NUS School of Computing  
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Group Project – Smart Fridge 5451

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Abstract

Smart Fridge 5451 is a simple fridge but much more. With the world being in the fourth industrial revolution, one of the most remarkable changes that we have been able to experience has been the automation of things around us. From the smallest devices such as watches or wall lights to larger machines such as those used in industrial manufacturing, we have been able to experience the extent of pervasiveness such devices have, and how beneficial they can be with being automated. Similarly, by making one of the most owned products smart, we want to ease the daily life of the consumers.

With this fridge we want to eliminate a few problems that our consumers encounter - we want to eliminate the headache of inventory checks, we want them to feel assured about their fridge’s temperature and humidity control, and we want them to have an interactive product with which they can interact and enjoy having at their homes.

Keywords: Smart Fridge, Object Detection, Android App, Pervasive computing.

# Introduction

The worldwide food waste volume is projected to be 1.6 billion tons according to the Food and Agriculture Organization of the United Nations and the food bought does not end up getting consumed before its expiration, ultimately having to throw it out. (Food and Agricultural Organization of the United Nations, 2013). As known, the kitchen generates the most garbage and consumes the most energy in the home, and manufacturers are constantly trying to produce new methods to build smarter devices in the kitchen (Nasir, Azir, Ali , Kadir, & Khan, 2018). The smart fridge can assist us in estimating the timing and volume of family members' meals, also assessing people's operation states to gain a better knowledge of their in-depth daily life behavior patterns (Fujiwara, et al., 2018).

In this report, we are looking at options of how a simple household object such as a fridge can contribute to helping the user reduce their food wastage and track the changes in the internal parameters of their fridge. Throughout the project, three distinct areas were focused upon, the first being the implementation where the hardware setup of the prototype and backend functioning is covered; the second, being the machine learning section where we discuss the model, we have used for object detection and finally moving to the front-end section where we discuss our android app and how we are displaying the information for the user. Overall, we are looking at ways through which would be able to lessen the burden of the user and ease their lifestyle by not worrying about the condition of the ingredients in their fridge and also providing them information about their ingredients so that they can consume them within their lifestyle.

## 1.1 Objective

The primary objective is to enable an inventory check with features such as storing the item names and their expiry dates along with maintaining a record of the fridge’s internal condition (temperature and humidity).

## 1.2 Value Proposition

Smart Fridge 5451 is a simple fridge but much more. With the world being in the fourth industrial revolution, one of the most remarkable changes that we have been able to experience has been the automation of most things around us. From the smallest devices such as watches or wall lights to larger machines such as those used in industrial manufacturing, we have been able to experience the extent of pervasiveness such devices have and how beneficial they can be with being automated. Similarly, by automating one of the most owned products we want to ease the daily life of the consumers.

With this fridge we want to eliminate a few problems that our consumers encounter - we want to eliminate the headache of inventory checks, we want them to feel assured about their fridge’s temperature and humidity condition, and we want them to have an interactive product with which they can interact and enjoy having at their homes.

The Smart Fridge 5451 will be capable of reporting its internal temperature concerning its surroundings and will have an alert system that notifies its users when the temperature and humidity of the fridge fall below a threshold value through our mobile application. What sets Smart Fridge 5451 apart from a typical smart fridge the most is the ability to use image processing to detect food and keep track of food stored in the fridge (i.e., detecting when a certain food is put in or taken out). This allows for more automated management - For example, if an orange has been in the fridge for 2 weeks, a notification would be sent to the user to notify him that it might be going bad or, when there is ever a power outage the ingredients in the fridge tend to heat up and get spoilt. But with this fridge, the user can get notified with the help of which they can remove their ingredients and prevent them from getting spoilt.

The interactive app will allow the user to check up on the temperature, humidity, and ingredients It will allow the user to input the expiry date of the object added to send the targeted notification for the items near and on their expiration. Such a product can be later modified and can hold very viable prospects to make it a market leader. The user insights and habits collected from the use of such a pervasive object give room to a large number of real-time opportunities which companies can turn into active revenue models. Some examples could be real-time recipe suggestions depending on the ingredients available in the fridge, ordering of most used grocery items when finishing, and many more possibilities.

## 1.3 Assumptions

For the prototyping of this fridge, we are considering a few assumptions.

