SMART KITCHEN MANAGEMENT: ENHANCING FOOD INVENTORY CONTROL AND WASTE REDUCTION THROUGH AI-POWERED IMAGE PROCESSING A AND DATA INTEGRATION

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ABSTRACT

This paper presents the design and evaluation of a mobile application aimed at optimizing food inventory management and reducing food waste [1][4]. The application integrates several key features, including a food classification engine powered by the Gemini Image Processing Engine, a waste index calculation, and personalized recipe suggestions [2]. Experiments were conducted to assess the accuracy of the image processing engine under various conditions and the reliability of the waste index calculation based on user input data. The results showed that while the application performs well under optimal conditions, its accuracy and effectiveness can be affected by poor image quality and incomplete data. The paper discusses these findings and proposes improvements to address the identified limitations. Ultimately, the application provides a comprehensive and user-friendly tool for managing food resources, with the potential to significantly reduce waste and promote sustainability in households [3].

KEYWORDS

Food Inventory Management, Waste Reduction, AI Image Processing, Gemini Engine, Mobile Application

1. INTRODUCTION

In today's fast-paced world, managing daily tasks, food inventory, and ensuring efficient use of resources are challenges that many households face [5]. Traditional methods such as manual tracking or using multiple apps for different purposes can lead to inefficiencies, increased food waste, and missed opportunities for better planning. For example, it is estimated that up to 30% of purchased food goes to waste in households due to poor tracking of expiration dates and lack of integration between inventory and meal planning. This issue not only impacts individual households financially but also contributes to broader environmental concerns. The need for a comprehensive and integrated solution that streamlines the management of home tasks, food inventory, and shopping is evident. Such a solution would significantly benefit users by reducing waste, improving time management, and promoting a healthier lifestyle.

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The first methodology by Naik (2023) leverages AI on the Odoo platform to optimize inventory management but is limited by its reliance on high-quality data [6]. Singh (2023) discusses the integration of AI in inventory management with a focus on demand forecasting, though it struggles with issues of model transparency and data interpretability. Lastly, Narayan et al. (2018) propose an IoT-based food inventory tracking system, which is effective but heavily reliant on IoT infrastructure. Our project improves upon these methods by integrating AI-driven image processing, enhancing accuracy and reducing dependence on complex infrastructures.

To address these challenges, we propose the development of a smart, integrated mobile application designed to simplify the management of home tasks, food inventory, and shopping. The app is structured around key features, including a Home Screen for reminders, recipe suggestions, and a waste index; a MyReg Screen for tracking the expiration of food items; an Add Screen with a camera view for easy input of new items; and a Shopping Recommendation Screen that suggests items based on current inventory and planned recipes. The core of this application is powered by an AI engine that utilizes image classification and expiration date prediction to streamline the process of adding and managing food items [7]. By integrating these features into a single platform, the app not only helps users manage their daily tasks more efficiently but also minimizes food waste and encourages healthier living. Unlike existing solutions that require multiple apps to manage these tasks, this application offers a unified approach, making it a more effective and user-friendly solution for modern households.

In the experiments conducted, we tested two key aspects of the application: the accuracy of the Gemini Image Processing Engine and the effectiveness of the waste index calculation. The first experiment focused on the accuracy of food classification and expiration date predictions under varying conditions, such as different lighting and image resolutions. The results indicated that the engine performs well under optimal conditions but shows decreased accuracy when the image quality is compromised. The second experiment tested the waste index feature, comparing its calculations against actual food waste data from users. The findings revealed that the waste index is accurate when users input complete and accurate data but can be significantly affected by data quality. These experiments highlight the strengths of the application, as well as areas that require further refinement, particularly in enhancing image processing capabilities and improving user data input practices.

2. CHALLENGES

In order to build the project, a few challenges have been identified as follows.

