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FreshSight: An Accessibility-Focused Approach to Produce Freshness and Shelf-Life Detection for Food Safety and Waste Reduction

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ABSTRACT

Colour-blind individuals encounter daily challenges, particularly in distinguishing colour-based indicators of food spoilage. This limitation significantly impacts their ability to assess the freshness and safety of fruits and vegetables accurately. Concurrently, global concerns regarding food spoilage have intensified, with millions worldwide affected by foodborne illnesses each year. The modern lifestyle, characterized by its rapid pace and time constraints, exacerbates this issue, often leading to unnoticed spoilage and substantial waste. The resulting annual waste, estimated at one-third of all edible food, imposes significant societal and environmental burdens, underscoring the urgency for effective solutions. FreshSight enables users, including those with colour vision deficiencies, to assess the condition of fruits and vegetables through a Convolutional Neural Network (CNN)-based real-time image analysis engine and an intuitive interface. This system provides immediate visual feedback to help users make informed decisions and avoid the consumption of spoiled produce. It also offers inclusive design features that support individuals with visual impairments. Beyond individual benefits, FreshSight promotes responsible food handling and contributes to the broader goal of sustainable food systems. By combining advanced technology with user-centered design, the solution enhances both safety and accessibility in everyday food-related decisions. In addressing the critical challenges of food safety, inclusivity, and waste reduction, FreshSight aims to support healthier lifestyles and contribute positively to environmental and societal well-being in the modern world.

KEYWORDS— *Colour vision deficiency, Food spoilage, Image analysis, Food safety, Responsible consumption, Accessibility, Sustainability*

INTRODUCTION

Colour-blind individuals face unique challenges in daily life, with their difficulties often overlooked by those with normal colour vision. One notable challenge is the inability to recognize spoiled food based on colour changes [1]. In the modern world, food spoilage is a major issue due to its harmful consequences for consumers [2]. Foodborne illnesses have become a significant global concern, affecting millions of people worldwide. More than 200 diseases result from consuming spoiled food contaminated with harmful bacteria like Salmonella and Shigella. Each year, approximately 3-5 billion people suffer from infectious diarrhoea, and nearly 1.8 million people die due to food contamination [1]. The fast-paced, work-centric lifestyle of modern society often leaves individuals with inadequate time to monitor their daily food consumption. As a result, individuals often become unaware of both the quantity and quality of food stored inside their refrigerators [3]. In many households, food can remain in refrigerators, undergoing colour changes and developing foul odours due to bacterial growth. Unfortunately, people often discover the spoilage long after it occurs, leading to significant food waste[1]. This food wastage poses a substantial societal burden, with roughly one-third of all edible human food being wasted annually [4]. The underlying causes and challenges associated with food spoilage, and colour-blindness in recognizing spoiled food. have been highlighted below,

Colour-blindness - Colour-blind individuals face challenges in recognizing freshness cues for produce, such as colour changes, because of their condition, which affects their ability to perceive certain colours. This difficulty in distinguishing between fresh and spoiled produce can lead to colour-blind individuals unintentionally consuming items that have gone bad, posing potential health risks [1].

Foodborne illnesses - Colour-blind individuals and others may unknowingly consume produce that has deteriorated or become contaminated due to the challenge of recognizing freshness based on visual cues. This can increase the risk of foodborne illnesses. The lack of recognition and subsequent consumption of spoiled produce can lead to a higher frequency of foodborne illnesses among colour-blind individuals and anyone else who, by mistake, consumes spoiled food. These illnesses may have monetary costs as individuals require medical treatment, medication, and may need to take time off work, impacting their finances and overall well-being. Additionally, it can place a burden on healthcare systems [5].

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Modern, Fast-Paced Lifestyle - Today's fast-paced lifestyles leave individuals with minimal time to assess the freshness of produce. Demanding work schedules and busy routines often leave little time for proper monitoring. To cope with their fast-paced lives, many individuals rely on pre-packaged produce, which may not always have visible freshness indicators. This reliance can complicate the assessment of freshness of the produce [6].

