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Smart Refrigerator For Enhancing User Convenience and Food Management

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***Abstract*—Many individuals face challenges in effectively managing their household food storage due to limitations in traditional refrigerator technology. These limitations include challenges in monitoring the weights of food, receiving timely reminders for restocking, and incorporating location-based services. Existing solutions lack real-time inventory information, fail to provide timely restocking reminders, and lack integration with location-based services.The proposed Smart Refrigerator solution offers accurate inventory management, remote monitoring and control, location-based notifications, Peltier cooling system, and enhanced user experience through IoT technology and innovative sensor systems. A mobile application complements the system, providing users with remote monitoring, control, and location-based notifications. Societal benefits include reduced food waste, improved food safety, enhanced user experience, and efficient household inventory management, contributing to sustainability and consumer well-being. The proposed Smart Refrigerator results demonstrated significant improvements in inventory management accuracy and user convenience with DS18B20 temperature sensors, load cells, and gas sensors, reducing food wastage.Enhanced remote monitoring, control capabilities, and location-based notifications contributed to increased user satisfaction.**

***Index Terms*—IOT technology,restocking reminders,location-based services, Arduino, mobile application,food wastage reduction.**

I. Introduction

In rapidly evolving technological landscape, the integration of smart devices into our daily lives has become increasingly prevalent. Among these innovations, the concept of a smart refrigerator stands out as a revolutionary advancement in kitchen appliances. Smart refrigerators have become essential in modern kitchens, transforming food preservation and household management through the integration of advanced technology.

A smart refrigerator combines a number of advanced parts to improve inventory control and food preservation. The integration of Arduino micro controllers facilitates automated and intelligent control, enabling the system to modify parameters in response to real-time temperature sensor data [1]. By keeping food at the right temperature, these DS18B20 temperature sensors prevent spoiling and increase shelf life. Additionally, the addition of gas sensors and peltier cooling systems expands the Smart Refrigerator's usefulness. To precisely measure the weight of the items stored inside the refrigerator, a load cell is built into the shelves [4]. For monitoring and analysis, real-time inventory data—such as item weight and quantity—is sent to a mobile application. The Power Supply ensures dependable operation and performance of the Smart Refrigerator system by supplying electrical power to its constituent parts [5]. All things considered, these cutting-edge parts come together to form a more intelligent and effective refrigeration system that overcomes the drawbacks of conventional refrigerators and offers consumers an improved experience with food preservation.

The proposed Smart Refrigerator solution integrates innovative sensor systems that continuously monitor the status of food items stored within. The collected sensor data is seamlessly transmitted to ThingSpeak, a platform known for its ability to collect, analyze, and act on IoT data. By utilizing ThingSpeak, the Smart Refrigerator system ensures that users have access to up-to-date information through a user-friendly mobile application.

II. Literature Survey

1) IoT applications in home appliances: Alsanad et al. [1], developed a smart refrigerator that improves food management through computational intelligence with an Arduino UNO microcontroller and a variety of sensors. The system uses an ESP8266 NodeMCU Wi-Fi chip for network connectivity, load cell sensors for weight measurement, LM35 and DHT22 sensors for temperature and humidity monitoring, and a Bluetooth HC module for Android application communication.

Das et al. [2] developed a smart refrigerator system that is integrated with IoT technology and Android application. It enables food inventory management using sensors to track the existing stock of foods. It later sends an SMS notification, using a GSM module, in case of a shortage of products such as eggs or milk. The hardware implementation of the system used an Arduino Uno, ultrasonic sensors, and infrared sensors.

Gupta et al. [3] proposed a smart refrigerator system that uses IoT technology. The system uses temperature sensors and a load cell (HX711) to monitor the refrigerator's internal conditions and food quantity. These components are combined into a mobile application, which was developed and tested using the IntelliJ Android emulator and provides users with real-time information on food inventory levels and refrigerator temperature.

Gupta et al. [4] addressed the challenges of water scarcity and inefficient water management in Indian agriculture. The system aims to optimize water usage for irrigation by utilizing field-deployed sensors to monitor soil moisture, ambient temperature, and humidity.

2) Smart Refrigeration Systems: Harshasree et al. [5] details developing and designing a smart refrigeration system using IoT technologies. This system was integrated with an MQ3 sensor for monitoring gas concentration and a DHT11 sensor for monitoring temperature and humidity.

