Pocket Pantry: A Smart Kitchen Storage System

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ABSTRACT
According to the USDA, 30-40 percent of the food supply in the United States is wasted [1]. A major factor contributing to this waste is spoilage and excessively repurchasing items that one already has due to forgetting that they have it in their pantry. Moreover, this can lead to unnecessary extra spending when grocery shopping. Additionally, consumers often forget items they needed to buy at the grocery store or are just generally unaware of how much of a particular food item they have in their pantry while at the grocery store. To address this growing need, we introduce Pocket Pantry: a human-computer interaction driven solution for consumers that (1) tracks contents of their pantry including product types, expiration and usage, and (2) a novel interaction platform that is integrated with existing pantry solutions.

Author Keywords
Interaction design; NFC; barcodes

CCS Concepts
•**Human-centered computing** → **Human computer interaction (HCI);** *Interactive systems and tools;* Interaction design process and methods;

INTRODUCTION
As homes and cities are becoming more digitized and "smart," new technologies are emerging to incorporate everyday items into this new realm. We see this in the growing trend of Internet-of-Things (IoT) devices such as Amazon Alexa and LG Smart Refrigerators. These devices make use of sensors to collect information about their surroundings and fuse this information with Internet services.

Furthermore, we see the emergence of ubiquitous technology in everyday life, including wearable technology and home automation. These devices allow for the human to better interact with their surroundings and automate tasks that were once arduous and time-consuming. For example, home automation technologies can automatically adjust the lighting of a room depending on the preferences of the end-user (i.e., mood and energy savings).

We draw from these ideas and introduce Pocket Pantry: a smart kitchen storage system that can be retrofitted into users' existing kitchen pantries. Simply put, Pocket Pantry is an all-in-one digital system that tracks food supply usage in a user's pantry. In doing so, Pocket Pantry solves the following problems:

- Reduces overall household food waste and increases awareness of already purchased food items
- Decreases time spent looking for food items
- Better informs the user of pantry items, including product descriptions and expiration information

At a high level, our system assumes that in the future, Near-field Communication (NFC) stickers will be commonplace on all food item packaging. These stickers will be placed on the opening ends of the food package so that once the package is opened, the sticker is torn, thus deactivating the NFC sticker. Inside the pantry, there is an NFC reader and an Internet-connected Raspbery Pi to collect the NFC sticker data. This information is backhauled over the network (i.e., wifi) to a database. Finally, the database is interacted with via a mobile companion app.

RELATED WORK
In this section, we present relevant prior work and their prototypes. We draw similarities and differences between our approaches and theirs. Furthermore, we look to areas of improvement in all approaches.

Smart Pantry Systems
The closest related work to Pocket Pantry is [2]. This paper presents a high-level architecture and implementation for a smart pantry system that maintains an inventory of all items within it. The authors make use of a Raspberry Pi, a stepper motor, a touch screen and a barcode scanner to provide the end-user with an Internet connected MySQL database of food items. Like our work, the user registers the food item into the smart pantry system. From there, the back-end system provides tracking information and relevant food item details

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in a touch screen interface. Similarly, our work integrates mobile shelving units, which move food items closer to the user depending on their location.

While this work is excellent and provides a starting point for locating and tracking food items within the pantry, it does not provide for a seamless user experience. The end-user still needs to scan a product's barcode when placing the item into their pantry. Additionally, this solution does not track the state of an item as it pertains to it being opened or unopened. Therefore, we extend this work to include these features through NFC stickers.

Similarly, [3] and [4] present work on an inventory tracking system via RFID tags. While this work focuses on more large-scale settings such as warehouses and grocery stores, the presented wireless sensing and tracking technique is paramount to the system's seamless operation. In this setting, all inventory is automatically tracked without any user intervention. Hence, Pocket Pantry extends this idea, except we minimize the requirements of the tracking tags for a kitchen pantry setting. As a result, Pocket Pantry opts to use short-range, NFC stickers.

Finally, Hsu et al. [5] argue that RFID technology is not an affordable solution for many end-users. Instead, they describe a smart pantry system that employs both a barcode scanning utility as well as a picture-identifier mechanism to register items in the pantry via a camera. While the barcode scanning system is similar to prior work, the picture-identifier approach is novel in that the camera resides within the pantry in order to register food items as they enter and leave the pantry. For this to work, the authors assume proper lighting conditions from within the pantry and an automatic or manual image recognition system to identify the product (akin to Google Lens).

