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Air Quality Monitoring System Design Based on Wireless Sensor Network Integrated with the Internet of Things

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***Abstract*— Government and officials set rules to keep the air clean and healthy. To accommodate this, an efficient air quality monitoring system is required. Real-time monitoring is crucial for observing air quality. This allows for immediate action if air quality declines. However, current systems often rely on just one measurement point, risking inaccurate results due to rapid pollutant dispersion. To overcome this problem, researchers propose designing an air quality monitoring system based on a wireless sensor network. Sensor nodes will be installed at various points within the area to be monitored, forming a connected sensor network using the ESP-Now protocol. The data obtained from each node will be sent to the base station, then the data will be transmitted via the Message Queuing Telemetry Transport (MQTT) protocol using the internet network. Thus, this design produces a wireless sensor network that is integrated with the internet of things (IoT). The advantages of the IoT system include ease of data storage and accessibility that can be accessed from anywhere as long as it is connected to the internet and has appropriate authorization.**

***Index Terms*— air quality sensor; ESP-Now; internet of things (IoT); wireless sensor network.**

I. INTRODUCTION

Regulations related to air quality in Indonesia have been issued through Government Regulations (PP) [1], [2], Minister of Environment and Forestry (LHK) Regulations [3], Minister of Energy and Mineral Resources (ESDM) Regulations [4]. In 2020, the MoEF has issued Minister of Environment and Forestry Regulation Number 14 of 2020 concerning the Air Pollutant Standard Index, which replaces Minister of Environment Decree Number 45 of 1997 concerning Calculation and Reporting and Information on the Air Pollutant Standard Index. In this replacement regulation, there are changes in the calculation of ISPU which now includes 7 (seven) parameters, namely particulates PM_{10} and $PM_{2.5}$, nitrogen dioxide NO_2, sulfur dioxide SO_2, carbon monoxide CO, ozone O_3, and hydrocarbons HC. Two additional parameters, HC and $PM_{2.5}$, have been included based on consideration of the great risks that HC and $PM_{2.5}$ pose to human health.

Many researchers have designed air quality monitoring systems [5], [6], [7], [8]. Air quality monitoring system research must be in line with policy regulations issued by the government. The policy is related to the Air Quality Standard Index (ISPU). ISPU is one of the parameters used to measure air quality at a location within a certain time span. ISPU provides information about the level of air pollution in an area, taking into account several air pollutant parameters that are commonly found. These parameters are particulates, pollutant gases, and ambient air quality. ISPU measurements and air quality monitoring in general are essential for understanding the impact of air pollution on human health, the environment, and the economy.

In general, checking air quality is still done manually by taking samples. Samples are analyzed by the laboratory to determine their content. As in the study of air quality analysis in underground parking spaces, sampling was carried out on weekdays and weekends at certain hours [9]. Some studies that are used as references regarding the impact of air quality are analyzed using questionnaire techniques to people who are in the area. As conducted by Westy conducted research on the description of the impact of industry on the surrounding community in Takalar Regency [10]. Furthermore, Aznaeni conducted research around the cement industry in the Bosowo area of Maros Regency [11]. Research on the impact of indoor air pollution and family health conditions was conducted by Indanazulfa [12].

An air monitoring system must have sensors that are distributed so that they can represent air quality over the area being monitored. Sensor network systems are well suited for this task. Previous researchers have only focused on how sensor readings can be transmitted through the internet network, which we know as the Internet of Thing (IoT) [13], [14], [15], [16]. IoT systems require an internet network for each sensor so that data can be sent. However, with a sensor network, not all sensor nodes must be connected to the internet, just one sensor node that is used as a sensor station that is tasked with sending data out of the sensor network system. Sensor stations can be connected to the internet network or other communication systems for data storage.

