ECE 24: DEVELOPMENT OF A SMART REFRIGERATOR

TEAM MEMBERS
Keidi Xhagolli
Wyatt Brisbane
Yelnur Abilakim
Oluwasijibomi Akinkugbe

FACULTY ADVISOR
Prof. Jaudelice de Oliveira

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Table of Contents

1 Abstract

Smart Devices have been making huge strides in the world today. From Amazon's Alexa devices to Apple's Home Dot and even Google's Lifx Mini Smart Bulb, smart devices are making the lives of individuals and businesses easier and more convenient. Smart Refrigerators are the next generation of smart devices.

There are smart refrigerators on the market, however their smart features usually provide help with cooking or maintenance. Almost none of them target the issue of food waste directly. Implementing features that can notify the owner of expired or close to expiring food can help fill a niche that no fridge manufacturer has yet filled.

The proposed solution includes an (a) application, (b) touchscreen, and (c) barcode reader. The touchscreen will be mounted on the refrigerator to allow the user to manually input and view refrigerator contents without opening it. The barcode reader will be used to automatically add food items to the smart refrigerator database to accurately predict the expiration date. The application will be used to send notifications about the approaching end date of and will additionally display the refrigerator's contents to the user.

2 List of Tables

3 List of Figures

4 Executive Summary

4.1 Quad Chart

ECE: 24 Oluwasijibomi Akinkugbe, Wyatt Brisbane, Keidi Xhagolli, Yelnur Abilakim, Dr. Jaudelice de Oliveira

Objective

To develop a smart refrigerator that allows the consumers to reduce the amount of food that goes to waste due to abandonment in the refrigerator and purchase of food items that are close to the expiration date and provide updated fridge food inventory at user’s fingertips.

Approach

The components of the project include:

- A barcode scanner outside the fridge to read the barcode from the product's package and identify the food type using an existing food database such as MyFitnessPal, for example.
- A touch screen outside the fridge to manually record the food type in case the original package does not contain a barcode or if the specific food is not in the database.
- Weight scales inside the fridge to track the amount of certain food of interest.
- A smartphone application to access and view the collected information.

Key Milestones

- Landing Page of Smart Fridge completed – 02/28
- Estimating expiration date database completed for data analytics – 02/14
- Programmed Raspberry Pi microcontroller into an Android tablet – 02/12
- Hardware components of project designed and printed – 01/31

Figure 1: Quad Chart showing the executive summary of the team's progress for the winter term

5 Introduction

5.1 Motivation

Food wastage is a problem that everyone has run into, especially college students, and it results in loss of both time and money. We are interested in working on this problem so we can help college students reduce the amount of food they waste and help them save money and time when budgeting for the desired period (monthly, weekly, bimonthly, etc.). Looking at the bigger picture, the food waste issue has major impacts on various aspects of life, with the most prominent ones on the Earth's environment. Environmental impacts of food waste include, but are not limited to, soil damage, increased trash production, less available land for wildlife, and increasing ocean dead zones, which lead to massive death of aquatic organisms. With our work, we will get a step closer to putting a stop to these destructive consequences of food waste.

5.2 Problem Statement

To develop a smart refrigerator that allows the consumers to reduce the amount of food that goes to waste due to abandonment in the refrigerator and purchase of food items that are close to the expiration date and provide updated fridge food inventory at user's fingertips.

5.3 Stakeholder Needs

Studies have shown that America wastes about 40% of the food it consumes1, and billions of pounds of food are wasted every day due to overbuying, poor planning, and simply forgetting when a food item was bought in the store and placed in the fridge. We, as a group, would like to reduce this amount of food waste by developing a smart fridge to help people keep track of what and when they buy groceries.

5.4 State of the Art

The first emergence of a smart refrigerator was introduced by Lucky- Goldstar (LG) in 2000. These smart refrigerators are connected to the internet and can be synchronized with other smart home device applications like Alexa to look up recipes based on their refrigerator contents and create grocery lists, allow users to remotely control the refrigerator's temperature and send alerts to users' smartphones when its door has been left open for a long period of time.

