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Article

Designing Air Quality Detection Systems with Over-the-Air Firmware Update Methods for Performance Enhancement

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A B S T R A C T

Implementing the Over-The-Air (OTA) system, which facilitates wireless and remote updates of software or firmware through internet connectivity, offers a significant advantage by saving both time and effort. This approach allows for firmware updates to be performed directly from any location, eliminating the need to physically visit each device. This is especially advantageous in the manufacturing of air quality monitoring devices, where adjustments to programs and software are often needed, particularly with seasonal changes. Updating firmware manually on numerous devices can be a time-consuming and labor-intensive process. To address this issue, the proposed device will be designed to support air quality readings and will utilize an internet connection to enable virtual firmware updates. The device will periodically check its program storage for new firmware versions. When a new version is detected, the device will automatically download and install the latest firmware available. This process reduces the need for manual intervention and improves operational efficiency. Additionally, deploying multiple devices across a large area is crucial for ensuring comprehensive coverage. This approach not only simplifies maintenance but also enhances the operational management of air quality monitoring systems. By leveraging OTA technology, the process of updating devices becomes more streamlined, scalable, and efficient, contributing to more effective environmental monitoring and management.

I. INTRODUCTION

Improving air quality has now become one of the top priorities worldwide due to its significant impact on human health and the environment. Air pollution can cause various health problems, including respiratory diseases, as well as disrupt ecosystems and contribute

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to climate change. Therefore, accurate and real-time air quality monitoring is essential to mitigate these negative impacts [1].

Good air quality is essential for public health. Various air pollutants such as Particulate Matter (PM2.5 and PM10), carbon monoxide (CO), nitrogen dioxide (NO2), sulfur dioxide (SO2), and ozone (O3) can cause serious health problems with prolonged exposure. According to the World Health Organization (WHO), air pollution is responsible for millions of premature deaths each year [2].

Today's wireless sensor technology has developed rapidly and offers a practical solution for continuous air quality monitoring. These sensors are able to detect various pollutants and provide real-time data that can be analyzed to take preventive measures [3].

Traditional air quality monitoring systems tend to be expensive, require intensive maintenance, and lack flexibility in upgrading features and capabilities. They often lack the ability to efficiently perform firmware updates, which are necessary to ensure the system is always up-to-date with the latest technologies and standards [4].

In this case, the solution that can be implemented is to implement an Over The Air (OTA) system or the update and update process of software or firmware wirelessly and remotely using internet network communication access. By implementing OTA, users can update program firmware without having to go to the device location to make physical contact with the device. This allows firmware updates to be performed in bulk and remotely without the need for direct manual intervention [5].

The OTA method allows firmware and software updates remotely without the need for manual intervention. This provides several advantages mainly Reduces the need for on-site maintenance. Allows for the rapid addition of new features and bug fixes, and Ensures that the device is always using the latest firmware with improved security and performance [6] There is a growing demand for air quality monitoring systems that are easily accessible and upgradeable. Systems with OTA capabilities can fulfill this need by providing a flexible and scalable solution [7].

Internet of Things (IoT) technology enables the integration of air quality sensors with a wider network for more comprehensive data collection and analysis. The collected data canbe analyzed using big data techniques to provide deeper insights into air quality patterns and trends [8][9]. Air quality detection systems using the OTA method are particularly relevant for implementation in smart cities, where various aspects of city infrastructure are connected and managed efficiently through information and communication technology [10].

Overall, the implementation of the OTA system is a strategic and important step in improving the efficiency, performance, and management of hardware for air quality readings. By allowing firmware updates to be performed wirelessly and remotely, OTA will help overcome the challenges of seasonal adjustment, while improving operational efficiency and overall system scalability. The designed device is expected to utilize the internet connection network in performing the update process, this is done virtually through checking and saving the program periodically. By determining the firmware update version, this system can also recognize if an update of the firmware is detected. The update process is carried out by downloading the latest program that has been prepared, after which the latest firmware or program can be directly used by the device. Based on this description, the author is interested in making a Final Project entitled “Designing Air Quality Detection Systems with Over-the-Air Firmware Update Methods for Performance Enhancement.”

