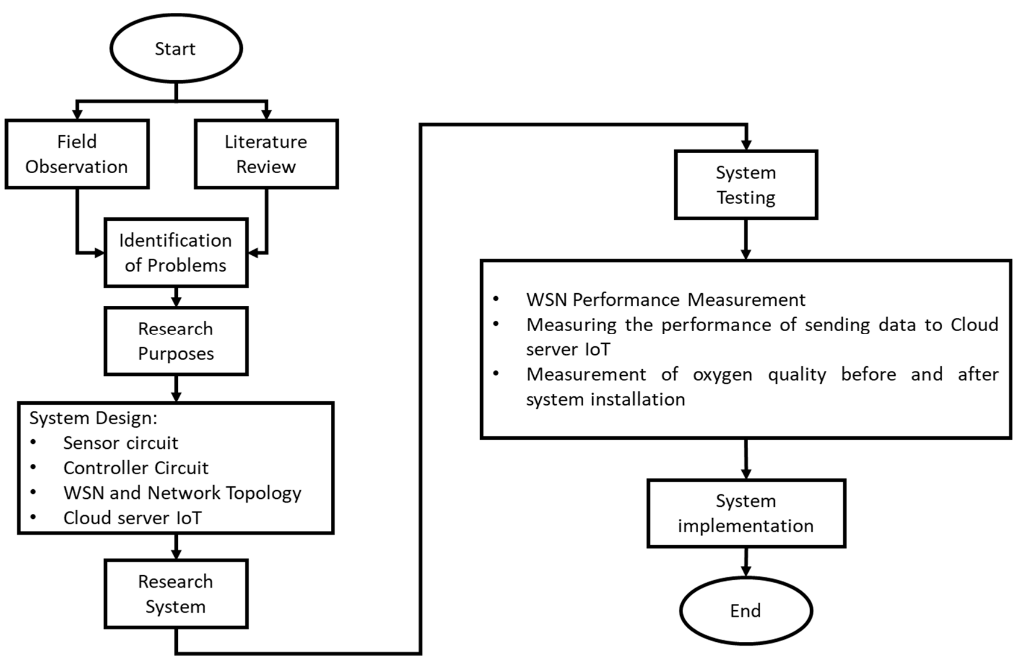

Figure 1. The research flow.

B. System Design

The system developed in this study can be seen in Figure 2. The system generally consists of three main parts: an oxygen level sensor, a fan controller circuit, and a cloud-based communication system.

An oxygen level sensor is a circuit that can measure air volume. The sensor will be located in the factory where the employees gather. The oxygen level sensor sends a message to the fan controller circuit to be able to turn on the fan when the air volume is less than the required capacity. The oxygen level sensor sends a message to turn off the fan when the air volume is appropriate. The oxygen level sensor and the fan controller circuit communicate using a radio frequency (RF) module. The oxygen level sensor also sends the air volume value to the internet using the Wi-Fi module. The Wi-Fi module can be interpreted as an internet protocol (IP) based communication wireless module. This module can send data to the internet as long as it gets network access from an internet source such as a Wi-Fi router. Oxygen level data can be monitored remotely and in real-time as long as internet data communication is in good condition. Visualization of oxygen level monitoring data in factory rooms can be viewed via internet computers or mobile devices connected to the cloud.

1) Oxygen Level Sensor Circuit

The oxygen level sensor consists of an oxygen level sensor, a microcontroller, an RF module, and a Wi-Fi module. The air sensor used is the Grove Gas oxygen sensor. This sensor is a kind of sensor for testing the oxygen level in the air based on the electrochemical cell principle [21]. When the voltage value is proportional to the oxygen level and the sensor is used, it is possible to determine the current oxygen concentration accurately. It works particularly well for measuring oxygen levels in environmental protection. When placed in the air, an organic reaction module called the Grove-Gas Sensor (O_2) can produce a small amount of current. The output voltage of this sensor will alter over time as the current varies without requiring external power. The output voltage value on this sensor is directly proportional to the oxygen concentration and refers to the linear characteristic graph of the oxygen concentration. It is especially suitable for detecting oxygen concentration in environmental protection. This sensor has a short response time of 15 s. This sensor is enough to be given a voltage of 3.3 V DC. The microcontroller used in the oxygen level sensor is Arduino Pro mini. This microcontroller is a circuit board from the Arduino family using an Atmega328P microcontroller chip. The Pro Mini has 14 digital input/output pins (6 are used as pulse width modulation outputs), 8 analog input pins, a resonator, a reset button, and holes for mounting pinheads, perfect for building low-power oxygen level sensors.

