Enhancing Refrigerated Warehouse Capacity by Analyzing Spatial Temperature Differences with IoT

Tanmay Wasu*,Ved Tare*, Yash Buty*, Shivani Mundhrikar*,P. B. Shiwalkar**

**Final Year Industrial Engineering Student, Shri Ramdeobaba College of Engineering and Management, Nagpur.*
***Professor Industrial Engineering Department, Shri Ramdeobaba College of Engineering and Management, Nagpur.*

---***---

Abstract: Refrigerated warehouse is a critical element in the supply chain of perishable goods. The specified storage conditions are to be adhered to in spite of varying ambient conditions due to different geographic locations in country like India. Even inside a fair-sized refrigerated warehouse or a cold storage non uniformity of values for critical parameters like temperature and humidity is un-avoidable. In the given situation variation of critical parameters vis-à-vis spatial location of the vantage point in the observable storage space of a refrigerated warehouse storing perishable spices is analyzed. To monitor the parameters at 3 different locations of each of the 5 floors, readings are noted using IoT techniques. Cause and Effect diagnostics is used to identify and correct the problematic locations to enhance the storage capacity of the warehouse.

Keywords: Raspberry Pi, Data Visualization, ThingsSpeak, ThingsView, SMS-Alert.

I. INTRODUCTION

One of the most important factors influencing the wholesomeness of foods is temperature. The temperature fluctuations can cause food degradation. Excess fruits and vegetables are frequently stored in the food industry because they cannot be consumed immediately but can be stored well. This paper focuses on the design of a similar cold storage monitoring system that will keep an eye on natural factors such as temperature. The goal of this paper is to monitor temperature in cold storage warehouses so that stored products do not get contaminated due to environmental conditions which will enhance the capacity of cold storage.

The monitoring node in this case is a RaspberryPi. Programming language used by Raspberry Pi is Python. The Raspberry Pi is a small but complete PC on a single board. DHT-11 sensor is connected to the Raspberry Pi which detects real time temperature and humidity, and Raspberry Pi sends this real time data to Thingspeak server and to a mobile application based on Thingspeak id in mobile. Thingspeak server is an open-source server used to store and display the real-time data. In case if there is any sudden change in the temperature and the temperature value falls outside the pre-set range in Raspberry Pi, then this IoT based device will send an autogenerated SMS alert to owner's mobile phone. This autogenerated SMS alert consist of the present temperature value.

II. COMPANY PROFILE AND PROBLEM IDENTIFICATION

Refrigeration System in Warehouse: In warehouse, refrigeration system is located at the 3rd and 4th floor. Cooling is ensured on other floors with the help of nitrogen circulation i.e., Ammonia gas circulates throughout warehouse in pipes, these pipeshave very low temperature due to the Ammonia gas flowing through them which is responsible for very low temperature of pipes. Temperature of air circulating through warehouse drops when it comes in contact with these pipes. This cools the surrounding environment in warehouse.

Exhaust fans facing upwards are present in the refrigeration system ensure the constant flow of surrounding air through the system. Also, the floor of warehouse is wooden and has slits in it which ensure free flow of cold air coming out of refrigeration system from 3rd and 4th floor to rest of warehouse.

Fig. 1. (Left) Refrigeration System arrangement

Fig. 1. (Right) Refrigeration System details

Problem Identification: To study the temperature difference at different geographical locations in a refrigerated warehouse to enhance the storage capacity of Goyal Warehouse Pvt. Ltd., a well-known warehouse in Nagpur to store perishable and non-perishable food products like different types of chilies, chili powder, pulses, dried turmeric fingers etc. Each floor is 30000 sq. ft. of area. And Each floor consist of 5 parts, 6500sq.ft per part.

III. Methodology

3.1. Hardware:

Raspberry Pi: The model of Raspberry Pi used in this paper is Raspberry Pi 3b+. The Raspberry Pi is a credit card-sized computer with an ARM processor that can run Linux. This item is the Raspberry Pi 3 Model B+, which has 1 GB of RAM, dual-band Wi-Fi, Bluetooth 4.2, Bluetooth Low Energy (BLE), an Ethernet port, HDMI output, audio output, RCA composite video output (through the 3.5 mm jack), four USB ports, and 0.1″-spaced pins that provide access to general purpose inputs and outputs (GPIO). The Raspberry Pi requires a microSD card with an operating system on it.

