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Professor Chen
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Implementation and Source Code Documentation

Note to Professor: Our Github codebase is included with the submission of this document as a ZIP file.

There are numerous user benefits of our IOT Smart Fridge tracking hardware and platform. It can help save the user's money and time by allowing them to check on what is in their fridge at any time and keep track of whether or not food is expired, preventing them from purchasing things they don't need or running home to check whether or not they have a specific item. It can proactively alert the user when foods are close to expiring/about to expire to help them plan on using them or purchasing more before they run out or expire. It can keep track of fridge conditions to see whether or not their fridge is functioning properly, alerting the user to prevent mass food spoilage in the case of fridge failure. It can help users utilize the groceries they already have through recipe suggestions via ChatGPT powered recipe suggestions. It allows the viewing of collected information in a convenient and easy to use app, which also allows for corrections in the case of misclassified/unidentified items.

The current status quo to the problem of fridge tracking includes many solutions, most of which are not perfect or accessible to most people. For starters, a user could keep a mental list of what items they have in their fridge at home. This is what most people do; however, people are bound to forget every item they have/do not have and can often end up purchasing duplicate items leading to more food waste, or not purchasing something they actually need, resulting in disappointment or frustration. Beyond this, a user could manually track their current stock of groceries with a spreadsheet/note on their phone. This requires substantial user effort, which most people are not willing to put in as it is quite inconvenient and involved, with the potential of mistakes or missed items. If users want a solution similar to what we are providing with our IOT Fridge Tracker, they have the option of purchasing a dedicated Samsung Family Hub smart fridge with built-in item tracking capabilities similar to our own solution. However, this is an extremely cost prohibitive solution, with users not only needing to buy a new fridge, but pay 2 to 3 times the cost of an equivalent non-smart fridge for these capabilities; most people will not purchase a new fridge just for this one feature, or even be willing to pay extra to obtain these features versus saving thousands of dollars when purchasing a fridge they need.

There are a few prior arts in the food tracking space. Two of the biggest players in this space are Samsung, with their previously mentioned Smart Hub smart fridge, and Amazon with Amazon Go.

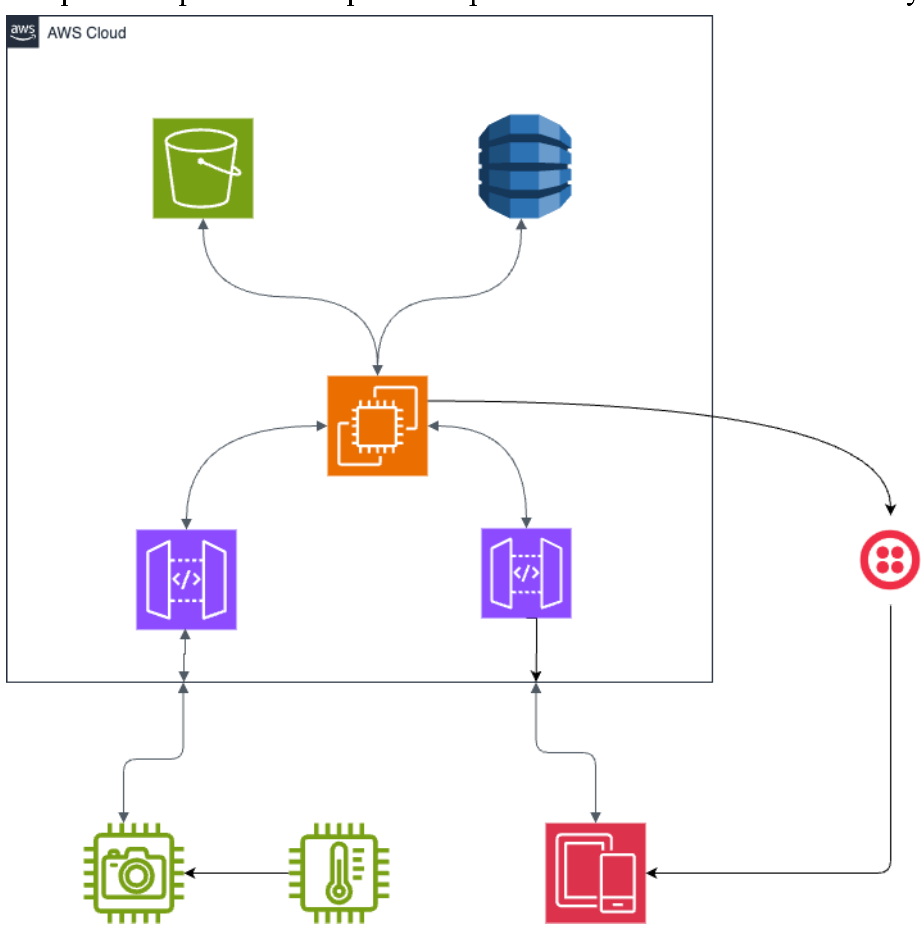
The Samsung Family Hub smart fridge has been around for many years, and in 2018 Samsung released a newer iteration of the fridge with additional capabilities; namely, IOT capabilities such as live fridge viewing and smart food recognition. It can automatically generate a list of the groceries currently in your fridge. However, the main drawback with this device is that it is extremely expensive. Most users are not willing to purchase a new fridge just to add this feature to their lives. Additionally, when people are in the market for a fridge, most would rather save a few thousand dollars instead of paying extra for a few convenient features. It is price-prohibitive for the vast majority of users.

