ECS725P Mobile Services

Smart Kitchen System

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INTRODUCTION

Food tracking technologies like MyFitnessPal and digital scales have significantly improved the ability for individuals to monitor their dietary intake and make more informed choices about their nutrition. (Jung et al., 2020) However, these technologies come with limitations, primarily in the form of user burden. Users are required to manually input food items into apps like MyFitnessPal, which can be time-consuming and prone to error. Additionally, digital scales, while accurate, require users to weigh each ingredient separately, adding complexity to meal preparation. (Jung et al., 2020) (Bracken & Waite, 2020) The solution would be to integrate advanced tracking capabilities seamlessly in the user's environment, greatly reducing the amount of user input needed to complete a daily food log. A Smart Kitchen equipped with sensors and optical recognition technology to weigh and track calories would eliminate much of this user burden. By seamlessly integrating into the cooking process, these advanced systems would automatically recognize and quantify ingredients as they are used, providing real-time feedback on nutritional content without the need for manual input or separate weighing. This would not only streamline the food tracking process but also empower users to make healthier choices effortlessly, ultimately leading to improved dietary habits and overall well-being.

SYSTEM CONCEPT

SYSTEM AIMS

Kantz's Activities of Daily Living involve routine activities such as eating and drinking. Real-time monitoring of ADLs can promote dietary control and potentially reduce risk of obesity or other health issues. (Luo et al., 2019) Bonaccio et al. (2013) found that increased nutrition knowledge is associated with a lower potential of obesity. A commonly proposed solution to increase nutrition awareness in ubiquitous computing studies is the development of a smart system. In Chen et al. (2008)'s ‘Calorie Aware Kitchen’, the study found that users of the nutrition tracking system had less total calories compared to their recommended intake, suggesting that an increased nutritional awareness can impact a user’s energy balance. (Chen et al., 2008) This project’s proposed Smart Kitchen builds on Chen et al.’s work. It aims to automate the way users track their nutritional intake and improve nutritional awareness amongst its users. The system will integrate sensor technologies seamlessly into the kitchen environment to provide users with real-time calorie and macronutrient information of meals prepared.

SYSTEM OVERVIEW

The system will consist of sensors placed where cooking occurs: weight and barcode sensors in the counter and stovetop and CMOS sensors positioned above stovetop hood. When a user begins preparing food, the system automatically tracks the nutritional content of the ingredients used. Weight sensors measure quantity, CMOS sensors capture images of the items used. These sensors work in conjunction in order to retrieve nutritional information from the system's backend database. If the item being tracked is a packaged food, a barcode sensor is used concurrently with the CMOS sensor.

In the backend database, the system stores nutritional information about food items. This includes information about the macronutrient composition of various ingredients and packaged foods such as calories per gram, carbohydrates, fats, sodium, protein, iron, zinc, and other vitamins and minerals. It also includes unique identifiers for specific food items such as names, descriptions and barcode data. This data is sourced from established databases like FoodData Central and third-party APIs like CalorieNinjas to provide users with a comprehensive repository of nutritional data. The database does not store any personal information about the user’s dietary restrictions or allergens; its primary focus is on data retrieval. When a user scans a barcode, the system retrieves nutritional data associated with that specific product from the backend database. This data is then integrated with information collected from other sensors, such as weight and CMOS sensors, to ensure accurate tracking of the user's nutritional intake. In the system, Total Daily Energy Expenditure (TDEE) is calculated using an algorithm based on the Harris-Benedict Equation. This equation calculates the Basal Metabolic Rate based on age, gender, height, weight and activity level. The Basal Metabolic Rate is calories burned by a human body at rest. For accuracy, the system incorporates additional activity data from connected pedometers to account for a user’s physical activity. Pedometers track steps taken, distance travelled and stairs climbed. The resulting data is used in the Harris-Benedict Equation. Through combining the BMR and activity level, the system outputs a user’s TDEE value. This value serves as a baseline for a user’s daily caloric intake. By displaying the TDEE alongside daily calorie count on the LCD tablet display, users can make informed decisions about their dietary goals, track their progress and make adjustments to their routine when necessary.

Users can access this information via a LCD tablet display installed in the kitchen. Beyond tracking, the system has a ‘Previous Logs’ and ‘Reccomender’ feature, where it can recommend lower calorie alternatives based on previous logs. The system also displays TDEE calculation from data manually inputted by the user.