1. The lowest and highest temperature for the temperature alert system is only a few degrees above and below the room temperature to test the functionality of the temperature system.
2. We are assuming that every time the fridge is opened, an item is either added to the fridge or removed from the fridge to make item tracking on the app easier

# Methodology

## 2.1 Approach

The basic approach to our project is to have a functioning fridge with an ultrasonic sensor, temperature and humidity sensor, and a camera. The sensors will record their values and send them to the Raspberry Pi, which then stores and process the data locally. The data is then validated to be under a certain threshold value which confirms the proper conditions for ingredients to be in. If the values are above or below the maximum and minimum values, then an alert is activated which is that the user is notified to act to regularize the values again.

## 2.2 Network Layout

The sensors will be communicating with the Raspberry Pi through physical connections of wires but after the sensors, there lies a myriad of network communication. The Raspberry Pi will be communicating with the cloud through Wi-Fi to feed the captured sensor data. This data will then be manipulated to form the rules for the alert system and be incorporated with the Android app with the help of APIs (application programming interfaces).

Diagram

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Figure 1: Process flow for SmartFridge5451

## 2.3 User Interaction

Here we are enabling user interaction with the object through an Android application. Through this application, we will be enabling the user to check the exact temperature and humidity of the interior of their fridge but will also allow the users to view the list of items available inside the fridge and set their expiration dates for getting notifications.

It was reported that the second most reported wasted food at home is usually produced (around 67% of food at home) and the top cause of wasting the food (almost 83%) is due to products being stale or getting spoilt (Food Insight, 2019). With such an application, we want to call onto the sustainable conscience of the people and compel them that with such a device they will be able to reduce food wastage. Why do we think such a strategy would work? It is found that people under the age of 45 years tend to be more conscious of food wastage while grocery shopping and eating at home (Food Insight, 2019). A leading example to prove this strategy is easily visible in Singapore with hawker shops, and how the younger generation is much more likely to buy their meals at affordable rates than to make an effort to cook at home.

## 2.4 Degree of Pervasiveness

For this certain project, to justify the degree of pervasiveness, we will be looking at its mobility, interactivity, invisibility, heterogeneity, and contextual awareness. In terms of mobility, a fridge being a bulky and large object cannot be easily transported the functions we add to the fridge can be tracked from a distance. The network flow of our project allows the user to get updates from anywhere in the world till the object is connected to a stable Wi-Fi connection. Similarly, when we discuss interactivity, the app will require sufficient interactivity not only with the end-user but also with the cloud. The server and the application will be constantly interacting with the cloud because of which it will be able to provide real-time updates on its interface with which the user will interact. Though there is minimal interaction between the user and the app, with the alert system developed, there are indirect interactions between the user and the application with the help of which the objective of the smart fridge can be realized.

Coming to the invisibility and heterogeneity of the smart fridge, we believe that the current model is not able to achieve the ideal degree of invisibility and yet the pervasive components do not have a high degree of heterogeneity. Both parameters lie at a neutral degree, as the pervasive components are easily maskable in the actual design of the fridge but due to their sensing abilities require considerable visibility to report accurate data. Finally, coming to the contextual awareness of the system. As the current object is not applying any major data analysis techniques or has any artificial capabilities but it does have the potential to have high contextual awareness if developed more. Processing the data gathered through user habits and using analytics to devise consumer insights and habits can help develop personalized and more tailored services for users. Similarly, by using advanced artificial intelligence techniques, our image recognition model can be modified and improved to unlock many more behavioral patterns of the user which can be used for personalization of the activities in the system developed. With personalization in pervasive devices, targeted content delivery and consumer loyalty are significantly targeted and increased (Espino, 2021).

# Business Model

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Key Partners**  1. Microprocessor’s company  2. Manufacturers | **Key Activities**   1. Platform/ software development and maintenance 2. Customer acquisition 3. Product assembling, testing, and packaging | **Value Propositions**  1. Automatic inventory check    2. Temperature/ humidity maintenance  3. Alert system  4. App for management and inspection of the fridge | | **Customer Relationship**    1. Review and feedback system    2. Customer support  3. Product insurance/ coverage | **Customer Segments**    1. Domestic Users familiar with IoT (Internet of Things) or IT (Information Technologies)  2. Corporate Users (e.g., hotels and real state agencies)  3. Residents who want a better or smarter home experience |
| **IT Infrastructure**  1. Network connection  2. Android/iOS platform  3. IoT data protocols | **Key Resources**  1. User platform  2. Development team  3.Marketing consultation | **Channels**  1. Retail stores  2. Website |
| **Cost Structure**   1. Technology development 2. Marketing (i.e., advertisements) 3. Cloud services (if needed) | | | **Revenue Stream**   1. Sales | | |

## Revenue Model

Smart Fridge 5451 has the potential to become a common household product. A fridge has become a necessary household object and many people prefer to buy such an object by looking at its features and its functionalities. We believe that Smart Fridge 5451 would benefit by being sold either through direct (physical stores) or web (online stores) sales. Even though revenue cost and prototyping cost for this product would be a considerable amount but once the masses realize the potential of this product, it will be able to creep up the market.

