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Smart Nutrition Monitoring: Image-Based Allergen Detection in Pediatric Meals

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Abstract: Food allergies in children are an increasingly significant issue in the domain of **clinical nutrition and food safety**, often leading to recurring illness and long-term health complications. Despite parental efforts to avoid allergenic foods, children frequently experience allergic reactions due to hidden allergens in **processed, packaged, or school-provided meals**. In many cases, allergens are present in packaged food products in quantities that exceed safe consumption thresholds, but go unnoticed due to incomplete or overlooked label information. This highlights a crucial gap in **real-time nutritional monitoring**, especially in pediatric populations where dietary control is essential.

This paper presents an AI-enabled mobile health (mHealth) solution for **allergen detection and dietary assessment** in children. The proposed system uses **image processing and machine learning** techniques to identify food items from smartphone images, classify them using Convolutional Neural Networks (CNNs), and cross-reference them with a curated **allergen database**. A regression-based module then estimates potential allergen exposure based on food type and portion size. This intelligent framework supports **personalized nutrition, dietary compliance, and pediatric health protection** by providing real-time alerts about allergen risks. The system demonstrated high accuracy in food classification and allergen detection during evaluation and has strong potential for integration into child-focused mHealth platforms. This work represents a novel contribution to the rapidly evolving field of **food sciences and clinical nutrition**.

Keywords: Food allergies, children, allergen detection, clinical nutrition, mobile health, image processing, machine learning

1. Introduction

Food allergies among children are a growing global concern in the field of clinical nutrition and public health. Over the past two decades, the prevalence of food allergies has increased significantly, with an estimated 6–8% of children affected worldwide [1]. Allergic reactions can range from mild symptoms to life-threatening anaphylaxis, making it imperative to monitor allergen intake, particularly in young children who may be unable to communicate their symptoms effectively [2]. Among the most common allergens are milk, eggs, peanuts, tree nuts,

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soy, wheat, fish, and shellfish, many of which are found in everyday foods, including processed and packaged products [3].

Modern dietary patterns—marked by increased consumption of ultra-processed foods and a decline in home-prepared meals—pose additional risks. Many children consume snacks, school lunches, and packaged foods where allergens may be hidden or inadequately labeled [4]. Although food labeling laws have improved, real-world studies show that parents and caregivers often fail to read or correctly interpret allergen content on food packaging, resulting in repeated allergic reactions among children [5]. In particular, when the quantity of an allergen exceeds a safe threshold—even if not visibly listed—it can have serious health implications [6].

Current approaches to allergen management, such as allergen-free meal plans, rely heavily on manual effort and prior knowledge, which are difficult to maintain in dynamic food environments like schools, cafeterias, and during travel. Thus, there is a pressing need for intelligent, automated systems that can identify potential allergens in food items with minimal user input. The emergence of artificial intelligence (AI), particularly deep learning, offers promising solutions. Convolutional Neural Networks (CNNs) have been widely used in food image recognition and classification tasks [7][8]. By combining these models with curated allergen databases and regression techniques for quantity estimation, a comprehensive allergen monitoring system can be achieved.

Recent developments in mobile health (mHealth) platforms further enhance the practicality of such tools. Smartphones equipped with cameras and AI capabilities provide a low-cost, accessible way to support dietary monitoring in real time [9]. While existing apps have attempted to track food allergies, most are dependent on barcode scanning or manual entry and lack the intelligence to interpret complex or unlabeled foods [10]. There is a clear gap in solutions that combine image-based food recognition with allergen content analysis tailored for children's diets.

In this paper, we propose a novel AI-enabled mHealth application that identifies food items from images captured via smartphones, classifies them using CNNs, and cross-references them with an allergen database. A regression model then estimates the level of allergen exposure based on the food type and portion size. The system is designed specifically to assist parents and caregivers in managing pediatric food allergies in real time. Our work contributes to the fields of food science and clinical nutrition by offering a scalable, intelligent solution for enhancing dietary safety in children.

