Real-Time Monitoring of Carbon Dioxide and Indoor Air Temperature Using Arduino in an Effort to Maintain Indoor Air Health

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Abstract. Air quality is believed to be one of the comfort factors for its residents. This study aims to develop an air quality monitoring information system by reviewing the concentration of carbon dioxide (CO_2) and air temperature. The embedded system was developed using the Arduino Uno R3 SMD Board, MG-811 Carbon Dioxide sensor, DHT11 thermal sensor, and ESP8266 WiFi adapter. The results of the developed system were tested in one of the lecture rooms at the Faculty of Science and Technology, Jambi University. The results of this study indicate that the developed system successfully monitors CO_2 concentration and air temperature in real time. Based on the monitoring results shown by the system, the lecture hall of the faculty of science and technology is still relatively safe to use but does not yet have the ideal room milk (-7 °C).

Keywords: Air Quality · Carbon Dioxide · Monitoring · Real Time · IOT · Arduino

1 Introduction

Indoor air quality is a very important problem because it is directly related to the health and comfort of building occupants [1]. Poor air quality in a room can be caused by many factors, one of which is high levels of carbon dioxide (CO_2) originating from the human body's metabolic processes [2]. Carbon dioxide (CO_2) is a chemical compound consisting of two oxygen atoms bonded to a carbon atom [3]. This compound is produced by all animals, plants, fungi, and microorganisms in the process of respiration and photosynthesis [4].

Excessive CO_2 concentration in a place can have a negative impact on living things around it [5]. In humans, CO_2 exposure can lead to reduced performance and productivity [6]. Apart from CO_2 according to Gondchawa, et al. (2017) air temperature also affects the productivity of a living thing. Based on these problems, research on monitoring changes in CO_2 concentration and air temperature in a room needs to be done. This research was conducted by developing information systems and embedded systems that can be used to monitor these problems in real time. The development of the information system is one of the applications of the Internet of Things concept.

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Internet of Things (IoT) is a concept that has been widely applied in various fields, one of which is air quality monitoring. By using the IoT concept, air conditions and quality such as temperature, carbon dioxide concentration, etc. can be measured and processed into information [8]. Measurement using the IoT concept is certainly very easy when compared to manual measurements because all processes are carried out automatically [9]. IoT which is generally connected to the Internet network has many advantages, one of which is that data monitoring can be done in real time [10].

In this study, the research team designed a monitoring information system to help monitor the condition of room air quality at a certain time. By using an Arduino board, a CO_2 gas sensor, and a temperature sensor placed in a classroom, researchers can measure the CO_2 concentration and air temperature to be sent and displayed on the monitoring information system. The measurement data will be processed using a Completely Randomized Design (CRD) experimental design to determine the increase in carbon dioxide concentration and air temperature based on the number of people who inhabit a room. The data can be used as a reference to determine a picture of a healthy room condition for studying or working.

2 Methods

This research has a systematic planning and workflow steps as follows (Fig. 1):

a. Identification of problems

At this stage, the identification of research problems and determining the boundaries of the problems to be discussed in the study are carried out.

b. Study of literature

Literature study is the stage of gathering information as a basic theory in research. The literature in question can be sourced from journals, books, online articles, and other sources related to this research. At this stage, information is sought on how to develop an information system and embedded system using Arduino Uno, as well as the impact of carbon dioxide exposure on human health. In addition, information about aspects of human thermal comfort in a room is also needed.

After system development is complete, system testing is carried out to ensure that the developed system meets the needs. The types of tests carried out are functionality testing and performance testing. The proposed system to be developed is illustrated by Fig. 2.

c. System development

At this stage, the system is developed using a prototype model. The stages in the prototype development model include communication, quick plan, quick plan modeling, construction of prototypes, and deploying, delivery, and feedback [11].

Communication: at this stage, communication with the client is carried out to determine the needs and workflow of the system.