RESEARCH AND REQUIREMENTS

USE CASES

Use Case Name: Track Nutritional Information
Actor: User
Description: Users utilise the system to track the nutritional content of homemade meals and/or prepackaged foods.
Precondition: All sensors are functioning. The user has access to the system and is prepared to track their food.
Normal Flow
1. The user begins food preparation by placing a food item on the counter.
2. The system automatically tracks the nutritional content of each ingredient using integrated sensors.
3. The system collects data on the nutritional values of the ingredient from its database.
4.Once prompted by the user that a meal is completed, the system aggregates the nutritional data of all ingredients to provide a total calorie count and nutrient profile for the meal.

Exception Flow: At Step 2, sensor error
2.1 System detects an error with one of the sensors during ingredient tracking.
2.2 System fails to log the nutritional content of the ingredient.
2.3 System prompts the user to manually input missing information.

Exception Flow: At Step 3, unidentifiable ingredient
3.1 System cannot match the CMOS sensor capture or the barcode scan to an item in its backend database.
3.2 System prompts the user to provide additional information or choose an alternative ingredient from the database on the LCD tablet.

Postcondition: Nutritional data for each meal is accurately logged and stored in the system.

Use Case Name: View Nutritional Information

Actor: User

Description: The user accesses the LCD tablet display to review a summary of their daily or weekly calorie intake, including detailed nutritional information.

Pre-condition: The user has interacted with the system to track calorie intake and all required sensors are functioning.

Normal Flow:
1. The user accesses the LCD tablet display.
2. The system presents an overview of the user's calorie intake on the LCD tablet, broken down by meals and snacks consumed throughout the day or week.
3. The system provides detailed nutritional information on the LCD tablet for each meal.

Alternative Flow: At step 2 after the uses accesses the LCD tablet Display
1.1 System detects a faulty sensor

1.2 System informs the user of the faulty sensor and prompts the user to reattempt accessing the LCD tablet

Exception Flow: At Step 2, connectivity issues
2.1 System detects connectivity issues between the LCD tablet display and the system's backend database
2.2 System displays an error message to the user and provides guidance on re-establishing a connection.

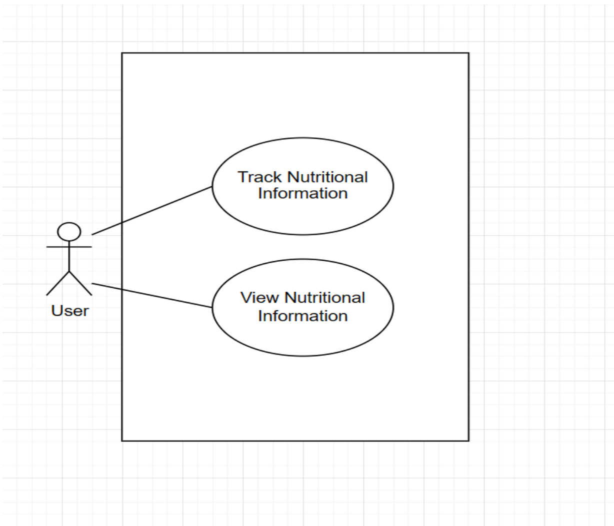

FIGURE 1: Use Case Diagram

REQUIREMENTS ANALYSIS

To support the use cases, we require the following:

FUNCTIONAL REQUIREMENTS

- *Sensor Data:* The system must seamlessly incorporate data from sensors (weight sensors, CMOS sensors, barcode sensors) to automate ingredient tracking and calorie logging.
- *Calorie Count:* The system needs to be capable of calculating calorie count for a food item given its weight. It needs to be able to provide users with the total calorie content of a meal based on ingredients used and their respective weight.
- *Nutritional Profile*: The system should be able to provide, once an item is detected, detailed nutritional information (i.e macronutrient profile) of a given ingredient in a meal.
- *Barcode:* The system should allow users to log snacks or packaged foods using barcode, and add append to their meal log.
- *Log:* The system needs to record the data of food weighed in a log for total daily intake count.
- *Data Processing:* The system needs to have sufficient capacity to hold and process data.

