I. INTRODUCTION

Banda Aceh is the capital of Aceh Province, the epicenter of governmental and economic operations and trade centers in Aceh Province. Banda Aceh is also the sixth largest and most populous city in Sumatra based on population and the westernmost city in Indonesia after Sabang. Therefore, the healthful environment of Banda Aceh needs to be maintained to support the daily activities of its communities. One of the factors that affect the healthful environment of Banda Aceh is the condition of its air quality. The significant presence of numerous vehicles and multiple industrial activities in Banda Aceh stands as the primary contributor to air quality degradation, leading to increased levels of pollutants such as carbon monoxide (CO), carbon dioxide (CO₂), and dust particles (PM₁₀).

To uphold healthy air quality for the communities of Banda Aceh, implementing hazardous gas monitoring is one of the viable solutions. Internet-of-Things (IoT) technology enables real-time air pollution monitoring by seamlessly transmitting data across networks, eliminating the need for direct human-to-human or human-to-computer interaction [1].

Efforts to monitor air pollution monitoring via wireless network technology have been extensively and widely carried out. For instance, M. Iqbal et al. [2] employed a Hybrid Mesh-Like Tree topology with a web-based application using WSN for air pollution monitoring, successfully displaying information about air pollution levels on the IPB Campus Dramaga. M. Fuad et al. [3] constructed a real-time CO air pollution monitoring system utilizing a wireless sensor network (WSN) with mesh topology, ZigBee protocol, and a web-based interface application for data management. Other scholars have carried out similar research studies [4-6].

This study incorporates distinct sensors of MQ-7 to sense CO, MQ-9 to sense CO₂, PM₁₀ to sense dust particles, DHT-22 to sense temperature and humidity, and anemometer to sense the wind speed. The monitoring process is conveniently accessible through a website interface, and the data can also be displayed on a mobile application, making it easier for users to access and enhancing efficient air quality monitoring.

The rest of this article comprehensively describes our work on doing the literature review in Section II, followed by the research method applied in this study in Section III. Finally, the result is discussed in Section IV and concluded in Section V.

II. LITERATURE REVIEW

A. Air Pollution

Air pollution can arise from either natural sources or human activities. Additionally, certain physical disruptions like noise pollution, heat, radiation, or light pollution are also categorized as forms of air pollution. The effects of air pollution vary in scope, ranging from direct and localized impacts to regional and even global consequences.

Table 1 illustrates the Air Pollutants Standard Index...
**Table 1. The range of ISPU numbers for different categories [7]**

<table>
<thead>
<tr>
<th>ISPU category</th>
<th>Color category</th>
<th>Number range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good</td>
<td>Green</td>
<td>1 – 50</td>
</tr>
<tr>
<td>Average</td>
<td>Blue</td>
<td>51 – 100</td>
</tr>
<tr>
<td>Not Healthy</td>
<td>Red</td>
<td>101 – 200</td>
</tr>
<tr>
<td>Bad</td>
<td>Orange</td>
<td>201 – 300</td>
</tr>
<tr>
<td>Dangerous</td>
<td>Black</td>
<td>≥ 301</td>
</tr>
</tbody>
</table>

Note: ISPU stands for “Indeks Standar Pencemar Udara” or Air Pollutant Standard Index ruled by the Minister of Environment and Forestry of the Republic of Indonesia under P.14/MENLHK/SETJEN/KUM.1/7/2020.

(ISPU) categories, as outlined in the regulations set forth by the Minister of Environment and Forestry of the Republic of Indonesia. ISPU is a dimensionless numerical measure to characterize ambient air quality at a specific location and time. This index gauges its impact on human health, aesthetic, and the well-being of other living entities.

**B. Internet-of-Things**

The IoT is a concept that enables specific objects to communicate and share data across a network without the need for direct human-to-human or human-to-computer interaction. This innovative concept comprises wireless technology, micro-electromechanical systems (MEMS), and the Internet [8]. These devices are embedded with sensors, software, and other technologies that enable them to gather and transmit data, often without requiring direct human intervention. Overall, IoT is a transformative technology that has the potential to revolutionize how we interact with the physical world and how various systems and processes are managed and optimized.

**C. ThingSpeak**

ThingSpeak is an open-source application designed for IoT applications, offering an API for collecting and storing data from connected devices accessible via the Internet or through Local Area Network (LAN). The platform encompasses a range of features provided by Thingspeak, including:

- Open API
- Real-time Data Collection
- Geolocation Data
- Data Processing
- Data Visualizations
- Device Status Messages
- Plugins.

IoT technology allows ThingSpeak to interface with various embedded devices and web services. It operates by utilizing an internet connection as a data sender. At the same time, the cloud-based infrastructure of ThingSpeak stores, analyzes, monitors, and processes the data obtained from sensors connected to microcontrollers hosts such as Arduino Uno, TI CC3200 modules, Raspberry-pi, and other hardware devices [9].