II. LITERATURES REVIEW

Air Quality Detection

Air Quality Detection is the process of monitoring and measuring the concentration of pollutants in the atmosphere using various sensors and analytical techniques to assess air

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conditions in an area. This involves identifying and measuring parameters such as Temperature, Humidity, and Hazardous Gases using DHT22 Sensors and MQ-135 Sensors. Detecting Quality in the Air is very important so that we can see a better environment [4].

Over The Air (OTA)

Over The Air (OTA) is a term commonly used in the context of wireless technology and communications. Literally, “Over The Air” means over the air. In the context of technology, OTA refers to sending data, firmware, or software updates over a wireless network, such as a cellular network or Wi-Fi, without requiring a physical connection such as a cable or external storage device. It is often used to update software on mobile devices, such as smartphones, tablets, or IoT (Internet of Things) devices, as well as to deliver media content such as streaming video or audio [5].

As the name suggests, Over The Air (OTA) refers to the programming, especially updating, of the software that controls the device firmware and/or applications installed on it via the device's wireless connection [11]. There are 2 types of OTA:

Local OTA (Offline)

Local OTA (Offline) Depends on

Distance (Distance Must Be Close)

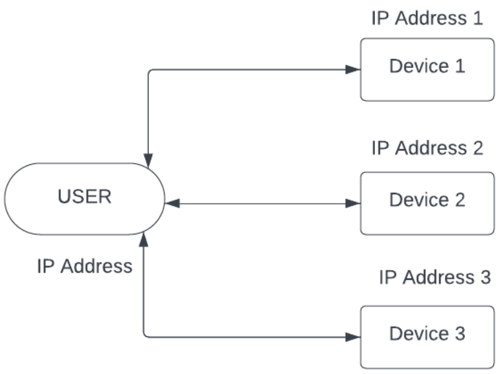

Figure 1. Over The Air (Offline)

Over The Air (OTA) benefit of OTA updates will be immediately apparent based on the description. Using OTA updates, you don't have to bother updating via a physical connection. It is even more suitable for IT departments in large businesses and organizations. While, for a single user, a physical connection and a few additional steps may not seem to matter, for an organization with hundreds of devices spread across a large building, the task of updating, not to mention the techniques that may be involved, such as different product models, different software versions, difficulty accessing the device, and so on, can take up a lot of time.

Another major benefit of using OTA updates is that most software that supports OTA updates features an immediate notification mechanism about update availability. While for traditional updates, it is the responsibility of the user, or the IT department , to take the initiative in checking if an update is available, OTA updates will immediately notify the user that an update is available and they can make the decision to update [6].

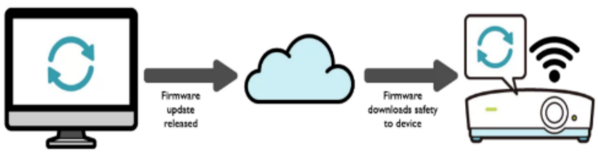

Figure 2. Over The Air (OTA) Concept

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Internet of Things (IoT)

Internet of Things (IoT) is a concept that describes a network of physical objects, such as devices, instruments, vehicles, buildings, and other items equipped with various electronic components, circuits, software, sensors, and network connectivity. This allows these objects to collect data and exchange information between each other.

The machine can report its inventory and monitor whether newly loaded drinks are cold. Kevin Ashton, a British technologist, was a pioneer in this concept and popularized the term "Internet of Things" to describe a system where objects in the physical world can be connected to the internet via sensors spread across various places [12].

One of the main advantages of IoT is its ability to interact without human intervention. Although IoT technology is still in its infancy, many initial applications have been developed in areas such as healthcare, transportation, and the automotive industry. However, IoT development also faces a number of challenges, including infrastructure, communication, interface, protocol and standards issues that must be overcome. Kevin Ashton first proposed the concept of IoT in 1999, and he referred to IoT as connected, uniquely identifiable objects that can be uniquely identified with radio frequency identification (RFID) technology. However, the exact definition of IoT is still in the process of being formed subject to the perspective taken. IoT is generally defined as "a dynamic global network. A dynamic global infrastructure with the ability to self -configure based on communication standards and protocols" [13].