- *Recommendations:* The system must be able to analyse the calorie count of stored ingredients, and make recommendations for high calorie (> 250 kcal per 100g) and low calorie (<50 kcal per 100g) ingredients when prompted by the user.
- *Nutritional Information:* The system needs to display daily or weekly overview of their caloric intake, macronutrient distribution and level of adherence to given nutrition goals.
- *LCD Display:* The system must have the capacity to store and process data from various sensors and display them on an LCD tablet for users to view nutritional information.
- *Integration with Nutritional Tracking Apps:* The system must integrate seamlessly with various nutritional tracking applications to enable users to synchronise dietary data between the smart kitchen system and their preferred tracking app.
- *Pedometer Connectivity:* The system must allow seamless communication between pedometers/ fitness trackers and the LCD tablet to facilitate the transmission of activity data.
- *Pedometer Data Synchronisation:* The system must ensure that activity data from pedometers is synchronised with nutritional tracking features.

NON FUNCTIONAL REQUIREMENTS

- *Reliability:* The system must be reliable to ensure accurate counting and logging of food items without consistent error.
- *Usability:* The system must provide a user-friendly and intuitive interface to encompass users of all skill sets and ability.
- *Performance:* The system must provide information quickly with minimal latency to users.
- ***Compatibility**:* The system must support interoperability and allow for integration with other services such as fitness trackers and nutritional databases.
- ***Maintainability**:* The system should provide regular system updates without increased downtime or cost.
- ***Compliance with NHS guidelines:***The system will enforce a minimum daily calorie intake of 1000 calories per user, aligning with National Health Service (NHS) guidelines.

HARDWARE REQUIREMENTS

Sensors are a type of transducer that converts heat, light, sound, weight and so on into electric signals.(Poslad, 2011) They can be used to monitor environments and detect changes within an environment.

WEIGHT SENSOR:
Weight sensors, also known as load cells, are installed beneath the countertop and stove top to measure the weight of ingredients and food items. Load cells convert force into an electrical signal, providing accurate weight measurements for calorie counting and nutritional tracking purposes. They are made up of a metal structure with strain gauges (Proctor, 2022). A load cell detects force by converting it into an electrical signal. It includes a metal structure, known as the spring element, that deforms under force. This deformation is detected by a strain gauge attached to the spring, converting it into an electrical signal.

(Proctor, 2022) These sensors ensure seamless integration into the smart kitchen infrastructure, delivering real-time weight data for nutrition tracking.

CMOS SENSOR:

CMOS sensors are placed above the counter and stove top to capture images of food ingredients during meal preparation. CMOS sensors offer low power consumption and flexibility, with customizable features such as pixel arrangements and sensitivity levels. (Ohta, 2020)

BARCODE SENSOR:

Barcode sensors are integrated into the counter and stove top surfaces to scan prepackaged food items using common barcode formats such as EAN-13 and GS1. (GS1, 2020) Barcode sensors provide accurate identification of prepackaged and processed foods.

MICROCONTROLLER:

A microcontroller serves as the “programmable” core of the smart kitchen system, facilitating sensor integration, data processing, user interaction, system control, and communication. (Poslad, 2011) In this system, the Arduino Uno R3 microcontroller was chosen for its support of sensors, ease of use, cost-effectiveness, and compatibility with various programming languages. (Hadwan et al., 2016)

LCD TABLET DISPLAY:

The smart kitchen system incorporates a high-resolution touchscreen LCD display for user interaction and data visualisation. The tablet serves as the primary interface for accessing nutritional information for the user. It is connected to other system components via Bluetooth.

SOFTWARE REQUIREMENTS

BLUETOOTH CONNECTIVITY

Bluetooth technology will be utilised to establish short-range wireless connection with external devices relevant to the system such as fitness trackers and mobile phone nutrition tracking applications. For users who want access to their nutrition log on their phones, Bluetooth can be used to send data from the Smart Kitchen to tracking apps such as MyFitnessPal and Cronometer.

PROGRAMMING LANGUAGES

1. Embedded C/C+: C or C++ are used frequently in the programming of microcontrollers like Arduino. C is a popular system programming language that has minimal execution time on hardware in comparison to other high-level programming languages. (Agnihorti, 2021)
2. Python: Python is chosen to perform complex calculations such as calorie counting. Libraries such as scikit-learn, NumPy and Pandas can be used for data processing and analysis. Furthermore, it will be used to implement the Harris-Benedict equation used to output a user’s TDEE.