**D. Real Time System (RTS)**

Real-Time Systems (RTS) refers to systems designed with specific and predetermined time constraints while emphasizing accuracy and optimal performance throughout their operation. These systems are required to generate accurate responses within predefined timeframes. Any lapse in meeting these limits could lead to performance degradation or system failure. RTS are characterized by their logical correctness, which hinges on both the accuracy of the system’s output and the timely issuance of these results. The primary objective of Real-Time Systems is to ensure that tasks are executed within stringent temporal boundaries. These systems find application in various domains, including monitoring and controlling equipment such as sensors, actuators, assembly lines, telescopes, or other instruments. Additionally, real-time control is crucial in telecommunications equipment and computer networks, where precise timing and responsiveness are vital for seamless operation and communication [10].

**E. ESP 8266 NodeMCU**

In the pursuit of expanding their microcontroller unit (MCU) board offerings beyond the traditional AVR processors, Arduino.cc embarked on the development of new boards based on alternative processors like ARM/SAM MCUs. This evolution gave rise to boards like the Arduino Due, necessitating adjustments within the Arduino IDE to accommodate these changes. To facilitate this transition and enable Arduino C/C++ code compiled with the new processors, Arduino.cc was introduced to the Board Manager and the SAM Core. The Core, in this context, encompasses a collection of essential software components that serve as prerequisites for both the Board Manager and the SAM Core. The Core, in this context, encompasses a collection of essential software components that serve as prerequisites for both the Board Manager and the SAM Core to successfully compile Arduino C/C++ source code into machine language suited for the targeted MCU.

In parallel, a group of innovative ESP8266 enthusiasts took the initiative to craft an Arduino core specifically tailored for the ESP8266 Wi-Fi System-on-Chip (SoC). This Core, available on the ESP8266 Core GitHub web
page, empowers developers to harness the capabilities of the ESP8266 within the familiar Arduino environment. As illustrated in Figure 1, the pinout configuration of the ESP8266 NodeMCU serves as a graphical representation of its various pin functionalities and placements [8].

F. Arduino Uno

Arduino Uno is an electronic board with an ATmega328 microcontroller, a chip that functions as a computer. Arduino Uno contains a microprocessor (in the form of Atmel AVR) and is equipped with a 16 MHz oscillator, which allows time-based operations to be carried out correctly, and a 5 volts regulator (voltage generator). Figure 2 shows the pinout of the Arduino Uno-R3 [11].

G. DC Power Supply

The power supply is an electronic device that converts AC into DC to power hardware. An AC source is from an alternating voltage source, while a DC source is from a direct voltage source. DC power supply or adapter has 4 main parts to produce a stable DC current. The four main parts include transformer, rectifier, filter, and voltage regulator [12].

H. Integrated Development Environment (IDE)

In Arduino programming, the integrated development environment (IDE) emerges as a pivotal tool. This application, readily available for download from the official Arduino website, is a comprehensive platform for programming Arduino boards. It has functionality for text editing, enabling the creation, opening, modification, and validation of code intended for subsequent upload to the Arduino board. Within IDE, the programming unit is called a “sketch,” an Arduino source code file with the “.ino” extension.

I. Carbon Monoxide Sensor (MQ-7)

The MQ-7 is a simple carbon monoxide (CO) sensor that detects CO concentration in the air. It can detect CO-gas concentrations anywhere from 20 to 2000 ppm. Ppm CO levels measurements were obtained from a comparison between the resistance of the sensor detecting CO (Rs) and the sensor not detecting CO (Ro) [13].

J. Carbon Dioxide Sensor (MQ-9)

The latest high-precision CO2 infrared analogue sensor has an effective measurement range from 0 to 5000 ppm. This sensor is based on non-dispersive infrared technology and has good selectivity and oxygen-free dependence [4].

K. Dust Particles Sensor (PM10)

It is an infrared-based dust sensor. The principle of this sensor, the light is reflected on the particles passing through the entire surface, and then the photodiode is converted into a voltage.

L. DHT-22 Sensor

The DHT-22 is an embedded temperature and humidity sensor, boasting a digital signal output meticulously calibrated via a sophisticated temperature and humidity sensing mechanism. This advanced technology guarantees heightened reliability and ensures prolonged stability over time. The sensor is seamlessly integrated with an 8-bit high-performance microcontroller, contributing to its robust functionality. Notably, each DHT22 sensor has an extremely precise humidity calibration, meticulously executed within a controlled calibration chamber [14].