Quick Plan: at this stage, the activities carried out are planning quickly after communication is carried out. Some of the plans carried out include formulating solutions to problems by:

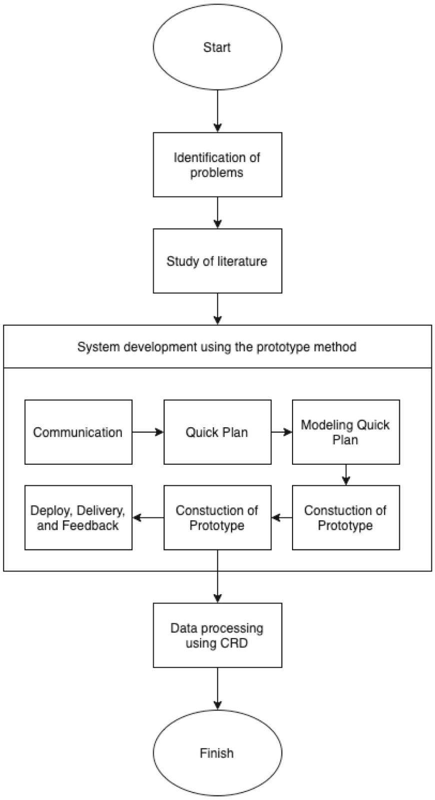


Fig. 1. Research Framework

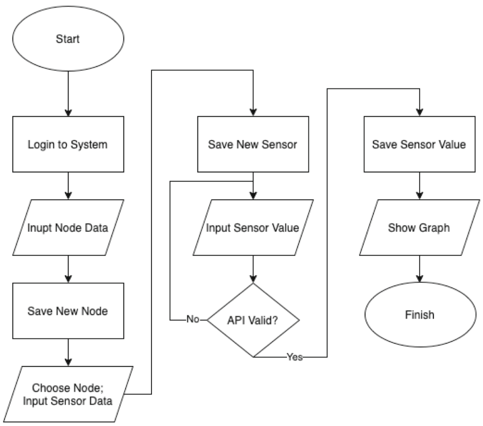


Fig. 2. System Architecture

- Determine the technology used;
- Describe the flowchart of the proposed system; and
- Determine who are the users involved in the proposed system.

Modeling Quick Design: At this stage there are several steps taken, including:

- Make a system design with the help of UML diagrams of the system to be developed. Some of the designs that will be made include: Use Case Diagrams, Activity Diagrams, and Sequence diagrams;
- Make a database design with the help of ERD (Entity Relationship Diagram) with the aim of knowing the relationship between tables; and
- Make a user interface design.

Construction of Prototype: at this stage there are several activities carried out, including:

- Translating the design of the UML system and the interface design of the system into the form of program code into a design prototype.
- Translating the database that has been created with the ERD diagram (Entity Relationship Diagram) into a real database form with MySQL software

Deployment, Delivery and Feedback: at this stage, the system is tested in terms of functionality and performance. In testing the functionality, the Katalon Recorder software is used, while in the performance test the JMeter software is used. After the developed system is free from all errors, the system is then introduced to the client.

d. System implementation testing

After the system has been developed, then implementation testing is carried out. The test was carried out in the lecture hall of the Jambi University Faculty of Science and Technology. The volunteers consisted of 35 students. This test was carried out following the CRD procedure with the number of volunteers as many as 35 students. In this test, the specifications of the room used in the study are as follows:

- The room has a width of 7 m, a length of 10 m, and a height of 2.9 m;
- There are 2 fans on;
- There is no air conditioning;
- No ventilation;

3 Result

3.1 Monitoring System.

See Fig. 3.

The system has been successfully developed with the following use cases:

- At the time of data collection, the window is closed; as well as
- The door is half open.

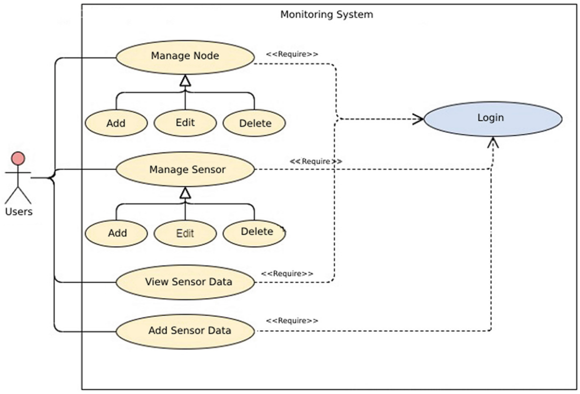


Fig. 3. System Architecture

The architecture of the system has the following picture (Fig. 4):
as for the entity relationship diagram of the system as follows (Fig. 5).
The developed system has an interface design as follows (Fig. 6).