DHT-11 Sensor: DHT11 is a low-cost digital sensor for sensing temperature and humidity. This sensor can be easily interfaced with any micro-controller such asArduino, Raspberry Pi, ESP-32, etc. to measure humidity and temperature instantaneously. DHT11 humidity and temperature sensor are available as a sensor and as a module.

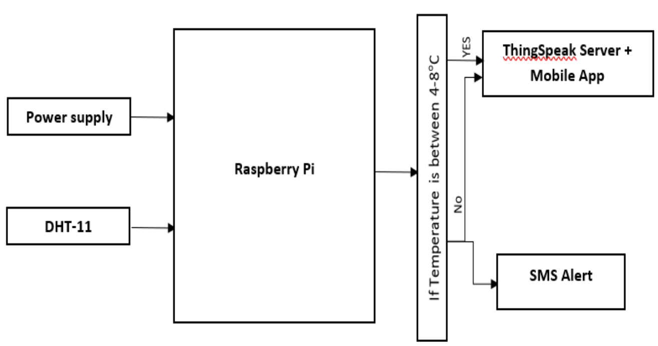


Fig 2. (left) Block Diagram of the proposed system

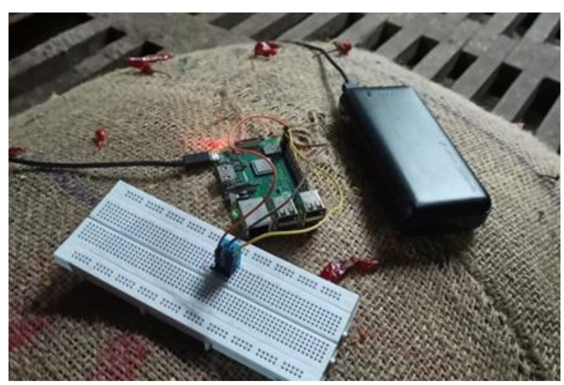


Fig 2. (Right) Raspberry Pie based IoT setup used to record temperatur

3.3. Python program for Data Collection and Visualization through Raspberry Pi:

```
final code.py 3 ●
C: > Users > HP > Desktop > liot project > final code.py > send_data
import requests as r
import Adafruit_DHT as dht
import time
from datetime import datetime
import os
import sys
import urllib.request as ul
import subprocess as sp

def send_data(temp, hum):
    url1 = "https://api.thingspeak.com/update?api_key=WCRXJ9YOAJ6XMXQC&"
    url2 = "field1="+str(hum)+"&field2="+str(temp)
    url = url1 + url2
    with ul.urlopen(url) as response:
        data = response.read()
        #print(data)

def clear():
    sp.call('clear', shell=True)        #Clear Screen

def sms_alert(temp):        #Sends SMS Alerts
    sms_url = "https://maker.ifttt.com/trigger/TEMP_ALERT/with/key/cfdLEQUFoMZQ1xvAH5skA1"
    data = { 'value1' : str(temp) }
    res =  r.post(sms_url, data = data)
    print(res)

def check_range(t):        #Checks the range
    if t < 4 or t > 8:
        return False
    else:
        return True

point = sys.argv[1]
file = open("data_log.csv", "a")
if os.stat("data_log.csv").st_size == 0:
    file.write("Sr. No. ,Point Name, Time, Humidity, Temperature\n")
file.write("\n")
```

Fig. 3. (Left) Python code for data collection and visualization

```
final code.py 3 ●
C: > Users > HP > Desktop > liot project > final code.py > send_data

def sms_alert(temp):        #Sends SMS Alerts
    sms_url = "https://maker.ifttt.com/trigger/TEMP_ALERT/with/key/cfdLEQUFoMZQ1xvAH5skA1"
    data = { 'value1' : str(temp) }
    res =  r.post(sms_url, data = data)
    print(res)

def check_range(t):        #Checks the range
    if t < 4 or t > 8:
        return False
    else:
        return True

point = sys.argv[1]
file = open("data_log.csv", "a")
if os.stat("data_log.csv").st_size == 0:
    file.write("Sr. No. ,Point Name, Time, Humidity, Temperature\n")
file.write("\n")
i = 0
chear()
print("Starting Temperature and Humidity Monitoring..")
time.sleep(2)
while True:
    humid, temp = dht.read_retry(11, 4)
    print("Temperature: {0:0.1f} C Humidity: {1:0.1f} %".format(temp, humid))
    now = datetime.now()
    i += 1
    file.write(str(i) + "," + str(point) + "," + str(now) + "," + str(humid) + "," + str(temp)+ "\n")
    file.flush()
    send_data(temp, humid)
    if not check_range(temp):
        sms_alert(temp)
        print("Alert! Temperature is above or below the given range, Please check the temperature. System will halt itself for a minute.'
        time.sleep(60)
    time.sleep(1)
```

