

CO₂ Monitoring System for Prototype of Building Air Quality Management Using Wireless Sensor Network

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Abstract

Carbon dioxide gas (CO₂) is a natural gas available in our air. It usually produced by the system that convert energy (either natural or artificial) like material burnout, natural respiration, and industrial process. In nature, right amount of CO₂ is needed by plants for photosynthesis and dispersed in atmosphere to stabilize our climate. However, exceeded amount of CO₂ will cause many problems, one of them is health problems. This problem usually appeared in the building with inadequate circulation system. To encounter that, the system to monitor and circulate CO₂ inside the building is needed. This research focused on developing the prototype system of CO₂ monitoring and circulation management inside the building. CO₂ monitoring done by our own-made low-cost sensor nodes. This system tested on building mock up consist of several rooms stacked vertically, which each room provided with one sensor node for CO₂ concentration monitoring, 2 fan (inwards and outwards) for air flow simulation, and external CO₂ source to simulate CO₂ generation inside the room. System reacted to CO₂ by stabilizing CO₂ concentration using fuzzy logic algorithm for fan's management. Experiment conducted give the conclusion that the system work effectively to manage CO₂ level on each rooms.

Keywords: Wireless Sensor Network, CO₂ monitoring, air quality management, fuzzy logic

I. INTRODUCTION

Carbon Dioxide is a gas that consists of three atoms. These atoms are two oxygen atoms and one carbon atom. This gas plays an important role in the daily lives of every living things in the planet. For example, the carbon dioxide is needed by plants to do the process of photosynthesis. The photosynthesis will then release oxygen, which is one of the most important gas for a human being. Therefore, carbon dioxide is needed by every living things inside the planet, and balances the earth's ecosystem. Carbon dioxide could be naturally produced from volcanoes, hot springs, and geysers. However, the gas could also be produced from human activities, such as, burning fossil fuel and industrial emissions. Using electronic goods could also produce carbon dioxide.

Since the industrial revolution, humans have been dependent of machineries and electronic goods to conduct their daily activity. As mentioned in the previous paragraph, the activities that used machineries and electronic goods will emit carbon dioxide. According to a research that was conducted by Samiaji [1], the concentration of carbon dioxide has increased dramatically in the Indonesian atmosphere throughout the years. In 2004, the concentration of carbon dioxide in the Indonesian atmosphere is 373 parts-per-million (ppm). That number has

increased to 383 ppm in 2010. On a global scale, Indonesia is also the largest county that emits carbon dioxide from biomass burning.

As mentioned in the first paragraph, Carbon Dioxide holds the key in balancing the ecosystem. Too much carbon dioxide that exists in the ecosystem will affect the balance of the ecosystem. Greenhouse gas is one of the major causes of global warming. The high concentration of greenhouse gas will block the infra-red ray that are reflected back in the atmosphere. This occurrence will cause the infrared ray to be trapped in the earth. Overtime, these rays will cause the temperature of the earth, as the heat of the infrared rays radiates and fills the earth's air. Greenhouse gas is comprised of several components. The main component of greenhouse gas is carbon dioxide. Several other component of greenhouse gas are water vapor, methane, nitrogen oxide, and ozone. The high composition of carbon dioxide inside the greenhouse gas means that the concentration of carbon dioxide will indirectly affects the earth's condition.

The global warming causes several environmental issues. The rise in the earth's temperature causes several species of plants and animals to lose their original habitat. The plants or animals could not live in their habitat due to the fact that the temperature for them to live is not optimal. Another issue that is caused by global warming is several health issues. The damage in the ozone layer of the earth could make humans vulnerable to ultra violet rays. This ray is detrimental for humans, as it could cause skin cancers. The rise in temperature could also spur the evolutions of several bacteria and virus that is very dangerous for a human being.