Amazon Go is an IOT-ran store with no cashiers, relying on an array of sensors to track individual people and the items they pick up in order to charge them for their purchases. It relies on thousands of cameras, RFID sensors, weight sensors in shelves, and facial recognition alongside other biometric authentication methods in order to keep track of who is in the store at any given time and what each individual takes. This is a very cool concept and works well. However, it requires a very large investment of sensors as well as enormous amounts of data processing in order to run the store. Implementing this technology on a smaller scale in someone's fridge would require tons of work for the end user, or potentially an even larger investment than something like the Samsung Family Hub.

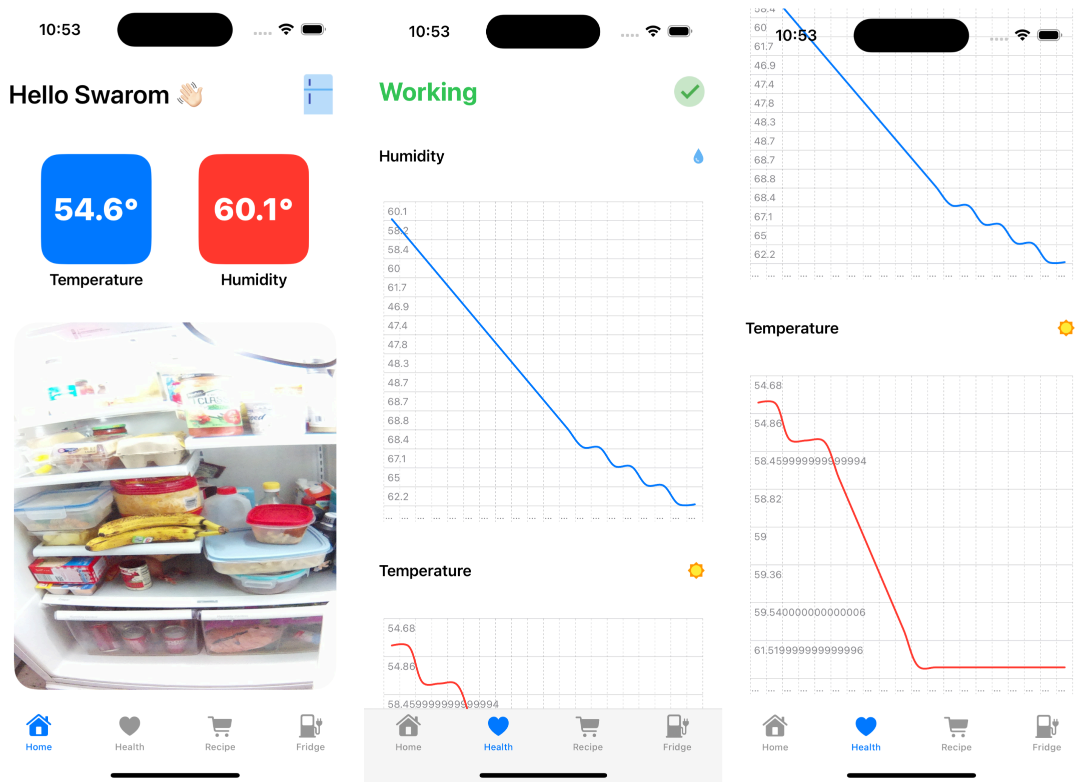
Our implementation seeks to solve the fridge tracking problem in a new way, applying many of the features and principles used in these prior arts in a much more affordable and user-friendly way. Our hardware prototype costs less than $100, which includes a Raspberry Pi, camera, temperature and humidity sensors. With just these cheap hardware components, alongside cloud-based image recognition and data processing, users can achieve all of the features offered by the Samsung Family hub and more at a much lower price. Moreover, our solution is designed to be fridge-agnostic, which allows users to take advantage of this solution regardless of what fridge they have at home already.