DATABASE MANAGEMENT SYSTEMS (DBMS)

Oracle will function as the primary DBMS for the Smart Kitchen system. It provides a comprehensive relation database management solution for our system to enforce proper data storage, management and retrieval within our Smart Kitchen.

CURRENT STUDIES

Sufficient literature exists to support the advantages of diet tracking technology over traditional methods. (Hassannejad et al., 2017) There have been technological advances in the collection and processing of dietary information, with mobile application food trackers like MyFitnessPal and Cronometer. However, digital food diaries still rely on manual user input and self reporting. (Jung et al., 2020) (Bracken & Waite, 2020) (Evenepoel et al., 2020)

Weiber's vision for ubiquitous computing states that in a smart environment, "computation is seamlessly used to enhance ordinary activities." (Coen, 1998) (Poslad, 2011) This means that the presence of technology in an environment does not intrude on the users of that environment physically.(Cook & Das, 2007)Newer technologies utilising wearable and non-wearable sensors offer a more passive means to measure food and drink consumption. They provide convenience for users to complete daily food logs. (Vu et al., 2017) There is a delicate balance between diligent monitoring and intrusive surveillance. In a study assessing the efficacy of sensor-based devices in monitoring food intake, Wang et al. (2022) uncovered a notable discrepancy: a considerable portion of these devices fell short of meeting the feasibility criteria necessary for aiding in dietary assessment. This shortfall stemmed from the fact that wearable sensors faced challenges in achieving widespread acceptance due to their perceived lack of social acceptability and discomfort during prolonged wear. (Wang et al., 2020) The study's findings underscored the necessity for discreet prototypes capable of integrating seamlessly into the physical environment.

To avoid dietary panopticons, a dietary feedback system has to be able to autonomously measure in a way that minimises user effort. This can be done conveniently and unobtrusively with at least one sensor measuring quantity and one classifying the food. A practical example of this would be through sensor technology. (Poslad, 2011) Sensors can be integrated into the kitchen to determine the weight of food, scanners can scan packaging of processed food items with barcodes and output the calorie count and amount of fat, salt and sugar consumed per meal. (Poslad, 2011) In 'Health to Eat: A Smart Plate with Real-Time Food Recognition, Classification and Weight Measurement for Diabetic Patients', Joshua et al., (2023) implemented a "Chenbo load cell weight sensor (1 kg), an HX711 weight weighing A/D module pressure sensor, and an IMX219-160 camera module (waveshare)" to track the calorie and macronutrient profile of foods. (Joshua et al., 2023)

Sensor technology has been widely adapted in prior studies. (Chang et al., 2006) (Mankoff et al., 2002) (Beaudin et al., 2006) Chang et al. present the 'Diet-Aware Dining Table' which tracks what and how much users eat on the dining table and then provides nutritional information. (2006) Mankoff et al. (2002)developed an application that tracks the nutrition of foods users have purchased and suggests healthier foods on the basis of an analysis of shopping receipt data. Primarily, this project is an expansion of the work of Chen et al. (2008)'s Calorie Aware Kitchen. However, the Smart Kitchen aims to improve upon the limitations present in the Calorie Aware Kitchen. (2008) The study found its participants expressed a strong desire to receive recommended values based on her family's nutritional needs. This recommendation would not only give her a nutritional target but also help her comprehend the displayed nutritional information. As such, this project has implemented a recommender system for low calorie food items (less than 100 kcal per 100 grams). Whether the user adopts the lower calorie alternative is not the job of the system. This recommender system builds on Mankoff et al.'s key principle of an "informed veto." The user is presented with an alternative or substitute the system believes is better to allow the user to make an informed choice based on their goals.

Chen et al.'s Calorie Aware Kitchen (2008) is also constrained to home cooked meals. In the proposed system, a barcode scanner is implemented for prepackaged and processed foods. This project also involves integration with mobile applications and fitness trackers. This removes another layer of "user burden" and lessens the "benefit-to-cost ratio" present in the Calorie Aware Kitchen prototype. Chen et al,., (2008) found that outside the cooking process, the system has reduced benefits for the user. By allowing the Smart Kitchen's output data to be sync to fitness tracking apps like MyFitnessPal the user can access the Smart Kitchen output outside of the physical environment. Thus, integration with nutrition mobile apps increases the convenience for the user. A sample use case is as follows: the user could use their chosen nutrition tracking app for meals eaten outside the home and then use the Smart Kitchen system for meals eaten at home for a comprehensive outlook on their daily intake. The Smart Kitchen would provide the tracking app with its aggregated information, increasing convenience and accessibility for the user.

