Automatic Air Quality Detection System Design in the Industrial Area

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Abstract - The industrial sector is an essential component of the economic structure. A large number of current enterprises degrade air quality in the environment as a result of chemical exposure. As a result, an air quality detection system was designed with the purpose of monitoring air pollutant levels, temperature, and humidity. The system is immediately integrated with smartphones via the Internet of Things. Carbon dioxide (CO_2) and carbon monoxide (CO) levels are measured using a MQ-135 sensor. Temperature and humidity are measured using DHT-11 sensors. The complete system is controlled by a NodeMCU ESP8266 connected to an Arduino. Data was collected from two industries using an IoT-based system for a continuous 24-hour cycle over seven days to capture real-time daily fluctuation trends. The continuous 7-day monitoring reveals a clear daily fluctuation trend synchronized with factory shifts, peaking between 12:00 and 14:00 WIB. Dutatex exhibits a higher pollutant load (peak CO_2: 820–850 ppm; CO: 8–9 ppm) than Bimatex (peak CO_2: 620–650 ppm; CO: 5–6 ppm), while both facilities successfully maintain peak temperatures below 33.0°C. These empirical results demonstrate that continuous 24-hour data acquisition provides a highly accurate and comprehensive assessment for monitoring industrial air quality and occupational health.

Keywords - Air Quality, NodeMCU ESP8266, IoT, MQ-135, Arduino.

1. INTRODUCTION

The textile industry is an economic sector that converts raw fiber materials into yarn, fabric, and completed items, including apparel and home goods [1, 2]. This industry covers the full supply chain, from development to distribution, and is critical to the economy [3]. The manufacturing process begins with the transformation of fibers (natural or synthetic) into yarn (spinning), then fabric (woven or knitted), and lastly a finished product ready for use [4]. The industrial sector is one of the most important manufacturing sectors in the national and worldwide economies, with a large workforce [5].

Indonesia is known for its extensive textile industry[6]. The textile and textile products sector has long been an important manufacturing sector in Indonesia, contributing significantly to the economy through employment and exports [7]. Pekalongan is one of Indonesia's cities with a strong textile industry, particularly in batik, a vital economic engine [8]. The batik business in Pekalongan has long been a part of people's lives and is an important component of their lives [9].

The textile sector emits pollutants like VOCs, PM, SO_2, and NOx, which can cause respiratory difficulties [10]. Furthermore, the industry's energy-intensive processes contribute significantly to greenhouse gas emissions and climate change, as well as the formation of smog and acid rain [11].

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The temperature and humidity of the surrounding environment might be affected by air quality caused by the vast number of textile companies [12]. This influence is mostly caused by greenhouse gas emissions and particulate matter discharged into the atmosphere [11]. The textile sector, particularly through its energy-intensive manufacturing processes, contributes significantly to world carbon emissions (about 10% of total global emissions) [5]. Greenhouse gases include carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), which are produced when fossil fuels are burned to run manufacturing machinery and boilers [1]. High humidity can degrade air quality because air pollution particles (such as PM10) cannot easily disperse into the atmosphere and instead remain suspended in humid air [13].

Air quality in Pekalongan is generally considered moderate, but the industrial sector, particularly the batik industry, contributes significantly to environmental issues [14]. According to real-time data from air quality monitoring systems (such as IQAir and The Weather Channel), the Air Quality Index (AQI) in Pekalongan is typically moderate (51-100)[15]. This signifies that the air quality is adequate, but it may cause moderate health risks to a limited group of persons who are sensitive to specific contaminants [16].

Several recent investigations have been conducted to determine the effects of general industrial exposure on air quality. These studies include an air quality monitoring system in general industry using multi-pollutant sensors [16]., a real-time air quality monitoring system utilizing electrochemical sensors [17], and an air quality monitoring system based on machine learning algorithms [18].

