Design and Evaluation of a Smart Household Commodities Replenishment System based on IoT

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Summary
With advances in technology, many people rely on technology to facilitate their lives. One of the important technologies nowadays is Internet of Things (IoT), where multiple things connect to the Internet to communicate and allows smart decision making. Grocery shopping is a repetitive task that people perform on a weekly basis and includes three main steps; knowing the consumption of all items, compiling a shopping list, and going to the grocery store. Therefore, it is a great candidate for automation. This domain is important since it touches on core life's aspects such as health and nutrition, finance, and time. In this work, we propose an IoT system that offers full automation of grocery shopping. The proposed system includes a smart replenishment algorithm based on user's consumption. Our evaluation results indicate that the proposed system is able to automate grocery shopping using the smart replenishment, which improves efficiency of household items consumption and reduces waste.

Key words:
Internet of Things, IoT, smart home, E-commerce, grocery management, grocery tracking, replenishment.

1. Introduction

With the fast-paced life that many people around the world live, it is easy to get overwhelmed with the multiple roles that one plays in life and tasks to fulfill each. The emergence of digital and mobile technology has introduced many digital solutions in different domains that provide assistance to people in their daily lives and make them easier and more productive. For example, mobile applications have been developed to help people manage their to-do lists, monitor their diet and health, track their finances, and find healthy meals based on available ingredients. Besides mobile applications, smart home systems appeared recently to provide more intelligent, remote controllable, and interconnected house equipment . Examples include smart TV, smart AC, smart windows, smart fridge, and smart appliances. The main technology that smart home systems are built upon and which made revolution in digital solutions is Internet of Things (IoT).

Internet of Things is defined as "a type of network to connect anything with the Internet based on stipulated protocols through information sensing equipment's to conduct information exchange and communications in order to achieve smart recognitions, positioning, tracing, monitoring, and administration" [1]. The main advantages of IoT is saving time, saving cost, and efficient use of resources. This paradigm has been used in different domains such as smart city and health. For instance, IoT has been used in traffic and waste management. In health, one of the most popular examples we always see in hospitals is medical equipment tracking, health monitoring, and elderly assistance [2].

In our busy lives, it can be a challenge to handle grocery shopping, which requires taking consumption of all items, compiling a shopping list, and making time for frequent trips to the grocery store. There are multiple challenges that people may face in each of these steps in order to keep up with their grocery needs. When checking items' consumption, one may forget to check some items or may find out that some products expired before they are fully consumed. Compiling a shopping list can be time-consuming and people use different applications for this task. Lastly, A trip to the grocery store may include struggles such as unavailable transportation, a forgotten shopping list, a traffic jam, and a long waiting queue at checkout. Moreover, elderly people may face challenges in compiling a shopping list and placing an order online or shopping in grocery store. Online grocery shopping has contributed to eliminating the burden of grocery store trip. Yet one must compile the shopping list manually and place an order online. This, although decreased the time needed for grocery shopping, has only solved the problem partially.

In this work, we adopt IoT technology to develop a smart solution in the domain of household commodities management and replenishment. This domain is important since it touches on core life's aspects such as health and nutrition, finance, and time. For this reason, we are witnessing an emergence of online grocery shopping recently worldwide that offer grocery shopping from the convenient of one's home. A recent survey has shown that the percentage of online grocery shopping increased in 2020 after Covid-19 outbreak to 63%, compared to 9% before the outbreak [3]. However, the propose goes beyond online grocery shopping to offer automation of groceries consumption checking, compiling a shopping list, and online orders placement. The main goal of this project is to improve the quality of life by facilitating tracking the household items and increase convenience in grocery

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shopping. This is achieved by saving time and efforts spent on items consumption checking, grocery list compilation, and grocery shopping. Also, the system improves efficiency of household items consumption and reduces waste.

The remainder of this paper is organized as follows. Section 2 reviews related work. Section 3 presents the system design, while section 4 explains the system evaluation. Finally, a summary with concluding remarks are provided in section 5.

2. Literature Review

Multiple efforts exist in the literature that propose different IoT-based systems for household grocery management. One of the main aspects of these systems is the sensing technology used to monitor the quantity of grocery items, such as pressure-based, camera-based, and vibration-based approaches. In the text below, we highlight the main recent contributions made in each category in this field and explain the main components of the systems.

