FRUITPAL: AN IOT-ENABLED FRAMEWORK FOR AUTOMATIC MONITORING OF FRUIT CONSUMPTION IN SMART HEALTHCARE

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This research proposes FruitPAL and FruitPAL 2.0. They are full automatic devices that can detect fruit consumption to reduce the risk of disease. Allergies to fruits can seriously impair the immune system. A novel device (FruitPAL) detecting fruit that can cause allergies is proposed in this thesis. The device can detect fifteen types of fruit and alert the caregiver when an allergic reaction may have happened. The YOLOv8 model is employed to enhance accuracy and response time in detecting dangers. The notification will be transmitted to the mobile device through the cloud, as it is a commonly utilized medium. The proposed device can detect the fruit with an overall precision of 86%.

FruitPAL 2.0 is envisioned as a device that encourages people to consume fruit. Fruits contain a variety of essential nutrients that contribute to the general health of the human body. FruitPAL 2.0 is capable of analyzing the consumed fruit and then determining its nutritional value. FruitPAL 2.0 has been trained on YOLOv5 V6.0. FruitPAL 2.0 has an overall precision of 90% in detecting the fruit.

The purpose of this study is to encourage fruit consumption unless it causes illness. Even though fruit plays an important role in people's health, it might cause dangers. The proposed work can not only alert people to fruit that can cause allergies, but also it encourages people to consume fruit that is beneficial for their health.

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CHAPTER 1

INTRODUCTION

This chapter provides a discussion of fruit consumption and fruit allergens in the Healthcare Cyber-Physical System (H-CPS) framework [**13**, **14**].

1.1. All About Fruit

Fruits are considered to be a more nutritious meal option due to their inherent health benefits. Fruits offer a range of beneficial nutrients, such as vitamins and dietary fiber, which play a crucial role in supporting human health [**14**]. Fig. 1.1 presents an illustration of the many vitamins that can be obtained from eating fruit [**14**]. Consuming a substantial quantity of fruits does not exhibit any adverse effects, so it is recommended to incorporate fruit in every meal. Because fruit is digestible and sweet, people eat them for meals or as snacks. Multiple studies recommend individuals to incorporate fruit into their regular dietary regimen due to their rich nutritional content [**5**, **21**, **46**].

The consumption of fruits has been found to enhance the immune system due to their rich content of various vitamins. Research has revealed that the consumption of fruits can contribute in terms of reducing the encouragement of diseases, such as cardiovascular ailments and metabolic syndrome [**19**]. The consumption of fruit is associated with a reduction in the consumption of unhealthy food and processed meals. Consuming a minimum of four to five servings of fruit every day has been found to have a positive impact on mood enhancement [**28**]. The risk of vitamin insufficiency can be avoided by the consumption of fruits. Fig. 1.2 displays diseases that can be prevented by the regular consumption of fruits.

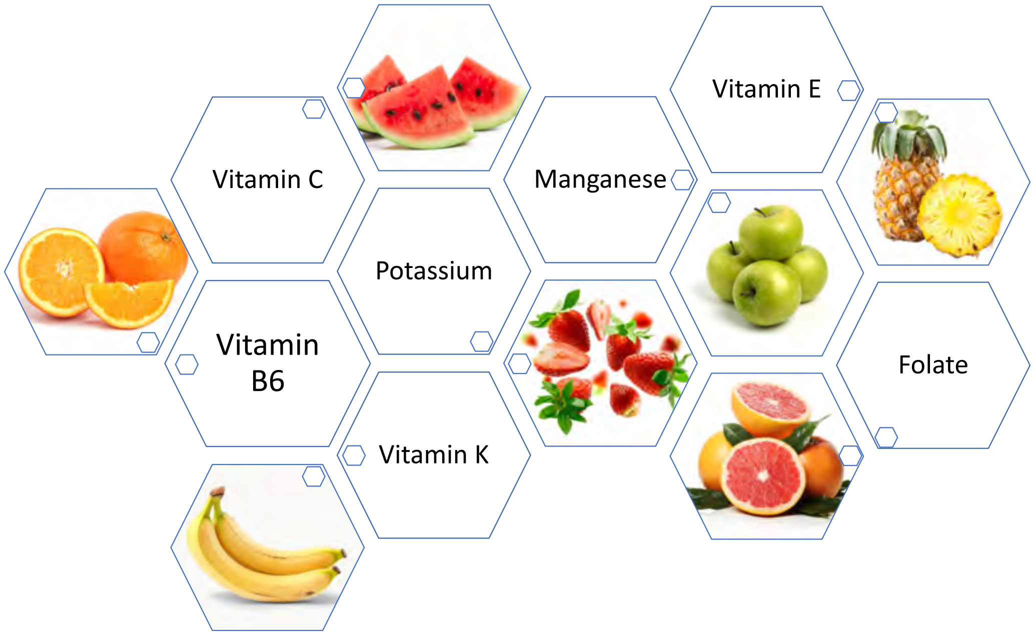

FIGURE 1.1. The Vitamins FruitPAL 2.0 Promotes [**14**].

