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Evaluating the Internet of Things Platform for CO2 Monitoring in Sugar Refineries

Des Try Ashilah[a], Mita Dian Cahyani[a], Rahmatan Amartya Ula[a], Khamdan Cahyari[b*]

[a]Undergraduate student of Chemical Engineering Department, Faculty of Industrial Technology, Universitas Islam Indonesia, Jl. Kaliurang Km. 14.5 Yogyakarta 55584, Indonesia
[b]Dept. Chemical Engineering, Faculty of Industrial Technology, Universitas Islam Indonesia, Jl. Kaliurang Km. 14.5 Yogyakarta 55584, Indonesia

Corresponding author: khamdan.cahyari@uii.ac.id

Abstract

The sugar cane industry in Indonesia makes a substantial contribution to CO_2 emissions, which have a negative impact on the environment and society. This study attempts to incorporate the Internet of Things (IoT) as a reliable indicator of air quality in the sugar cane industry, specifically focusing on the CO_2 metric. The research aims to monitor the air quality and provide air quality information. This aligns with the eleventh Sustainable Development Goal, which emphasizes the importance of Sustainable Cities and Communities. The implementation of a smart factory concept utilizes IoT technology to actively monitor and analyze gas emissions in real-time monitoring and assessment of the air quality so that when the CO_2 level exceeds the safe limit, it can provide a warning and appropriate action can be taken immediately. The system comprises a PIC microcontroller, an ESP-8266 (wi-fi) module, and a gas analyzer. These components work together to identify and alert users when gas emissions exceed pre-established thresholds. Furthermore, the system provides consumers with regular data and notifications, thereby enhancing environmental management and monitoring. The evaluation of IoT-based CO_2 monitoring can raise public awareness and air quality information. Aligning with the United Nations' Sustainable Development Goals, implementing IoT technology in the sugar industry offers a practical approach to reducing emissions and promoting sustainability.

Keywords: Gas analyzer, Gas emission; Internet of things; Sugar industry; Sustainability development goals

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1. Introduction

The CO_2 emissions can negatively impact the environment, especially global warming and climate change. Naturally, the earth has its cycle to capture and sequester CO_2 which maintains the balance of CO_2 in the atmosphere, such as photosynthesis. However, the CO_2 cycle has been disturbed due to human activities such as deforestation and the burning of fossils. The side effects are species extinction, pollution, rising sea levels, unstable food security, and even threats to economic stability [1]. Air pollution has caused respiratory diseases among patients in Indonesia. Approximately 22% suffer from acute upper respiratory infections, 7.7% from upper respiratory tract diseases, and asthma takes up to 2.2% [2].

In the 1930s, Indonesia stood as the largest sugar exporter worldwide after Cuba [3]. sugarcane agriculture has increased by over 2.7 hectares for the state's plantations and has increased by around 11,680 hectares for the private plantations from 2020 to 2021 [4]. Madukismo sugar industry is one of the sugar production in Yogyakarta, Indonesia which was part of the PT Madubaru in 1995 [5].

The Madukismo sugarcane industry starts with the milling station the sugarcane raw material to extract the sugarcane juice, the outcome of this process is raw sap and sugarcane bagasse. The bagasse is utilized as fuel in the boiler stations. Components of water, sucrose, monosaccharides, organic acids, protein, wax, inorganic materials, and dirt are present in the raw sap. The raw sap goes to the purification station to remove 10-25% of the impurities, that is the non-sugar components with a continuous alkaline suffocation system. The water in the purified sap is reduced through the evaporation station which changes the sap concentration from ±150 brix to a minimum of 600 brix. The concentrated sap is crystallized in the crystallization station by evaporating the water content which will produce crystallized thick sap. The sugar crystal and Stroop from the crystallized thick sap are separated in the separation station using a centrifugation process at a speed of 0-1000 rpm. The treatment station is the final step to dry, filter, and pack the sugar before commercialization [6]. There are three types of waste produced by the industry. The wastes are identified based on their phases, thus the solid, liquid, and gas wastes. The usage of boilers to produce heat in the industry has produced around 28.56% of the process CO_2 emissions to the surrounding environments [5].

Table 1. Total CO_2 emissions from process fuel source in madukismo [7].

