FOOD ALLERGEN DETECTION: LEVERAGING CNN FOR ALLERGEN DETECTION IN FOOD TO PROTECT THE CONSUMERS

Contextual Report

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I. Abstract:

Food allergies impose a significant health concern on the community. Even a small amount of certain food items can cause an allergic reaction within the human body. The symptoms can range from mild hives or itchiness to life-threatening anaphylaxis. In most cases, such reactions can be prevented by simply being aware of the allergen-based food items and avoiding the consumption of the same. With the prevalence of food allergies and the potential risks they pose to consumers especially those with severe allergies, there is a pressing need for efficient and accurate methods to identify allergic substances in food products. Individuals often face challenges in identifying allergens present in food products particularly when dining out or encountering unfamiliar items in the food. To address this concern, this study introduces a novel approach leveraging Convolutional Neural Networks (CNNs) for allergen detection in food products which is aimed to enhance consumer safety and facilitating informed dietary choices. The proposed project is to develop a food allergen detector so that people allergic to certain food substances can make informed decisions about the food they buy and consume. Ultimately, it will improve food safety for the consumers which will also promote informed food choices and mitigate the risk of allergic reactions.

Keywords: Food allergy, Food science, Object detection, Convolutional Neural Network.

II. Acknowledgement:

Sincere gratitude and appreciation to all the individuals who played a pivotal role for the completion of this research. Special thanks to our course instructor Mr. Ajaya Kumar Sharma who gave all the necessary information about how research is supposed to be done. Likewise, Mr. Devashish Kumar (Project Supervisor) gave his invaluable guidance and support throughout the process with all the weekly progress and feedback sessions being favorable for the success of this project. Additionally, Mr. Sudhir Kumar gave major suggestions about formats which must be maintained in the contextual report. Lastly, thanks to all the respondents for their willingness to share their insights and experiences. This project could not have been completed without their valuable contributions.

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1. Introduction:

1.1 Background:

The significance of correctly identifying allergenic components present in food items has been highlighted considering the increased awareness of food allergies in recent years. Around 2% to 10% of people worldwide suffer from food allergies. The National Health and Nutrition Examination Survey (NHANES) found that 9% of people had a food allergy, with 7% of children and 10% of adults having a food allergy. The three primary risk factors for developing a food allergy are asthma, atopic dermatitis, and a family history of atopy. Numerous studies have established these risk variables, which imply that atopic dermatitis-related breakdown of the skin barrier may lead to percutaneous sensitization to foods, ultimately resulting in food allergy (Dimassi et al., 2020).

The escalating concern for food allergens has prompted increased attention from both the food industry and regulatory bodies, emphasizing the need for effective tools and solutions to assist individuals in navigating potential allergen risks. The controlled production of food products relies heavily on the availability of methods capable of detecting traces of allergenic ingredients (Van Hengel, 2007). Consequently, there arises a crucial need for innovative approaches to allergen detection that can bridge the gap between technological advancements and real-world application in the realm of food safety and allergen management.

1.2 Problem Statement:

Identifying the allergens in food products is often challenging for individuals, particularly when facing unfamiliar items in the food. Existing allergen detection methods, such as manually inspecting the food labels or relying on allergen information provided by the manufacturer are often time-consuming which also lacks real-time feedback. The detection of allergen based food items in images is also difficult due to the lack of convenient methods and specialized datasets for efficient identification (Mishra et al., 2022). There is a pressing need for a robust solution that can provide individuals with an effective and timely information about potential allergens in food items, enabling them to make informed dietary choices and mitigate the risk of allergic reactions.

1.3 Proposed Solution:

A deep learning approach utilizing Convolutional Neural Networks (CNNs) is proposed for allergen detection in food products through image analysis. CNNs offer a powerful framework for feature extraction from images, enabling the identification of patterns associated with allergenic ingredients. By leveraging a dataset of labeled food images and allergen information, CNNs can learn to accurately detect potential allergens in new food images based on these learned features (Ciocca, Napoletano and Schettini, 2018). Likewise, to address the lack of specialized datasets, the research team created the Allergen30 dataset, comprising annotated images of commonly used food items containing allergens (Mishra et al., 2022). This method will furnish individuals with vital details regarding their dietary decisions and minimize the potential for allergic reactions.

1.4 Project aim:

The major goal of this project is to create a food allergen detection system that allows people who are allergic to certain food ingredients to make informed decisions and be aware about the food they buy and consume.

1.5 Objectives:

The project's objectives are:

- Capturing/uploading food images.
- Identifying the food from the provided image.
- Inputting allergic food substances.
- Detecting allergenic food substances in the image.
- Creating an intuitive mobile application that informs users about the presence of potential allergens in food products.

1.6 Intellectual Challenges:

Key challenges in the project include developing an effective allergen detection algorithm capable of differentiating between various allergens present in a single food product, addressing limitations in the training dataset used for CNN model development, and accommodating the diverse range of cuisines and food items encountered globally. Identifying allergen-containing food products based on visual cues alone can be challenging due to variations in appearance, size, and context. Developing algorithms that can accurately detect these items is a significant intellectual challenge (Mishra et al., 2022). Likewise, Choosing the most suitable deep learning model and optimizing it for allergen detection requires careful consideration of factors such as accuracy, speed, and deployment requirements (Mishra et al., 2022). These challenges underscore the need for innovative solutions and interdisciplinary collaboration in the field of food allergen detection.

1.7 Structure of Project:

Chapter Name	**Contents**
Introduction	• Background • Problem Statement • Proposed Solution • Project Aim • Objectives • Intellectual Challenges
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Market Research	Secondary Market Research
Primary Market Research	Data Collection • Questionnaire and its objective • Data Analysis • Overall Analysis
Artefact Planning	• Requirements 1. Functional Requirements 2. Non-Functional Requirements 3. Usability Requirements • Development Methodology

	• Testing Strategy • Evaluation Strategy • Personas and Scenario • System Design 1. Software development tools required. 2. Operating System required. 3. Software required for clients. 4. Hardware Requirement 5. Use Case Diagram 6. Activity Diagram
Conclusion	Conclusion of the contextual report
References	References used for this report.
Appendix	• Project proposal form • Ethics form • Weekly progress report • Questionnaire and Responses

2. Project Plan:

2.1 Gantt Chart (For this semester):

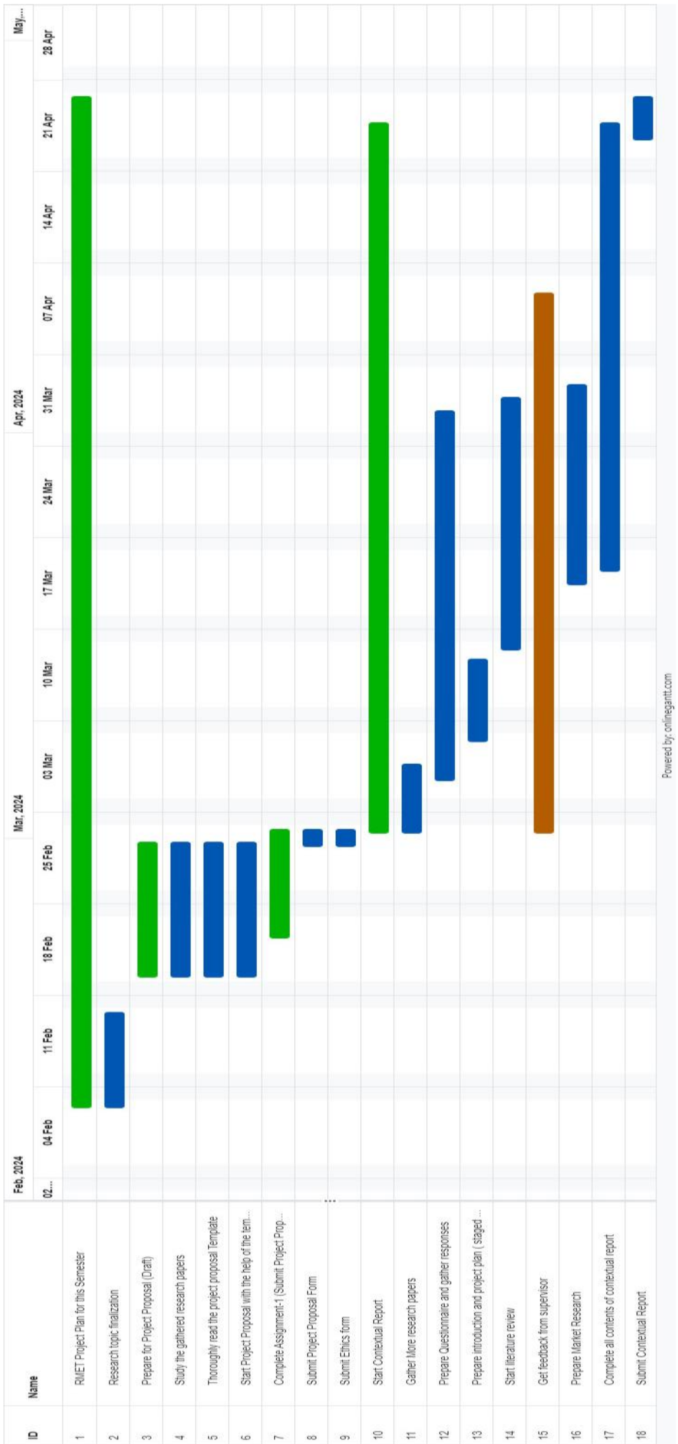


Figure 1: Gantt Chart for this semester.

The Gantt chart in Fig-1 outlines the schedule of project plan for this semester spanning from February to April of the year 2024. The green line indicates the overall task whereas, the blue line indicates the sub tasks.

2.2 Gantt Chart (For next semester):

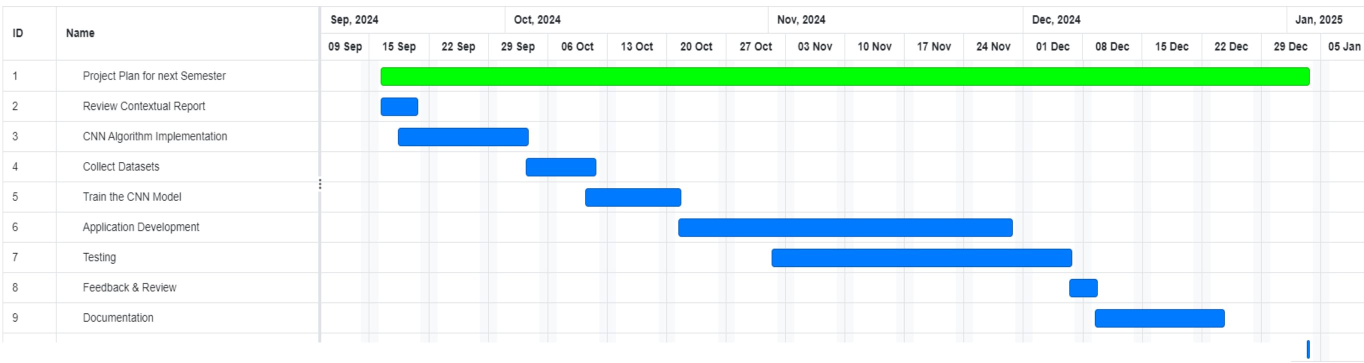


Figure 2: Gantt chart for next semester.

The Gantt chart depicted in figure-2 shows a project timeline from September 2024 till January 2025, outlining all the necessary tasks required for next semester. It also represents the duration of each task where blue line representing the tasks which is needed to be completed. This chart will be providing a clear roadmap for the completion of the project.

2.3 Work Breakdown Structure:

Figure 2: Work Breakdown Structure.

3. Literature Review:

Food allergies are a significant health concern affecting individuals worldwide, with certain food items capable of triggering allergic reactions ranging from mild symptoms to severe anaphylaxis. Detection of allergen-containing food products is crucial to prevent adverse reactions and ensure the safety of consumers.

3.1 Food allergen:

[Allergen: a substance that causes an allergic reaction.]

Food allergens can simply be understood as substances that are present in certain foods that can trigger an abnormal immune response towards some individuals, leading to allergic reactions. When a person with a certain food allergy consumes or comes in contact with a specific allergen, their immune system mistakenly identifies the allergen as harmful and produces antibodies to fight it. This immune response can result in a range of symptoms from mild reactions like itching and coughing to severe and potentially life-threatening reactions like anaphylaxis.

Common food allergens according to NHANES:

- Milk
- Eggs
- Peanuts
- Tree Nuts (Example: Almonds, walnuts, cashews, etc.)
- Soy
- Wheat
- Fish
- Shellfish

3.2 Brief introduction to deep learning:

Machine learning has been emerged as an effective tool for data processing across various domains. Traditional machine learning techniques often require manual feature extraction methods due to their inability to analyze raw natural data. However, with the advancement in terms of hardware computing capabilities and storage capacities, machine learning can be enhanced by adding more complex structures to achieve a deeper representation of data (Schmidhuber, 2015).

Representation learning allows a machine to extract features from raw data for tasks like detection, classification and regression. Deep learning can basically be understood as a subset of representation learning method which refines multilevel representation by utilizing deep artificial neural networks (ANN). ANN is composed of multiple layers of neurons (nonlinear modules). Due to its robust feature learning capabilities, deep learning can effectively solve many complex problems exhibiting strong performance in terms of classification/regression tasks if there is a sufficient data support representing the specific problem (Zhou *et al.*, 2019). With its sophisticated automatic feature learning capabilities, deep learning is practiced in the field of food science. This includes food calorie estimation, food allergen detection, detection of fruits and vegetables, etc.

