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Air Monitoring and Pollution Mitigation System in Urban Areas Using IoT

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ABSTRACT

Urban air monitoring and pollution mitigation systems are important efforts to maintain air quality in increasingly dense urban environments. This project aims to design and implement an Internet of Things (IoT)-based system that is capable of monitoring air quality and mitigating pollution automatically. This system used a Sharp GP2Y1010AU0F dust sensor to detect dust particles, a DHT22 sensor to measure temperature and humidity, and an HC-SR04 ultrasonic sensor to detect water levels in case of flooding. Additionally, it used the SG90 servo to automatically open and close the water valve, and 5V mini water pump to spray water from the underground tank, thereby reducing air pollution levels. The implementation of this system was carried out using plastic containers separated by plywood as a water storage medium and sensor installation. Data from sensors was sent to Blynk's IoT Platform for real-time monitoring. Apart from that, this system was also integrated with Telegram to provide notifications to residents if pollution levels worsen. Hence, they can immediately take preventative action by staying at home. Test results showed that the system was able to detect changes in air quality and water levels with precises accuracy. Apart from that, this system can also carry out pollution mitigation measures automatically by spraying water when pollution levels exceed a predetermined threshold. This project is expected to contribute to improving air quality in cities and can be widely implemented in various cities with high levels of pollution.

KEYWORDS: *Air monitoring, IoT, Sensors, Pollution mitigation, Urban.*

1.0 INTRODUCTION

Clean and healthy air is one of the basic needs of every human being. However, with increasing urbanization and industrial activity in big cities, air quality is decreasing, threatening the health of residents and the environment. Air pollution has become a serious problem that can cause various respiratory diseases, cardiovascular diseases [1], and even premature death [2]. Therefore, monitoring air quality and mitigating pollution are very important things to do. Data from the World Health Organization (WHO) shows that air pollution causes around 7 million deaths each year worldwide [3]. In Indonesia, big cities such as Jakarta, Surabaya, and Bandung often experience high levels of air pollution, especially from motor vehicles, factories, and forest fires [4].

Therefore, there is a need for a device that can detect air pollution levels, provide information to the public, and a device that can mitigate air pollution by spraying water into the air to reduce pollution levels. Previous research on IoT-based air pollution monitoring systems shows that Internet of Things (IoT) technology is very effective in monitoring air quality in real-time [5-16]. To meet this need, the researcher designed a device that combines an IoT-based tool [17-19] with an air pollution monitoring tool using wireless sensor and actor networks [20], air temperature monitoring device [21] and informs the public through Telegram notifications [22-23].

This research project aims to design and implement an Internet of Things (IoT)-based urban air monitoring and pollution mitigation system [24]. This system is not only able to monitor air quality but can also provide notifications to residents via Telegram if pollution levels exceed safe limits, so they can take preventive measures by staying at home. In addition, this system is also equipped with a mitigation mechanism that automatically sprays water to reduce pollution levels in the air. With this system, it is expected to help the government and the community monitor air quality more effectively and take quick and appropriate mitigation actions. The implementation of this system is expected to improve the quality of life of urban residents and protect them from the negative impacts of air pollution.

2.0 THEORETICAL BASIS

2.1 ESP32

The ESP32 is a microcontroller with integrated Wi-Fi and bluetooth features, often used in IoT applications. This microcontroller has high processing power and low power consumption, making it suitable for various remote monitoring and control applications. Key Specifications [25]:

1. CPU: Dual-core Xtensa® 32-bit LX6
2. Speed: Up to 240 MHz
3. Memory: 520 KB SRAM
4. Connectivity: Wi-Fi 802.11 b/g/n, Bluetooth v4.2 BR/EDR and BLE.

Figure 1: ESP32 [25]

The physical form of the ESP32 is as shown in Figure 1. An ESP32 was used in this study as a data processing and communication center. With the Wi-Fi feature, ESP32 can send and receive data from the Blynk IoT platform, allowing remote monitoring and control of connected sensors, actuators, and pumps [25].