Process Fuel Sources	Annual Total CO_2 emissions (tCO_2)	Percentage (%)
Sugarcane Bagasse	122,223.56	93
Fuel Oil	4,537.18	3
Firewood	4,692.51	4
Total CO_2 emissions	131,453.25	100

The development of technology in the aspects of the Internet of Things, and the ever-changing environment, raises potentiality in the application of the Internet of Things in the sugar cane industry as a Smart factory. A smart factory, as defined in the context of Industry 4.0, is a manufacturing or production system characterized by interconnected processes and operations via cyber-physical systems, the Internet of Things (IoT), and state-of-the-art digital technologies [8][9]. This concept represents the ultimate goal of digitization in manufacturing, where the production floor is highly digital and collects and shares data continuously through connected devices and production systems [10].

The use of technologies in advanced and coordinated systems to self-operate and optimize manufacturing processes is the rise of Smart Manufacturing Systems. Smart factories predominantly in technology-based solutions that are efficient, event-driven, and information-driven. With its ability to give real-time responses to carry out customer needs and changing demands, it has the advantage of improving efficiency and quality while managing waste and costs in small amounts [11]. The use of smart meters in collaboration with external services can deliver real-time data and make decisions, such as by improving energy efficiency in the production process and a factory automation system in environmental controls [12].

The proactive system detects abnormalities, manages quality control, and monitors safety and maintenance. This results in a prediction and fast response time for the employees and systems before the problem occurs. This proactive capability of smart factories may enhance uptime, productivity, and quality while avoiding security risks [29].

A study created an IoT-based system to measure real-time CO_2 contents with NODE MCU-ESP8266 module, MQ135 gas sensor, and DHT-11 sensor [13]. It offers comprehensive information on indoor CO_2 levels to ensure the health and safety aspects of the environment. It uses ThingSpeak to plot real-time temperature, humidity, and CO_2 against a time graph [13]. A CO_2 IoT-based monitoring uses NodeMCU ESP8266, DHT-22 sensor, and MQ-135 sensor in building rooftop areas [14]. It was proven that the system shows lower CO_2 levels in a garden-exhibited area compared to an ordinary roof area which indicates an efficient CO_2 identification, thus manifesting bright future aspects of the system.

The high CO_2 emissions and their negative impact on the environment and society have pushed future generations to solve the issue. The industry plays an important role in CO_2 emissions, and the reliability of IOT applications in the smart industry has opened another potential for a more efficient and intelligent industry. This paper proposes an idea to integrate IOT as a good air quality indicator based on the CO_2 parameter in the sugar cane industry as its way to obtain the Sustainability Development Goals Number 11 Sustainable Cities and Communities.

2. Method

2.1 Material

2.1.2 Gas Analyzer (MQ-9 Sensor)

An instrument called a gas analyzer is used to determine the composition and ratios of a gas component. An analyzer for gases can measure the following: carbon dioxide (CO_2), oxygen (O_2), and carbon monoxide (CO). Gas analyzers are frequently utilized in the manufacturing sector to enhance safety and production procedures. In the automotive industry, gas emission testing equipment is used to monitor the combustion gasses from cars or motorbikes in order to conduct research and develop a plan of action to guarantee that the engine of the vehicle satisfies regulations

[15]. The MQ9 gas sensor is very sensitive to methane, carbon dioxide, and carbon monoxide. The sensor is inexpensive, versatile, and capable of detecting a variety of gasses, including flammable gasses and those that include carbon monoxide. The CO and CO_2 detectors have a 10-1000 ppm and a 100–10,000 combustible gas capability, respectively.

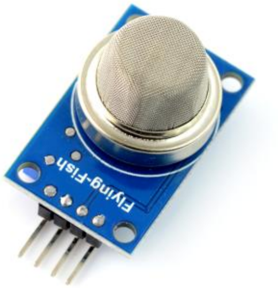

Figure 1. MQ-9 sensor.

The sensor detects the changes in the electrical resistance when different gas concentrations happen with the use of a metal oxide semiconductor (MOS) which is sensitive to CO_2. The CO_2 will change the electrical conductivity of MOS by binding, where the conductivity changes are directly proportional to the air CO_2 concentration [16].