The RF module used in the oxygen level sensor is Nrf24. Nrf24 is a radio communication module that uses the 2.4 GHz industrial, scientific, and medical (ISM) frequency [22]. This module uses the serial parallel interface (SPI) interface to communicate. The working voltage of this module is 3.3 to 5 V DC. This module uses an SPI interface to communicate with the microcontroller. Nrf24 has hardware in the form of baseband logic Enhanced ShockBurst and a protocol accelerator that allows for high-speed communication. The data rate reaches 2 Mbps. The Wi-Fi module used in the oxygen level sensor is the NodeMCU ESP8266. NodeMCU is an open-source IoT platform. It consists of hardware in the form of System on Chip ESP8266 from ESP8266 made by Espressif System, and the firmware used, which uses the Lua scripting programming language [23].

The oxygen level sensor workflow can be seen as shown in Figure 3. The programming language of oxygen level sensors uses the Arduino IDE. After this circuit is turned on, the first process is to start the radio and Wi-Fi network. RF and Wi-Fi initiation are running a data communication protocol for each module. The oxygen level sensor will then perform the data retrieval of the air

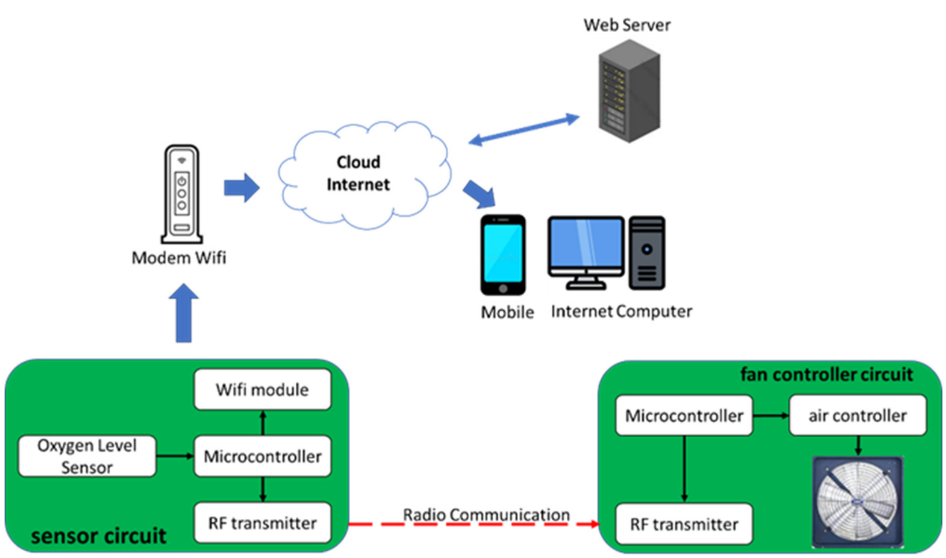

Figure 2. The overall system design.

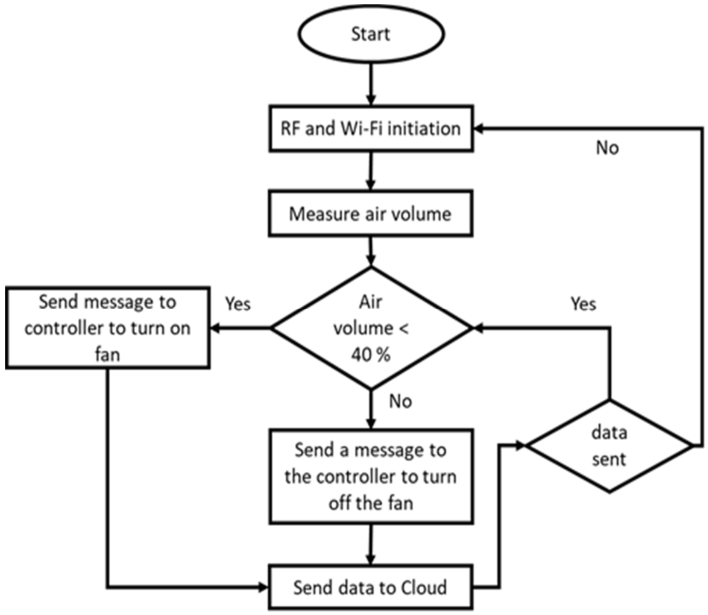

Figure 3. The process flow of the oxygen level sensor.

