

SMART PANTRY MANAGEMENT SYSTEM USING IOT FOR EFFICIENT INVENTORY MONITORING AND FOOD WASTE

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ABSTRACT

Inefficient pantry management and food waste are persistent issues in modern households, particularly for time-constrained individuals who routinely neglect to restock essential food supplies. Ultimately, unnecessary purchases and expired goods brought on by a lack of real-time monitoring skills lead to avoidable waste. The current research effort is the design of an IoT internet things based smart pantry management system to automate inventory monitoring. The system is comprised of a ESP32-CAM module, a NodeMCU ESP32 microcontroller and force-sensitive resistors (FSRs). Taken together, these parts could potentially offer a live video feed of what's in the pantry, and alert when supplies are getting low. Users can get visual updates and alerts with the help of the Blynk mobile app. Functional tests were performed to check whether the system streams photos and gives live notifications. The findings indicated that it was possible for the system to send an alert to the user when item quantities were less than a defined value and the results verified this visually with the mobile interface, which was remotely based. This item will enable customers to optimise their food purchasing plans by lowering the risk that food would expire and the need for unnecessary replenishment of products. In conclusion, it is shown that the support of inexpensive IoT components in home inventory systems can have a substantial positive effect on pantry management, on the reduction of food waste and on the support of more environmentally friendly consumption habits.

1. Introduction

Food waste is a growing concern for today's households, due to a lack of organized pantry storage, buying too much and no tracking of older items in the pantry. This causes problems for the household budget but also has implications for the environment by throwing away expired products (Tan et al., 2021; Mohapatra et al., 2023; Patil & Bhosale, 2020; Singh & Kaur, 2021). Recent developments in the Internet of Things (IoT) have the potential to address such challenges. IoT-Individuals can monitor their devices in real-time and communicate with them, allowing households to receive automated alerts, monitor food usage, and access pantry

status. (Ali et al., 2021; Kumar & Gupta, 2021). Regarding food management, these technologies may assist with planning, decreasing food waste, and increasing sustainability. (Rahman & Hossain, 2022).

Numerous commercial smart kitchen systems are available, but many are costly, require proprietary hardware, and do not include features like real-time visual confirmation and notifications for the user. This presents an opportunity for low-cost, accessible systems in the home (Jain & Verma, 2022). This study presents a Smart Pantry Management System that uses IoT products, including NodeMCU ESP32, force-sensitive resistors (FSRs), and ESP32-CAM in addition to the Blynk mobile app. The system gives users real-time notifications and video streaming of their pantry to make tracking inventory more efficient. The goal is to demonstrate how affordable IoT technology can prevent food waste, better manage households, and support sustainable living (Chaudhary & Sharma, 2023; Lee & Park, 2023).

2. Materials and Methods

The study is using the Prototyping Model, which includes six basic stages. Requirement gathering the process started with a requirement gathering phase, where user needs were elicited through ad hoc interviewing and online surveys to understand the common challenges of pantry management as reported by Misra and Sood (2021). The Quick Design stage is then conducted where the basic system architecture was sketched using wireframes and flow diagrams to model the interaction and sensor flow by both Kumar and Thomas (2020). For the Build Prototype, the NodeMCU ESP32, Force Sensing Resistors (FSRs) and ESP32-CAM, were built and programmed with smartphone communication, in a connected system operation, by the Blynk platform, using in ArduinoIDE (Santos, 2022; Kumar & Gupta, 2021). Phase four is the Initial User evaluation where 3 users tested the prototype and gave feedback concerning usability and functionality. The complete prototyping is shown in Figure 1.