2.1.3 *ESP-8266 (wi-fi)*

Internet access can be linked to a Wi-Fi network. The USART module of the PIC works on +5v, and it was used to send the program via a serial communication channel using AT commands. Additionally, it is possible to converse via the Internet from any location at any time in several locations [17].

Figure 2. ESP-8266 (WI-FI).

2.1.4 *PIC Microcontroller*

A PIC microcontroller has 32 digital input/output pins, including several types of analog, serial, and interrupt pins. The PIC microcontroller is an independent controller unit that may be programmed using the MPLAB compiler. It is the ideal microcontroller to utilize because it features flash memory storage. The amount of power used is lower. It might also be able to communicate with various sensors [17].

Figure 3. PIC microcontroller.

2.2 *Method*

The method that is used consists of 4 phases [18]. Those phases are to observe the application, identify the problem, develop the solution, and test the solution (see Fig. 4). In this paper, the method is only until the second phase.

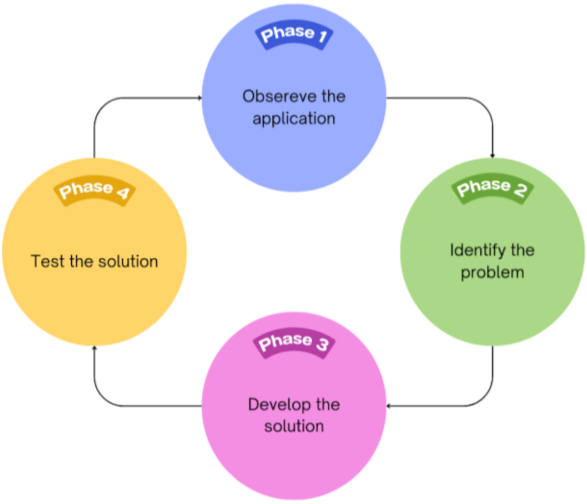

Figure 4. Methodology scheme [19].

In the first phase of the methodology, the CO_2 levels or ranges that needed to be considered were determined by characterizing the variable that the Internet of Things system would monitor. Thus, the CO_2 levels to be taken into account in this study are shown in Table 2.

Table 2. CO_2 levels and range.

Range (ppm)	**Level**	**Description**
$CO_2 < 400$	0	Outdoor Spaces
$400 \leq CO_2 < 800$	1	Good ventilation
$800 \leq CO_2 < 1500$	2	Stifling space
$1500 \leq CO_2$	3	Inadequate ventilation

This phase also included looking into and choosing free hardware and software tools for CO_2 monitoring and analysis in the factorial field. However, in phase 2 of the methodology, taking into account the four layers of the IoT architecture (capture, storage, analysis, and visualization), the architecture of the IoT system to be implemented was specified in three views (business, functional, and implementation). The technologies and tools chosen in the first phase were considered.

2.3 *Framework of Method*

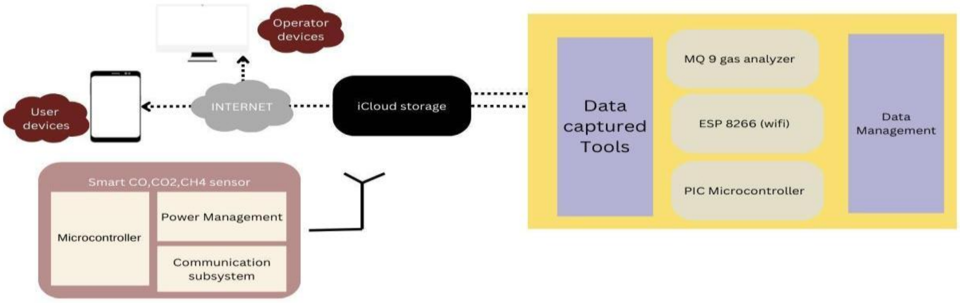

Figure 5. The framework of method.