Despite these amazing capabilities, most of the smart refrigerators still do not have the popularity that most smart home appliances like Amazon's Ring Doorbell, or Apple's Home Dot due to its limited functionality. To increase the popularity regarding these smart home refrigerators, most technology companies are incorporating new advanced technologies like cameras, artificial intelligence. Most of Samsung's smart refrigerators have a touchscreen that performs like a tablet with the same capabilities of an Amazon Alexa with the ability to play music, control temperatures and alert consumers of recipes based on current refrigerator contents. On the other hand, Lucky-Goldstar's current smart refrigerators only inform consumers when the filter of the refrigerator needs to be changed.

Our proposed smart refrigerator will have more capabilities and will be better suited to solve the food waste problem that other smart refrigerators have not been able to solve. The final protype of the project will be able to identify the food item once scanned with the barcode scanner, check the predicted expiration date of the item according to the database and send notifications when the food item is approaching its predicted expiration date. It will also be able to give the user an exact description of the current contents of his/her refrigerator to prevent overstocking on items that are already present in the refrigerator.

5.5 Approach

We aim to develop a smart fridge with the following components:

- A barcode scanner outside the fridge to read the barcode from the product's package and identify the food type using an existing food database such as MyFitnessPal, for example.
- A touch screen outside the fridge to manually record the food type in case the original package does not contain a barcode or if the specific food is not in the database.
- Weight scales inside the fridge to track the amount of certain food of interest.
- A smartphone application to access and view the collected information.

The main constraint is the size of the fridge and limited available space inside it. Due to the latter, only a few weight scales can be integrated into the fridge shelves so as not to take up too much space.

6 Materials and Methods

6.1 Software

- Python used for a program that can correctly identify the item scanned through the data and display the item on the touchscreen
- Fusion 360 for hardware case
- Flutter for App development on both android and iOS devices
- Database for identifying product information key to predicting food expiration date

6.2 Hardware

- Raspberry Pi microcontroller for controlling the barcode scanner and weight scales
- Arduino kit for incorporation with the scales
- Touch screen for manually recording food type and amount
- Barcode scanner module compatible with the Raspberry Pi
- Digital scales for measuring amounts of certain foods
- Fridge for prototyping and testing
- Miscellaneous wires and connectors

7 Results

7.1 Specifications, Constraints, and Standards

There are only a few self-imposed specific constraints and standards that we followed for this project's hardware. Since there are no comparable products on the market currently, there are no common specifications we had to follow due to market pressures. Our primary specifications for this design are portability and compatibility with existing fridges. This is considered essential to the project because we want it to be accessible to low-income families and students who might not have enough funds to purchase a whole new refrigerator just for this feature.

On the software side, there are a few standards we must follow such as having a clean, intuitive application that can be easily used by anyone, and our system must be able to recognize at least the most common food items and reliably guess their expiration date. Also, our software must be compliant with common communication standards such as the ones used for Wi-Fi and internet data transfers to transfer information from the Pi directly to the user's smartphone. We will not collect the user's personal information so there is no need to comply with privacy of data standards. We are currently working on satisfying these standards.

There are little ethical concerns regarding this project, the worst thing that could happen is someone taking a bite out of a food item that has slightly gone past its expiration date. As far as environmental impacts are concerned, the hardware will eventually fail and turn into e-waste, but we believe that all the food items that will be saved from becoming garbage will severely outweigh the small amount of e-waste that will be produced at the end of its lifecycle.

7.2 Concepts

To follow these standards, the concept we decided to focus on was a small portable box to fit on the side or top of the fridge. This allows for the device to be utilized on any number of refrigerators, not just the one we use for our project. The device itself will be mounted onto the fridge using strong neodymium magnets. The device should be able to scan food in a way that it can accurately tell what it is to estimate its expiration - this could be done with a camera or a barcode scanner. As for software, the device should compare input items to those in a large database of common items, to minimize the amount of manual input needed.

7.3 Detailed Design

We started with the question of how we can reduce overall food waste efficiently. Since most businesses have some framework in place to minimize food waste, even though they are not perfect, we thought we would make more of an impact if we helped consumers directly. Since we all had run into the issue of forgetting food in the fridge, it seemed like the best opportunity for improvement. From there we thought of diverse ways to notify the consumer of food that is close to its expiration date.