Figure 3. Illustration Internet Of Things

ESP32 microcontroller

Figure 4. ESP32 microcontroller

The ESP32 microcontroller is a very popular and powerful development platform, mainly used in Internet of Things (IoT) projects and wireless networking applications. Developed by Espressif Systems, the ESP32 offers a variety of features that make it highly desirable for DIY projects, prototyping, and even commercial products.

Arduino Integrated Development Environment (IDE)

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Arduino Integrated Development Environment (IDE) is software used to program and develop Arduino devices. It provides a unified development environment that allows users to write, edit, test, and upload code to Arduino boards easily.

Figure 5. Arduino IDE software

Liquid Crystal Display (LCD) I2C

LCD (Liquid Crystal Display) I2C is an LCD display module that is equipped with an I2C (Inter-Integrated Circuit) interface. This module is often used in electronics projects, especially in microcontrollers such as Arduino, to display text and visual information simply.

LCD (Liquid Crystal Display) 16×2 is a very popular display media used as an interface between the microcontroller and the user. With this 16×2 LCD display, the user can see/monitor the state of the sensor or the state of the program running. This 16×2 LCD viewer can be connected to Arduino.

Figure 6. 12C LCD

This time we will create an LCD to display text. Assemble the project according to the image below:

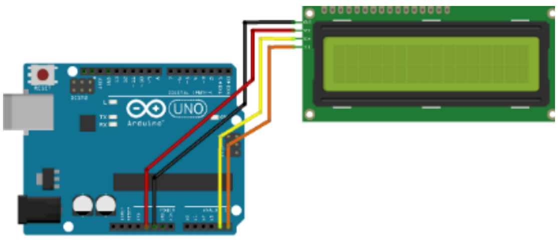

Figure 7. LCD to Arduino

The pins on the SDA / SCL can use the SDA, SCL pins listed on the Arduino or you can also use Pins A4, A5. Next, please enter the program that has been created.

LM 2596 Regulator Module

The LM2596 Regulator Module is a DC voltage regulator module that uses the LM2596 voltage regulator chip. This module is used to regulate DC voltage from a higher voltage source to a lower voltage according to needs.

The LM 2596 Regulator Module is a series of DC / DC converter modules with a fixed frequency of 150 kHz fixed-voltage (PWM step-down) using the LM2596 Regulator IC,

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which is capable of driving 5A loads with high efficiency, low draw and excellent line and load regulation.

Figure 8. LM2596 Regulator Module

Censorship

Sensors are devices that receive or respond to signals or stimuli. Sensors have a function, namely to identify and communicate physical quantities such as temperature, pressure, distance, humidity and gas. Sensors can basically be classified as input transducers because they can convert electrical energy such as light, pressure, movement, temperature or other physical energy into electrical signals or resistance which will be converted back into voltage or electrical signals. There are 4 parts to the sensor, namely:

1. Passive Sensor

Passive sensors are a type of sensor that can produce an output signal without requiring an external electricity supply. A thermocouple which produces a voltage value according to the heat or temperature it receives.

2. Active Sensor

Active Sensors are a type of sensor that requires an external power source to operate. The physical properties of Active sensors vary with respect to the external effects they provide. This active sensor is also called an Automatic Generating Sensor (Self Generating Sensor).

3. Analog Sensors

An analog sensor is a device that produces an analog output according to the calculated quantity. This sensor also works by observing changes in external factors around it. Examples of analog sensors are accelometers, pressure sensors, speed sensors, light sensors and temperature sensors.

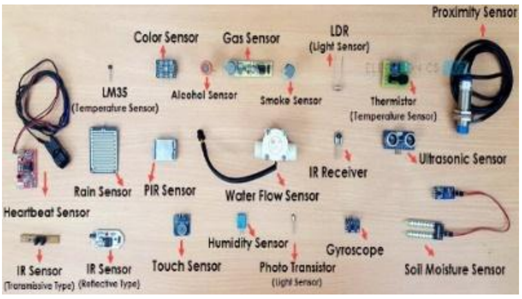

Figure 9. Sensor

4. Digital Sensors

A digital sensor is a device whose signal output value is directly converted into a signal in digital form. Signals are usually measured in two states in digital sensors, namely on and off.