While prior works detail strides in improving the kitchen pantry experience, none provide a practical solution that makes use of short-range NFC stickers with a cost-effective infrastructure. We view these requirements necessary for creating a product that consumers will prefer and enable a large-scale roll out in the market.

Inventory Management with Internet-of-Things (IoT)

It is evident that IoT devices are playing a significant role in enabling smart homes. Many existing works such as [6] and [7] introduce modernization and added efficiency to commonplace home organization systems such as pantries, closets, and shelves. These papers highlight the use of Internet-connected microcontrollers to track the quantity of specific household items.

While we build on these technologies and approaches, our prototype is specifically tailored to account for the expiry state of a food item. In many cases, consumers are not aware of the presence of food items in their pantry that are about to expire. Specifically, many consumers do not keep track of when a food item has been opened. We demonstrate how our prototype addresses this problem in Section 3.1.

On the other hand, we note that there is prior work in developing "smart canisters" to track items within food containers [8] [9]. For example, Khan et al. offers a prototypical Bluetooth LE canister solution that automatically senses the quantity of a particular item within the canister. The smart canister then broadcasts this information to a base-station, for it to shuttle that data to the cloud. The end-user views the canister information on a smartphone app.

These approaches, while novel, are centered around the collection and storage of food quantity information. None of the showcased work details physical tracking of the food items. Furthermore, prior approaches make use of weight sensing to track quantity of a particular item in a canister. This involves moving the food item from its original packaging into a smart canister, which is both cumbersome and unnecessary. Instead, Pocket Pantry does not require any additional interaction from the end-user and scales to the entirety of the kitchen storage options.

Inventory Tracking with Augmented Reality (AR)

While not strictly core to Pocket Pantry, we wish to detail relevant work in inventory management using Augmented Reality (AR). AR technologies have seen a recent uptick in popularity given the recent increase in consumer accessibility of products such as the Microsoft HoloLens. We note that prior work [10] [11] explores approaches to enabling assisted living technologies within the home for the elderly and disabled. By using the HoloLens, Mahroo et al. demonstrate that mixed and augmented reality can enable new kinds of interactions with appliances. Their prototype tracks the person's location within their home and overlays images of real objects on top of their actual location in the physical space.

Although AR technology is not a critical component of Pocket Pantry, we envision that future work can build upon our prototype to enhance the end-user's experience. Nevertheless, we are motivated by the great advancements accomplished in AR and its increasing accessibility to software developers and researchers alike. For this reason, we opt to include a discussion on the fusion Pocket Pantry with other relevant works that add to the end-user's interaction experience.

SYSTEM/PROJECT

As is shown in Figure 1, our system has two major components: the pantry and the mobile companion app. Our pantry prototype consists of a 'Lazy Susan', which provides a convenient method to look for food items and an NFC reader device with connection to a Raspberry Pi for tracking the contents of the pantry. The mobile app is an interface for the user to manage pantry supplies.

Hardware Design

We note that due to COVID-19, our project unfortunately required a shift in development. Therefore, our project group split up hardware and software tasks among group members to work on it from the safety of their homes. As a result, our prototype largely lacked sufficient testing and implementation, though we are encouraged by the simplicity in our prototype's implementation, especially since it is largely beneficial and merits further improvement.