Convolutional Neural Networks (CNN) includes a set of component such as convolutional layers, pooling layers and fully connected layers, currently regarded as one of the most popular machine intelligence models for big data analysis across numerous research areas (Zhou *et al.*, 2019).

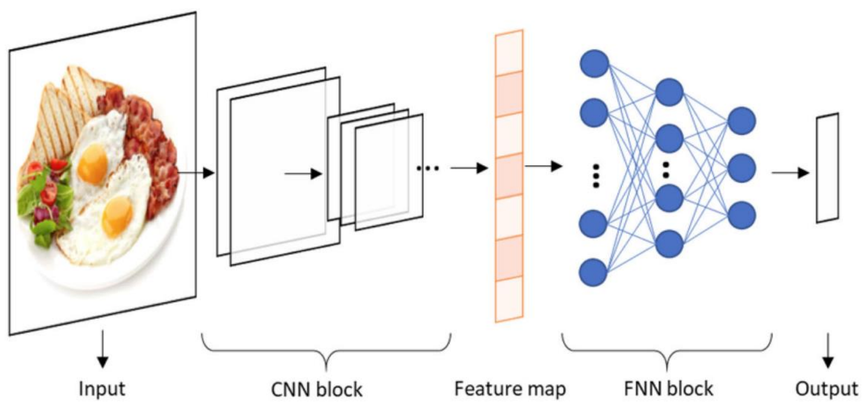


Figure 3: Basic CNN model architecture.

Figure-4 depicts a typical CNN model architecture for classification problem. Convolution operations are performed by traversing input matrices with convolution kernels which can be seen as filters for feature extraction. Unlike the filters used in traditional image processing methods which require manual parameter setting, the parameters within the kernel can be automatically learnt by the deep learning method (Zhou *et al.*, 2019). Convolutional layers are constructed by a set of convolution kernels, whose parameters (channels, kernel size, padding, strides, activation, etc.) should be set and optimized according to the specific problem. Likewise, the output computed from the convolutional layer is then subsampled by the pooling layers. Sequence of pooling layers and convolutional layers can learn high level features representing the original input. The fully connected network (FNN) block which is composed of fully connected neural units is then placed at the end as its classifier or used to generate numerical output for regression problems by exploiting the learned feature map.

3.3 Relevant topics and algorithms:

Support Vector Machines (SVM): SVM is a supervised learning algorithm commonly used for classification tasks. SVMs have been applied in various domains, including image classification and pattern recognition, and could potentially be used for allergen detection based on image features.

Random Forest: Random Forest is an ensemble learning method that combines multiple decision trees to improve classification accuracy. Random Forest has been used in image analysis tasks and could be adapted for allergen detection by training on features extracted from food images.

K-Nearest Neighbors (KNN): KNN is a simple and intuitive algorithm used for classification and regression tasks. KNN works by finding the nearest neighbors to a data point based on feature similarity. KNN could be applied to allergen detection by comparing the features of food images to a database of known allergen-containing items.

Transfer Learning: Transfer learning is a technique where a pre-trained model is adapted to a new task with limited data. Transfer learning could be beneficial for allergen detection by leveraging pre-trained models on large image datasets and fine-tuning them on allergen-specific features.

In general, Convolutional Neural Networks (CNN) has shown promising results in terms of enhancing allergen detection in food items through image analysis. The research paper

"Allergen30: Detecting Food Items with Possible Allergens Using Deep Learning-Based Computer Vision" by Mishra et al. (2022) contributes to this field by training a deep learning-based object detection model to identify allergen-based food items in images.

3.4 Research paper analysis:

3.4.1 Research paper 1

Allergen30: Detecting Food Items with Possible Allergens Using Deep Learning-Based Computer Vision

Mayank Mishra, Tanmay Sarkar, Tanupriya Choudhury, Nikunj Bansal, Slim Smaoui, Maksim Rebezov, Mohammad Ali Shariati, Jose Manuel Lorenzo

Deep learning algorithms, such as CNN, have revolutionized the field of computer vision and have been successfully applied to various domains, including food allergen detection. Mishra et al. (2022) highlights the potential of CNN in automating the detection of allergen-based food items by leveraging the hierarchical feature extraction capabilities of deep neural networks. Convolutional Neural Networks (CNNs) are widely utilized in computer vision tasks due to their ability to extract high- and low-level features from images. The core operation of CNNs involves sliding predefined kernels across input image matrices, generating feature maps that capture relevant information. These convolutional layers are interspersed with activation functions like ReLU to introduce non-linearity and pooling operations, such as max pooling, to reduce spatial size and extract key features. The resultant feature representations are then fed into a neural network for final predictions. By training CNN models on annotated datasets of food images, researchers can develop robust systems capable of identifying allergen-containing foods with high precision and efficiency.

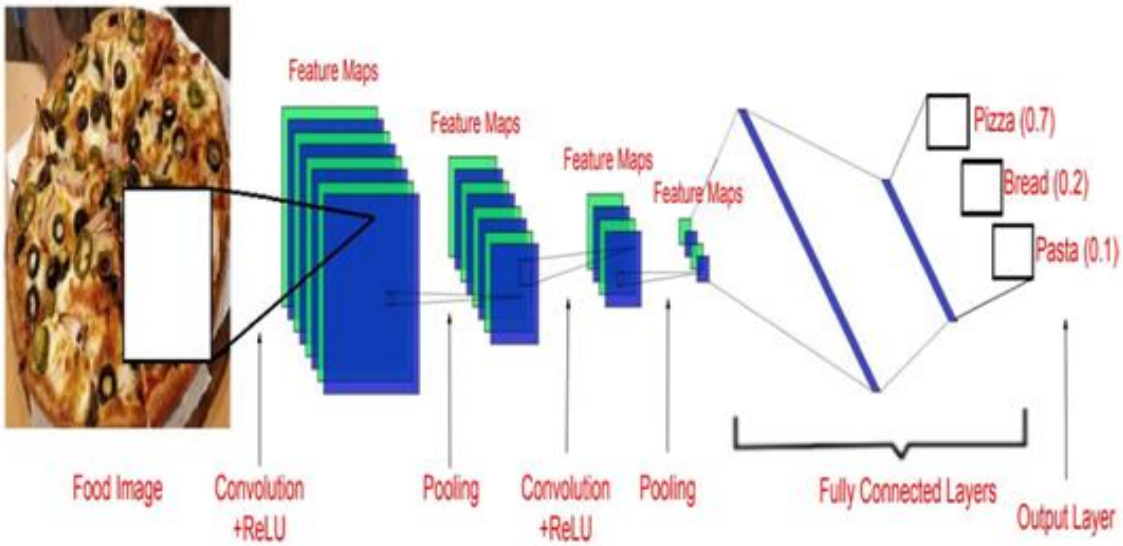


Figure 4: Representation of CNN architecture in Allergen30.

Central to the success of deep learning models for allergen detection is the availability of high-quality annotated datasets. Mishra et al. (2022) introduce the Allergen30 dataset, a curated collection of more than 6,000 annotated images of 30 commonly used food items that can trigger allergic reactions. The dataset includes detailed annotations of allergen-containing regions within the images, enabling the training of CNN models to recognize and localize allergens accurately. The creation and annotation of specialized datasets like Allergen30 play a crucial role in advancing research in food allergen detection using deep learning techniques.

In this research paper, Mishra et al. (2022) also compared the performance of different state-of-the-art object detection methods, including YOLOv5 and YOLOR, on the Allergen30 dataset. The researchers evaluate the accuracy and speed of these models to determine the most suitable approach for allergen detection in food images. Model selection and optimization are essential steps in developing effective allergen detection systems, as they influence the model's ability to identify allergen-containing food items while maintaining real-time performance.

3.4.1.1 You Only Look Once (YOLO):

YOLO is one of the most popular one-stage object detecting framework (Redmon *et al.*, 2015). This contrasts with two-stage object detection method which will initially propose regions of interest and subsequently classify them. On the other hand, the YOLO framework merges the region proposal and detection steps by operating on a dense sampling of potential locations. In result to this integration, the YOLO detector executes the interface significantly faster than the two-state counterparts.

3.4.1.2 YOLO Framework Workflow:

A CNN architecture is pre-trained initially for a specific classification task. The input image is segmented into an S x S grid. Likewise, Each grid cell is tasked with detecting the presence of an object whose center falls in that specific grid. It then predicts B bounding boxes along with a confidence score for each bounding box. Additionally, each grid cell will predict K conditional class probabilities, which represent the probability of a class given the presence of an object.

3.4.1.3 Bounding Box:

The bounding box is represented by four parameters: x, y, w, h. The (x, y) corresponds to the center coordinates of the object in relation to the grid cell. Similarly, the (w, h) represents the width and height respectively which are relative to the entire image.

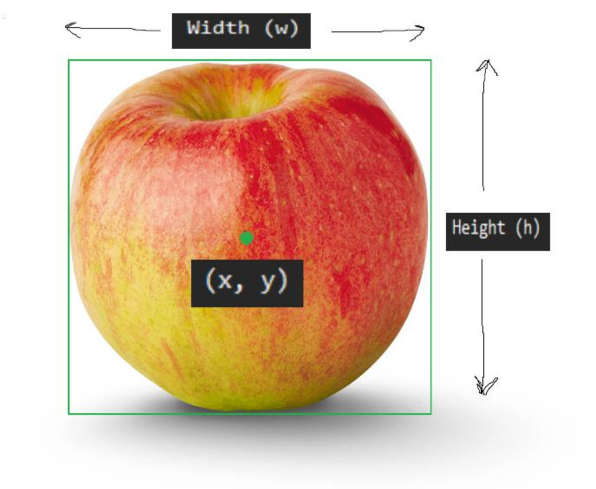


Figure 5: Bounding box image.

3.4.1.4 Confidence Score:

The confidence score simply reflects the model's certainty that an object exists within a bounding box. It's calculated as Pr(object)×IoU(pred, truth), where Pr(object) represents the likelihood of an object's presence and IoU(pred, truth) measures the overlap between the predicted and actual bounding boxes.

3.4.1.5 Conditional Class Probabilities:

When a cell contains an object, it assigns a probability to the object for each of the K class labels. Regardless of the number of bounding boxes, the model predicts a single set of K probabilities per cell. The model's output tensor dimension is S*S*(5B + K).

3.4.1.6 Loss function:

The YOLO loss function promotes the model to predict a precise bounding box coordinates and align predicted conditional class probabilities with the actual ones. The loss function comprises with two components: localization loss for accurate bounding box predications, and classification loss for conditional loss conditional class probabilities. The localization loss (L_loc) is calculated using the difference between the predicted and actual bounding box coordinates and dimensions. The classification loss (L) is computed based on the difference between the predicted and actual confidence scores and conditional class probabilities for each grid cell.

$$\boldsymbol{L}_{\text{loc}} = \lambda_{\text{coord}} \sum_{i=0}^{S^2} \sum_{j=0}^{B} \mathbb{1}_{ij}^{\text{obj}} \left[\left(x_i - \hat{x}_i\right)^2 + \left(y_i - \hat{y}_i\right)^2 \right] + \lambda_{\text{coord}} \sum_{i=0}^{S^2} \sum_{j=0}^{B} \mathbb{1}_{ij}^{\text{obj}} \left[\left(\sqrt{w_i} - \sqrt{\hat{w}_i}\right)^2 + \left(\sqrt{h_i} - \sqrt{\hat{h}_i}\right)^2 \right]$$

$$\boldsymbol{L}_{\textbf{cls}} = \sum_{i=0}^{S^2} \sum_{j=0}^{B} \mathbb{1}_{ij}^{\text{obj}} \left(C_i - \hat{C}_i\right)^2 + \lambda_{\text{noob}j} \sum_{i=0}^{S^2} \sum_{j=0}^{B} \mathbb{1}_{ij}^{\text{noob}j} \left(C_i - \hat{C}_i\right)^2 + \sum_{i=0}^{S^2} \sum_{c \in \text{classes}} \mathbb{1}_{ij}^{obj} \left(p_i(c) - \hat{p}_i(c)\right)^2$$

$$L_{\text{final}} = L_{\text{loc}} + L_{\text{cls}}$$

The equations as depicted above are indicator functions denoting whether the *j*th bounding box of the *i*th grid cell is crucial for object detection and whether the *i*th grid cell contains an object respectively. The confidence score for any of a grid cell *i* is represented by C*i*, and the predicted confidence is denoted by ^(C*i)*. P*i*(c) which represents the conditional probability of a grid cell *I* containing an object *c* from a set of given classes, while p*i*(c) indicates the predicted conditional class probability.

3.4.1.7 System Overview:

The figure as depicted below is broadly categorized into two stages, dataset creation and object detection training model.