Fig. 3. (Right) Python code for data collected and visualization

3.2. IoT enabled features:

ThingSpeak Server: ThingsSpeak is an IoT analytics platform service that allows us to collect, visualize and analyse live data streams in cloud. We can send data to ThingsSpeak any device at any remote location.

ThingView – ThingSpeak viewer: ThingView is a mobile application which help us to get the real time data from our Raspberry Pi to our mobile at any location away from the setup by entering ThingSpeak server's API key and id.

3.4. Data Collection:

The cold storage plant is of five floors (ground + 4). Refrigeration system is installed at 4th floor making it the most ideal for storing chilies. IoT based system is kept at three different locations on each floor and thus 15 readings were obtained at each location. The setup was kept on different sacks which were kept at a manual height as shown in Fig 2. b. An average from the 15 readings was calculated for each location. These readings are shown in Table 1 and points were named as G1a, G1b, G1c, FL1a, FL1b, etc. for all 5 floors. FL1c and FL3a were found to be the locations in which temperature is constantly deviating the ideal range making these 2 locations unsuitable for storage of chilies. This means almost 12000 sq. ft area is wasted out of 60000 sq. ft. of area.

The collected data is being stored in an excel sheet and is also visible at ThingSpeak server and in ThingView mobile application. The person in charge at warehouse has access to the mobile application to monitor real time temperature value.

3.4.1. Collected Data:

READING NO.	TEMPERATURE (°C) AT SENSOR LOCATIONS														
	G1a	G1b	G1c	FL1a	FL1b	FL1c	FL2a	FL2b	FL2c	FL3a	FL3b	FL3c	FL4a	FL4b	FL4c
1	8	8	9	7	7	7	7	7	7	9	6	6	6	5	5
2	8	7	10	7	8	7	7	7	6	9	6	6	5	5	5
3	8	7	10	7	7	7	6	7	6	8	6	6	5	5	5
4	8	7	9	8	7	7	6	6	6	9	7	6	5	5	5
5	7	8	10	7	7	7	6	6	6	9	6	6	5	5	5
6	8	8	9	7	7	7	6	6	6	9	6	6	5	5	5
7	7	8	9	8	7	7	7	7	7	8	6	7	6	6	5
8	7	8	10	7	7	7	7	6	7	8	6	7	5	6	5
9	7	8	9	7	7	7	7	6	6	9	6	6	5	5	6
10	8	8	9	7	7	7	6	6	6	8	6	6	5	5	6
11	8	8	10	7	7	7	6	6	6	8	6	6	6	5	6
12	8	8	10	7	7	7	6	6	6	8	6	6	5	5	6
13	8	8	10	7	7	7	6	6	6	8	6	6	5	5	5
14	7	8	10	7	7	7	6	6	6	8	6	6	5	5	5
15	7	8	10	7	7	7	6	6	6	8	6	6	5	5	5
Mean	**7.6**	**7.8**	**9.6**	**7.13**	**7.06**	**7**	**6.33**	**6.26**	**6.2**	**8.4**	**6.06**	**6.13**	**5.2**	**5.13**	**5.26**