Unawareness of produce quantity and quality - In households, produce items may linger in refrigerators for extended periods without being consumed. This extended storage affects the freshness and quality of the produce. The lack of awareness about the quantity and quality of stored produce often results in the frequent disposal of significant amounts of food. This leads to financial wastage and contributes to environmental concerns related to food waste [7].

BACKGROUND AND RELATED WORK

A. Freshness Assessment of Fruits and Vegetables

The term "fresh" is commonly used, especially concerning food, and holds significant importance for consumers, particularly in the acceptance of fruits and vegetables. It creates specific consumer expectations as a crucial factor impacting the quality of the fruits and vegetables [8]. A remarkable 59% of consumers give priority to the freshness of products when making their purchasing decisions [9].

Fruits and vegetables play a vital role in daily human meals, and as the incidence of diseases rises, people have become more attentive to natural and organic products, especially fruits and vegetables. The emphasis on the freshness of these products is driven by the growing awareness of their impact on human health [10]. The quality of fruits and vegetables has a direct influence on human health. With the increase in diseases in contemporary times, people are increasingly concerned about the freshness of the fruits and vegetables they consume [10]. Additionally, the nutritional value of perishable food items, like fruits and vegetables, is closely tied to their freshness levels [11]. The issue of waste in Fresh Fruits and Vegetables (FFVs) is a significant challenge in the food supply chain industry, contributing to a substantial portion of annual food losses. Approximately one-third of all edible human food is wasted annually, posing a burden on society [4]. This underscores the critical importance of assessing and managing the freshness of fruits and vegetables throughout the supply chain.

B. Colour Blindness and Freshness Perception

Colourblind people or people with a colour vision deficiency face many challenges in their daily activities [12]. Globally, approximately 300 million people about 1 in 12 men and 1 in 200 women experience some form of colour blindness, representing roughly 4.5% of the world's population.[13] Colour blindness, a condition affecting the ability to see certain colours like red, green, blue, or their combinations, presents challenges for individuals. The most prevalent type is red- green colour blindness, where these colours appear the same, while another common type is blue- yellow colour blindness, making it difficult to distinguish between these hues. Unfortunately, there is currently no known treatment for colour blindness [13]. This condition poses unique challenges for individuals, particularly in recognizing colour changes indicative of freshness. For those with colour blindness, identifying spoiled fruits and vegetables based on colour becomes a challenge, highlighting an aspect often overlooked by those with normal colour vision [1]. The difficulties faced by colour-blind individuals in perceiving freshness add a layer of complexity to their overall experience [14].

C. Global and Local Consumption Patterns of Fruits and Vegetables

The significance of fresh vegetables and fruits in human nutrition lies in their rich nutrient content, encompassing essential vitamins (B, C, K) and minerals (calcium, potassium, magnesium), along with dietary fibre. This nutritional profile contributes to a balanced diet, aiding in the prevention of chronic diseases like heart disease, cancer, diabetes, and obesity, particularly in developing countries. Over recent years, global production of fresh vegetables and fruits has surged by 30%, escalating from 30 million tons to 60 million metric tons [14]. This increase reflects a growing recognition of the importance of fruits and vegetables in promoting health and preventing chronic diseases. In the context of Sri Lankan agriculture, fruits and vegetables hold pivotal importance for both farmers and consumers. A significant portion of the Sri Lankan population incorporates vegetables into their daily diet, often accompanying the staple food, rice. According to the Household Income and Expenditure Survey 2016, approximately 8% of the total household expenditure on food and beverages in Sri Lanka is allocated to vegetables. This underscores the frequent purchase of fresh vegetables as a dietary staple in the country [15]. Additionally, the HIES (2009/10) reveals that an average Sri Lankan household spent Rs. 13,267 on food, with Rs. 386 allocated to fruits, constituting a budget share of 2.91%. Further, the allocation of the food budget to fruits in urban, rural, and estate sector households stood at 3.4%, 2.9%, and 1.5%, respectively. This implies that urban areas accord greater significance to fruits in their budgetary considerations [2]. Despite this expenditure, the average consumption of fruits and vegetables in Sri Lanka is around 150 grams per day, with per capita consumption approximately 112 grams per day. This figure is 50% lower than the World Health Organization's recommended daily intake of 400 grams. Factors contributing to this low consumption include limited availability, affordability, and awareness, particularly in rural areas[27]. In 2023, Sri Lanka observed an uptick in fruit consumption, reaching 12.8 million tons, against a national requirement of 19.6 million tons. This increase was largely attributed to higher outputs in bananas, mangoes, pineapples, and papayas. Concurrently, the country's fruit exports also saw a rise, with a total of 38,201 metric tons shipped abroad[28].