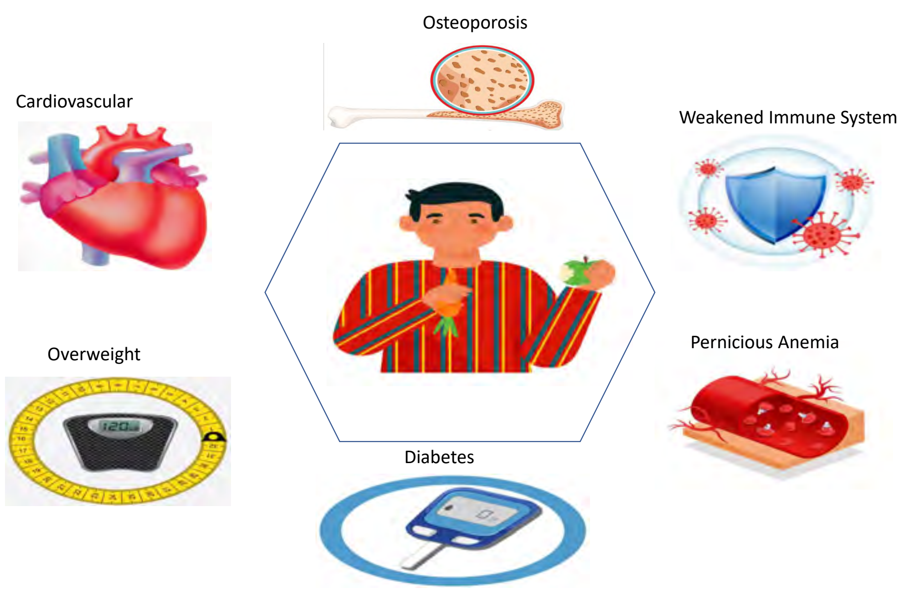

FIGURE 1.2. Preventable Diseases by Eating Fruit.

Fruit does not require preparation, so it can be eaten whenever and wherever required. Nevertheless, many individuals fail to consume a sufficient amount of fruits on a daily basis. The publication of the 2021 report by the Nation Survey of Children's Health (NSCH) revealed that a significant proportion of children, specifically 32.1%, did not consume a daily serving of fruit [**25**]. The rationale behind the decreased consumption of fruits is attributed to the increased prevalence of junk food advertisements.

Fruits are generally considered to be a nutritious dietary component. However, there are instances where fruit consumption can potentially lead to significant negative impacts on human health. Individuals who have allergies to certain fruits should avoid them. Due to the nutritional importance of fruit as a food source, fruit allergy is a prevalent medical condition that affects the immune system [**13**]. Also, individuals who have diabetes or pre-diabetes should exercise caution while selecting fruits for consumption and prioritize those fruits with lower sugar content [**33**]. Fruits are considered a health food source unless they cause illness for the human body.

1.2. Immune Mediated Disorders

The immune system might be disordered by various allergenic substances, causing wheezing, itching, runny nose, watery or itchy eyes, and other symptoms that cause a reaction of the immune system [**2**]. For significant reactions, allergenic substances might make the immune system react unpredictably and cause diseases or even worse. Bacteria, viruses, and fungi are harmful infections that cause the immune system to be overrun trying to fight those infections and save the infected person [**2**]. An allergy occurs when the allergic person either consumes or comes in contact with an allergen that the immune system considers as a harmful object.

1.2.1. Why are Allergies Dangerous

Allergenic substances can be found in different environments. Plant allergies, for example, is a type of allergy that is caused by a specific kind of plant. People with plant allergies have to be away from the plants that trigger their immune systems. Houseplants need to be chosen cautiously to avoid plant allergy [**7**]. Also, the gender of the plant is vital in avoiding allergies [**7**]. Even though a household may not have plant allergens, it is necessary to be careful because plant allergies might affect anyone who comes close to the houseplant.

Food allergies are difficult to diagnose, so parents are required to continue monitoring their children to determine if they have any allergies. When infants are coming close to being weaned, new food should be introduced to determine if they are allergic to it. Giving infants a tiny amount of peanut butter, for instance, is recommended because peanut allergies are common for children. If the infants are allergic, the immune system will be triggered.

Soybeans, wheat, milk, and tree nuts are examples of most common food hypersensitivities [**6**]. Some people are allergic to healthy and necessary food. For example, milk is the main source of calcium to build the bones of the person.

1.3. Research Problem

Allergy can cause death, and it occurs quickly. Food allergens are one of the critical kinds of allergens because it is hard to avoid them. Fruits are an important food due to their value and pleasant taste, even though fruit allergies are widespread. Fruit allergens affect the skin, mouth, and face. Food allergy is a type of allergy that involves syncope, hypotension, bradycardia, and retching [**9**]. Identifying the allergy reduces the risk to humans and the number of patients in the immediate care facility.

1.4. Proposed Solution

Certain individuals may experience severe allergic reactions upon consumption of particular fruits due to an erroneous recognition of proteins present in the fruit by their immune systems as potential threats. Individuals with allergies are advised to manage their dietary intake and refrain from consuming foods that contain allergens derived from fruits. Creating a device that can alert people with fruit allergies is necessary. The FruitPAL device offers the capability of accurately predicting the identities of 15 distinct varieties of fruits. Furthermore, it functions in real-time, hence enabling it to potentially protect human lives by promptly transmitting an alarm to a connected mobile device. The notification alerts the caregiver to promptly intervene in order to divert the user's focus towards it. The device transitions into an active state when the user is in proximity to fruits that have the potential for triggering allergic responses. FruitPAL is a crucial instrument for those who have problems recognizing fruit that can have a detrimental impact on their health.

1.5. FruitPAL: A Smart Healthcare Framework for Automatic Detection of Fruit Allergens

Diseases of the immune system have the potential to impact the entirety of the human body, and in severe cases, may result in death. The primary function of the immune system is to preserve the human organism and maintain its overall well-being. The immune system may exhibit allergic reactions to certain fruits, hence potentially compromising its functionality. People with particular needs may encounter challenges in acknowledging the potential risks linked to the use of fruits, thus necessitating the need for vigilant monitoring. Anaphylaxis is a life-threatening allergic reaction which can be caused by fruit allergies and can cause death [**54**]. We present "FruitPAL" (fruit allergy prediction device), a novel method for the automatic detection of allergy-causing fruits. A large number of fruits can cause allergic reactions to humans, which can be detrimental to an individual's health [**52**]. The acquisition of timely information using a system like FruitPAL is highly advantageous due to the rapid onset of allergic reactions caused by allergens. Individuals who exhibit allergies to fruits are advised to exercise caution and carefully read the ingredient list before to consuming any food product. Food labels are required by the law to introduce the major allergens such as almonds and walnuts for the consumers [**6**].