Figure 10. Digital Sensors

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DHT22 sensors

DHT22 is a temperature and humidity sensor that is often used in electronics projects, especially in the fields of Internet of Things (IoT) and environmental monitoring. This sensor is also known as DHT22 or AM2302.

The DHT22 sensor uses very low power, making it suitable for battery applications and operating for a long time without the need for regular battery replacement. This sensor has a low noise level, making it suitable for applications that require stable and accurate measurements [14].

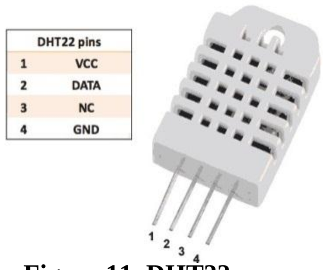

Figure 11. DHT22 sensor

MQ-135 sensors

MQ-135 is a gas sensor used to detect several types of dangerous gases such as ammonia (NH3), methane (CH4), carbon monoxide (CO), and volatile organic compounds (VOC). This sensor is quite popular because of its simple but effective ability to detect these gases [15].

Figure 12. MQ-135 sensor

Table 1. Characteristics of the MQ-135 Sensor

No	Part MQ-135	Details
1.	Source Voltage	5 Volts
2.	Detection Gas	Benzene, Ammonia(NH3),Smoke, Carbon Dioxide (CO2), Nitrogen Oxide (Nox), AlcoholAnd etc.
3.	Level Measurement	10-100 PPM Benzene, 10-300 PPM Ammonia, 10-300 Alcohol and etc.
4.	Output	Analog

III. FRAMEWORK

Research Framework

The framework for the research stages of this final assignment is made in the form of an overall diagram. So the overall diagram of the stages of this research will produce a system that can work well and will also produce a system that can function and can be seen in Figure 3. 1 which shows the overall framework of this The framework for the research stages of this final assignment is made in the form of an overall diagram. So the overall diagram of the stages of this research will produce a system that can work well and will also produce a system that can function.

The following is an explanation of the Research Framework diagram above:

1. Start/Start
2. Literature study, namely collecting data from various sources such as books, theses, journals and the internet, where these sources will become references for this writing.

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3. Hardware design , this stage will be described in the form of a block diagram, then prepare the necessary components and then install them into hardware .
4. Software design (Software), this stage is described in the form of a flowchart which shows how programming applications such as the Arduino IDE work.
5. Hardware and Software Integration , At this stage a combined installation of Hardware and Software is carried out
6. Testing the tool and collecting data, then testing the function and performance of the tool system. After that we will make a final report, at this stage we will also carry out analysis and draw conclusions obtained from research on air quality detection tools using the Over The Air method (OTA) for Firmware Upgrade Optimization.
7. Done/Finish

Device Design

The device design stage is divided into 2 stages, namely the software design stage and the software design stage (hardware). Tool design begins with designing the block diagram of the overall system. The overall working system of the circuit can be known from the circuit block diagram which is one of the most important parts in designing a device.

Software Design (software)

The working process of this device is that when the device is going to upgrade the program, first the device needs to be on and connected to an internet connection. When the device is connected to the internet, the device will enter standby or run the main program while validating new program input. To update the firmware, the main program must first be changed to .BIN format so that it can be read by the microcontroller.

After being converted to .BIN format, the program needs to be uploaded first to the server, after that, over a certain period of time, the device will validate the new program input. When a new program is detected on the server, the program will be downloaded by the device and when it has finished downloading, the latest version of the program will be installed on the microcontroller.