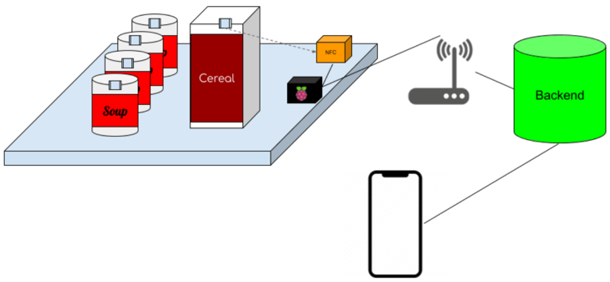

Figure 1. System Diagram without Lazy Susan

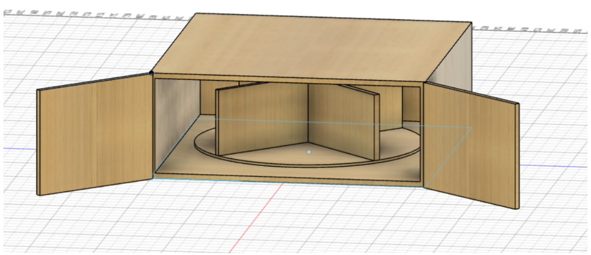

Figure 2. Shelf Prototype including the Lazy Susan

'Lazy Susan' Movable Shelf

We implemented an inexpensive smart shelf prototype by combining a 'Lazy Susan' with the pantry. A 'Lazy Susan' is basically a rotating tray made of wood or plastic. We built the 'Lazy Susan' prototype with wood and an Arduino Servo motor. There is a small hole at the center of the disk that is connected with the servo motor at the bottom of the shelf. When the user uses the speech recognition function in the mobile app to interact with the smart pantry, the disk automatically rotates around to show the desired product to the user. The rotating disk is divided into 4 sections as is shown in Figure 2. The motor calculates the angle to rotate based on the motor's current angle and the section where the product is stored. Since the disk rotates around in constant speed, it takes 1∼3 seconds until the product is shown, which we believe is minimally latent for the end-user.

NFC Stickers

Moreover, we install an NFC reader into the pantry shelf to detect when a food item is present. We envision that food item manufacturers will place inexpensive NFC stickers on the opening ends of the food package as an active mechanism for tracking their products. These NFC stickers must be programmed by the manufacturer with a globally unique identifier (GUID) or with a universal product code (UPC). In effect, once the package is opened by the consumer, the sticker is torn, thus deactivating the NFC sticker.

We note that the Pocket Pantry's NFC reader needs to be strategically installed within the shelf so that the reader has enough range to passively scan the food items (at most 20.0 cm). Optimizing the placement of the NFC reader should be carefully studied in future work.

Raspberry Pi - NFC Reader Hub

In order to store and backhaul NFC reader data, we make use of an inexpensive Raspberry Pi computer with a connection to the Internet. Although our group did not achieve this in the semester-long project, we envision a simple software implementation that continually collects product UPCs/GUIDs from the NFC reader and periodically uploads the data to the cloud. We urge that there be proper security implementation of cryptographic schemes and software design in this system, however we assume that correct privacy and security guarantees are considered in our prototype.

Mobile App

In conjunction with our hardware prototypes, we present a mobile companion app that serves as a digital interface to the Pocket Pantry. The app was built with Google's Flutter platform, which can be deployed to both Android and iOS mobile operating systems via their mobile app stores.

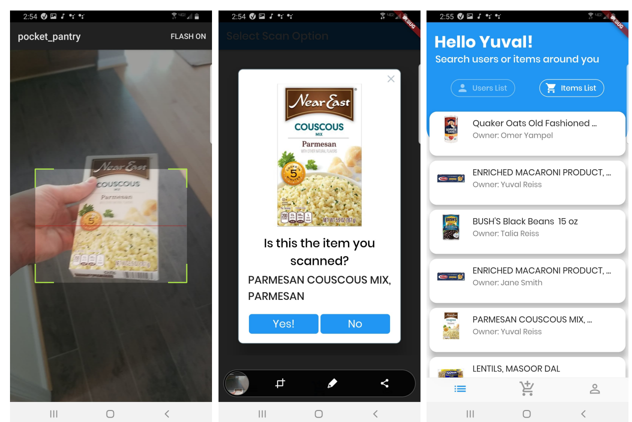

Figure 3. Scanning an item via the app

User Interface/User Experience

Our app connects to the Pocket Pantry database and displays each food item within the Pantry. Our Pocket Pantry app presents the end-user with additional information regarding each food item, such as its quantity, brand, expiration date, the date it was added to the shelf, and if the item has been opened.

The Pocket Pantry app also provides a fail-safe mechanism for end-users to add their food items to the inventory database, in the case that any of the hardware components in the Pocket Pantry fail or need replacement. To achieve this, we add barcode and NFC scanning functionality (if the NFC reader is present on the smartphone), in order register the food item (see Figure 4).

Managing Inventory

Upon registering the food item, the Pocket Pantry app will issue a query to the publicly available UPC barcode lookup

Figure 4. User registering food item via mobile app barcode scanner

database located at (https://www.upcitemdb.com/). The query returns to the Pocket Pantry app in order to populate the Pocket Pantry app's locally cached database.

