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An Analysis of Data Acquisition System of Temperature, Oxygen, and Carbon Dioxide in Refrigerator with Arduino Mega 2560

Sri Wahyu Suciyati[1*], Muhammad Syarif Hidayatullah[2], Gurum Ahmad Pauzi[3]

[1, 2, 3] Departement of Physics, Faculty of Mathematics and Natural Sciences, University of Lampung, Bandar Lampung, 35141, Indonesia

*email: sri.wahyu@fmipa.unila.ac.id

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ABSTRACT

The influence of storage room conditions can cause the quality of post-harvest fruit to decline, so monitoring is necessary. Monitoring is carried out using a data acquisition system designed to measure the temperature, oxygen, and carbon dioxide in the refrigerator storage room automatically. System design is divided into two stages, namely hardware design and software design. The hardware is composed of a sensor unit, a data processing unit (Arduino Mega 2560), and a display unit. On the other hand, the software uses the Arduino IDE. The test results of temperature (DS18B20), oxygen (Figaro KE-25), and carbon dioxide (MH-Z14a) from the system obtained an accuracy value of 98.29% with an error of 1.71%; 98.57% with an error of 1.43%, and 94.58% with an error of 5.42%. The device can display real-time measurement data output to 20x4 LCD with IIC and save the data on a micro-SD card.

INTRODUCTION

Geographically, Indonesia has potential agricultural resources for export, such as pineapple. As a horticultural product, a product's quality is evaluated based on the harvesting and post-harvest conditions because all horticultural products have living tissue and are still metabolized after harvest (Brizzolara et al., 2020; Rab et al., 2013). Currently, the quality of harvested products has improved but post-harvest handling such as storing fruit before export is still not optimal. Storage is directly related to the quality and shelf life of the fruit related to the process of respiration and transpiration of the fruit after harvest (Lufu et al., 2019; Dandago et al., 2017).

Storage is a process that determines the quality of post-harvest pineapple or another fruit. Inconsistencies in storage rules can make fruit rot faster, both microbiologically, chemically, and physically. It is related to the factors that affect the freshness of the fruit due to loss of moisture through transpiration on the skin's surface (Rab et al., 2013). Agricultural products should be stored in the network at low temperature and high humidity to reduce transpiration losses while improving export quality and fruit life. However, according to (Lin et al., 2018), low-temperature storage can cause physiological damage to the fruit. The respiratory rate indicates a strong correlation with the rate of change in fruit composition and means prolonging quality fruit's life span (Thu et al., 2017; Cukrov et al., 2015). Fruit breathing rate can be triggered by an increase in temperature so that a decrease in nutrients occurs more rapidly (Fagundes et al., 2013).

Fruits stored at low temperatures with closed air circulation are generally better because the respiration process and bacteria or fungi growth can be inhibited (Alhamdan et al., 2015). However, applied to certain fruits requires further observation due to differences in natural properties between fruit types. Therefore, it is necessary to monitor post-harvest fruit storage space to maintain the fruit's quality from the effects of continuous fruit respiration and transpiration. This effect can increase the temperature, oxygen gas, and carbon dioxide in the storage room.

This research is a preliminary study that aims to determine the environmental conditions of the low-temperature storage room (refrigerator) and its effect on the quality of fruits. The monitored environmental conditions are temperature, O_2 gas (oxygen), and CO_2 gas (carbon dioxide). These observations require a tool to detect air conditions changes because who cannot see them with the naked eye. In contrast, fungal growth that appears on the surface of the fruit skin can still be seen with the naked eye and can be identified using a light microscope. We cannot know the length of storage time, temperature, O_2 gas, and CO_2 gas directly, so additional tools are needed to measure them. Currently, measuring instruments used to measure temperature, O_2, and CO_2 gas concentrations in fruit storage rooms do not yet have an automated data recording system. Several studies show that manual data collection means inefficient in terms of time, such as the temperature on the respiratory rate in closed storage systems (Rahmadhanni et al., 2019), the effect of temperature on the physical properties of pineapple (Rahmadhanni et al., 2020), the level of storage and maturation of post-harvest tomato quality (Abiso et al., 2015), quality changes and volatile compounds on freshly cut pineapple during storage (Thu et al., 2017), environmental storage effects, levels maturity, and pre-disinfection treatment - tomato quality storage (Tolesa & Workneh, 2017), results of temperature variation on maturity and weight loss in tomatoes (Tadesse et al., 2015).