Zhao et al. [6] focuses on developing a holistic smart fridge control system that would utilize IoT technologies to improve user experiences and functionalities. The leading platform for realization is based on Raspberry Pi 4 Model B running Home Assistant Operating System, integrated with several sensors for environmental monitoring, RFID for inventorying food products, and a camera for internal real-time tracking.

Mallikarjun et al. [7] presents a system using IoT and machine learning-based solution for improving refrigerator functionality. Sensors inside the refrigerator monitor ingredient quantities, which are then processed by a control module and sent to the cloud for remote access via an Android app. In addition, the system uses a simple machine learning algorithm to classify vegetables by color and recommend recipes depending on available components.

3) Sensor Technologies for Food Management: kumar et al. [8] examines various strategies for mitigating food waste in households and restaurants, primarily due to overcooking and the expiration of items. The study emphasizes the importance of IoT-based monitoring systems in maintaining ideal storage conditions, which help to protect food quality and extend shelf life by continuously tracking environmental elements like temperature and humidity.

Kalimuthu et al. [9] developed a smart mini-refrigerator using Peltier temperature control and worked toward developing a portable and eco-friendly alternative to the refrigeration systems.

Haque et al. [10] developed a system that uses IoT technologies to improve refrigerator monitoring and maintenance. It uses sensor modules, including a load cell, to monitor contents and control modules, such as the ESP8266, for data processing and transmission. A transmission module with an LCD and Wi-Fi enables real-time updates to the ThingSpeak server. While the system lacks detailed discussions of sensor accuracy, scalability for larger deployments, and user interface considerations, which may limit its applicability in commercial and domestic settings.

III. METHODOLOGY

The process of developing a smart refrigerator utilizing modern IoT technology to enhance convenience and efficiency in food storage management. It employs various sensors and components to ensure optimal food storage conditions and streamline inventory management.

A. System Architecture

The Smart Refrigerator system architecture is composed of modern technology-based Arduino micro controller, Internet of Things, and sensor provisions that lead to amplifying convenience and effectiveness in food management.

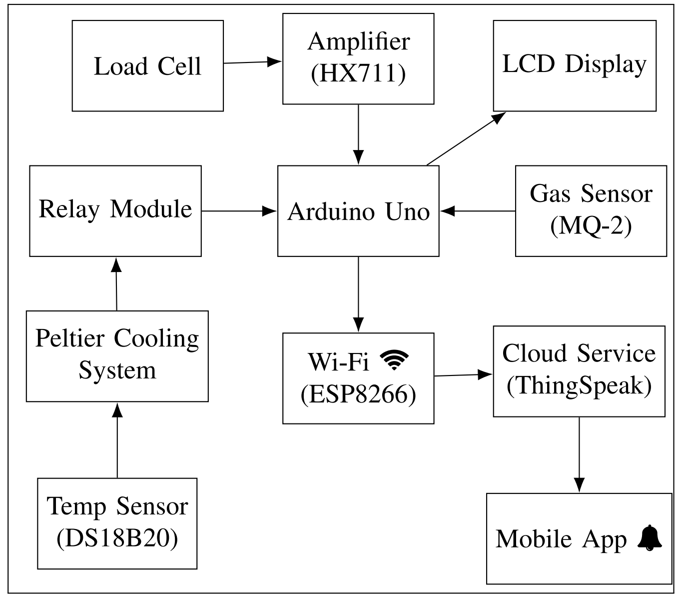

Fig. 1. Architectural Diagram of proposed Smart Refrigerator System

At its core the Arduino Uno microcontroller, a modular platform that serves as the main processing unit. The system's backbone is the Arduino Uno microcontroller, which communicates with a variety of sensors and actuators that are required for operation. It processes data from sensors such as the DS18B20 temperature sensor, which is noted for its great accuracy when monitoring inside refrigerator temperatures. This information is required for the precise regulation of the Peltier cooling system, which ensures optimal storage conditions for food freshness by altering cooling levels depending on real-time temperature readings.

Furthermore, the Arduino controls load cells (HX711) built inside refrigerator shelves, allowing for real-time inventory management by precisely weighing stored objects. This feature enables the system to send warnings via the mobile application when inventory levels fall below predefined thresholds, ensuring timely restocking of critical commodities.