Aside from the global warming phenomenon, another negative aspect that is caused by high concentrations of carbon dioxide is health issues. As one of the signs of a living being, humans needs to breathe air in order to live. The air that a human breathes consists of several gas. One of those gas is carbon dioxide. It is fine for a human to breathe carbon dioxide on a normal level. However, if the concentration of carbon dioxide in the air is high, it could be very detrimental to the human's health. According to the National Occupational Safety and Health Administration, the normal concentration of carbon dioxide in the air is 1000 parts-per-million-by-volume (ppmv). If the number rises to 30000 ppmv, then humans will feel nauseous [2]. This is caused by the rise in activity of the heart and lungs due to the lack of oxygen. When the number reaches 50000 ppmv, humans will feel dizzy and experience blurry visions. The most dangerous concentration of carbon dioxide is 100000 ppmv, where humans could lose consciousness and even death.

Based on that fact, the National Occupational Safety and Health Administration provides several guidelines of carbon dioxide concentration in several locations that are mainly used by humans during their daily activities, one of which is office complex. According to the administration, the tolerable carbon dioxide level for an office with 8 hours of work every day is 5000 to 10000 ppmv. For a short 15 minutes work span, the tolerable carbon dioxide concentration in the air is 30000 ppmv. This guidelines is based on the effectiveness or work rate of a worker when exposed to different levels of carbon dioxide concentrations [3]. The number of concentration of carbon dioxide in an office complex could affect the productivity and the well-being of the workers.

There have been several research that studies about carbon dioxide and the effects it has on global warming. That is emitted in the air are mainly caused by the buildings, where 47% of the carbon dioxide emissions are caused by the industrial sector [4]. In terms of buildings that emits carbon dioxide, 80% of those emissions are from the buildings from the industrial sector. Our preliminary studies shows that the carbon dioxide has actually a larger concentration inside a building than outside of it.

Without us realizing, the concentration of carbon dioxide pollutants inside a room is larger than the concentration outside of it. This is actually a combination of pollutants that comes from the outside air to the room. One of the contributors of carbon dioxide inside the room is the respiration process of the human. The process of human respiration emits carbon dioxide. Those carbon dioxide will be trapped inside the building as commonly those buildings has a small number of ventilation. In addition to the human respiration, the electronics that were used inside the room also emits carbon dioxide. As mentioned in the previous paragraph,

the concentration of carbon dioxide could affect the human's health, therefore, the number of concentration could be an indicator for the sickness building.

Several researches have tried to solve this problem by using computer science. In 2015, Spachos and Hatzinakis used wireless sensor networks to monitor carbon dioxide indoors. The experiment succeeded in monitor the concentrations of carbon dioxide through wireless sensor networks [5]. A study conducted by Ahriman et al. also used wireless sensor networks in order to monitor carbon monoxide levels indoors [6]. Zhou and Chef explored the possibilities of using wireless sensor networks to monitor carbon dioxide levels in mines, forest, and many other places [7].

Based in the facts listed above, we propose a system to monitor the concentration of carbon dioxide inside a room in an office building. The system will give the carbon dioxide level readings from the sensors that are placed inside the building. The data that were gathered from this system will be used for further studies regarding efficient building designs and carbon dioxide levels. The steps in designing a building can be seen in figure 1.



Fig. 1 Six steps in building designs.

We will also place several fans that are controlled by the system to circulate the air inside the building. The study will be conducted on a smaller scale on a specially constructed mockup of a building. The rest of this paper is organized as follows. The first section will introduce the background of the system. The next section will discuss several literature that are used in the system. The third section will show the design of the whole system. The next section will discuss the implementation and the experiment results from this study. The final section will conclude this paper.

II. LITERATURE REVIEW

In this section, we will discuss the literature that we have read in developing this system. This includes the development process of the system and also the algorithms that we used inside the system. The development process will follow the five-stage systems development process by Nunamaker and Chef [8]. The algorithm that we used in this system includes Fuzzy

A. Five-Stage Systems Development Process

In order to create a complete prototype of the system, we followed the five-stage systems development process that was proposed by Nunamaker and Chef. Figure 2 will help readers to further understand about this development process. The first process that will be done is idea brainstorming. This is conducted based on the problem and what solution that we could offer to tackle the problem. After we have brainstorm our idea, the next process is to identify and prepare the components that will be used in the prototype. After we have gathered the required components, it is recommended to do another session of brainstorming with the basic knowledge from the first session of brainstorm.