Table 1. Observed real time temperature data

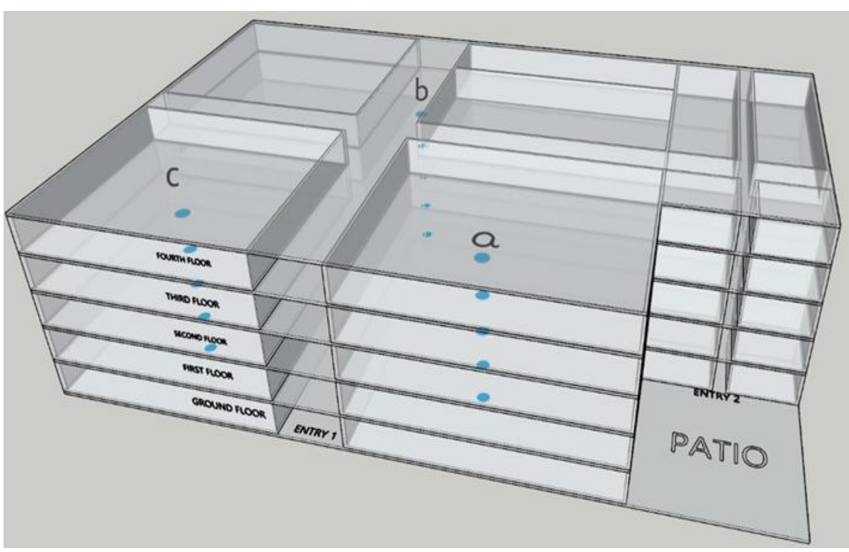


Fig. 4. (Left) 3-D drawing of warehouse (sensor location displayed with points a, b, c)

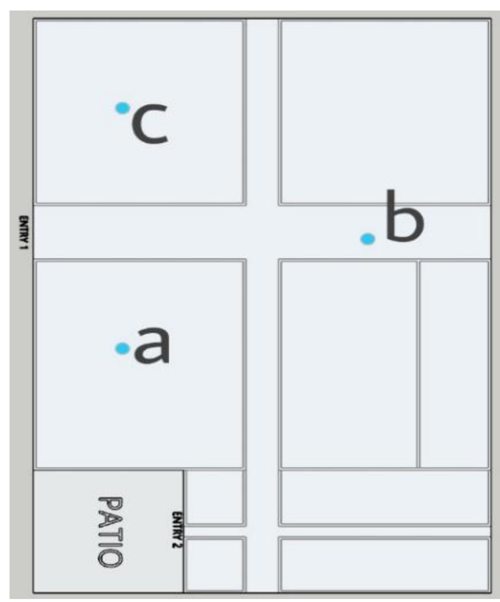


Fig. 4. (Right) Warehouse Layout Top View (sensor location displayed with points a, b, c)

IV. ANALYSIS OF DATA AND ACTUATION

Analysis of the collected data is done to find out the causes which are affecting the temperature at two points. For this, a Cause-Effect diagram or an Ishikawa diagram was used to solve the problem. Sometimes this diagram is also called as Fish Bone diagram as it has a shape of fish. Right side of the diagram consists effect and left side of the diagram consists different causes. Major cause categories are shown as gross fish bones. Following causes of temperature fluctuations are identified through brainstorming:

Environmental, Material, Personnel, Machine, Measurements and Thermoregulation.

Environmental: This cause is a result of fluctuations in outer temperature due to various atmospheric changes. Normally the refrigeration process is carried out for 10-15 hours depending on the product stored in the warehouse. In winter, the refrigeration process is quite easy and is carried out approximately for 8 hours while in summer, process of refrigeration is takes more time as outer temperature is usually very high. Hence, Refrigeration process is carried out for 15-18 hours during summer.

Personnel: This cause is a result of human intervention in the refrigeration process such as door left open for longer duration of time, in-appropriate location allocated to a particular food material.

Machines: This cause results due to mal functioning of the machines used in the warehouse. Mal-functioning can be result of any fault in the machine or power failure.