D. Limitations of Existing Methods and the Novelty of FreshSight

The Consumption of fruits and vegetables plays a pivotal role in daily human diets. With the rise in diseases, people are more cautious about natural products, especially fruits and veggies. Among these, the freshness of fruits and no-cooked vegetables is a big deal because it directly affects human health[10]. The quality of fruits is closely linked to how fresh they are. Consumers judge fresh produce's quality based on how it looks (blemishes, colour, size, and texture), ripeness, smell, and taste. Importantly, the quality changes a lot during the growth of the fruit, from before it's picked to after, and even during storage [17]. The usual ways of checking fruit and vegetable quality use our senses (sensory evaluation) or involve chemical analysis. However, these methods have issues like being easily affected by other things, not being very accurate, being slow, and needing a lot of resources. There are smarter ways of checking the quality of fresh produce including using things like Raman spectroscopy, near-infrared spectroscopy, Red, Green, and Blue (RGB) vision detection, electronic nose, acoustic characteristics, dielectric properties, and other new methods. Each of these has its strengths. Near-infrared spectroscopy is good at looking inside fruits and veggies. RGB vision detection is quick and automated, mainly checking how fruits and veggies look. Electronic nose technology acts like an animal's sense of smell, quickly and precisely notifying about the smell of fruits and veggies. Acoustic characteristics technology listens to the sounds fruits and veggies make to figure out if they're ripe and fresh. Dielectric property technology is fast and non-destructive, notifying about water content and hardness. Raman spectroscopy uses light to give detailed information about the chemicals in fruits and veggies. It's special because water doesn't interfere with it. Raman spectroscopy is excellent at finding tiny things other methods might miss. Looking at how molecules vibrate quickly notifies the quality and nutrition of fruits and veggies, even their structure. It can also find harmful stuff and pesticide residues on the surface [18]. Non-destructive methods, while valuable in quality assessment, may not universally address all chemical and physical quality parameters. The considerable expense associated with the specialized equipment and the necessity for employing distinct instruments to analyse various parameters contributes to the major disadvantages of these methods. The high cost of acquiring and maintaining such equipment, coupled with the need for expertise in handling different instruments, poses financial and operational challenges [19].

E. Implications of Freshness on Produce Quality

Freshness plays an important role in the overall quality of produce, impacting economic considerations, health and safety, environmental sustainability, consumer satisfaction, and food wastage. The interconnectedness of these factors underscores the need for effective management throughout the supply chain.

Economic Considerations

The economic implications of managing fruit and vegetable waste are substantial, with findings indicating a noteworthy impact on financial resources. According to [20], fruit waste accounted for 12%, and vegetable waste accounted for 24%, resulting in a substantial total loss of 54,891,539 USD. Notably, the summer season saw the highest fruit waste at 15%, contributing to heightened economic losses during this period. Additionally, the economic impact of vegetable waste was significant, with percentages of 28% in summer and 24% in spring, underscoring the seasonal variability in economic losses associated with different types of produce. Retailers grapple with the intricate challenges of managing fresh inventory, leading to significant economic repercussions. The difficulty of maintaining freshness, spanning from the distribution centre to the store shelf, contributes significantly to this wastage. Retailers find themselves wasting twice the value of their profits due to these challenges. The economic considerations related to freshness extend beyond the store level; they permeate the entire supply chain. The complexities of handling and maintaining consistent temperatures in the supply chain pose significant challenges, resulting in over 10% of fresh food shipments being rejected upon arrival at their destination. This rejection further exacerbates economic losses and underscores the pervasive nature of the freshness challenge throughout the entire supply chain [3].