The immune system can be irritated by the different categories of the fruit. For instance, a person who is allergic to one citrus fruit is also allergic to the other items in the same category [**22**]. The various categories of fruit are illustrated in Fig. 1.3, and it lists all fruit that FruitPAL is able to detect. However, there are some fruit that can belong to more than one category based on their characteristics, such as pomegranates.

The objective of FruitPAL is aimed to detecting fruit that causes allergies for people who lack recognition and suffer from fruit allergens and alert caregivers. FruitPAL is a state-of-art device that uses a recent technology in the object detection field. This recent technology which has been used in

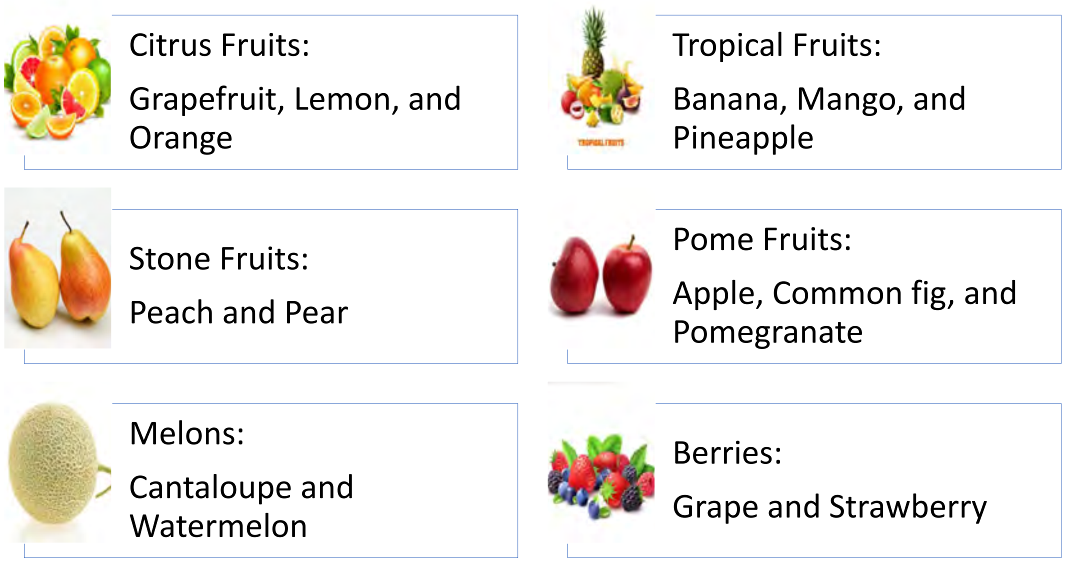

FIGURE 1.3. Fruit categories [**13**].

FruitPAL device is You Only Look Once version 8 (YOLOv8). YOLOv8 is a pre-training model that is used to detect fruit. The MS COCO model has annotated the dataset that trained the model used in FruitPAL. FruitPAL can detect more than 14 different classes of fruit that cause allergy to allergic people. The proposed device is a real-time device that can detect fruit allergens quickly to protect the immune system by alerting the caregivers. By using FruitPAL, we aim to protect the lives of people with fruit allergies under the domain of smart healthcare.

1.5.1. Contributions of FruitPAL

FruitPAL is an object detection device that protects human life. FruitPAL serves as a reminder to the caregivers who look after allergic individuals who are vulnerable to forgetfulness, letting them know when their patients are going to consume fruit that triggers their allergies. This cautionary notice is used to protect lives and eliminate any possible dangers. Because the structure of the system is automated, there is no need for human involvement, which puts the system at a unique advantage. Fig. 1.4 illustrates a group of people who are targeted to be helped by our proposed work.

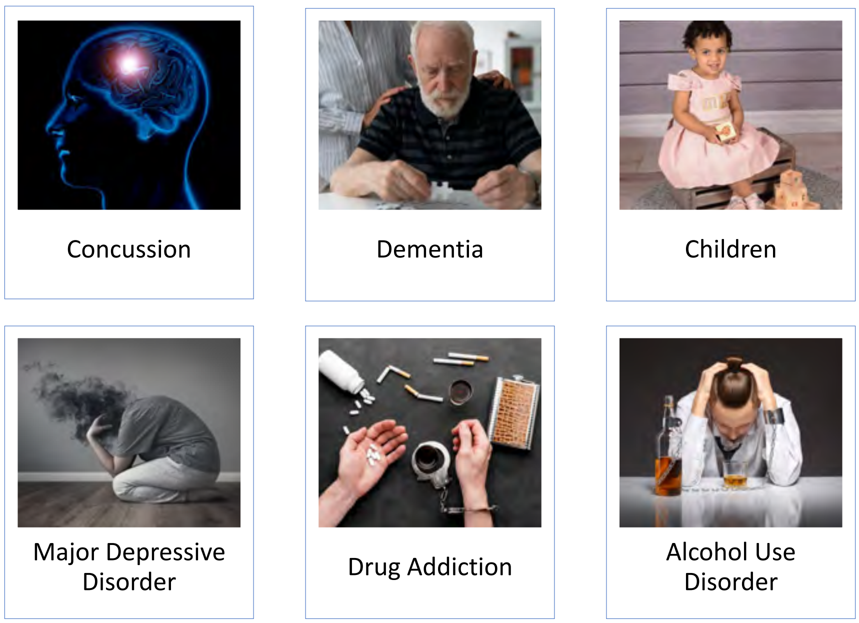

FIGURE 1.4. FruitPAL Protects Those Categories of People.