The MQ-2 gas sensor, which detects dangerous gas concentrations values in the refrigerator environment, is one of the smart refrigerator's key sensors.

The Peltier cooling system, which is controlled by the Arduino via a relay module, uses thermoelectric cooling technology to keep temperatures steady without the use of standard compressor-based processes.

A stable power supply is provided to ensure continuous operation of the refrigerator and its components.

The proposed system uses an internet-connected Wi-Fi module (ESP8266) to allow for seamless connection and remote access. This integration sends sensor data to the ThingSpeak cloud platform, where customers may monitor refrigerator conditions in real time using a customized mobile app.

The mobile app, created with MIT App Inventor, provides an intuitive interface for users to examine detailed data such as temperature measurements, inventory status, and alerts. Location-based notifications improve user convenience by alerting users to make timely purchases when they are near grocery stores, ensuring effective food supply management.

The system architecture is intended to facilitate integration and programming using the Arduino IDE. Arduino microcontrollers are programmed to manage sensor inputs, control actuators, and build communication protocols with external platforms such as ThingSpeak for data synchronization and analysis. This seamless connection enables reliable operation and responsive performance, which is supported by a stable power supply to assure the smart refrigerator system's continuous functionality.

The system's usability is centered on its user-friendly interface, which incorporates an LCD display with real-time temperature, inventory level, and system alarms. The mobile application improves the user experience by allowing complete control over refrigerator settings and notifications based on current sensor data. Users can remotely monitor and regulate their refrigerators, ensuring effective food storage management and proactive preservation of ideal storage temperatures.

B. Temperature Control

DS18B20 temperature sensors are deployed within the icebox to monitor its internal temperature.The temperature information is processed by the Arduino to be fed into the dynamic control of the Peltier-based cooling system.

C. Peltier cooling system

The Peltier cooling system is a thermoelectric technology based on the Peltier effect, utilizing Peltier modules, also known as thermoelectric coolers. When powered with electrical current, these modules generate a temperature difference, moving heat from one side to the other, thereby removing heat from the fridge compartment to maintain the desired temperature for optimal food preservation.

The system includes heat sinks and a fan for efficient heat dissipation; the heat sinks spread the heat generated by the Peltier modules, while the fan enhances airflow and accelerates heat removal, ensuring the refrigerator compartment remains in a consistently cool condition.

D. Inventory Management

Load cells are integrated into the icebox system to measure the weight of stored items accurately. This enables real-time inventory tracking, allowing users to monitor their supplies and receive notifications when specific items need replenishing.

E. Remote Monitoring and Control

Wi-Fi module(ESP8266) facilitates internet connectivity for the system. The data is transmitted from the sensors to the ThingSpeak platform.

F. ThingSpeak Integration and Mobile App

ThingSpeak is an open-source IoT platform for collecting, storing, analyzing, and visualizing applied data in real time. The mobile application is interfaced to collect real-time data by using ThingSpeak, which allows the user to have detailed information regarding the status and content of his refrigerator.

Through a dedicated mobile application developed using MIT App Inventor, users can remotely monitor the refrigerator's temperature, view weight levels, and adjust settings as needed. Location-based reminders prompt users to purchase items when they are in proximity to a grocery store, enhancing convenience.

G. Shopping Alert And Gas Sensor Alert

When the weight of the items stored in the load cell falls below a predefined threshold value, indicating that certain essential items are running low, the system triggers a shopping alert. This alert notifies users through the mobile application, prompting them to restock the items.

If the gas sensor detects a gas concentration exceeding the threshold value, it triggers an alert to notify users and ensure safety.

H. Programming and Integration

The Arduino IDE is utilized for programming the Arduino micro controller. It is designed to efficiently manage sensor data, control systems, and facilitate communication with the IoT module and mobile application.