volume. This section is an important part of the system as a whole. The sensor compares the oxygen value read with the area around the sensor. If the sensor measures the oxygen concentration of less than 40%, it will send a message via radio to the controller circuit to turn on the fan. We set a value of 40% so that it is above the average human air requirement, which is 20% of the air composition in the environment [24]. This message is in the form of a data packet containing commands for control, such as values 1 to turn on the fan and 0 to turn off the fan. Then, the oxygen level sensor sends data to the internet using the Wi-Fi module. This process continues without stopping.

2) Controller Circuit

The fan controller circuit functions as a circuit that regulates the flow of air entering the factory room. This circuit consists of a microcontroller, RF module, and relay. The microcontroller and RF module used are the same as those used in the sensor module. The relay on the controller circuit functions as a fan on and off control. The relay used is a 5 V, 2 channels relay with an output of 250 VAC 10 A. This type is suitable for fan control whose input voltage is 220 VAC. This type of relay is commonly used for large loads. The relay is equipped with an optocoupler to isolate one circuit from another to make the controller circuit safer.

The process flow in the fan controller circuit can be seen in Figure 4. In the initial stage, this circuit initiates RF and then waits for the message from the oxygen level sensor. If the message is received, the message will be read and executed according to the content. The message is 1; then the controller will turn on the fan, and 0 to turn off the fan. If the message is not received, the circuit will continue to be in the standby state. After turning the fan on or off, the circuit will return to standby to receive the next signal. This process continues without stopping.

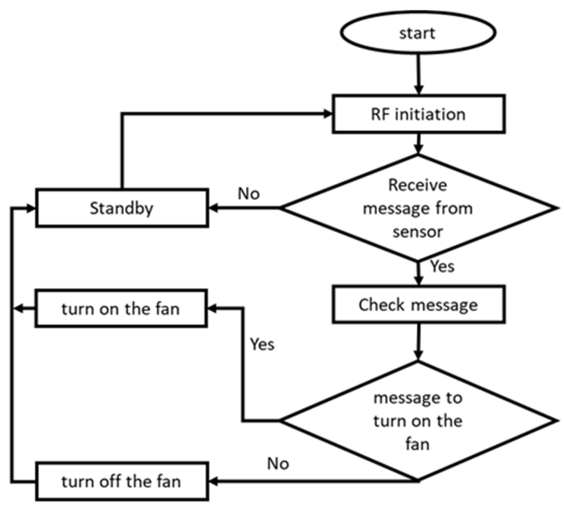

Figure 4. The process flow of the fan controller circuit.

3) WSN and Network Topology

WSN is a common method used for monitoring and controlling systems for large areas. WSN consists of connected nodes based on the type of topology arranged in the communication system [25]. Some of the most commonly known topologies are point-to-point and mesh topologies. The point-to-point topology is usually used for simple WSN systems, and the system being built. The number of nodes involved in this system is 3:1 oxygen level sensor node and 2 fan controller circuit nodes. The sensor node circuit is the central node, and the controller node functions as an actuator in turning the fan on and off. The oxygen level sensor and the controller circuit are set not to use an address. This serves to ease the communication process that the microcontroller must do. When the oxygen level sensor node sends a signal, the two controller nodes can receive it simultaneously. This is because the process of sending data is broadcasted.

4) Cloud Server IoT

In this system, the IoT cloud server used is Thingspeak. Thingspeak is an IoT platform in the cloud that can send or receive data with HTTP communication protocol. In addition, it can also display data values through the free dashboard provided. Thingspeak functions as a data collector from node devices in the form of sensors connected to the internet. It also enables the retrieval of data from the software for visualization, notification, control, and analysis of historical data. The main element of Thingspeak is the channel, which contains a data field, a location field, and a status field [26]. In the system that was built, data transmission to Thingspeak is done every 15 seconds. The data sent is data on the volume of oxygen in the factory room. To access this oxygen level monitoring data, it has been set up for an internet computer at the factory and several mobile devices used by officers, supervisors, and plant managers.