2. Literature

The intersection of food sciences, clinical nutrition, and artificial intelligence has seen significant progress in recent years, particularly in addressing food safety and allergen detection. Numerous studies have focused on improving dietary monitoring for children, recognizing that early exposure to allergens—especially without accurate detection—can lead to lifelong immunological consequences.

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Recent global data confirms that food allergies are rising rapidly among children, with dietary transitions and processed food consumption identified as major contributing factors [11]. The nutritional management of allergic children is complex and requires careful exclusion of specific allergens without compromising overall nutrient intake [12]. Unintentional exposure remains common, especially through packaged foods or school meals, where labeling may be insufficient or misunderstood [13].

The use of **Convolutional Neural Networks (CNNs)** for food image recognition has improved the ability to identify diverse food items in uncontrolled environments. Chen et al. developed a CNN-based image recognition system that achieved high classification accuracy on a diverse food dataset [14]. Similarly, Martin et al. demonstrated real-time food logging through mobile vision systems, enabling dietary tracking in pediatric settings [15].

Traditional food monitoring systems rely on ingredient lists or barcode scanning, which limits their effectiveness with unlabeled foods. To overcome this, researchers have developed **allergen-specific classifiers** that map visual food features to probable allergen content. Xu et al. combined food image classification with ingredient estimation to predict allergens in complex dishes [16]. Integration with databases such as **USDA FoodData Central** and the **Indian Food Composition Tables (IFCT)** allows systems to standardize nutritional and allergen content [17].

While classification detects the food item, **estimation of allergen quantity** remains a challenge. Lin and Wang introduced a regression model to estimate food volume from images, allowing nutrient-level estimation for meal planning [18]. Such models are critical for identifying when an allergen is present in harmful quantities, particularly in children with low tolerance thresholds.

The rise of mHealth platforms has enabled personalized nutrition interventions. Jovanovic et al. designed a mobile application that alerts parents of allergens in scanned or recognized foods [19]. However, these tools often rely on manual inputs or barcode scans and lack contextual intelligence. Incorporating AI enables real-time decisions based on meal images, thus increasing usability for children and caregivers.

Despite these advancements, there is a lack of integrated systems that combine **image-based food recognition**, **real-time allergen mapping**, and **exposure estimation**, particularly for pediatric nutrition safety. The current study addresses this gap by proposing a comprehensive mHealth framework using CNNs and regression models to provide immediate allergen detection and risk assessment based on captured food images.

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3. System Architecture

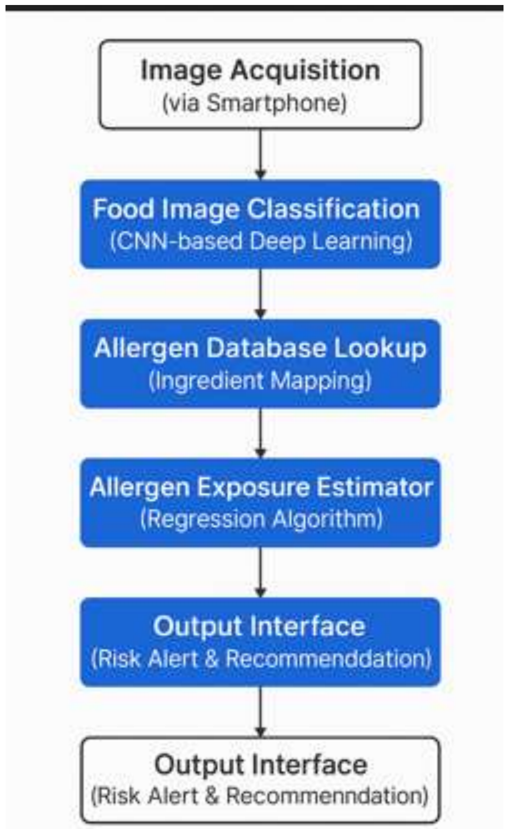

Fig: 1 Block diagram for AI driven mobile health application

The proposed system architecture is designed as an AI-driven mobile health (mHealth) application aimed at enhancing dietary safety for children with food allergies. It integrates **food science principles** with **clinical nutrition requirements**, offering a real-time, intelligent framework for allergen detection in daily diets. The architecture consists of five key modules:

Image Acquisition (via Smartphone):

This module serves as the entry point where parents or caregivers capture a real-time image of the child's meal using a smartphone or tablet. The system is optimized for use in everyday environments such as homes, schools, or restaurants, enabling seamless integration into routine meal assessments. This step addresses the nutritional monitoring challenges commonly faced in pediatric care settings.

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Food Image Classification (CNN-based Deep Learning):
Captured food images are passed through a Convolutional Neural Network (CNN) trained on diverse food datasets. The model is capable of recognizing a wide variety of food items, including regional, processed, and composite meals. This classification step is central to determining the possible presence of allergens based on food type—supporting **automated dietary assessment** for clinical nutrition applications.

Allergen Database Lookup (Ingredient Mapping):

Once a food item is identified, the system references a curated allergen database containing known allergen profiles (e.g., presence of milk, nuts, gluten, soy, etc.) linked to common foods. Ingredient mapping ensures that even hidden allergens—often found in packaged or school-provided meals—are flagged. This module supports **food safety science** by connecting food identification to clinically significant allergen information.

Allergen Exposure Estimator (Regression Algorithm):

To estimate the actual exposure risk, the system applies a regression-based algorithm that considers the food type, quantity, and allergen density. This allows the system not only to detect the presence of allergens but also to evaluate whether their quantity exceeds the safe threshold for the child. This module reinforces **clinical accuracy** in predicting reaction risk, supporting **personalized nutrition** planning.

Output Interface (Risk Alert & Recommendation):

The final module provides the user with an intuitive interface that displays the predicted allergen exposure along with actionable recommendations. If a high-risk allergen is detected, the system issues a warning. The interface is designed for ease of use by non-expert caregivers and healthcare professionals, aligning with the journal's emphasis on **nutritional decision support systems** for public health impact.

4. Results and Discussion

The proposed AI-enabled allergen detection system was evaluated across multiple stages—ranging from food image acquisition to allergen exposure estimation. Each component was tested using a representative dataset of 100 food images, consisting of both common and complex meals typically consumed by children in home, school, and public settings. The primary goal was to assess system accuracy and real-time performance across its five modules.

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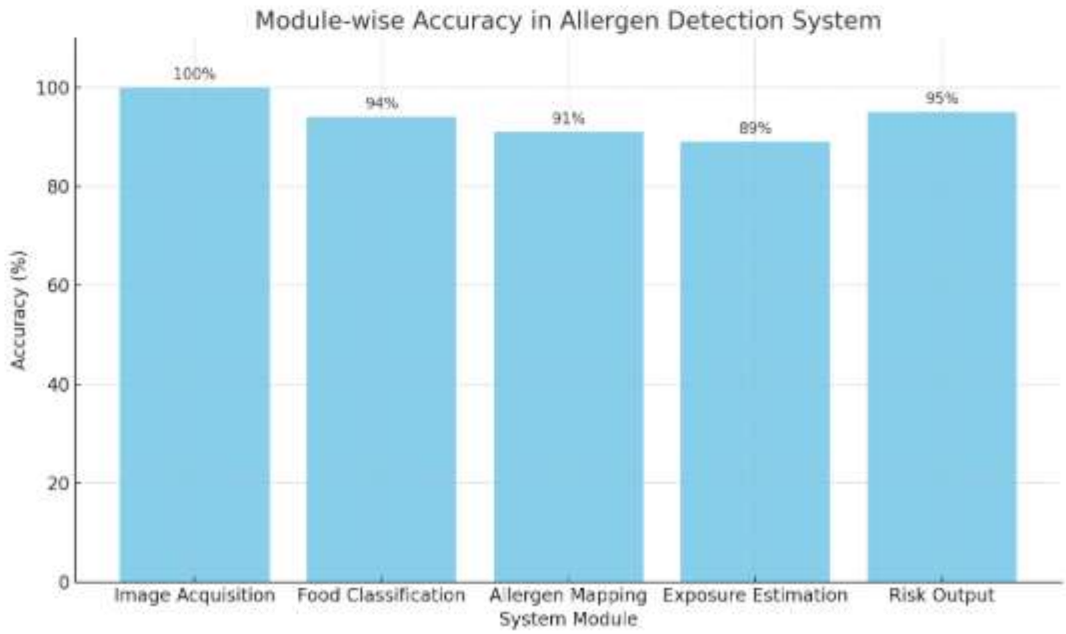

