Low-Cost Smart Refrigerator

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***Abstract*— This paper presents Smart Home concepts for Internet of Things (IoT) technologies that will make life at home more convenient. In this paper, we first describe the overall design of a low-cost Smart Refrigerator built with Raspberry Pi. Next, we explain two sensors controlling each camera, which are hooked up to our Rasberry Pi board. We further show how the user can use the Graphical User Interface (GUI) to interact with our system. With this Smart Home and Internet of Things technology, a user-friendly graphical user interface, prompt data synchronization among multiple devices, and real-time actual images captured from the refrigerator, our system can easily assist a family to reduce food waste.**

Keywords: Internet of Things (IoT); Smart Home refrigerator

I. Introduction

Each year, according to United Nations Environment Programme, around 1.3 billion tons of food is wasted [1]. Much food waste comes from restaurants, from stores, and from homes [3]. However, little has been said about the food waste that comes from the consumer's refrigerator, such as forgotten leftovers or expired ingredients. In general, we put food into a refrigerator to make it last longer. Most home cooks remove ingredients from the refrigerator to cook meals, and then return the leftovers to the refrigerator. However, some food is forgotten or goes uneaten due to personal taste. Consumers also throw out food to clear space for fresher options.

Fortunately, with the rapid growth of technology and the Internet, a number of companies have proposed ideas for the smart home technologies, such as smart refrigerators [4,5,2] that can manage a food supply, pet pet care systems [12], e-Healthcare applications [6], or home automation system [13]. However, the prices for such smart refrigerators were too high, making them unpopular with middle-class families.

To solve this problem, we propose in this paper a cloud-based smart refrigerator based on an open-source, low-cost hardware architecture. The proposed system is designed to make it convenient for users to input food data, and can be added to refrigerators currently on the market. Our system has two cameras for users to capture images of food: an outer camera for food being brought in from outside and an inner camera that enables users to keep track of the food in the refrigerator. In addition, the system includes an Android application that lets users easily check a grocery list from their mobile devices.

II. Related Work

In 2013, Samsung announced the production of a smart refrigerator with an LCD screen, known as the T9000 [5]. Although it was still a prototype, the LINUX-based system inside the refrigerator contains several amazing functions, such as Samsung's smart home applications, Google calendar applications, and Evernote applications. The prototype allowed users to use Evernote as a cloud-based service to create ingredient lists and shopping lists, which could be accessed from any compatible device.

Three years later, Samsung released a new kind of smart refrigerator at CES 2016 [6]. With a 21.5-inch touchscreen and a built-in camera, Samsung's Family Hub is the latest model of smart refrigerator. In previous models, users still needed to manually enter the list of foods, leading to fatigue when users grew tired of typing. This new model both solves that problem and adds a built-in camera that allows the user to check the actual image inside the fridge with a smartphone. The Family Hub also allows users to access e-mail, browse photos, or watch television using mirror-casting. By naming the new product the Family Hub, Samsung is trying to give their product a central role in the household.

However, there are still a few problems like:

- *High price*. The lowest price for a Family Hub on Samsung's official website is USD $5599.99, which is obviously too expensive for an average family.
- *Built-in hardware.* In previous designs, the touchscreen was installed inside the refrigerator. Thus, when the refrigerator is broken, the whole refrigerator has to be sent back to the manufacturer to get fixed.
- *Customization.* Besides Samsung, LG also has a built-in application for one of its refrigerators [7]. However, users can only use the applications released by their refrigerators' vendors. Some old models have stopped updating their applications.
- *Management*. Various products use barcode scanners to add new items. However, this is less convenient than it sounds, especially in Asia, where traditional markets sell food without barcodes. Forcing users to manually type in names wastes a great deal of time.

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III. System Overview

In this paper, we use an open-source hardware platform to develop our cloud application, which allows the sensors to communicate, and the data to be synchronized from multiple devices at any time, as shown in Figure 1.