The next process is to analyze and design the system. In this process, we will analyze and design the solution that is very possible to be done. Every possible solution will be re-analyzed so that it fits all the requirements that is proposed in the problem. The next step is to actually build the system and also perfecting the system. With the solution and the proposed system design, we will create the system according to the proposed design. The final step will be to analyze and evaluate the created system. This process will evaluate the system and create several adjustments if necessary.

In this study, we followed this guidelines proposed by Nunamaker and Chef in order to build a carbon dioxide monitoring system. This is done so that the prototype will have a good quality and also has a good reliability when finally implemented.

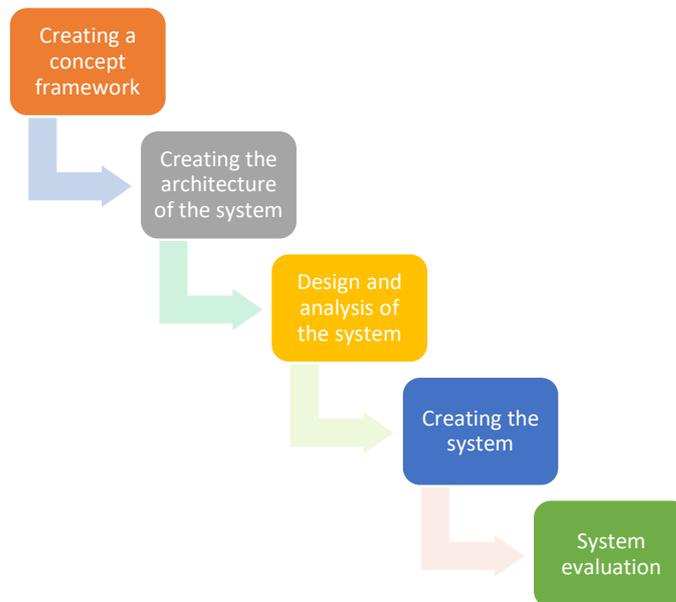


Fig. 2 Six steps in building designs

B. Fuzzy logic

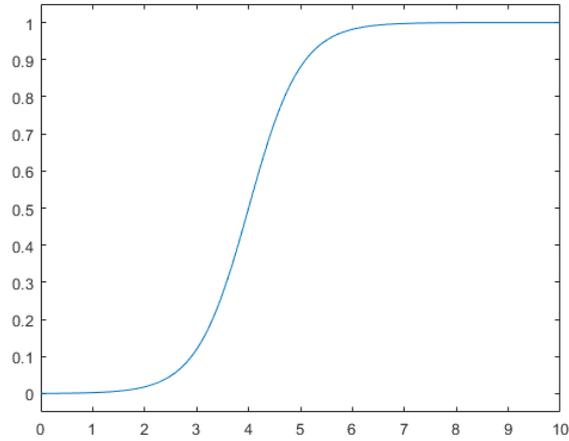


Fig. 3. A Sigmoid membership function.

The fuzzy logic was first proposed by Zadeh in 1965 [9]. The Fuzzy logic is a technique that automates decision making with fuzzy sets. In other words, the fuzzy is done to create a mapping network that is correct without the need for learning algorithms. Inference that is done on the fuzzy logic could be used on the data that is imprecise. A Fuzzy controller is used to regulate the system based on the fuzzy rules. The measurement mechanism is done in the form of fuzzified, the inference is the computed, and the computation results are the de-fuzzified and converted into a certain value. The membership function that is used in the system uses a sigmoid function that could be defined as:

$$f(x, a, c) = \frac{1}{1 + e^{-a(x-c)}} \tag{1}$$

The sigmoid membership function of the sigmoid function could be seen in figure 1.