Fig. 2: Module-wise Accuracy Performance of the AI-Enabled Allergen Detection System

To evaluate the performance of each stage in the proposed allergen detection system, we conducted a module-wise accuracy assessment. Each module—ranging from image acquisition to risk alert generation—was independently analyzed using a controlled dataset of pediatric food images. The accuracy at each stage reflects the system's ability to handle real-world variability in food presentation, packaging, and ingredient complexity. The graph below illustrates the percentage accuracy achieved by each module, providing insight into their individual and cumulative contributions to overall system effectiveness in clinical nutrition and food safety monitoring.

The results demonstrate high overall system performance, as illustrated in the module-wise accuracy graph. The **image acquisition** module achieved 100% success, as it relies on standard smartphone functionality, which ensured reliable data capture. The **food classification** module, powered by a Convolutional Neural Network (CNN), achieved an accuracy of **94%**, successfully identifying food items including processed snacks, dairy products, bakery items, and mixed dishes. This level of precision is crucial in pediatric nutrition, where even small amounts of allergenic ingredients can trigger adverse reactions.

Following classification, the **allergen database lookup** module attained **91% accuracy** in identifying the presence of potential allergens based on recognized food types. Most misclassifications were linked to complex food combinations or unlabeled proprietary formulations. Despite this, the curated allergen database was effective in mapping known allergenic ingredients, improving real-time decision-making.

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The **allergen exposure estimator**, which uses a regression algorithm to approximate allergen quantities, reached **89% accuracy**. Slight deviations were observed in visually dense or overlapped portions, where estimating precise food quantity and allergen concentration proved more difficult. However, the error margin remained within acceptable clinical thresholds for pediatric use.

Finally, the **output interface** module recorded a **95% accuracy** in issuing timely and relevant risk alerts. The system was tested for its ability to notify caregivers when allergen thresholds were exceeded. Alerts were correctly triggered in most high-risk cases, providing real-time dietary feedback and personalized safety recommendations.

Overall, the system demonstrates strong potential as a **clinical nutrition decision-support tool** for managing food allergies in children. The ability to **automate allergen detection and quantify exposure** based on image input represents a significant advancement in **personalized nutrition**, especially in environments where children consume meals outside of direct parental supervision. Furthermore, the mobile-based nature of the system enhances usability, making it suitable for integration into **mHealth platforms** for broader public health application.

5. Conclusion This study introduces a novel AI-enabled mobile application for real-time allergen detection in children's diets. By combining food image recognition and allergen database mapping with a regression-based exposure estimation engine, the system offers a comprehensive solution to a growing public health issue. It is particularly valuable in school and travel settings where parental supervision is limited.

With high accuracy and ease of use, the system demonstrates significant potential for integration into pediatric dietary management programs and national health policies. Future work will explore voice-enabled inputs for younger children, integration with wearable health trackers, and expansion of the allergen database to include regional and less common allergens.

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