III. Results and Discussion

This section describes the results of system design and system testing. As shown in Figure 1, the system test consists of WSN performance measurement, measuring the performance of sending data to Cloud server IoT, and measurement of oxygen quality before and after system installation.

A. System Design Results

Figure 5 shows the oxygen level sensor hardware that has been built. This circuit works with an input voltage of 3.3–5 V DC and a maximum current of 1.5 mA. The sensor and microcontroller interfaces use analog pins. The interface between the RF module and the microcontroller uses a serial peripheral interface (SPI). The interface between the Wi-Fi module and the microcontroller uses a serial pin (Rx/Tx). The source of voltage comes from electricity. This circuit is protected by heat and water-resistant electronic boxes. This circuit will be placed in the factory room where many employees pass.

Figure 6 displays the fan controller circuit hardware that has been built. This circuit works with an input voltage of 3.3–5 V DC and a maximum current of 1.5 mA. The relay and microcontroller interfaces use digital pins. The source of voltage comes from electricity. This circuit is protected by heat and a water-resistant electronic box. This circuit will be placed in the ventilation section of the factory room. The fan connected to the controller circuit leads into the factory room. This is done so the fan can draw oxygen outside the factory into the indoor space.

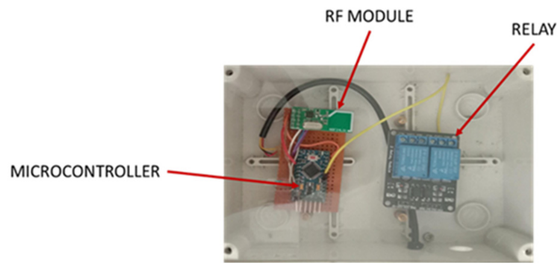

Figure 6. The fan controller circuit.

After completing the oxygen level sensor and controller circuit, a trial installation of the system was carried out in the factory room. Figure 7 shows the layout of the system in the factory room. The installed system comprises 1 sensor circuit, 1 fan control circuit, and 2 industrial fan units.

System testing is carried out for 24 hours before being used further by the factory. This system is installed in a mechanical factory with a dimension of 20×20×8 m. The oxygen sensor is placed on the wall at a height of 1.5 m. This height describes the minimum average height of workers in the factory. The control circuit and fan are installed at a height of 7 m from the floor. The installation of this fan and control circuit slightly modified the shape of the air ventilation in the factory room, which was previously without a fan. Oxygen level data is automatically and in real-time sent to Thingspeak every 15 s. Figure 8 shows a sample of the observation data on the factory's oxygen level.

B. WSN Performance Measurement

This study measured the quality of data transmission in the RF network. The way to measure the quality of data transmission is to send data every 1 second from one node to another in the factory space for every certain distance, say 10 m, 30 m, and so on, then measure packet error rate (PER). PER is a measure used to measure the failure rate in data transmission. The results of measuring

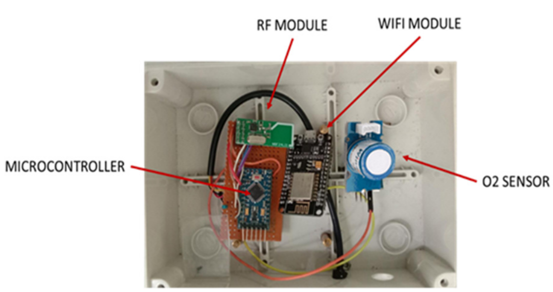

Figure 5. The oxygen level sensor.

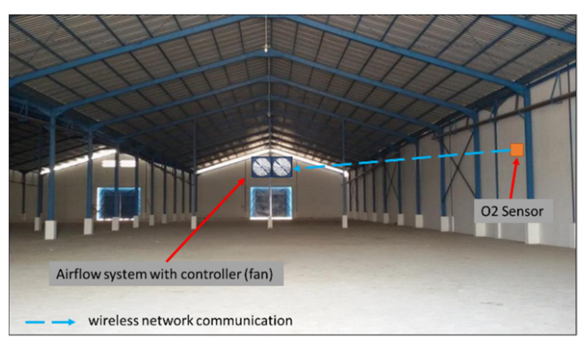

Figure 7. The system layout in the factory.