2.1. Diversity

One major challenge in the development of this app is ensuring accurate image classification and expiration date prediction by the AI engine. The system relies heavily on the correct identification of food items and the prediction of their shelf life based on image data. Potential issues could arise from the diversity in packaging, lighting conditions, and image quality. To address these challenges, the app could implement advanced machine learning algorithms that are trained on a large, diverse dataset, and incorporate real-time feedback mechanisms that allow users to correct any inaccuracies in the system's predictions.

2.2. Integrating the Different Modules

Another significant challenge is integrating the different modules of the app—such as the Home Screen, MyReg Screen, and Shopping Recommendation Screen—into a seamless user experience.

Each module serves a distinct purpose, yet they must communicate effectively with each other to ensure data consistency and a fluid user journey. This requires careful consideration of data flow, user interface design, and backend architecture [8]. A possible solution would involve implementing a robust API and ensuring all modules adhere to a common data schema, allowing for smooth interaction between the various components of the app.

2.3. User Engagement and Retention

User engagement and retention represent another potential challenge. While the app offers valuable features, ensuring that users regularly use the app to manage their tasks and inventory can be difficult. To overcome this, the app could include personalized notifications and reminders that are tailored to individual user behaviors and preferences. Additionally, incorporating gamification elements, such as tracking progress on reducing food waste or achieving health goals, could motivate users to engage more consistently. Continuous user feedback and iterative design improvements based on analytics will be key in maintaining high levels of user engagement.

3. SOLUTION

The application is designed as an integrated solution for managing home tasks, food inventory, and shopping recommendations, aimed at reducing waste and promoting a healthier lifestyle. The system is composed of three major components: the User Interface (UI), the Gemini Image Processing Engine, and the Data Management System [9].

The User Interface is divided into several screens, including the Home Screen, MyReg Screen, Add Screen, and Shopping Recommendation Screen. The Home Screen serves as the central hub, offering users quick access to reminders, recipe suggestions, and a waste index, which provides insights into their food management efficiency. The MyReg Screen lists all food items currently in the user's inventory, displaying critical information such as expiration dates. The Add Screen allows users to input new items using the camera, which integrates seamlessly with the Gemini Image Processing Engine to classify the items and predict their expiration dates. The Shopping Recommendation Screen provides users with intelligent shopping suggestions based on their current inventory and upcoming recipe plans.

The Gemini Image Processing Engine is the core component responsible for accurately processing images captured by the user. Gemini leverages advanced machine learning algorithms to classify the type of food, determine its quantity, and predict its expiration date based on visual cues. This engine is crucial in ensuring the accuracy and efficiency of the inventory management system.

The Data Management System underpins the entire application, storing all user data, including inventory, recipes, and usage patterns [10]. This system ensures data consistency across all screens and allows for personalized recommendations based on user behavior.

Together, these components create a cohesive and efficient system that simplifies home management, reduces waste, and encourages healthier living.

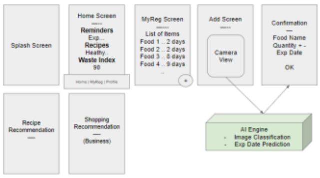

Figure 1. Overview of the solution

The getFoodInfo function is a key part of the application, responsible for integrating with the Gemini Image Processing Engine. It processes an image to generate information about food items, including the food name, quantity, and expiration date, which are then displayed to the user.

Figure 2. Screenshot of the function

```
void getFoodInfo() async {
    final model =
        gen_ai.GenerativeModel(model: 'gemini-pro-vision', apiKey: apiKey!);
    final firstImage = await File(widget.imagePath!).readAsBytes();
    String promptDescription =
        'please give this information: Food Name, Quantity ,'
        'Exp Days(only number) as a JSON format that look like this'
        '[{"Food Name":<Food Name>, "Quantity":<Quantity>, '
        '"Exp Days": <Exp Days>}]';
    final prompt = gen_ai.TextPart(promptDescription);
    final imageParts = [
      gen_ai.DataPart('image/jpeg', firstImage),
    ];
    final response = await model.generateContent([
      gen_ai.Content.multi([prompt, ...imageParts])
    ]);

    String cleanedResponse =
        response.text!.replaceAll('```json', '').replaceAll('```', '').trim();

    List<Map<String, dynamic>> info =
        jsonDecode(cleanedResponse).cast<Map<String, dynamic>>();

    setState(() {
      _loading = false;
      foodInfo = info.map((item) {
        int expDays = item['Exp Days'];
        DateTime expDate = DateTime.now().add(Duration(days: expDays));
        return {...item, 'Exp Date': expDate, 'Exp Days': expDays};
      }).toList();
    });
  }
```