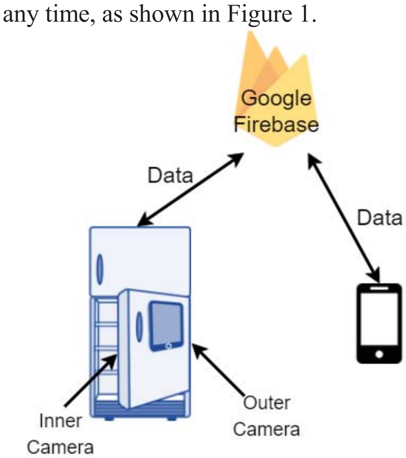

Figure 1. Overall System architecture

In Figure 1, users first mount a Raspberry Pi device with sensors and cameras on the refrigerator, and then download the Android app onto the appropriate mobile devices. Both the inside and outside modules contain sensors, each with a camera. The inside camera will be triggered when the door is open, which allows the user to see the image from the last time the door was opened. The outer camera makes it easier for users to enter new food data by simply placing the food item close to the camera to be captured. With both built-in sensors, users can check their food stock from the captured images or from the list of food item. As mentioned in the introduction section, not every food item can be tagged or named precisely; thus, we provide both mechanisms for users to keep track of the contents of their refrigerators.

The Android application allows users to check their food lists anytime, anywhere. Firebase, a cloud service provided by Google, allows users to synchronize data on multiple devices. User data will be stored on Firebase's Real-Time Database, and synchronized within seconds once any data has been modified, inserted, or deleted. Firebase also supports iOS and Raspberry Pi, which allows the project to easily add new features.

A cloud platform is a simple way of storing and synchronizing data that plays an irreplaceable role in the Internet of Things (IoT). With this Smart Home and Internet of Things technology, a user-friendly GUI application, cloud-based services, and real-time captured images from the refrigerator, users can easily keep track of their food supplies from any device at any time.

IV. Hardware Design

This section discusses the hardware design of the main control board. Figure 2 demonstrates the hardware design between Raspberry Pi and the two sensors.

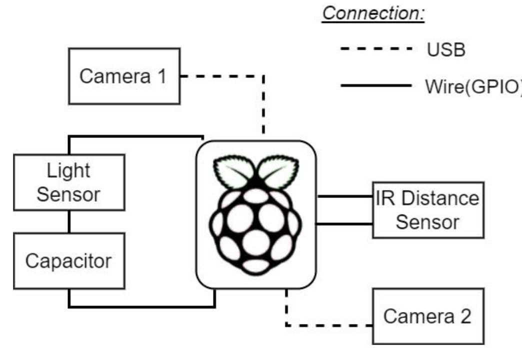

Figure 2. Hardware design of Raspberry Pi

Our system uses Raspberry Pi 2 Model B V1.1 as the main board (Figure 3), which contains an HDMI output for the touchscreen, 40 GPIO pins for the two sensors, and USB ports for the Wi-Fi adapter and two cameras. Since the original model of Raspberry Pi has no built-in wireless adapters, we added a XiaoMi USB Wi-Fi adapter for the Wi-Fi features. In addition, we added two Logitech HD C525 webcams to the system. There are two reasons why we choose to use webcams. The first reason is because webcams can adapt to a variety of refrigerator designs, hooking onto the refrigerator with the camera pointed at whatever angle is most convenient. The second reason is based on the limitations of the CSI interface available for the Raspberry Pi. Since each board can only install one CSI interface camera by default, it is easier to use two webcams rather than building a customized chip that contains multiple CSI interfaces.

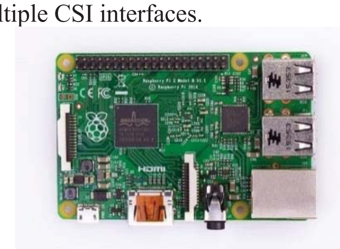

Figure 3. Raspberry Pi 2 Model B [8]

For inside the refrigerator, we installed a light sensor to detect whether the door is open or closed. The required materials for this model are: one light sensor (Figure 4) and a capacitor. The light-sensor model was designed to read the light degree and to control the camera. When the refrigerator door is opened, the light degree increases. This is because when the light degree changes, rather than directly raising the electric current, it will lengthen the response time and slow down the bandwidth, raising speed. We then used this feature to determine whether the refrigerator door was open or not. If the value rises very high, it will trigger the inner camera and capture an image of the refrigerator.