The original idea involved a camera mounted on the door of the fridge pointed towards the fridge's cavity. We would use machine learning to identify the food in the fridge and using a database, it would get an estimate of the expiration date. That was a good start, but after some brainstorming, we realized that, not only would the camera have trouble with items behind other items, but it would also need a very precise learning algorithm. So, we decided on using a barcode scanner on top of the fridge, which the user can use to simply scan their food before they put them in the fridge. As far as the notification part, we were debating between developing an application that receives the data from the sensor and lists it on your phone. Or we would have the sensor connected to an Arduino which would simply send a text message to your phone whenever something was about to go bad. We finally decided on the former but using Raspberry Pi rather than Arduino because of its superior power at comparable price and size.

Delving further into the concept we realized that adding an interactive interface would be necessary, because not everyone has a smartphone to begin with, and even if they do, they might want to enter a food item manually into the system without the hassle of having to go through their phone every time. It also offered the advantage of showing the foods that are closest to their expiration date directly on the refrigerator, so the consumer is more aware of their near expired food, and they choose to consume that first. Also, integrating scales into the Raspberry Pi would help the user automatically keep track of certain foods that you cannot reliably count, such as grapes or cheese. Integrating them directly into the fridge's shelves would be ideal, but that would require the building of a refrigerator from the ground up. So instead, we decided to simply leave the scales resting on top of the shelves. And of course, we will make modifications to this concept as we get further into the development of this project.

The exact design includes three major physical components, a Raspberry Pi microcontroller, a barcode scanner module, a touch sensitive screen, and digital scales. The Raspberry Pi will act as the brains of the system, taking in and processing the information input into it from both the barcode scanner module, the touch sensitive screen, and the digital scales. The Raspberry Pi, the screen, and the barcode scanner will be packaged together in a plastic housing to make them more compact and secure. The scales will be placed on top of the shelves inside the fridge. There will also be several software components to the system, which include a data analyzer, an interactive interface, and a phone application. The data analyzer will receive the barcode data and cross-reference it with a database that contains data, such as the name of the food as well as rough estimates of expiration dates, for most common foods. The interactive interface will handle both the output and input of the touchscreen. It will show what is currently inside the fridge and at what quantities, it will also allow the user to reduce the amount of each item in the fridge and manually input an item if it does not have a barcode or it so happens not to be in the database. The phone application will allow the user to do exactly what the tablet does, but in a more convenient way since the user can use the phone on the go.

8 Discussion

8.1 Hardware

Once all the hardware for the project was acquired, a housing to contain all of it for the final product needed to be designed. Each piece was measured and had all dimensions noted to allow an accurate 3d model of the tablet screen and Raspberry Pi to be made in Fusion360. With this model, a housing could be designed to hold the screen, while still allowing room for any cables that may attach underneath. The goal was to be able to utilize a team members own 3d printer, a Creality Ender 3v2, to produce the model, which gave the group more freedom to prototype and try new designs when earlier ones failed. These early failures were due to faults in the design where parts were made too thin for the printer to create. This was solved through slight design modifications to the model in Fusion360. The overall design of the casing included a lower base, which supports the screen and contains all the internal components, and a cover, which magnetically snaps to the base to hold the screen down. An issue that was soon discovered was that the modeled parts would be too large to fit in the print space of the 3d printer. The solution for this was to split each part in half and designing small pins to lock each part together. This had the benefit of decreasing print cost in the event of a print failure as well as fitting each piece comfortably within the print space. A holder for the barcode scanner was also designed, allowing for the user to easily mount the handheld barcode scanner to the side of the refrigerator magnetically. After all parts were printed and assembled using the custom pins, a test fit with the touch screen and other hardware was done with no issues.

8.2 Raspberry Pi Controller

The Raspberry Pi controller needed to be set up with a proper environment to implement the database and the application. At first, a Windows 10 environment was thought to be the most optimal by the team due to its familiarity and built-in features. Once Windows 10 was running on the Pi, it proved less than optimal because the loading and response times were unacceptable. From there, a team discussion led to the possibility of loading a Linux based system such as Ubuntu onto the Pi due to its commonality and programming ease. Further research into the matter raised the possibility of using Android 10, another Linux based system, as our operating system. Android 10 was chosen because an Android compatible application would be developed anyway, so having the Pi run Android as well makes the application development a little easier overall. Once Android 10 was loaded, the system proved to be quite responsive, and it seemed to be running well on the Pi. At this point, the system's compatibility with a touchscreen and a barcode scanner was tested. Luckily for us, the touchscreen and the barcode scanner were compatible with the system right out of the box. Further testing was conducted to make sure all the hardware was fully compatible and all the built-in software was stable.