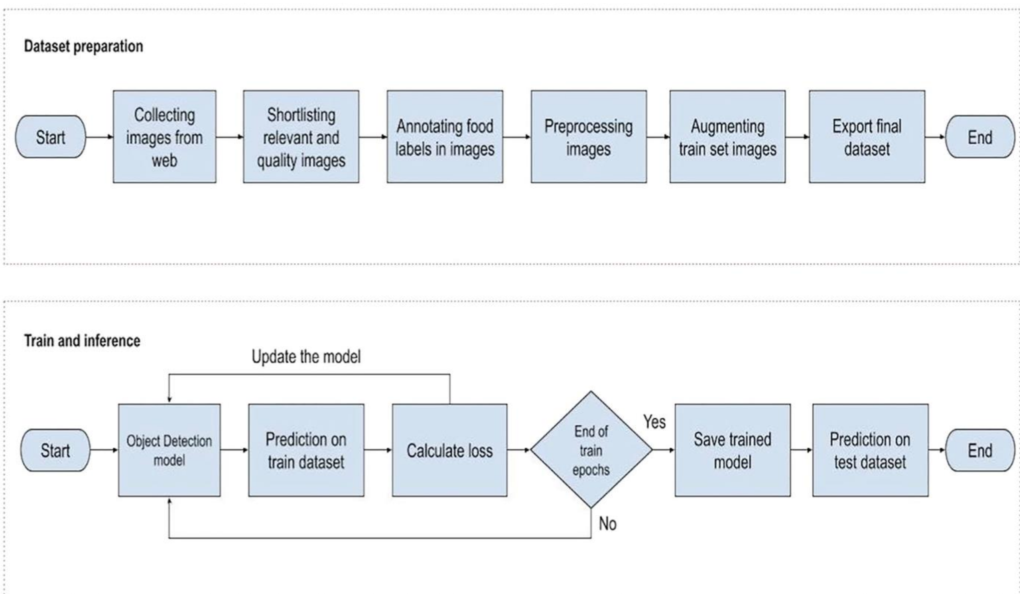


Figure 6: The flow of approach.

In the dataset creation phase, relevant food images were gathered from the internet and bounding box annotation is done around the food items. These annotated images serve as the foundation for the subsequent object detection training.

Likewise, the second phase involves defining a model architecture along with relevant loss function, optimizer and hyperparameters this model then makes predictions on the training set and self-adjusts to reduce the loss value. After a specified number of training steps, the trained model will be used to make predictions on the test set. The performance of the model on this unseen data provides an indication of the effectiveness of the trained model.

3.4.1.8 Dataset Description:

The researcher has modeled a dataset named as Allergen30. The dataset basically consists images of food items that are known to trigger allergic reactions including annotation boxes in each image that precisely pinpoints the position of the food item. The selection of food items for this dataset was based on three factors:

a) Food items known to contain a significant amount of allergen.
b) Food items consumed on a regular basis.
c) Food items which can be visually distinguishable.

S. no	Allergen	Food label	Description
1	Ovomucoid	Egg	Images of egg with yolk (e.g., sunny side up eggs)
2	Ovomucoid	Whole egg boiled	Images of soft and hard boiled eggs
3	Lactose | histamine	Milk	Images of milk in a glass
4	Lactose	Ice-cream	Images of ice cream scoops
5	Lactose	Cheese	Images of Swiss cheese
6	Lactose | caffeine	Milk based beverage	Images of tea/coffee with milk in a cup
7	Lactose | caffeine	Chocolate	Images of chocolate bars
8	Caffeine	Non milk based beverage	Images of tea/milk without milk in a cup
9	Histamine | gluten	Cooked Meat	Images of cooked meat
10	Histamine | gluten	Raw Meat	Images of raw meat
11	Histamine	Alcohol	Images of alcohol bottles
12	Histamine	Alcohol glass	Images of wine glasses with alcohol
13	Histamine	Spinach	Images of spinach bundle
14	Histamine	Avocado	Images of sliced avocado
15	Histamine	Eggplant	Images of eggplant
16	Salicylate	Blueberry	Images of blueberry
17	Salicylate	Blackberry	Images of blackberry
18	Salicylate	Strawberry	Images of strawberry
19	Salicylate	Pineapple	Images of pineapple
20	Salicylate	Capsicum	Images of bell pepper
21	Salicylate	Mushroom	Images of mushrooms
22	Salicylate	Dates	Images of dates
23	Salicylate	Almonds	Images of almonds
24	Salicylate	Pistachios	Images of pistachios
25	Salicylate	Tomato	Images of tomato and tomato slices
26	Gluten	Roti	Images of roti
27	Gluten	Pasta	Images of one serving of penne pasta
28	Gluten	Bread	Images of bread slices
29	Gluten	Bread loaf	Images of bread loaf
30	Gluten	Pizza	Images of pizza and pizza slices

Figure 7: Description of class label present in dataset.

3.4.1.8 Collection and Annotation:

The Allergen30 dataset was compiled using the images referenced from search engines like Google and Bing. Likewise, the images were selected based on JavaScript queries for each food item from a predefined list. The dataset was then refined by removing the images with incomplete RGB channels. Likewise, the images collected from different search engines were compiled. While merging those images, several duplicate images were encountered. The duplicate images were removed using image hashing. Additionally, EAST text detector was used to segregate images which were irrelevant, especially those with excessive texts (Zhou et al. 2017).

After the collection of dataset, the images were annotated Roboflow's online platform which uses their self-serve annotation tool. Likewise, bounding boxes were created around the food items in the images with the corresponding labels assigned using the class selector tool. For seeding up the annotation process, the researcher used Roboflow's model assist labeling tool. This tool trains a model on a sample of the annotated data which will automatically add annotations when more images are added to the dataset. The dataset collection and annotations were manually reviewed for accuracy and quality.

3.4.1.9 Data preprocessing, Augmentation and its Impact:

Post annotation, the dataset is then split into training 70%, validation 20%, and testing 10% sets. The images are resized to 416*416. To aid training, each image in the training set is augmented thrice which will provide diverse samples to enhance the model's robustness and generalizable.

Figure 8: Annotated image sample from the Allergen30 dataset.

Dataset Impact:

The Allergen30 dataset represents pioneering efforts in utilizing deep learning-based computer vision techniques to detect allergens in food from images. This can help a broad audience prevent avoidable allergic reactions by increasing allergen awareness. This dataset's specific focus eliminates the need for training models on extensive food image collections and promotes research into computer vision methods to comprehend with the challenging visual cues related to food items.

3.4.1.10 Summary for this research:

In summary, the research paper portrays a novel approach to detecting food items with potential allergens using deep learning techniques. The study focuses on leveraging object detection using CNN algorithm, specifically the variants of the YOLO framework architecture to identify the allergens containing in food items from images. The researcher highlighted the essence of addressing food allergens to prevent allergic reactions and improve food safety.

In this research paper, the researchers have emphasized the need for expanding the dataset to include more food labels and images for enhancing the performance of the allergen detection models. Additionally, the research paper has significant implications in the field of food safety as well as allergen detection. Moreover, the research paper provided valuable insights into the application of deep learning for detecting allergens in food items which highlighted the potential of artificial intelligence (AI) technologies to revolutionize food safety practices.

Although deep learning-based approaches show a promising food allergen detection, several challenges persist in the field. Mishra et al. (2022) highlights the complexity of visual cues in food images, the need for model generalization to new allergens, and the importance of scalability for accommodating diverse food products. Future research directions may involve expanding existing datasets, refining model architectures, and exploring real-time deployment scenarios to enhance consumer protection and food safety practices.

The research conducted by Mishra et al. (2022) underscores the potential of leveraging CNN for allergen detection in food to protect consumers with food allergies. By advancing deep learning techniques and dataset creation efforts, researchers can contribute to the development of reliable and efficient systems for detecting allergen-containing food items. The findings from this study pave the way for further innovations in food allergen detection using computer vision, ultimately benefiting individuals with food allergies and promoting safer food consumption practices.

3.4.2 Research Paper 2

Food Classification from Images Using Convolutional Neural Networks

David J. Attokaren, Ian G. Fernandes, A. Sriram, Y.V. Srinivasa Murthy, and Shashidhar G. Koolagudi

Department of CSE, National Institute of Technology Karnataka, Surathkal, Mangalore, India- 575 025.

This research paper presents a method for classifying food images using Convolutional Neural Networks. It showcases a pivotal role in which food monitoring plays regarding health concerns highlighting its importance in everyday life. The authors has described a specific methodology that leverages CNN which is different from traditional artificial neural networks due to their direct estimation capability from image pixels.

3.4.2.1 Proposed Methodology:

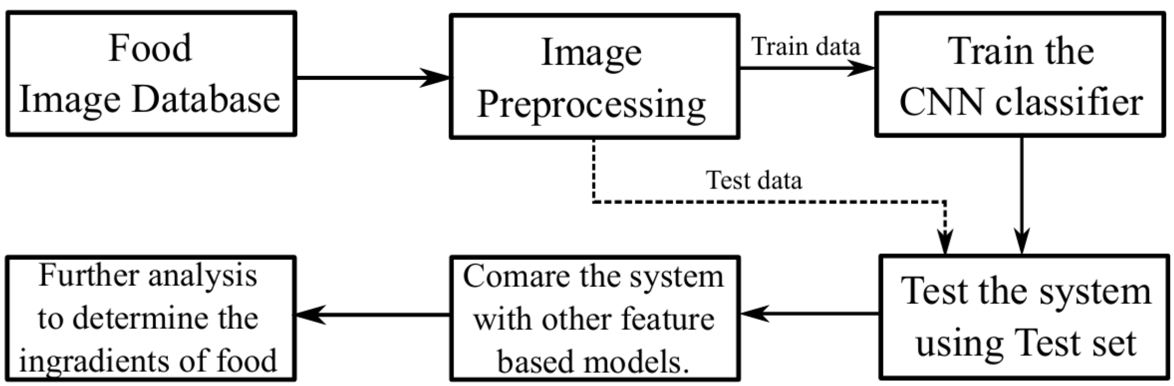


Figure 9: Methodology used in Research paper 2.

The above figure depicts a proper flow diagram done by the researcher. In using this approach, a trained model can be achieved which can identify the image according to the trained dataset.

3.4.2.2 Datasets Used:

In this research paper, the researchers used a dataset called "Food-101" to make the system more realistic. This dataset comprises 101,000 images of food with 101 categories. Each food category includes 750 training set and 250 test set of images. Likewise, a significant portion of training and testing images contain noise, intense colors and they were also mislabeled. The researchers labeled the training and testing images properly. Additionally, all these images were also resized to a dimension of 299x299 for consistency.

3.4.2.3 Results and Analysis:

Model Evaluation:

With several models saved by the researchers, they were able to select the models and evaluate them with the highest/loss accuracy. Additionally, a confusion matrix was utilized to know the output produced by CNNs.

3.4.2.4 Obtained Result:

The confusion matrix discussed previously will display the classes that were correctly vs incorrectly labeled. From the results, the researchers stated that it was evident that CNNs were more suitable for image classification. They offered features like filtering and Max-pooling, providing a better recognition rate for image classification than traditional neural networks.

Sl.No.	Model	Dataset	Accuracy (in %)
1.	SVM	Food-101	50.76
2.	Neural Networks	Food-101	56.40
3.	RFDC-based Approach	Food-101	56.76
4.	Resnet18	Food-101	67.23
5.	CNN	UEC-FOOD100	78.77
6.	CNN (ILSVRC)	Food-101	79.20
7.	CNN (Food-101)	EgocentricFood	90.90
8.	Proposed Approach	Food-101	**86.97**

Figure 10: results obtained for various classifiers used from Food-101 dataset.

The figure above showcases the results obtained for various classifiers used in the research from the Food-101 dataset. The current system developed using Convolutional Neural Networks on the Food-101 dataset achieved an accuracy of 86,97%. Initially, Support Vector Machines (SVMs) and neural networks were considered as they were designed to capture highly non-linear patterns. Likewise, Random Forest Decision Classifier (RFDC) was used since it was currently the most accepted classifier for nonlinear patterns as mentioned by the researcher. As a result, RFDC provided better accuracy compared to the other two classifiers. Later, Resnet18 model was tested with the dataset and it provided better accuracy when 10 classes from the Cifer10 dataset were used which resulted around 86%. However, this same model performed less effectively with dataset from Food-101 with a performance around 67.23%. Since CNN was capable of automatically estimating features and are highly efficient at mapping non-linear relations, an accuracy of 86,97% was achieved.

3.4.2.5 Research paper analysis:

In summary, the performance of the system is robust, and it deemed as satisfactory from the users perspective. However, Convolutional Neural Networks (CNNs), which are integral to the system, required high-performance of computing resources in order to process large amount of datasets. The researchers also claimed that CNNs are capable of training highly non-linear data, but this comes with repercussion of higher computational time in terms of network training. Nevertheless, the performance is paramount and one the system is adequately trained, the result can be generated in less time.

The task of classifying the image can further be enhanced using distinct features which can be categorized as food images. Since CNNs require high computational time, the researchers stated that a feature-based approach is highly recommended. Furthermore, they also stated that a comprehensive dataset containing all the food categories is not available.

4. Market Research

4.1 Secondary Market Research/Competitor Analysis:

In recent years, the development of applications related to food science and safety has been increasing significantly. These advancements are driven by the increasing prevalence of food allergies globally along with the demand for a reliable approach to help the individuals manage their dietary restrictions effectively.

One such example of the application is Open Food Facts. This is an application which enables users to scan the product barcodes to check whether the allergens are present in it or not. This app can detect up to 14 different potential allergens which provides users with an instant information about the food product they consume (Bradley, 2024).