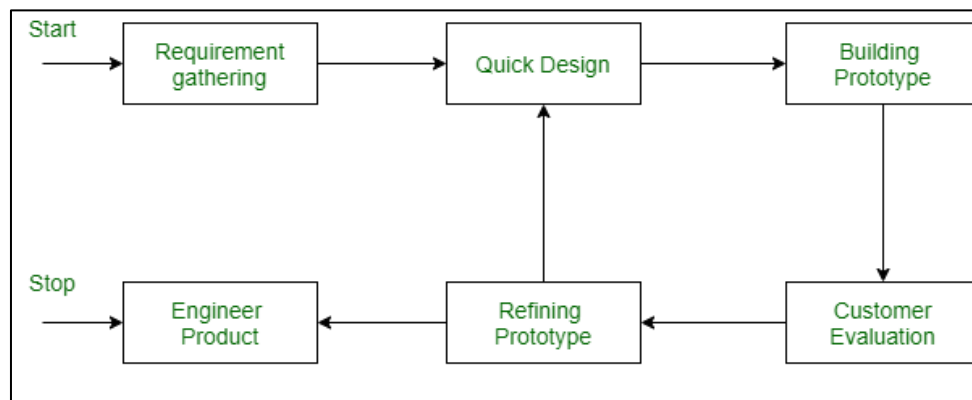


Figure 1. Prototyping Model.

As a result of the feedback received, the refinement phase of the feedback tool focused on user-suggested enhancements, such as tuning the sensor calibration, adjusting the camera angle, and increasing the clarity of notifications. The last step, Maintenance, was the outdoor testing of the system in various illumination and Wi-Fi surroundings to verify its stability over time. The

system was based on a modular development methodology that permitted the sensor, the camera, the mobile interface to be tested independently from full integration. Iteration The development was performed in an iterative manner with the user inputs evolving continuously. All the progress and modification were recorded orderly. The prototype systems were NodeMCU ESP32 for system control and network connectivity (Santos, 2022; Kumar & Gupta, 2021), FSRs for monitoring the presence of items inside the pantry (Ali et al., 2021; Rahman & Hossain, 2022), ESP32-CAM for live streaming and Blynk Legacy Application for sending user notifications and remote video access.

3. Results

IoT Modern Pantry was tested on three levels in the testing phase of its development viz., Unit testing, Integration testing and User Acceptance testing (UAT). All the tests contribute to the system's merit in terms of functionality, robustness, and usability.

3.1 Unit Testing

Unit testing aims to verify the functionality of individual components in isolation. For instance, the Force Sensitive Resistor (FSR) was tested to confirm its ability to detect pressure changes when groceries were placed in the container. The test was successful as the LED illuminated when no pressure was sensed. However, issues with connectivity and configuration caused the failure of the notification system through the Blynk application and the ESP32-CAM live video feed. These issues were solved through a recalibration of the FSRs, an offset that was adjusted, and an adjustment of the reconnection routine on the ESP32. After these changes were implemented, the FSRs reliably detected item removal, the ESP32-CAM streamed video to the Blynk app without interruption, and the notifications were issued promptly.

3.2 Integration Testing

During the Integration Testing phase, the evaluation focused on the seamless interaction of individual components within the system. The assessment involved linking the FSR sensor to the NodeMCU ESP32 and transmitting data to the Blynk app. While the sensor detection and ESP32-CAM operated as intended at this stage, notifications via the Blynk platform displayed inconsistency, indicating possible instability in mobile app communication. After tuning the network configuration and pulling back on sensor polling, notification delivery improved to 1-2 seconds, demonstrating coordination among sensors, controller, and mobile app were working successfully.

3.3 User Acceptance Testing (UAT)

User Acceptance Testing (UAT) was conducted to validate the system's capability from the perspective of real users. Unlike all prior phases, UAT evaluated the system's usability, reliability, and applicability in the real world. All test cases were successful in this phase. Users were able to get notifications and could view the pantry contents through the camera, showing that the system functioned as intended and was ready for real-world usage.

3.4 Summary of Results

Figure 2 presents the count of successful and failed test cases for each phase of testing, which illustrates the improvement the system made from early development to readiness for deployment.