## Market Competition

### 3.2.1 Indirect Competitors

The traditional fridges are simple coolers with necessary sensors to provide lighting and save power. However, the market size of the traditional fridges is still exceptionally large (over 99% in 2019).

The critical points of the users are that the traditional fridges are only containers. It is easy to forget what is in the fridge and miss the expiration date. So, smart fridges are a way to provide management functions to avoid these problems.

### 3.2.2 Direct Competitors

(1) Electrolux Screen Fridge (LG/Siemens/SAMSUNG/Whirlpool)

The majority of smart fridges on the market now are Screen Fridge. However, the reason these smart fridges can be called ‘smart’ is mainly that they are combined with other smart devices like TV, DVD player, internet browser, and so on. For the fridge itself, the ‘smart’ parts are that we can know the environment status like temperature, spare room, and power consumption and control the fridge remotely. And the most important is that the majority of them do not have a function to trace the status of the food itself.

In common, these fridge bands position themselves as high-end products and hope the fridge to be a central terminal of the smart devices in a house. So, the prices of the fridges are expensive.

But for our product, we focus on the fridge itself to solve the critical points for the fridge users. It is and only is a fridge, so it can be much cheaper than those Screen Fridge.

(2) Husky Intelligent Fridge

This kind of fridge is something more like a vending machine. It allows customers to just open the fridge door and choose their goods, instead of pressing some buttons. The fridge can automatically detect what the customer has taken, and charge based on e-payment. For the operators, it can provide the entire stock online at any moment and send warnings on low inventory.

It is an outstanding idea to combine a smart fridge with a vending machine, however, it is not suitable for home use. A vending machine has a high frequency of inventory changes. So, it has nice support on the sales. But for a home user, we usually care more about the food quality rather than the quantity.

Compared to the Husky Intelligent Fridge, we have more functions to help the users to keep track of the status of the food, and it is more suitable for home use.

## Marketing and Advertising Strategies

### 3.3.1 Market size and potential growth

Smart home applications usage has been growing steadily in recent years. The global smart home market is projected to grow from about USD 80 billion in 2021 to reach almost USD 140 billion by 2026.

### 3.3.2 Advertising strategy

Revenue and cost are our major concerns in defining the promotion strategy. The advertisement would focus on how the fridge’s ability to ease everyday tasks. With the pandemic in recent years, people are spending more time at home (e.g., work from home, quarantine). The main focal point for our advertisements would be how the fridge could automate processes and save time. Below are two potential advertising strategies that suit the products.

**Collaborative promotions:**

Smart Fridge 5451 can collaborate with other stakeholders in the ecosystem to attract more users and brand ourselves. For example, we can work with hotels and real state agencies to feature or showcase the product to gain public notability.

**Social Media Marketing:**

Smart Fridge 5451 can engage with social media platforms and websites to attract more interest and consumers to the website or the product. The channels include Facebook, Instagram, and Twitter through which we can help advertise the functionalities of the fridge.

### 3.**3.3 Quantifying business growth**

To ensure customer satisfaction and continuous growth, customer support and evaluations are important:

1. Measure customers’ satisfaction (e.g., usage) with online surveys.
2. Maintain a good line of communication (e.g., website or hotline) and provide technical help to customers.

# Prototype

## Implementation

For the implementation of the project, we look at the assembly and the execution of the above-discussed services.

**4.1.1. Hardware Requirements**

The sensors used in this project are the Ultrasonic Ranger, the BME280, and the Raspberry Pi camera. Along with these, because we require ambient lighting in the setup, we utilized the LED strip W2812B along with a micro: bit powered by a battery source to power the lighting inside the fridge.

Diagram

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Figure 2: Schematic diagram of connections

**Raspberry Pi**

Raspberry Pi is a single-board computer or a microcomputer which are incredibly versatile and can be used to create pervasive and ubiquitous devices. It can act as an interface to capture sensor values and as a medium to send these values from the sensor to the cloud. It also can process the data locally as it has a considerable amount of storage and processing power. For our project, we are using the Raspberry Pi as a local interface which is capturing our sensor values which we trigger through a python program. Through the python program, we also trigger the algorithm for object detections and finally compile all sensor values into a data packet and send it to the Firebase real-time database to be stored in JSON format.