Arduino Mega is a platform, which is a combination of hardware, software, and IDE (Integrated Development Environment). Arduino Mega can be considered as a microcontroller board based on ATmega2560. Arduino Mega works as the main processor in the system to carry out the task of processing data from sensors and displaying information on the LCD. Apart from being a processor, the Arduino Mega can be used to control sensors, motors, and various other types of actuators (Junaidi and Prabowo, 2018). Based on this functionality, several studies have used Arduino as a data acquisition and control system. Several studies related to the design of monitoring systems such as (Argo et al., 2010), O_2, and CO_2 gas monitoring systems in storage cabinets (Judge, 2013) created Arduino-based air quality monitoring systems to detect carbon monoxide gas. They are using the MQ5 sensor while the data output is sent to the laptop via a serial port.

In contrast to the above study (Muktiawan, 2016), the rice and egg monitoring system in the Arduino-based storage space is made with outputs sent wirelessly to smartphones. Further (Winata et al., 2016) made the Arduino monitoring system use Micro Secure Digital Card (SD) as a storage medium for automatic voltage measurement results from solar panels. Research-related data acquisition systems have been conducted by several researchers, such as (Mardhiya et al., 2017), to measure the level of dissolved O_2 in Arduino-based shrimp pond water. Dissolved O_2 levels are detected using dissolved oxygen sensors (DO), and the results are displayed in real-time through a series to a PC (Personal Computer). Later, (Sandi et al., 2018) devised a detector data acquisition system to detect oxygen gas, hydrogen gas, temperature, and pressure based on the Arduino Mega 2560 with website release. Besides, the design of control systems and monitoring of air condition in controlled atmospheric storage based on Arduino Uno microcontroller has also been done (Widyaningrum et al., 2018) and monitoring internal environment parameters wireless network by (Noh et al., 2013). Unfortunately, these studies are not explicitly designed for use in cold storage rooms, so it is advisable to establish a temperature and gas data collection system in cold storage rooms or refrigerator.

METHODS

The research begins by providing the tools and materials needed for hardware and software design. The hardware design is combined with the software to form a data acquisition system that refers to the (Widyaningrum et al., 2018) design in general. The system is then tested to ensure the system's accuracy and precision for detecting real-time conditions of temperature, O_2 gas, and CO_2 gas in the refrigerator. Figaro KE-25, MH-Z14a, and DS18B20 have been used to detect temperature, O_2 gas, and CO_2 gas integrated with Arduino Mega 2560. The measurement output is then displayed on a Liquid Crystal Display (LCD) with a resolution of 20x4, and the logger data is stored using a micro-SD card.

1. Design of Hardware

The hardware used in this research includes the DS18B20 sensor, KE-25 sensor, MH-Z14a sensor, Arduino Mega 2560, 20x4 LCD with I2C, DS-3231 Real-Time Clock (RTC), and Micro SD Card. The hardware block diagram is shown in **Figure 1**.

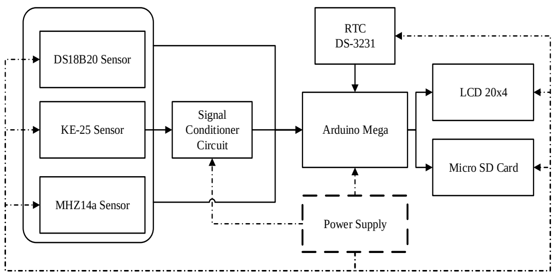

Figure 1. Hardware Diagram Blocks

In this study, the hardware block diagram is divided into three parts, input, process, and output, where the input section consists of three sensors, an RTC, and a power supply. The process includes the signal-sensing circuit and the Arduino Mega. Meanwhile, the output part consists of a 20x4 LCD and a micro SD card. The signal-sensing circuit uses a non-inverting amplifier circuit to reinforce the output voltage from the KE-25 sensor (**Figure 2**). The goal of this circuit is to make the output of the sensor readable by the Arduino Mega.