The above-mentioned studies on air quality impacts were conducted on a questionnaire basis and did not look at air quality data directly. This is because air quality monitoring technology is still rarely installed for industrial purposes, public facilities and private rooms such as homes and offices. Nationally, the application of embedded system applications for air quality monitoring has been made by KLHK. KLHK built a portal for air quality monitoring in 50 major cities. The address of the air quality monitoring portal built by KLHK is https://ispu.menlhk.go.id. On the portal, realtime monitoring is carried out, the data is updated twice a day in the morning and evening. The parameters monitored on the KLHK website portal are PM_{10}, $PM_{2.5}$, NO_2, SO_2, CO, O_3. Some studies use data from KLHK applications such as those conducted by Putri [17]. Agusta conducted research based on air quality data taken from the Global Atmospheric Monitoring Station (SPAG) in Kotobang Hill, West Sumatra [18].

For the design of air quality monitoring applications, many have been proposed for urban areas [19], industrial areas [20], closed rooms [12], [14], [21], [22], [23], and hospital sanitation purposes [20]. These designs can be adopted for air quality monitoring applications in other fields such as indoors in homes and offices as well as in public places such as parks and highways. However, the proposed design is still a single sensor node integrated with the IoT system. The use of one sensor node in one area creates doubts because it does not represent the condition of the monitored area. In this journal, researchers will propose readings from more than one sensor in one area. The system is known as a sensor network system. Sensor networks make the readings more accurate because the sensor nodes are installed at several points in the area to be monitored. This represents the condition of the monitored area. An example of a CO gas monitoring application in a road area if one sensor is placed, it is less representative, it would be better if sensors are installed along the road area.

Sensor network applications mostly use wireless media. Some common protocols that are often used are zigbee, bluetooth low energy (BLE), LoRa, Narrowband IoT (NB-IoT). Air quality design using the LoRa protocol has been done [19], [25] as well as the zigbee protocol [26]. Both protocols are special communication devices that are separate from the main board in an embedded system. Currently there are ESP32 and ESP8266 devices that already have Wi-Fi capabilities. as a developer Espressif Systems has created the ESP-Now wireless protocol for ESP32 and ESP 8266 devices.

ESP-Now is a peer-to-peer (P2P) wireless communication protocol developed specifically for ESP8266 and ESP32 devices. It enables direct communication between two or more ESP devices without the need for access points or other Wi-Fi network infrastructure. The protocol supports AES-128 encryption to protect data transmitted between devices. The protocol is designed to have low latency and efficient power consumption, making it suitable for real-time applications of wireless sensor networks.

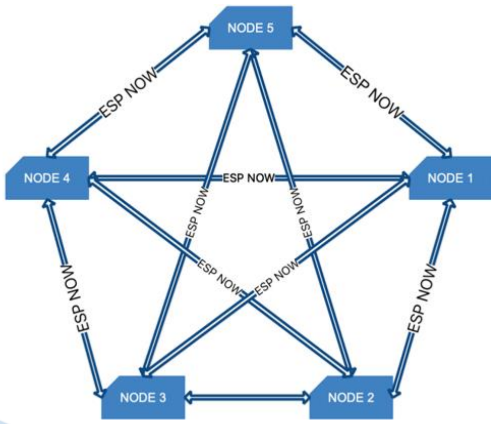

Fig. 1. ESP-Now Possible Topologies

Based on Figure 1 ESP-Now can build various types of topologies, namely P2P, mesh, star, tree or hybrid, a combination of two or more types of topologies mentioned. ESP-Now can also detect the presence of new sensor nodes as done by Arlingga [27].

The purpose of this research is to propose the design of a wireless sensor network-based air monitoring system using the ESP-Now protocol. With ESP8266 and ESP32 devices as microcontrollers that have peer-to-peer communication features to form a sensor network with the ESP-Now protocol. ESP devices can also be connected to various air quality sensors. ESP also has a wifi module so that data from the sensor network built can be sent via the internet network.