Health & Safety

The paramount importance of food safety in human life cannot be overstated, as highlighted by[4]. Foodborne illness constitutes a significant global health challenge, affecting one in ten people annually according to the World Health Organization. In the United States alone, the Centres for Disease Control and Prevention (CDC) reports an alarming statistic of approximately 48 million people falling victim to foodborne illnesses each year, with 128,000 individuals requiring hospitalization. Contaminated foods, primarily caused by the consumption of fresh produce, contribute significantly to these incidents[5]. emphasize the need for pre-monitoring the freshness state of food to mitigate the magnitude of foodborne illnesses. However, a notable challenge exists in the absence of a simple system for accurately assessing the freshness of food before consumption. Consuming contaminated fruits poses severe health risks due to the presence of various disease-causing microbes and pathogens. These contaminants can originate from water, soil, manure, wildlife, birds, or other sources, especially when consumers handle or prepare food. The consequences of consuming non-fresh fruits include a range of diseases such as vomiting, diarrhoea, abdominal cramps, nausea, fever, joint/backaches, and fatigue. Certain demographic groups face higher risks of foodborne illnesses. Individuals suffering from diseases like AIDS, cancer, kidney issues, or other chronic diseases are particularly vulnerable. Senior citizens are also at an elevated risk of these illnesses. Additionally, individuals with autoimmune disorders such as lupus, those on immune-suppressing medications, newborns, unborn babies, children under 5 years, pregnant women, and individuals with a history of drug or alcohol addiction are considered high-risk groups [6].

Consumer Satisfaction

Consumer satisfaction is intricately linked to the freshness of produce, with a profound impact on individuals' choices when selecting fruits and vegetables.[7] emphasize that the nutritional value of perishable items, such as fruits and vegetables, is directly correlated with their freshness. Fresh produce tends to be richer in essential nutrients, contributing significantly to overall consumer health. When deciding where to purchase food, consumers heavily prioritize freshness. Notably, 59% of consumers place a remarkable emphasis on the quality of fresh offerings during their purchasing decisions. This emphasis on freshness, however, often leads to inconsistent experiences for shoppers. The discrepancy arises when products labelled as “fresh” fail to meet consumers' expectations, creating a challenge in ensuring consistent quality across the spectrum of fresh produce [9]. Addressing this inconsistency is important for enhancing overall consumer satisfaction in the realm of fresh food.

Food Wastage

The issue of food wastage poses a significant global concern. A staggering one-third of the food produced worldwide is discarded, despite the alarming fact that there are a billion people facing malnutrition. The potential impact is noteworthy — the saved food could provide sustenance for nearly two billion more individuals [20]. According to the Food and Agriculture Organization (FAO) of the United Nations, food waste encompasses anything altering the accessibility, edibility, health, safety, or quality of a product, rendering it unsuitable for consumer consumption[23]. Particularly troubling is the wastage of fruits and vegetables, accounting for over 42% of the discarded food. These items, being the most consumed globally, face significant losses throughout the food supply chain, with an estimated 40-50% of them being wasted[20]. In simpler terms, more than one-third of the fruits and vegetables produced globally end up as waste, equivalent to a staggering 28 million tons[20]. The problem of food wastage extends beyond the broader supply chain and touches our households. Often, unnoticed food in our refrigerators goes bad, changes colour, and emits unpleasant Odors due to bacterial formation[1]. Addressing this issue and embracing sustainable practices in assessing food freshness is not only crucial for reducing food wastage but also plays a pivotal role in resource conservation and minimizing the ecological footprint associated with food production and consumption.

