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Implementation Analysis of a Temperature and Humidity Control System For a Nodemcu-Based Smart Food Storage Box

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ABSTRACT

An optimal food storage system is essential to maintain quality and prevent spoilage due to changes in temperature and humidity. This study aims to analyze the implementation of a temperature and humidity control system in a smart food storage box based on Arduino and NodeMCU. This system uses a DHT22 sensor to detect temperature and humidity in real-time, a Peltier module as a cooler, and a fan and heater to control air conditions in the box. Arduino Uno is used as the main controller, while NodeMCU ESP8266 plays a role in data communication to the IoT platform for remote monitoring. The methods used in this study include hardware and software design, temperature and humidity stability testing, and system efficiency analysis in maintaining optimal food storage conditions. The test results show that the system is able to maintain temperatures in the range of 5–15°C with a deviation of ±1°C and humidity in the range of 50–70% RH, depending on the type of food stored. In addition, IoT integration allows real-time data monitoring through a cloud-based application. The conclusion of this study shows that the developed Smart Food Box system can operate effectively in maintaining food quality. The use of IoT technology increases the ease of remote monitoring and control, so this system has the potential to be applied on a household and industrial scale.

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INTRODUCTION

Suboptimal food storage can cause quality degradation, bacterial growth, and faster spoilage. The main factors that affect food durability are temperature and humidity. If the temperature is too high, food will easily spoil, while uncontrolled humidity can cause mold growth or dehydration in certain foods. Therefore, a storage system is needed that can control temperature and humidity automatically to extend the shelf life of food. Currently, many food storage methods are still conventional, such as refrigerators or closed containers, which do not have automatic monitoring or control systems. The disadvantage of this method is the inability of users to monitor storage conditions in real time and adjust temperature and humidity according to the specific needs of the stored food. With the development of Internet of Things (IoT) technology and automation, smarter and more efficient food storage solutions can be developed.

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This study aims to analyze the implementation of a temperature and humidity control system on a smart food storage box based on Arduino and NodeMCU. This system is designed using a DHT22 sensor to detect temperature and humidity in real-time, a Peltier module and fan to control temperature, and a NodeMCU ESP8266 to send data to an IoT platform so that users can monitor storage conditions via mobile devices. With this system, it is expected that users can more easily control the food storage environment automatically, maintain food quality longer, and reduce the potential for waste due to damaged or stale food. In addition, this research is also the first step in the development of IoT-based food storage technology that can be integrated with other smart home devices.

Literature Review

Control System

A control system can be said to be a relationship between components that form a system configuration that will produce the expected system response. So something must be controlled, which is a physical system, which is usually called a control (plant). Input and output are variables or physical quantities. Output is what is produced; while input is what influences control, which regulates output. The two dimensions of input and output do not have to be the same. In the control system, there are open loop systems and closed loop systems. Open loop control systems or feed forward control generally use controllers and control actuators which are useful for obtaining good system responses. The output of this control system is not recalculated by the controller. A condition of whether the plant has actually reached the target as desired by the input or reference cannot affect the performance of the controller (Haris Abdul, 2014).

Control system is a process of regulating or controlling one or more quantities (variables, parameters) so that they are at a certain price or in a certain price range. In the industrial world, a safe and highly efficient work process is required to produce products with good quality and quantity and at a predetermined time. Automation is very helpful in terms of operational smoothness, security (investment, environment), (production costs), product quality, etc. (Faroqi et al., 2016).

Internet of Things

IoT (Internet of Things) allows users to manage and optimize electronics and electrical equipment that uses the internet. It is speculated that some time soon communication between computers and electronic equipment is able to exchange information between them thereby reducing human interaction. This will also increase internet users with various internet facilities and services (Junaidi, 2016). The main challenge in IoT is bridging the gap between the physical world and the information world. Such as how to process data obtained from electronic equipment through an interface between the user and the equipment. Sensors collect raw physical data from real-time scenarios and convert them into machine-understood formats so that they can be easily exchanged between various forms of data formats (Things) (Suresh et al., 2014).