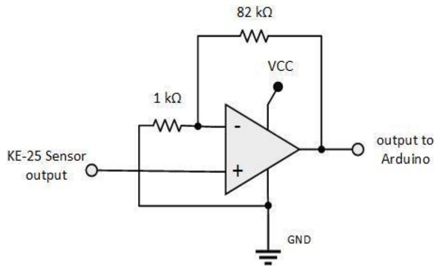

Figure 2. Schematic of Signal Conditioning Circuit for the O_2 Sensor

In the schematic (**Figure 2**), there is a signal conditioning circuit for the O_2 gas sensor using IC LM358 with a non-inverting type of gain (not flipped). This type's use is because the input from the O_2 gas sensor is positively charged, and the desired output is also positive. The other purpose of the signal conditioning circuit is to change the input voltage from the Figaro KE-25 sensor, ranging from 0 to 60 mV to 0 – 5 V, so that the Arduino can be easily read it.

2. Design of Software

This tool's software uses the Arduino IDE software version 1.6.7, with the primary C++ programming language already simplified into the Arduino libraries, making it easy to use and apply. Arduino IDE is instrumental in writing the program, compiling it, and uploading it into the Arduino Mega 2560. In detail, this design is depicted in a flowchart, which can be seen in **Figure 3**.

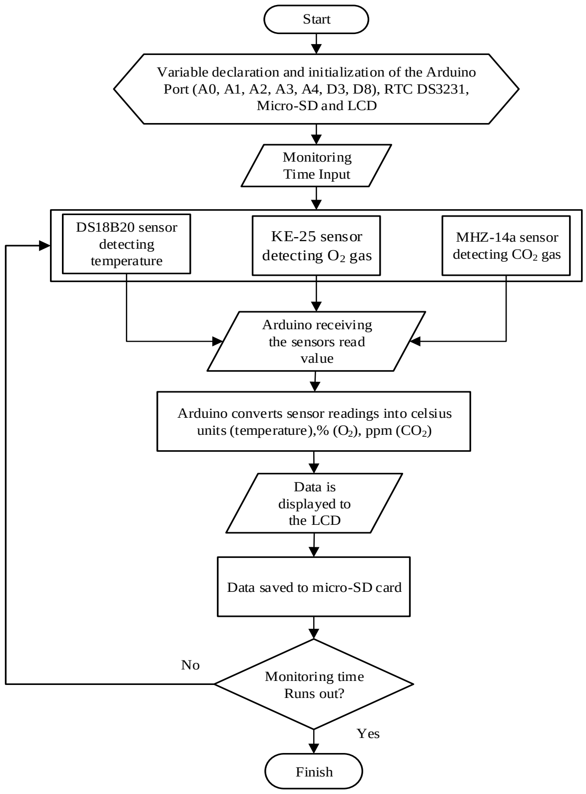

Figure 3. Software Design Flowchart

RESULTS AND DISCUSSION

Display of LCD 20x4 Character and SD Card Testing

In addition to being displayed on the LCD, data is also recorded and stored on a micro-SD card. The recording of this data is compiled through the list of programs below:

```
// Writing the measurement data
myFile = SD.open("data_pengukuran.txt",
FILE_WRITE);
if (myFile) {
myFile.print(now.day(), DEC);
myFile.print("\t");
myFile.print(now.hour(), DEC);
myFile.print(":");
myFile.print(now.minute(), DEC);
myFile.print("\t");
myFile.print(kal_Celcius);
myFile.print("\t");
myFile.print(kal_oxy);
myFile.print("\t");
myFile.println(kal_ppm);
myFile.close();
Serial.println("SUKSES!");
}
else
{
Serial.println("GAGAL");
}
```

The display results obtained from this program are as shown in Figure 4.

Figure 4. Display Data to 20x4 Character LCD

After the program is run, notifications from the serial monitor of the measurement data have been successfully recorded and stored. The data consisted of time, temperature, oxygen gas concentration (%), and carbon dioxide concentration (ppm) recorded in real-time (**Figure 4**).