8.3 Database

To estimate how long each product that the user places into the fridge should last, the system must have access to the information about each food item's expiration date. As such, a database containing shelf lives of various products was acquired[10]. It originally came in a PDF format but was transformed into an Excel table because the latter is easier to parse. The table currently features approximate shelf-life ranges for over 180 most common food items found in an average household. The mean of the lowest and highest values of the range will be used to provide the user an expected period the food item can be safely stored in the refrigerator before consumption.

8.4 Application Development

Before the start of the winter term, the flutter was the primary application software that the team planned to use to develop the app for the project. Due to prior knowledge and experience with XCode to develop iOS applications, the software team decided to begin with the iOS application development and then later begin the Android development using Android Studio to mimic the iOS application. Problems arose during Android application development as the two cross-platform application development software had different functionalities and syntax, thus making it harder to create the same application on two different operating systems. Therefore, in week 7 of the Winter quarter, the software team decided to scrap the prior progress and begin anew on the initial primary application development software, Flutter. Steady progress has been made despite the initial setback and the front-end aspect of the application has been completed.

8.5 Poster Presentation Comments/Suggestions

During the team's poster presentation for the project, the reviewers (both peer and faculty) brought up a few suggestions and comments about the project which the team has taken into consideration and would include those suggestions in the design and implementation of the project in the following weeks. Such suggestions/comments include:

- The application relies heavily on the user's input and engagement. From manually inputting food items with the touchscreen tablet or scanning through the barcode scanner to even opening the application to view the user's fridge contents.
- Whether the project includes both cooked (e.g., rice, sauces, etc.) and fresh food items (fruits, vegetables) or even canned food items (like condensed milk, tomato paste, etc.)
- Scope of the final prototype, whether the prototype can be easily appended to current refrigerators or if users need to buy a compatible refrigerator for the prototype.

9 Budget Update

The table below shows the project's updated budget.

ECE 24: Development of A Smart Fridge Project Proposal					
	Equipment	Description	Quantity	Base Price ($)	Amount ($)
1	**Barcode Scanner**	The barcode scanner will be used to scan the food item and cross reference the item with the database to correctly identify the item and its expiration date	1	$13.99	**$13.99**
2	**Scales**	The scales will be incorporated into the miniature refrigerator to weigh items that are difficult to weigh.	3	$7.98	**$23.94**
3	**Raspberry Pi Microcontroller and Touch Screen**	The Raspberry Pi Microcontroller will be used to interface with the software program and barcode scanner.	1	$135.99	**$135.99**
					$173.92

Table 1: A detailed table showing the equipment and description for each description that make up the proposed budget for the senior design project.