Developments in mobile technology have also contributed to the development of the Internet of Things, namely research on privacy in the field of regional surveillance, detecting

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locations based on Location. *Based Service*so that someone can feel comfortable using a mobile device without having their personal privacy disturbed (Elkhodr et al., 2012).

The issue of Cloud Computing is also a research topic for the Internet of Things by combining cloud computing technology and the Internet of Things called CloudThings (J. Zhou et al., 2013); (H. Wang, 2011).

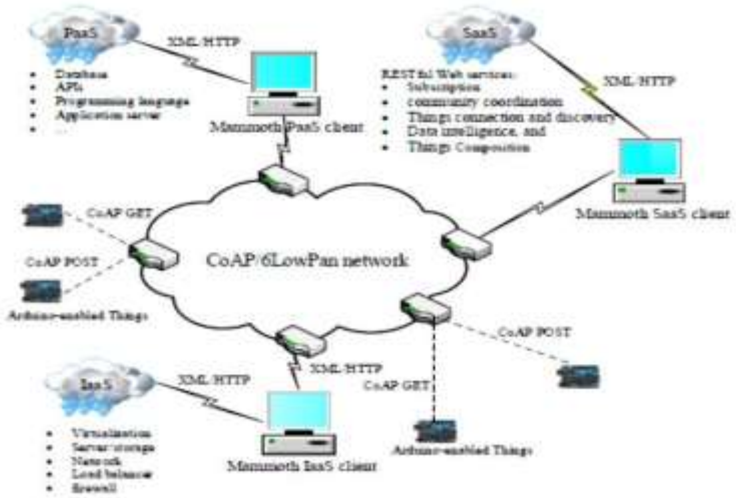

Figure 1. CloudThings Architecture

ESP8266 NodeMCU

ESP8266 ESP-12 variant, namely NodeMCU, which is an open source Internet of Things platform. There is hardware in the form of SoC (System on Chip) ESP8266, so that programming can be done directly to ESP8266 without using additional microcontrollers. Programming NodeMCU only requires a USB data cable extension that is exactly the same as a smartphone charging cable, because NodeMCU has compiled ESP8266 into a board with various features like a microcontroller, as well as access to WiFi with a USB to serial communication chip. The ESP8266 image is in image 2 below:


Figure 2. ESP8266 NodeMCU

NodeMCU measures 4.83cm long, 2.54cm wide, and weighs 7 grams. This board is equipped with WiFi features and its Firmware is open source. The specifications owned by NodeMCU are as follows:

1. *Board*This is based on ESP8266 serial WiFi SoC (Single on Chip) with on board USB to TTL. The wireless used is IEE 802.11b/g/n.
2. Tantalum capacitors 100 micro farad and 10 micro farad.

3. 3.3v LDO regulator.
4. *Blue LED*as an indicator.
5. Cp2102 usb to uart bridge.
6. Reset button, usb port, and flash button.
7. There are 9 GPIOs which include 3 PWM pins, 1 x ADC Channel, and an RX TX pin.
8. 3 ground pins.
9. S3 and S2 as GPIO pins.
10. S1 MOSI (Master Output Slave Input) is the data path from the master to the slave, sc cmd/sc.

Figure 3. GPIO NodeMCU ESP8266 v2

The following is an explanation of the NodeMCU pins:

1. RST: functions to reset the module. with a digital value range of 0-1024.
2. EN: Chip Enable, Active High.
3. IO16 :GPIO16, can be used to wake up the chipset from deep sleep mode.
4. IO14 : GPIO14; HSPI_CLK.
5. IO12 : GPIO12: HSPI_MISO.
6. IO13: GPIO13; HSPI_MOTION; UART0_CTS.
7. VCC: 3.3V power supply (VDD).
8. CS0 : Chip selection.
9. MISO: Slave output, Main input.
10. IO9 : GPIO9.
11. IO10 GBIO10.
12. MOTION: Main output slave input.
13. SCLK: Clock.
14. GND: Ground.
15. IO15: GPIO15; MTDO; HSPICS; UART0_RTS.
16. IO2 : GPIO2;UART1_TXD.
17. IO0 : GPIO0.
18. IO4 : GPIO4.