M. Anemometer Sensor

Wind speed characterizes how fast air traverse certain points or a designated location. This measurement can be computed as an average across a defined time interval, often expressed in units like miles per hour. Alternatively, it can also be assessed as an immediate reading denoted as peak wind, gust, or storm speed, capturing the highest velocity reached at a given moment [15].

III. METHODOLOGY

Table 2 displays the elements employed for building a prototype IoT system for air quality monitoring in air pollution case studies. Meanwhile, the stages of building the prototype are shown in the flowchart depicted in Figure 3.

A. Research Work Flow

The flowchart of the study is outlined as shown in Figure 3. The stages involved in designing the prototype commence with two key components: hardware and software design. In the hardware design phase, the assembly of hardware devices takes precedence, while the software design includes the implementation of Arduino...
programming and the installation of ThingSpeak.

Following the completion of these design phases, a prototype trial is initiated. Upon successful validation of the prototype, the subsequent step involves conducting comprehensive data analysis, facilitating insights and conclusions drawn from the acquired information.

### IV. RESULTS AND DISCUSSION

The prototype design yields a comprehensive array of six sensors, including Carbon Monoxide (CO) sensor, Carbon Dioxide (CO$_2$) sensor, wind speed sensor (anemometer), dust particles (PM$_{10}$) sensor, temperature sensor, and humidity sensor, with the concept of IoT using Arduino based on android applications and Wi-Fi communication. This system is intended for remote monitoring.

Illustrated in Figure 4 is the designed hardware system prototype. This comprehensive circuitry integrates the interconnections between various components. The prototype features Arduino linked to the NodeMCU for Wi-Fi connectivity. Furthermore, the CO, CO$_2$, anemometer, humidity, and temperature sensors establish connections to the Arduino microcontroller, fostering sensor data acquisition. The communication between these devices is facilitated through serial Inter-Integrated Circuit (I2C) communication.

#### A. Prototype Communication Test to Server (Thingspeak)

During this testing phase, the evaluation of communication between devices encompasses examining the source code software employed for the sensors being tested. The software's functionality is assessed by connecting the Arduino IDE, the Arduino board, the ESP8262 module, and the sensors. To enable seamless communication and connectivity, Arduino is linked with the ESP8266. This configuration facilitates the ESP8266's ability to connect to a pre-configured Wi-Fi network. Subsequently, as data is gathered and processed, the ESP8266 is responsible for transmitting this processed data to the Thingspeak server. This data transmission is executed using the Transmission Control Protocol/Internet Protocol (TCP/IP), ensuring a robust and reliable transfer of information.
This testing phase is essential to validate the coordination and efficacy of the software components involved in the data acquisition, processing, and transmission process within the IoT framework.

Figure 5 illustrates the interface presented upon accessing the Air Pollution channel. This visual representation shows data derived from six distinct sensors. As can be seen in Figure 5, it has succeeded in displaying data values from the sensors. When the sensor is turned on, it will show 0 value. Then, the sensors will detect the temperature and humidity. For instance, the temperature reading is accurately depicted as 28 degrees Celsius, while the humidity reading corresponds to 82. The visual depicted within Figure 5 serves as conclusive evidence of the successful functioning of the air monitoring system.

### B. Data Collection

The data collection process was carried out at two locations, namely the Simpang Lima Intersection area and the Jeulingke Bus Stop area in Banda Aceh.

1. **Simpang Lima Intersection Banda Aceh**

   The data collection process was carried out on Tuesday, January 4th, 2022, as initial data gathering after the conclusive rectification of various prototype anomalies. As shown in Figure 6, the prototype was strategically positioned approximately 0.5 meters above the road surface in this stage. The data recording process was conducted within the time frame from 10:23 AM to 1:40 PM.

   The highlighted red circle in Figure 7 shows the precise geographical region from which data was gathered, employing Google Maps as a reference. During data collection, which exceeded two hours, the study was conducted within the Simpang Lima Intersection area of Banda Aceh. It is pertinent to note that, during this data gathering, a series of intermittent network disruptions were encountered. These disruptions were attributed to the utilization of a personal smartphone hotspot as the means of establishing Wi-Fi connectivity.

2. **Jeulingke Bus Stop Banda Aceh**

   The next data collection process was carried out two days after the initial data collection, on Thursday, January 6th, 2022, due to rainy weather conditions in the earlier several days. At this stage, the researcher strategically positioned the prototype approximately 1 meter above the road surface as shown in Figure 8. The data recording process was conducted within the time frame from 09:55 AM to 2:20 PM. The readings are derived within a capturing radius of approximately 5 to 10 m from the sensor’s location.

   In Figure 9, the highlighted red circular marker shows the specific region chosen for data collection area, as depicted on Google Maps. The data collection is carried...
over duration of two hours within the area.