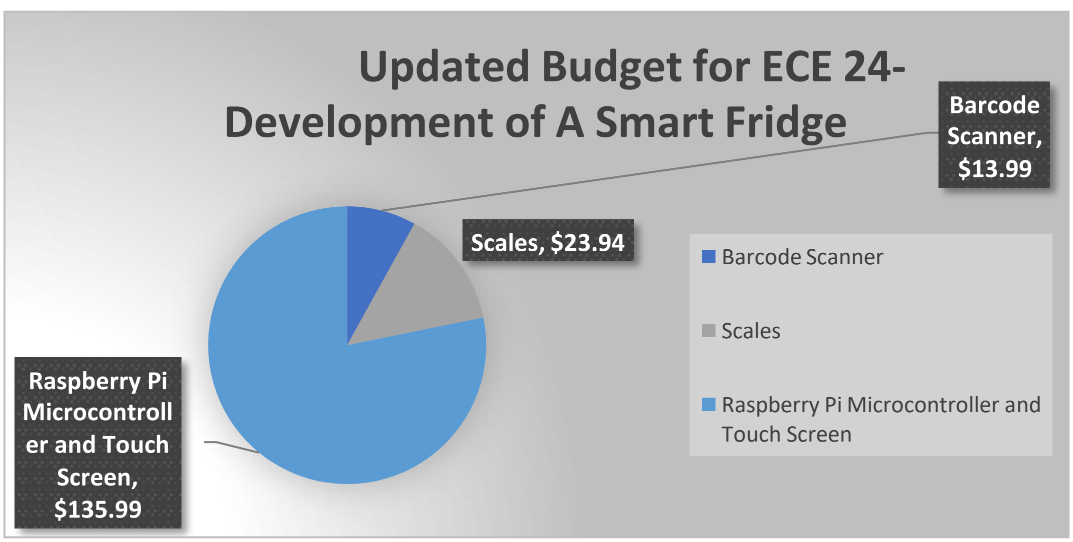

Figure 2: A detailed pie chart showing the percentage of each piece of equipment on the total budget. This pie chart is used to better visualize the budget as well as the which equipment takes a bigger bulk of the budget.

10 Project Management Update

10.1 Description of Work

10.1.1 Work Package 1 (WP1) – Technical Lead: O. Akinkugbe, K. Xhagolli, W. Brisbane, and Y. Abilakim

This Work Package is the purchase and testing of equipment. This includes the purchase of the barcode scanner, wine cooler, scales and raspberry pi microcontroller and the starter kits for the Arduino and Raspberry Pi microcontrollers. This is to ensure that the various parts can work together to produce the final protype.

10.1.2 Work Package 2 (WP2) – Technical Lead: O. Akinkugbe and Y. Abilakim

The second work package includes the purchase and installation of the software applications for the frontend and backend components of the project. These software applications include the application for the development of the smart refrigerator application, the database used to predict expiration dates and the programming language.

10.1.3 Work Package 3 (WP3) – Technical Lead: W. Brisbane and K. Xhagolli

The WP3 includes the assembly and alignment of all the parts of the project. This covers the assembly of the barcode scanner, touchscreen, and Raspberry Pi microcontroller.

10.1.4 Work Package 4 (WP4) – Technical Lead: O. Akinkugbe and Y. Abilakim

In this Work Package, the hardware and software components of the project are both programmed independently. Once the programming of both hardware and software are completed, they will then be used to test the final project.

10.1.5 Work Package 5 (WP5) – Technical Lead: O. Akinkugbe, K. Xhagolli, W. Brisbane, and Y. Abilakim

In This Work Package, the entire project, and its components (application, database, mini refrigerators, scales, Raspberry Pi microcontroller, Touchscreen, and barcode scanner) will be tested for functionality.

10.2 Schedule

The planned schedule for this project is based off various due dates along with group estimates on how long each task should take. This plan is visualized in a Gantt chart, shown below in Figure 3.

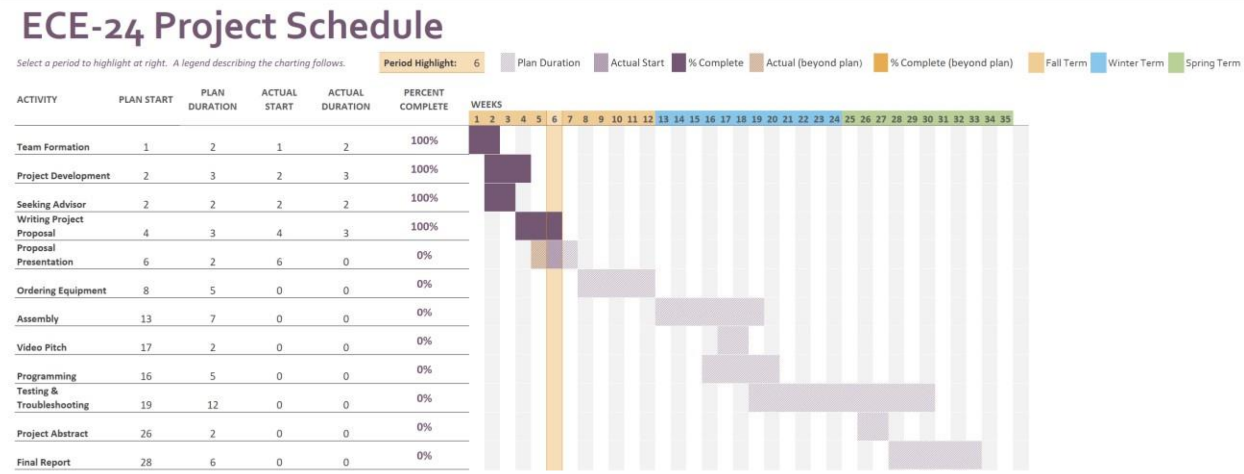

Figure 3: Gantt chart showing the planned schedule for the project, including information for how long each project. The selected period shows the current point in the timeline.