3.2 Internal System Testing

The testing stage is carried out to ensure the system that has been made has run as needed. At this stage, two testing processes are carried out, namely functional testing and performance testing. For functional testing, researchers used the Katalon Recorder application, while for performance testing, researchers used the JMeter application.

Functional Testing

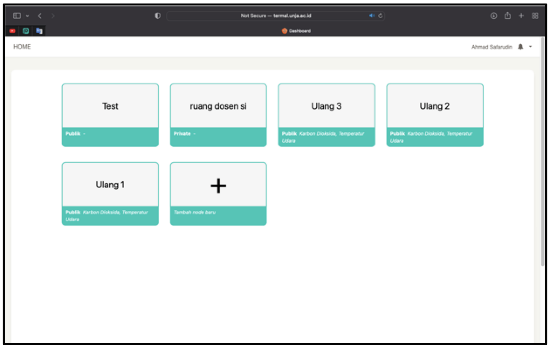
At the functional testing stage, researchers used the Katalon Recorder software to test the features of the system automatically. To ensure a feature has been running well, a test case is made in the form of steps that are carried out when carrying out the function.

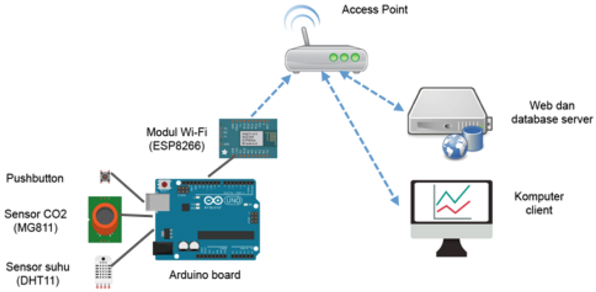
In Katalon Recorder there are several components such as commands, targets, and values. Commands are actions performed by the user, such as open, type, click, submit, and so on. A target is an HTML element identified using the attributes name, id, and so on. Each HTML input element has a value. The value component in Katalon Recorder is the data owned by the HTML input element which is retrieved based on the target element.

In testing using the Katalon Recorder, the user registers all actions taken by the user to run a feature. Katalon Recorder will execute all of these actions sequentially, and will display a failure message if there is an error. Screenshots of test results using the Katalon Recorder can be seen in appendix 2. Here are the results of the tests that have been carried out in Table 1.

Performance Testing

In the performance testing stage, the researcher uses the Apache JMeter software. JMeter is used to test the speed and resilience of the website against user access. In





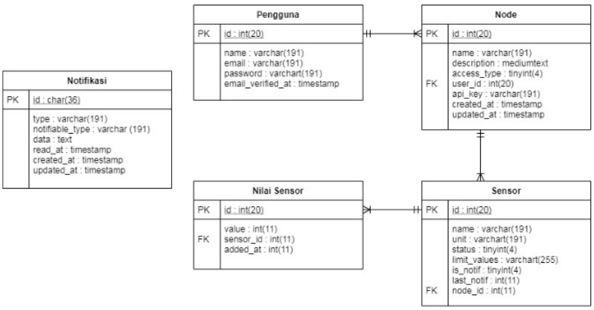


Fig. 4. Use Case Diagram

using JMeter, the researcher created a test plan that serves as a container for loading test scenarios. In JMeter there are three main components, including Thread Group, Sampler, and Listener. Thread Group is a virtual user created to simulate website access. The created virtual user will access a website using a certain protocol. The sampler aims to handle those access requests. There are various protocols supported by JMeter, including HTTP/HTTPS, FTP, SMTP, and others. In this study, researchers tried to test access to website pages using the HTTP protocol. While the Listener is the part that serves to display the test result data in tabular form. Some of the data displayed by