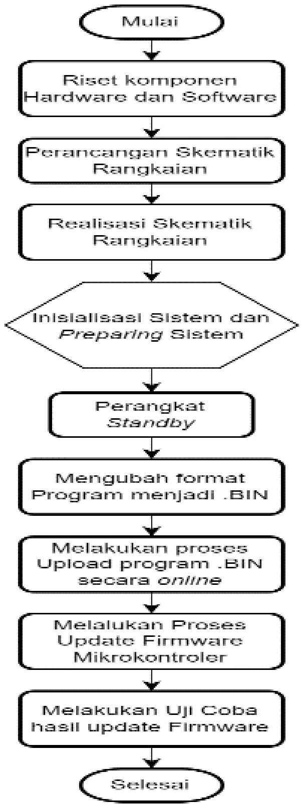

Figure 13. Software Flowchart

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Hardware Design (hardware)

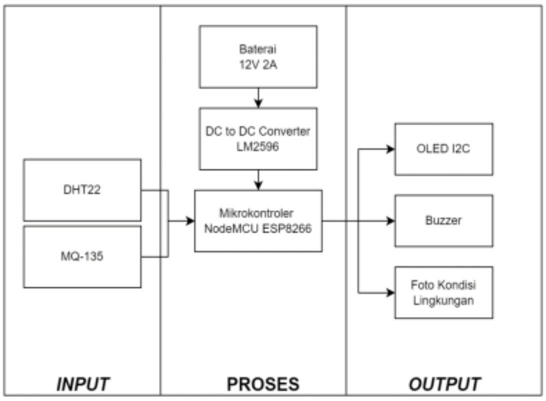

Figure 14. Hardware Block Diagram

From the block diagram above, it can be seen that the working process of this device starts from the 12V 2A battery which will provide working voltage to all devices including the microcontroller and sensors. The working voltage will be reduced from 12V to 5V because the microcontroller device works in that voltage range. Then, the NodeMCU ESP8266 microcontroller will receive input data from the DHT22 sensor in the form of air temperature and humidity values and data from the MQ-135 sensor in the form of particle values in the air. The output of this device is an OLED LCD to display data and a buzzer as sound output.

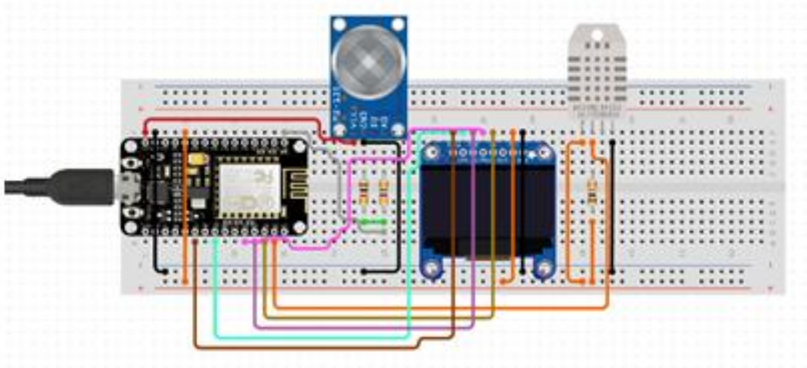

Figure 15. Schematic Layout

The following is an explanation and function regarding the Schematic Layout which is shown in Figure 3.4 Schematic Layout Components used

1. NodeMCU ESP8266 is an ESP8266 based microcontroller which has Wi-Fi capabilities, used to collect data and send to the server.
2. DHT22 is a Temperature and Humidity Sensor which is used to measure air temperature and humidity.
3. MQ-135 is an air quality sensor used to detect dangerous gases in the air
4. OLED Display is a small screen that is used to display data from sensors in real-time

Mechanical Design

The mechanic or final task is to position the sensors correctly according to their position so that each can work well and optimally. Hardware design is a prototype for hardware design, where the hardware is designed using a PCB which aims to protect the sensor components on the device.

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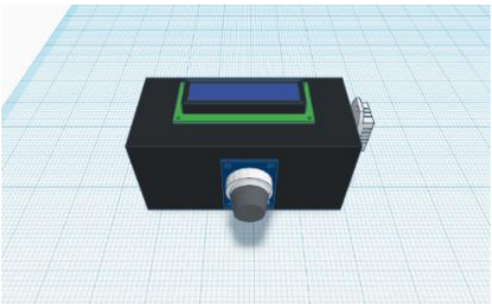

Figure 16. Hardware Mechanical Design

Method Development

After collecting data from previous research, development was carried out, namely OTA, which allows software updates quickly and efficiently without the need for physical intervention and Firmware Updates will be successful and can provide information on environmental air quality conditions.