19. IO5 : GPIO5.
20. RXD : UART0_RXD; GPIO3.
21. TXD : UART0_TXD; GPIO1.

AT Command

The ESP8266 wireless module that is already available on the NodeMCU board has factory firmware that supports AT-Command commands. A collection of Hayes Command lists is a description of AT-Command. Hayes command was developed by Dennis Hayes in 1981 as a list of commands to configure a modem using a serial interface line (Yuliansyah, 2016). Here are some examples of Hayes Commands and their functions on the ESP8266 module.

Table 1. AT-Command List

AT-Command	Function	Response
AT	Working	OK
AT+RST	Restart	OK [System Ready, Vendor:www.ai-thingker.com]
AT+GMR	Firmware Version	AT+GMR 0018000902 OK
		AT+CWLAP+CWLAP:(4,"AP 1",-
AT+CWLAP	List Access	38,"70:62:b8:6f:6d58",1)+CWLAP:(4," AP 2",-
AT+CWJAP?	Join	83,"f8:7b:8c:1e:7c:6d",1) Query
AT+CWJAP="SSID"," PAS S"	Access Point	AT+CWJAP?+CWJAP:"AP1" OK

Representational State transfer(REST)

REST is a software architectural style in the World Wide Web (Lewis & W., 2012). REST was first introduced by Roy Fielding in 2000. REST specifically refers to the principles of network architecture. This architecture runs through HTTP (Hypertext Transfer Protocol). The characteristic of REST is that the interaction between client and server is facilitated by a number of unique operational types for each resource. These operational types can be POST, GET, PUT, and DELETE (George, 2011). In this study, an http server will be used with the REST operational used is GET. The data obtained is then stored in a database. Later, the data will be analyzed in order to obtain conclusions in this study.

Thermoelectric Module

In electronics there are various components made of semiconductor materials. Semiconductors themselves are a very important part of thermoelectric modules or peltier modules. Thermoelectric modules consist of many semiconductor connections designed into a thermoelectric device or module. Semiconductors in the module will be connected and form a thermocouple. A thermoelectric module composed of Bismuth Teluride ceramic material type P and type N connected in series can be used and can produce up to 130ºC (Riffat & Ma, 2003). The schematic diagram of the thermoelectric module can be seen in the image below:

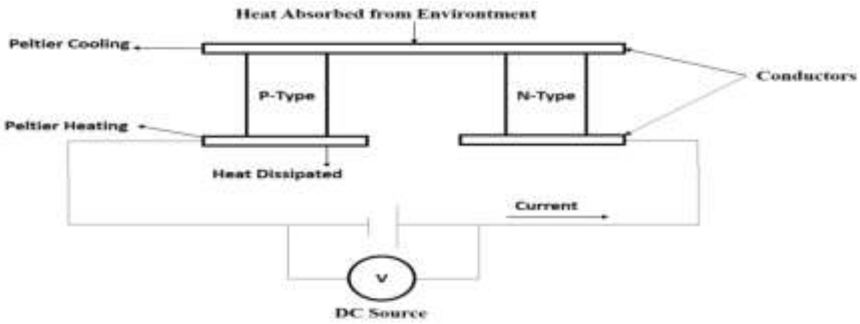

Figure 4. Peltier Schematic

The working principle of the thermoelectric module is based on the Peltier effect. The Peltier effect will create a temperature difference caused by the provision of voltage between two types of electrodes connected to the semiconductor material sample. When using a thermoelectric module, it must be supported by a process heat dissipation on the hot side. If the hot temperature is the same as the ambient temperature, then on the cold side a lower temperature will be obtained (tens of degrees Kelvin). The cooling rate can be reduced by the current value passing through the thermoelectric module. In thermoelectrics, the electron heat exchanger acts as a heat carrier. The action of heat pumping is caused by the function of the number of electrons passing through the PN junction (Bansal, 2009).