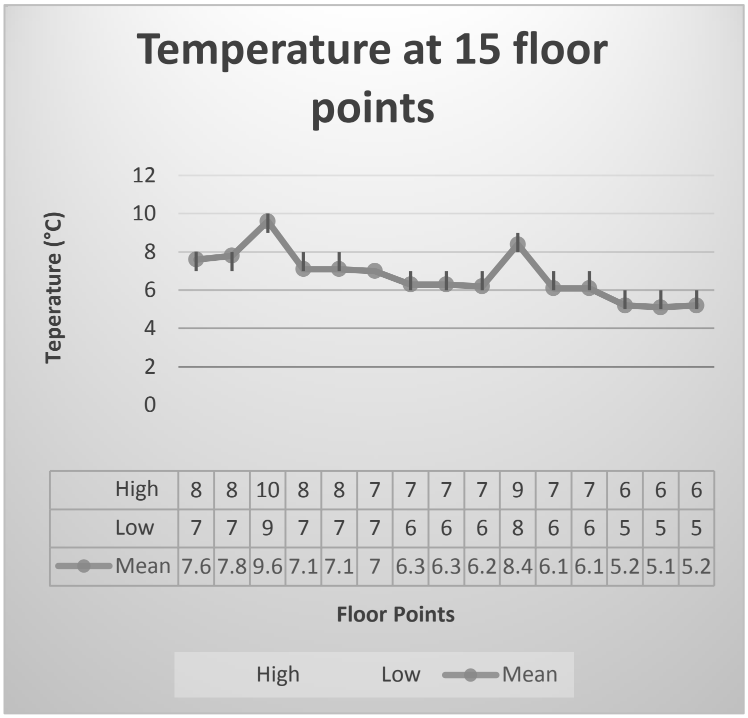
Material: Temperature of a warehouse needs to be altered as per the need of different types of materials. Fruits, vegetables, and dairy products can't be stored in temperature below 0°C whereas quality of food products like spices and lentils is affected due to extremely low temperature.

Thermoregulation: Location of sensors placed in the warehouse to collect different types of data plays important role in the study as in-appropriate location can give in-correct data. Failure of components used for data collection like sensors, connectivity. protocols can lead to wrong or irrelevant data collected.

Measurements: If two individual readings taken in between a very long interval of time then it can mis-guid the whole study as many changes and fluctuations in the temperature will go un-noticed. Cold storage warehouse charges Rs. 15 to 25 per sack stored in the warehouse. The charges are not variable for different floors or different locations at a particular floor. However, the charges per sack vary with the size of sack and type of food material stored in it. Normally the sacks filled with chilies are stored in the warehouse right after the process of harvesting and drying is completed. Dry chilies, when stored in the warehouse as appropriate temperature of 4-8°C absorbs the moisture and the weight of every sack increases in the range of 200 gm to 500 gm. As the data collected by our Raspberry Pi based IoT setup showed, the mean temperature recorded at location C of the ground floor was 9.6°C but the appropriate temperature for chilies is 4-8°C. Hence, the moisture content on ground floor will not be adequate to increase the weight of chilies. This will directly result in financial loss of the business men who stored their chilies on the ground floor as the opportunity cost of weight of chili sacks which never increased.

A Kruskal-Wallis test was selected to observe the relationship between indoor and outdoor temperature. The average outdoor temperature was noted as 29°C and indoor temperature was measured by a Raspberry Pi based IoT setup. The null hypothesis was defined as "There is a relation between outdoor and indoor temperature of warehouse." and alternative hypothesis was defined as "There is no relationship in the outdoor and indoor temperature of warehouse." After conducting this test in Minitab software which is statistical tool used commonly to analyze data. It was observed that there is a relation between outdoor and indoor temperature readings of the warehouse i.e., we accept the null hypothesis

.



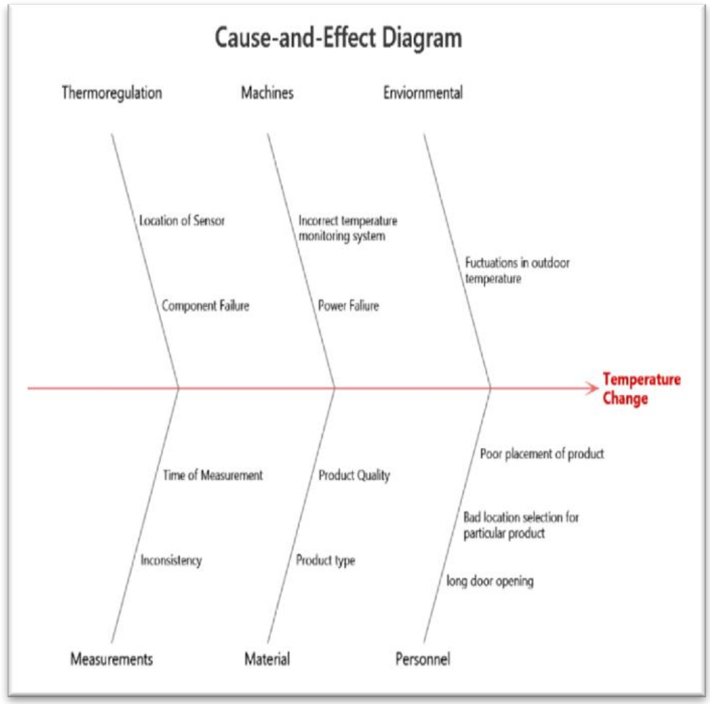


Fig. 5. (Left) Graph of temperature values at different floor points in warehouse