Temperature Sensor Test (DS18B20)

DS18B20 sensor output in degrees Celsius, it is a digital sensor that has been calibrated by the manufacturer. This test is performed to determine whether the DS18B20 temperature sensor's reading is good or not, referring to the standard temperature gauge (HTC-2 digital thermometer). The data were obtained after placing the two tools in the refrigerator, which was set at a temperature of 5.5 - 20.5 °C.

The accuracy and error of the DS18B20 sensor are calculated using equation (1),

$$A = 1 - \left|\frac{Yn - Xn}{Yn}\right| \times 100\ \%$$

$$\%Error = \left|\frac{Yn - Xn}{Yn}\right| \times 100\ \% \qquad (1)$$

where A = Accuracy (%), Xn = Temperature value is readable on the HTC-2 digital thermometer (°C), and Yn = temperature value is readable at the temperature sensor DS18B20 (°C). The average accuracy of the DS18B20 sensor is 98.29%, with an error percentage of 1.71%.

Plotting data from a standard temperature device (HTC-2 digital thermometer) against the DS18B20 temperature sensor shows a linear graph (**Figure 5**). Analysis by the linear regression method shows that the relationship between the data measured by the HTC-2 digital thermometer and the data sensor temperature DS18B20 has a very strong relationship, as evidenced by the determination coefficient R^2 is 0.99993.

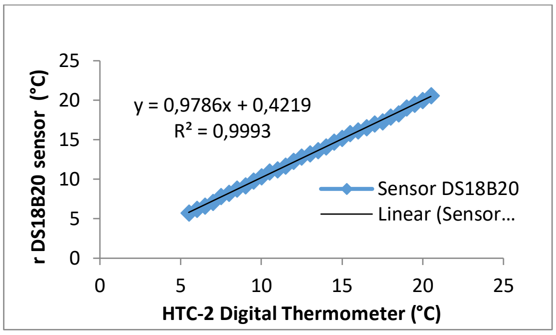

Figure 5. Graph of DS18B20 Linearization Test against HTC-2

Oxygen Sensor Testing (Figaro KE-2)

The Figaro KE-25 sensor has an output in the form of a voltage (V) and is not equipped with an internal ADC, requiring an analog value conversion process to a digital value. This conversion process can be done using the ADC facility belonging to the Arduino Mega 2560. Data collection for calibration of Figaro KE-25 sensor was done once with a specified gas concentration range of 18.5 - 23.5%. The range of concentration values is based on the gas composition in the atmosphere, where for oxygen gas, its content is 20.9%. Variation in these concentration values was intended to optimize the reading accuracy of the Figaro KE-25 sensor.

The data collection from the Figaro KE-25 sensor is compared with the data collection from the KXL-803 (gas analyzer). The results are plotted, and a linear graph of the Figaro KE-25 sensor calibration is obtained (**Figure 6**), with a coefficient of determination R^2 of 0.9939. This value indicates a solid relationship between the two data, namely the concentration of O_2 (%) and the sensor output (mV).

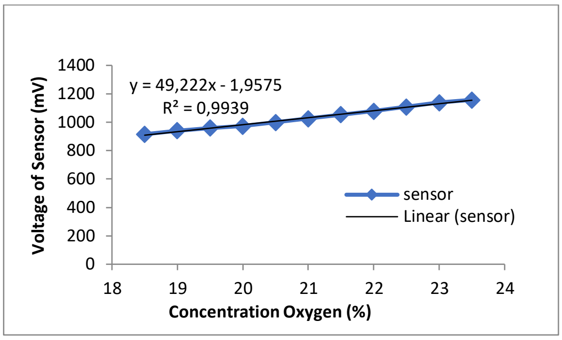

Figure 6. Graph of Calibration Figaro KE-25 Oxygen Sensor

Figure 6 shows the Figaro KE-25 sensor reading having a linear relationship with concentration O_2. The regression equation obtained can be used in the Arduino program to change the Figaro KE-25 sensor voltage value to a value of oxygen concentration (%).

