

IOT Based Smart Interactive Refrigerator Using Machine Learning

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Abstract: *The Internet of Things (IoT) has revolutionized the concept of home automation, with smart appliances playing a crucial role in enhancing user convenience. This project presents the design and development of an IoT-based smart interactive refrigerator integrated with machine learning capabilities. The system enables real-time monitoring of temperature, humidity, and stored items using IoT sensors. Through machine learning algorithms, the refrigerator can identify food items, track their quantity, predict spoilage, and provide personalized suggestions such as grocery reminders and recipe recommendations. The interactive interface allows users to access the refrigerator data remotely via a mobile application, ensuring efficient inventory management and reduced food wastage. This intelligent solution demonstrates how IoT and machine learning can be combined to create a sustainable, user-friendly, and energy-efficient smart home appliance.*

Keywords *The project focuses on combining the Internet of Things (IoT) and Machine Learning to create a smart refrigerator that can recognize food, manage inventory, and connect with home automation systems. It aims to improve energy efficiency, monitor food in real time, and make kitchens smarter and more convenient.*

INTRODUCTION

An IoT-based smart interactive refrigerator powered by machine learning bridges the gap between sensors, connectivity, and intelligent algorithms. It monitors temperature, humidity, and food stock levels in real time while machine learning enables object detection, spoilage prediction, and personalized recommendations. With Wi-Fi or mobile connectivity users can remotely access refrigerator status, get grocery reminders, and receive recipe suggestions based on available ingredients. The system enhances user convenience, promotes sustainability by reducing food waste, and supports energy efficiency. By combining IoT and machine learning this project advances modern smart kitchens and smart homes providing intelligent recipe suggestions and provides the exact recipe to the humans

according to the available items. It is designed to be both sustainable and user-friendly integrating hardware and software to improve food management and overall user experience. The system uses an ESP32 microcontroller with Wi-Fi and Bluetooth connectivity for communication with cloud servers and mobile applications. The refrigerator uses temperature, humidity, and weight sensors to continuously track internal conditions and food quantity. A camera module supports object detection and inventory monitoring through machine learning techniques. All collected data is analyzed to estimate food spoilage, recommend suitable recipes, and send timely alerts. A touchscreen interface allows convenient user interaction, while cloud connectivity ensures secure data storage and remote access. Real-time notifications inform users about expiring items, low stock, or abnormal conditions. The display provides detailed information on food inventory, recipe ideas, and nutritional values. With machine learning, the system gradually learns user preferences and improves the accuracy of its predictions and suggestions. Cloud integration also supports safe data management from any location, creating a smart refrigerator that enhances daily use, encourages sustainability, and helps reduce food waste.

I. RELATED WORK

An IoT-enabled smart refrigerator integrated with machine learning combines sensor technology, wireless connectivity, and intelligent control to bridge the gap between traditional and fully automated kitchen systems. It continuously monitors parameters such as temperature, humidity, and the quantity of stored food items, while applying intelligent algorithms to detect spoilage, recognize products, and generate personalized recommendations. Through mobile and cloud access, users can remotely check refrigerator conditions, receive grocery reminders, and view recipe suggestions based on available ingredients. This system supports sustainable living by reducing food waste, improving energy efficiency, and enhancing overall convenience. The design integrates both hardware and software components, using an ESP32 microcontroller to manage sensor data, control communication modules, and execute machine-learning-based decision processes..

Embedded sensors measure internal conditions such as weight, temperature, and humidity, while a camera module identifies objects and tracks inventory using machine learning algorithms. The collected data is processed to forecast food spoilage, suggest suitable recipes, and send instant alerts to the user. A touchscreen interface supports direct interaction by displaying food details, nutritional information, and personalized recommendations. Cloud-based integration provides real-time notifications about expiring items, restocking needs, and unusual conditions, making the refrigerator more adaptive and user-oriented. Over time, the system learns user habits, allowing it to improve its prediction accuracy and manage food resources more efficiently.