Environmental Impact

Examining food waste from an environmental standpoint reveals hidden costs and substantial impacts on the ecosystem. As reported by[20], the generation and disposal of food waste result in not only economic losses but also pollution problems due to unpleasant Odors, the release of leachate into the environment, and pollution in landfills. The environmental toll extends throughout the entire food supply chain, where significant flows of resources, including water, fossil fuels, and chemicals, are utilized for the production, transportation, processing, storage, and preservation of food[24]. At each stage of the food supply chain, there are substantial emissions and environmental impacts, both locally and globally, as noted by[25]. Agricultural practices significantly contribute to environmental pollution, often stemming from a lack of awareness regarding the freshness levels of produce. Farmers, when informed of the optimal freshness levels, can adopt a more environmentally friendly approach by reducing the use of excessive fertilizers, pesticides, and water. Furthermore, knowledge of the ideal freshness levels enables precise harvesting, mitigating overharvesting or underharvesting risks and promoting resource conservation, thereby minimizing unnecessary environmental impact. The accumulation of wet organic materials in landfills has further adverse consequences, including leachate leakage, the attraction of insects, unpleasant Odors[26], and the production of harmful greenhouse gases[20]. The overall environmental impact underscores the need for sustainable practices throughout the food supply chain to mitigate these adverse effects on the ecosystem.

F. Existing Solutions and Limitations

Several software applications, including FarmSoft [30], Clarifruit [31], and GoMicro [32], have been developed to assess the freshness of fruits and vegetables. FarmSoft[30] provides comprehensive farm management and quality tracking from planting to harvest using historical and environmental data, while Clarifruit[31] leverages computer vision to analyze visual attributes such as color, size, and defects, offering real-time quality assessments. GoMicro[32] enhances smartphone cameras with attachments for detailed image capture, which are analyzed with machine learning algorithms to detect spoilage and defects. Despite these advancements, current solutions face significant limitations. Accuracy and reliability are affected by external factors such as lighting conditions, camera quality, and background interference, which can lead to inconsistent results. Accessibility for color-blind users remains limited, as most applications do not explicitly support individuals with protanopia, deuteranopia, or tritanopia, nor do they implement mechanisms such as color correction algorithms, simulated views, or alternative indicators like color-to-text or shape-based cues. Furthermore, many applications depend on manual user input, introducing potential errors and reducing reliability, while the need for frequent database updates to reflect varying produce characteristics adds additional complexity and resource requirements. These limitations highlight the gaps that existing solutions have not addressed. FreshSight differentiates itself by providing color-blind-friendly visualizations, including simulated views for different types of color vision deficiency, and by offering color-to-text and shape-based indicators to enhance accessibility. It also automates the entire image capture and analysis process, reducing reliance on user input, and employs robust machine learning models validated under diverse real-world conditions, including varying lighting, camera quality, and produce types. By addressing these challenges, FreshSight offers a more inclusive, reliable, and practical solution for assessing produce freshness, filling the gaps left by previous applications.

METHODOLOGY

A. **Use of machine learning for freshness and shelf-life assessment**

Dataset Description

The dataset used in this study was curated to provide comprehensive coverage of freshness levels for fruits and vegetables, categorized into three main criteria: fresh, moderate, and spoiled. This dataset was obtained from a combination of sources, including a dataset provided by Dr. Fahad Tahir, which detailed freshness categorization, and an additional shelf-life dataset sourced from Kaggle [29]. By combining and refining these datasets, a unified dataset was created, comprising 25,115 images. This dataset was split into 70% for training and 30% for testing, ensuring robust model development and evaluation.

Model Development

Data Preprocessing: Images were preprocessed to adjust for lighting and background variations, ensuring consistency in the data used for model training. This involved several steps. Image Resizing: All images were resized to a standard dimension of 128x128 pixels to maintain uniformity across the dataset. Data Preprocessing: Images were preprocessed to adjust for lighting and background variations, ensuring consistency in the data used for model training. This involved several steps. Normalization: Pixel values were normalized to a range of [0, 1] to standardize the input data and facilitate faster convergence during training. Augmentation: Techniques such as rotation, flipping, and color adjustment were applied to augment the dataset, enhancing the model's ability to generalize from the training data.