The Internet of Things (IoT) is a network of physical devices connected via the internet that automatically gather, exchange data, and communicate without human involvement [19]. This concept enables items such as sensors, machines, and appliances to connect with one another and with the cloud in order to control and automate numerous activities, increase efficiency, and simplify life [20]. IoT devices have sensors that collect data from their surroundings [19]. This data is subsequently transmitted across the internet to other devices or the cloud [20]. The received data is used to execute automated commands [21]. Humans serve as regulators and supervisors, but they are not required to continually contact directly with each device [13].

This research extends beyond the publicly released technical implementation of a basic IoT architecture based on the NodeMCU ESP8266, MQ-135 sensors, and DHT-11. This study is unique in that it analyzes situational data on air quality fluctuations in the batik industry cluster in Pekalongan, which has distinct pollutant characteristics from the fabric manufacturing process. Unlike prior research, which focused solely on the data transmission mechanism to the Blynk platform, this study investigates the real-time relationship between artisanal industry production activities and local air quality degradation. Thus, the primary contribution of this research is not hardware assembly, but rather modeling air pollution profiles in dense creative industry locations, which can be used to inform local governments' environmental impact mitigation policies.

2. RESEARCH METHOD

The study was undertaken at PT Duta Ananda Utama Textile (Dutatex) Pekalongan. This company works in the textile industry, primarily creating Sapphire brand textiles and sarongs. The second location is near PT Bama Prima Textile (Bimatex). PT Bimatex is a significant manufacturing company in Pekalongan that produces high-quality fabrics. The research monitoring was conducted using an IoT-based data acquisition system, enabling continuous 24-hour recording over a seven-day production cycle. This automated approach was implemented to capture real-time daily fluctuation trends of CO_2, CO, temperature, and humidity, providing authentic empirical evidence of environmental changes during both peak operational hours and non-production periods.

Figure 1a shows the block diagram of the tool design, while Figure 1b depicts the sensor system circuit. The autonomous air quality detection system in the Pekalongan industrial area measures polluting gases, specifically CO_2 and CO gas, as well as their impact on the temperature

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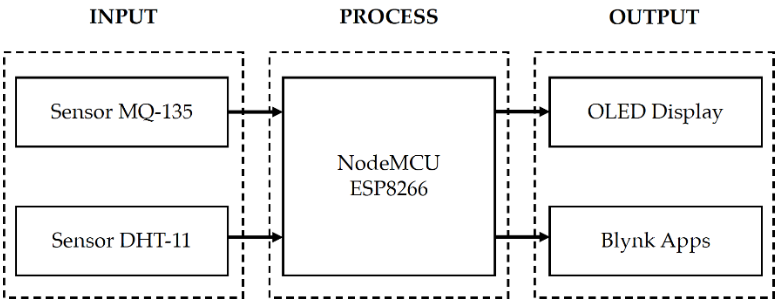
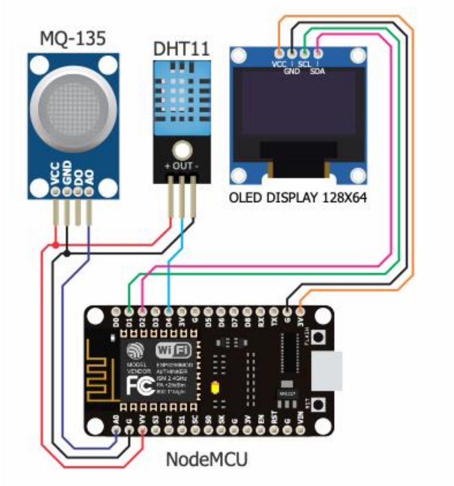
and humidity of the air surrounding the industry. The major components of the air quality detection system in this study are the NodeMCU ESP8266 microcontroller, which regulates system operations, the MQ-135 sensor, which measures air quality, and the DHT-11, which measures temperature and humidity. The ESP8266 was utilized in this investigation due to its low cost and ease of integration. The main advantage of this module is its ability to connect devices directly to the internet network via integrated Wi-Fi connectivity, eliminating the need for other modules. From a development standpoint, the ESP8266 is extremely versatile because it supports a variety of popular programming environments, including the Arduino IDE. With its dependable signal range stability and low cost, the ESP8266 is an excellent choice for prototype-scale research on air quality monitoring systems. The system is immediately integrated with the Blynk app for smartphones via the Internet of Things. The data of CO_2, CO, temperature, and humidity readings can also be seen on an OLED display.