The touchscreen display further enhances convenience by offering easy access to inventory information and customized suggestions. With secure cloud storage and remote accessibility, users can monitor and manage their refrigerator from any location. Through this adaptive intelligence, the system gradually understands user preferences and consumption patterns, functioning as a smart household companion. By blending automation, sustainability, and convenience, the intelligent refrigerator transforms everyday food management into a more efficient and environmentally conscious process.

II. METHODOLOGY

with cloud services display is mounted on the fridge for local in touchscreen or LCD interface is integrated into the refrigerator to enable direct user interaction, while the power circuitry is designed to maintain stable operation and reduce energy consumption. This setup helps the system regulate data flow smoothly and maintain real-time communication with cloud services, ensuring that both local features and background processes function reliably. Predictive algorithms analyze the collected sensor information to estimate food spoilage duration, evaluate nutritional quality, and understand consumption patterns. By comparing historical temperature variations with spoilage-related gas data, the system can more accurately forecast how long stored items will remain fresh. During data acquisition, sensor readings and images are captured in real time; the sensor data is cleaned to remove noise, and the images undergo preprocessing steps such as resizing, normalization, and segmentation before analysis. The ESP32 handles the core data processing tasks and sends the refined information to the cloud using IoT protocols like MQTT or HTTP. This approach allows the refrigerator to manage data traffic efficiently while ensuring continuous communication with cloud services, supported by a display mounted on the fridge for local access and power circuits that maintain smooth performance. The filtered sensor information and processed images are transmitted securely through IoT protocols, enabling the refrigerator to function as an intelligent IoT-based system that uses machine learning for prediction and automation. The smart refrigerator monitors food items, temperature, humidity, and stock levels in real time using sensors, Wi-Fi, and machine-learning techniques. It connects to a mobile app or touchscreen display so users can view inventory, receive expiry alerts, explore recipe suggestions, and get reminders for restocking.

Using sensors, Wi-Fi connectivity, and machine-learning techniques, the smart refrigerator monitors food items, temperature, humidity, and stock levels in real time. It can connect to a mobile app or a touchscreen panel, allowing users to check inventory, receive expiry reminders, explore recipe suggestions, and get alerts for restocking. By learning from the user's eating patterns, the system provides personalized meal recommendations, reduces food waste, and supports a more automated and efficient kitchen experience. Sensor readings and images are collected in real time, and the system uses preprocessing techniques such as noise removal, resizing, normalization, and segmentation to prepare the data for analysis. Predictive algorithms then study this information to estimate food spoilage time, assess nutritional quality, and identify consumption trends. By comparing temperature changes with gas concentration data, the refrigerator can more accurately predict the freshness and remaining shelf life of stored food items. To ensure accurate measurements, the system continuously monitors environmental factors inside the refrigerator, such as temperature stability, humidity variation, and door-opening frequency. These parameters help the model understand how external conditions influence food spoilage. When unusual patterns are detected, such as sudden temperature spikes or prolonged door openings, the system adjusts its predictions to maintain accuracy role in enhancing user convenience. This project presents the design and development of an IoT-based smart interactive refrigerator integrated with machine learning capabilities. The system enables real-time monitoring of temperature, humidity, and stored items using IoT sensors. Through machine learning algorithms, the refrigerator can identify food items, track their quantity, predict spoilage, and provide personalized suggestions such as grocery reminders and recipe recommendations next stage will be food spoilage To the extension of refrigerator to undergo the further spoilage. The image-processing module helps the refrigerator identify food items stored on different shelves. Using simple computer-vision techniques, the system can detect changes in item size, color, or shape to determine whether food is fresh or approaching spoilage.