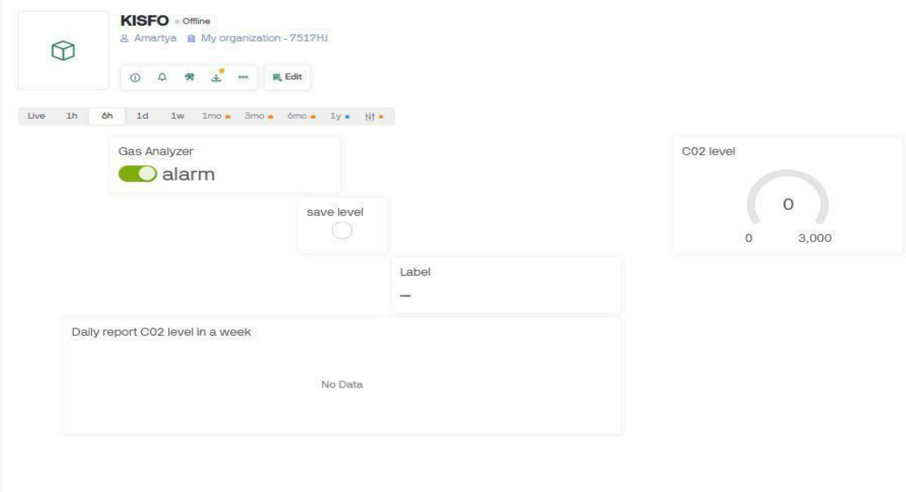

Figure 6. The dashboard of application.

In Data Captured Tools MQ9 sensor catches the CO, CO_2, and CH_4 gases, and receives the real-time data, which will collected in the microcontroller and ESP 8266 wifi as the distribution data by using local wifi or LoRa the data management will stored at iCloud to processing and matching with the Limitation if there is higher than limit alert will send through the application into user devices and operator devices.

Control panel through the application both of the user and the technician, this application is connecting the website database to collecting the data from user weekly, user can tracking the air condition among 7 days later. technician use the database to monitoring pattern of the equipment.

3. Results and Discussion

a. System Implementation

The implementation of an IoT-based gas analyzer can help the sustainability of the industry and society. The gas analyzer will detect the air quality which can send awareness to the people inside and outside of the refinery as an alarm in case of emergency through the application. The application can be accessed by society and the factory’s workers. The workers will have more precise real-time data about the air quality, such as the composition, graphical representation over time, and decision-making. Through this system, it is expected to raise consciousness among the people. Based on a studies, stated that 89% of the surveys believe that the usage of applications to raise environmental awareness can help reduce environmental pollution [20].

To develop the IoT system, there is an architecture that consists of four layers (capture, storage, analysis, and visualization) which are represented by business, functional, and implementation views (see Fig. 6). The architecture is presented from the stakeholders' perspective in the business view, making it possible to recognize the value that the IoT system brings to the particular use case. The various processes that emerged in each of the four architectural layers that were taken into consideration are explained in the functional view. Lastly, the technologies and/or tools selected to carry out the procedures outlined in the functional view are displayed in the implementation view.

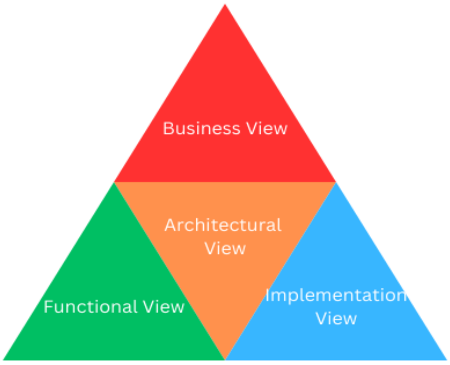

Figure 6. Representative of IoT architecture [19].

In the capture layer in the business view, CO_2 levels are measured, which enables Wi-Fi level consultation, using CO_2 sensors housed in various places in the sugar plant (see fig. 10). The CO_2 levels data are kept in a non-relational database either locally or in the cloud at the storage layer after they are routinely consulted. The database's contents are consulted in the analysis or processing layer to carry out statistical analysis as well as analysis based on data analytics models.