2.2 ESP32 Expansion Board

The ESP32 expansion board is an add-on board that makes it easier to develop research with the ESP32. This board provides various interfaces such as GPIO, ADC, and DAC, as well as connectors for sensors and other modules.

Key Specifications [26]:

1. GPIO, ADC, DAC interface
2. Connectors for sensors and other modules
3. Socket for ESP32

Figure 2: ESP32 expansion board [26]

With a physical form as shown in Figure 2, the ESP32 Expansion Board makes it easy to install and test various sensors and actuators. This board also provides a stable and secure connection for the ESP32 [26].

2.3 Arduino IDE [27]

Arduino IDE, which has a logo such as in Figure 3 is an integrated development environment used to write and upload code to microcontrollers such as ESP32. This IDE supports various programming languages such as C and C++, and provides many libraries to facilitate development.

Key Specifications:

1. Programming Language: C/C++
2. Libraries: supports various libraries for sensors and modules
3. Compatibility: supports a wide range of microcontrollers including ESP32.

Figure 3: Software Arduino IDE

Arduino IDE is used to write, compile, and upload code to ESP32 in this study. This IDE provides a user-friendly interface and rich libraries to control the various sensors and actuators used.

2.4 DHT22 Temperature and Humidity Sensor [28]

DHT22 is a digital sensor used to measure temperature and humidity. This sensor has high accuracy and can be used in various environmental applications.

Key Specifications:

1. Temperature Range: -40°C to 80°C
2. Temperature Accuracy: ±0.5°C
3. Humidity Range: 0% to 100% RH
4. Humidity Accuracy: ±2% RH

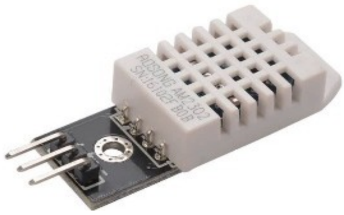

Figure 4: DHT22 sensor

With a physical form as shown in Figure 4, DHT22 is used to monitor temperature and humidity. The data generated by this sensor is sent to ESP32 for analysis. If the temperature and humidity exceed normal limits, the system will activate mitigation actions such as turning on the water pump to flush the environment.

2.5 Sharp GP2Y1010AU0F Dust Sensor [29]

Sharp GP2Y1010AU0F is an optical sensor used to measure the concentration of dust in the air. This sensor works by using infrared light reflected by dust particles.

Key Specifications:

1. Measuring Range: 0 to 500 µg/m³
2. Operating Voltage: 5V
3. Power Consumption: Maximum 20 mA.

Figure 5: Sharp GP2Y1010AU0F dust sensor

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The physical Sharp GP2Y1010AU0F dust sensor is shown in Figure 5. The Sharp GY2Y1010AU0F dust sensor is used to monitor air quality by detecting dust concentration. Data from this sensor is sent to the ESP32 and if the dust concentration exceeds the safe limit, the system will activate mitigation actions to reduce air pollution, and send a notification to Telegram.

2.6 Ultrasonic Sensor HC-SR04 [30]

HC-SR04 is an ultrasonic sensor used to measure distance. This sensor sends out ultrasonic waves and measures the time it takes to receive the waves reflected by the object.

Key Specifications:

1. Measuring Range: 2 cm to 400 cm
2. Accuracy: ±3 mm
3. Operating Voltage: 5V
4. Frequency: 40 kHz

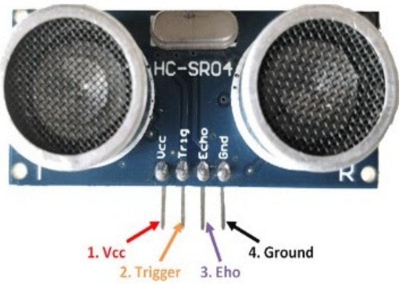

Figure 6: Ultrasonic Sensor HC-SR04

With the physical form as shown in Figure 6, ultrasonic sensors are used in this system to detect flood water levels, and the distance from the device to the surface of the flood water. Data from the sensor will be sent to ESP32 and if the flood water level and distance exceed the safe limit, the system will activate mitigation actions to reduce flooding.