System Performance Test

Overall System Performance in the Air Quality Detection System Design Tool Using the Over The Air (OTA) Method, Users can monitor Air Quality and Environmental Conditions in Real Time and it is also possible to carry out OTA Firmware updates.

The device that will be made uses an internet connection network. The update process will be carried out virtually by means of the device periodically checking the program storage. By determining the firmware update version, the system can recognize if a firmware update is detected. The update process is carried out by means of the device downloading the latest program that has been prepared. When the download process is complete, the latest firmware or program can be used directly by the device.

In this test, the system will be tested with connected hardware and software devices. Here's how the system works, namely:

1. Initialization, NodeMCU is initialized and connected to Wi-Fi, DHT22 and MQ-135 sensors are initialized.
2. Data Collection , NodeMCU collects data from DHT22 and MQ-135 sensors
3. Data Processing, Data from Sensors is processed by NodeMCU.
4. Data Delivery, Processed data is sent to the server via a Wi-Fi Internet Connection.
5. Data Display, Data is displayed on the OLED display for Real-Time monitoring.

IV. METHODS

The working process of this device is that when the device will upgrade the program, the device first needs to be on and connected to an internet connection. When the device is connected to the internet, the device will enter standby or run the main program while validating the new program input. To update the firmware, the main program must first be converted into .BIN format so that it can be read by the microcontroller. After being converted to .BIN format, the program needs to be uploaded to the server first, after which during a certain period of time the device will validate the new program input. When a new program is detected in the server, the program will be downloaded by the device and when it has finished downloading, the program with the latest version is installed in the microcontroller.

V. RESULT

This chapter explains the assembly process, test results and discussion of the performance results of the devices that have been made. The sub-chapters that will be discussed include a test overview, test data from sensor reading results, responsive functions to sensor reading

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results and analysis of overall function and performance. This test is carried out to determine whether the work of the device being made is in accordance with the initial planning.

Hardware Assembly and Installation Stages

This device will have several main components, namely the Wemos D1 Microcontroller, MQ Sensor, I2C LCD, and DHT22 Sensor in the main circuit. The Wemos D1 microcontroller component in this device functions as the main microcontroller which will process all incoming data and process the data and provide output in the form of predetermined conditions. In this case, the microcontroller will process the data from the sensor readings and then process the data and send the data via an Internet connection.

Next, the MQ sensor component will read the value of particles in the air. Later, these values will be displayed on the LCD and can be seen directly by the user. Lastly, the component used is the DHT22 sensor which reads values from the surrounding environment. The variables that will be calculated from this component are the temperature and humidity values of the air in the surrounding environment, so any changes that occur in the temperature and humidity of the air around the sensor can be detected directly by the DHT22 sensor.

Testing Stages

In its implementation, basic performance testing of devices that support its main performance will be carried out, namely testing the ability to read variable values for each sensor and overall and functional testing of the system.

Device Working Voltage Measurement Test

Test Measurement of the working voltage of the hardware is carried out to see whether the voltage used for each component is in accordance with the working voltage of that component or not.

Table 2. Characteristics of the MQ-135 Sensor

No	Test Point	Reference	Information	Test results	Average	Accuracy
1.	Battery	12V	VDC output	11.8V	13.74V	85.5%
			VDC output	11.9V		
			VDC output	11.8V		
			VDC output	11.8V		
			VDC output	11.8V		
2.	LM2596 DC to DC Converter	12V	Input LM2596	11.8V	13,74V	85,5%
			Input LM2596	11.9V		
			Input LM2596	11.8V		
			Input LM2596	11.8V		
			Input LM2596	11.8V		
		5V	Output LM2596	5V	5.08V	98,4%
			Output LM2596	5.1V		
			Output LM2596	5V		
			Output LM2596	5.2V		
			Output LM2596	5.1V		
3.	Wemos D1 Mini	5V	VIN Wemos	5V	5.02V	99,6%
				5.1V		
				5V		
				5V		
				5V		
4.	LCD 12C	5V	VIN LCD 12C	4,9V	4.92V	98,4%
				5V		
				5V		
				4.8V		
				4.9V		

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5.	MQ Sensor	5V	VIN PZEM-017	5V	5.08V	98,04%
				5.1V		
				5.2V		
				5.1V		
				5V		
6.	DHT22	5V	VIN DHT22	5V	4.92V	98.04%
				4.9V		
				4.8V		
				4.9V		
				5V		

In the table above it can be seen that each test point has different test results. The Power Supply Regulator has an input voltage of 220VAC because it uses direct electricity which is usually available at home, while the output is 12VDC because it has gone through a rectification process so that the voltage changes from AC (Alternate Current) to DC (Direct Current). This 12V DC voltage will enter the LM2596 DC to DC Converter component and then reduce the value again to 5V.