II. METHODS

A. System Design

In this design, a wireless sensor network system was built consisting of 5 sensor nodes, each node could read the temperature and humidity of the air using the DHT11 sensor, as well as the level of CO_2 in the air with the MQ136 sensor. Each node can communicate and exchange data using mesh topology. In the whole system, there is 1 sensor node that functions as a base station that serves to send data to the Message Queuing Telemetry Transport (MQTT) server on the internet network. Data sent to the MQTT server can later be read by the Node Red application. A dashboard is provided as an interface with the user to view the temperature, humidity and CO_2 values from each sensor node. The dashboard display can be accessed easily through the Node-RED application on computers and smartphones. Figure 2 is the design of the system integration that will be built.

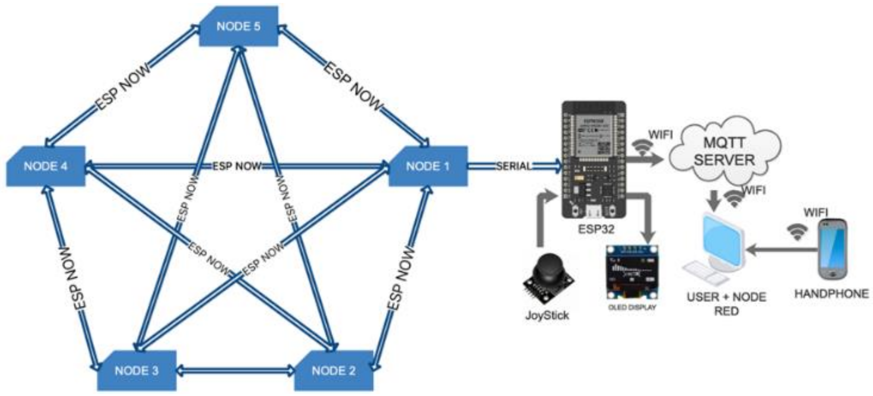

Fig. 2. Wireless Sensor Network with ESP-Now Protocol

The explanation of the design of Figure 2 is as follows:

- The communication protocol between sensor nodes uses ESP-Now with a mesh communication topology.
- In each sensor node there is an ESP8266 as the brain of the sensor node, an MQ135 sensor that functions to measure CO_2. There is a local display in the form of an Oled LCD to display the readings of the measured quantities.
- In sensor node 1, besides exchanging data with other sensor nodes through the ESP-Now protocol, this sensor node also sends data to an ESP32 using a serial communication line. The data sent is sensor reading data from the five sensor nodes that are interconnected via the ESP-Now protocol.
- The ESP32 will send data received from sensor nodes 1-5 via a serial line to the MQTT server.
- Data from the MQTT server will be read by Node-RED and will be displayed in the form of a dashboard of readings of each sensor node that can be accessed from a desktop or smartphone.

B. *Sensor Node Design*

The microcontroller used in sensor nodes 1-5 is the ESP8266 with a schematic design as shown in Figure 3 for sensor node 1 and Figure 4 for sensor nodes 2-5. In general, both schematics have the same design. Each sensor node is connected to DHT 11 and MQ 136 sensors for temperature, humidity and CO_2. There is an oled lcd display on each sensor node to display the sensor readings. The difference between the two schematics is that sensor node 1 is connected to an ESP32. This ESP32 will be the base station in the wireless sensor network in this design.