In the design and utilization of Peltier modules as coolers and heaters, several developments are needed to maximize the performance of the Peltier effect. Based on theoretical calculations carried out with a realistic model of the Peltier module, it indicates that the Coefficient of Performance (COP) and heat pumping capacity depend on the length of the thermoelement that makes up the module. This dependence will increase significantly with a decrease in the length of the thermoelement. For commercially available modules that have a thermoelement length of 1.5 mm, the results indicate that the COP value and heat pumping capacity are 70 and 30%, which are ideal values. Reducing contact resistance, especially thermal contact resistance, is an important requirement to achieve further improvements in both COP and heat pumping capacity (Min, Gao, 1999).

METHOD

The type of research used in writing this thesis is experimental research. Experimental research is a type of research used to see cause-and-effect relationships. Experimental research is a research activity that aims to assess the effect of a treatment or action compared to other actions. Experimental research uses a specially designed experiment to generate the data needed to answer the research question. Experimental research is conducted systematically, logically, and carefully in controlling conditions. In this study, the connection of components of tools with different characteristics was carried out. This study aims to study something by varying several conditions and observing the effects that will occur.

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This research is supported by literature research, namely by reading and studying literature on how to design a Smart Food Box Using a Microcontroller-Based Peltier TEC1-12706 Thermoelectric Module and assembling the components needed to build a Smart Food Box that can withstand heat and cold from food.

RESULT

Minimum Specifications *Hardware*

The hardware in this study uses an ESP8266 chip with the advantage of being able to transmit WiFi signals that can function as a master or slave that has been packaged in a module with the aim of making it easier to use. With the packaging of the ESP8266 chip and equipped with a power supply circuit and a USB to Serial CH340G converter chip, it is then known as NodeMcu Lua. The complete specifications have been described in the previous chapter.

Minimum Specifications *Software*

Next, one of the most frequently used software to create programs so that NodeMcu Lua can function as expected is the Arduino IDE compiler with the latest version, namely Arduino IDE 1.8.13. The work or writing of the program is done on a computer or laptop with standard specifications because the Arduino IDE compiler that is run does not have to be on special specifications to be able to work. But to program NodeMcu on the Arduino IDE compiler, you must first add the NodeMcu library to the board manager so that the Arduino IDE compiler used can recognize the NodeMcu board. To add NodeMcu to the Arduino IDE board manager, do the following:

1. Open the Preferences menu on the Arduino IDE by clicking the file menu then preferences.

Figure 5. Preferences Menu in Arduino IDE

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2. Then in the Preferences menu add board manager URLs with the link ("http://arduino.esp8266.com/stable/package_esp8266com_index.json").

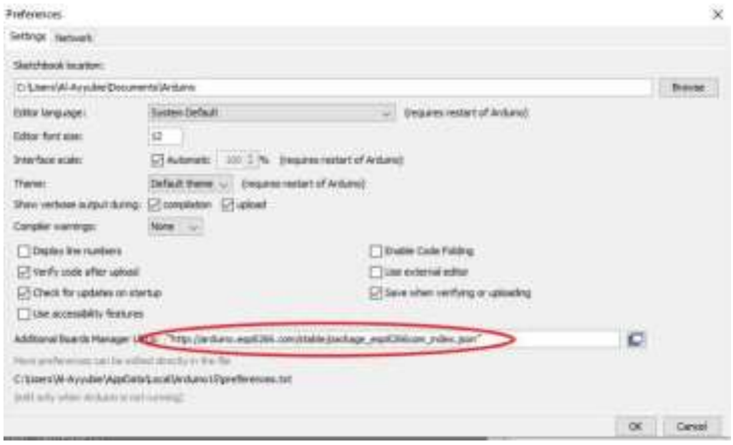

Figure 6. Adding ESP8266 Link to Additional Board Manager

3. If the URLs have been added to the Additional Boards Manager, by clicking the Tools menu then board manager to search for and install or add the ESP8266 or NodeMcu board.