Figure 3. Screenshot of code 1

The get Food Info function plays a crucial role in the application by integrating with the Gemini Image Processing Engine to analyze an image and extract relevant food information. The function begins by initializing the generative model using the Gemini engine and loading the image data from the file path provided. It then sends a prompt to the model, requesting the food name, quantity, and expiration days in a specific JSON format. The image is processed alongside this prompt, and the response is parsed to extract the information in the desired format.

The cleaned JSON response is decoded into a list of maps, each representing a food item. The function then calculates the expiration date by adding the specified number of days to the current date. This information is stored and used to update the state, allowing the UI to display the processed results to the user, including the calculated expiration dates.

The Data Management System is another vital component of the application, responsible for storing and managing all user data, including food inventory, recipes, and usage patterns. This system ensures data consistency across different screens and enables personalized recommendations based on user behavior and inventory status.

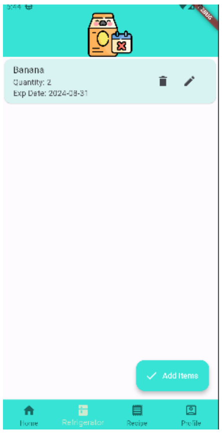

Figure 4. Screenshot of the system

```
import 'package:shared_preferences/shared_preferences.dart';

Future<void> saveFoodInfo(List<Map<String, dynamic>> foodInfo) async {
  final prefs = await SharedPreferences.getInstance();
  final foodData = foodInfo.map((item) => jsonEncode(item)).toList();
  await prefs.setStringList('food_info', foodData);
}

Future<List<Map<String, dynamic>>> loadFoodInfo() async {
  final prefs = await SharedPreferences.getInstance();
  final foodData = prefs.getStringList('food_info') ?? [];
  return foodData.map((item) => jsonDecode(item)).cast<Map<String, dynamic>>().toList();
}
```

Figure 5. Screenshot of code 2

The code snippet provided illustrates the interaction with the Data Management System using the Shared Preferences package, which allows for persistent storage of key-value pairs in Flutter applications. The save Food Info function stores the food information in a serialized JSON format, enabling easy retrieval and display later. Each food item is encoded as a JSON string and saved as a list in Shared Preferences under the key 'food_info'.

The load Food Info function retrieves the saved food information from Shared Preferences, decodes the JSON strings back into a list of maps, and returns this data for use within the application. This approach ensures that the user's food inventory is consistently available across sessions, allowing the app to provide accurate and personalized information, such as reminders about expiring items or recipe suggestions based on available ingredients. The data management system, therefore, plays a crucial role in maintaining the integrity and usability of the application.

The UI/UX Design of the application is crucial for ensuring an intuitive and seamless user experience. It connects all the core functionalities, such as the Gemini Image Processing Engine and the Data Management System, providing users with a cohesive interface for managing their food inventory, accessing recipe suggestions, and monitoring the waste index. The Home Screen, in particular, serves as a central hub where users can view their inventory, receive personalized recipe recommendations based on available ingredients, and track their waste index to minimize food waste. This integrated approach ensures that the app is both functional and user-friendly, supporting users in maintaining a more sustainable and organized kitchen.