(a)



(b)

Figure 1. (a) Block diagram of tool design. (b) Sensor system circuit.

The MQ-135 sensor's analog signals are converted into parts per million (ppm) values by calculating the sensor resistance ratio. This technique begins with determining the sensor resistance in clean air (R_0) as a reference point, which is then compared to the sensor resistance when exposed to the target gas (R_s). To acquire specific ppm values for CO_2 and CO gases, use the power regression formula with the sensor characteristic curves from the datasheet. The curve constant parameters (a and b) are changed based on the sensor's sensitivity to each gas to ensure reading accuracy when using the standard sensor library. To convert analog readings to ppm values, use equations 1 and 2 [22].

$$R_s = \left(\frac{V_c \; x \; R_L}{V_{out}}\right) - R_L \quad (1)$$

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$$PPM = a\ x\ \left(\frac{R_s}{R_0}\right)^b \quad (2)$$

Where V_c is the input voltage, V_{out} is the output voltage, R_L is the sensor module's load resistor, R_0 is the sensor resistance in clean air, an is the intercept constant, and b is the curve slope.

3. RESULTS AND DISCUSSION

The MQ-135 sensor detects a wide range of chemicals, including ammonia (NH_3), benzene, alcohol, smoke, and carbon dioxide (CO_2) [13]. Its main advantages are its high sensitivity to hazardous gases in the air and its integration flexibility, as this sensor outputs two types of signals: a digital signal for specific threshold detection and an analog signal (0-4.2V) for more precise concentration measurements in Parts per Million (PPM) [23]. The MQ-135 sensor uses Tin Dioxide (SnO_2) to maintain stability and respond quickly to changing environmental conditions [24]. Furthermore, its small size makes it an excellent choice for portable air quality monitoring devices and IoT systems that require real-time pollution detection.

The DHT-11 sensor can monitor temperature and humidity in a single, cost-effective module [25]. The primary advantage of this sensor is its digital data output, which eliminates the requirement for external analog-to-digital conversion (ADC) and reduces the possibility of signal interference during data transmission. The manufacturer has calibrated the DHT-11 to deliver stable relative humidity (20-90% RH) and temperature (0-50°C) data over time [26]. In practice, this sensor is extremely efficient because it only requires a single data cable interface, which saves pin consumption on microcontrollers like the ESP8266 and Arduino. Figure 2 depicts the design of an industrial air quality detecting system.

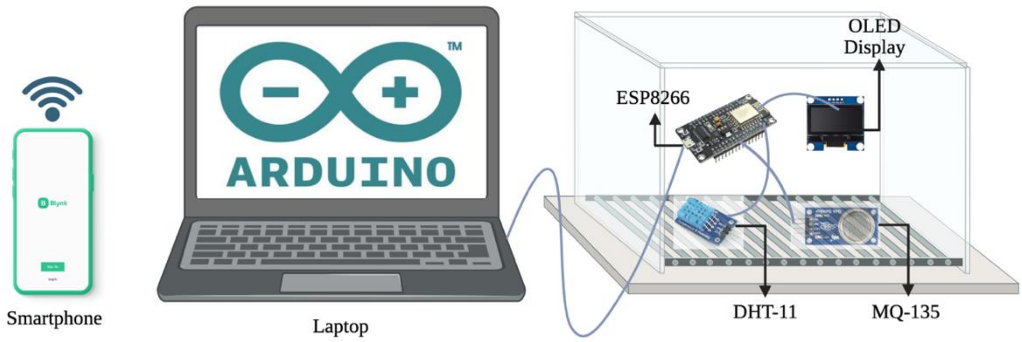

Figure 2. Design of an IoT-based air quality detection system.