Figure 7. Searching for NodeMcu Board in Board Manager

4. After entering the board manager menu, then search for ESP8266 and then select install on the right button.

Figure 8. View After Successfully Installing the ESP8266 NodeMcu Board

Hardware Testing

After planning and creating the application, the next step is to test the hardware and software that has been created. Testing is done to find out whether the hardware and software that has been created can run as desired. The testing and analysis carried out include testing the operation of the hardware and software used for the Smart Food Box application that will be designed.The purpose of hardware testing is to find out that the device related to the microcontroller has been able to function properly. In this test, a multitester is needed to measure the required voltage and measure the data that has been filled in the microcontroller.

The initial test is to measure the voltage on the power supply by connecting the voltage to the step-down circuit section. voltage. The voltage source used in this application uses 3 18650 batteries that have a voltage of 3.7 volts for each battery. 3 batteries are connected in series to get a voltage of 3.7 volts times 3, then a voltage of 11.1 volts DC will be obtained.

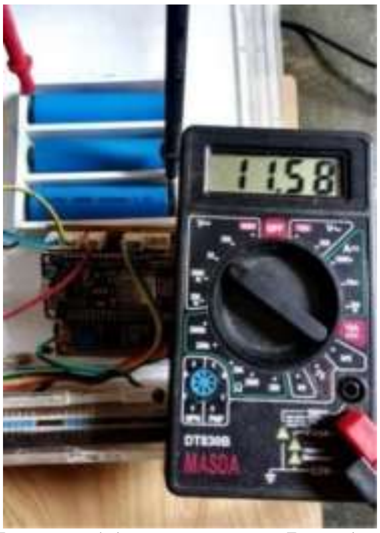

Figure 9. Battery Measurement Results 18650 x 3

To supply voltage to the microcontroller, the 11.1 voltage must be lowered first because the microcontroller uses 5 volt DC voltage. For this purpose, the LM2596 voltage reduction module is used.

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Figure 10. Measurement results of 5 Volt DC voltage that has been reduced

For the supply voltage given to the nodemcu directly comes from the battery because the nodemcu board module has its own 5 volt voltage regulator circuit. For that, the voltage sourced directly from the battery can be used. The next check is the I2C Converter module for the LCD Display. This module also uses a 5 volt voltage that can be taken from the output of the LM2596 module.

Figure 11. LCD I2C Voltage Measurement Results

The results of the source voltage measurements can be seen in table 4.1 below:

Table 2. Source Voltage Measurement Results

NO	Measurement	Voltage
1.	Battery OutputSource	11.58 Volt
2.	OutputLM2596 Module Circuit	4.81 Volt
3.	SupplyI2C Module	4.81 Volt

The second test is a circuit test. This test is carried out to check whether the voltage is properly connected to each component which is connected to its Vcc pin. This test is very important to do so that the circuit can run properly. The first test is testing on nodemcu. This test is to ensure that the nodemcu module used is in good condition. Nodemcu testing uses a program that is almost the same as testing the Arduino Uno board, namely by entering the blink.ino program. But in this case because the LED on the nodemcu is not connected to pin 13 like the Arduino Uno, it is necessary to make adjustments to the blink.ino program. The LED on the nodemcu is connected to pin 2, for that adjustments are made as in the program below:

```
void setup() {
 / initialize digital pin LED_BUILTIN as an
 output. pinMode(2, OUTPUT);
}
/ the loop function runs over and over
again forever void loop() {
 digitalWrite(2,
 HIGH);
 delay(1000);
 digitalWrite(2,
 LOW);
 delay(1000);
}
```

If the upload process is successful and the LED on the nodemcu lights up and goes out within 1 second, then it is certain that the nodemcu board is in good condition and can be tested on other components.