Another application known as AllergyEats mainly focuses on ensuring safe dining experience for the users. This application allows users to search for restaurants near them by providing a ranked list based on allergy-friendly ratings (Bradley, 2024). This feature particularly offers a suggestion for individuals with food allergies who wants to dine outside without risking their exposure towards allergens. Additionally, there is a growing trend towards smartphone-based immunoassays for food allergen detection which offers real-time and portable solutions leveraging the capabilities of smartphones. (Ross, Bremer and Nielen, 2018).

These applications play a pivotal role in guiding the individuals with food allergies to make informed dietary choices and avoid the risk of potential allergic reactions. As the presence of food allergies continues to be a significant health concern, the demand for an effective and user-friendly food allergen detecting solutions are likely to grow.

5. Primary Market Research:

5.1 Data Collection:

The process of gathering the data involved the distribution of questionnaire which was created using Google Forms and it was shared across multiple social media platforms. This approach ensured extensive reach and accessibility which allowed the collection of responses from a diverse pool of participants. A total of 100 responses were collected through the distribution of the questionnaire. An Excel sheet of the responses from the questionnaire is available in the **Appendix** section.

5.2 Questionnaire and its objectives:

1. **What is your age?**
   Objective: This question will aim to collect demographic information about the age of the respondents which will basically help to analyze response based on different age groups.
2. **What is your gender?**
   Objective: Similar to age, this question collects demographic data regarding the gender of the respondents.
3. **Do you have any known food allergies?**
   Objective: This question will be addressing the primary focus of the research by identifying the respondents who have any known food allergies. Analyzing the presence of food allergies among the survey population is essential for evaluating the relevance and potential impact of food allergen detection solutions.
4. **Please specify the allergens you are allergic to if you have any known food allergies:**
   Objective: This survey question will seek to gather detailed information about the particular food allergens that respondents are allergic to.
5. **How concerned are you about allergens present in the food you consume? (On the scale of 1-5)**

Objective: This question analyzes the level of concern respondents give regarding allergens in the food they consume. Understanding the degree of concern can hep prioritize feature and functionalities in food allergen detection.

6. **How often do you encounter challenges in identifying allergens in food products?**

   Objective: This question evaluates the frequency of challenges faced by the respondents in terms of identifying allergens in food products which considers the importance of issues related to allergen detection in real-world scenarios.

7. **What methods do you currently use to identify allergens in food products? (Check all that apply)**

   Objective: This question evaluates the existing practices done by the respondents for allergen detection. Understanding the methods used by them can inform the design and features of food allergen detection.

8. **How satisfied are you with the effectiveness of these methods in allergen detection? (Scale: 1-5)**

   Objective: From this question, the respondents satisfaction level can be evaluated with the effectiveness of their current allergen detection methods, highlighting areas for improvement and help prioritize the features in food allergen detection.

9. **Would you be interested in using a mobile application for food allergen detection?**

   Objective: This question will basically explore respondents willingness and interest towards using mobile application for food allergen detection.

10. **What features would you expect from such an application?**

    Objective: This question will observe the respondent's preference and expectations regarding the features and functionalities of the food allergen detection application. Gathering such input can guide in terms of design and development process ensuring user requirement.

11. **How important is accuracy in allergen detection for you when considering such a system? (Scale: 1-5)**

    Objective: This question evaluates importance of accuracy influencing the perceptions of the respondents towards food allergen detection.

12. **Are there any additional features or functionalities you would like to see in such a system?**

Objective: This open-ended question allows respondents to provide some idea, suggestions or any additional feedback for enhancing food allergen detection system.

13. **Do you have any additional comments or suggestions regarding food allergen detection and related technology?**

    Objective: This final question offers respondents an opportunity to deliver their additional thoughts, concerns or suggestions related to food allergen detection.

5.3 Data Analysis:

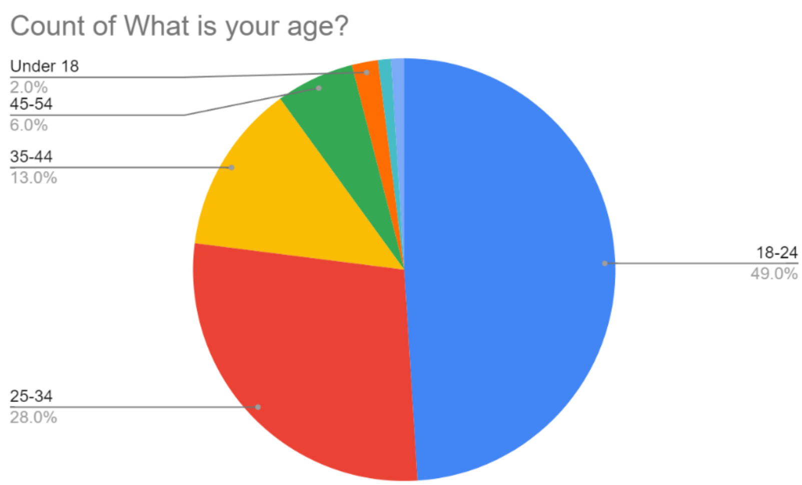


Figure 11: Age distribution of respondents.

The depicted figure above indicates a pie chart the visualizes the age distribution of a group of people who were asked about their age. The chart indicates that the majority of respondents are young adults between the ages of 18 and 24. The particular reason behind this is that most of the survey participants were university students.

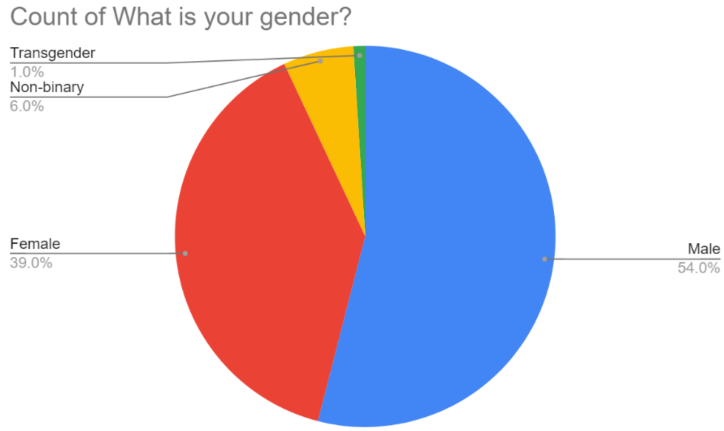


Figure 12: Gender distribution of respondents.

The above pie chart in Figure-12 illustrates the distribution of responses to a gender related question. The chart represents that more than half of the respondents were identified as male, followed by a substantial number of females and smaller percentage for non-binary and transgender individuals. This visualization helps in understanding the gender composition of the surveyed group.

Figure 13: Pie chart showing the respondents who have and doesn't have food allergies.

The figure above refers a pie chart providing a visual representation of a yes/no question response. This chart provides a clear and immediate understanding of the proportion of respondents who have known food allergies versus those who do not. It also shows that majority (65%) of the respondents do not have known food allergies whereas, substantial minority (35%) do have food allergies. This visual representation is really convenient in terms of health and wellness to understand prevalence of conditions like food allergens.

Please specify the allergens you are allergic to if you have any known food allergies:
I am allergic to peanuts.
Eggs
I am diabetic but I must strictly avoid eating sweet foods and potatoes.
Gluten
Yes, I am allergic to dairy products.
No, I don't have any known food allergies
I am not allergic to any foods I consume.
Yes, I am allergic to peanuts.
I am allergic to soy
No, I have no food allergies. However, I do have a friend allergic to eggs.
I don't have any allergies
Yes, I am allergic to fish.
I can't consume dairy products.
No, no such food allergies
yes, I am allergic to dairy products
I am allergic to peanuts
No food allergies
Dairy products
I am allergic to mushrooms.
I am allergic to egg.
I don't have any food allergies but my grandmother is allergic to peanuts.

Figure 14: Table chart showing the food allergies of the respondents.

The figure depicted above is an illustration of table chart which shows the collection of individual responses to a question about known food allergies. Several respondents have mentioned that they are allergic to peanuts. Likewise, allergens to eggs, dairy products, gluten, soy, fish, papaya, tree nuts and mushrooms were also reported. However, one individual also mentioned dietary restrictions due to diabetes. Some respondents who is not allergic to any known food items also contributed to the survey by mentioning their friend's food allergy.

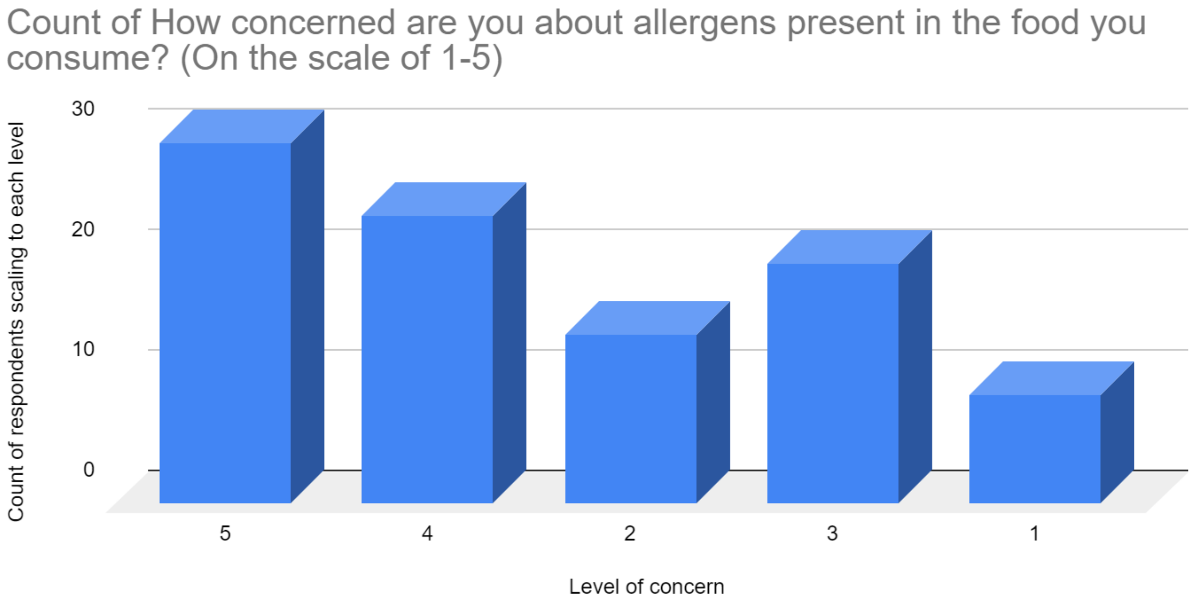


Figure 15: Level of concern of respondents regarding food allergens.

The bar graph presented above illustrates different levels of concern the respondents have regarding allergens in their food, on a scale from 1-5. The x-axis of the graph denotes the level of concern with 1 indicating as the least concern and 5 indicating the highest concern. Likewise, the y-axis represents the count of people corresponding to each level. From the figure, it can be clearly observed that majority of respondents are very concerned about the allergens in their food.

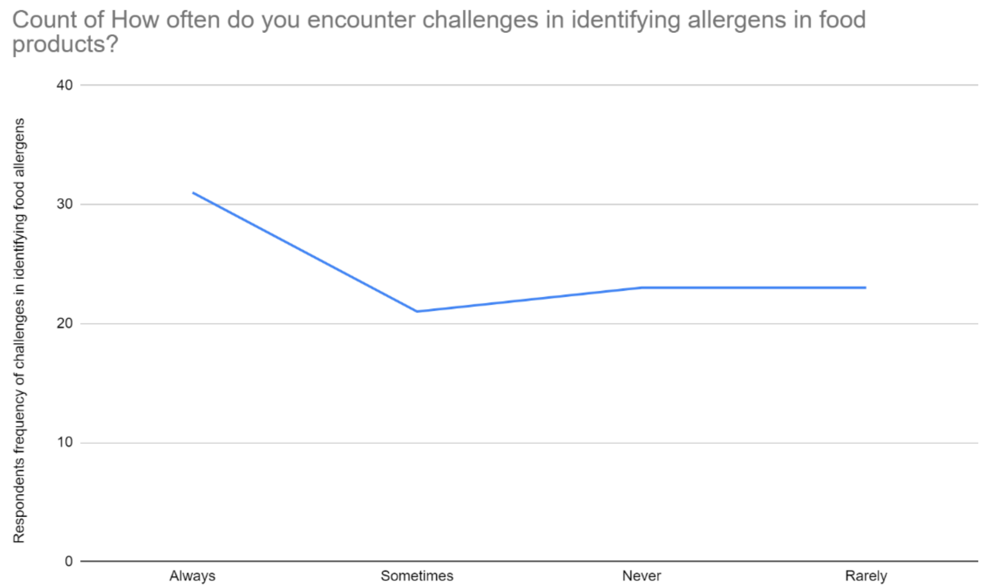


Figure 16: Line graph of respondents who encounter challenges identifying allergens in food.

The figure above represents a line graph that illustrates the count of respondents who encounter challenges in identifying allergens in food products. The line graph shows a significant number of respondents, over 30 of them always face challenges identifying allergens in food. The number sharply decreases for those who face challenges sometimes, with respondents consisting of around 20. However, respondents who indicated who never or rarely face this challenge appeared to be similar which were over 20 but less than 25. This visual data underscores the need for a better allergen identification method in food items to assist individuals who frequently encounter such challenges.