The next step is testing the Figaro KE-25 sensor's output data for a gas concentration range of 18.5 - 23.5%. The test was carried out three times, and it compared the results with the KXL-803 reading output. **Figure 7** is the reading of the Figaro KE-25 sensor's average value compared to the KXL-803 Gas analyzer.

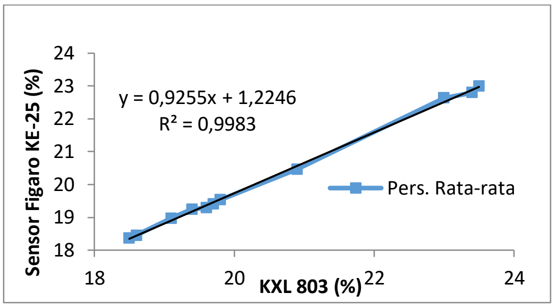

Figure 7. Graph of Figaro KE-25 Oxygen Sensor Test against Gas Analyzer KXL-803

The oxygen sensor's accuracy for the gas analyzer reading is calculated using equation (1). The average accuracy of the oxygen sensor is 98.57% with an error of 0.073%, while the standard deviation value (ΔS) is generated from three repetitions measurement, the average value was ± 0.014%. It means that the sensor has a good quality of accuracy and precision of measurement.

CO_2 Sensor Testing (MH-Z14a)

The MH-Z14a sensor was used to measure CO_2 gas in this study. Measurements were performed three times, and the average value of CO_2 concentration was obtained. **Figure 8** shows the importance of CO_2 gas measurement by MH-Z14a sensor compared to HT-200 Gas Analysis. The sensor output linearity test is indicated by the determination coefficient R^2 0.9979, which suggests that the two sensors' relationship is healthy. The sensor accuracy calculated using equation (1) is 95.48% with a percent error of 4.52% (in ppm scale).

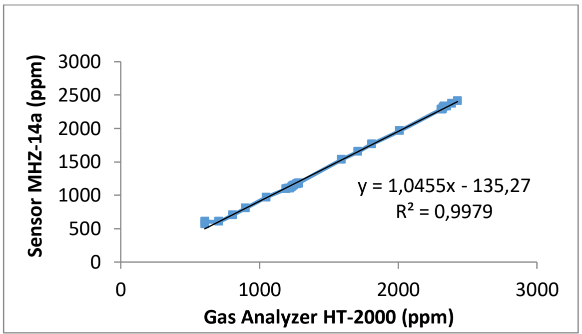

Figure 8. Graph of MHZ-14a CO_2 Sensor Test against Gas Analyzer HT-2000

Overall Analysis

This analysis was conducted to determine the data acquisition system's overall performance by applying it to refrigerator storage space. Data observations were carried out for 24 hours in a home refrigerator, starting from 6 February 2020 at 10.02 WIB to 7 February 2020 at 10.02 WIB. The data were obtained by conditioning the refrigerator to empty, assuming no external influence. The data is displayed and recorded, as shown in **Figure 4**.

Data measurements are plotted into three graphs, namely the map of the relationship between temperature and time (**Figure 9a**), O_2 and time (**Figure 9b**), as well as CO_2 concentration and time (**Figure 9c**).