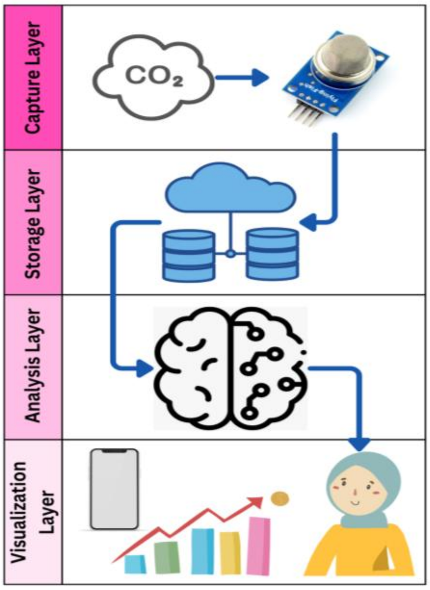

Figure 7. Business view [19].

Comparably, Fig. 7 shows processes in the functional view of the four architectural layers of the IoT for tracking and evaluating CO_2 levels in factory environments. CO_2 levels in volts are detected in the capture layer by the MQ9 sensor and immediately converted into PPM. After the CO_2 levels are measured, the MQ9 sensor has to produce a JSON message containing the sensor's values in PPM. JSON (JavaScript Object Notation) is a lightweight data-interchange format that is easy to read and write. It is commonly used for exchanging data between web servers, web applications, and mobile apps [21]. This message must then be sent wirelessly and through Wi-Fi using ESP-8266 to the storage layer.

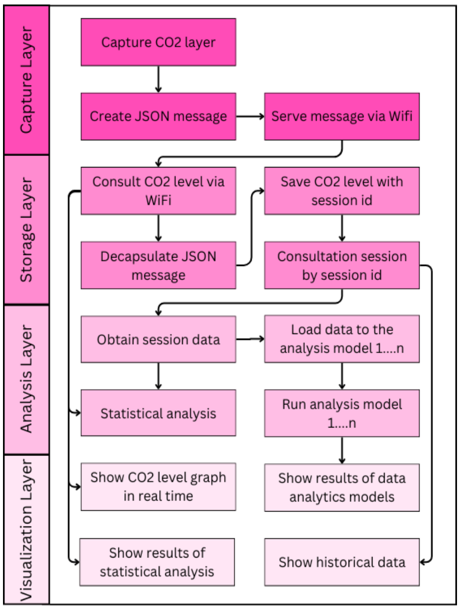

Figure 8. Functional view [19].

As a result, the JSON messages produced by the sensor are periodically consulted in the storage layer through HTTP requests. HTTP (Hypertext Transfer Protocol) requests are the primary method by which clients, such as web browsers, communicate with servers to retrieve or modify resources on the web [22]. The data from a capture session is stored in a non-relational database using a session ID to distinguish between captures. The analysis layer views the data linked to a specific capture session, analyzing CO_2 levels using measures like mean, minimum, maximum, and standard deviation. Machine learning models can be applied to determine the distribution of the data. The visualization layer displays a graph illustrating CO_2 levels' variation over time.

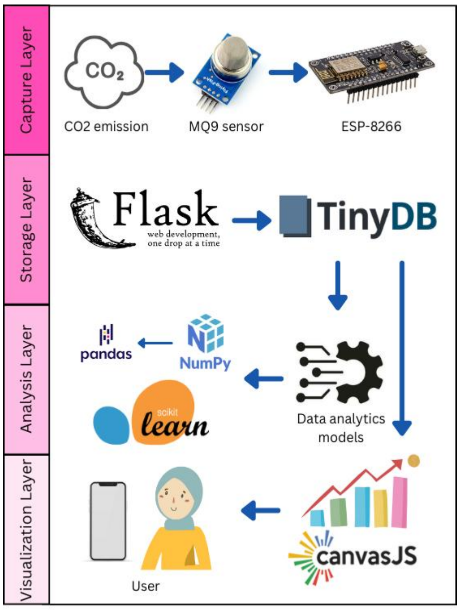

Figure 9. Implementation view [19].

The implementation view is shown in Fig. 9. The IoT system comprises an MQ9 sensor and ESP-8266 that facilitates WiFi connectivity and enables a mini server to provide CO_2 level readings via JSON messages. The captures can be used for statistical analysis with the NumPy Python library because they are kept in the free NoSQL database manager TinyDB. For supervised and unsupervised learning models, the system additionally makes use of the Python libraries pandas and scikit-learn. The Python Matplotlib library is used for clustering analysis graphs in the visualization layer, while the CanvasJS Javascript library is used for real-time graph generation with CO_2 levels. The Python microframework Flask is used to implement a client-server web application that frames the four layers. The capture, storage, and analysis layers make up the IoT system's backend, and the tool's front end is connected to the visualization layer.