What methods do you currently use to identify allergens in food products? (Check all that apply)
Reading food labels, Avoiding certain food categories or cuisines, Searching it in the internet
Reading food labels, Avoiding certain food categories or cuisines, Searching it in the internet, Asking the waiter when I dine outside in restaurants with family and friends.
Reading food labels, Avoiding certain food categories or cuisines
Reading food labels, Searching it in the internet
Reading food labels, Searching it in the internet, I ask the restaurant staff about the ingredients of the food I am gonna consume.
Searching it in the internet
Searching it in the internet, I do have a friend who is allergic to egg. He searches it in the internet.
Reading food labels, Searching it in the internet, Asking restaurant staff about ingredients when dining outside
Avoiding certain food categories or cuisines, Searching it in the internet
Reading food labels, Avoiding certain food categories or cuisines, Searching it in the internet, Consulting with my doctor.
Reading food labels, Avoiding certain food categories or cuisines, Searching it in the internet, I also ask the restaurant staff about the ingredients when I go to eat outside.
Reading food labels, Consulting allergen information provided by manufacturers, Avoiding certain food categories or cuisines, Searching it in the internet, I consult with my doctors and restaurant staffs
Reading food labels, Avoiding certain food categories or cuisines, Searching it in the internet, I ask the restaurant staff if I encounter any unfamiliar ingredient in my food.
Avoiding certain food categories or cuisines, Searching it in the internet, I ask staffs in the restaurants whether the food I consume contains mushrooms or not.
Reading food labels, Avoiding certain food categories or cuisines, Searching it in the internet, Reading food labels carefully and carrying an epinephrine injector
Reading food labels, Consulting allergen information provided by manufacturers, Avoiding certain food categories or cuisines, Searching it in the internet
Consulting allergen information provided by manufacturers, Avoiding certain food categories or cuisines, Searching it in the internet
Reading food labels, Avoiding certain food categories or cuisines, Searching it in the internet, I ask restaurant staffs about the food ingredients in the menu.
Consulting allergen information provided by manufacturers, Searching it in the internet
Reading food labels, Avoiding certain food categories or cuisines, Searching it in the internet, ask dem chef

Figure 17: Few responses about the methods respondents use to identify allergens in food.

The table chart figure depicted above is a compilation of various methods respondents employ in terms of identifying allergens in food products. The respondents have mentioned their preferred methods, with some of them opting a single approach while others using multiple strategies. Among all these responses, reading food labels and searching it on the internet appeared to be the most common practices. Likewise, the respondents also added that they consult with the restaurant staff while dining out. These diversity of responses highlights the importance of easy accessible allergen information to ensure food safety concerning allergens.

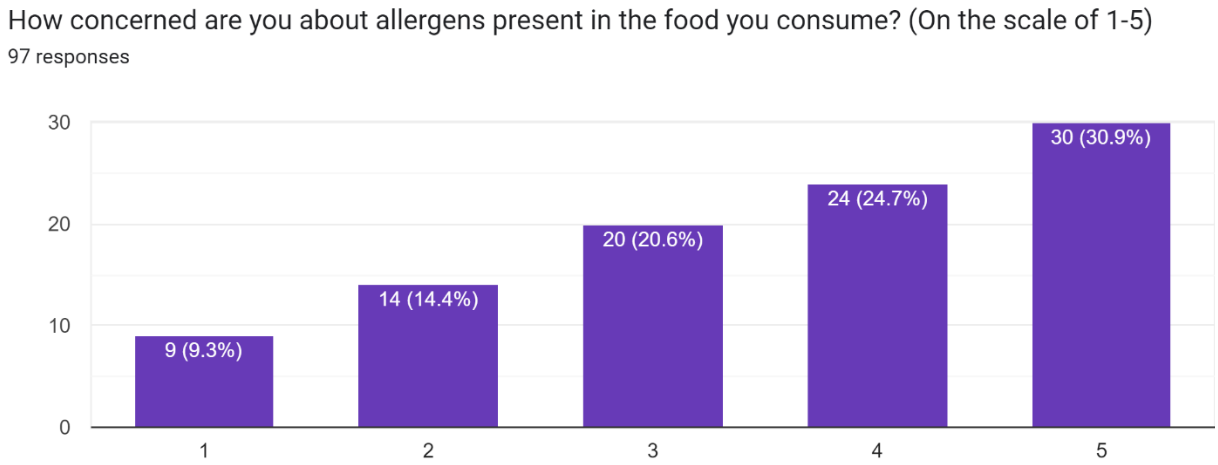


Figure 18: levels of concern respondents have regarding allergens in their food.

The bar graph depicted in the figure above illustrates the levels of concern respondents have regarding allergens in their food on a scale of 1 to 5, with 1 indicating as least concerned and 5 indicating highest concern. From this figure, it can clearly be observed that majority of respondents were highly concerned about the allergens present in food. Some respondents who aren't allergic to food substances gave a neutral level of concern.

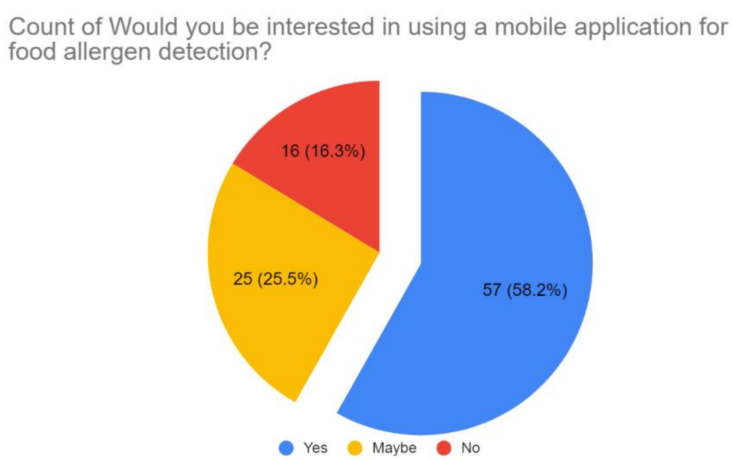


Figure 19: Pie chart of respondents interested in using mobile application.

The pie chart above depicts the survey responses in which the respondents were asked whether they are interested in using a mobile application for food allergen detection. 58.2% of respondents answered that they are interested in using the application, which indicated a positive response. Likewise, 25.5% of the respondents were uncertain about it. Lastly, the smallest group, 16.3% of the respondents were not interested. This data suggests that there is a pressing demand for a mobile application which can assist individuals to identify allergens in food since the majority of the respondents are interested in using technology for this purpose.

	What features would you expect from such an application?
1	An app that can identify whether allergens are present in a certain food when their picture is shown.
2	An app that provides immediate answer on whether the food contains egg or not.
3	Gives me information about the food I should eat or not.
4	Identify allergens for different cuisines.
5	Real time food allergies detection and easy to use app interface.
6	User-friendly application I guess.
7	An app that alerts and warn me about the food I eat.
8	Food allergen detection in real-time.
9	An app that warns the user about the food they can't consume.
10	Alerts and warning about food allergens for the consumers.
11	Real-time allergen detection from food images
12	Instant allergen detection
13	Real-time food allergy detection feature.
14	Easy-to-use interface with instant allergen detection.
15	Easy-to-use interface.
16	Food allergy side effect warning.
17	Real-time and quick detection of food allergens.
18	Instant detection of allergic substances present in my food.

Figure 20: Features respondents expects in the app.

When asked about the features the respondents expect from such applications, most of the respondents answered that they want the application to have an easy navigation with simple user-friendly interface. However, the main emphasis was on real-time, quick, and efficient allergen detection with food images for allergen detection.

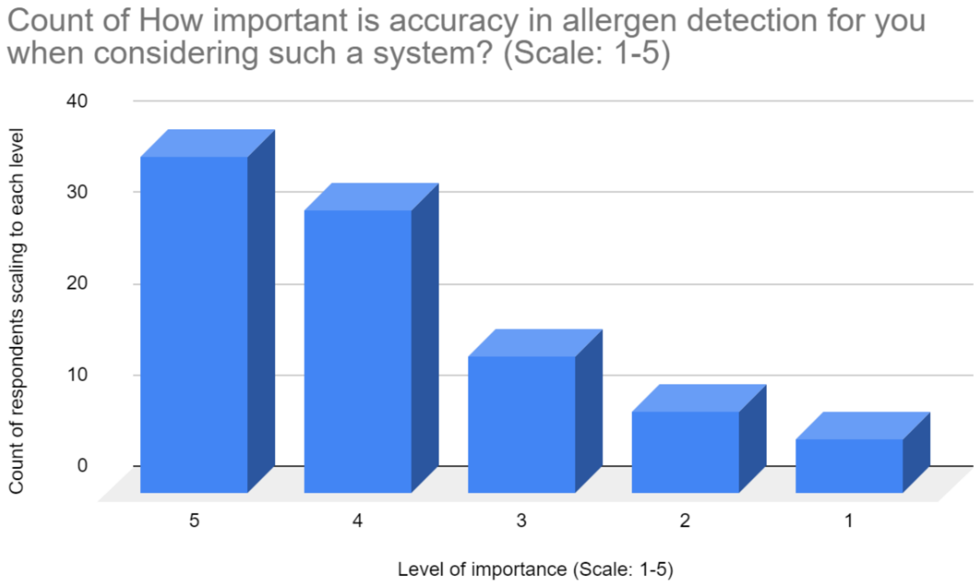
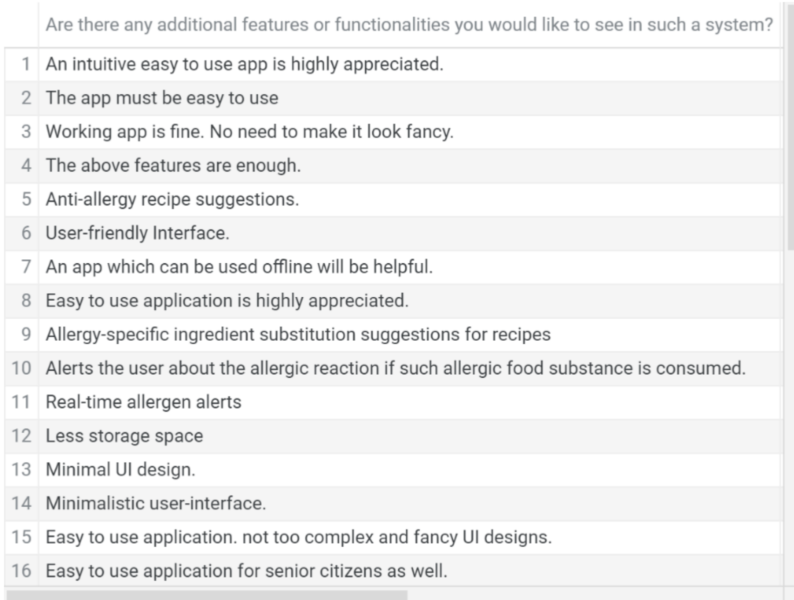


Figure 21: Importance of accuracy in food allergen detection.

The figure above represents a bar graph of the questionnaire responses regarding the importance of the accuracy in food allergen detection on a scale of 1 to 5, where 1 indicates as not important and 5 indicates very important. The figure clearly reveals that the majority of respondents, almost forty and thirty of them, consider the accuracy to be very important since they scaled it 5 and 4. The number of respondents reduces as the importance scaling lowers, with very few of them considering the accuracy not to be important. This data suggests that the accuracy of allergen detection is in fact a crucial factor when developing such application.



	Are there any additional features or functionalities you would like to see in such a system?
1	An intuitive easy to use app is highly appreciated.
2	The app must be easy to use
3	Working app is fine. No need to make it look fancy.
4	The above features are enough.
5	Anti-allergy recipe suggestions.
6	User-friendly Interface.
7	An app which can be used offline will be helpful.
8	Easy to use application is highly appreciated.
9	Allergy-specific ingredient substitution suggestions for recipes
10	Alerts the user about the allergic reaction if such allergic food substance is consumed.
11	Real-time allergen alerts
12	Less storage space
13	Minimal UI design.
14	Minimalistic user-interface.
15	Easy to use application. not too complex and fancy UI designs.
16	Easy to use application for senior citizens as well.

Figure 22: Additional features users recommend.

When the respondents were asked whether they want to recommend any additional features or functionalities in the application, the figure depicted above showcases some of the responses. This emphasizes the essence of an intuitive and user-friendly interface to not be overly complex to use for senior citizens. The respondents also expressed a suggestion for the application that can be used offline also consisting of less storage space.

5.4 Overall Analysis:

The questionnaire analysis provided a detailed understanding of the concerns, requirements and, attitude and behaviors regarding food allergen detection among the respondents. The pie chart illustrated that the age and gender distribution of respondents revealed that most of them were young adults between the age of 18-24 years. This demographic data suggested a high level of interest in food allergen detection among younger individuals.

Moreover, it appears that a significant number of respondents reported having known food allergies, which highlighted the prevalence of health concerns within the surveyed group. The variety of food allergens reported further emphasizes a diverse nature of food allergies and it's importance of developing a wide range of allergens in allergen detection systems. Likewise, the level of concern about food allergies was also high among the respondents which is shown in the bar graph above. This finding emphasizes the essence individuals place for allergen detection and awareness in terms of maintaining their dietary safety. Majority of the respondents were interested in using a mobile application for food allergen detection, as indicated in the responses in the survey. Their preference for desired features in such an application revolved around wanting an easily navigable, user-friendly interface with the main emphasis regarding real-time, quick, and efficient allergen detection of food images for allergen detection.