Model Architecture

The Convolutional Neural Network (CNN) architecture used for this study included multiple layers designed to extract and learn hierarchical features from the images: Convolutional Layers: These layers apply filters to the input images to detect local features such as edges, textures, and patterns. Pooling Layers: Pooling layers reduce the dimensionality of the feature maps, retaining the most important information while reducing computational load. Fully Connected Layers: These layers integrate the extracted features and perform the final classification, determining the freshness and shelf life of the produce. Activation Functions: ReLU activation functions were used in the convolutional layers to introduce non-linearity, and a softmax activation function was applied in the output layer to produce probabilistic predictions. Convolutional Neural Networks (CNNs) were employed for image analysis and classification. The models were trained using the annotated dataset, with the freshness scores paired with shelf lives, serving as the ground truth. The model uses layers to detect patterns and features in these images, enabling it to classify new images into the appropriate freshness category along with the corresponding shelf life.

Model Training

The model was trained using the Adam optimizer, known for its efficiency in handling large datasets and its adaptive learning rate capabilities. The loss function used was categorical cross-entropy, suitable for multi-class classification problems. The training process involved iterating over the dataset in batches, updating the model parameters to minimize the loss function. Validation and Hyperparameter Tuning: A portion of the training data was set aside for validation to monitor the model’s performance and prevent overfitting. Hyperparameters such as learning rate, batch size, and the number of epochs were fine-tuned based on validation performance. Specifically, grid search was used for hyperparameter tuning. Grid search involves systematically testing all possible combinations of hyperparameters to determine the best configuration. Additionally, k-fold cross-validation was employed to ensure the model's performance was consistent across different subsets of the data, further refining the model's accuracy and robustness.

Model Testing

The effectiveness of the CNN model in predicting the freshness and shelf life of fruits and vegetables was evaluated using the confusion matrix. This matrix provides insights into how accurately the model predicts values compared to the actual ones. In Figure 1, the confusion matrix displays high values along the diagonal, indicating strong predictive accuracy. This analysis suggests that the prediction model exhibits considerable accuracy in its predictions. Out of the dataset, 30 images were used for testing, of which 27 were correctly identified, resulting in a system accuracy rate of 90%. This accuracy rate was determined using the following formula.

Accuracy Level = (Number of correctly recognized images / Number of total tested images) × 100%

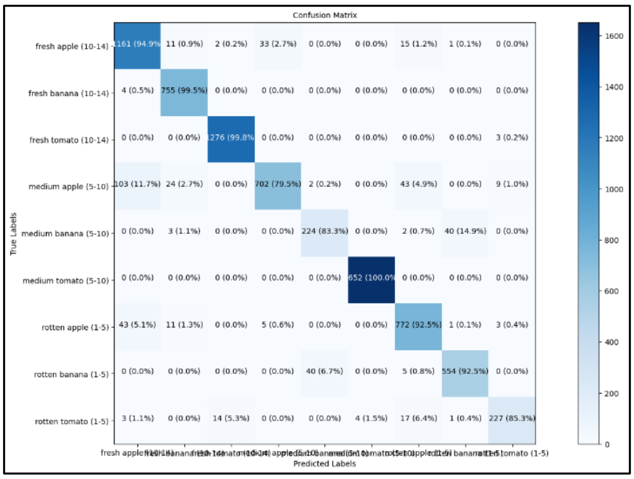

Figure 10: Confusion Matrix for freshness and shelf-life prediction

In addition to accuracy, further evaluation was performed using standard classification metrics: precision, recall, and F1-score. These metrics provide a more detailed understanding of the model’s performance for each freshness category. Precision measures the proportion of correctly predicted positive instances out of all predicted positives, recall measures the proportion of correctly predicted positives out of all actual positives, and the F1-score is the harmonic mean of precision and recall. The results, derived from the confusion matrix (Figure 1), are presented in Table 1.