Relay Testing

In the Smart Food Box application to be designed, the heater and cooler used are peltier TEC1-12706 which can work at a voltage of 7 - 24 Volts. To switch the peltier to the on and off position, a relay is used as an electric switch that can work at high voltage and current. The circuit used to control the relay can be seen in the image below:

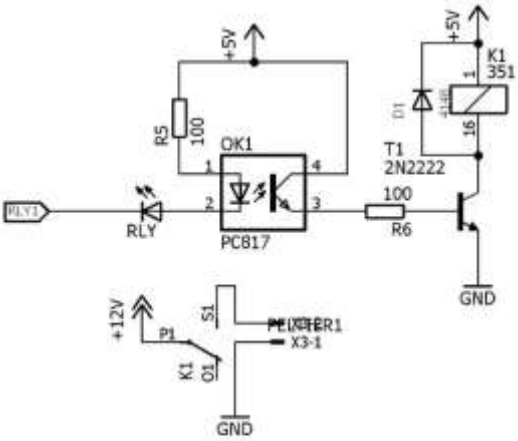

Figure 12. Relay Circuit Schematic

In the circuit above using optocoupler PC817 which can be used to minimize the reverse current from the relay to the nodemcu which can interfere with the performance of the nodemcu. Furthermore, the output of the optocoupler is fed to the transistor base for a larger voltage change because the supply to the relay also requires a large voltage. To be able to test the circuit above, you can also use the blink program whose output is adjusted to the pin connected to control the relay. The nodemcu pins used to control the relay can be seen in the table below:

Table 3. Description of Relay Pins connected to the Microcontroller

Relay	Nodemcu Pin	Programming
Relay1	D1	5
Relay2	D2	4

On nodemcu, for writing programs in arduino IDE is different from what is written on the nodemcu board. For pin D1 written on the nodemcu board must be written with pin number 5 in the arduino IDE programming. For more details see table 3.

```
#include <LiquidCrystal_I2C.h>
#include <Wire.h>

LiquidCrystal_I2C lcd(0x27, 16, 2);

void setup() {

  / put your setup code here, to
  run once: Serial.begin(115200);
  Wire.begin(0, 2);


  lcd.begin(16, 2);
  lcd.home();
  lcd.print("Hello World");

   pinMode(5, OUTPUT);

   pinMode(4, OUTPUT);
}
void loop() {
  / put your main code here, to run
  repeatedly: lcd.clear();
  digitalWrite(5, HIGH);
  lcd.setCursor(0, 0);
  lcd.print("Relay 1 ON");
  delay(1000);
  digitalWrite(4, HIGH);
  lcd.clear();
  lcd.setCursor(0, 0);
  lcd.print("Relay 2 ON");
  delay(1000);
```