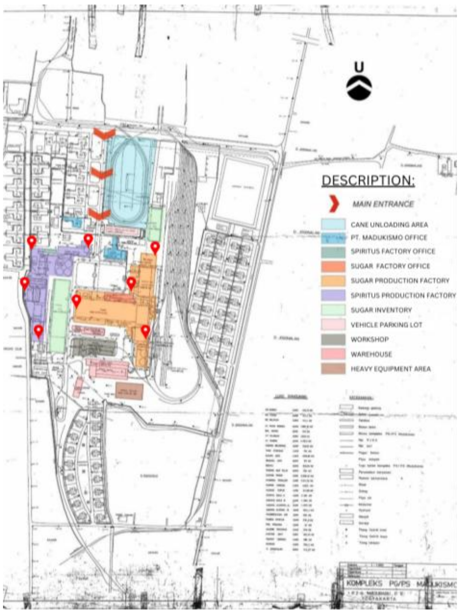

Figure 10. Sensor locations on PT Madukismo.

The implementation of the sensor location is located in two sectors. The Spiritus area, namely the Process area (991.6 m^2), near the boiler, separation area (992.4 m^2), and residue area (1,072 m^2). The Sugar processing area is Bagasse room (465 m^2), machine room (1,603.32 m^2), process area (4,791.5 m^2), and grinding area (1,535 m^2) [23]. The area is chosen because these sectors are where the production process is located. Considering the vast area, various sensors are pinpointed in one sector for more accurate data results.

The innovation has promising applications for air quality monitoring, as demonstrated by the study conducted various CO2 sensors were deployed in a 320 m^3 room which was commonly occupied by 27 people. The study found that the sensors, including Amphenol, Alphasense, and Plantower, showed good agreement in the readings. CO_2 concentrations peaked above 2000 ppm, reaching as high as 3000 ppm without forced ventilation [24].

The weakness of gas analyzers lies in their potential for inaccuracy and the limitations of the sensors used in their design. These limitations can lead to errors in the measurement of gas emissions, which can have significant consequences in industries where accurate monitoring is crucial for environmental and health regulations. Additionally, the complexity of gas analyzers can make them difficult to maintain and repair, further compromising their performance and accuracy.

The future aspect of gas analyzers is likely to involve advancements in technologies that enhance their accuracy, efficiency, and ease of use. Some potential developments that could shape the future of gas analyzers include:

- Increased Use of IoT and Cloud Computing: Integration of the Internet of Things (IoT) and cloud computing technologies could enable real-time monitoring and remote access to gas emission data, allowing for more efficient and effective management of emissions.
- Advancements in Sensor Technology: Improvements in sensor design and materials could lead to more accurate and reliable measurements, as well as the ability to detect a broader range of gasses and concentrations.
- Enhanced Data Analytics and Visualization: The integration of advanced data analytics and visualization tools could help users better understand and interpret gas emission data, facilitating more informed decision-making and improved environmental management.
- Increased Focus on Sustainability and Energy Efficiency: As concerns about climate change and energy consumption continue to grow, gas analyzers may be designed with sustainability and energy efficiency in mind, potentially incorporating renewable energy sources or energy-harvesting technologies.
- Increased Use of Wireless Communication Technologies: Wireless communication technologies like Wi-Fi, Bluetooth, or cellular networks could be used to transmit data from gas analyzers, making them more convenient and accessible.

4. Conclusions

The collaboration system between IoT and the industry is more beneficial for society. Through this IoT application, the industry can monitor air quality systems through manageable real-time data for society around the industry. According to previous study, the sensor can effectively detect the CO_2 level in the environment. The air quality information is sent to the application users, ensuring a safe condition in the nearby industry areas. This IoT implementation is advantageous for two parties, that is the industry and the society by monitoring and maintaining safety conditions around the Industry area. This opens further opportunities for the industrial company to apply IoT with its advanced features for more sustainable and green productions.

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