Fig. 5. (Right)Cause-and-Effect analysis

V. Results

A Raspberry Pi based IoT setup created by us was able to record real time values of temperature and humidity. Python 3 was selected as programming language to program Raspberry Pi. Raspberry Pi 3B+ model was used as a communication protocol. The Raspberry Pi is programmed in such a way that the real time recorded data is visible in an excel sheet and can also be seen in ThingsSpeak server as well as ThingsView mobile application. Raspberry Pi is programmed to continuously monitor the real time data and send an alert message (SMS) to the cell phone of person in-charge when temperature value drops more than 4°C or increases more than 8°C.

After temperature and humidity values were recorded at 15 different locations i.e., 3 locations on every floor of warehouse. From which, a temperature difference was observed at the serially third location of ground floor and firstlocation of third floor. The causes of this temperature differences might be environmental, machine, thermoregulation, personnel, material and measurements. Cause and effects diagram was made, which depicted the main causes of the temperature difference at those 2 points. The temperature difference directly results to financial losses incurred by those who stored their chili harvest at those particular points as the chilies will not gain weight or will gain less weight than expected due high temperature. Later, a Kruskal-Wallis test was performed on the data where recorded indoor temperature values were compared with the outdoor temperature value. In this analysis, the null hypothesis that there is a relation between indoor and outdoor temperature values was found to be true.

It was found that if the financial losses incurred by those who store their chili harvest at the locations which show temperature difference has to be eliminated or reduced then a better refrigeration system will have to be installed at the warehouse or some other food product will have to store in at those 2 particular locations whose ideal temperature for storage is around 9°C like some dry fruits etc. This results in effective use of the cold storage warehouse and capacity of the warehouse is enhanced by 12000 sq. ft.

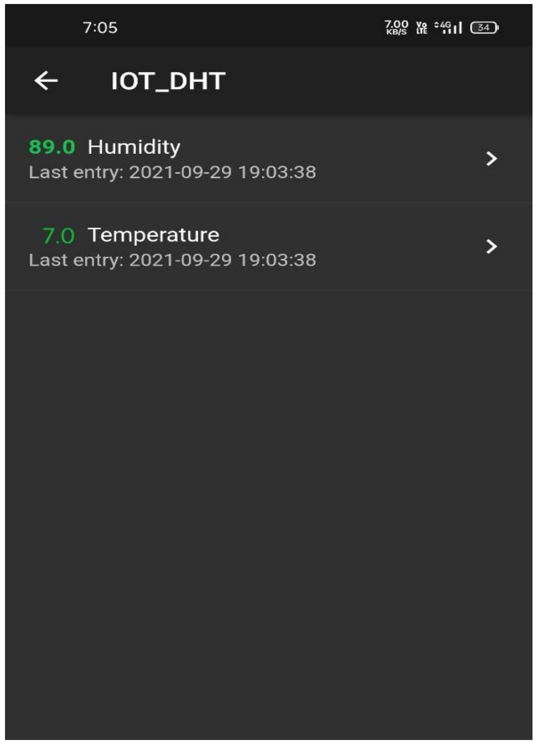


Fig. 5. ThingsView mobile application screenshot displaying graph of humidity and temperature values