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```
        digitalWrite(5, LOW);
        digitalWrite(4, LOW);
        lcd.clear();
        lcd.setCursor(0, 0);
        lcd.print("2nd Relay
        OFF"); delay(1000);
        lcd.clear();
        delay(1000);
}
```

The results of the relay circuit testing can be seen in the image below:

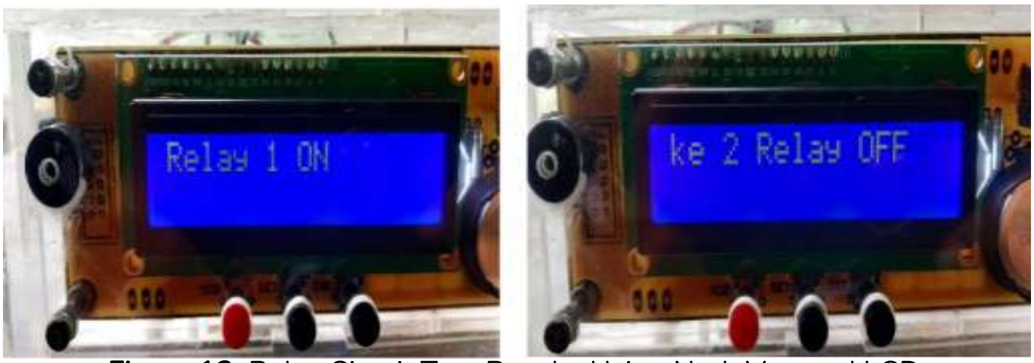

Figure 13. Relay Circuit Test Results Using NodeMcu and LCD

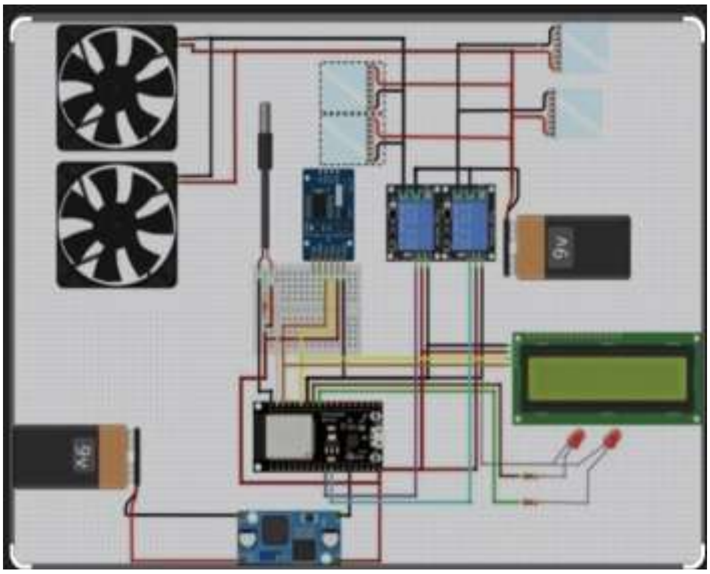

Figure 14. Smart Food Box Wire

Next is the LM35 sensor test. The LM35 sensor is a temperature sensor that is often used in various applications. The use of the LM35 sensor aims to provide temperature information on the food box. Whether the food that is put in is hot or cold, the temperature sensor has a role to measure the temperature of the food that is put in so that it can activate the heating or cooling peltier. After conducting the overall test, good results were obtained for the Smart Food Box application in detecting food temperature and the resulting temperature.

For the cooling peltier, it can be produced perfectly if the heat dissipation from the opposite side of the peltier can be disposed of properly using a heatsink. For the heating peltier, a heatsink is not provided because the temperature to be utilized is hot. For the connection to the web server, it is also quite good to do, considering that the device connected to the smartphone requires an internet network, so fast and stable internet is needed to support the work performance of the monitoring work system on the smartphone. Next, a peltier test will be carried out to withstand hot and cold temperatures on food. The test was carried out for 1 hour to withstand cold and hot temperatures on food.

CONCLUSION

The analysis of the implemented system demonstrates that the integration of NodeMCU with temperature and humidity sensors (e.g., DHT11/DHT22) provides an effective solution for real-time environmental monitoring in a smart food storage box. The system successfully maintains temperature and humidity within predefined thresholds using actuators such as fans or heaters, thereby helping to preserve food quality and extend shelf life. The use of NodeMCU, with its built-in Wi-Fi capability, enables remote monitoring and control via IoT platforms, allowing users to track environmental conditions through a smartphone or web interface. The system responded accurately to changes in environmental conditions, with minimal response delay and stable performance during testing. Overall, the implementation of this temperature and humidity control system proves to be efficient, low-cost, and scalable, making it suitable for broader applications in smart storage and home automation systems. Further improvements can include adding alert systems, power optimization, and integration with machine learning for predictive control.

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