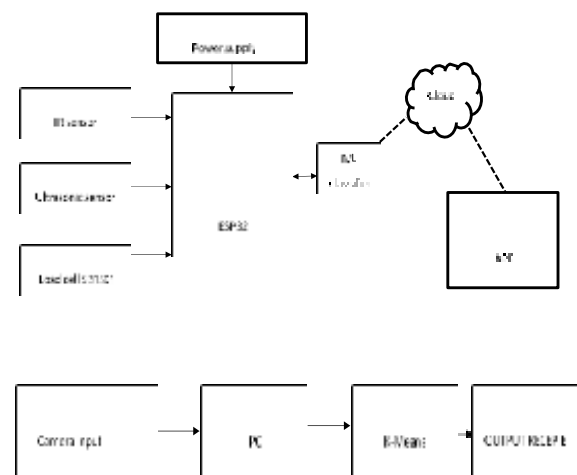


Fig.1. Block diagram Iot based smart refrigerator

III. SIMULATION

The simulation model for an IoT-enabled smart refrigerator powered by machine learning integrates multiple hardware and software modules to monitor and optimize food storage conditions. The system uses temperature, humidity, and weight sensors that are connected to a microcontroller such as an ESP32 or Raspberry Pi, which serves as the central processing unit. These sensors gather real-time measurements and transmit the values to a cloud platform through Wi-Fi or lightweight communication protocols like MQTT. In the simulated environment, virtual nodes handle data routing, device communication, and power management to ensure that the system operates smoothly under different conditions. Machine-learning models then analyze the incoming data to forecast spoilage patterns, adjust cooling operations, and generate alerts when items need restocking or when abnormal conditions are detected. The circuitry is designed to keep power consumption low while maintaining stable connectivity and supporting future scalability. By observing usage trends, the refrigerator gradually adapts to user habits and improves its decision-making through predictive analysis. With the combined use of IoT sensors, basic image-recognition modules, and environmental control features, the system can identify stored items, monitor their freshness, estimate expiration timelines, and provide personalized recommendations. All collected data is processed in the cloud, where the algorithms detect items nearing spoilage, suggest replenishment, and optimize energy consumption for more efficient performance.

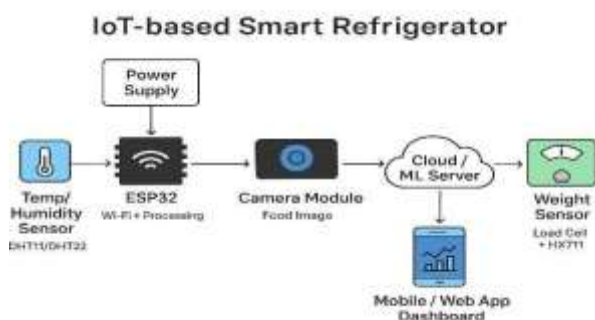


Fig.2. simulation diagram

The Internet of Things (IoT) has revolutionized the concept of home automation, with smart appliances playing a crucial role in enhancing user convenience. This project presents the design and development of an IoT- based smart interactive refrigerator integrated with machine learning capabilities. The system provides real-time monitoring of temperature, humidity, and stored food items using integrated IoT sensors. With the help of machine-learning algorithms, the smart refrigerator can recognize different food items, track their quantity, predict potential spoilage, and offer personalized suggestions such as grocery reminders and recipe recommendations. The response time of the sensors, including modules like weight and temperature sensors, refers to the duration required for these components to detect changes and collect accurate data for processing.

The IoT-based smart refrigerator simulation employs the ESP32 microcontroller because it offers built-in Wi-Fi, multiple GPIO pins, and compatibility with both analog and digital sensors. In this setup, a DHT22 humidity sensor monitors the internal moisture levels to maintain suitable storage conditions, while an MQ-series gas sensor detects gases such as ammonia or ethanol that indicate early food spoilage. A load cell paired with an HX711 amplifier functions as the weight sensor, allowing the system to track the quantity of stored food items. The entire unit operates on a regulated 5V power supply, ensuring stable voltage for the ESP32 and all connected modules. Sensor readings are transmitted to cloud platforms such as ThingSpeak, Firebase, or Blynk through Wi-Fi, where machine-learning algorithms analyze the data to identify spoilage trends, assess freshness, and send timely alerts when food is nearing expiration or stock levels are low. Users can access real-time information on humidity, gas concentration, and weight through a mobile or web-based dashboard. Simulation environments like Proteus, MATLAB with ThingSpeak, or Work Wi-Fi are used to test and validate the system before implementing the physical prototype, ensuring accurate component connections, dependable data transmission, and reliable algorithm performance. MATLAB/Simulink and Python are often used for modeling, simulation, and data analysis, while IoT platforms like Azure IoT Central help replicate connected devices virtually. Overall, this simulation helps developers design an efficient, smart, and adaptive refrigerator that minimizes food waste, improves inventory tracking, and enhances user convenience. Proteus, or MATLAB with Thing Speak can be used to emulate the ESP32 and the connected sensors. This simulation which provides grocery list to shopping which are items not there in the refrigerator which will be the essential for food wastage across the world .converting the common refrigerator into the modern refrigerator is the crucial step toward s food wastage step essential. The simulation model of an IoT-based smart refrigerator powered by machine learning is designed to connect various hardware and software components that monitor and optimize food storage conditions. It typically includes sensors for temperature, humidity, and weight, all linked to a microcontroller such as an ESP32 or Raspberry Pi, which acts as the main processing unit. These sensors continuously collect real-time data and send it via Wi-Fi or MQTT protocols to a cloud platform for analysis. Within the simulation, and having implementation and performance is a main step in refrigerator improvement towards the project and refrigerator ,maintained securely

