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Air quality monitoring using multi node slave IoT

Faisal Fajri Rahani[1*], Haris Imam Karim Fathurrahman[2]
[1]Department of Informatics, Universitas Ahmad Dahlan, Indonesia
[2]Department of Electrical Engineering, Universitas Ahmad Dahlan, Indonesia

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ABSTRACT

Jakarta is the city with the second poorest air quality in the world. IQAir data show that Jakarta's air quality is 159. In addition, the concentration of air particles in Jakarta is 14.2 times higher than the annual guidelines of the World Health Organization (WHO). According to the WHO, exposure to air pollution causes around 7 million premature deaths and millions of years of lost health time each year. Air pollution also stunts children's growth, impairs lung function, etc. Therefore, we need a system that can be used to combine air quality to determine how dangerous a place is with air quality. Knowing air quality, certain policies or actions being taken to overcome this danger. This research aims to build and test a prototype air quality monitoring system using multi-node slaves with the Internet of Things. The prototype development process was carried out by adapting the architectural framework of the air quality monitoring system with the Internet of Things. The testing of prototype results is carried out to sound sensor values and functional success. The results of the test show that the system can run well according to the design made. The DSM501A sensor device functions to detect particles of a size larger than one micrometer, which usually include cigarette smoke, house dust, ticks, spores, pollen, and mildew, and works well so that the controller can read the surrounding air conditions well.

Corresponding Author:

Faisal Fajri Rahani,
Department of Informatics,
Universitas Ahmad Dahlan,
Jl. Ring Road Selatan, Kragilan, Tamanan, Banguntapan, Bantul, Daerah Istimewa Yogyakarta, Indonesia
Email: faisal.fajri@tif.uad.ac.id
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1. INTRODUCTION

The new WHO guidelines recommend air quality levels for the six pollutants proven to be most harmful to health [1]. The pollutant content is particulates (PM), ozone (O_3), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and carbon monoxide (CO) [2]. Of all parameters, the parameters that have a negative impact in a relatively small range are CO and PM_{10} [3]. Particulate matter with a diameter of at least 10 or 2.5 micrometers (µm) (PM10 or PM2.5) can penetrate deeply into the lungs and enter the bloodstream [4], [5]. As a result, these pollutants trigger cardiovascular and respiratory diseases and affect other body organs. Particulate emissions are mainly caused by burning fossil fuels in various sectors such as transportation, energy, households, industry, and agriculture [6]. In 2013, the International Agency for Research on Cancer (IARC) of WHO classified outdoor air pollutants and particulate matter as carcinogenic (carcinogenic) [7]. Nearly 80% of $PM_{2,5}$ deaths could be avoided if the world could reduce current air pollution according to updated WHO guidelines [8], [9]. The WHO has set the average 24-hour PM2.5 pollution limit from 25 micrograms/m3 in 2005 to 15 micrograms/m3 this year [10], [11]. Air quality monitoring data from the website https://www.iqair.com/ show that the air quality in the city of Yogyakarta for one month from 13 June 2023 to 13 July 2023 is of moderate quality, even at certain times it is considered dangerous for people who are sensitive to quality. It is necessary to take early action to address problems in the future [12].

The emergence of the digital era has an impact on various fields in human life [13]. Several previous researchers have conducted research on the Internet of Things. This research refers to several previous studies. The research creates a system that is used to connect each Supervisory Control and Data Acquisition (SCADA) controller in the industry with IoT using ESP32. The proposed SCADA system consists of current and voltage sensors for data collection, an ESP32 organic light-emitting diode (OLED) microcontroller for receiving and processing sensor data, and a Things Board IoT server for historical data storage and human-machine interaction [14].

Other research with the ESP32 concerns low-level microcontroller programming using the STM32, working with real-time systems (using Mbed OS as an example), and using low-power wireless technologies such as LoRa, 6LoWPAN, NB-IoT, ZigBee, and Bluetooth Low Energy. (BLE). Special protocols must also be used, for example, MQTT application layer protocol, and use of special cloud services, e.g. B. Arctic Cloud, IBM Cloud, Intel Cloud [15]–[17].