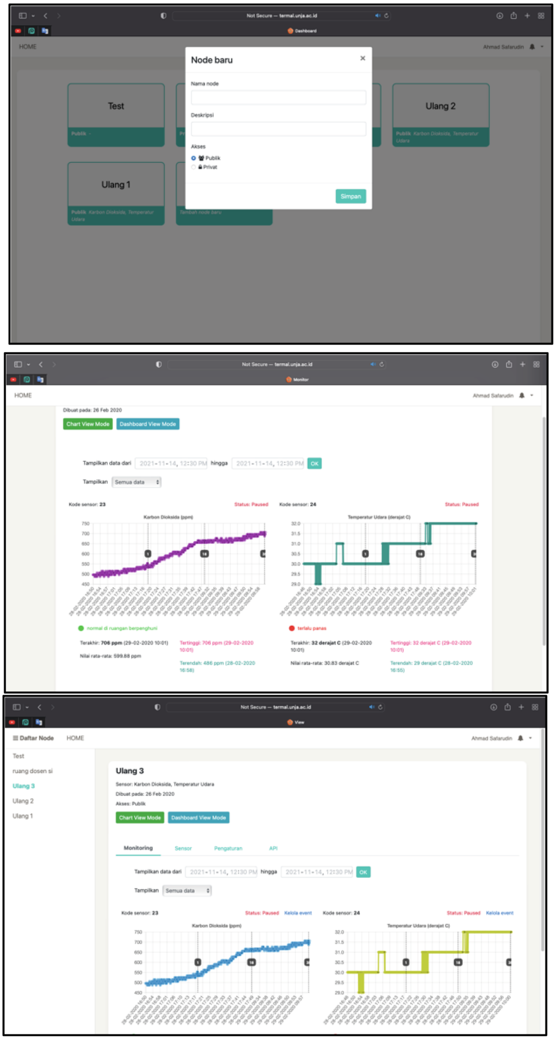


Fig. 5. Entity Relationship Diagram

JMeter include access status, access time, the amount of data sent and received, and the length of time connecting.

Performance testing begins with making a test plan. The next step is to create a Thread Group and determine the number of virtual users that will be used. In creating a virtual user, there is a Number of Thread which shows the number of virtual users to be created. There is also a Ramp up Period which shows the length of time it takes for all virtual users to access the website. Loop Count is the part that shows the number of repetitions by each virtual user.

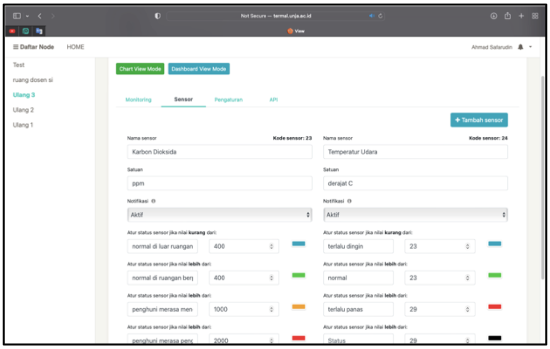


Fig. 6. Monitoring System Interface

Table 1. Functional Test Result

Test Case	Description	Result
tc_login	Log into the system using your email and password	Succeed
tc_add_node	Creating new nodes	Succeed
tc_edit_node	Change node data	Succeed
tc_delete_node	Deleting nodes	Succeed
tc_add_sensor	Adding new sensors	Succeed
tc_edit_sensor	Changing sensor data	Succeed
tc_delete_sensor	Remove sensors	Succeed
tc_monitor_sensor	View sensor data	Succeed

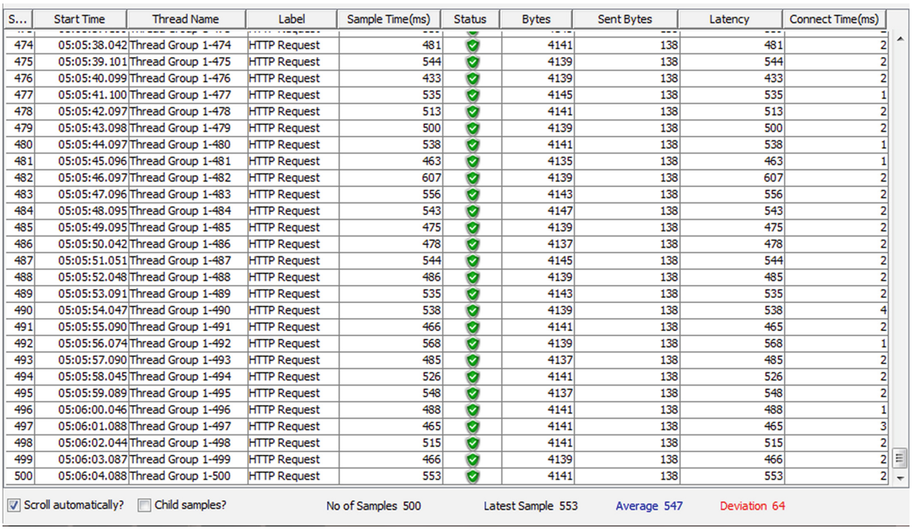
In this study, the number of virtual users created was 500 users. If the distance between user access is 1 s, then the value of the Ramp up Period is the number of users multiplied by 1 s, which is 500 s.