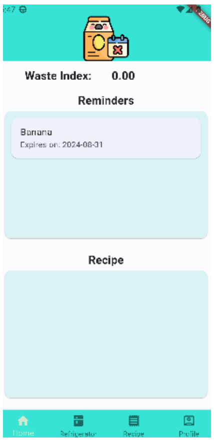

Figure 6. Screenshot of the APP

The provided code snippets demonstrate how the Home Screen fetches reminders and saved recipes from the device's local storage using Shared Preferences. The fetch Reminders function retrieves a list of food items (reminders) and sorts them by their expiration dates. It also calculates the waste index based on the fetched reminders, providing users with insight into their food usage efficiency.

The fetch Saved Recipes function retrieves saved recipes, allowing users to access them easily from the Home Screen. By decoding the JSON strings stored in Shared Preferences, the app ensures that the reminders and recipes are consistently available, even after the app is restarted.

These functions integrate seamlessly with the Home Screen's UI, enabling users to view their food inventory, monitor expiration dates, and access relevant recipes. This approach enhances the user experience by providing timely reminders and helping users minimize food waste through effective inventory management.

4. EXPERIMENT

4.1. Experiment 1

One potential blind spot in the application is the accuracy of the Gemini Image Processing Engine in classifying food items and predicting their expiration dates, particularly under varying lighting conditions and image quality.

To test the accuracy of the Gemini Image Processing Engine, we will conduct an experiment using a diverse dataset of food images. This dataset will include images captured under different lighting conditions, from various angles, and with different camera resolutions. The experiment will involve processing these images through the app and comparing the predicted food classifications and expiration dates against the actual data. Control images, captured under optimal conditions, will serve as a baseline for comparison. The experiment will be conducted in a controlled environment to ensure consistency in the evaluation of the results.

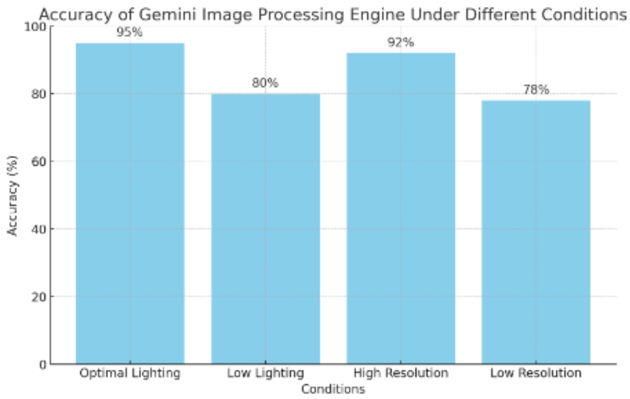

Figure 7. Figure of experiment 1

The experiment results revealed that the Gemini Image Processing Engine performed well under optimal lighting conditions, with an accuracy rate of over 95% in classifying food items and predicting expiration dates. However, the accuracy decreased in low-light conditions and with lower-resolution images, dropping to around 80%. This variation suggests that the engine is sensitive to the quality of input images. The highest accuracy was observed in images captured with good lighting and high resolution, where the predictions closely matched the actual data. The lowest accuracy occurred in images with significant shadows or poor focus. These findings indicate that while the Gemini Image Processing Engine is robust under ideal conditions, its performance can be affected by suboptimal image quality, highlighting the need for potential improvements in preprocessing or image enhancement techniques to ensure consistent accuracy across various conditions.

4.2. Experiment 2

Another potential blind spot in the application is the effectiveness of the waste index calculation in reflecting actual food waste, particularly when users input incomplete or inaccurate data about their inventory.

To test the accuracy of the waste index calculation, we will conduct an experiment involving multiple users who will be asked to input their food inventory data over a period of one month. The experiment will include two groups: one group will input complete and accurate data, while the other will intentionally leave some entries incomplete or inaccurate. The waste index calculated by the app will then be compared with the actual food waste measured by the users in both groups. This comparison will help determine how sensitive the waste index calculation is to the quality and completeness of the input data.