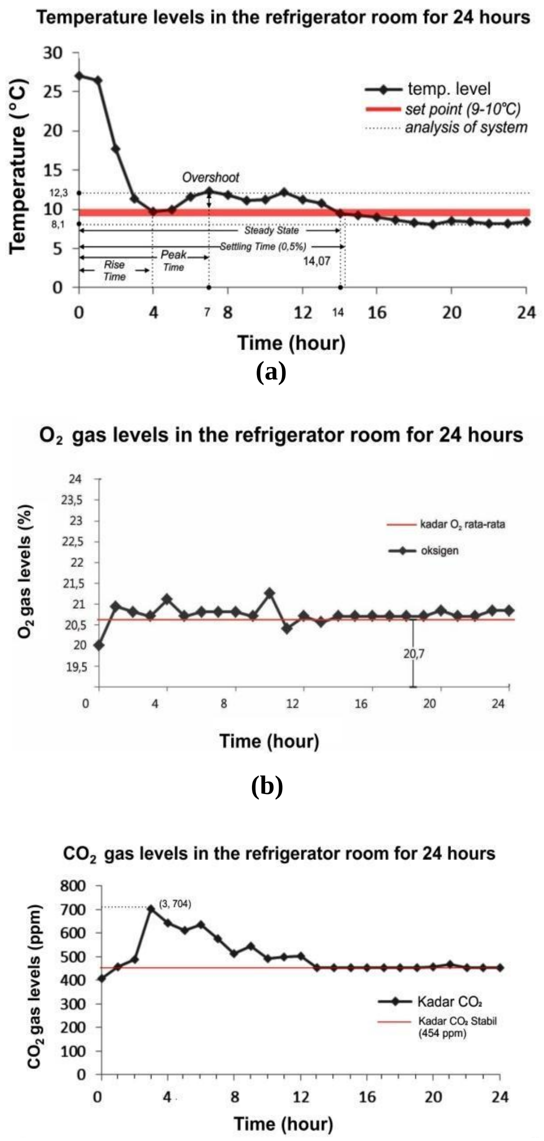

Figure 9. (a) Temperature, **(b)** O_2, and **(c)** CO_2 Measurements against Time in a 24-Hour Refrigerated Storage Space

This graph (**Figure 9a**) has a response character LHP (left-hand plane) is a chart that has a muted pattern and outputs the final response in the form of a steady state so that it can be approached with a transient response system analysis. At 13.3 hours, the refrigerator's temperature has reached a settling time of around 10 °C. After 14 hours, and the temperature indicates a stable trend at the setpoint value. Over time it comes to a steady state; this is related to the temperature rise (overshoot) that occurs on the 7th and 11th hours due to internal processes in the refrigerator. If the evaporator cooling process goes smoothly, the contents of the fridge will be cold. When the refrigerator temperature has cooled, and the temperature control cutting temperature has been reached, the contacts open. The electric current is cut off (off) until the compressor, fan, and motor timer stop. This condition lasts until the cutting temperature is reached again and the contacts are close to activating the compressor, fan, and motor timer. Settling time (Ts), i.e., the size of time starting the response, has entered 5% or 2% or 0.5% of the steady state. From these results, the cooling process in the refrigerator takes 4 hours to the desired setpoint. However, to reach a stable setpoint condition, it takes an additional 10 hours from the time the refrigerator is activated. From a practical point of view, the system has both measured and provided information about the temperature in the refrigerator and is in accordance with the reference (Ramadhani et al, 2019). The drawback is the long cooling time to the setpoint because the refrigerator has been used for 5 years. In general, the internal equipment condition of the refrigerator affects the room conditions in the refrigerator.

Figure 9b has a generally stable pattern from start to finish. In the initial conditions, the O_2 concentration in the refrigerator was 20%. The change in the O_2 concentration value occurred during the first hour, which was 20.9%. After 24 hours, the average O_2 gas in the refrigerator was 20.7%, which corresponds to the O_2 outside the fridge. This situation is caused by the absence of fruit or vegetables in the fridge, increasing O_2 levels due to the respiration process.

The graph of measurement results in CO_2 (**Figure 9c**) shows the value of CO_2 that increases and decreases to stabilize at the 13th hour with a CO_2 concentration of 454 ppm. If viewed from the health, the content of CO_2 in the cooling chamber enters into the second category, where the CO_2 gas concentrations have been an effect on human health if it is continuously inhaled (Cha, 2019)

CONCLUSION AND SUGGESTION

Based on the research results, it can be concluded that the data acquisition system for temperature, O_2, and CO_2 gases has been successfully realized in the refrigerated storage room. The characteristics obtained from each sensor are, the temperature has an accuracy value of 98.29% with an error of 1.71%, the O_2 sensor has an accuracy value of 98.57% and an error of 1.43%, and the CO_2 sensor has an accuracy value of 94.5% and an error of 5.43%. The average O_2 gas concentration in the refrigerator is still considered normal, about 20.7%, while the CO_2 content is slightly higher than normal air, about 454 ppm.

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