Based on performance tests carried out on systems hosted on servers with Intel i5 processor specifications, 8GB RAM, and 240GB SSD storage, no errors were found that could interfere with system access. In this test, the researcher uses a local network to access the system. Test results may differ depending on the type of network, internet access speed, and the robustness of the system used. In this test the results were obtained which are shown in Fig. 7.

3.3 Implementation System Testing

After testing the system implementation, the following results were obtained (Tables 2 and 3):

From the data above, the system shows that the room where the implementation test is carried out has a hot room temperature with a relatively safe concentration of CO_2 in the air. Figure 8 displays and notifications provided by the system.



S...	Start Time	Thread Name	Label	Sample Time(ms)	Status	Bytes	Sent Bytes	Latency	Connect Time(ms)
474	05:05:38.042	Thread Group 1-474	HTTP Request	481		4141	138	481	2
475	05:05:39.101	Thread Group 1-475	HTTP Request	544		4139	138	544	2
476	05:05:40.099	Thread Group 1-476	HTTP Request	433		4139	138	433	2
477	05:05:41.100	Thread Group 1-477	HTTP Request	535		4145	138	535	1
478	05:05:42.097	Thread Group 1-478	HTTP Request	513		4141	138	513	2
479	05:05:43.098	Thread Group 1-479	HTTP Request	500		4139	138	500	2
480	05:05:44.097	Thread Group 1-480	HTTP Request	538		4141	138	538	1
481	05:05:45.096	Thread Group 1-481	HTTP Request	463		4135	138	463	1
482	05:05:46.097	Thread Group 1-482	HTTP Request	607		4139	138	607	2
483	05:05:47.096	Thread Group 1-483	HTTP Request	556		4143	138	556	2
484	05:05:48.095	Thread Group 1-484	HTTP Request	543		4147	138	543	2
485	05:05:49.095	Thread Group 1-485	HTTP Request	475		4139	138	475	2
486	05:05:50.042	Thread Group 1-486	HTTP Request	478		4137	138	478	2
487	05:05:51.051	Thread Group 1-487	HTTP Request	544		4145	138	544	2
488	05:05:52.048	Thread Group 1-488	HTTP Request	486		4139	138	485	2
489	05:05:53.091	Thread Group 1-489	HTTP Request	535		4143	138	535	2
490	05:05:54.047	Thread Group 1-490	HTTP Request	538		4139	138	538	4
491	05:05:55.090	Thread Group 1-491	HTTP Request	466		4141	138	465	2
492	05:05:56.074	Thread Group 1-492	HTTP Request	568		4139	138	568	1
493	05:05:57.090	Thread Group 1-493	HTTP Request	485		4137	138	485	2
494	05:05:58.045	Thread Group 1-494	HTTP Request	526		4141	138	526	2
495	05:05:59.089	Thread Group 1-495	HTTP Request	548		4137	138	548	2
496	05:06:00.046	Thread Group 1-496	HTTP Request	488		4141	138	488	1
497	05:06:01.088	Thread Group 1-497	HTTP Request	465		4141	138	465	3
498	05:06:02.044	Thread Group 1-498	HTTP Request	515		4141	138	515	2
499	05:06:03.087	Thread Group 1-499	HTTP Request	466		4139	138	466	2
500	05:06:04.088	Thread Group 1-500	HTTP Request	553		4141	138	553	2

Scroll automatically? Child samples? No of Samples 500 Latest Sample 553 Average 547 Deviation 64