2.7 Servo Motor SG90 [31]

SG90 is a servo motor that is often used in robotics and automation applications. This motor has a rotation angle of up to 180 degrees and can be controlled with a PWM signal.

Key Specifications:

1. Rotation Angle: 0 to 180 degrees
2. Operating Voltage: 4.8V to 6V
3. Torque: 1.8 kg-cm

Figure 7: Servo motor SG90

With the physical form as shown in Figure 7, the SG90 servo motor is used to open and close the water valve that connects the miniature street to the underground water tank. This motor is controlled by the ESP32 based on data from the HC-SR04 ultrasonic sensor. When the water level returns to normal, the servo will automatically close the water valve.

2.8 LCD 16x2 I2C [32]

LCD 16x2 I2C is a display module that uses the I2C interface to communicate with microcontrollers such as Arduino and ESP32. This module can display two lines of text with each line consisting of 16 characters, and the use of the I2C interface allows savings on the GPIO pins needed to control the module compared to traditional parallel interfaces.

Key Specifications:

1. Display Size: 16 characters x 2 lines
2. Operating Voltage: 5V
3. Interface: I2C (uses only two pins for communication: SDA and SCL)
4. I2C Address: Usually 0x27 or 0x3F (depending on module)
5. Contrast: Adjustable by potentiometer or I2C commands.

Figure 8: LCD 16x2 I2C

With a physical form as shown in Figure 8, the 16x2 I2C LCD is used in this project to display real-time data from various sensors such as temperature, humidity, water level, and dust concentration. By using the I2C interface, this module only require two pins from the microcontroller. Hence, that is the other GPIO pins can be used for additional sensors and actuators. In addition, this module is equipped with a potentiometer to adjust the display contrast, which makes it easier to read information in various lighting conditions.

2.9 Blynk Platform [33]

Blynk is a platform for Mobile OS applications (iOS and Android) aimed at controlling Arduino, Raspberry Pi, ESP32, WEMOS D1, and similar modules via the internet. With the physical form as shown in Figure 9, the Blynk platform is used in this study as a cloud or storage or monitoring of air data on each sensor received. By using Blynk, users can access the platform for free up to 3 devices

Figure 9: Blynk Platform

2.10 5VDC Submersible Water Pump

A 5VDC submersible water pump is used to circulate water as part of a pollution mitigation mechanism. This pump is activated by a relay based on the detected temperature conditions [34].

Specifications:

1. Working voltage: 5VDC
2. Water discharge: 200 L/h

Figure 10: 5VDC submersible water pump

With a physical form as shown in Figure 10, a mini water pump is used to spray mitigated flood water into underground water tanks. Then, it is sprayed around to cool the environmental temperature and reduce pollution.

2.11 5VDC 10A 2-Channel Relay [35]

The 5VDC 10A 2-Channel relay with the physical form as shown in Figure 11, which is used to control high voltage or large current circuits using low voltage signals from the ESP32. These relays allow the safe disconnection and connection of circuits.

Specification:

1. Working voltage: 5VDC
2. Maximum current: 10A

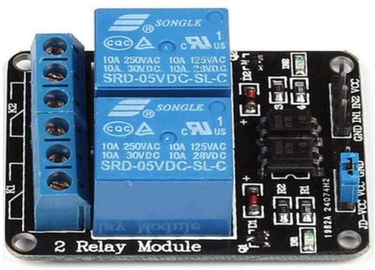

Figure 11: 5VDC 10A 2-channel relay

Pin Chart:

1. VCC: This pin is used to connect 5V DC working voltage
2. GND: This pin is connected to ground.
3. IN1 and IN2: These pins are used to receive control signals from the microcontroller. IN1 controls the first relay, and IN2 controls the second relay.
4. COM, NO, NC:
   - COM (Common): This pin is connected to the common terminal of the relay.
   - NO (Normally Open): This pin is a contact that is initially open and will close when the relay is activated.
   - NC (Normally Closed): This pin is a contact that is initially closed and will open when the relay is activated.

2.12 12V 5A adapter

The 12V 5A adapter, with the physical form shown in Figure 12, is a device that converts AC (Alternating Current) voltage from the main power source into a stable and regular DC (Direct Current) voltage for use by electronic devices.