The results of intensive monitoring over seven days with a full 24-hour cycle revealed a very apparent daily fluctuation pattern at both research sites, Dutatex and Bimatex (Figure 3). The findings reveal that the concentration of emission gases such CO_2 and CO, as well as environmental temperature parameters, are heavily influenced by the industrial operational rhythm. In the early morning (00:00-05:00 WIB), all parameters are at their baseline, reflecting environmental conditions independent of machine activity. However, because the production process begins at 06:00 WIB, gas concentrations and temperatures gradually increase until they peak in the afternoon between 12:00 and 14:00 WIB. Peak CO_2 emissions at Dutatex were found to be higher than at Bimatex, indicating a higher workload intensity or machine capacity at that site. Thermal characteristics at both sites demonstrate a synchronous trend with the increase in pollutant gases, with room temperature rising but remaining below the maximum limit of 33°C based on revised measurement data. This is followed by a large fall in air humidity as the temperature rises, supporting the negative association between temperature and humidity in the manufacturing region. Empirically, the graph pattern, which creates a repeated cycle over seven

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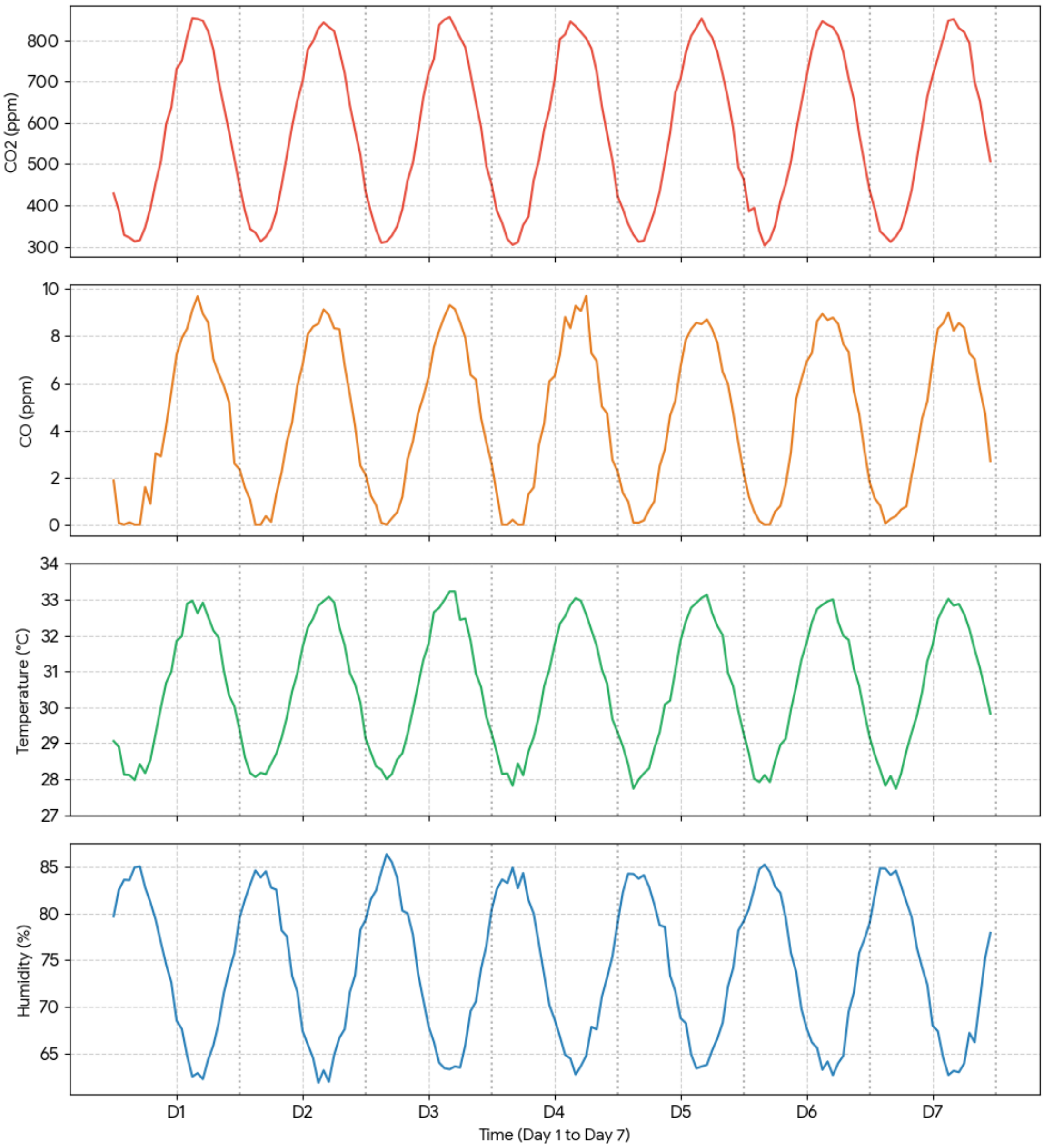
days, shows that industrial machinery is directly responsible for gas and heat emissions in the study area, rather than constant background pollution.