Fig. 7. Performance Test Result

Table 2. Result obtained from the system: concentration of CO_2

Numper of Participant	Repetition (ppm)			SUM	AVG	DEV
	I	II	III			
1	501	546	542	1589	530	24.9
18	574	650	656	1880	627	45.7
35	657	677	706	2040	681	24.6
Total	1732	1873	1904	5509		

Table 3. Result obtained from the system: air temperature

Numper of Participant	Repetition (°C)			SUM	AVG	DEV
	I	II	III			
1	28	30	30	88	29.3	1.2
18	29	30	31	90	30	1
35	30	32	32	94	31.3	1.2
Total	87	92	93	272		

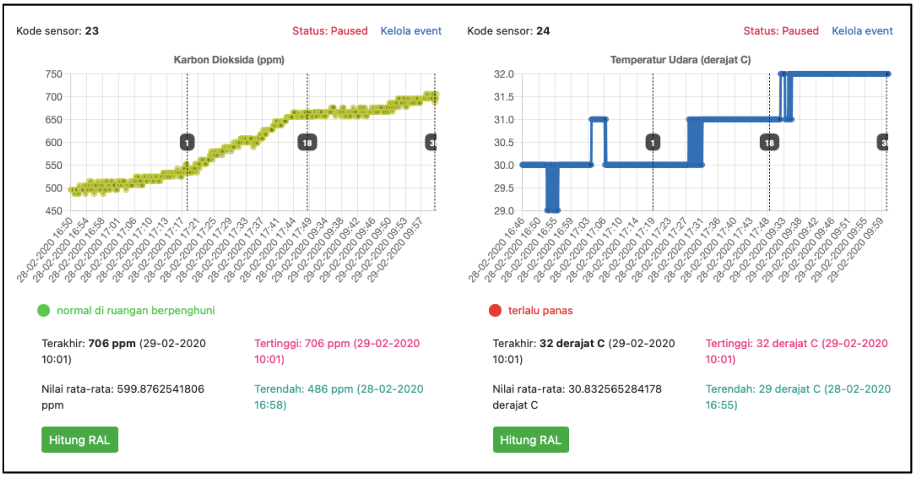


Fig. 8. Monitoring System Detection Results

4 Discussion

The system created is not a development of an existing system, but a new system design. Therefore, the user's description of the system created is still general. During development, feedback from users is also needed on the results of the prototype being developed. Software developers will make changes to improve the prototype made to become software that can be used by users. Based on these things, the prototype development model was chosen because it was considered more appropriate to the situation experienced by users and software developers.

System development begins with the communication stage, where software developers together with users discuss and identify problems and needs of the system being developed. The next stage is a quick plan which aims to determine the system workflow, determine users, and choose the technology used. The next stage is the quick design modeling, which is the stage where the software developer describes the system flow in the form of use case diagrams, activity diagrams, and sequence diagrams. At this stage, the developer also designs the database using ERD and designs the system interface. The construction of prototype stage is the stage where the coding is done. At this stage, database creation is also carried out according to the previously determined ERD design. The last stage is deployment, delivery, and feedback where the developer introduces the software to the user. Based on the test results, no errors were found either in terms of functionality or system performance.

Based on the system implementation test, it is known that the place where this research was conducted has a relatively safe CO_2 concentration (compared to the ideal temperature exposure according to Wisconsin Department of Health Services (2021)) but has a relatively hot room temperature (obtained an average room temperature of ±30 °C but according to the ideal temperature of the study room is 21 °C) [12].

5 Conclusions

After this research, the research team concluded that: A real-time monitoring system can be developed using a prototype software development model. The prototype model itself consists of several stages which include: A. Communication, which is the stage where software developers together with users identify problems and system requirements; B. Quick plan which aims to determine the types of users, the technology used, as well as an overview of the system workflow; C. Quick design modeling is a stage that aims to describe the system into use cases, activity diagrams, and sequence diagrams, as well as describe database design using ERD; D. Construction of prototype is the stage of coding and database creation; E. Deployment, Delivery, and Feedback are the stages of system testing and implementation.

The monitoring information system developed is proven to be able to more easily monitor real-time air quality in a room. Where this system was tested, it was found that the room temperature was too hot but still relatively safe (in terms of CO_2 concentration).

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