1.5.2. Novelties of FruitPAL

The novelties of the proposed "FruitPAL" are as follows:

- The technology can identify, on its own, which fruits can provoke allergic reactions, and cause unwanted situations for the consumers.
- The technique is characterized by its real-time nature, enabling it to yield results promptly.
- An alert will be automatically created, emailed, and delivered to the caregivers who have been assigned to that position up to the point

when the system identifies a change in status.

- Users have the ability to connect directly with the system through the utilization of the Global System for Mobile Communications (GSM), which provides a channel for such interaction.

1.6. FruitPAL 2.0: A Smart Healthcare Framework for Automatic Monitoring of Fruit consumption

Consumption of fruits supplies the human body with a diverse range of vitamins, which could boost the immune system. For instance, oranges and bananas are examples of fruits that contain vitamin C [**46**]. Consumption of fruits has been shown to help lower disease risk such as cardiovascular and metabolic syndrome [**19**]. However, many individuals fail to incorporate the consumption of a sufficient quantity of fruits into their daily dietary routine. 76% of Americans, according to a 2015 report by the Centers for Disease Control and Prevention, do not consume enough fruit daily [**21**]. Motivating people to eat fruit can change daily intake.

This thesis proposes FruitPAL 2.0, a novel method for encouraging consumers to consume fruit daily. The many health perks of fruit can be achieved with FruitPAL 2.0. The primary aim of monitoring the fruit intake of FruitPAL 2.0 is to provide valuable insights into how fruit contains health nutrients.

Vitamins are vital components that play a crucial role in supporting human health. Fig. 1.1 illustrates the various vitamins that can be promoted by FruitPAL 2.0.

1.6.1. Problems Addressed in FruitPAL 2.0

Many vitamins and natural sugars can be found in fruit. Since fruits have healthy nutrients, we should eat them every day. Reduction of eating fruit can cause vitamin deficiency, weight gain, and cardiovascular disease. Numerous studies advise people to add fruit in their daily intake because of their nutrients [**5**, **21**, **22**, **46**]. So, encouraging the community to eat fruit can increase public health and boost productivity.

1.6.2. Novel Solutions Proposed

Fifteen different fruit types can be accurately detected by using the proposed “FruitPAL 2.0”. It is a real time device that can detect and analyze fruit intake. Then, it notifies the user of the nutrients in the fruit they ate, which can create motivation. The novelties of the proposed “FruitPAL 2.0” are:

- The proposed work automatically detects and analyzes the fruit that was eaten.
- FruitPAL 2.0 has the ability to classify fifteen types of fruit.
- The nutrient information message is automatically sent to the consumer on time.
- The system uses Global System for Mobile Communications (GSM) to send the message to the user.

1.7. FruitPAL vs FruitPAL 2.0

FruitPAL 2.0 represents an updated iteration of the FruitPAL. The main objective of FruitPAL 2.0 is to encourage individuals to consume fruit.

On the other hand, FruitPAL refers to the automated identification of fruit allergens. Both devices utilize the Allergic-fruit dataset [**1**]. However, FruitPAL 2.0 has improved metrics in comparison to FruitPAL.

1.7.1. Deep Learning

The term "Deep Learning" is derived from the practice of incorporating additional layers within the hidden layers. These algorithms draw inspiration from the cognitive processes of the human brain. Currently, the computer possesses the capability to accurately identify photos and promptly identify things in real-time.

1.7.2. Image Classification

Image classification is used to identify one object per image [**18**]. The image can be owned by multiple classes, which is called multi label. Multi class, a type of image classification, is images that are categorized into distinct categories that have been determined. Annotations are not a requirement for an image classification dataset.

1.7.3. Object Detection

Object detection is the process of recognizing every object in an image [**18**]. The main objective of an object detection algorithm is to predict bounding boxes and identify objects in real-time. In order to build a dataset for object detection, it is necessary to annotate each object present in the image. Real-time object detection applications may employ many methods, including Faster-RCNN, DPM, or the YOLO family [**13**]. Table 1.1 illustrates the difference between image classification and object detection.

Table 1.1. The difference between Image Classification and Object Detection

%	**Image classification**	**Object Detection**
Object	Object per Image	Multiple object per Image
Dataset	Without annotations	With annotations
Metrics	Accuracy	mAP50 & mAP50-90
Example	Face ID	FruitPAL

1.7.4. You Only Look Once (YOLO)

The YOLO family is a forward pass algorithm that demonstrates real-time capabilities, exhibiting a high mean average precision (mAP) [**38**]. The YOLO algorithm employs a singular neural network to carry out the tasks of object classification and prediction of bounding boxes for identified items [**12**]. The implementation of YOLO can be achieved through the utilization of PyTorch, which is a framework specifically designed for deep learning purposes.

1.7.4.1. YOLOv8

YOLOv8 is the last version of the YOLO family, which is used in FruitPAL [**13**]. YOLOv8 is an excellent option for a variety of tasks related to object detection, image segmentation, and image classification [**11**]. The YOLOv8 architecture includes several detection models that have been pre-trained on the COCO dataset, as illustrated in Table 1.2 [**24**]. Time respond decreases and mAP50-95 increases with an increase in parameters, although high-performing devices are required with high parameters model.