Algorithm 1 Proposed Smart Refrigerator Management

Result: Efficient food storage and safety management using a Smart Refrigerator
Input: Temperature data from sensors, weight data from load cells, gas concentration data
Output: Temperature reading, inventory updates, safety alerts
Initialize System: Setup and test all components.
Temperature Monitoring: Read temperature from DS18B20 sensors.
Start: while True **do**
  Weight Monitoring: Measure item weight using load cells.
  if weight is below the predefined threshold **then**
    Trigger Alert
  end
  Gas Detection: Check gas concentration values.
  if detected gas level is above threshold **then**
    Send Alert
  end
  Mobile App Communication: The mobile application is interfaced to collect real-time data by using Thing Speak cloud platform. Provide location-based shopping reminders.
  Data Transmission: Transmit all collected data to the user's device.
end
End

The Smart Refrigerator Management System algorithm will be able to monitor the temperature inside very efficiently, even in terms of weight and gas levels. This algorithm initializes the system, which checks all the components for their functioning, and then reads the temperature data from the DS18B20 temperature sensors. The given algorithm will work in infinite loops and measure the weight of shopping items with the help of load cells to give shopping alerts in case the weight defined goes below the threshold. The system shall also monitor the levels of gas and alert the user if the gas exceeds the threshold through a mobile application. The system would also have communication with a mobile app to send updates about the temperature, weight, and gas levels.

IV. IMPLEMENTATION

The Smart Refrigerator is made up of a state-of-the-art Arduino microcontroller that adopts IoT technologies and sensors to increase the effectiveness and simplicity of food management.

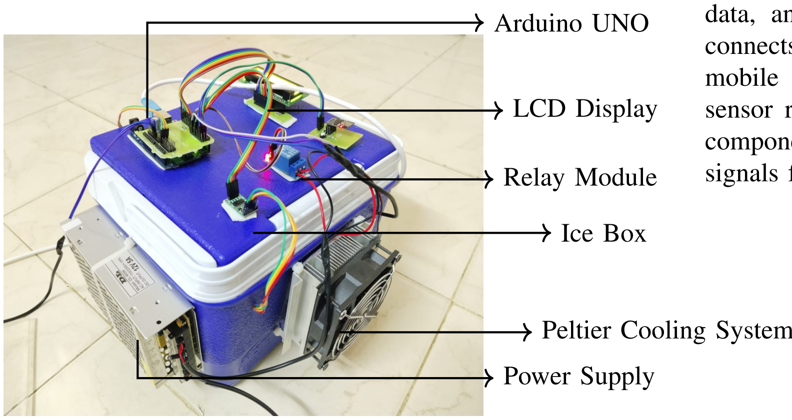

Fig. 2. Proposed Smart Refrigerator

As shown in Figure 2, the smart refrigerator assembles IoT technology to enhance the functionality of the device and boost user convenience. The base unit is an Arduino UNO. The ATmega328P microcontroller forms the basis of this system to process and control its functions due to its cost-effectiveness and user-friendly programming using the Arduino IDE.

Standard load cells were chosen along with an HX711 amplifier to provide accurate data. An MQ2 gas sensor is used to monitor the level of different gases in the refrigerator that can be harmful to humans. The ESP8266 module ensures affordability, available Wi-Fi connectivity, and ease of integration, guaranteeing effective data transmission from the refrigerator to the cloud.

ThingSpeak is an open-source IoT platform pertinent to real-time data aggregation, storage, analysis, and visualization emanating from sensors. It is a robust solution for data management with a smart refrigerator. The MIT App Inventor tool can be utilized for quick and easy development of user-friendly mobile applications related to remote monitoring and control of the refrigerator with real-time updates on temperature, inventory levels, and gas concentration.

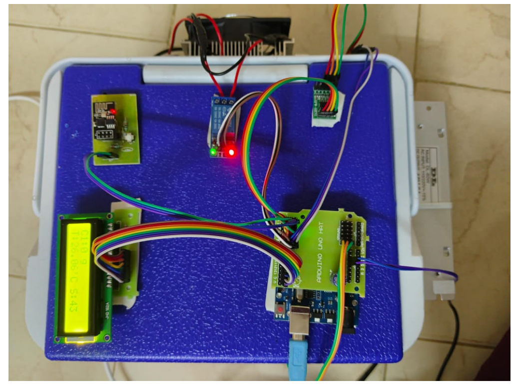

Fig. 3. Top view of the System

The setup of the icebox system described in Figure 3 consists of various interconnected electronic components managed by an Arduino UNO microcontroller. Key parts include the LCD to display real-time temperature data, item capacity data, and gas sensor values. The ESP8266 Wi-Fi module connects it to the internet for remote monitoring using a mobile application. An amplifier module ensures accurate sensor readings, while a relay module handles heavy-power components, such as the Peltier elements and fan, based on signals from the Arduino.