(a)

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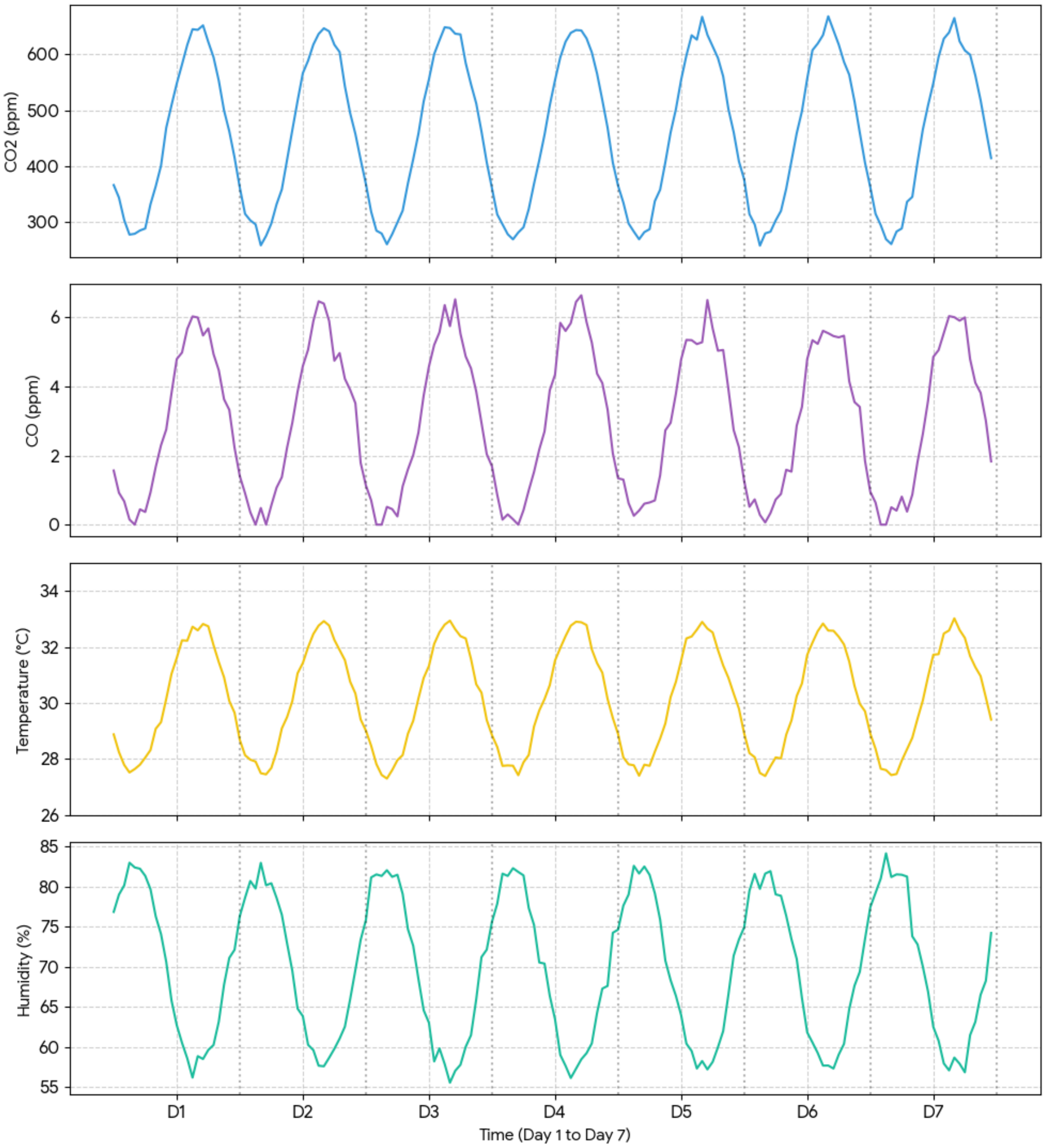