III. RESEARCH METHOD

A. Network Model

The prototyping process was conducted using Arduino that has been equipped by a sensor that could measure carbon dioxide. The carbon dioxide sensor that will be used is a COZIR ambient. The Node Cluster semantic sequence to read the concentration of carbon dioxide could be seen in Figure 4.

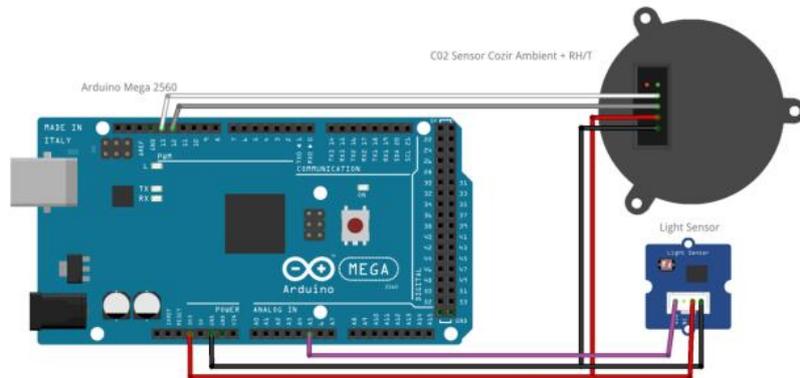


Fig. 4. The Node Cluster semantic sequence.

The carbon dioxide concentration level that could be detected by the sensor is 0 – 10.000 ppm. In addition, the sensor is also equipped with a built-in humidity sensor. The mechanism that is used to transmit the data is by using the Universal Synchronous Asynchronous Receiver Transmitter (USART). This sensor is connected to the microcontroller by using the Rx and Tx port. The picture of this sensor could be seen in Figure 5.

Every node sensor will read a certain concentration of carbon dioxide, temperature, and humidity. The data will be sent to the sink node by using the radio frequency medium. After the data have been successfully gathered in the node sink, the data will be transferred to the serial Raspberry Pi by using the interface serial that is available inside the device. All of the data from the Raspberry Pi will then be transferred to the server node that is available in Amazon. The service that is used to transfer the data is Amazon Web Service (AWS).



Fig. 5. The carbon dioxide sensor that is used in this system.

In the sever node, the data is created in a tabular matter by using a simple RDMS in the form of PostgreSQL. From the data that have been gathered in the server node, the information of the carbon dioxide and the other components for every node could be retrieved from the website. The scheme of the carbon dioxide monitoring system can be seen in Figure 6.

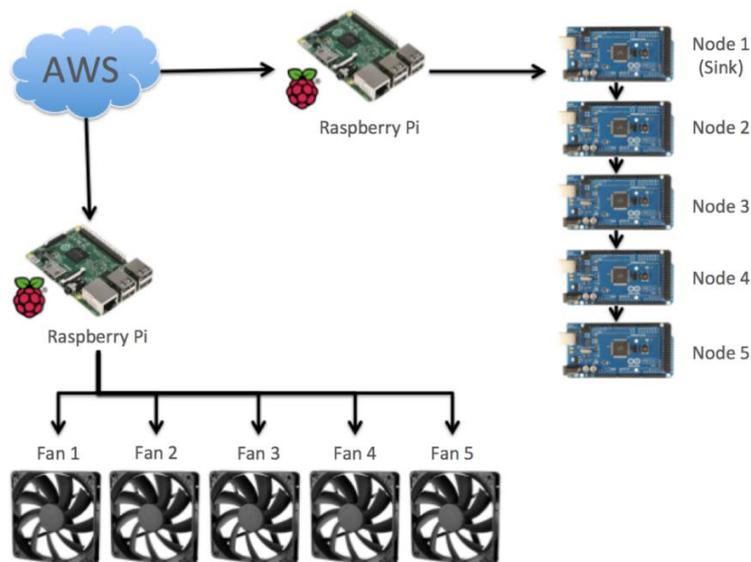


Fig. 6. Carbon dioxide monitoring system scheme.