This adapter is used for:

1. Provides stable voltage can provides a stable 12V voltage to avoid fluctuations that can damage electronic components.
2. Provides sufficient current, with a maximum current of 5A, this adapter is able to provide enough power to operate several components at once, such as relays and water pumps.
3. Convert AC to DC can converts the AC voltage from the mains power source (generally 220V or 110V) to a lower, more stable DC voltage.

Technical specifications:

a. Output Voltage: 12V DC
b. Maximum Current: 5A
c. Maximum Power: 60W
d. Input Voltage: 100-240V AC, 50-60Hz
e. Output Connector: Barrel jack (generally with an outer diameter of 5.5mm and an inner diameter of 2.1mm).

Figure 12: 12V 5A adapter [36]

2.13 Telegram

Telegram has a logo as shown in Figure 13. It is a cloud-based instant messaging application known for its speed, security and multimedia capabilities. Telegram can also be used as an IoT medium to send notifications to users who access it.

Specification:

1. Text Messaging: Send and receive text messages in real-time
2. Bots and Automation: Automated accounts that can perform tasks, provide information, or integrate with other services.
3. Privacy Settings: Control who can see your phone number, last seen, and other personal information.

Figure 13: Telegram

Telegram bots are special accounts that do not require a phone number to set them up. The bot connects to its owner's server, which processes input and requests from users. In this case the bot will receive data from the dust sensor connected to the ESP32 to display in Telegram notifications [37].

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3.0 METHOD

Data collection in this study was carried out through several stages, namely as follows:

1. Temperature and Humidity Sensor Data Collection:
   a. Tools used: DHT22 sensor
   b. Method: The DHT22 sensor is connected to the ESP32 and measures the temperature and humidity periodically. The resulting data is sent to the ESP32 for processing and then sent to the Blynk platform.
   c. Purpose: To monitor environmental temperature and humidity conditions.
2. Dust Sensor Data Collection:
   a. Tools used: Sharp GP2Y1010AU0F sensor.
   b. Method: Dust sensor is connected to ESP32 and measures the concentration of dust in the air in real-time. Data from the sensor is displayed to Blynk. Then ESP32 will also send notification messages using Telegram for pollution level notifications.
   c. Objective: To monitor air pollution levels in urban environments.
3. Water Level Data Collection:
   a. Tools used: Ultrasonic Sensor HC-SR04
   b. Method: Ultrasonic sensor is installed to detect the water level on the road. Data from this sensor is sent to ESP32 which will process it and send it to Blynk for monitoring.
   c. Purpose: Detect flooding and activate the servo to open the water valve if necessary.
4. Display Data Collection:
   a. Tools used: 16x2 I2C LCD.
   b. Method: Data from various sensors is displayed in real-time on a 16x2 LCD connected to the ESP32. This display makes it easy to monitor environmental conditions locally.
   c. Purpose: To provide direct information about environmental conditions.

The system block diagram illustrates the relationship between various components in a smart urban air monitoring system is depicted in Figure 14. It helps visualize the flow of data and power between the major components.

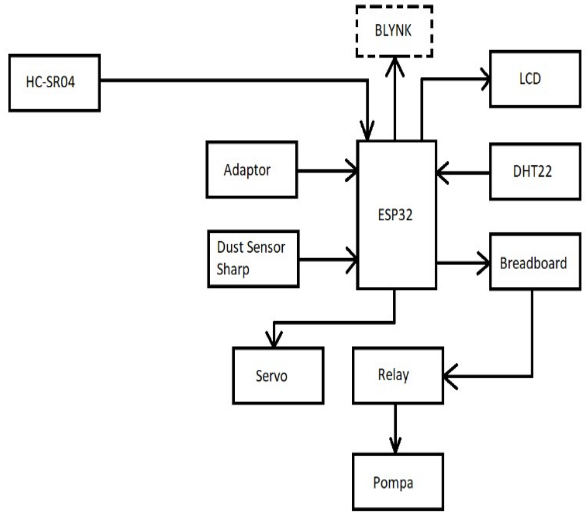

Figure 14: System block diagram

Explanation of how the system works as follows:

1. The ESP32's power source comes from an adapter.
2. Input sources are obtained from several ultrasonic sensors, dust sensors, temperature and humidity sensors.
3. ESP32 will process all data input from the sensor to be processed by the microprocessor. Then display the processed data to the 16x2 LCD.
4. ESP32 will also connect to the internet where the processed data be uploaded to the Blynk server. Then displayed on the dashboard containing widgets according to their addresses.
5. The ultrasonic sensor will detect if the water level exceeds the normal limit, then the servo to mitigate the water from going down to the underground water tank.
6. The temperature and humidity sensor will detect if the temperature exceeds the normal limit or is too hot, then the pump will turn on to suck water from the underground water tank, then flush the surroundings.
7. The dust sensor will send a notification to Telegram if the pollution level is hazardous to health.

4.0 RESULT AND DISCUSSION

4.1 Results

The tool testing was conducted to evaluate the performance of the IoT-based air monitoring and pollution mitigation system in urban areas. The following are the test results from several scenarios that have been carried out.

- **Data Collection from Sensors on LCD Display**
  – Readings from the temperature and humidity sensor (DHT22) show temperature and humidity variations that correspond to actual environmental conditions.
  – Readings from the dust sensor (Sharp GP2Y1010AU0F) show dust concentrations within normal limits and are able to detect increased air pollution.
  – Readings from the ultrasonic sensor (HC-SR04) show accurate water levels and are responsive to changes in water levels on the road.

- **Data Collection from Sensors on Blynk and Telegram Platforms**

1. Dust sensor test was conducted using smoke from paper burned indoors. The test results showed that:
   a. Normal Condition: the concentration of dust particles in a normal room is 22.11µg/m³. The display of the test results is shown in Figure 15 and the test graph is shown in Figure 16.
   b. Pollution Condition: when paper smoke is released, the concentration of dust particles increases significantly to 209.34µg/m³. The display of the test results is shown in Figure 17 and the test graph is shown in Figure 18.
   c. Recovery: after the smoke cleared, the concentration of dust particles slowly dropped to normal levels of around 41.53µg/m³.

The dust sensor test results confirm that the Sharp GP2Y1010AU0F dust sensor was highly effective in detecting significant changes in dust particle concentration. The sensor's response to fluctuations in dust levels demonstrates its ability to monitor air quality in real-time. This makes it a reliable tool for environments where dust concentration monitoring is critical.

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Figure 15: Normal condition sensor test results on the blynk platform