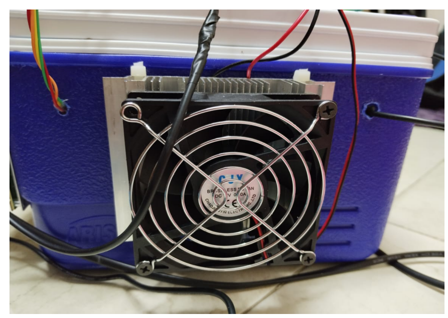

Fig. 4. Peltier Cooling System

A Peltier cooling system is attached to the exterior of the icebox as shown in Figure 4. It includes a fan and heat sink setup, connected with wires to the system's electronic components, ensuring efficient cooling and temperature regulation.

The inner view of the smart refrigerator is shown in Figure 5. This smart refrigerator system's internal setup houses multiple components, all mounted inside the cooler. The load cells are rigidly mounted and seated into the icebox. The MQ2 gas sensor is placed on a surface inside the icebox system to detect gas concentration levels that could signify spoilage, and temperature sensors keep track of the internal temperature. The temperature data collected by the DS18B20 sensors is sent to the Arduino microcontroller, which processes this data to regulate the cooling system effectively. These sensors were chosen due to their high precision, a wide range of temperature readings, and a digital output making integration simpler with Arduino.

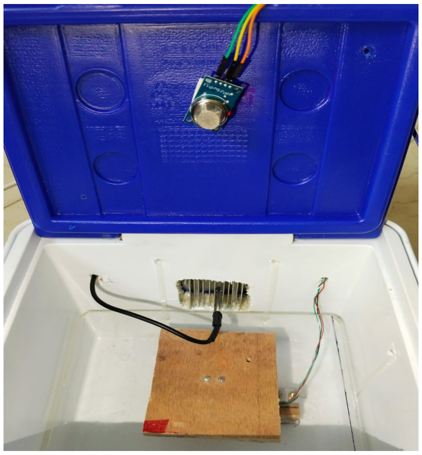

Fig. 5. Inner View of Smart Refrigerator

A. STATE OF ART

Key unique features and enhancements are incorporated into the proposed smart refrigerator.

The implementation of smart refrigerator system [1] can be costly due to the need for advanced sensors, robust microcontrollers, and IoT modules, making them unaffordable for many consumers. High-quality sensors like load cells, RFID tags, and precise temperature and humidity sensors add to the expense. Whereas the proposed model addresses these concerns by using affordable components such as the Arduino UNO microcontroller, DS18B20 temperature sensors, and ESP8266 Wi-Fi modules. These components are cost-effective yet efficient, reducing the overall cost of the smart refrigerator system without compromising functionality.

The method in [2] relays on a GSM module for sending SMS notifications, especially for low-stock alerts like eggs and milk, presents multiple limitations. Chief among these is the ongoing cost of SMS messaging services, as well as the dependency on cellular network coverage, which can be unreliable or expensive in certain areas. Users might encounter issues related to signal strength or network availability, negatively impacting the system's overall effectiveness and usability. The proposed method tackles this limitation by proposing the use of Wi-Fi module for communication instead of GSM. The adoption of Wi-Fi, specifically through the ESP8266 module, offers notable advantages.

The primary limitation with the existing method in [5] is the use of the MQ3 sensor, which is designed for alcohol detection and may not accurately detect gases relevant to food spoilage. Additionally, the DHT11 sensor lacks the accuracy needed for critical temperature and humidity measurements. The proposed method addresses these limitations by replacing the MQ3 sensor with the MQ-2 gas sensor for better detection of food spoilage gases and the DHT11 with the more accurate DS18B20 temperature sensor. Furthermore, WiFi connectivity issues affecting real-time monitoring are mitigated by using the ESP8266 WiFi module, which ensures stable data transmission to the ThingSpeak cloud platform for enhanced real-time monitoring and data visualization.

The RFID technology in the model [6] helps manage food inventory, but requires manual input to update the information related to food, which is very cumbersome and a possible way to errors. In the proposed method, load cells are utilized for measuring the weights automatically.

The proposed model uses IoT technologies like location-based notifications, real-time inventory management using load cells with ThingSpeak, and data visualization. It has a Peltier cooling system, gas sensors for monitoring food freshness where as [7] lacks the detailed implementation of these advanced IoT features, focusing more on machine learning for recipe suggestions and sensor integration without the extensive real-time monitoring and control capabilities.