The insights provided by the respondents will offer valuable guidance for the development of the application to assist individuals with food allergies in making safe dietary choices. Furthermore, this data also emphasizes the ongoing need for awareness about food allergies to ensure their wellbeing.

6. Artifact Planning:

6.1 Requirements:

Requirements act as a foundational blueprint for the Food Allergen Detection application outlining its functionalities and performance expectations. Requirements basically serve as a comprehensive guide for the development and refinement of the app.

6.1.1 Functional Requirements:

Functional requirements deal with the specific features and capabilities of the application, ensuring that it meets the users expectations.

S.N	Requirements	Priority*
1	User must be able to capture photo of the food using the app camera.	MUST
2	User must be able to upload picture of food from the gallery.	MUST
3	The app should detect the food allergen in real-time.	SHOULD
4	User must be able to input their allergic food substance before the allergen detection process starts.	MUST

6.1.2 Non-Functional Requirements:

Non-Functional requirements ensure that the app is operated reliably and efficiently.

S.N	Requirements	Priority*
1	The app must provide fast response times for tasks like allergen detection, food recognition and image processing.	MUST
2	The app should be compatible with various mobile operating systems.	COULD

3	The app must provide quick and efficient allergen detection, ensuring users to make informed dietary decision.	SHOULD
4	Users should not encounter critical system malfunctions, the system should achieve 'uptime' 99.99%.	MUST

6.1.3 Usability Requirements:

Usability requirement focuses on the user experience which ensures that the app is easy to use.

S.N	Requirements	Priority*
1	The app should incorporate a user-centric design.	MUST
2	The app must have a clear and intuitive navigation	MUST
3	The text should be clear and easy to read without any grammar & spelling errors.	MUST

6.2 Development Methodology:

The development methodology chosen for this project is Agile methodology using sprint planning. This methodology was chosen due to its flexibility and adaptability. Unlike waterfall, agile accommodates changes in requirements and priorities at any given stage of development process which is crucial for developing applications like food allergen detection as its flexibility allows the application to adjust and progress on a timely basis.

Moreover, sprint planning which is known as a fundamental component of agile will guarantee a steady work pace and timely feature delivery. By scheduling work for a fixed time period which is known as sprints, ongoing progress and updates can be ensured for a usable work feature to be delivered.

6.3 Testing Strategy:

6.3.1 Internal Testing (White-box testing):

For this project, internal testing will be performed to guarantee the precision and dependability of the food allergen detection app. This method will examine the internal structure of the algorithm and codes to identify potential errors and enhance performance. These are the following internal testing techniques which will be applied for this project:

- Unit Testing: Separate components of the app will be tested independently to confirm their overall functionality.
- Integration Testing: Various modules of the code will be combined and then tested together to ensure that they function correctly when integrated.
- Regression Testing: Functionalities which were validated previously will be executed again to ensure whether the recent changes or additions have not affected the code.

6.3.2 External Testing (Black-box testing):

External testing mainly focuses on evaluating the usability and functionality of the application from user's point of view. Using this method will reveal the defects in user experience, irrespective of their technical skills. These are the following external testing techniques which will be applied for this project:

- User Acceptance Testing: Real users will participate in testing the app to evaluate the efficiency and user satisfaction of the app.
- Usability Testing: This testing will focus on evaluating the user interface and overall experience of the application.
- Compatibility Testing: The app will be tested across various deices, OS and screens dimensions to ensure compatibility and consistent performance.
- Functional Testing: Overall feature and functionality of the application will be systematically tested, ensuring that they operate as anticipated and meets the specified requirement.

6.4 Evaluation Strategy:

For the evaluation plan of Food Allergen Detection application, **DECIDE** framework will be implemented. This will solely focus on continuous improvement of the app based on user feedback. DECIDE framework comprises of six stages, they are:

D- Determine the Goals:

Goals:

- To ensure reliable and efficient detection of allergens present in food products.
- To optimize performance providing allergen detection of food in real-time.
- To create an intuitive user-friendly interface for easy navigation.

E- Explore the Questions:

Questions asked to the individuals:

- Do you or someone whom you might know have any food allergies?
- How often do you encounter challenges in terms of identifying allergens in food products?
- What sort of features would you suggest to enhance your user experience with the food allergen detection app?

C- Choose the evaluation method and approach:

The chosen evaluation method and approach for this project are "Internal Testing" and "External Testing".

- Internal Testing: Unit testing, Integration testing, and Regression testing.
- External Testing: User Acceptance testing, Usability testing, Compatibility testing, and Functional testing.

I- Identify the Practical Issues:

The practical issues which will be identified for this project will based on the user feedback on the accuracy of food allergen detection and the usability of the application all done before the app's final release.

D- Decide the Ethical Issues:

Ethical considerations:

- To ensure that the algorithm for food allergen detection are transparent and based of reliable source to avoid misleading users.
- User privacy and confidentiality will be secured and respected.
- Sharing user data with third parties without proper consent or authorization will be prohibited.

E- Evaluation, Analyze, Interpret, and Present the Data:

The data will be collected through a questionnaire which will be shared across multiple social media platforms. This approach will provide valuable insights regarding user preferences and specific areas for improvement in the application.

6.5 Personas and Scenarios:

Persona 1:

Mr. Pradhan is a parent of a young child who has multiple food allergies. He is extremely health conscious and always prioritizes the well-being of his child when it comes to food consumption. He is meticulous about checking food labels to make sure that his child is consuming a safe and allergen-free product. One day, while browsing on the internet, Mr. Pradhan stumbles upon a food allergen detection app. The app's intuitive interface allowed him to effortlessly scan the food image and pinpoint the potential allergens present in it, after inputting a specific allergenic food substance. With this app, he now an quickly determine if a certain food product is safe for his child to consume, minimizing the likelihood of allergic reactions. The apps real-time information gave reassurance to Mr. Pradhan, knowing that he now has an efficient way to detect food allergens and make informed decisions about the food choices for his child.

Persona 2:

Varsha is a university student who has a severe gluten allergy. As a busy student who balances both her academics and extracurricular activities, she often relies on dining at college cafeterias and local restaurants nearby her college for her meals. However, she frequently faces challenges while identifying gluten-free options as some menus can be vague or cross contamination may occur during food preparation. The ease her worries and assure that she can safely consume her meals, Varsha discovers an application that detects food allergens in real-time. With the assistance of this app, she can quickly identify food items with potential gluten ingredients and confidently choose the dish which is safe for her to consume, allowing her to focus on her studies without worrying about her food allergies.

6.6 System Design:

6.6.1 Software Development Tools required:

- Flutter 3.19
- Android Studio
- Dart v 3.2.4
- Python v 3.12.2
- Visual Studio code
- PyCharm’s Community Edition
- Visual Paradigm Community Edition
- Google Colab

6.6.2 Operating System required:

- Windows: 64-bit Microsoft@ Windows@ 10,11.

6.6.3 Software required for clients:

- IOS 15.0 or Android 10
- Phone camera containing at least 12 megapixels.

6.6.4 Hardware Requirement:

- Personal Laptop: A device that supports sufficient processing power and memory to run machine learning algorithms and development tools (8 GB RAM or more, 1280 x 800 minimum screen resolution).
- Phone camera (at least 12 megapixel): For testing image capture/upload functionality, phone camera may be required for capturing food images.
- 100 GB of available disk space minimum (Windows Installation, IDE + Android SDK + Android Emulator, and other necessary software).

6.7 Use Case Diagram:

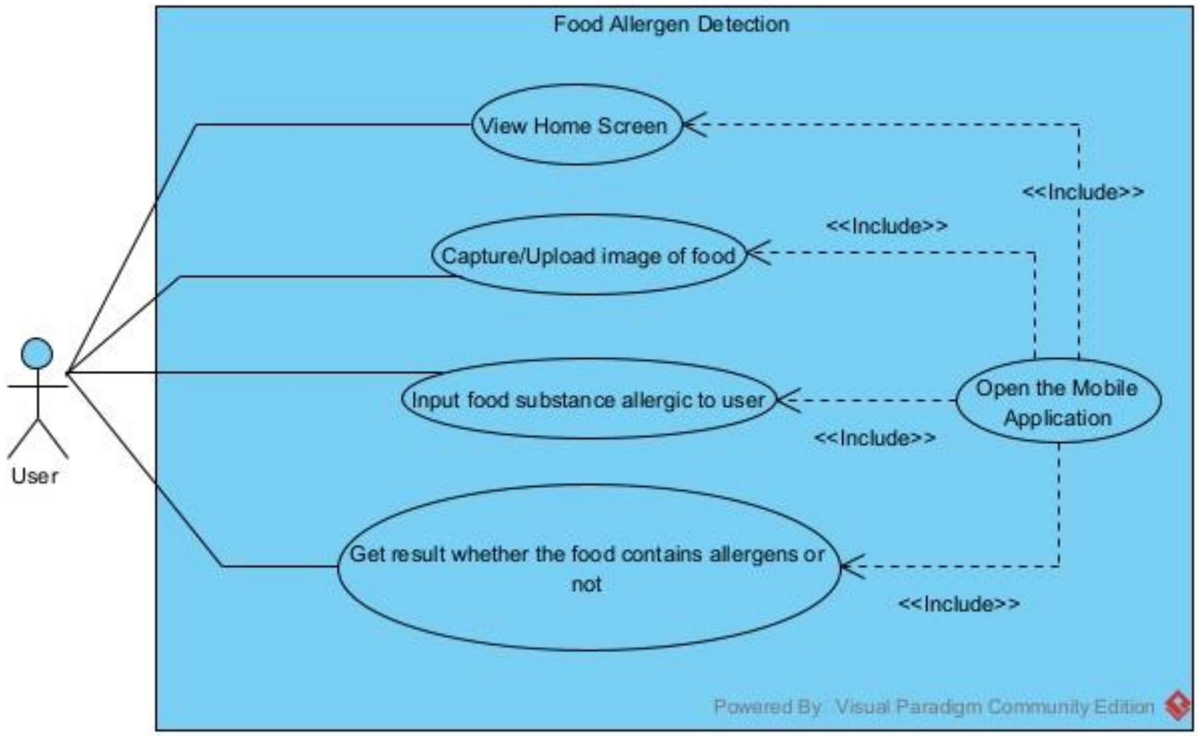


Figure 23: Use Case Diagram.

The use case diagram depicted above illustrates the functionality of the application designed for food allergen detection. It portrays an outline of the interaction between the user and the app's feature. The diagram shows an actor who is the user, starts by opening the mobile application. Once the app opens, the user will be able to view the home screen where they are given an option to capture or upload the image of the food for detection process. Following this, the user have to proceed to input the food substance they are allergic to. The application will they analyze the image and shows result indicating whether the food contains allergens or not. This diagram showcases how the user engages with the application.

6.8 Activity Diagram:

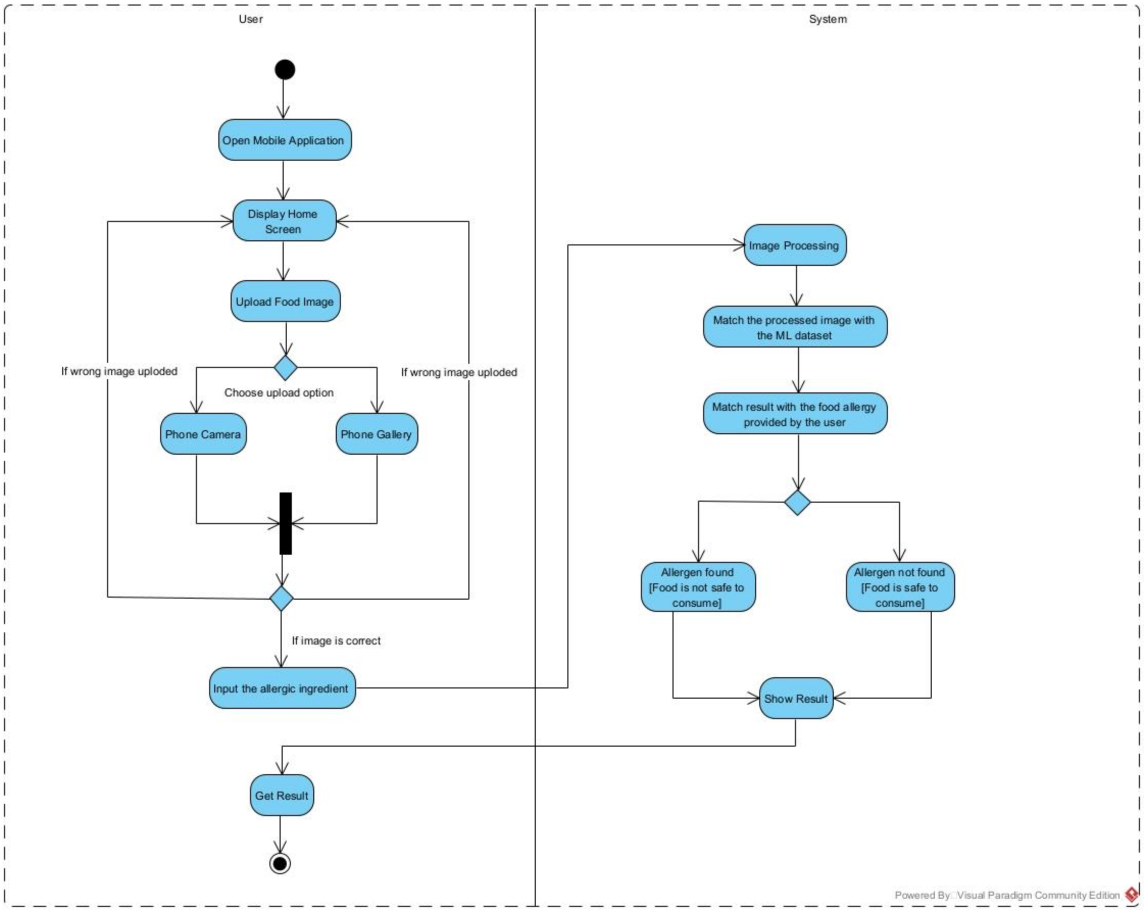


Figure 24: Activity Diagram.