Several works has used the pressure-based approach, such as [4, 5, 6, 7, 8, 9, 10, 11, 12]. For instance, the work in [4] proposed a system for smart kitchen, which consists of five modules, namely a smart container, gas leakage detection, smoke detection, smart stove, and a website. The smart container uses load sensors to measure the weight of the container's content and inform the user through the website if the weight is less than a customized threshold. The website can also recommend recipes to the user based on exiting ingredients, which was also implemented in [5]. Similar work was done in [6], where different types of sensors were used to detect gas leakages, water tank overflow, and bucket management system.

Desai et al. [7] built a prototype for an IoT-based grocery monitoring system, which consists of load sensors and wireless transmission modules connected to a central node. The latter processes the data received from the load sensors, which are uploaded online for further analysis. An IoT-based grocery monitory system was proposed in [9], where different types of sensors are used to monitor the quantity left in different items such as oil, egg, and salt. Amutha et al. [12] designed a smart kitchen cabinet using load sensors and Radio-Frequency Identification (RFID) tags. The proposed system tracks weights of multiple containers in the cabinet, computes the monthly requirements of a family for each grocery item, and automatically prepares a shopping list.

The camera-based approach has been used by several researchers in the literature. For instance, Balaji et al. [13] used a surveillance camera to perform live video analysis based on image processing and pixel estimation algorithm to detect the quantity of product left in a grocery item container. Two different techniques are used in the work [14], namely camera-based approach and pressure-based approach. The proposed system include four modules, namely receiving module, refrigerator, cabinet, and data storage module. In the refrigerator module, The camera-based approach is used by installing multiple cameras to monitor the availability of different grocery items using image processing and convolutional network. The pressure-based approach is used in the cabinet module, similar to previously mentioned efforts [4-11]. The data returned from the refrigerator and cabinet modules are stored in the data storage module and retrieved by the receiving module to be viewed by the user.

The third sensing technology is vibration-based approach. This technique was used by [15], which showed that the resonance frequency of a container filled with liquid can be used to indicate the liquid level. The authors used curve fitting and SVM prediction models for continuous and discrete predictions, respectively. The authors in [16] used ultrasonic sensors to measure the quantity of product in a grocery item by calculating the time difference between the transmitted waves and the received waves. In their work, data obtained is used to inform the user if consumed calories reach a predetermined threshold.

Majority of the existing research efforts focus on grocery items monitoring using different techniques, but far too little attention has been paid to designing a smart replenishment system. Further, current literature pays particular attention to either the customer side [4-16] or market side by investigating the potential of IoT in warehouse and inventory management [17,18]. Yet, there is a lack of research on comprehensive systems that eliminate the burden of grocery store trips. The most related research to our work is [12]. The system computes the grocery requirements of a household by summing up the daily consumption during a particular period of time, and automatically prepares a shopping list by multiplying the computed requirement by the number of days. The system does not take into account the cases where items are expired before being fully consumed or fully consumed in a short period of time. This work seeks to fill this gap. Our proposed system covers the whole customer journey starting from automation of items consumption tracking, compiling a shopping list using a smart replenishment algorithm, and online orders placement.

3. System Design

The proposed system comprises three main parts, namely: the customer sub-system, the market sub-system, and a data storage. The customer's sub-system contains two components; hardware and software components. The system's block diagram is shown in Fig. 1, which displays the relationship between the parts of the proposed system and the connections between different blocks. In this section, we first explain the architecture design and then explain each system's component in more details.

3.1 **Architecture Design**

The proposed IoT system follows layered architecture, which has four main layers as shown in Fig. 2. Layered architecture divides the system into layers with related functionalities. The higher levels are responsible for the complex functions, while the lower levels are responsible for simpler functions and represent the core functions that are related directly to the system. We explain each layer below.