Table 1: Precision, Recall, and F1-Score for Each Freshness Category

Class	Precision	Recall	F1-Score
Fresh Apple (10–14)	0.8211	0.9493	0.8805

Fresh Banana (10–14)	0.9391	0.9947	0.9661
Fresh Tomato (10–14)	0.9770	0.9977	0.9872
Medium Apple (5–10)	0.9551	0.7091	0.8139
Medium Banana (5–10)	0.8726	0.8589	0.8657
Medium Tomato (5–10)	1.0000	1.0000	1.0000
Rotten Apple (1–5)	0.9150	0.9239	0.9195
Rotten Banana (1–5)	0.9224	0.9250	0.9237
Rotten Tomato (1–5)	0.9639	0.8481	0.9024

The results show that the model performs strongly across all categories, with F1-scores exceeding 0.80 in every case. Notably, Medium Tomato achieved perfect precision and recall, while Medium Apple exhibited slightly lower recall, suggesting potential benefits from additional training data for that category.
Figure 2 presents the four-tier architecture of the proposed solution, showing the components and their connection between the functional architecture and the database design.

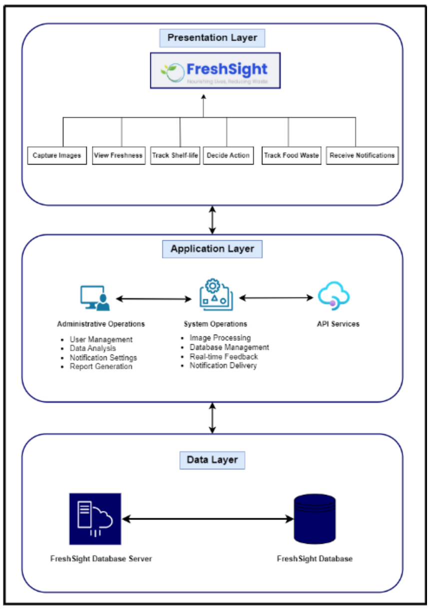

Figure 11: High-level architecture of the proposed solution

The proposed solution has been developed as a mobile responsive web application. The high-level architecture of FreshSight consists of several interconnected components, each playing a crucial role in delivering a seamless and effective user experience:
User Interface (UI): The UI is the front-end component that allows users to interact with FreshSight. It is designed to be intuitive and accessible, providing clear instructions and real-time feedback on produce freshness. The interface includes options for capturing images, viewing freshness scores, and accessing additional information or settings.
Camera Module: The camera module enables users to capture images of produce. It utilizes the smartphone's built-in camera to take photos under different lighting conditions. The module is optimized to ensure high-quality image capture, crucial for accurate freshness assessment.
Image Processing Engine: This component is responsible for analyzing the captured images. It employs advanced

algorithms to detect color variations and other visual indicators of freshness. The engine processes the image data to identify spoilage signs such as discoloration or bruising.
Color Analysis Algorithm: The color analysis algorithm plays a critical role in evaluating produce freshness. It uses color correction techniques to adjust for variations in lighting and then analyzes the corrected image to determine freshness levels. The algorithm is designed to cater specifically to the needs of color-blind users by translating color information into actionable freshness scores.
Database: The database stores information about various types of produce and their freshness characteristics. It includes reference images and freshness criteria for different fruits and vegetables. The database is regularly updated to ensure accurate and relevant assessments.
Feedback System: The feedback system delivers results to the user through the UI. It provides a freshness score, and actionable recommendations based on the image analysis. Users receive real-time feedback on the quality of their produce, helping them make informed decisions.
Cloud Integration: FreshSight incorporates cloud integration for data storage and processing. Cloud services handle large-scale data operations, such as updating the produce database and refining image analysis algorithms based on user feedback. Cloud integration ensures that the app remains up to date with the latest freshness criteria and technological advancements.
Data Privacy and Security Module: This component ensures the security of user data, including captured images and personal preferences. It employs encryption and secure communication protocols to protect user information from unauthorized access.
Analytics and Reporting: FreshSight includes analytics capabilities to track usage patterns and user feedback. This data helps in refining the app and enhancing its performance. Reports generated from analytics provide insights into user behavior and app effectiveness.
The FreshSight solution thus integrates these components to deliver a comprehensive tool for assessing produce freshness. It leverages advanced image processing, color analysis, and cloud technologies to provide accurate, real-time feedback, empowering color-blind individuals to make better food choices.