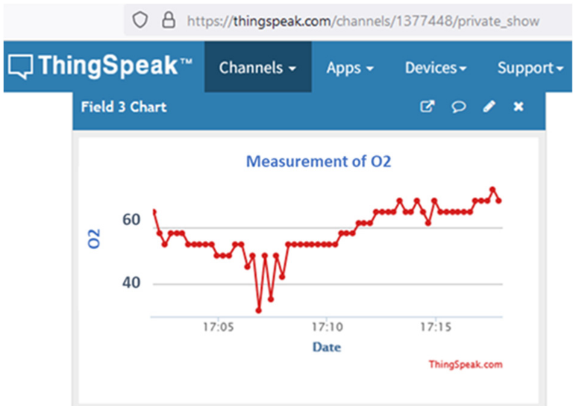

Figure 8. Oxygen observation data of factory room at Thingspeak.

the quality of data transmission in the RF network can be seen in Figure 9.

Based on the graph in Figure 9, it can be seen that the RF network formed has an error value of 0% when measured from a distance of 0-80 m, while at a distance of 90 m and 100 m, the PER values are 13% and 18%, respectively. At large distances of 100 m, PER increases sharply. From these results, it can be concluded that the value of the performance of data transmission in the RF network is very good. This is based on the theory that the maximum distance of data transmission using RF with the ISM band frequency of 2.4 GHz is the maximum distance achieved is 100 m [27]. This distance can be achieved if objects or walls do not block data transmission.

C. Measuring the Performance of Sending Data to Thingspeak

The performance of sending data to the web server has been measured. This measurement method sends data packets to the server every 15 seconds, then measures the data packets sent to the server. A data packet is a measurement value of oxygen level. This measurement was carried out for 12 hours in the factory room. The measurement results can be seen in Figure 10.

Based on the graph in Figure 10, it can be seen that the amount of data successfully sent to the server was 233 to 240 total data. The significant data loss occurred in the 2nd, 7th, and 12th hours; there were 7 missing data. At the 4th and 5th hours, all data is received by the server.

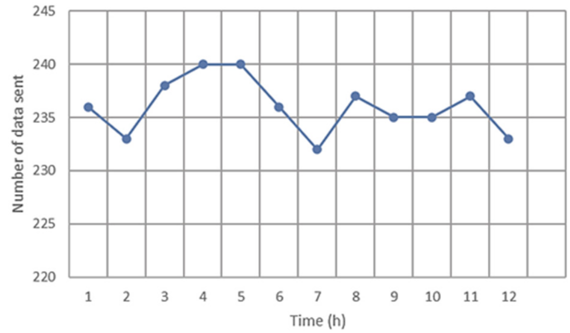

Figure 10. The Measurement result of data transmission performance to Thingspeak.

The average data that was successfully sent to the server was 236 data. The average hourly data loss rate is 1.67%. From the measurement results, it can be concluded that the performance of sending data to the server (Thingspeak) is excellent. From these measurements, it can be concluded that the system is reliable in sending data to the internet.

D. Measurement of Oxygen Quality Before and After System Installation

This measurement is the most important in this study. This measurement aims to determine the effect of the system's installation on the airflow in the factory room. These measurements were carried out every 18 hours before and after the system was installed. The results of measuring the quality of oxygen in the factory room can be seen in Figure 11.

Figure 11 shows a graph measuring the oxygen level in the factory room before and after the system's installation. The oxygen level before system installation was in the range of 30–57%. It is in the 64–86% range after the system is installed. The average system can increase oxygen level by up to 82% from its pre-installation state. The increment means the system can draw the air outside the plant and circulate it into the factory space. Based on the results of these measurements, it can be concluded that the system can increase airflow into the factory room so that the volume of oxygen consumed by employees is larger.