Table 1.2. YOLOv8 Detect Models

Model	**Parameters**	**mAP50-95**	**Speed CPU**
YOLOv8n	3.2 M	37.3%	80.4ms
YOLOv8s	11.2 M	44.9%	128.4ms
YOLOv8m	25.9 M	50.2%	234.7 ms
YOLOv8l	43.7 M	52.9%	375.2 ms
YOLOv8x	68.2 M	53.9%	479.1 ms

1.7.4.2. YOLOv5 V6.0

FruitPAL 2.0 incorporates YOLOv5, the most popular version of the YOLO family [**14**]. YOLOv5 v6.0 provides enhanced speed, reduced size, and improved accuracy [**8**]. As shown in Table 1.3, the YOLOv5 v6.0 architecture has a number of detection models that have been pre-trained on the COCO dataset [**8**].

Table 1.3. YOLOv5 v6.0 Detect Models

Model	**Parameters**	**mAP50-95**	**CPU Speed**
YOLOv5n6	3.2 M	36.0%	153ms
YOLOv5s6	12.6 M	44.8%	385ms
YOLOv5m6	35.7 M	51.3%	887ms
YOLOv5l6	76.8 M	53.7%	1784ms
YOLOv5x6	140.7 M	55.0%	3136ms

1.7.4.3. YOLOv8 vs YOLOv5 V6.0

It is evident that YOLOv5 v6.0 exhibits a superior mean Average Precision (mAP50-95) in comparison to YOLOv8. Nevertheless, YOLOv8 offers advantages such as a decreased number of parameters and enhanced CPU performance.

1.8. PyTorch and TensorFlow

PyTorch and TensorFlow are the most commonly used deep learning frameworks. PyTorch has significant popularity within the research community, while TensorFlow is predominantly favored within the industry [**39**]. For certain applications, TensorFlow must be used instead of PyTorch. Converting the YOLO model from PyTorch to TensorFlow involves the use of the Open Neural Network Exchange (ONNX) [**4**].

1.8.1. Healthcare Cyber-Physical System (H-CPS)

A cyber-physical system (CPS) refers to an assemblage of computational devices that engage in communication and interaction with one other, while also interfacing with the physical environment through the utilization of sensors and actuators [**32**]. The use of Cyber-Physical Systems (CPS) within the domain of intelligent healthcare has given rise to the emergence of a groundbreaking concept known as H-CPS. The implementation of the Hospital Consumer Assessment of Healthcare Providers and Systems (H-CPS) is contributing to the enhancement of overall quality standards seen in hospital environments.

1.9. Organization of the Thesis

This thesis is structured into six chapters. The second chapter includes an exposition of related research. The third chapter of the thesis focuses on the datasets utilized in FruitPAL and FruitPAL 2.0. Further elaboration was provided regarding the collocation and processing of the photos. The fourth and fifth chapters of the thesis discuss FruitPAL and FruitPAL 2.0, respectively. Finally, summary and future works are discussed.

CHAPTER 2

RELATED RESEARCH

This chapter provides a detailed review of related research on fruit detection in terms of quality of food, wearable devices, and nutritional values [**13**, **14**].

2.1. Quality of Food

The mentioned research adopts various methodologies to evaluate the quality of the food. The Dietary Intake Monitoring System was proposed in [**37**] as a means to quantify the temperature of food and monitor changes in weight for the contents of a patient's plate. Fruit in storage can be evaluated for quality via laser diagnostics [**34**]. The quality of baby food can be evaluated using an electronic tongue to determine whether the quality is sufficient or not [**43**]. An application, with CNN model and Fruits 360 dataset, to classify fruit and show the allergen information is mentioned in [**44**]. Using image segmentation to classify the quality of Manalagi apple on smart agriculture was discussed in [**36**]. Despite the value of consuming high-quality fruit, there exists a prevailing reluctance towards its consumption. Preventing fruit eating can be beneficial if the fruit can trigger an allergy.

2.2. Wearable Devices

The detection of food consumed can be achieved through the classification of sound. Monitoring food consumption using two microphones to capture sounds of swallowing and eating was mentioned in [**40**]. A wearable device on the neck that can detect sound of solid and liquid food and keeps track of eating habits was presented in [**29**]. A wearable sensor with a microphone and a camera is meant to identify chewing activity based on sound features and video sequence analysis, recording both in order to show the consumption rate [**31**]. Nevertheless, the analysis of sound can be inefficient and lead to the dissemination of inaccurate information.

2.3. Detection of Unhealthful Nutritional Intake

The automatic approach can enhance convenience and efficiency. A wearable device to detect food nutrition automatically is discussed in [**27**]. An automatic device to monitor food intake and stress has been used in [**41**]. This work is an update of [**41**], a smart application that can automatically analyze images and show the food's nutritional value [**35**]. A smartphone app called DiaWear that tracks calories for people who need to control their dietary habits is developed in [**50**]. However, these approaches alert people about unhealthful nutritional intake, but encouraging consumption of fruits that are high in nutrients is necessary.

2.4. Quantity of Crop

The field of Smart Agriculture encompasses a range of publications. Most publications focus on the quantity of crop. Object detection in greenhouses to count and recognize pepper plants is involved [**53**]. A faster RCNN is applied to detect the fruit in [**45**]. Also, ResNet object detection with the ImageNet dataset is used to count the fruit and flowers [**42**]. An automated robotic application to detect mangoes, almonds, and apples in orchards was discussed in [**15**]. The mentioned research works count the fruit planted in crops that assist the substance of the food chain.

Fruit consumption can result in two different outcomes: one of them is helpful to human bodies, and the other can have negative effects in the body. The consequences on human health, both positive and negative, are discussed in this thesis. Table 2.1 presents many models and datasets that have been utilized in related research. FruitPAL and FruitPAL 2.0 are completely automated devices that contain efficiency models, YOLOv8 and YOLOv5 V6.0.