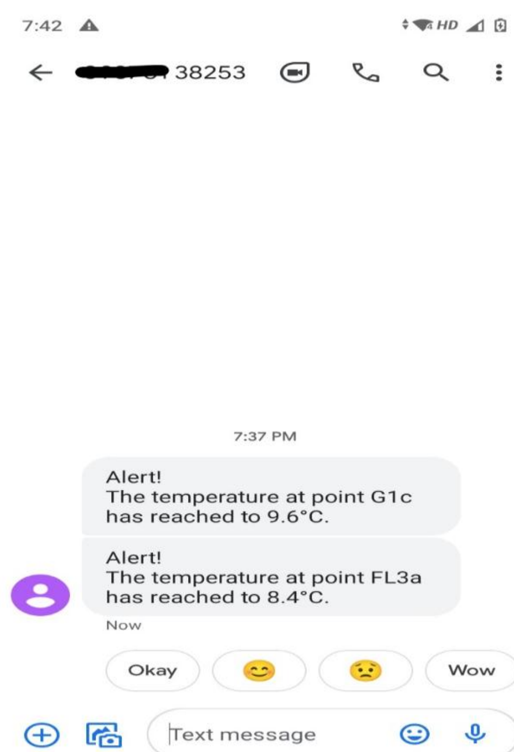


Fig. 6. SMS-Alert screenshot

VI. DISCUSSION

The temperature at which food is stored is one of the most important factors influencing its quality. Temperature fluctuations are common in the cold store temperature ranges that are either above or below the optimal temperature range. Temperatures in the cold store rise, causing favorable conditions for microorganism formation When the temperature is lower than the specified one, food can degrade. Also, a harvest of chilies is stored for an average duration of 6 months at the cold storage. In this time, the dry chilies absorb moisture in air and due to this, can gain up to 500 gm weight per sack. If the temperature is not maintained at appropriate value, then chilies won't gain weight. This will result in financial losses of the customers of Cold storage warehouse. By finding this out, the capacity of warehouse was enhanced, as now some different food product can be stored at those locations who require that particular temperature to maintain good quality. Hence, impartial monitoring of data at different warehouses of any facilities can be used for capacity enhancement.

VII. CONCLUSION

The suggestions made to the Board of Directors of Cold storage warehouse Pvt. Ltd. were, to install better refrigeration system to enhance the storage capacity and customer satisfaction. The other suggestion was to store not chilies but some other food products at locations where temperature difference was observed like Squash, Tomato, Beans, Watermelon, Pepper, Musk-melon, Honey dew etc.

From first reading to the last i.e., 15^{th} reading, physically sensor was moved so the readings were not taken simultaneously, so between 1^{st} and last reading there was a time lapse (at least 1-2 hours). We demonstrated that the temperature topology in real time can be developed if there is a provision that all those 15 sensors are physically present. Then the user will get the real time data of this complete storage volume and the user will also be able to identify the location where deviation may occur.

Our sensor is connected to the Raspberry Pi by the means of wires, one such setup costed us Rs. 5000/-. If the warehouse owner is willing, he/she can have 15 Raspberry Pi devices connected with 15 different sensors and the real time data of those 15 locations will be displayed on the screen simultaneously. By observing the values taken by us, we will be able to find a definite volume at which there will be no guarantee of a uniform temperature and in future if we get some electronic solution for having only 1 Raspberry Pi device and 15 sensors, then that Raspberry Pi device will process and send the signal for 1 sensor at a time i.e., Data Acquisition. Data Acquisition means there will be a certain frequency in recording time of 15 sensors, we will consider the reading of one of the sensors and will record it and then we will convert it into signal. If that data is transmitted with the help of internet, considering the time lapse of 30 seconds, the cycle will get completed in 5-7 minutes.

REFERENCES

[1] Bogdanovská, G., Stehlíková, B., Kačur, J., (2019), "Analysis of Temperatures in the Cold Storage of Finished Products", Advances in Science and Technology Research Journal, Volume 13, Issue 3, pp. 54-66

[2] Yadav, R., Gupta, S., Singh, M., Verma, A., (2020), "Remote Monitoring System for Cold Storage Warehouse using IOT", International Journal for Research in Applied Science & Engineering Technology (IJRASET), Volume 8 Issue V, pp. 2810-2814

[3] Nirenjena, S., BalaSubramanian, D., Monisha, M., (2018), "ADVANCEMENT IN MONITORING THE FOOD SUPPLY CHAIN MANAGEMENT USING IOT", International Journal of Pure and Applied Mathematics, Volume 119 No. 14, pp. 1193-1196

[4] Kumar, A., (2019), "Exploring the relationship between ICT, SCM Practices and organizational performance in agri-food supply chain" ICT practices in food SCM

[5] Pal, A., Kant, K., (2020) "Smartsensing, communication, and control in perishable food supplychain", ACM Transactions on Sensor Networks, Vol. 16, No. 1, Article 12 pp. 12.7-12.41

[6] Usharani, N., Suruthi, D., Sangeetha, V., Punitha, L., (2020) "Arduino based smart IoT based food quality detection technology", International Research Journal of Engineering and Technology (IRJET) Volume: 07, pp. 3569-3573