An automatic air volume increase system that focuses on human needs has never been studied by other researchers. Other researchers focus on air volume

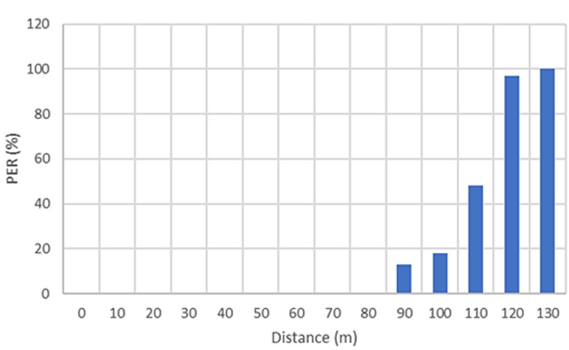

Figure 9. The results of measuring the quality of data transmission in the RF network in the factory room.

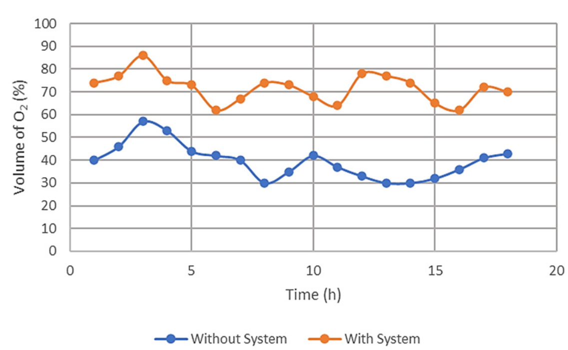

Figure 11. The results of oxygen quality measurement before and after the system installation.

automation systems for agricultural spaces to increase crop production [7]. The system built in this study is easy to install, has low power, and is reliable. This system is sufficiently supplied with a voltage of 3.3–5 V for the sensor and fan controller circuits, or a power of less than 1 W. Worker health is vital in factory productivity. This work supports the workforce to have adequate oxygen capacity at work. The results achieved in this study indicate that it is a new and impactful research in terms of system functionality and industrial applications.

E. Discussion

This research is an occupational safety and health (K3 in Indonesia) study, a preventive measure against occupational diseases (or PAK in Indonesia) and environmental pollution. The application of industrial K3 is usually only based on manual rules or work and environmental standards. This research provides a new approach to industrial K3 automation systems. Lack of oxygen will cause several unhealthy body symptoms and some acute diseases that factory workers may suffer. The system built can improve the oxygen level needed by workers where previously it was at an average level of 34% to an average of 71%. This is enough to meet the oxygen needs of workers.

The built system is easy to implement because it has a small hardware size of 10×6.8×4.9 cm, low power, and good connectivity with a series of controls. The RF-based wireless network used has the ability to transmit point-to-point data up to 80 m. This is practical and saves costs compared to using a wired network. With factory rules that do not allow workers to carry communication devices such as cell phones, the 2.4 GHz network does not experience a lot of noise when sending messages. In addition, this communication is also supported by the factory room's shape and the system's proper installation height. This system was tested while the factory was without workers and continued to be monitored after the space was used. With the fan running, it is proven to increase the oxygen level in the room. Based on sensor readings, this increase ranges from 18–24% over the fan off.

System development will continue to be carried out by considering other aspects such as airflow systems, thermodynamics, etc. In addition, applying the system to a larger size will create complexity in sending sensor data to the controller. This is very interesting to be further explored.

IV. Conclusion

The development of air control systems in factories based on WSN and IoT has been successfully carried out. The system consists of oxygen-level sensor hardware and a fan controller circuit where each circuit is connected in an RF network. Oxygen level measurement data can be sent to the internet. The system is tested to determine its performance by measuring WSN communication and data transmission quality to the internet. The quality of data transmission in RF networks is excellent, with a data loss rate of less than 20% at a distance of more than 80 m from the data transmission source. Meanwhile, the performance of sending data to the server experienced an average failure of 1.66% of the amount of data that must be sent every hour, which was 240 total data. This system also has an outstanding influence on the air circulation in the factory room. Oxygen level increased 82% from pre-system status.

Declarations

Conflict of Interest

In compiling this paper, the authors solemnly declare that there are no competing interests.

CRediT Authorship Contribution

Rifki Muhendra: Conceptualization, Methodology, Software, Visualization, Investigation, and Writing - Review and Editing; Aisyah Amin: Data Curation, Writing - Original Draft, Investigation, Writing - Review and Editing, Supervision.

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