(b)

Figure 3. (a) Dutatex (b) Bimatex.

Further empirical comparisons of the two locations reveal that Dutatex accumulates gaseous pollutants at a substantially faster rate than Bimatex throughout the production cycle. During peak operating hours, CO_2 concentrations at Dutatex reach 820-850 ppm, while Bimatex's are substantially lower, at 620-650 ppm. This huge discrepancy is accompanied by greater CO levels at Dutatex (8-9 ppm) than at Bimatex (5-6 ppm), indicating that the mechanical capacity, volume of combustion activity, or machine density in the Dutatex production region is significantly larger. Nonetheless, the temperature profiles at both locations exhibit very identical trends, with peak temperatures effectively maintained below the 33°C threshold, with Dutatex at 33.0°C and Bimatex at 32.8°C. This extremely near temperature stability suggests that both plants use quite adaptive ventilation systems or spatial layouts, despite Dutatex having a substantially higher gas emission load. As a result of this temperature control, the humidity decrease in Bimatex is less dramatic (at least 56%) than in Dutatex (at least 52%), resulting in a slightly more stable

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micro-thermal workspace environment. This long-term observation yields a more accurate empirical picture than instantaneous data collection, allowing the recorded daily fluctuation dynamics to serve as a solid foundation for studying work environment management in the Pekalongan textile industry. Figure 4 depicts the relationship between CO_2 and CO as a function of air humidity and temperature.