B. Sink Node

The sink node is used to transfer the data to the server. The data transfer is used by using the Representational State Transfer Application Program Interface (RESTful API). One of the reason why this data transfer method is chosen the REST provides interface that is uniformed on every required components. By using the principal of software engineering, we will generalize and simplify so that the transferred data could be standardized into a certain format. The structure of the REST API can be seen in Figure 7.

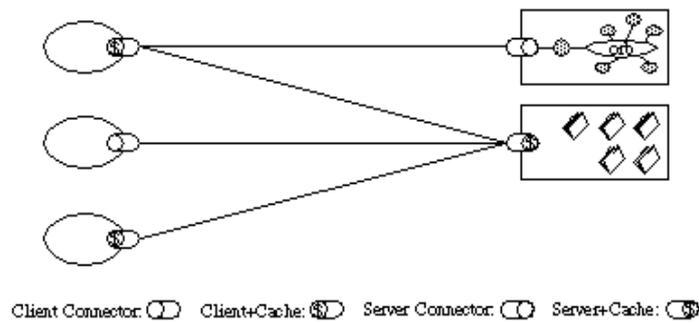


Fig. 7. The REST API Architecture, this figure show that the REST is a stateless system.

The data that is received by the Raspberry Pi using serial communication is obtained from the hop of the final node in the Arduino. After the data have been read from the Arduino through a serial communication, the available data will be parsed into JSON. After it has been parsed into JSON, we then post the data by using the request library that is available in the Python to the API endpoint. The REST API is constructed using express, which is a micro-framework from node js. The diagram of the data transfer can be seen in Figure 8.

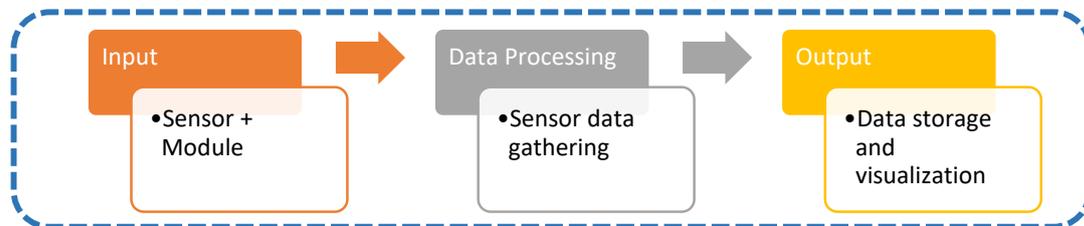


Fig. 8. The data transfer diagram in the carbon dioxide monitoring system.

C. Software and Application

In the system, we used Real-Time Operating System (RTOS) that consists interface, commonly known as API. There are several benefits from using RTOS:

- Optimization of development program process.
- Synchronization that is safe and secure.
- Resource management.
- Timing management.

The basic principal of RTOS is multitasking and concurrency. The main component of RTOS that is used to control and manage lots of resource is known as the thread. The timing process of a task is called scheduling.

On the other hand, context switching is the ability for the operating system to save all the state from a task that is being paused. In this study, the RTOS have been ported to the Arduino.

IV. RESULTS AND DISCUSSION

A. *Experiment Scenario*

In this study, the experiment was conducted to simulate the usage of Wireless Sensor Network (WSN) on several rooms to monitor and control the concentration of the carbon dioxide on each of those rooms. The rooms are simulated as a model that we have constructed using wood and then filled with gas of carbon dioxide using carbon dioxide tube.

The equipment that are used in this experiment is:

- Node that are used to gather the intensity of carbon dioxide.
- Sink node.
- Web services.
- Computation unit for decision making.
- Model of a building.

The experiment steps are:

- Conduct the simulation process by filling the building room model with carbon dioxide.
- After there is enough flow of the carbon dioxide inside the room model, turn off the carbon dioxide gas.
- Turn on the sensor, the data will be sent to the server and the computation using fuzzy logic will be conducted by a computation unit.
- After we have obtained the result, the information to turn on the fan or not will be sent to the node that acts as an actuator.