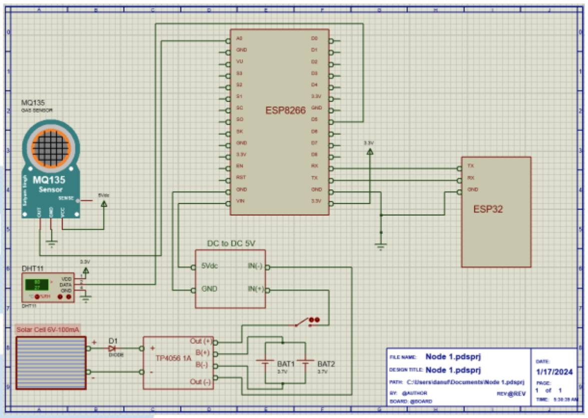

Fig. 3. Sensor Node 1 Circuit Schematic

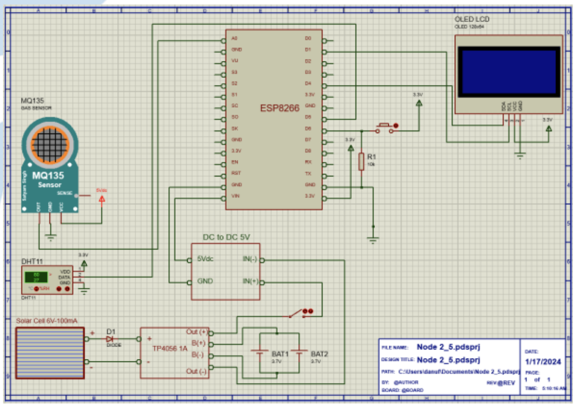

Fig. 4. Sensor Node Circuit Schematic 2-5

C. *Sensor Node Design*

The ESP32 microcontroller is used in the base station design. The components contained in the base station are an oled LCD and a joystick as an interface console. The base station is connected to sensor node 1 using serial communication between ESP microcontrollers. Where sensor node 1 is a sensor node that holds data from sensor nodes 1 to 5. The base station works to send data from sensor network readings through the MQTT Server protocol installed on cloud computing as shown in Figure 2.

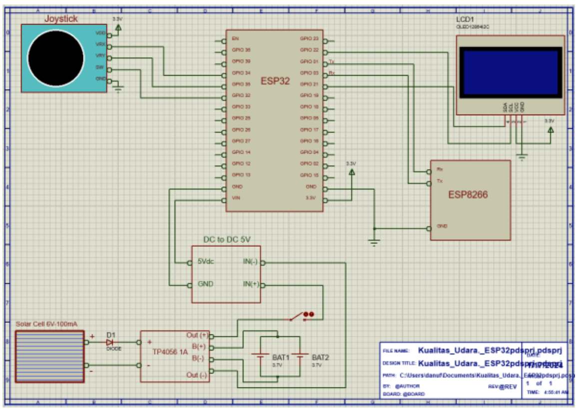

Fig. 5. Base Station Circuit Schematic

D. Display and Data Center Design

The display of the sensor network reading results is shown in Figure 7. The display is made with the Node-RED application. To be able to display the results of sensor network readings, Node-RED subcribes data to the MQTT server. The Node-RED program flow display built is shown in Figure 6. The workings of the Node-RED system are as follows:

- A palette of MQTT input nodes, used to receive data from the MQTT Server.
- A Remote Desktop Node, used to access the dashboard display from a computer or smartphone.
- A CSV Node, used for parsing data from the MQTT server.
- 15 switch nodes to direct the parsed data to the appropriate gauge.
- 15 gauge dashboards, used to display data from each sensor to the dashboard in the form of a gauge.

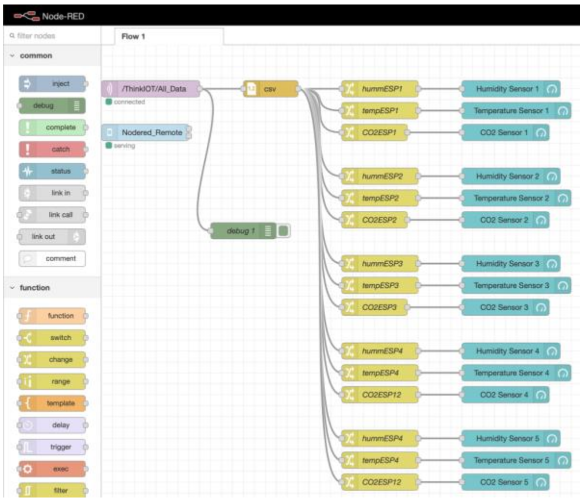

Fig. 6. Node-RED Programming Flow Diagram

Figure 7 shows the Node-RED dashboard when the system is running normally.