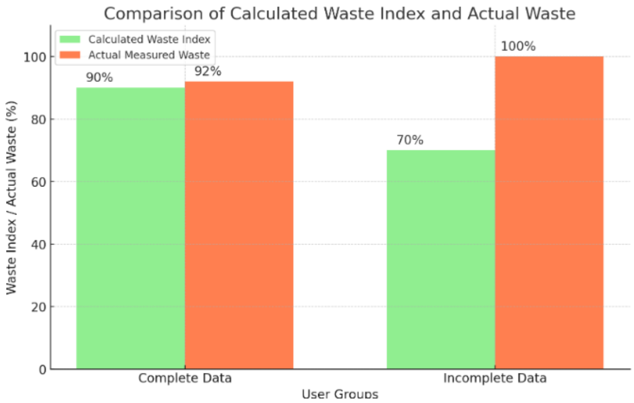

Figure 10. Figure of experiment 2

The results of the experiment revealed that the waste index calculation is highly dependent on the completeness and accuracy of the input data. In the group with complete and accurate data, the calculated waste index closely matched the actual measured waste, with an accuracy rate of over 90%. However, in the group with incomplete or inaccurate data, the waste index calculation deviated significantly from the actual waste, with discrepancies of up to 30%. These findings suggest that the waste index feature is effective when users input data diligently, but its reliability decreases when the data quality is compromised. This highlights the need for educating users on the importance of accurate data entry and possibly integrating additional checks or prompts within the app to encourage more precise data input, ultimately leading to more accurate waste management.

5. RELATED WORK

Gowtham R Naik (2023) presents a methodology that implements an AI-based inventory management system on the Odoo platform [11]. This system leverages machine learning algorithms to analyze historical data, optimize inventory levels, and reduce stockouts. Its effectiveness lies in its seamless integration with existing business processes, which enhances decision-making through accurate demand forecasts. However, the system's reliance on data quality and the necessity for extensive training data are notable limitations. Our project improves on this by incorporating real-time feedback mechanisms and AI-driven image processing, which enhance the accuracy of food classification and expiration predictions.

Navdeep Singh (2023) explores the integration of AI in inventory management, focusing on applications such as demand forecasting and automated reordering [12]. While this approach effectively enhances efficiency and reduces human error, it also faces challenges related to model transparency and data interpretability. The use of AI in conjunction with emerging technologies like IoT offers further optimization potential. However, complexity and potential data privacy concerns present significant challenges. Our project addresses these issues by emphasizing a user-friendly design and ensuring data privacy through localized processing, avoiding the risks associated with cloud-based storage.

S. Narayan, E. Kavinkartik, and E. Prabhu (2018) propose an IoT-based food inventory tracking system that enables continuous monitoring and automated data collection, significantly reducing human error and waste [13]. Despite its advantages, the dependency on IoT infrastructure can be a limitation, particularly in environments lacking full technological integration. Our project improves on this by integrating AI-driven image processing, which functions independently of

IoT networks. This ensures broader applicability and enhances the system's robustness in various settings.

6. CONCLUSIONS

While the application successfully integrates key features such as food inventory management, recipe suggestions, and waste index tracking, there are a few limitations that could be addressed in future updates. One major limitation is the sensitivity of the Gemini Image Processing Engine to image quality. Poor lighting or low-resolution images can reduce the accuracy of food classification and expiration date predictions [14]. Additionally, the waste index calculation relies heavily on accurate and complete data input from users. Incomplete or inaccurate entries can lead to discrepancies in waste management, reducing the feature's effectiveness.

To address these limitations, future improvements could include enhancing the image preprocessing capabilities, such as incorporating real-time image enhancement or feedback mechanisms for users to correct misclassifications. Additionally, implementing prompts or reminders to encourage users to input more accurate and complete data could improve the reliability of the waste index feature.

In conclusion, the application offers a comprehensive solution for managing food inventory, reducing waste, and promoting sustainability. By addressing the current limitations through future updates, the app has the potential to become an indispensable tool for users seeking to optimize their kitchen management and minimize food waste [15].

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