Overall, the proposed smart refrigerator system builds upon existing methods by incorporating low-cost components such as Arduino UNO, DS18B20 temperature sensors, and ESP8266 Wi-Fi modules to reduce costs while maintaining functionality. Unlike GSM-based systems, it communicates over Wi-Fi, ensuring continuous operation while decreasing operational costs. Upgraded MQ-2 gas sensors and DS18B20 temperature sensors improve sensor accuracy, allowing for better monitoring of food freshness and storage conditions. Automated inventory management using load cells eliminates error-prone manual RFID input, allowing for exact stock monitoring. ThingSpeak, which is backed by a user-friendly smartphone interface created with MIT App Inventor, allows for real-time data monitoring and control.This interface contains elements like location-based notifications for timely alerts and reminders, which improves usability, affordability, and efficacy in smart food management as compared to standard refrigeration systems. Furthermore, the use of a dynamic Peltier cooling system improves food freshness by enabling precise temperature control while contributing to energy economy and lower maintenance costs.

V. RESULTS AND DISCUSSION

The smart refrigerator was quite promising to improve efficiency in food management and user convenience. Internal temperature, inventory level monitoring, and cloud connectivity for remote monitoring with control (ThingSpeak) were effectively accomplished using different components such as Arduino Uno, temperature sensors, load cells, and Wi-Fi modules. An LCD display was also incorporated to give real-time feedback to users for more interactive and improved feedback mechanisms.

The weight-monitoring mechanism could alert the user if a certain food had reached critically low levels, at which the food item could be refilled in time to prevent running out of food. The gas-sensors level further enabled the system to detect indicators of food spoilage and alert a user.

Wi-fi module is responsible for sending data from sensors of the refrigerator to the ThingSpeak platform. ThingSpeak offers tools for real-time data visualization, which can be critical for monitoring temperature changes and other sensor

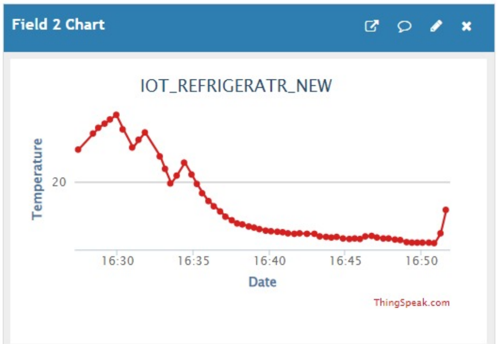

Fig. 6. Visualization of Temperatures in ThingSpeak

data effectively. As shown in the Figure 6 the temperature values are visualized in the ThingSpeak.

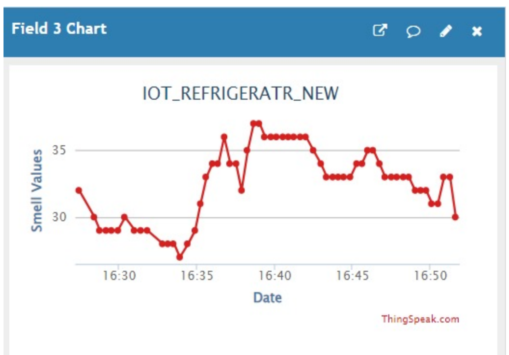

Fig. 7. Visualization of Gas Concentration levels in ThingSpeak

The gas sensor gives its outputs in the form of signals, that is, concentration of gases received by the ESP8266 module. An ESP8266 is programmed to read signals from a gas sensor, which returned information on gas concentration and then sent it over the ThingSpeak.As shown in the Figure 7 the gas concentration values are visualized in the ThingSpeak.

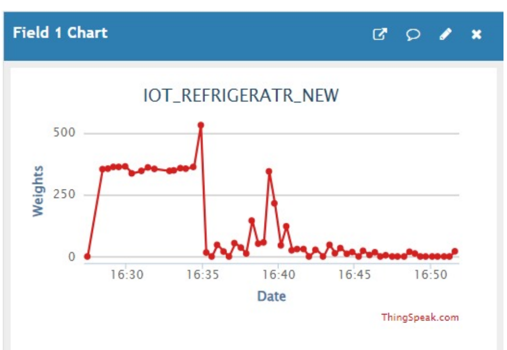

Fig. 8. Visualization of Weights in ThingSpeak

Load cell measures the weight of stored items and outputs electrical signals that are amplified by an HX711 amplifier.The applied signals are then amplified by an amplifier, HX711, and this signal is digitized, then, through an ESP8266 Wi-Fi module, the digitized data is sent into ThingSpeak, where in it will be visualized as shown in Figure 8.