DESIGN

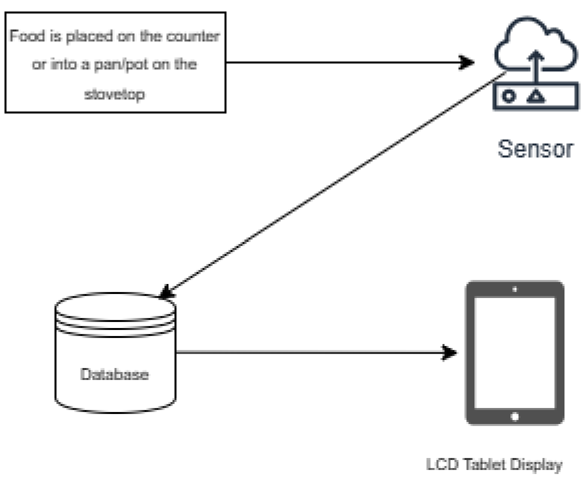

Figure 2: A Graphical Representation of the Smart Kitchen System.

The design requirements of this project aim to improve existing systems found in current literature. To increase the nutritional awareness of its users, the system will first measure what food is being prepared or consumed. Secondly, the system will provide dietary feedback. To improve on existing studies, the system must further reduce the "benefit-to-cost' ratio as defined by Chen et al. (2008).

MEASURING FOOD INTAKE

Our system attempts to achieve these specific aims:

1. The system must reduce user effort via autonomous measuring of food items.
2. The system must be as unobtrusive as possible so it can be better integrated into the user's long term routines.

Weight sensors are an effective mechanism for measuring quantity. In this Smart Kitchen system, a load cell is used to measure weight. Measuring what type of food is being prepared presents a greater challenge than weight. Chen et al. (2008) suggest computer vision as a solution for future studies. However, computer vision is expensive. Radio Frequencey Identification (RFID) is another solution that has been adopted in previous studies kike the 'Diet Aware Dining Table' by Chang et al., (2006). There are two disadvantages to RFID: it is expensive and cannot be used effectively for whole foods that are often ingredients of a larger meal. Adopting barcode sensors is not only the more cost-effective and widely used option, it allows the proposed system to include prepackaged and processed food, which is an improvement on older solutions. For measuring what type of food is being prepared that is whole/fresh, implementing a CMOS sensor is the more cost-effective solution. WiFi is used for communication between the sensors in the Smart Kitchen. For the exchange of data from the counter to the sensor, it provides high-speed data transmission necessary for real-time updates. HTTP is the protocol used for data transmission that allows the Smart Kitchen to send requests and receive responses over the network, ensuring secure and seamless communication. The specific WiFi technology chosen for the system is 802.11ac, as it provides fast communication, low latency, and is one of the most commonly used WiFi standards in modern consumer devices. (Chen et al., 2021) The microcontroller used in the Smart Kitchen handles initial data collection from the sensors, processes the data then transmits it to the backend server. The data collected from the sensors (weight measurements, barcode information and image results) are stored in the systems backend database. The database functions, as discussed earlier, as a collection of nutritional information that can be retrieved when prompted. Data is encoded for exchange using JSON as Python has built-in support for JSON parsing. (Chen et al., 2021) Real-time analysis is conducted on sensor data to extract the calorie count per gram and the item's macronutrient profile, which is then presented to the user via the LCD tablet interface.

The smart kitchen environment would function almost 1:1 with a normal kitchen environment. A user places individual food items on the counter for preparation.It would present real-time detection of all actions that impact the nutritional profile of a meal, such as adding ingredients or removing them. Incorporating sensors under the stovetop also accounts for ingredients added during the cooking process. Numerous weight sensors integrated underneath the counter and stove top will measure the weight of the items placed on top of it. These two locations are chosen as they are most common for food preparation. The CMOS sensors embedded above the counter will recognise the ingredients via images. To solve the lighting issues present with CMOS technology, a white LED light can be included in the stand hosting the CMOS sensor to ensure that food on the counter or stovetop is visible. Plastic covering should also be provided for sensors over the counter to shield them from moisture.