Another study was conducted on encrypted communication between the IoT cloud and embedded IoT systems. It uses the encrypted MQTTS protocol with an SSL/TLS certificate [18], [19]. The JSON-type data format is used between the cloud structure and IoT devices. The embedded system used in this experiment is Esp32 Wrover. The embedded IoT system measures temperature and humidity with a DHT22 sensor [20]. Another research topic is creating a system to monitor the power usage of a system. Energy data are collected and processed through the ESP32-S2 microcontroller using field instrumentation devices connected to a voltage source and load. An open-source decentralized Peer-to-Peer (P2P) energy trading system, designed on blockchain and Internet of Things (IoT) architecture [21]. Other research in the agricultural sector is carried out by creating an agricultural monitoring system. A general reference architecture that also considers a very important nonfunctional requirement, namely energy consumption limitation.

Monitoring research was also carried out to predict the value of PM2.5 pollutants using the LSTM method. In this study, an LSTM algorithm based on Bayesian optimization is proposed, which can provide an effective prediction of PM2.5 on construction sites [22]. In this research, the Internet of Things (IoT) technology was used for six months to monitor the construction sites in China in real time. The PM2.5 concentrations caused by different construction processes were determined by data cleaning and analysis. The average increase in PM2.5 particles from excavation and support work, reinforcement and concrete work was 17 $\mu g/m^3$, 20 $\mu g/m^3$ and 21 $\mu g/m^3$ respectively. Then, feature extraction is performed using a gray correlation algorithm to remove unnecessary information. A Bayesian optimization algorithm is then introduced to tune the hyperparameters and optimize the performance of the LSTM model. Finally, the validity of the proposed model is verified using a two-based model. The results showed that the accuracy of the LSTM model increased by 6% (R2 from 0.88 to 0.94) after Bayesian optimization. And the optimized model also shows better evaluation indicators, RMSE = 13.06 $\mu g/m^3$, MAE = 8.61 $\mu g/m^3$ [23], [24].

This air is for the PM2.5 particular category. The monitoring results are, of course, only the average air quality where the sensor is placed at one point. This would certainly be different if the sensors could be spread out into several points to produce more detailed reading results. It is hoped that the results of this more detailed monitoring can produce accurate data to be used for good policy. This research creates an air quality monitoring system using multinode slaves based on the Internet of Things which is expected to expand the scope of monitoring PM2.5 pollutants to obtain real-time and accurate data results. Internet of Things is a technology that connects communication devices with electronic devices that are used everyday using the internet as a medium to communicate between devices and users [25]. This research is categorized into a basic research scheme in the form of activities to create a prototype of a multinode PM2.5 air quality monitoring system. The aim of this research is to build a prototype air quality monitoring system specifically for PM2.5 using a multi-node sensor method so that more precise system monitoring values are obtained for each point where these sensors are placed. These multinode sensor data can also be data in real time according to what is needed by policymakers. The prototype results is carried out to evaluate sensor value and functional success.

2. METHOD

In this section, we discuss research related to the development of a new mobility aid for visually impaired. It describes the steps to be implemented, including research steps, component selection, and system algorithms.

Research Phases

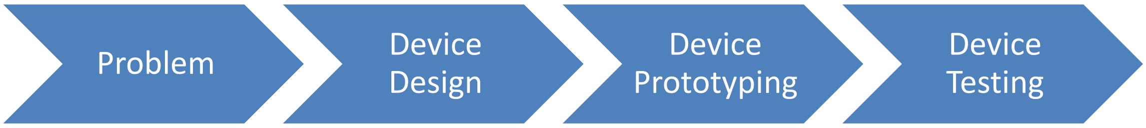

Figure 1. Research method

Problem

At this initial stage, the research begins by identifying the problem you want to research. This involves selecting a relevant research topic and developing a strong theoretical basis. The main focus at this stage is to have a clear understanding of the research problem that needs to be addressed. At this stage, researchers are also conducting studies on solutions can solve existing problems. At this stage, researchers studied the problem of worsening air quality in several large cities in Indonesia. The researchers created a prototype design for a tool to detect air quality at several points directly.

Device design

At this stage, the researcher will design the tools used to solve existing problems. At this stage, the researcher designs the device to be made, the need to be used, and the manufacturing process.