Scenario 1: No items present in the refrigerator

The LCD display shows the values of weights of items stored inside the refrigerator, temperature of the system and the gas concentration level present inside the system. In the Figure 9, the value of C1 is 0 grams, it represents the current weight inside the refrigerator, which reads 0 grams, indicating there are no items present. The value of T is 18.75 degree celsius, this is the temperature inside the refrigerator. The value of S is 30, it represents the gas concentration levels inside the system.

Fig. 9. LCD display Initial State

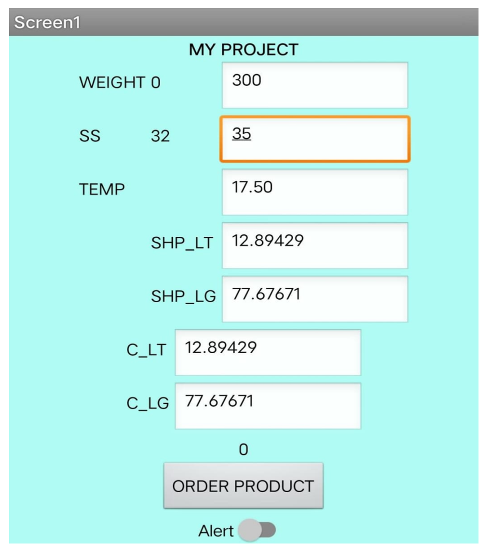

Fig. 10. Mobile App Initial State

In the application developed in attached Figure 10, the user can set a threshold for weight and smell value to give an alert. In this display is real-time weight information (0 grams), temperature (17.50°C), and smell value (32). Also, at this level, there are shows actualized and sent geographic coordinates for better location identification (current longitude,current latitude,shop longitude and shop latitude). Also, there is an ”ORDER PRODUCT” button for ordering products in case the stock is low.

Scenario 2: Shopping Alert For Depleted and Spoilage Prevention

If in the LCD display, the value of C1 is 373 grams, current weight inside the refrigerator, indicating there are items present. The value of T is 16.13 degree celsius. The value of

S is 33, it represents the gas concentration levels inside the system.

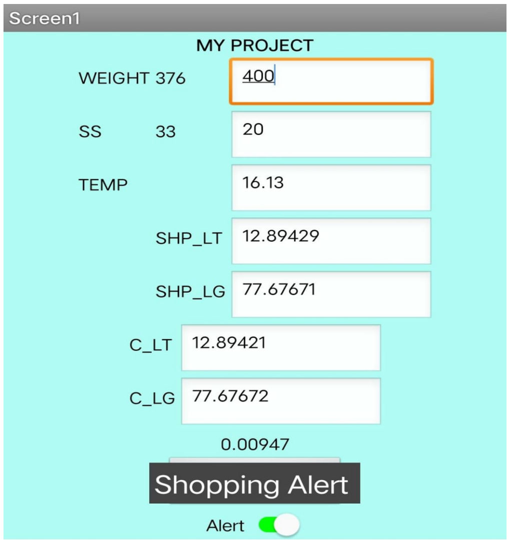

Fig. 11. Mobile App with Shopping Alert

In the mobile app as shown in the Figure 11, the user can set a threshold for weight and smell value such as 400 and 20 to give an alert. In this display is real-time weight information (376 grams), temperature (16.13°C), and smell value (33).

When the weight of the items stored in the load cell falls below a predefined threshold value, indicating that certain essential items are running low, the system triggers a shopping alert. This alert notifies users through the mobile application as shown in 11, prompting them to restock the items.

Scenario 3: Food Spoilage Warning System

If in the LCD display, the value of C1 is 374 grams, indicating there are items present. The value of T is 16.13 degree celsius. The value of S is 33, it represents the gas concentration levels inside the system.

In the mobile app as shown in the Figure 12, the user can set a threshold for weight and smell value such as 300 and 20 to give an alert.