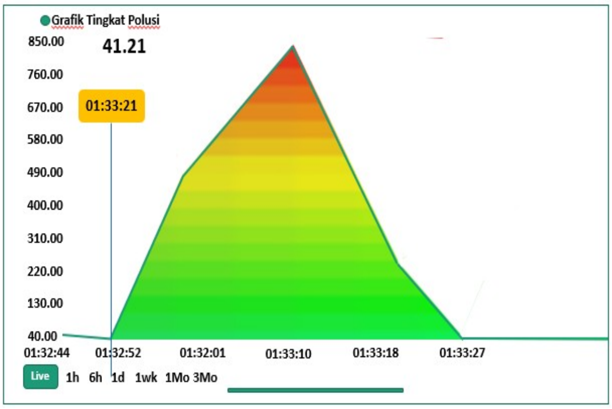

Figure 16: Normal condition sensor test graph on the blynk platform

Figure 17: Results of sensor testing using smoke on the blynk platform

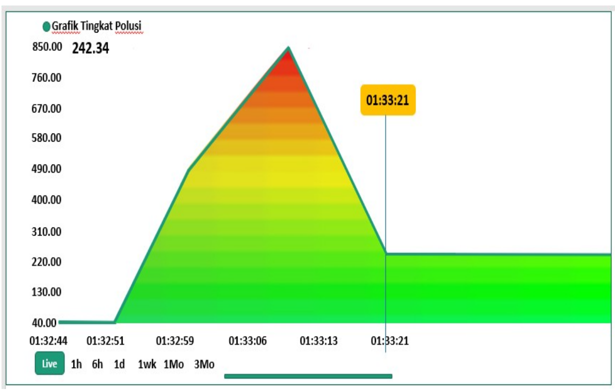

Figure 18: Sensor testing graph using smoke on the blynk platform

2. Temperature and humidity sensor testing were done using a match to trigger the DHT22 sensor. The test results showed that:
   a. Normal Conditions: indoor air temperature ranges from 30°C to 32°C, and relative humidity ranges from 60% to 80%.
   b. Pollution Conditions: when a match is lit, the air temperature rises sharply to 35°C.
   c. System Response: when the air temperature reaches above 34°C, the system automatically activates the 5V mini water pump to spray water around as shown in Figure 19, and lowers it, lowering the air temperature back to the normal level of about 30°C.

The test demonstrated that the system effectively regulates indoor air temperature by monitoring environmental conditions.

3. Ultrasonic sensor testing was conducted using tap water as a rain simulation. The test results showed that:
   a. Normal Condition: the water level inside the container remains within normal limits with minor variations.
   b. Rain Simulation Condition: when the water level reaches less than 28 cm from the sensor, the system automatically activates the SG90 servo to open the water valve as shown in Figure 20 allowing tap water to enter the water tank.

The test demonstrated that the HC-SR04 ultrasonic sensor accurately detected water levels with high precision. It successfully controlled the servo to open the water valve in a timely manner based on the detected measurements.


Figure 19: Condition of water pump turning on when temperature is above 34 degrees celsius


Figure 20: SG90 servo test results for opening the water valve

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4. Notification system testing was equipped with notifications via Telegram to alert residents. The test results as shown in Figure 21. The result of notification activation, which the system send a notification when the dust particle concentration exceeds 150µg/m³ or when the air temperature exceeds 34°C. Based the resident response revealed the notifications help residents take precautions, such as staying home and avoiding outdoor activities.

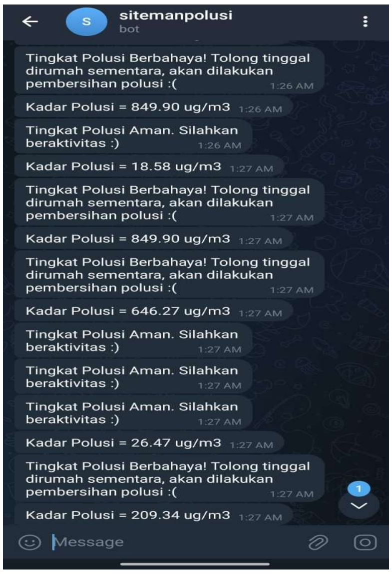

Figure 21: Notification message test results to Telegram

This test proved that integration with Telegram is effective in providing important information to residents in real-time.

- **Actuator Function**
  1. The SG90 servo works well, opening and closing the water valve according to the water level data collected by the ultrasonic sensor.
  2. The relay works well in turning on and off the 5V DC water pump based on the detected temperature and pollution conditions.

- **Data Submission to Blynk Platform**
  1. The display of WiFi Connection Success and Connected to Blynk is shown in Figure 22
  2. The Blynk app displays real-time and historical data accurately, allowing remote monitoring of environmental conditions.

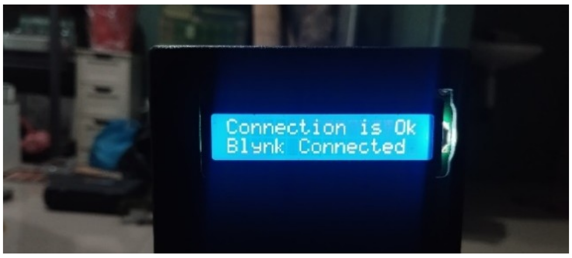

Figure 22: WiFi connection successful and connected to blynk

4.2 Discussion

Tests with smoke from burning paper showed that the dust sensor was able to detect a significant increase in the concentration of dust particles from the normal condition of 44.53µg/m³ to 242.34µg/m³. This shows that the sensor is very sensitive and reliable in detecting sudden increases in air pollution, which is very important in urban environments that are susceptible to various sources of pollution. Challenge: Although dust sensors can detect changes in dust particle concentration with high sensitivity, the main challenge may lie in the environmental variability that affects sensor readings. For instance, weather factors like rain or strong winds can interfere with the accuracy of dust sensors due to changes in airborne particles. However, the dust sensors may struggle to differentiate between particle types (e.g., dust from smoke, industrial pollutants, or vehicle emissions). This could make air quality monitoring less specific. The development of distinguishing algorithms that can identify pollution sources based on the detected dust patterns could enhance the accuracy of monitoring and the understanding of pollution sources in urban areas.