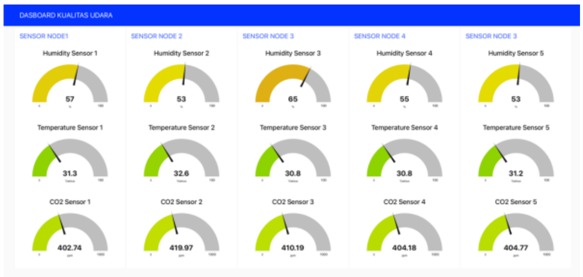

Fig. 7. Node-RED Dashboard View

Figure 7 shows the sensor readings from the five sensor nodes that have been made in the form of a gauge on the Node-RED dashboard.

III. Results and Discussion

A. Wireless Sensor Network Testing

Testing the sensor network is done by comparing the sensor readings at node 2 with the display at node 1. If the readings are the same then the data from node 2 can be successfully sent to node 1. The same is done for the other nodes.

Here are the test results on the sensor network (SN):

TABLE I. Network Testing Between Sensor Nodes

WSN Position	Displayed data sources				
	SN 1	SN 2	SN 3	SN 4	SN 5
SN 1	OK	OK	OK	OK	OK
SN 2	OK	OK	OK	OK	OK
SN 3	OK	OK	OK	OK	OK
SN 4	OK	OK	OK	OK	OK
SN 5	OK	OK	OK	OK	OK

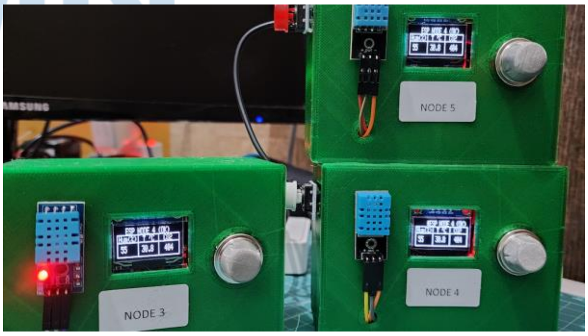

Fig. 8. Sending node 4 sensor values to nodes 3 and 5

From the test results, it was found that the sensor nodes could read and communicate well.

The next test is to turn off sensor node 3 as a sample of problem nodes and then read the status value of node 3 from other nodes. Here are the test results:

TABLE II. NETWORK TESTING BETWEEN SENSOR NODES

Sensor Nodes	SN 3 Off
1	BAD
2	BAD
3	OFF
4	BAD
5	BAD

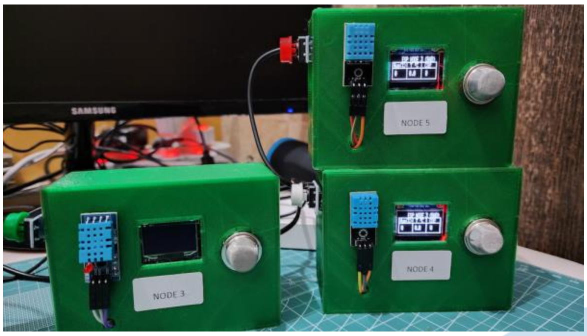

Fig. 9. Bad status display on nodes 4 and 5 when node 3 is OFF

From the test results, it is found that the bad status on one node can be read and detected by other sensor nodes. So it can be said that the network created has been running normally.

B. *IoT System Integration Testing*

Testing the integration of the IoT system with WSN is done by looking at the delivery results on the Node-Red dashboard. Figure 8 is the Node-Red dashboard test which is done by turning on the five sensor nodes and comparing the readings on the Node-Red dashboard with the readings on the display of each sensor node. If the readings are the same then the dashboard is appropriate.