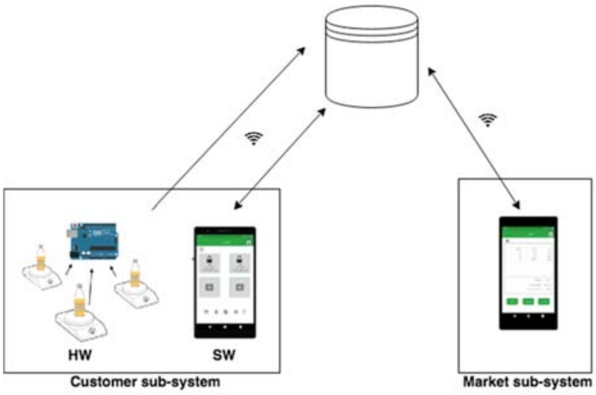

Fig. 1 Block diagram of the proposed system

- Perception layer: This is the physical layer, which includes the sensors, hence sensor layer. Its main purpose is reading data and sensing changes from the environment. This layer is where the load sensors exist to measure items' weight.
- Network layer: This layer acts as a communication layer as it connects the sensors in the lower layer to the server in the higher layer to transmits the sensors data.
- Data storage layer: This layer acts as a storage where the database is stored in the cloud. It receives data from the sensors in the lower layer and the user through the higher layer.
- Application layer: This layer presents results and delivers the system's various services and functionalities to the user. This layer also includes file storage, where the shopping list of the customer is stored locally. The file stores the items ids and quantity for each item.

3.2 Data Storage

The system includes a data storage, which is a database that stores system's data such as sensors, customers, items, products, and orders. The customer data includes ID, name, phone number, email, username, password. It also stores user's preference such as the products he likes and whether he would like automatic reorder once an item is fully consumed (zero amount left) or almost fully consumed (a quarter left). In addition, the database stores the sensors data, including sensor ID and weight, which is deducted to compute the item's weight.

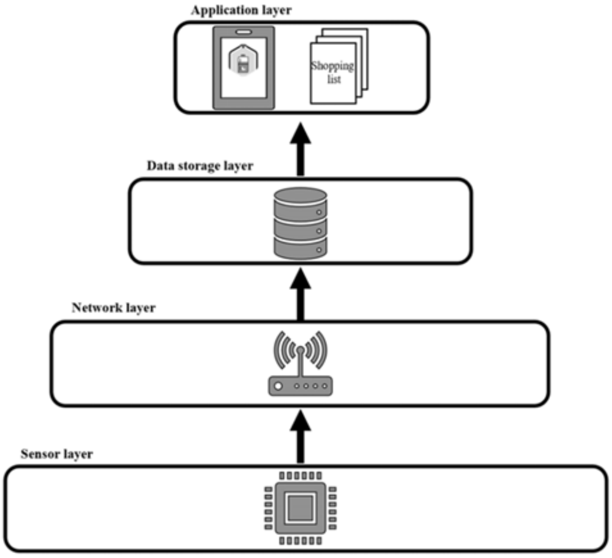

Fig. 2 System architecture

The data stored for each item includes item's ID, current weight, original weight, current quantity, original quantity, expiration date, date of addition to the system, suggested item for this item, suggestion flag, and decision flag. Further, the database stores orders' data such as status, date, time, and total price. Moreover, the data storage contains the market's data where all available grocery products are stored. This includes product ID, name, brand, size, description, and price. In the data storage, each sensor is paired with one item, a customer owns zero or more items and zero or more products. The latter relationship allows storing whether a customer likes/unlike a specific product. An order contains zero or more products, hence determining the quantity, and a customer has zero or more orders.

3.3 Customer Sub-System

Our system is an IoT system that tracks user's consumption of various household items and automatically places an order when an item is close to being/already fully consumed. As mentioned previously, the customer sub-system consists of hardware and software components, which are explained below.

3.3.1 Hardware component

Load sensors are attached to different household items to track user's consumption. These sensors send data about the current quantity of items on a regular basis. The main hardware used in the proposed system are shown in Fig. 3 and listed in Table 1.

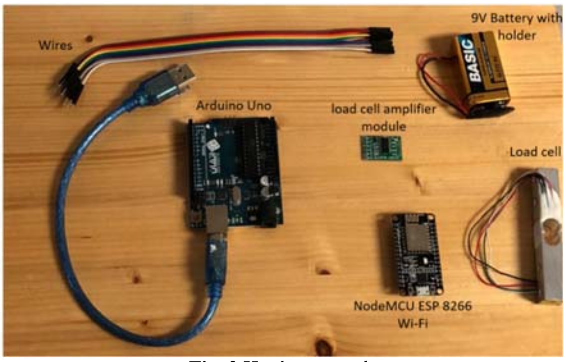

Fig. 3 Hardware used.

Table 1: Hardware components and their purposes.