The depicted figure above is an activity diagram which illustrates the overall workflow of food allergen detection application. The process starts when the user opens the mobile app which will navigate them to the home screen where the user will have an option to upload the food image. If an incorrect image is uploaded either from phone camera or gallery which is not related to food, the user is prompted back to the home screen again. Once the correct image is uploaded, the app will then let the user input information about the allergic food substance they can't consume. On the other hand, the system will then begin the image processing task and compares it with a machine learning dataset to identify potential allergens based on user input. If any allergens are detected, the system will indicate that the food is not safe to consume. Likewise, if no allergens were found, the system will indicate that the food is safe for consumption. Finally, these results will be displayed to the user accordingly.

7. Critical Analysis:

Food allergen detection is in fact a crucial area of research due to its presence of food allergies and severe intolerances they have. The advancement of technology, particularly in the realm of machine learning and computer vision, has opened up new opportunities regarding its innovative solution in the field. However, several challenges and consideration were encountered while examining it. One primary challenge is related to the vast diversity and complexity of food items and allergens. Foods greatly differ in their appearance, texture and composition which makes it difficult to develop an all-purpose detection solution. Moreover, from the research done for machine learning algorithms, Convolutional Neural Networks (CNNs) has shown a promising result for image recognition and classification tasks. However, their performance might also be constrained by the factors like the quality of the dataset, model generalization, and complexity of the algorithm. While technological advancement offer promising opportunities for improving food allergen detection, their challenges and considerations must also be addressed in order to develop an effective and reliable solution.

8. Conclusion:

Summing up everything which has been stated so far, this contextual report has offered a thorough analysis of various aspects regarding the development and implementation of food allergen detection application. Valuable insights were obtained through conducting literature review, primary and secondary market research with regards to the existing technologies, current market scenario, and user preferences. Likewise, adapting the use of Agile methodology will ensure a flexible and iterative development approach, enabling continuous refinement based on user feedback.

The integration of artificial intelligence like Machine Learning algorithms, Convolutional Neural Networks (CNNs), and image recognition techniques showcases the potential of leveraging a cutting-edge solution to enhance the accuracy and effectiveness for detecting food allergens in the application. Despite the identified challenges, the report highlights a promising prospect of the food allergen detection application to meet user needs and promote food safety.

As the project advances, the insights derived from this contextual report will serve as a blueprint for informed decision making, user centric design and effective project management. By prioritizing the user feedback and enhancing the features and functionalities of the application, this project will aim to develop a sturdy and user-friendly solution that offers a real-time allergen detection for individuals with food allergies to make knowledgeable dietary choices reducing the risk of severe anaphylaxis.

9. References:

- Dimassi, H. *et al.* (2020) 'Food allergies and allergens: Characterization and perceptions among diagnosed food allergic individuals in Lebanon,' *World Allergy Organization Journal*, 13(11), p. 100481. https://doi.org/10.1016/j.waojou.2020.100481.
- Van Hengel, A.J. (2007) 'Food allergen detection methods and the challenge to protect food-allergic consumers,' *Analytical and Bioanalytical Chemistry*, 389(1), pp. 111–118. https://doi.org/10.1007/s00216-007-1353-5.
- Ciocca, G., Napoletano, P. and Schettini, R. (2018) 'CNN-based features for retrieval and classification of food images,' *Computer Vision and Image Understanding*, 176–177, pp. 70–77. https://doi.org/10.1016/j.cviu.2018.09.001.
- Wang, L. et al. (2021) 'A comparative analysis of novel deep learning and ensemble learning models to predict the allergenicity of food proteins,' bioRxiv (Cold Spring Harbor Laboratory) [Preprint]. https://doi.org/10.1101/2021.03.10.434710.
- Mishra, M. *et al.* (2022) 'Allergen30: Detecting Food Items with Possible Allergens Using Deep Learning-Based Computer Vision,' *Food Analytical Methods*, 15(11), pp. 3045–3078. https://doi.org/10.1007/s12161-022-02353-9.
- Attokaren, D. J., Fernandes, I. G., Sriram, A., Murthy, Y. V. S., & Koolagudi, S. G. (2017). Food classification from images using convolutional neural networks. *Deapartment of CSE, National Institute of Technology Karnataka,*. https://doi.org/10.1109/tencon.2017.8228338
- Zhou, L. *et al.* (2019) 'Application of Deep Learning in Food: a review,' *Comprehensive Reviews in Food Science and Food Safety*, 18(6), pp. 1793–1811. https://doi.org/10.1111/1541-4337.12492.

- Schmidhuber, J. (2015) 'Deep learning in neural networks: An overview,' *Neural Networks*, 61, pp. 85–117. https://doi.org/10.1016/j.neunet.2014.09.003.
- Redmon, J. *et al.* (2015) 'You only look once: Unified, Real-Time Object Detection,' *arXiv (Cornell University)* [Preprint]. https://doi.org/10.48550/arxiv.1506.02640.
- Abrams, E.M. and Sicherer, S.H. (2016) 'Diagnosis and management of food allergy,' CMAJ. Canadian Medical Association Journal, 188(15), pp. 1087–1093. https://doi.org/10.1503/cmaj.160124.
- Bradley, J. (2024) *4 food allergy apps to help keep you safe*. https://www.verywellhealth.com/food-allergy-apps-to-help-keep-you-safe-1324320.
- Ross, G.M.S., Bremer, M.G.E.G. and Nielen, M.W.F. (2018) 'Consumer-friendly food allergen detection: moving towards smartphone-based immunoassays,' *Analytical and Bioanalytical Chemistry/Analytical & Bioanalytical Chemistry*, 410(22), pp. 5353–5371. https://doi.org/10.1007/s00216-018-0989-7.
- Ciocca, G., Napoletano, P. and Schettini, R. (2018) 'CNN-based features for retrieval and classification of food images,' Computer Vision and Image Understanding, 176–177, pp. 70–77. https://doi.org/10.1016/j.cviu.2018.09.001.
- Farinella, G.M. et al. (2016) 'Retrieval and classification of food images,' Computers in Biology and Medicine, 77, pp. 23–39. https://doi.org/10.1016/j.compbiomed.2016.07.006.

10. Appendix:

10.1 Appendix 1- Project Proposal Form

BSc Project Screening Form: Guidelines

Part 1 – Project Proposal

Student Name	Justin Shakya
Student Number	2146510
Degree Pathway	BSc. (Hons) Computer Science and Software Engineering
Supervisor Name	Devashish Kumar
Course Coordinator name	Ajaya Sharma
Title of Project	Food Allergen Detection: Leveraging CNN for allergen detection in food to protect the consumers.
Abstract of the project	Food allergies impose a significant health concern on the community. Even a small amount of certain food items can cause an allergic reaction within the human body. The symptoms can range from mild hives or itchiness to life-threatening anaphylaxis. In most cases, such reactions can be prevented by simply being aware of the allergen-based food items and avoiding the consumption of the same. With the prevalence of food allergies and the potential risks they pose to consumers especially those with severe allergies, there is a pressing need for efficient and accurate methods to identify allergic substances in food products. Individuals often face challenges in identifying allergens present in food products particularly when dining out or encountering unfamiliar items in the food. To address this concern, this study introduces a novel approach leveraging Convolutional Neural Networks (CNNs) for allergen detection in food products which is aimed to enhance consumer safety and facilitating informed dietary choices. The proposed project is to develop a food allergen detector so that people allergic to certain food substances can make informed decisions about the food they buy and consume. Ultimately, it will improve food safety towards the consumers which will also promote informed food choices and mitigates the risk of allergic reactions.
Project deliverables	• **Food Allergen Detection mobile application:** A mobile application having an intuitive user interface which enables a user to capture or upload the food images and receive information on whether the potential allergens in the food are present or not after they input the food substance they are allergic with.

	• **Final project report** • **Academic Poster**
Description of your artefact	**Project Background:** In recent years, there has been growing focus from both the food industry and regulatory bodies on identifying allergenic ingredients in food products. This heightened attention has led to enhanced measures aimed at safeguarding consumers with food allergies. The controlled production of food products and control activities executed by food inspection agencies rely on the availability of methods capable of detecting traces of allergenic ingredients. (Van Hengel, 2007). This project builds upon existing research in the fields of computer vision, machine learning, and food science, drawing inspiration from recent advancements in allergen detection and image recognition technologies. By combining interdisciplinary expertise and innovative approaches, the project endeavors to bridge the gap between technological innovation and real-world application in the realm of food safety and allergen management. **Problem Statement:** Individuals often face challenges in identifying allergens present in food when encountering unfamiliar items in the food. Current methods of allergen detection, such as manual inspection of food labels or reliance on allergen information provided by manufacturers, are often time-consuming and lacks real-time feedback. **Proposed Solution:** To address this concern a deep learning approach like CNN is suggested for recognizing allergens in food products through images. CNNs (Convolutional Neural Networks) utilize deep learning techniques to extract features from food images, allowing it to identify patterns associated with allergenic ingredients. CNNs learn patterns from a dataset of labelled food images and allergen information, enabling them to accurately detect potential allergens in new food images based on these learned features (Ciocca, Napoletano and Schettini, 2018). This method aims to furnish individuals with vital details to guide their dietary decisions and minimize the potential for allergic reactions.

	Aim & objectives of the project: Project Aim: The primary aim of this project is to develop a food allergen detector so that people allergic to certain food substances can make informed decisions about the food they buy and consume. Objective: • To capture/upload the food images. • Input the food substance to which a user is allergic with. • Detect the allergenic food substances present in the image. • Develop an intuitive mobile application that allows user to receive information on whether the potential allergens in the food are present or not. **List of features that the artefact will include:** • Image capture/upload functionality for users to input food images. • Real-time feedback on allergen detection results presented through the user interface. • User-friendly interface allowing users to interact with the system. **Added value that the project provides:** The project offers a convenient and reliable solution for food allergen detection. With the help of deep learning, the system reduces the reliance on manual inspection and provides users with immediate feedback on allergen content in food products. Enhanced Food Safety: By identifying allergens in food products, the project enhances food safety measures, helping individuals with food allergies make informed dietary choices and avoid potential allergic reactions. Improved Quality of Life: For individuals with food allergies, the ability to quickly and reliably detect allergens in food items can significantly improve their quality of life by reducing the risk of accidental exposure to allergenic ingredients and associated health complications. Awareness and Education: The project raises awareness about food allergies and the importance of allergen detection which serves as a valuable educational tool for individuals and food service providers.

	Intellectual challenges involved: • Developing an effective allergen detection algorithm that can differentiate between various allergens present in a single food product. • Limitations in the dataset used for training the CNN model. • As there are a wide variety of cuisines in the world including all the food items of each and every culture would be difficult.
What methodology (structured process) will you be following to realise your artefact?	**Development Methodology:** The research will adopt Agile methodology with the Scrum framework for its development process. This choice stems from Agile's reputation for breaking down large projects into manageable tasks, resulting in swifter software delivery. Agile principles prioritize flexibility, iterative development, and continuous improvement, aligning well with the dynamic nature of software development. Software development is inherently complex and demands multidimensional growth. Relying solely on a single model, such as waterfall or prototype, may not suffice to meet the diverse requirements of a product. Agile development, with its adaptive nature, early delivery approach, and flexible life cycle, emerges as the most suitable option for tailored product development needs (Srivastava, Bhardwaj and Saraswat, 2017). By embracing Agile, the research can be capitalized on its inherent strengths, facilitating quick and effective software development while remaining adaptable to evolving project requirements. **Research Methodology:** Qualitative and Descriptive research. **Structured Process:** • Collect the necessary resources required for the project such as, journals, books and literature related to food allergens and deep learning techniques. • Learn about the domain and technical knowledge and skills required for the project thoroughly. • Gather a dataset comprising a wide range of food images, intended to aid individuals in avoiding potential allergic reactions.

	• Train and optimize machine learning models like CNNs, to detect allergens in food based on the extracted images. • Build a mobile application and showcase the artefact to help the food allergenic consumers be aware about the food choices they make. **Testing and Evaluation:** The application will undergo testing such as unit testing and integration testing to ensure the overall functionality and effectiveness. Furthermore, performance evaluation will be employed to assess the application's performance in terms of responsiveness and scalability.
How does your project relate to your degree course and build upon the units/knowledge you have studied/acquired	The food allergen detection project directly correlates with my degree course in computer science and software engineering. Throughout my course of study, I have acquired knowledge and skills in various areas that directly contribute to the development of this project. During the first year of my course, I gained an understanding of object-oriented programming (OOP) concepts and database connectivity using languages such as Python and Java. Additionally, I learned to create ER diagrams and other UML diagrams such as activity diagrams, class diagrams and use-case diagrams which provided a solid foundation for software development. Likewise, my understanding of the fundamentals of computer studies, including topics like computational thinking, and problem-solving, provides a solid framework for approaching the challenges of this project. Moving into the second year, I further strengthened my proficiency in OOP and delved into more advanced topics such as design patterns and data structures. Furthermore, I acquired knowledge of software engineering principles and methodologies, including Agile, Kanban, and various project management tools. These concepts have equipped me with the necessary skills to develop scalable and robust software solutions. Furthermore, the exploration of mobile app development with Flutter also aligns with the project as it leverages modern technologies for building cross-platform mobile applications. The project integrates concepts from artificial intelligence, machine learning, and deep learning, which was also introduced in my coursework. Leveraging these technologies, particularly in the context of food allergen detection, allows me to apply theoretical knowledge to real world problems and explore innovative solutions.