Furthermore, we add speech recognition functionality to the Pocket Pantry app to add a hands-free feature when interacting with the smart pantry. In our implementation, the end-user can find items stored in the pantry by saying the product's name. This action rotates the 'Lazy Susan' in the corresponding shelf so that the user can conveniently find the food item of interest.

We envision future versions of Pocket Pantry will build upon AR technology to provide an even more seamless user experience. For example, the end-user can view the items in their Pocket Pantry using an AR headset without even opening the pantry door. Similarly, the AR headset can be used as a mechanism for presenting to users metadata information pertaining to food items in their Pocket Pantry. In this manner, red outlines can be visually overlayed through the AR headset when the end-user is looking at a recalled or expired food item.

DISCUSSION AND LIMITATION

In this section, we detail the benefits and drawbacks of our Pocket Pantry design. We further discuss areas of improvements and look to future work in order to build upon our prototype.

Hardware Design

While we recognize that our system is in its early prototype phase, we are encouraged by the large community of Do-It-Yourself (DIY) experimenters who popularize projects built with Raspberry Pis and commercially available sensors. Although our application was not packaged in a photo-ready production, we envision that a commercial Pocket Pantry product can be marketed to consumers in the near future due to the inexpensive hardware components.

We note that our hardware components require a constant source of power, for example, from an electrical outlet or battery. However, we are encouraged by the recent trends in self-powered radio tags for activity sensing [12] as a replacement for the power source.

Additionally, we propose to expand the storage space on the 'Lazy Susan' as our current prototype only has 4 sections. We see that this could be improved in a subsequent version of the Pocket Pantry by adding more sections or creating custom-made 'Lazy Susan' discs for different shelve sizes.

Mobile App

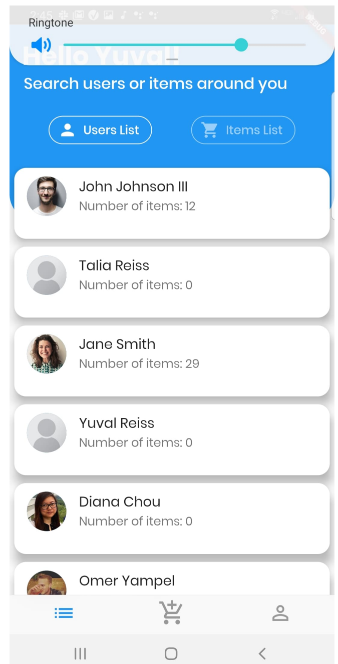

Figure 5. Users list on the mobile app

We note that the Pocket Pantry app was designed as more than just a snapshot of the user's pantry. In addition to tracking the inventory, we allow for each user's pantry inventory list to be shared with others online (see Figure 5). In doing so, this enables an interactively social experience to facilitate a virtual "food co-op". In this manner, users who may be missing an ingredient or a food item for a certain recipe can request to borrow or pay for the food item from a nearby user. This collaborative feature not only adds to the social experience of sharing food items, but also prevents an extra trip to the super market, saving time (and potentially money) to the end-user.

Although the Pocket Pantry app is the core interface to the physical Pocket Pantry, we believe that speech recognition and other forms of hands-free interaction are convenient methods for users. On the other hand, we note that realistically, the Pocket Pantry's 'Lazy Susan' may take longer to rotate the food item for the user instead of manually finding an item in the back of the pantry's shelf (due to speech recognition delays or intermittent/slow Internet speeds). We identify that the "worst case" latency for end-user with fast Internet connections occurs when the cross-section corresponding to the food item is directly opposite of the current angle (since the rotating speed is constant).

We envision solving this problem by applying an acceleration force to the rotation, since the rotation time is the same regardless of the distance from the target position. Of course, our solution must adhere to the laws of physics so that food items are not launched at the target user, potentially hurting them in the process. We must explore this solution carefully in future work.

CONCLUSION

We introduce Pocket Pantry: a smart pantry that tracks the inventory of food items and provides an interactive experience for its end-users. We provide related works and inspiration so that future work can improve on our results. We showcase the hardware and software components of our prototype and detail the advantages of using inexpensive NFC stickers for passively tracking food items. Finally, we discuss the benefits and drawbacks to our system and offer areas of improvement for future fork.

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