TABLE 2.1. Related Works

Works	**Model**	**Dataset**
B. Rohini [**44**]	Image classification (CNN)	Fruits 360
M. Muladi [**36**]	Image classification (Backpropagation)	Custom Dataset
S. Päßler [**40**]	Support Vector Machine	Custom Dataset
H. Kalantarian [**29**]	Vibration Sensor	Custom Dataset
J. Liu [**31**]	Extreme Learning Machines	custom dataset
Y. Song [**53**]	Image classification (CNN)	PASCAL-VOC
Sa, Inkyu [**45**]	Object detection (Faster R-CNN)	ImageNe
M. Rahnemoonfar [**42**]	Object detection (ResNet)	ImageNet
S. Bargoti [**15**]	Object detection (Faster R-CNN)	PASCAL-VOC
M. Alakananda [**35**]	Object Detection (API)	Food-A-Pedia
B. Issam [**16**]	Image classification (CNN)	CVL single digit
M. Hossain [**26**]	Image classification (CNN)	supermarket produce
Current Work		
A. Alkinani [**13**]	Object Detection (YOLOv8)	Allergic-fruit
A. Alkinani [**14**]	Object Detection (YOLOv5 V6.0)	Allergic-fruit

CHAPTER 3

ALLERGIC-FRUIT DATASET

This chapter explores a detailed dataset that is utilized in both FruitPAL and FruitPAL 2.0 [**13**, **14**].

3.1. Collocating Images

The quality of the dataset that is used in the object detection application can drive the quality of the results. FruitPAL and FruitPAL 2.0 devices use a specific dataset for fruit allergens that has been created by us [**1**]. Our dataset has around 3000 images that are collected from Open Images Dataset V7 [**3**]. What makes our dataset distinguished in the fruit allergens field is that this dataset contains high quality images that have been captured in different environments, as shown in Fig 3.1. In addition, there are 15 classes used in our dataset: Apple, Banana, Cantaloupe, Common fig, Grape, Grapefruit, Lemon, Mango, Orange, Peach, Pear, Pineapple, Pomegranate, Strawberry, and Watermelon.

3.2. Annotation

All classes in the Allergic-fruit dataset are annotated into different approaches based on:

- Whole fruit.
- Cut fruit.
- Fruit with rots.
- Fruit inside boxes.
- Fruit mixed with others.

Figure 3.1. Sample Images from the Allergic-fruit Dataset [**13**].

When annotating images from this dataset, we started by using the predictions generated by a model that was trained with Roboflow Train. Pre-training the model is an proficient approach employed for annotating fruits in the allergic-fruit dataset. At the beginning of creating the dataset, the MS COCO model which has 55.8% mAP is used. However, the MS COCO model has only three different kinds of fruit which are apple, banana, and orange. Three versions of the pre-trained model have been built at our end. The first version was trained based on the pictures annotated by the MS COCO model. The second and third versions relied on the previous versions' pre-trained model. Fig. 3.2 illustrates that each version's improvement mAP, precision, and recall were dominated by the number of annotated images in each version of the allergic-dataset. Figs. 3.3 and 3.4 display the performance of the first version of the pre-trained model. Also, the second version evaluation is displayed in Figs 3.5 and 3.6. The evaluation of the third version is shown in Figs 3.7 and 3.8. Fig. 3.9 shows the annotated image by pre-training model.

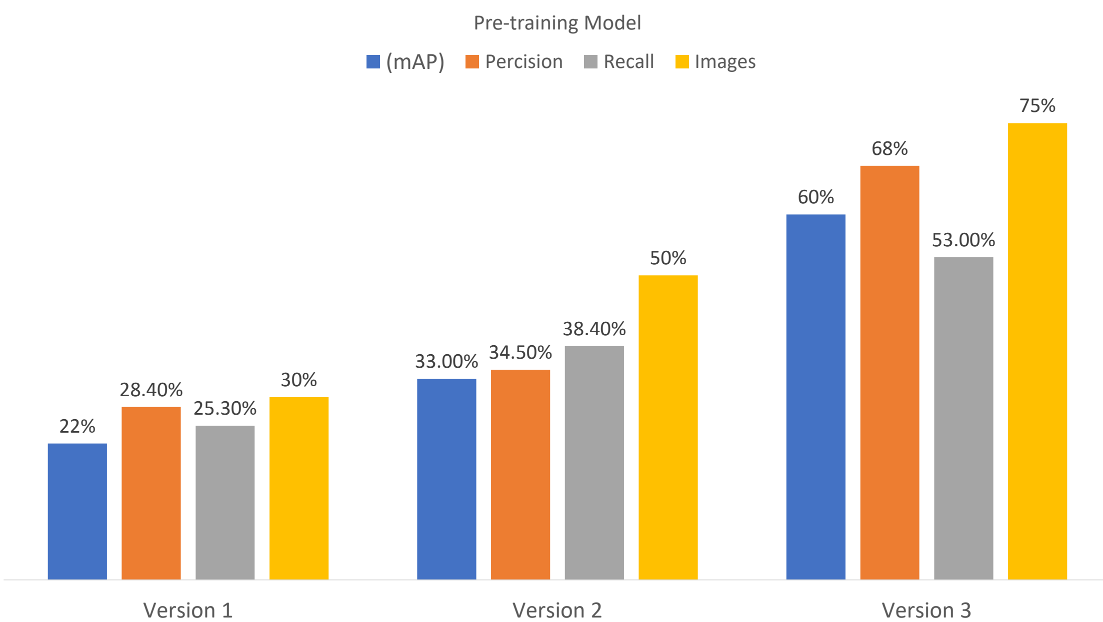

FIGURE 3.2. Pre-trained Model used to annotat the allergic dataset [**13**]

The Dataset Health Check is analyzed in Table 3.1. A total of 16,000 boundary boxes have been drawn across 16 different classes, resulting in an average of 5.3 objects per image. Table 3.2 shows the boundary boxes for each class in terms of training, validation, and testing.