The DHT22 sensor successfully detects the increase in temperature caused by a lit match. When the air temperature exceeds 34°C, the system automatically activates a 5V mini water pump to spray water into the surrounding environment, which helps lower the temperature back to normal levels. This capability is essential in managing the hot and dry air conditions that often occur in urban areas. Challenges: Although the DHT22 sensor is effective at detecting temperature increases, the system activated to lower the temperature using a mini water pump may face challenges in energy efficiency. Continuous use of the water pump to regulate temperature on a larger scale could lead to energy waste, especially in larger urban environments. Limitations: This system may become less effective under extreme conditions, such as very high temperatures or rapid temperature changes. It may also be insufficiently responsive in handling more complex temperature fluctuations beyond the set threshold (34°C). Insights for Future Research: The automatic temperature control system can be improved by incorporating multi-parameter sensors, such as humidity or air quality sensors, to provide a more holistic response to the dynamic environmental conditions.

The use of ultrasonic sensors to detect water levels in rain simulations shows that the system can manage potential flooding by opening the water valve when the water level reaches less than 28 cm from the sensor. This is important to prevent flooding and keep urban drainage systems effective. However, the ultrasonic sensors for detecting water levels can be affected by physical disturbances such as dirt, dust, or plants around the sensor, which may obstruct sound waves and reduce measurement accuracy. Consequently, the sensors may be less effective in very turbid or foamy water conditions, which can impact the clarity of detection. On the other hand, threshold settings like 28 cm might be less flexible, considering that rainfall conditions can vary significantly from one region to another. Insights for future study can develop the AI-based detection algorithms that can adjust thresholds and identify other environmental factors, such as water flow or local rainfall, could improve the system's performance in varying weather conditions.

Test results show that notifications via Telegram were received quickly by residents, allowing them to take necessary precautions, such as staying home and avoiding outdoor activities. This feature increases people's awareness and response to their environmental conditions. Although Telegram notifications can enhance public response to environmental changes, there are challenges related to network coverage. Limited internet access in some areas or issues with cellular connectivity can lead to delays or failures in message delivery. Notifications via Telegram require users to have access to a device that supports the application and is connected to the internet, which may not always be available to everyone in more remote areas. Future study can develop more diversified notification system, such as through voice messages or other applications that are more commonly accessed in specific regions, while also taking local network capabilities into account, would further improve the effectiveness of the system in delivering information quickly and efficiently.

This monitoring system has significant potential in enhancing the response to environmental changes in urban areas. Further development is needed to address the existing limitations. Future research could focus on improving sensor accuracy, optimizing energy efficiency, and diversifying communication methods to expand the system's range and effectiveness. By overcoming these challenges, the system could become more reliable and dependable in handling various urban dynamics.

5.0 CONCLUSION

The IoT-based urban air monitoring and pollution mitigation system that has been developed shows positive results in various aspects. The IoT-based Urban Air Monitoring System is designed to accurately detect and monitor air quality, including dust particles, temperature, and humidity. Tests show that the sensors used provide consistent and reliable results under various environmental conditions. Automatic Pollution Mitigation Mechanism using 5V mini water pump is effective in reducing the negative impact of air pollution. The system successfully reduces the concentration of dust particles and air temperature by spraying water into the surrounding environment, demonstrating the efficiency of its automatic operation. Integration with Telegram for Resident Notifications has proven effective in notifying residents when air pollution levels exceed a specified threshold. Prompt notifications allow residents to take appropriate precautions, increasing their safety and environmental awareness.

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