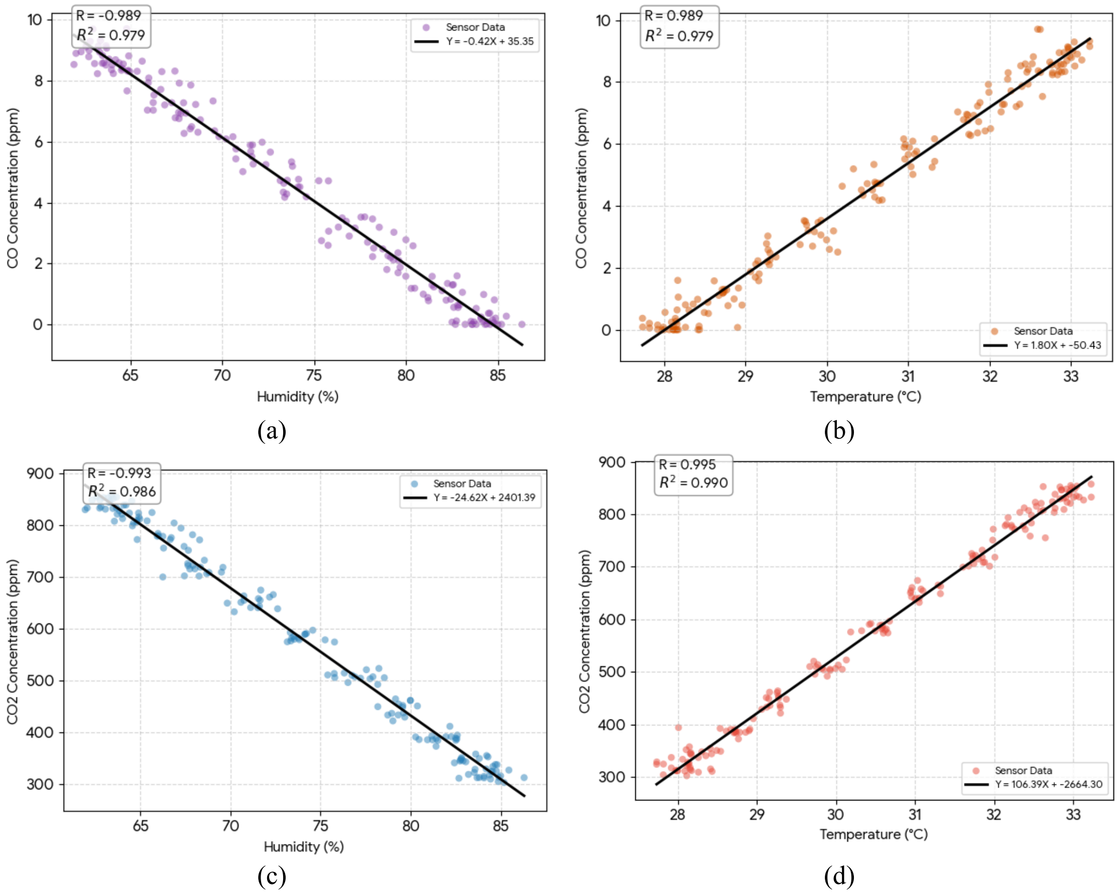

Figure 4. (a) Correlation of CO and air humidity. (a) The relationship between CO and temperature. (c) The relationship between CO_2 and atmospheric humidity. (d) The relationship between CO_2 and temperature.

The lower the humidity inside the factory, the faster the concentration of CO_2 and CO gas builds up. Dry air in the manufacturing area is a significant indicator of the accumulation of dangerous pollutant gasses as a result of mechanical activity. This linearly expanding regression line demonstrates that every increase in temperature in the factory area corresponds exactly to an increase in the amount of stored CO_2 and CO gasses. The coefficient of determination R2 values above 0.96 for these four regression models demonstrate that changes in temperature and humidity accurately explain over 96% of the variation in pollutant gas accumulation in the factory region. This occurrence demonstrates that thermal radiation and gas emission release come from the same source, which is the combustion activity and operation of textile industry equipment during the manufacturing cycle.

4. CONCLUSION

Based on the findings of the research and analysis, the following conclusions can be drawn: CO_2, CO, temperature, and humidity in the Pekalongan industrial region can be detected using an air quality detection system based on the ESP8266 microcontroller, MQ-135 sensor, and

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DHT-11 sensor. The system was developed automatically utilizing IoT technology incorporated into a smartphone. Continuous 24-hour monitoring over a 7-day cycle confirms that gas emissions CO_2 and CO and thermal variations are strictly driven by industrial production schedules, with Dutatex exhibiting higher pollutant loads than Bimatex. Furthermore, linear regression models validate a near-perfect statistical correlation ($R^2 > 0.96$), demonstrating that temperature shares a strong positive linear relationship with gas accumulation, while humidity displays a strong inverse correlation. These empirical findings confirm that thermal radiation and gas emissions originate from the same mechanical source, proving that long-term continuous data acquisition provides a highly accurate assessment for factory ventilation and occupational health management.

5. ACKNOWLEDGMENT

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