Device prototyping

After the design is made, at this stage, the researcher conducts prototyping by implementing the design of tools that have been made previously in the finished product. At this stage, the device is also programmed according to its designation.

Device testing

The final stage of this exploration involves assaying the results of the tests. This conclusion will give an overview of the strengths or weaknesses of the created device.

Device Design

The hardware design in this research is divided into several parts of the system. These parts consist of a controller unit, a a sensor unit, a data display unit, power supply unit, and a wireless communication unit. Each block of this unit will be connected to a controller unit which is the main brain for this system to run. The system diagram for this research is shown in Figure 2.

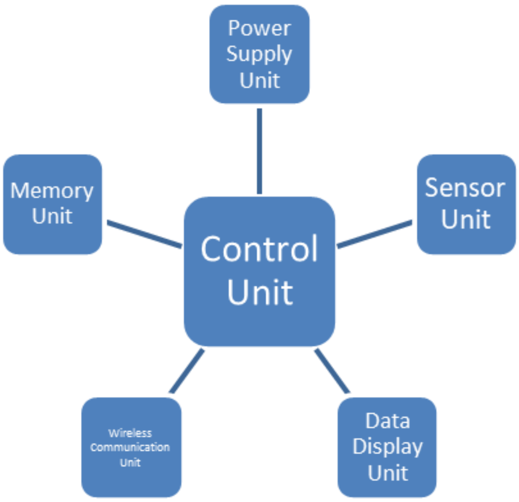

Figure 1. Air quality monitoring system diagram

The controller unit is used as the main brain of this monitoring system. The controller used in this research is ESP 32. ESP 32 is a type of microcontroller, which is an affordable microcontroller with integrated WiFi and dual-mode Bluetooth. This microcontroller has input and output pin components that are used to connect this controller to other devices that will be controlled or integrated with the controller.

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The sensor unit is the input unit of this system. The sensor used for this research is the DSM501A Dust Sensor. The DSM501A dust sensor is a low-cost, compact-size sensor for particle density sensors. Used for quantitative particle measurement (> 1 micron) with the particle counter principle, can detect tobacco smoke and pollen, house dust. This sensor is composed of a light-emitting diode lamp, detector, signal amplifier circuit, and heater, it can be used in applications such as air purifiers or air purifiers, and users can use this sensor easily with PWM sensor output.

The memory unit is used to store monitoring data. This data can then be sent directly to the wireless communication unit to the smartphone device or can be stored temporarily for data backup purposes. The data display unit is used to display the used working status of the monitoring device. The power display unit will display the system connection status, sensor reading status, and the data status sent by the nodes used. The power supply unit is used to input power from this device. The power supply unit used in this research uses a battery device that according to system specifications can be used to power this device for a maximum of 15 hours without additional power.

The multinode working system in this prototype is shown in Figure 3. This system contains one master node and several slave nodes. The aim of using several slaves is to obtain a wider distribution of data from each node. The master node functions to obtain data from the node itself and collect data that has been processed from the slave nodes. Communication between these nodes uses wireless communication, which makes the application easier and expands its reach.

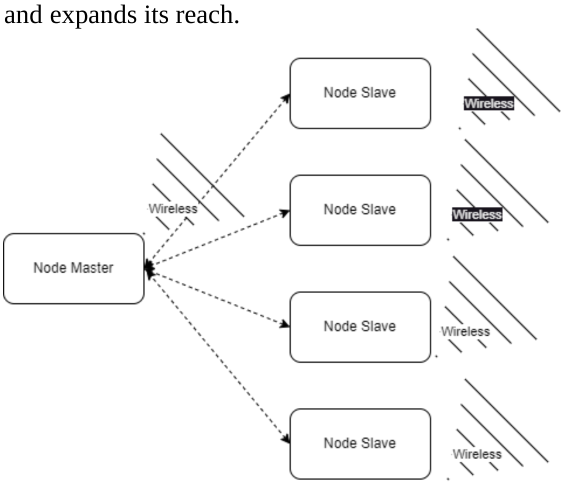

Figure 2. Master-slave schematic diagram for several nodes

The software design used in this research is shown in Figure 4. This system starts when the system is turned on by turning the switch node to the on position. Next, the controller will connect to the master node. This connection aims to send sensor data from the slave node to the master node. After the data connection is OK, the system will read the sensor. The sensor data readings will be processed by the controller, and then the processed data will be stored in memory. Sensor reading data and connection status will be displayed on the screen of each node. After that, the controller will send sensor reading data and node identity numbers to the master node. The activity of reading sensors and sending data is carried out repeatedly over a certain period of time. To stop this process, this is done by switching off the sensor node.