The IoT-based smart refrigerator simulation uses the ESP32 microcontroller because of its built-in Wi-Fi, multiple GPIO and ability to support both analog and digital sensors. In this a humidity sensor (DHT22) measures the interna level to maintain ideal storage conditions, while a gas sensor (MQ series) detects gases such as ammonia or ethanol that infood spoilage.

IV.IMPLIMENTATION

HARDWARE DESIGN

ESP32 (3-pin) — central MCU: read sensors, pre-process data, send data over Wi-Fi (MQTT/HTTP), optionally run TinyML inference, handle OTA updates.

DHT22 (Humidity & Temperature) — measures humidity and temperature to track storage conditions and feed features for freshness prediction.

MQ-series Gas Sensor (e.g., MQ-135) — analog output correlated with VOCs/poisonous gases (ammonia/ethanol) that indicate spoilage. Read via ADC.



Fig 3: hardware equipment

Display Unit (LCD / Touchscreen)

LCD (Liquid Crystal Display)- is used as a local user interface for the smart refrigerator. It displays real-time sensor readings such as temperature, humidity, gas concentration (VOC), and food weight inside the fridge. Along with sensor data.

SOFTWARE DESIGN

Model Conversion

The trained model is converted into TensorFlow Lite Micro format for ESP32 deployment.

Real-time Prediction

ESP32 feeds live sensor data into the ML model.

The model predicts the freshness condition in real time.

Output Display

Predictions are shown on the LCD screen.

Results are also uploaded to the cloud dashboard for remote monitoring.

Feedback Loop

User feedback and new data are stored in the cloud to improve future model accuracy. At runtime, the ESP32 executes the lightweight model to infer the condition of food. Predictions are displayed locally on an LCD and transmitted to the cloud for remote monitoring and user alerts. his software design enables intelligent, real-time, and interactive decision-making inside the refrigerator. Data collected by the ESP32 can be sent to a cloud-based dashboard, where time-stamped readings are stored, visualized through graphs, and monitored through automated alerts. The cloud platform can also run advanced machine-learning models, allowing the ESP32 to focus solely on transmitting raw sensor data, which reduces processing load, lowers costs, and improves overall system efficiency. For local interaction, an LCD or touchscreen display is integrated into the smart refrigerator to present real-time measurements such as temperature, humidity, VOC gas levels, and the weight of stored food items. The display can also provide system messages, warnings, and operational updates All sensor data captured by the ESP32—including temperature, humidity, gas concentration, and weight—is preprocessed to remove noise, normalized for consistency, and further analyzed .

V. RESULT

Based on the image provided, you're asking for a result section for an IoT-based smart interactive refrigerator project. I'll provide a similar structure and content, but tailored to a project that uses machine learning instead of a camera module. This is a common approach for projects that focus on inventory management and food freshness prediction continuously towards the project.

Performance Analysis

The project's performance is evaluated by analyzing the interaction between the hardware and software components. The Round-Trip Time (RTT) is measured to assess system responsiveness and efficiency. It represents the time needed for data to travel from the sensors to the Firebase database and back to the mobile application. The RTT is broken down into four levels for detailed analysis:

Level 1: Response of the Sensors. This is the time taken for sensors (like weight or temperature sensors) to collect data.