Device	Quantity	Purpose
Arduino Uno R3 board	1	Used to program sensors
Load cell	3	Used as a weight sensor
HX711 load cell amplifier module	3	Used to easily read load cells to measure weight
NodeMCU ESP8266 WiFi Lua Board, CP2102	3	Used to send data via wireless with built-in Wi-Fi
Battery 9v	3	Used to supply power for NodeMCU
Battery holder	3	Used to connect the battery with NodeMCU
Male-female wires	12	Used to connect HX711 with NodeMCU
USB cable Type-A to B	1	Used to connect Arduino UNO with laptop
USB cable Type-A to Micro-B	1	Used to connect NodeMCU with laptop

The hardware component contains two main controllers, namely Arduino Uno and NodeMCU. Arduino Uno is used to calibrate the sensor until it gives accurate readings. Once the calibration value for each sensor is determined, the other controller is used, which is NodeMC. This controller is provided with network properties (SSID and password) and a calibration value, it then takes the readings directly and send them to the database. Below we explain the main steps related to the hardware component of the system.

1. We designed and created a wooden base for each sensor in order to place the item on (see Fig. 4). This avoids having the sensor move and hence provides consistent reading for the items' weight.
2. We connected the sensors with Arduino and HX711 load cell amplifier module, as shown in Fig. 5.
3. We used Arduino IDE to tune the parameter "collaboration factor" for each sensor in order to retrieve accurate weight for the item placed on top of the sensor. The values -244, -232, and -238 were determined empirically for sensor 1, 2, and 3, respectively .
4. We tested the system to check if it retrieves the items' weights from the sensors and save the values in the database. At this stage, the WIFI module (NodeMCU) was connected to the laptop through a wire (see Fig. 6).
5. We connected the sensors with the WIFI module (NodeMCU) to allow sending the weight reading to the database wirelessly (see Fig. 7).

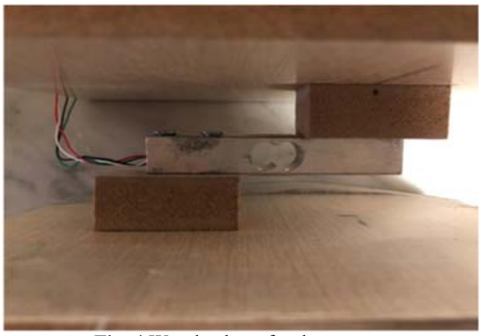

Fig. 4 Wooden base for the sensors

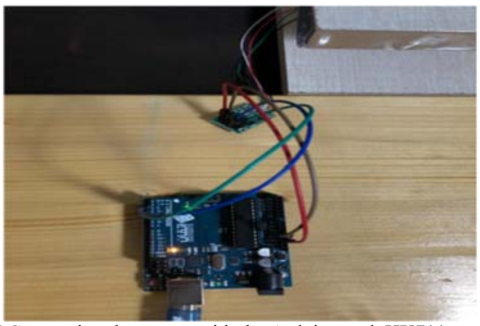

Fig. 5 Connecting the sensor with the Arduino and HX711 amplifier

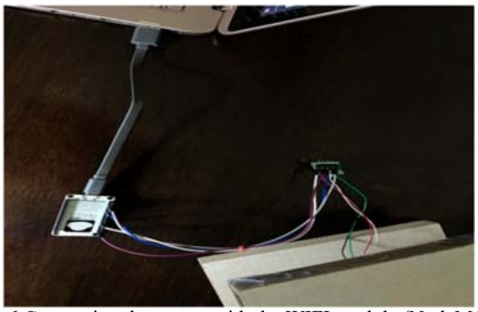

Fig. 6 Connecting the sensor with the WIFI module (NodeMCU)

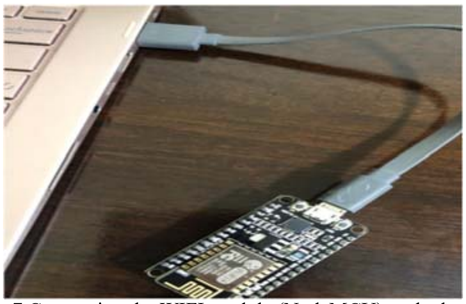

Fig. 7 Connecting the WIFI module (NodeMCU) to the laptop

3.3.2 Software component

The proposed system consists of a mobile application that acts as a household commodities management and replenishment system and serves the customer by offering various services, which are explained below.