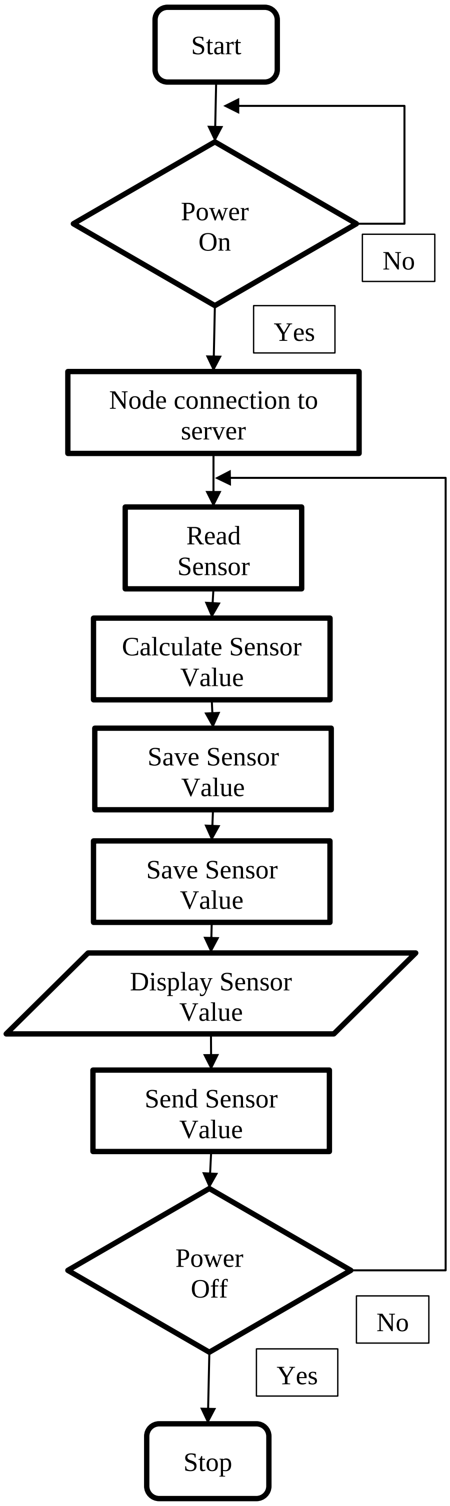

Figure 3. Work diagram flow

Wiring Diagram Hardware

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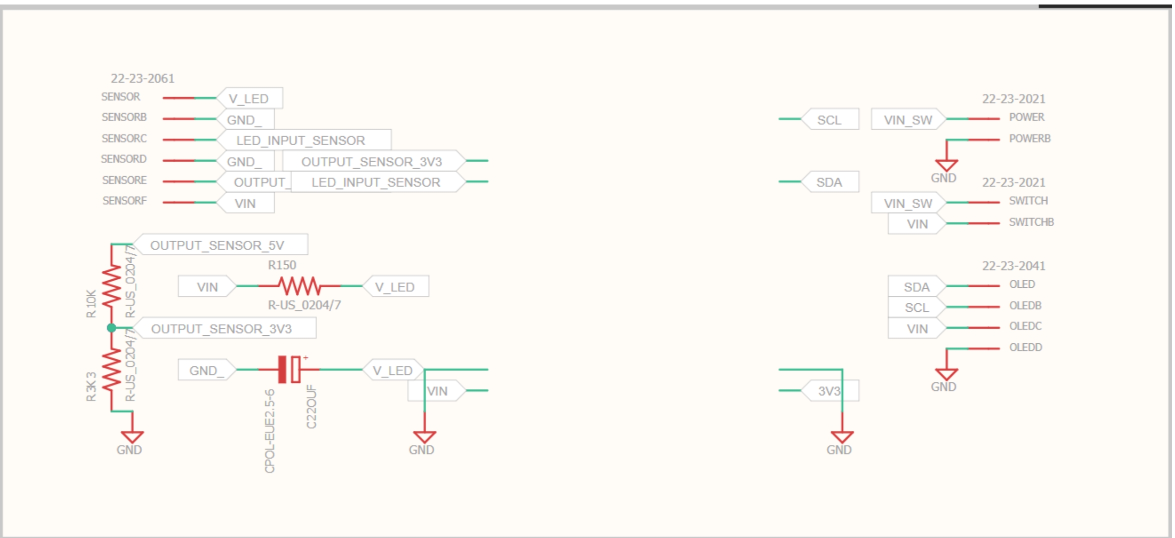