3.3. Image Augmentation

Increasing the number of images that have been duplicated in the dataset has been done by a technology called image augmentation. a technique to increase the number of images used. Image augmentation, generating

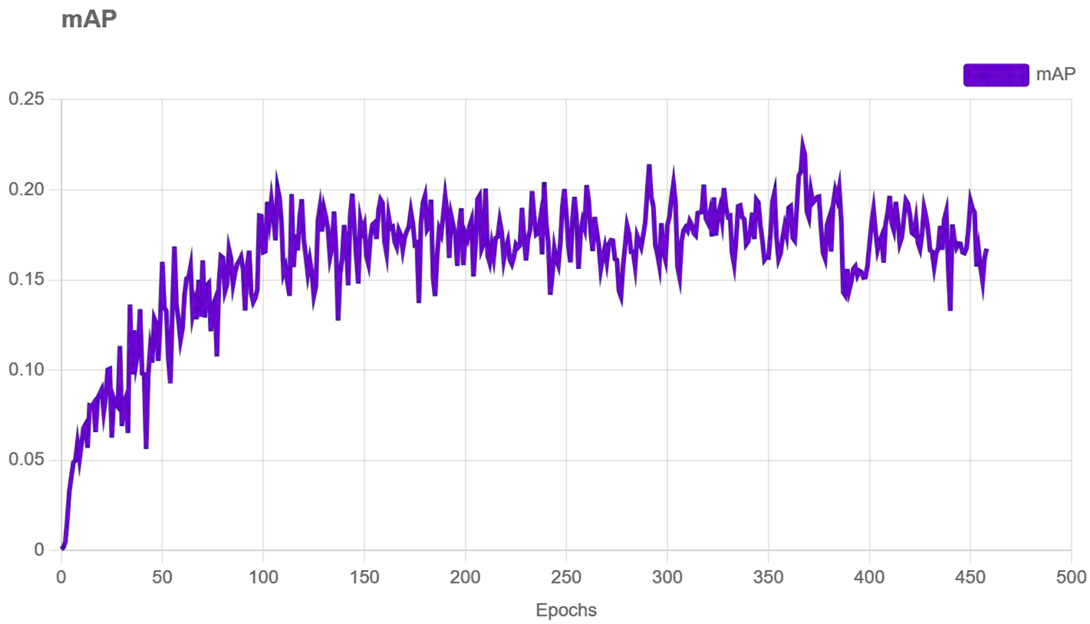

FIGURE 3.3. The mPA of the first version of the model that was used to annotate the dataset

synthetic images to enhance the model [**10**], has been used in our dataset. To increase the accuracy of the dataset, Image augmentation has been applied on the annotated images, which are:

- Grayscale: apply to 3% of images.
- Saturation: Between -5% and +5%.
- Brightness:Between -10% and +10%.
- Exposure: Between -10% and +10%.
- Blur: Up to 0.5px.
- Noise: Up to 1% of pixels.
- Mosaic: Applied.

The dataset has been evaluated with different sets of image augmenta-

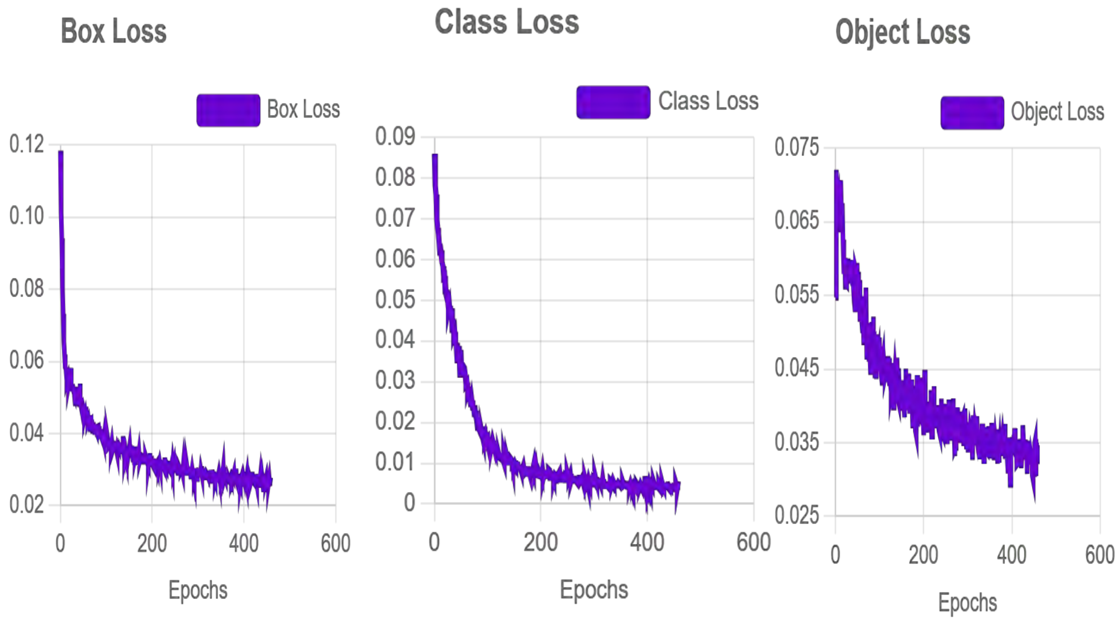

FIGURE 3.4. The evaluation of the first Pre-trained Model utilized for the dataset's annotation

tion on YOLOv8. The first evaluation without image augmentation, in Fig. 3.10 shows the metrics on 105 epochs, which are mAP50, mAP50-95, precise, and recall. Also, Fig. 3.11 shows the box loss, class loss, and difi loss on training. Additionally, Fig. 3.12 illustrates the validation results for the box loss, class loss, and difi loss. The second set of image augmentation is:

- flip: horizontal, vertical
- Saturation: Between -25% and +25%.
- Noise: Up to 5% of pixels.