Our final solution is composed of a Raspberry Pi with an attached serial camera as well as a temperature and humidity sensor placed inside the user's fridge Using image recognition, the device adds items to our cloud database as groceries are added to the fridge. Our cloud server keeps track of date and time the items were added and calculates their expiration date from public expiry data as well as the condition data from inside the fridge. The item information is stored in a database; database entries and sensor data are viewable from our app with the added ability to be edited by the user in the case of incorrectly categorized or unrecognized items.

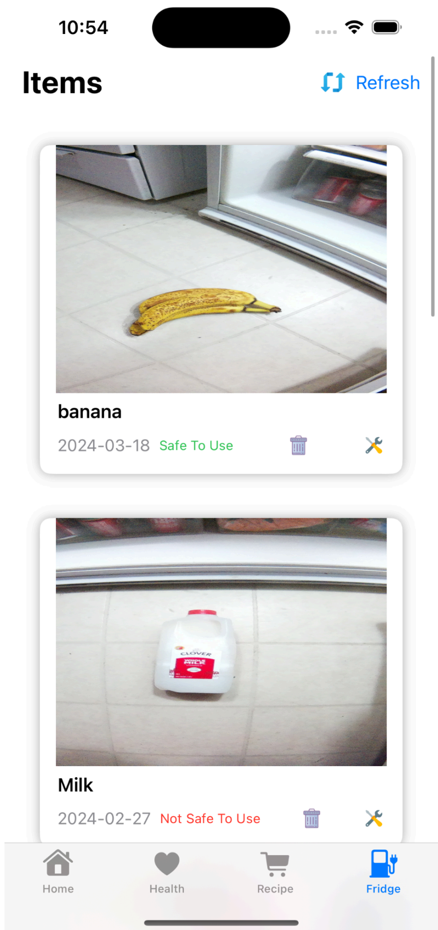
Digging into our hardware and software specifics, we utilized a Raspberry Pi 4 with an attached SMRAZA CSI Camera. It is 5MP allowing for good enough quality for image classification while not requiring too many resources to process, and it also features a 160-degree FOV to allow close placement to items in the user's fridge without compromising on the available image framing. It also features an adjustable focal length to fit the user setup. Our temperature and humidity sensor is a DHT 22 sensor. It takes up only 3 pins on the Pi, and was extremely simple to implement into our software. In terms of the backend functionality, our Raspberry Pi device communicates to our web server to store information and communicate with mobile devices. The user's mobile device will communicate with our public API via our app to retrieve their fridge's stock and condition information. We utilized an AWS EC2 Linux Server for our backend processes, which runs a Flask Server for API endpoints. It also periodically runs a cron job in order to keep the device connection alive and check the expiration date list in our database in order to verify whether or not the user needs to be alerted about expirations. We used a DynamoDB NoSQL database to store all of the fridge state information. All photos are kept in an S3 Bucket that the EC2 instance has access to. In order to notify the user, we utilized Twilio, a low-cost and easily accessible SMS notification service. We also took advantage of OpenAI's API in order to power our recipe suggestions service, which takes the list of items currently in a user's stock and provides potential recipes to help the user use their food effectively.