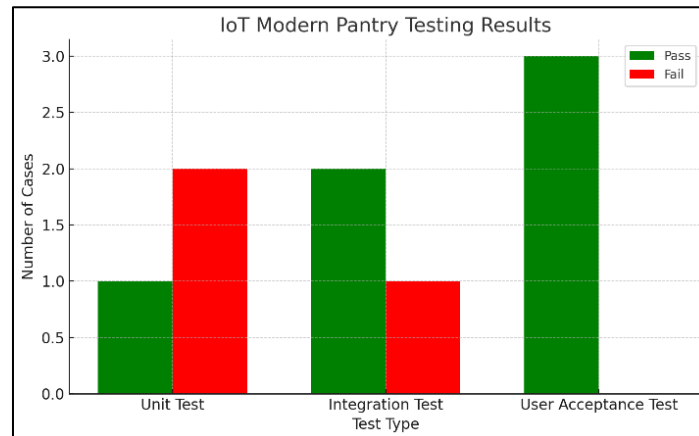


Figure 2. Testing Results by Phase.

4. Discussion

The Smart Pantry Management System illustrates the capability of IoT to solve regular problems in everyday homes including food waste and disorganized pantry management. The results show that the system can reliably track pantry stock levels, notify users in time, and even stream live video access, leading to better household planning and decision-making. These findings complement more recent research, which presents IoT as a solution to mitigate food waste and propagate efficiency improvements in domestic spaces (Tan et al., 2021; Mohapatra et al., 2023; Jain & Verma, 2022). A key advantage of this system is its modular design. Each component such as sensors, camera, mobile application was tested independently to support easy troubleshooting and confirmed stable device operation. Additionally, low-cost components such as ESP32 and FSR sensors created an economical system while providing useful functionality (Kumar & Gupta, 2021; Rahman & Hossain, 2022).

However, several limitations were identified. First, FSR sensors do not accurately measure weight differences between identical products, indicating they are limited to item-level inventory tracking tasks. Second, the whole system is contingent on a stable Wi-Fi and power supply, which may be imperative in low coverage areas. Finally, the prototype presented limited scalability; adding more sensors or devices may lead to a complicated and slower working environment (Ali et al., 2021; Velasco et al., 2020; Chaudhary & Sharma, 2023). In the future, these issues could also be addressed through the implementation of more accurate load-cell sensor(s), cloud-based storage and dashboards for historical inventory tracking, and cross-platform mobile applications (Lee & Park, 2023). These changes would enhance the accuracy, scalability, and lifespan of the system.

5. Conclusion

This study showed that an IoT-based Smart Pantry Management System can efficiently assist families with food management by using low-cost sensors, microcontrollers, and mobile connectivity. The prototype was able to monitor pantry items, send notifications to users in a timely manner, and allow verification through live video, demonstrating its effectiveness in reducing food waste and manage inventory (Patil & Bhosale, 2020; Singh & Kaur, 2021). The assessment has established that the system works well and is intuitive to use, even for non-technical users. Feedback from users demonstrated the usefulness of receiving notifications in real time and confirming by visuals as well as the convenience of the mobile interface. These results are consistent with more recent studies surrounding the incorporation of IoT, in supporting household sustainability and convenience (Tan et al., 2021; Mohapatra et al., 2023; Jain & Verma, 2022).

While the project has many positive aspects, it also highlighted limitations. The FSR sensors precluded accurate weight measurement, the system relied too heavily on stable Wi-Fi and power, and scalability in its current form is limited. Improvements to these problems in future work, such as using load-cell sensors, creating cross-platform mobile applications, and moving to cloud-based dashboards would improve the robustness and application of the system (Chaudhary & Sharma, 2023; Lee & Park, 2023). In summary, this study provides evidence that IoT-based solutions can make a real difference in addressing food waste and increasing household efficiency. Furthermore, the results support the continued development of affordable, scalable smart home applications that will encourage sustainability and resource efficiency (Rahman & Hossain, 2022).

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