Figure 5. Wiring diagram device

Some of the components used in this device are an ESP 32 controller with wireless connections in the form of Bluetooth and WiFi. The power source device uses a 16850 battery as the main power source of this device. The power source device outputs a 5v power supply used for the ESP32 MCU and Oled Display as well as a 3v power supply used for the sensor power supply. The pin allocation used in this study is shown in Table *1*.

Table 1. PIN assignment

Components 1	Pin		Components 2
ESP32	VIN	5V	Power Supply
	GND	GND	
Power Supply	5V	VCC	Oled Display
	GND	GND	
ESP32	D22	SCL	Oled Display
	D21	SCA	
Logic Level Converter	5V	5V	Power Supply
	3V	3V	
	GND	GND	
ESP32	D25	Low Level 3	Logic Level Converter
	D26	Low Level 4	
Sensor DSM501A	5V	5V	Power Supply
	GND	GND	
Sensor DSM501A	PM2.5	High Level 3	Logic Level Converter
	PM1	High Level 4	

Test Plan

Testing will be carried out by carrying out a series of experiments to assess functionality and data reading tests. The process involves validating the function of the tool and testing the readings of the sensors. The results of this test will be the basis for ensuring that the tool functions according to the initial planned design.

3. RESULTS AND DISCUSSIONS

Device Prototyping

This section will explain the stages of implementation and test results of the devices created. The results of the design of a prototype tool are shown in Figure 6.

Figure 4. Prototype device

The prototype of this device was made using a hollow PCB. This prototype is divided into several main parts. The first part is the control unit in the form of the ESP32, which is the core of this device. The second part is the power supply. This part consists of an 18650 battery that uses a power supply module. This module will provide a power supply to other devices, either 5V or 3.3V. The third part is the display component. This component will display the data and tool status in real time. This device is connected directly to the ESP32 as a control and power supply for the power supply.

The fourth device is a logic-level converter. This device is used to change the logic from sensors that use 5v logic to the logic used by the ESP32, namely 3.3v. The final part is the sensor. This sensor is connected to a power supply for 5v power and is connected to the controller via a logic level converter. In this study, three nodes were used as a test, as shown in Figure 7.