The reason why the voltage needs to be reduced to 5V is because the average working voltage of the microcontroller and sensor is in the range of 3.3V to 6V, so a voltage of 5V is often chosen because it is the middle value of that range. In the table above it can be seen that all components, both microcontrollers and sensors, have a working voltage of 5V, this is to prevent component damage due to overvoltage.

DHT22 Sensor Testing

The functional test on the DHT22 sensor was carried out to test the sensor's ability to detect environmental temperature values in a certain area. In the scenario, the sensor will read the temperature and humidity values of the air over a certain period of time with the aim of testing the reading results in different weather conditions to see whether this will affect the final reading results. In this trial, the temperature and humidity variables will be tested five times, with each test adjusted to the respective observation hours. The test results can be seen in table 4.2 below:

Table 3. Results of Trial Use of the DHT22 Sensor

No	Conditions around the area	Humidity (H)	Temperature Value (C),
1	*Indoor*	65% Humidity	32.00 ^{o}C
2	*Indoor* (Bathroom)	68% Humidity	31.90 ^{o}C
3	*Outdoor* (Sunny)	58% Humidity	35.20 ^{o}C
4	*Outdoor* (Shady)	49% Humidity	36.30 ^{o}C
5	*Indoor*	62% Humidity	33.40 ^{o}C

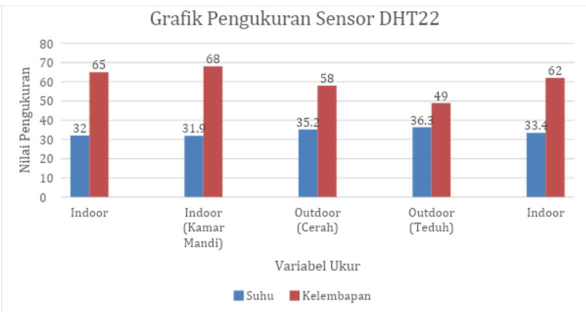

Figure 17. DHT22 Sensor Measurement Graph

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From the measurement results in Figure 4.1, it can be seen that the temperature data changes when the measurement conditions change from indoor to outdoor, as well as when the humidity conditions change while in the bathroom. The most dominant measurement results occurred when the temperature sensor was placed outdoors with a calculated temperature of 36.30^{o}C and a humidity level of 49%. The results of this measurement show that the temperature and humidity sensor works well in measuring the surrounding conditions and none of its constituent components are damaged.

VI. CONCLUSION

From the tests that have been carried out, the device is made in 3 devices that are placed in 3 locations to check air quality using variables of air temperature, air humidity and particle values in the air. In the scenario, the device will be tested to make changes to the threshold variables in the program remotely using an internet connection. The process will help users save time to change the threshold value effectively and efficiently.

Based on the results and discussion after testing, the following conclusions can be drawn. The air quality detection system built is able to monitor and measure air quality parameters in real-time. The sensors used can detect various air pollutants such as PM2.5, PM10, CO2, and others with high accuracy. The OTA method allows device firmware updates to be performed wirelessly. This increases flexibility and efficiency in system maintenance, reduces the need for manual intervention, and minimizes device downtime. With the implementation of the OTA method, developers can easily perform bug fixes, feature enhancements, and device performance optimization without having to physically access the device. This ensures the system is always up-to-date with the latest technologies and fixes. The system is designed to be easily expandable, allowing the addition of new devices to the monitoring network without difficulty. The OTA method also facilitates simultaneous updates on multiple devices, improving scalability and system management. The design of air quality detection system with OTA method for firmware upgrade optimization provides an effective and efficient solution for environmental monitoring, device maintenance, and continuous improvement of system performance.

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