<table>
<tr><td rowspan="1">Resources</td><td colspan="2">
Software Development Tools required:
• Flutter 3.19
• Android Studio
• Python v 3.12.2
• Visual Studio code
• PyCharm's Community Edition
• Visual Paradigm Community Edition
• Google Colab

Operating System required:
• Windows: 64-bit Microsoft@ Windows@ 10,11.

Software required for clients:
• IOS 15.0 or Android 10
• Phone camera containing at least 12 megapixel
Hardware Requirement:
• Personal Laptop: A device that supports sufficient processing power and memory to run machine learning algorithms and development tools (8 GB RAM or more, 1280 x 800 minimum screen resolution).
• Phone camera (at least 12 megapixel): For testing image capture/upload functionality, phone camera may be required for capturing food images.
• 100 GB of available disk space minimum (Windows Installation, IDE + Android SDK + Android Emulator, apk files and other necessary software).
</td></tr>
<tr><td>Have you completed & submitted your ethics form?</td><td>YES</td><td>NO</td></tr>
<tr><td colspan="3">If the project is a development of previous work by yourself or others, give details below. Failing to declare such previous work here may be treated as an academic offence</td></tr>
</table>

Supervisor Signature: Deen Ar K 2024/03/01

Course Coordinator Signature 2024/3/1.

After the proposal has been signed off by both the supervisor and course coordinator scan the proposal and upload on BREO <u>with</u> signatures. Projects that follow proposals that have not been approved may be cancelled and there will be no compensation for any time lost.

List of references:

- Van Hengel, A.J. (2007) 'Food allergen detection methods and the challenge to protect food-allergic consumers,' *Analytical and Bioanalytical Chemistry*, 389(1), pp. 111–118. https://doi.org/10.1007/s00216-007-1353-5.
- Ciocca, G., Napoletano, P. and Schettini, R. (2018) 'CNN-based features for retrieval and classification of food images,' *Computer Vision and Image Understanding*, 176–177, pp. 70–77. https://doi.org/10.1016/j.cviu.2018.09.001.
- Srivastava, A.K., Bhardwaj, S. and Saraswat, S. (2017) 'SCRUM model for agile methodology,' *Srivastava, a., Bhardwaj, S., & Saraswat, S. (2017). SCRUM Model for Agile Methodology. 2017 International Conference on Computing, Communication and Automation (ICCCA). doi:10.1109/ccaa.2017.8229928* [Preprint]. https://doi.org/10.1109/ccaa.2017.8229928.

Part 2 – List of relevant resources

Fill in this section after your project proposal has been approved by your supervisor. Use Harvard referencing (see https://lrweb.beds.ac.uk/a-guide-to-referencing). Modify the list below as appropriate. This list is part of Assignment 1 and will be submitted with the Project Proposal.

1. *Books:*

- Koppelman, S.J. and Hefle, S.L. (2006) *Detecting allergens in food.* Woodhead Pub Limited.

2. *Journal Papers:*

- Van Hengel, A.J. (2007) 'Food allergen detection methods and the challenge to protect food-allergic consumers,' *Analytical and Bioanalytical Chemistry*, 389(1), pp. 111–118. https://doi.org/10.1007/s00216-007-1353-5.
- Jia, W. *et al.* (2018) 'Automatic food detection in egocentric images using artificial intelligence technology,' *Public Health Nutrition*, pp. 1–12. https://doi.org/10.1017/s1368980018000538.
- Ciocca, G., Napoletano, P. and Schettini, R. (2018) 'CNN-based features for retrieval and classification of food images,' *Computer Vision and Image Understanding*, 176–177, pp. 70–77. https://doi.org/10.1016/j.cviu.2018.09.001.
- Abrams, E.M. and Sicherer, S.H. (2016) 'Diagnosis and management of food allergy,' *Canadian Medical Association Journal*, 188(15), pp. 1087–1093. https://doi.org/10.1503/cmaj.160124.
- Srivastava, A.K., Bhardwaj, S. and Saraswat, S. (2017) 'SCRUM model for agile methodology,' *Srivastava, a., Bhardwaj, S., & Saraswat, S. (2017). SCRUM Model for Agile Methodology. 2017 International Conference on Computing, Communication and Automation (ICCCA). doi:10.1109/ccaa.2017.8229928* [Preprint]. https://doi.org/10.1109/ccaa.2017.8229928.

3. *Web Sites with relevant information:*

   - *Deep learning* (2017). https://www.deeplearningbook.org/.
   - Atlassian (no date) *What is Agile? | Atlassian.*

     https://www.atlassian.com/agile.

4. *Relevant software:*

- Flutter 3.19
- Android Studio
- Python v 3.12.2
- Visual Studio code
- PyCharm's Community Edition
- Visual Paradigm Community Edition
- Google Colab

5. *Relevant hardware:*

- Personal Laptop: A device that supports sufficient processing power and memory to run machine learning algorithms and development tools (8 GB RAM or more, 1280 x 800 minimum screen resolution).
- Phone camera (at least 12 megapixel): For testing image capture/upload functionality, phone camera may be required for capturing food images.
- 100 GB of available disk space minimum (Windows Installation, IDE + Android SDK + Android Emulator, apk files and other necessary software).

6. *Other*

   a. ...
   b. ...

10.2 Appendix 2- Ethics Form:

FACULTY OF CREATIVE ARTS, TECHNOLOGIES AND SCIENCE

Form for Research Ethics Projects (Ethics Form)

Student Name	Justin Shakya
Student Number	2146510
Degree Pathway	BSc. (Hons) Computer Science and Software Engineering
Supervisor name	Devashish Kumar
Supervisor Signature	
Title of project	Food Allergen Detection: Leveraging CNN for allergen detection in food to protect the consumers.

SECTION A Proposal

Please summarise in the research proposal (Screening Form) the ethical issues involved and how they will be addressed.

In any proposal involving human participants please provide information on how:

- informed consent will be obtained
- confidentiality will be observed
- the nature of the research and the means of dissemination of the outcomes will be communicated to participants.

Please answer the following questions by circling **YES** or **NO** as appropriate.

Does the study involve vulnerable participants or those unable to give informed consent (e.g. children, people with learning disabilities, your own students)?	YES / NO
Will the study require permission of a gatekeeper for access to participants (e.g. schools, self-help groups, residential homes)?	YES / NO
Will it be necessary for participants to be involved without consent (e.g. covert observation in non-public places)?	YES / NO
Will the study involve sensitive topics (e.g. obtaining information about sexual activity, substance abuse)?	YES / NO
Will blood, tissue samples or any other substances be taken from participants?	YES / NO
Will the research involve intrusive interventions (e.g. the administration of drugs, hypnosis, physical exercise)?	YES / NO
Will financial or other inducements be offered to participants (except reasonable expenses or small tokens of appreciation)?	YES / NO
Will the research investigate any aspect of illegal activity (e.g. drugs, crime, underage alcohol consumption or sexual activity)?	YES / NO
Will participants be stressed beyond what is considered normal for them?	YES / NO
Will the study involve participants from the NHS (patients or staff) or will data be obtained from NHS premises?	YES / NO

If the answer to any of the questions above is "Yes", or if there are any other significant ethical issues, then further ethical consideration is required. Please document carefully how these issues will be addressed.

Signed (student):
Date: 01/03/2024

Countersigned (Supervisor): Dev. M. K
Date: 01/03/2024

10.3 Appendix 3- Weekly Progress Report

UNIVERSITY OF BEDFORDSHIRE

DEPARTMENT OF COMPUTER SCIENCE AND TECHNOLOGY

FINAL YEAR UGPROJECT

WEEKLY PROGRESS REPORT FORM

Student's Name: Justin Shakya	Supervisor's Name
Week #-5	Report No. 1

Summary of progress (including any problems)	For the first week of the progress report, the week was revolved around research topic selection which was quite difficult since the next semester will also be connected to this assignment. The topic was selected along with the three research papers regarding the topic. - Lastly, draft for project proposal was also prepared.
Plan for next week	- Study the three research papers thoroughly. - Try to identify the research gap between them - find the datasets. - Prepare project proposal.
Supervisor's comments	Move as per your plan.

Student's Signature .... Date 2024/2/23

Supervisor's Signature .... Date 2024/2/23.

UNIVERSITY OF BEDFORDSHIRE
DEPARTMENT OF COMPUTER SCIENCE AND TECHNOLOGY

FINAL YEAR UGPROJECT

WEEKLY PROGRESS REPORT FORM

Student's Name	Supervisor's Name
Justin Shakya	Devashish Kumar
Week 6	Report No. 2

Summary of progress (including any problems)	- More Research papers were gathered related to the topic. - The main focus of this week was to complete the project proposal.
Plan for next week	Start preparing Literature review!
Supervisor's comments	Try to complete literature review within 3 days

Student's Signature ....Date 01/03/2024..................

Supervisor's Signature ....Date 01/03/2024..................

UNIVERSITY OF BEDFORDSHIRE
DEPARTMENT OF COMPUTER SCIENCE AND TECHNOLOGY

FINAL YEAR UGPROJECT

WEEKLY PROGRESS REPORT FORM

Student's Name Justin Shakya	Supervisor's Name Devashish Kumar
Week -7	Report No. 3

Summary of progress (including any problems)	for this week, introduction for the contextual report was prepared which includes project background, problem statement, proposed solution, aim/objective and its intellectual challenges. However, improvements are yet to be made in it from supervisor's feedback. Likewise, questionnaire was also prepared.
Plan for next week	↳ Prepare project plan for your assignment. (Gantt Chart) ↳ Work on contextual report.
Supervisor's comments	• Organize content and share as discussed • Progress is good.

Student's Signature .... Date 06/03/2024

Supervisor's Signature ....Dev Ar Ku.... Date 06/03/2024

UNIVERSITY OF BEDFORDSHIRE
DEPARTMENT OF COMPUTER SCIENCE AND TECHNOLOGY

FINAL YEAR UGPROJECT

WEEKLY PROGRESS REPORT FORM

Student's Name Justin Shakya	Supervisor's Name Devashish Kumar
Week - 8	Report No. 4

Summary of progress (including any problems)	Prepared project plan for the assignment. ↳ Gantt Chart (for this semester) ↳ Gantt Chart (for next semester) Likewise, worked on contextual report as well. ↳ Prepared Literature review. However, more elaborations & improvements are yet to be made.
Plan for next week	↳ Gather responses from the questionnaire. ↳ Work on contextual report and also get feedback from supervisor & course instructor.
Supervisor's comments	Include suggestions on questionnaries and start collecting data

Student's Signature ....Date 14/03/2024......

Supervisor's Signature ....Date 14/03/2024..........

UNIVERSITY OF BEDFORDSHIRE

DEPARTMENT OF COMPUTER SCIENCE AND TECHNOLOGY

FINAL YEAR UGPROJECT

WEEKLY PROGRESS REPORT FORM

Student's Name Justin Shakya	Supervisor's Name Devashish Kumar
Week - 9	Report No. 5

Summary of progress (including any problems)	Gathered a total of 44 responses from the prepared questionnaire Likewise, worked on contextual report as well (Acknoledgement content was completed)
Plan for next week	↳ Gather more questionnaire responses. ↳ Work on contextual Report ↳ Prepare primary Market research.
Supervisor's comments	Try to gather responses of 100 people.

Student's Signature ....Date 25/03/2024.

Supervisor's Signature ....Date 29/03/2024.......

UNIVERSITY OF BEDFORDSHIRE
DEPARTMENT OF COMPUTER SCIENCE AND TECHNOLOGY

FINAL YEAR UG PROJECT

WEEKLY PROGRESS REPORT FORM

Student's Name Justin Shakya	Supervisor's Name Devashish Kumar
Week - 11	Report No. 6

Summary of progress (including any problems)	For this week, around 60 responses were gathered from the questionnaire. Worked on primary market research. However, more elaborations are needed in it.
Plan for next week	Work on contextual report. ↳ complete it ~~before~~ by 17th of April and verify it to the supervisor.
Supervisor's comments	Make changes as suggested in the contextual report.

Student's Signature ....Date 10/04/2024.

Supervisor's Signature ....Date 12/04/2024.....

10.4 Appendix 4- Questionnaire and Survey Responses

Questionnaire:

https://docs.google.com/forms/d/e/1FAIpQLSfd324U8VAfb9OArvcsKS_2ZnX3Sx4-68fVp_CPd9yKfSz9oA/viewform?usp=sf_link

Responses:

https://docs.google.com/spreadsheets/d/1yMe_7z38H3JCFnwf4E2WHXBQsrOW0udMgG4D_qr2Ovo/edit?usp=sharing