Once the user registers and logs in, he is allowed to set up the system for the first time and add different grocery items. For each item, the user scans the item's barcode, enters the item's expiration date, enter the quantity, and scans the sensor bar code. The system then validates the entered data, pairs the item with the sensor, and asks the user to places the grocery item on the sensor in order to measure the item's original weight. Next, the system stores the data in the database. The system also allows the user to delete any added item.

The system tracks the user's consumption of the entered items. The sensors send the items' weights to the database periodically. The system retrieves these data from the database and displays them to the user graphically based on the percentage of the current weight to the original item's weight (see Fig. 8). The system also displays the remaining days until expiration for each item. Once an item is expired, the system notifies the user and add the item to the shopping list based on the user's consumption, which is explained below.

One of the important features in the proposed system is the smart replenishment algorithm, which analyzes the user's consumption and once an item is consumed, it either adds the same item or suggests a new item. The smart replenishment flowchart is depicted in Fig. 9. As shown in the figure, the system continuously tracks consumption of the items. If an item is fully or almost fully consumed, depending on the user's preference, the system checks if the item was consumed in a short period of time P, set by the user. If so, the system *upgrades* the item by suggesting a bigger size or more quantity of the same item. For instance, if the user prefers to order weekly, it is advised that the value of $P = 4$. Therefore, if the user consumes an item before four days pass, then he needs to upgrade the item to avoid repetitive orders. However, if the user consumes the item in a week, the system *replenishes* the item by adding the same item to the shopping list. If the item is not consumed, the system checks if it is expired. If so, it means

Fig. 8 Visualization of current item's quantity

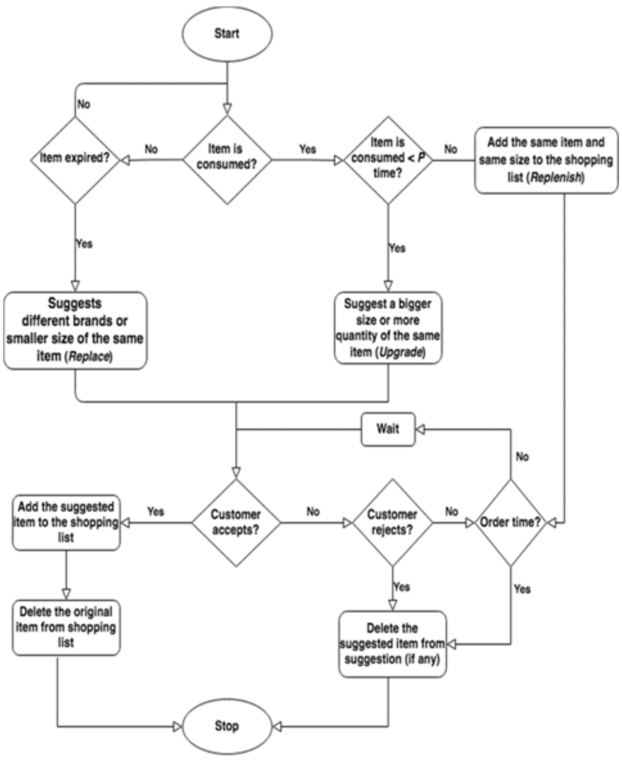

Fig. 9 Smart replenishment algorithm

that the item expired before full consumption, the system then *replaces* the item by suggesting different brands or smaller size of the same product. The notion is that the size of the item might be too big for the user's need or he perhaps did not like to item. Suggested products will be based on the market dataset.

Once an item is suggested to the user, he should respond by either accepting or rejecting the suggestion. If the user accepts, the suggested item will be added to the shopping list and the original item is deleted. If he rejects, the suggested item will be deleted from the suggestions. If no respond is received until order time, according to user's preference, the system considers it a rejection.

The proposed system places orders automatically according to the user preferences by sending the shopping list and user information to the market. Once the order is placed, the user will be able to track it to see when it is prepared and delivered. Further, the system allows the user to configure the system according to his/her preference such as turn on/off automatic order, when to add an item to a shopping list (almost/fully consumed), when/how often to place an order (e.g. weekend, at least 3 items, once an item is fully or almost fully consumed). The user is also able to view the status of placed orders.

3.4 Market Sub-System

The market sub-system is a mobile application that receives the user's orders. The user is be able to view details of the received orders, change the order status to being prepared, being delivered, and delivered.