Level 2: Data Processing by the Controller. The time required for the microcontroller to process the sensor data.

Level 3: Updation of Data in Firebase. The time it takes for the controller to upload the processed data to the Firebase database.

Level 4: Retrieval of Data and ML Prediction. The time for the mobile application to fetch the data from Firebase and run the machine learning model for predictions (e.g., food spoilage, reordering needs).

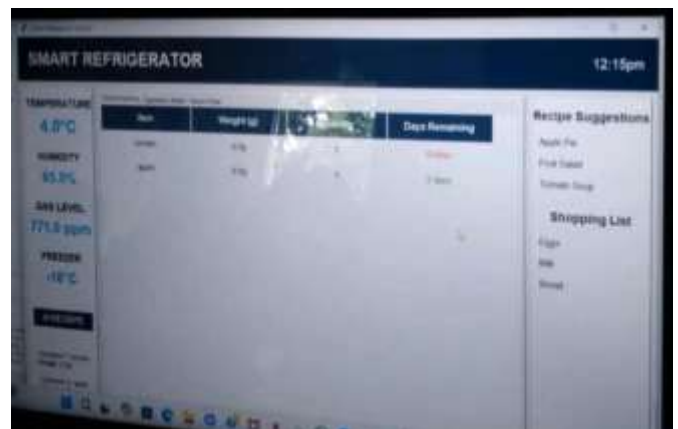


Fig 4 .Software output

Machine learning models—such as Decision Trees, Logistic Regression, and Neural Networks—are trained using frameworks like Scikit-learn or TensorFlow. The data is categorized into labels such as Fresh, Borderline, or Spoiled to help identify the freshness status of the stored food.

The Internet of Things (IoT) has revolutionized the concept of home automation, with smart appliances playing a crucial role in enhancing user convenience. This project presents the design and development of an IoT- based smart interactive refrigerator integrated with machine learning capabilities. The system uses IoT sensors to monitor temperature, humidity, and stored items in real time. With machine-learning algorithms, the refrigerator can recognize food items, track their quantity, predict spoilage, and provide personalized suggestions like reminders and alerts.

VI. CONCLUSION

The smart refrigerator project demonstrates how IoT technology and machine learning can work together to create an intelligent and efficient food management system. Equipped with sensors for temperature, humidity, and weight, along with a camera module, the refrigerator continuously monitors the condition and quantity of stored items. Machine-learning models classify different food items, estimate their shelf life, and predict potential spoilage by analyzing real-time sensor data and historical usage patterns. Based on this information, the system alerts users about items nearing expiration, recommends replenishments, and provides helpful suggestions that support better planning and reduce food waste.

By integrating cloud-based analytics with local sensing, the refrigerator can track consumption habits, forecast inventory needs, and optimize storage efficiency. This ensures that food is used before it spoils and that space inside the refrigerator is utilized effectively. The project highlights how everyday household appliances can be transformed into smart, self-managing systems that enhance convenience and support sustainable living. Through predictive analysis, automated alerts, and personalized recommendations, the smart refrigerator improves resource usage, reduces waste, and contributes to a more efficient and environmentally friendly kitchen environment.

VII. FUTURE SCOPE

The smart refrigerator of the future can be connected to online grocery services to automatically reorder items that are running low or nearing expiration. With the help of advanced AI, it can identify ingredients, suggest recipes, and track users' dietary habits. Machine learning can further optimize energy consumption by adjusting cooling patterns according to usage, while cloud and mobile connectivity allow users to monitor and control the refrigerator remotely. These features also support waste analysis to minimize food wastage, making the appliance smarter, more efficient, and environmentally friendly. Future versions may include dedicated mobile apps for easy access and integration with voice assistants like Alexa or Google Assistant, enhancing user interaction. Advanced AI and deep learning can improve freshness detection and decision-making, while automated inventory management can generate shopping lists and prevent shortages. Additionally, energy optimization algorithms could reduce power consumption, and cloud-based big data analytics can track usage trends to offer personalized suggestions. When combined with other IoT-enabled kitchen devices, such as smart ovens and cooking assistants, the refrigerator can form part of a fully connected and intelligent kitchen ecosystem.

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