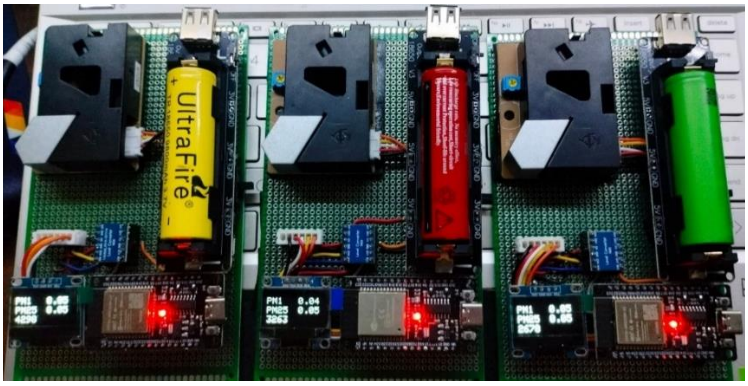

Figure 7. Making a prototype with three nodes

Device Testing

Test sensor readings

At this stage, each device is tested for its sensor reading function. The sensor reading on each device is a program implementation of the sensor datasheet document used. The results of the implementation of sensor readings are shown in Figure 8.

```
09:34:06.163 -> lowpulseoccupancy:0    ratio:0.00    Concentration:-0.05
09:34:06.202 -> lowpulseoccupancy:0    ratio:0.00    Concentration:-0.05
09:34:06.272 -> PM1 0.05  PM25 0.05
09:34:08.284 -> lowpulseoccupancy:0    ratio:0.00    Concentration:-0.05
09:34:08.321 -> lowpulseoccupancy:0    ratio:0.00    Concentration:-0.05
09:34:08.389 -> PM1 0.05  PM25 0.05
09:34:10.425 -> lowpulseoccupancy:0    ratio:0.00    Concentration:-0.05
09:34:10.459 -> lowpulseoccupancy:0    ratio:0.00    Concentration:-0.05
09:34:10.537 -> PM1 0.05  PM25 0.05
```

Figure 5. Sensor reading test

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Sensor reading category test

In this section, the device is tested for use to read environmental conditions along with the interpretation of sensor readings based on World Health Organization (WHO) standards. In this section, the device reads the environment and then converts it into PM2.5 data in units of µg/m3. The data is converted into Air Quality Index (AQI) and, after that, the data is categorized according to air quality levels. This conversion system will make it easier for users to interpret air quality data directly. The test data for reading and converting sensor data can be seen in Table 2.

Table 2. Sensor category conversion table

No	PM 2.5 (µg/m^3)	AQI Level	Status
1	0,02	0,08	Good
2	0,05	0,21	Good
3	1,00	4,13	Good
4	15,10	82,26	Moderate
5	20,50	93,80	Moderate
6	56,20	179,58	Unhealthy
7	2,20	9,09	Good
8	5,50	22,73	Good
9	155,40	281,79	Very Unhealthy
10	25,70	54,91	Moderate

Functional test

The functional table for this testing can be seen in Table 3. This table shows that all components connected to the electronic circuit have been successfully used according to their function. All components of the system involve the verification function of each element involved in the mobility aid device. First, the ESP32 is evaluated to ensure its function as a primary microcontroller capable of coordinating overall system operation. This device is used to receive sensor input, process data, and provide processed output. The power supply works according to its function to consistently produce 5V and 3.3V power supply when the tool is used. The oiled LCD is used to display data or device status. As a device status indication device, this part works according to its function well. Logic level converter as a device to change logic signals from 5V to 3.3V or vice versa for sensor data. This device works well, so that the main controller can read the analog data of the sensor can be read by the main controller. Lastly, the DSM501A sensor device works well to detect particles of a size larger than one micrometer, which usually includes cigarette smoke, house dust, ticks, spores, pollen, and mildew, so that the controller can read the surrounding air conditions well.

Table 3. Functional test

No	Components	Components Function	Identification	Input Voltage
1	ESP32	As a control component in the system. This device is used to receive sensor input, process data, and provide processed output.	Successful	5V
2	Power Supply	As a power supply component whose job is to provide power supply to other components.	Successful	3.7V-4.2V
3	Oled LCD	As a component that functions to display data or device status.	Successful	5V
4	Logic Level Converter	As a component that functions to change 5V logic to 3.3V or vice versa.	Successful	5V and 3.3V
5	Sensor DSM501A	This module is designed to detect the particle of the size bigger than one micrometer, which usually includes cigarette smoke, house dust, tick, spore, pollen, and mildew.	Successful	5V

4. CONCLUSION

In this research, we have succeeded in designing and integrating all components of the tool system for multi-node air quality detection to work well. All components such as the ESP32, power supply, Oled LCD, logic level converter, and DSM501A sensor function well in system functional testing. The sensor can detect air quality according to the surrounding conditions. The controller can obtain the sensor data well and can process the data and display the data well. The device module can communicate well between devices so that sensor data can be obtained as one at the master node. This device works well, so that the main controller can read the analog data of the sensor can be read by the main controller. Lastly, the DSM501A sensor device works well to detect particles of a size larger than one micrometer, which usually includes cigarette smoke, house dust, ticks, spores, pollen, and mildew, so that the controller can read the surrounding air conditions well.

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