C. Prototype Performance Analysis

1. Comparison of the prototype with the AQMS (Air Quality Monitoring System) DLHK3 Banda Aceh Station

There are 9 sensor parameters employed for air quality monitoring at AQMS DLHK3 station, Banda Aceh, namely: SO2, CO, O3, HC, PM10, PM2.5, anemometer, and DHT (Temperature and humidity) sensors. Meanwhile, the prototype has been developed utilizing 5 sensors: CO, CO2, PM10, DHT22 (temperature and humidity), and anemometer. The AQMS DLHK3 station is permanently located in the governor's office. Sensor readings from this station are then similarly visualized on the ISPU display unit in Simpang Lima Intersection, Banda Aceh. In comparison, the prototype is designed to be portable, offering deployment flexibility in various locations, with monitoring facilitated exclusively through a smartphone application. The AQMS DLHK3 Banda Aceh and the prototype have shared similar 2 air pollution sensor parameters: CO and PM10 sensors. This similarity provides an opportunity for comparison, enabling an estimation of the accuracy of the prototypes. The comparison is drawn between the CO and PM10 sensor data collected by the prototype at the Jeulingke Banda Aceh bus stop area and the data generated by AQMS DLHK3 Banda Aceh.

Table 3 shows that the data obtained from the air pollution detection equipment owned by DLHK3 Banda Aceh are much lower than the data obtained by the prototype. This variance is due to factors of geographical location and altitude disparities between the two monitoring points.

Figure 10 clearly illustrates the separation between the DLHK3 equipment and the prototype equipment, measuring approximately 59.66 m in distance. This spatial disparity fundamentally contributes to the observable variations in the acquired results. Notably, the dissimilarity in detector readings stems from the specific positioning of the devices in relation to the primary source of air pollution—the adjacent highway. Furthermore, the vertical positioning or height differential introduces another influential factor. The AQMS DLHK3 station is positioned at an altitude of roughly 2 meters above the ground surface. Conversely, the prototype's location maintains an altitude of approximately 1 m above the ground. This divergence in altitude introduces variance in the air pressure experienced by each device. It's crucial to note that while air pressure does influence the readings, its impact on the differences observed is relatively marginal. The primary influence is the spatial distance and dispersion of pollution sources originating from lower areas.

The relative height above sea level contributes to air pressure dynamics. However, it's noteworthy that both locations exhibit comparable air pressure levels due to their similar heights above sea level, thereby minimizing the impact of air pressure differentials on the observed result disparities.

2. Communication Delay Testing

During each reading cycle within the application and microcontroller, assessing potential communication delays across various communication pathways is important. These include the communication segments such as Arduino-NodeMCU, NodeMCU-ThingSpeak, and Arduino-ThingSpeak.

Table 3 The air pollution data detected by DLHK3 and proposed prototype at Jeulingke Bus Stop Banda Aceh

<table>
<thead>
<tr>
<th>No</th>
<th>Air detector</th>
<th>CO (µg/m³)</th>
<th>Dust (µg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>DLHK3</td>
<td>2020</td>
<td>9</td>
</tr>
<tr>
<td>2</td>
<td>Proposed prototype</td>
<td>2572.34</td>
<td>46</td>
</tr>
</tbody>
</table>

Figure 10. Estimated distance between the location of the DLHK3 and the prototype equipment
Communication between Arduino and NodeMCU exhibits negligible delay, owing to their direct wired connection that facilitates serial communication. In contrast, NodeMCU communicates with ThingSpeak over the internet. NodeMCU sends data every second to ThingSpeak's servers. However, due to the constraints of a free-tier ThingSpeak account, the server processes and retrieves sent data every 15 seconds.

In the context of Arduino to ThingSpeak communication, a delay of approximately 1.1 seconds is recorded. This delay encompasses the time taken for data transmission and processing. It's imperative to note that these delays play a role in the overall timing and synchronization of data exchange within the IoT system.

V. CONCLUSION

The study's findings lead to the conclusion that the developed IoT-driven pollution monitoring system effectively facilitates real-time surveillance of Carbon Monoxide (CO), Carbon Dioxide (CO₂), dust particles (PM₁₀), temperature, and humidity levels. By successfully utilizing sensor readings, the system seamlessly enables wireless air pollution monitoring. This achievement is realized through the synergistic utilization of ThingSpeak and mobile applications, achieving a communication delay of approximately ±1.1 seconds.

This air pollution monitoring prototype emerges as a versatile tool, bestowing the convenience of portable, anytime, and anywhere monitoring air pollution levels. Notably, it empowers users to track air quality dynamics effortlessly.

However, it's important to highlight that the anemometer sensor incorporated within this prototype currently has limitations. The sensor exhibits insensitivity to minute wind movements, resulting in an inability to measure wind values accurately. Despite this constraint, the prototype is a commendable achievement in IoT-driven air pollution monitoring.

REFERENCES