For the outside of the refrigerator, we designed a distance-measuring sensor with another camera. Both camera and sensor face down, allowing users to automatically take pictures of food. The distance-measuring sensor we used for the system is a SHARP GP2Y0A41SK0F (Figure 5), which is an infrared proximity sensor that can detect objects within 4 to 30 cm. Similar to the light sensor, its output voltage drops when it detects an increase in distance. In other words, when an object approaches, the output voltage will increase up to 3 volts, allowing us to trigger the camera when it reads an increased output voltage. To avoid triggering the camera every time an object approaches by accident, the distance-measuring sensor will only work when the software program starts the detection, as described in the software design section.

Figure 4. Light sensor [9]

Figure 5. Sharp IR distance measuring sensor [10]

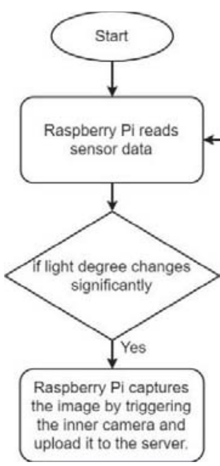

Figure 6. Process of light sensor triggering the camera

The 7-inch touchscreen in this system has an 800*480 resolution and is manufactured by Waveshare[11]. Compared to Raspberry Pi's official touchscreen, the Waveshare model is less sensitive, but it is a good choice for a reasonable cost. With both 7-inch size, the official touch screen from Adafruit is USD $79.95, but the touchscreen from Waveshare only costs USD $55.99.

V. Software Design

We first discuss how we use Raspberry Pi to communicate with then sensors, and then explain our Android GUI for the system.

A. Light sensor and distance-measuring sensor

Figures 6 and 7 illustrate how both sensors trigger the camera. Both processes were designed to first read the sensor data, and then trigger the camera whenever needed. The light-sensor program will keep running in the background after the device starts, and each time the user opens the door, the camera will be triggered. Thus, the distance-measuring sensor will only start when the user has requested access to the food data, preventing the system from accidentally triggering the camera.

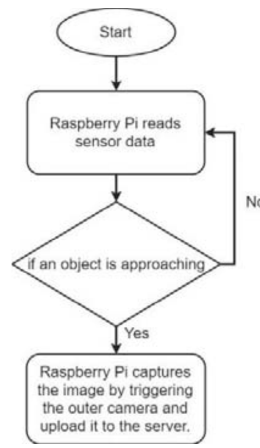

Figure 7. Process of distance sensor triggering camera

B. Raspberry Pi GUI

The overall design of the Raspberry Pi GUI is similar to the Android GUI. Users can select items from a listed view. A calendar-based view allows users to check expiration dates within the current month. When the user wants to insert new items, the system will trigger the outer camera with the distance-measuring sensor.

C. Android GUI

Our Android GUI application is compatible with Android 5.0 Lollipop or higher for API level 21. The API was based on default settings from Android Studio SDK tools. Figure 8 illustrates the Android GUI, tested on a smartphone with Android version 6.0.1 Marshmallow. The interface is a simple listed view of the food list. Users can simply check the current food stock, including quantities.

Figure 9 illustrates the interface of the refrigerator's actual image, captured from Raspberry Pi. Users can directly check the actual image and its latest update time from their refrigerator in the application

Figure 8. Android listed view GUI

Figure 9. Android refrigerator view GUI

VI. Conclusion and Future Work

In this paper, we presented a low-cost smart refrigerator, which presents Smart Home concepts with Internet of Things (IoT) technologies for reducing food waste and facilitating more convenient living at home. Our Android application provides real-time updates even when the user is outside the house. The Raspberry Pi system allows users to easily enter new food information by taking photos of the food, or to check the images that were captured from the inside the refrigerator. With a cloud-based service, data captured from Raspberry Pi can be easily synchronized and accessed between multiple devices. Furthermore, since the system can be attached to a traditional refrigerator, users can easily build their own low-cost smart refrigerators and manage their food supplies from any mobile device.

In the future, we plan to install more sensors on the Raspberry Pi and try other power supplies that are more convenient and eco-friendly for reducing the need for an extra plug for the system. Moreover, we plan to extend our system and apply it to other smart home applications, such as applying it to monitoring cabinets, drawers, or even living rooms.

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