B. *Results*

The hardware and the components that are used in this study can be seen in Figure 9, 10, 11, 12, 13, and 14.

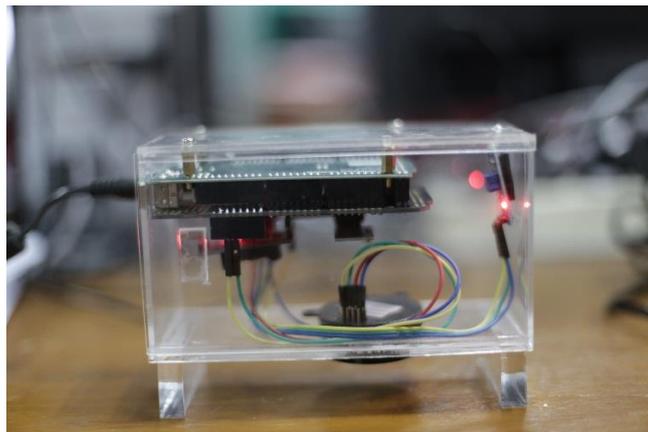


Fig. 9. Side-view of the node that is inside the cluster.

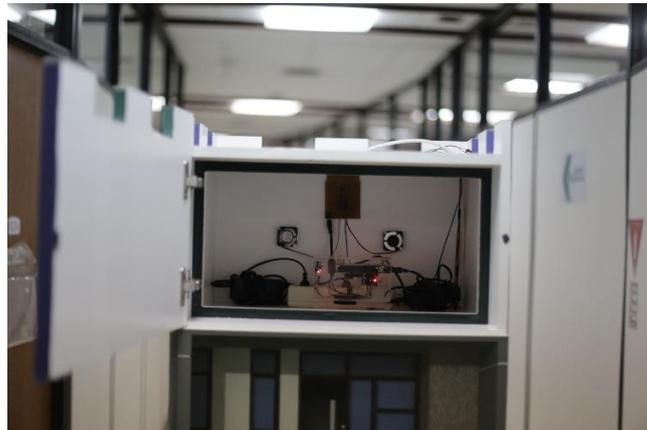


Fig. 10. The front-view of the model building that contains the fan and node.



Fig. 11. The whole building model that is used in this experiment.



Fig. 12. The carbon dioxide that supplies the gas inside the building model.

No	Node Id	CO2	Temperature	Humidity	Light
1	1	1181	30.41	71.30	1005
2	2	1173	30.03	72.64	1006
3	3	1159	29.98	72.84	1005
4	4	1106	30.00	72.50	1006
5	5	1118	29.94	72.83	1006
6	6	1266	29.53	74.94	999
7	7	1368	28.99	77.00	449
8	8	1510	29.49	77.07	44
9	9	1409	30.47	73.36	30
10	10	1164	31.29	68.62	28
11	11	1004	32.22	63.57	28

Fig. 13. The table that displays the results from that were read from the sensor.



Fig. 14. The graph that shows the intensity of carbon dioxide overtime.

C. Analysis

The performance of the algorithm, namely the fuzzy logic algorithm, is suitable in use for the current condition. The mathematical model in this study will be easier to create. However, the drawback of using this logic is that over fitting may occur at a certain point. The fuzzy logic also successfully controls the fan inside the building to turn on only when needed.

V. CONCLUSION

Wireless Sensor Network is a solution to monitor and gather data of the intensity of the carbon dioxide remotely. It is portable and it used a relatively low resource. In this study, we have successfully developed a sensor node to monitor and gather data of carbon dioxide concentration. The sensor node that we have developed used Arduino as a microcontroller, RTC as a timer supply, carbon dioxide sensor to read the intensity of carbon dioxide, temperature, humidity, and also radio model NRF24L01 as a communication media for each node. The experiment have been conducted in order to test the implementation of Fuzzy logic algorithm for detecting when the fans inside a building should be deployed. The experiment has been conducted successfully, as it is shown that the fan is only turned on when needed.

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