11 References

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12 Appendices

```dart
// }
class MyApp extends StatelessWidget {
  const MyApp({Key? key}) : super(key: key);

  @override
  Widget build(BuildContext context) {
    const title = 'Smart Fridge Contents';

    return MaterialApp(
      title: title,
      theme: ThemeData(
        appBarTheme: const AppBarTheme(
          backgroundColor: Colors.white,
          foregroundColor: Colors.black,
        ), // AppBarTheme
      ), // ThemeData
      home: Scaffold(
        appBar: AppBar(
          title: const Text(title),
        ), // AppBar
        body: GridView.count(
          // Create a grid with 2 columns. If you change the scrollDirection to
          // horizontal, this produces 2 rows.
          crossAxisCount: 2,
          // Generate 100 widgets that display their index in the List.
          children: List.generate(50, (index) {
            return Center(
              child: Text(
                'Item $index',
                style: Theme.of(context).textTheme.headline5,
              ), // Text
```

PROBLEMS OUTPUT DEBUG CONSOLE TERMINAL

Figure 4: Screenshot of flutter code for the application development on both iOS and android devices.

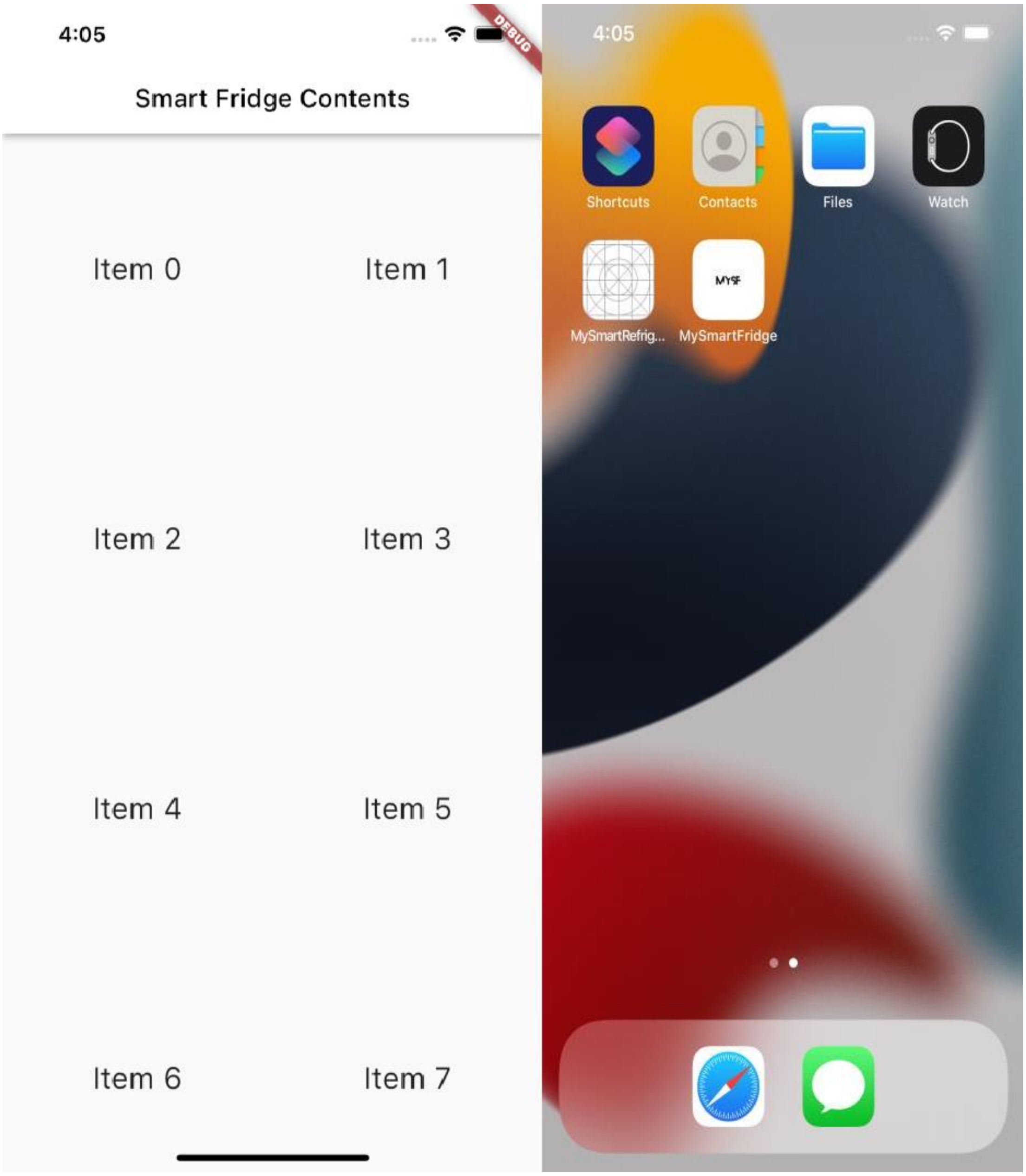

Figure 5: iOS application landing page (left) and application icon displayed on user's home screen(right).

Figure 6: Completed 3d model of the exterior housing with screen included

Figure 7: Completed assembly of the housing with screen installed

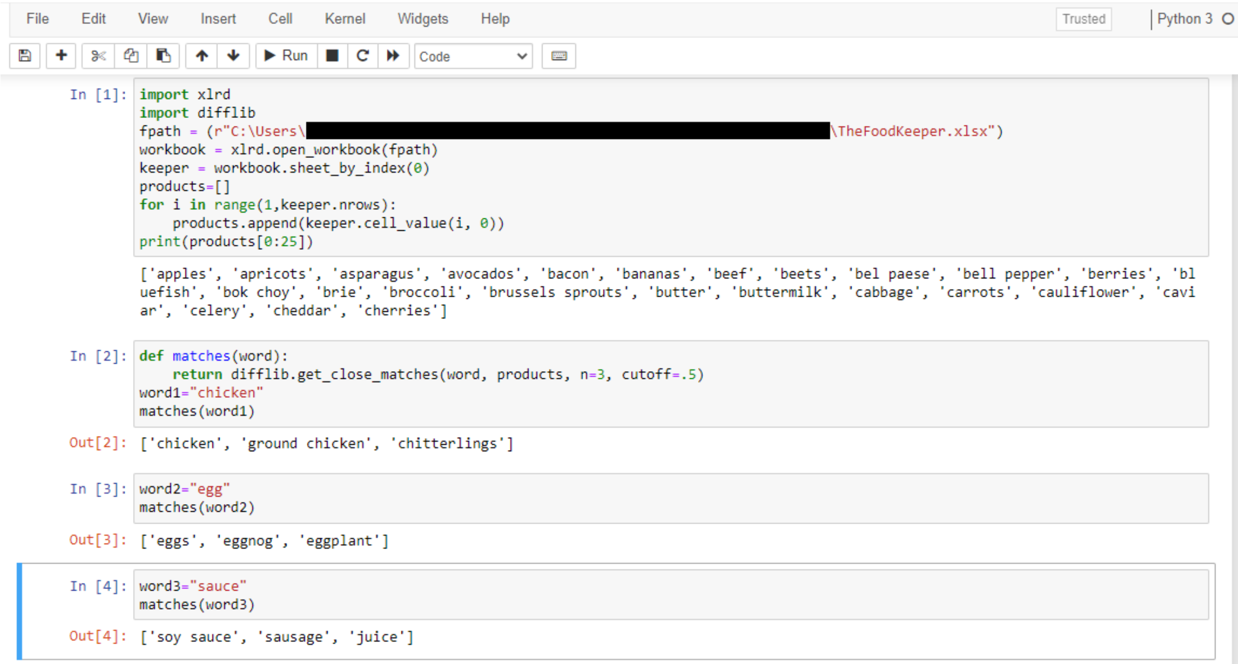

Figure 8: Screenshot from Python of the code used to estimate expiration date using a database