RESULTS AND FINDINGS

Following functional testing, the prototype underwent evaluation by both experts and non-experts. The aim was to assess the overall suitability and completeness of the solution in addressing the defined problem and meeting user expectations. The evaluation process surfaced several key insights. The concept was praised for aligning well with current consumer demands, particularly in promoting transparency and quality in food products. Suggestions were made to enhance the system by integrating real-time data and exploring technologies like blockchain to improve consumer trust. The inclusive design was highlighted as a valuable feature, especially for users with color vision deficiencies, reinforcing its importance in supporting informed choices and health-conscious decisions. Feedback from participants involved in distribution and agriculture emphasized the system's potential to revolutionize distribution processes and promote sustainability through more accurate freshness assessments.
On the usability front, the prototype's interface was regarded as intuitive and accessible to a broad range of users. Nevertheless, recommendations were given to introduce customizable visual themes and additional cues to further enhance accessibility for all users. The system's potential for widespread adoption was recognized, particularly due to its user-centric design and relevance to the retail and food industries. Additional emphasis was placed on the importance of making the solution adaptable for various user needs and retail environments. Overall, the evaluation reflected positively on the system's ability to meet key objectives such as enhancing transparency, promoting inclusivity, and delivering reliable freshness assessments. Consistent suggestions for improvement included stronger real-time integration, customizable interface elements, and enriched accessibility support. These insights provide a clear direction for further refinement and optimization, helping to ensure the solution meets real-world needs effectively and remain aligned with user expectations in diverse contexts.

CONCLUSION

A. Limitations of the current system

While FreshSight effectively aids color-blind users in assessing produce freshness, several limitations persist. The application's reliance on visual indicators may not account for all spoilage factors, such as microbial growth or internal decay. Variations in lighting conditions and camera quality can also affect the accuracy of color detection. Moreover, FreshSight's current focus on color may overlook other sensory cues like texture or smell. The app's effectiveness in diverse environmental conditions and its scalability to accommodate a wider range of produce types are areas that require further research and development to enhance reliability and user trust.

B. Future work

Further improvements recommended by industry experts and feedback from end users will be considered in future work. Introducing customization features will allow users to tailor freshness assessments and shelf-life parameters to their specific needs. Expanding the deep learning model to detect freshness and shelf life across a broader range of produce will provide more comprehensive insights. Future iterations will also aim to incorporate additional food quality indicators, such as texture and aroma, to offer a more holistic assessment of produce quality. Enhancing user engagement through gamification and sustainable food management challenges is another area of focus. Ensuring cross-platform compatibility and the inclusion of a language selection feature will further enhance accessibility. Additionally, gathering user feedback will remain crucial for continuous improvement, and the implementation of accessibility features will promote inclusiveness, particularly for users with visual impairments, ensuring the solution is adaptable for a wide and diverse audience.

C. Concluding remarks

The primary objective of this research is to validate FreshSight as an effective tool for color-blind individuals in assessing produce freshness, thereby enhancing their ability to make informed food safety decisions. The implications of this study are significant. Firstly, FreshSight offers a practical solution to the challenge of identifying produce quality for color-blind consumers, which can improve food safety practices and reduce food waste. The insights gained from this research underscore the potential of smartphone-based applications to assist underserved groups by leveraging accessible technology. As smartphone usage continues to rise, FreshSight can provide an essential service, enabling users to make safer and more efficient food choices. The benefits of this application are substantial, promising improved food safety outcomes and contributing to a reduction in food waste, thus supporting overall community health and sustainability.

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