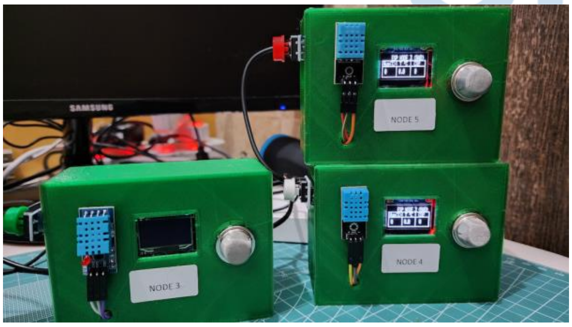

Fig. 10. Bad status display on nodes 4 and 5 when node 3 is OFF

C. *Sensor Node Range Testing*

The test was conducted by placing sensor node 2 in an outdoor location, then walking away from sensor node 2 with sensor node 5. Position the sensor node 5 display to sensor node 2. Continue walking away from sensor node 2 until the "BAD" status is detected on the display. Do this several times to determine the disconnection location of sensor node 2 from sensor node 5.

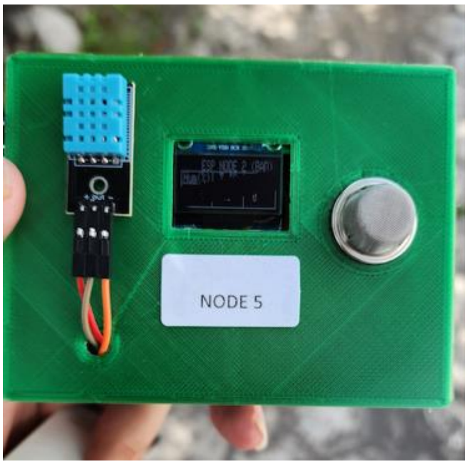

Fig. 11. Bad status on Node 5

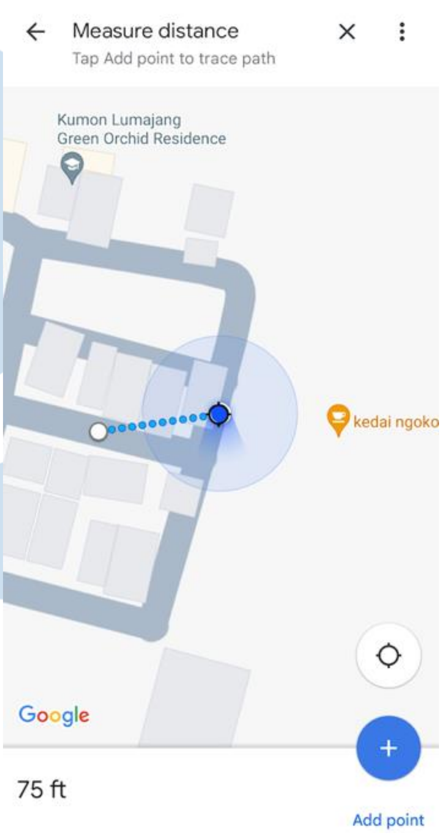

Fig. 12. Distance between Node 2 and Node 5 when the connection is lost

From the test results above, it is obtained that the farthest distance 2 sensor nodes can still communicate with each other is around 75 feet or 22 meters. This cannot be a reference only gives an idea of the communication distance of 2 nodes. Because the ability of 2 sensor nodes is influenced by the thickness and material of the barrier between the two sensor nodes. Barriers can be in the form of sensor container boxes, walls between 2 sensors, etc.

IV. Conclusion

The design of an air quality monitoring system based on a wireless sensor network makes the data more reliable for measuring the area being monitored. Because the nature of pollutants and polluting gases is unevenly distributed due to certain conditions. Because of this, the installation of air quality sensors is carried out at more than one point to guarantee the measurement. In this study, in addition to measurements using a sensor network, data collected by 5 sensor nodes can be sent to the internet network as an IoT system so that data can be stored in a data center and can be accessed anywhere. Further development of this research is to determine the standard value of air quality based on the installation site of the sensor network.

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