When the gas concentration level inside the system are higher than the predefined threshold value, indicating that spoilage of food items present inside the refrigerator, the system triggers a smell sensor alert. This alert notifies users through the mobile application as shown in 12, prompting them to restock the items.

Overall, the Smart Refrigerator system offers a wide range of advantages and applications across residential, commercial, and institutional settings, revolutionizing the way refrigeration is managed and enhancing food safety, efficiency, and convenience for users.

Smart refrigerators are an improvement over the traditional model as shown in table I, with this superior model incorporating the use of advanced technologies for convenience and increased efficiency of management of food on a daily basis. They offer features that are quite unavailable with normal

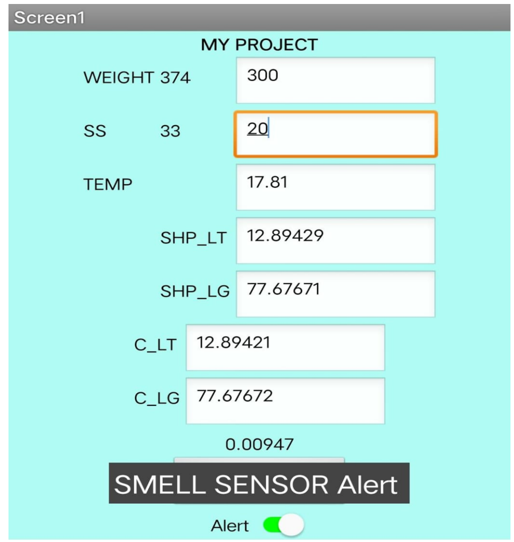

Fig. 12. Mobile App with Smell-Sensor Alert

refrigerators, making food management quite simple and much more effective.

TABLE I
COMPARISON BETWEEN SMART REFRIGERATOR AND TRADITIONAL REFRIGERATOR

Feature	Proposed Smart Refrigerator	Traditional Refrigerator
Temperature Management	Utilizes DS18B20 temperature sensors for precise temperature control, maintaining consistent internal conditions.	Relies on less precise thermostats, leading to potential temperature fluctuations.
Inventory Monitoring	Equipped with load cells to monitor food inventory in real-time, alerting users when items need restocking.	Requires manual checks, increasing the likelihood of running out of essential items.
Spoilage Detection	Incorporates MQ2 gas sensors to detect spoilage gases like ethylene, providing early warnings to prevent food waste.	Lacks spoilage detection, often leading to unnoticed food spoilage.
User Interface and Alerts	Features an integrated mobile app and LCD display for real-time alerts and updates.	Typically offers no user interface for remote monitoring or alerts.

The smart refrigerator system is based on different configurations, each of which provides distinct trade-offs with respect to accuracy, efficiency, and user convenience. It includes DS18B20 digital temperature sensors for precise control, gas sensors for detecting hazardous concentrations, and load cells for accurate real-time inventory data. A Peltier system provides efficient cooling, while IoT allows for real-time monitoring and automatic control, which reduces manual intervention and saves energy. A dependable power supply provides smooth operation. The smartphone app provides real-time temperature and inventory updates, restocking and spoiling alarms, GPS shopping reminders, and messages regarding gas concentrations and weight thresholds, all of which keep users informed about food freshness and inventory levels.

VI. CONCLUSION AND FUTURE SCOPE

In conclusion, the smart refrigerator presents a comprehensive and innovative solution for efficient food management and user convenience. By integrating a variety of components, including sensors, micro controllers, and connectivity modules, the system enables real-time monitoring of internal temperature, inventory levels, and fruit ripeness. The implementation of weight monitoring mechanisms and shopping alerts further enhances user experience and minimizes food wastage. Additionally, the integration of gas sensors for spoilage detection adds another layer of intelligence to the system. Overall, the smart refrigerator system exemplifies the potential of IoT technology to revolutionize traditional appliances, offering improved efficiency, convenience, and sustainability in food storage and management.

The system can be further developed by researching more into superior sensor technologies, which will advance the accuracy and reliability of the system. Predictive maintenance machine learning algorithms could further enhance the system by forewarning potential issues and setting the best maintenance schedule for the appliance, thereby minimizing downtimes. The diversity of the original data, from commercial kitchens to residential homes.

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