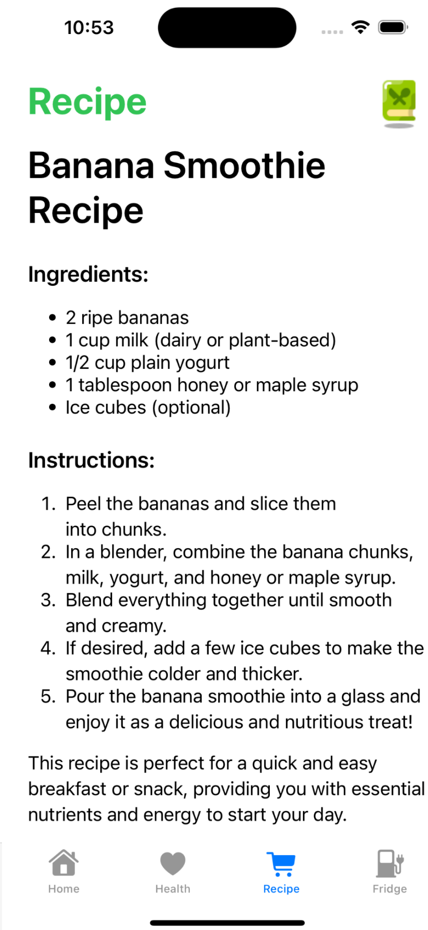


The results of our implementation were successful, given the scope of the project and the limited time we had to complete it. Below are a showcase of some screenshots from our app, showing various features we completed:



In the leftmost screenshot is our home page, which provides the user with the most recently captured image of the inside of their fridge, along with the current temperature and humidity conditions. The middle and right screenshots illustrate the temperature and humidity graphs, allowing the user to see at a glance whether or not their fridge is working properly, or if it has been degrading over time. The conditions in these screenshots are not representative of what an actual fridge would show, as the sensor was not installed correctly. The graphs are displaying test data.





Next are our item tracking and recipe generation pages. The leftmost screenshot shows the captured images of items added to the fridge, along with their classified names and expiration dates, which also indicate whether or not the expiration date has passed for a better user experience. The expiration date is also affected by the temperature in the fridge. If the temperature increased above a certain threshold the counter for that specific item would be increased, depending on the item each counter had a specific limit and once this limit was surpassed it would mean the item was expired.

The rightmost screenshot shows our recipe suggestion feature. At the user's request, the OpenAI API is queried, fed with a list of what is currently in the user's fridge. It then returns some potential recipes that can be made with items currently in the fridge, helping users use all of their groceries.

After completing the project and implementation, our team had a few key learnings from our work together. Originally, we wanted to implement ML algorithms to allow for more accurate expiration date prediction, but instead opted with a rule-based algorithm, as we found that we had a lack of training data to successfully implement this algorithm. We discovered that open-source image classification models have limits due to poor quality or quality of training data, making it difficult to find one that works perfectly in a wide variety of environments with our camera. Additionally, we learned a lot about configuring security with cloud computing and ensuring our edge devices have appropriate permissions in order to enforce the security policies we enacted.

If we had more time, and the scope of the project was larger, we would have many ideas for things we could work on in order to improve our solution. First off, we would want to train our own custom food recognition model with multiple fridge and camera combinations for better accuracy. We would implement an ML algorithm for expiration date calculation by gathering lots of data to enhance its accuracy. We would enhance our equipment for durability and its setup in the fridge through the use of custom enclosures and mounting hardware for the device and sensors, as well as to provide easy camera pivoting and display viewing while the device was being used. We would like to find a hardware solution to automatically capture an image upon the fridge opening or closing in order to automate the fridge image capture process, making it more convenient for the user. Lastly, we would test the system in a wide variety of fridges to gather data on the ideal temperature/humidity sensor placement and camera placement for best possible accuracy. This would allow us to inform the user on how to set up the device for the best accuracy and user experience, regardless of the type of fridge they own.