**Ultrasonic Ranger**

To understand how we connect the ultrasonic ranger to the raspberry pi, we need to first look into how it works. The ultrasonic ranger has three parts, the control circuit, ultrasonic transmitter, and receiver. But the sensor itself has four pins, namely- VCC (Power), TRIG (Trigger), ECHO (Echo), and GND (Ground). The basic functioning of the sensor is that it produces a 40KHz ultrasound wave upon calling which propagates through the air and when it hits an object in its path, the signal hits the object and bounces back (Electronicshub.org, 2018). With this, you calculate the distance with the help of the sound pulses. Since the sensor works at 5V compared to the raspberry pi which works at 3.3V, hence to avoid damage to the device we use two resistors along with the sensor to make the connections to the raspberry pi. In this case, we have utilized a 1k W and 2kW resistor joined in parallel to complete the circuit.

**BME280**

The BME280 is an environmental sensor that can sense the temperature, and humidity along with the barometric pressure with great precision and accuracy. It can be used in I2C or SPI setups. It can be powered using a Raspberry Pi as it has a 3.3V regulator soldered onto it along with a level shifter for ease in connections with a microcontroller or microcomputer. For this project, we utilized the 4 out of the 8 pins present on the sensor, namely- Vin, GND, SDI, and SCK. After connecting the sensor to the device, we used the “Adafruit Circuit Python BME280” library to capture values and receive them.

**Raspberry Pi Camera**

The Raspberry Pi Camera can capture high-definition pictures along with videos while being easy to use. It has a predefined port present on the device because of which there is no hassle in connections. For this particular, we utilized the Pi Camera library to capture the pictures to send them for object detection.

**Adafruit NeoPixel Digital RGB LED Strip WS2812B**

Since for capturing the images, there needs to be ambient lighting, we have used the Neo Pixel Digital LED strip which is powered with the help of a micro: Bit which uses batteries as its power source. The strip was manipulated with the help of MakeCode once uploaded onto the micro: Bit.

A picture containing diagram

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Figure 3: LED light strip connected to micro: bit

**4.1.2. Backend Setup**

Firebase Realtime Database offers the use of their NoSQL cloud database where the data uploaded is synced across all platforms in real-time and retains the data even if the app goes offline. The data is stored in JSON format and allows the developer to structure their data with the help of the ‘Firebase Realtime Database Security Rule’ which is flexible and can be manipulated accordingly when the data is read from or written to the database.

For our database, we configured the database to the local python code running on the device, so that the values captured could be updated on a real-time basis and, the database also was integrated with the front-end application to integrate the values of the object detected on to the same platform. The data updated onto the database was collected in two nodes, one being the ‘Most Recent’ node where the most recent values were updated and this node was used to update the values on the application, and the second node is the ‘Log’ which can be used to display the history of the parameters and items inside the fridge.

## Machine Learning

The essence of calling the fridge smart comes from its ability to identify items inside the fridge. The way this is implemented is using Computer Vision (CV) from the field of Artificial Intelligence. The camera module attached to the door of the fridge captures the image which is processed and the objects in it are then identified.

Object Detection is the subcategory of the problem addressed within the CV. This problem combines image classification and object localization. There is a subtle difference between the problems. Image classification involved the assignment of labels to whole images, and object localization attempts to draw bounding boxes around one or more objects in the image. Object detection combines the two tasks to draw bounding boxes around each object in a whole image and proceeds to assign labels to each image.

The machine learning implementation was divided into 3 steps:

1. Data Preparation – Involves data retrieval and pre-processing

2. Model building

3. API for accessing the model

**1. Data Preparation**

The data was sourced from Google images, with a web scraper code written in Python. The scraper, given keywords (grocery items of interest), queries Google images and downloads the images into a directory structure.

For object detection, since the task is more complex and bounding boxes are required, this data had to be annotated. The annotations were done using the MakeSense AI tool. The annotations involve sifting through all images and drawing bounding boxes around each of the objects. Herein also lies the justification for using a transfer learning approach. The advantage of transfer learning is that it produces good results even with a small set of images. Since each of the images needed to be annotated manually, transfer learning would give the best results with the dataset size.

After the annotations, the dataset consisted of 384 images each with an associated XML file containing the annotations of the bounding boxes.