VISUALISING FOOD INTAKE

The system aims to:

1) Increase nutritional awareness of users via visualising food intake

2) Make recommendations in line with healthy eating
3) Present information is a manner that is accessible
4) Incorporate synchronised data from nutrition tracking apps and fitness trackers for added user convenience

The main interface for visualising dietary intake in the proposed system is a touch screen LCD tablet. As discussed earlier, the tablet will allow for the display of macronutrient breakdown, calorie count per meal and total calories consumed. When the Smart Kitchen detects an ingredient, the display provides real-time feedback on its calorie and macronutrient profile such as protein, carbohydrates, fats, sodium, potassium, iron, fibre and so on. Once displayed on the tablet, it is up to the user to decide how to use this information. One example is an athlete looking to increase their daily protein intake. The user can set a goal to weigh out at least 30 grams of dietary protein per meal. If a user desires to lose body fat, they can take measures to ensure their total meal calories do not surpass 600 kcal for example. Aside from real-time awareness of nutritional effects, the display also presents the user's TDEE and their total daily calorie count compared with their TDEE. This allows the user to see how much they have consumed for the day, their daily allotment of calories and whether they are under or over their daily amount. Quantitative values like these are presented in a clear, accessible manner. The display provides a ‘Previous Log’ and ‘Recommended’ feature, so users can determine:

a) Their past daily or weekly intake.
b) Recommended ingredients previously used that are under 100 kcal per 100 gram. The recommender features allows the user to make decisions for healthy eating goals.

Like the sensors, the LCD tablet will also be built to withstand moisture, dirty hands, heat and other variables common in kitchen environments.

Figure 3: Visual Representation of potential LCD display

LIMITATIONS OF SYSTEM

CONCURRENCY AND OVERLAP: An assumption is made that the user will place items individually at a time, rather than more than one or all at once. Placing items individually is a limitation as it requires greater effort from the user to track their nutrition.

CMOS TECHNOLOGY: Despite being a cost-effective and compact investment, CMOS technology can present limitations in the smart kitchen environment. A significant constraint is sensitivity to ambient lighting conditions (Arar, 2020) which can impact the clarity and thus accuracy of image. This places the burden on the user to possess a well lit kitchen. Furthermore, CMOS sensors do not provide the level of resolution found in alternative solutions such as computer vision. CMOS technology is also vulnerable to noise (Arar, 2020) which can negatively impact the clarity of images, thus leading to a roll on effect in the calorie count. The solution to this would be to introduce supplementary solutions to address CMOS's challenges, however this might impact the cost.

NUTRITIONAL LITERACY: This system assumes that the user has some degree of nutritional literacy: they are aware of what calories are, what micronutrients are and the role they play in the body. It also presumes a pre-existing habit of nutrition tracking with a fitness tracker or nutrition tracking app. To users with less nutritional knowledge, majority of the concepts presented by the Smart Kitchen system are novel. The system should include a more educational feature to help users understand the impact of calories and specific macronutrients in human health. Nutritional literacy is a limitation as there is no clear cut solution. Implementing educational features might be at the detriment to users with higher nutritional literacy, as it might mean more time spent using the LCD display than is deemed 'useful' therefore upsetting the "benefit-to-cost ratio" illustrated in Chen et al.'s Calorie Aware Kitchen(2008).

CONCLUSION AND RECOMMENDATIONS

This report proposes a solution to address the user burden associated with tracking applications like MyFitnessPal or digital scales for nutritional awareness. Through an extensive review of current literature on diet tracking systems, it is evident there is a need for a more seamless, convenient, and automatic system for nutrition tracking. By leveraging sensor and optical recognition technologies, the proposed Smart Kitchen has the capacity to automate daily food logging, thus empowering users to implement healthier eating habits effortlessly. This system's significance lies in its improvements over previous iterations of nutrition tracking Smart Kitchens, including synchronisation with mobile tracking apps and fitness trackers, the ability to track prepackaged foods, and a recommender system for low-calorie ingredients. These upgrades provide users with better tools to make informed choices about their daily diet, leading to improved habits and overall health. Further studies should focus on addressing the limitations present in this proposed system. This could involve providing educational materials and interactive resources to increase the nutritional literacy of users who are not familiar with food tracking. Additionally, future systems could explore the adoption of computer vision for higher quality optical recognition, enhancing the accuracy and reliability of ingredient tracking.

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