4. System Evaluation

In this section, results of the experimental evaluation of the proposed system are presented in Figs. 10-13, which correspond to four consumption scenarios. The experiments were performed by four different users, where each user consumes three different items, namely milk, juice, and cereal, in seven days. Each figure presents the weights of the three items each day. Although the system monitors the items' consumption continuously, we only report the items' weights daily for simplicity. The day zero corresponds to the original item's weight before consumption. Further, the figures show the system's response to the user's consumption by either replacing, upgrading, or replenishing the items, indicated by colored stars. The green, blue, and yellow stars represent system's suggestions to upgrade, replace, and replenish the corresponding item, respectively. In all scenarios, the automatic order was turned off, and an item is considered consumed when the user consumes three-quarters of the product. The value of parameter $P = 4$. Therefore, an item is considered consumed in a short period of time if three-quarters of the product is consumed in four or less days.

In Fig. 10, we can see that the system suggests an upgrade to the cereal on the third day since the user consumed the product (less than a quarter left) in a short period of time (less than four days). The two other items were not consumed, nor did they expired during the period of seven days, hence received no action from the system. In Fig. 11, the system suggests to replace the milk and cereal on the sixth day because the items expired before being consumed. The cereal received an upgrade suggestion in Fig. 12 since it was consumed in a short period of time, while the juice and milk were replenished (added to the shopping list) on the fifth and sixth day, respectively, because they were consumed before the order day (seventh day). In the last scenario in Fig. 13, the system replenishes the milk and cereal on the sixth and seventh days, respectively, since they were consumed before the order day.

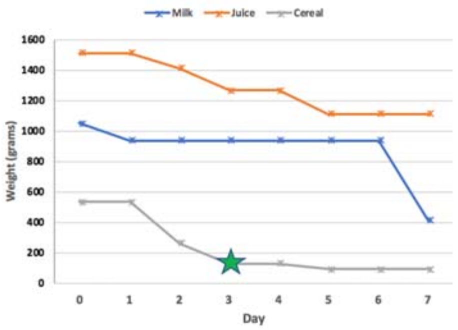

Fig. 10 System response to the first consumption scenario

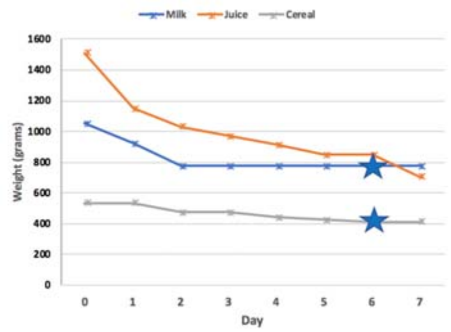

Fig. 11 System response to the second consumption scenario

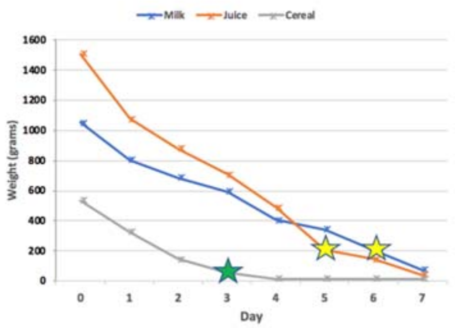

Fig. 12 System response to the third consumption scenario

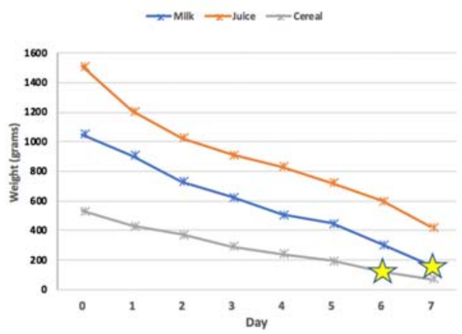

Fig. 13 System response to the fourth consumption scenario

5. Conclusion

This work proposes a smart IoT-based household groceries tracking and replenishment system. The system consists of customer and market sub-systems, and the customer sub-system contains hardware and software components. The main contributions of this work is the proposed smart replenishment algorithm based on user's consumption. Further, unlike majority of existing works, the proposed system covers the whole customer journey starting from automation of items consumption tracking, compiling a shopping list using a smart replenishment system, and online orders placement. We presented the system design, including architecture design, data storage, customer sub-system, and market sub-system. Moreover, we evaluated the system using four different consumption scenarios. Our results indicate that the proposed system behaves as expected and that it is capable of successfully automating the task of grocery shopping using smart replenishment, which in turn can improve quality of life.

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