**2. Model**

This project implements a custom object detection model built in Python using the library Detecto. Detecto is a Python package that facilitates the building of computer vision and object detection models. The package itself is built on top of PyTorch and is based on the principle of transfer learning. The model used in this project uses the Faster R-CNN ResNet-50 FPN as the base model, which is then fine-tuned and trained on a custom dataset (grocery items).

The model was trained for 60 epochs with a batch size of 5 and resulted in an accuracy of 98% on the training dataset.

**3. API for accessing the model**

To integrate the machine learning model with the physical implementation, a REST API was set up using Flask in Python. The web server resides in the cloud along with the trained ML model. It is accessed by making an API call from the Raspberry Pi.

The Raspberry Pi captures the image using the PiCamera, encodes the image into base64 format, and sends it as a String in JSON to the Flask API. On the server-side, the Flask API receives the encoded image and decodes the string to reproduce the image. This decoded image is then sent to the trained ML model to retrieve the predictions. Once the objects are detected, these detected object labels are relayed back to the Raspberry Pi as a response where the labels are then processed and stored in the Firebase database.

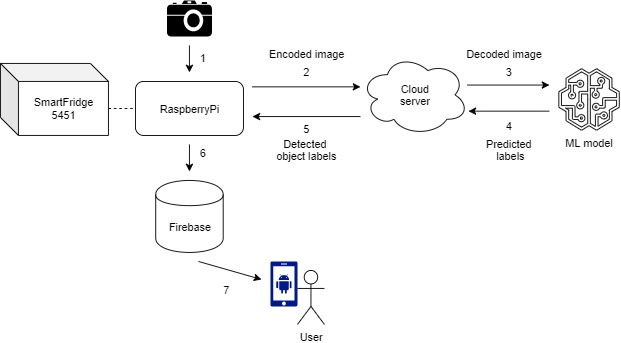


Figure 4: Workflow

## Android Application

### 4.3.1 Overview

The Android Application was developed with Android Studio using Java. The key functions in the application can be divided into two parts - data synchronization and the UI (User-interface).

Data transmission was implemented with the use of Firebase, which provides our application with an effortless way to update or obtain data from a database. UI was designed to be minimalistic and have a clean and easily readable interface, ensuring its ease of use.

### 4.3.2 Data Transmission

There are two major components for the application’s data transmission – Status and items.

1. Status

Receive the most recent log of the fridge and check its status. If the temperature or humidity is too high or too low, a notification would be sent to the user.

2) Items

Each item has the 3 following attributes: 1) Type, 2) Added date, 3) Expiry date. Whenever an item is added to the fridge, image processing is used to determine its type and the add date is automatically marked, updating the database. The expiry date for an individual item can be inputted by the user with a *DatePick* Dialog when they click on the item, and a notification would be sent to the user if an item becomes expired.

### 4.3.3 User-interface

In the UI part, we used two *CardViews* to display the temperature and humidity. Each card is a simple large square with huge fonts to ensure readability. A *ListView* is used to list all the items in the fridge. When there are exceptions (e.g., High temperature), the app will send notifications to the user when in the background, and display warning icons next to the corresponding exception when in the foreground.

Conclusion

With the rising pervasiveness in regular household objects, we have comprehensively covered another such item which has the potential of become a household favorite. We have broadly laid out the idea along with its explanation and highlighted the business model that we can undertake with this prototype. The methodology is written to explain how such a convoluted object can be made much simpler with the help of some illustrations and derived the path that we took upon in order to execute such an object. We highlighted its scope, in the competitive market of smart object, and laying out the possible marketing and advertising options.

Coming to the prototype, we have in detail explained our project in three distinct subtopics, namely- Implementation, Machine Learning, and the Android App. In this section, we have extensively explained the how we have been able to arrange and assemble the components of the device and integrated it with the backend along with the frontend. We have also provided ample description of the machine learning algorithm along with our approach and implementation for the Android Application. In conclusion, we have completed a project on how we can build we create and develop a smart fridge with the help of pervasive computing.

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Appendix

A bag on a table

Description automatically generated with medium confidence

Figure 5: Physical setup of the Smart Fridge prototype

A picture containing indoor

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Figure 6: Internal setup of the Smart Fridge prototype

Graphical user interface, text, chat or text message

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Figure 7: Local output of the device

Graphical user interface, text, application, email

Description automatically generated

Figure 8: Output on real-time database

Graphical user interface, application

Description automatically generatedA screenshot of a phone

Description automatically generated with medium confidence

Figure 9: Output on the Android application and notification from application