Figs. 3.13, 3.14, and 3.15 show the evaluation on 151 epochs. The model training was automatically stopped because there is no improvement over the epochs. Choosing the right augmentation plays a critical role in evaluation.

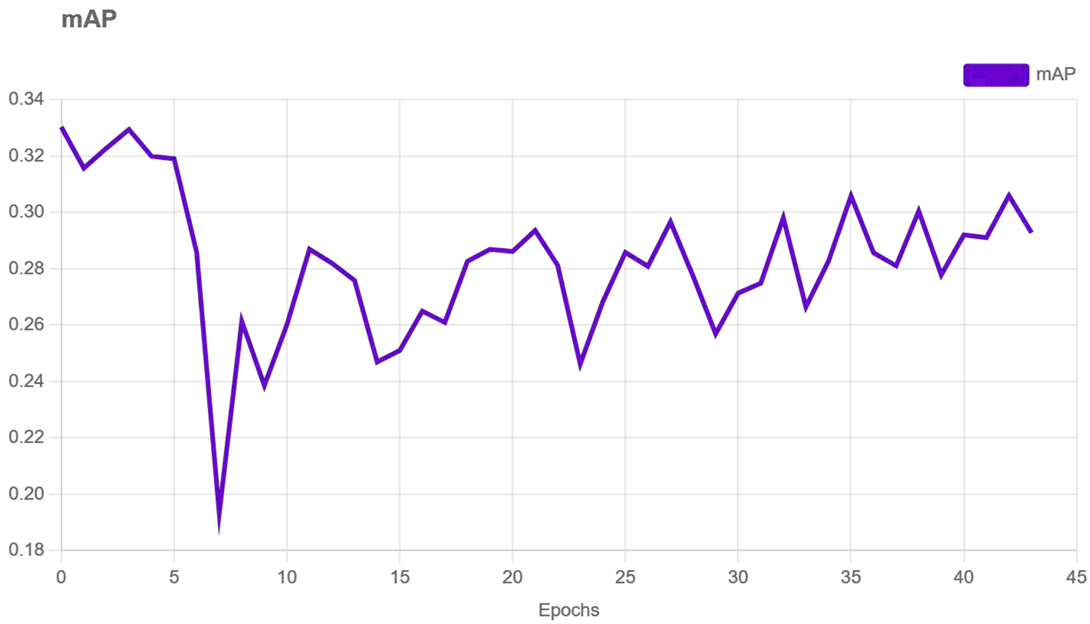

FIGURE 3.5. The second model version's mPA, which was used to annotate the dataset

The third set of image augmentation that was evaluated is shown in Figs. 3.16, 3.17, and 3.18 is the following:

- Grayscale: Apply to 3% of images.
- Saturation: Between -5% and +5%.
- Brightness: Between -10% and +10%.
- Exposure: Between -10% and +10%.
- Blur: Up to 0.5 px.
- Noise: Up to 1% of pixels.
- Mosaic: Applied.

Image augmentation increased the number of the images in the dataset to 12,061 images. The images were split between Training set, Validation set,

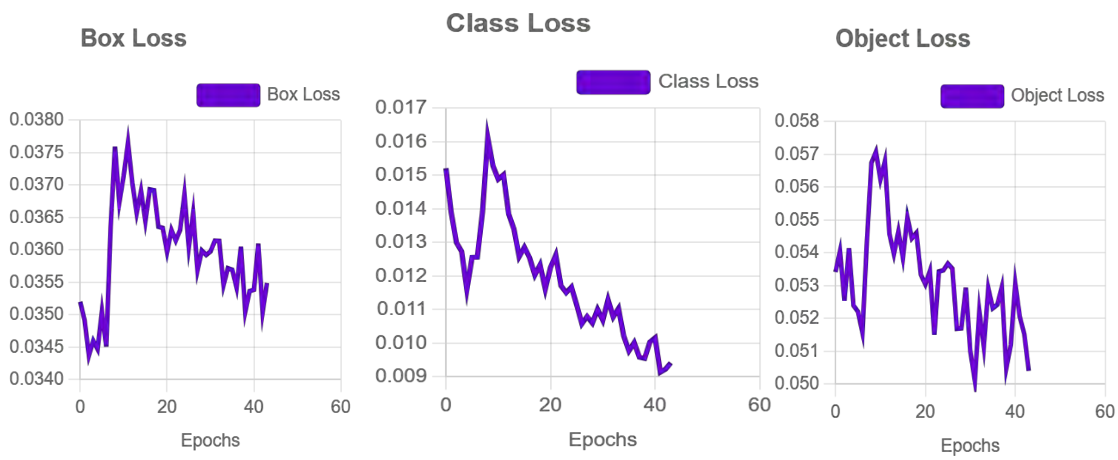

FIGURE 3.6. The evaluation of the second Pre-trained Model used to the annotation of the dataset

and Testing set ,as shown in Fig. 3.19. The YOLOv8 model was utilized to evaluate the dataset in order to examine the impact of augmentation on the metrics, as shown in Fig. 3.20.

3.4. Evaluation

The dataset was evaluated on YOLOv8m 4.5 and YOLOv5m V6.0 5.4. Table 3.3 displays evaluation of the Allergic-fruit dataset. The dataset exhibits a notable level of image quality, with annotations that demonstrate a high degree of accuracy. Table 3.4 presents the YOLOv8m and YOLOv5m V 6.0 mAP50 values for each class in the dataset.

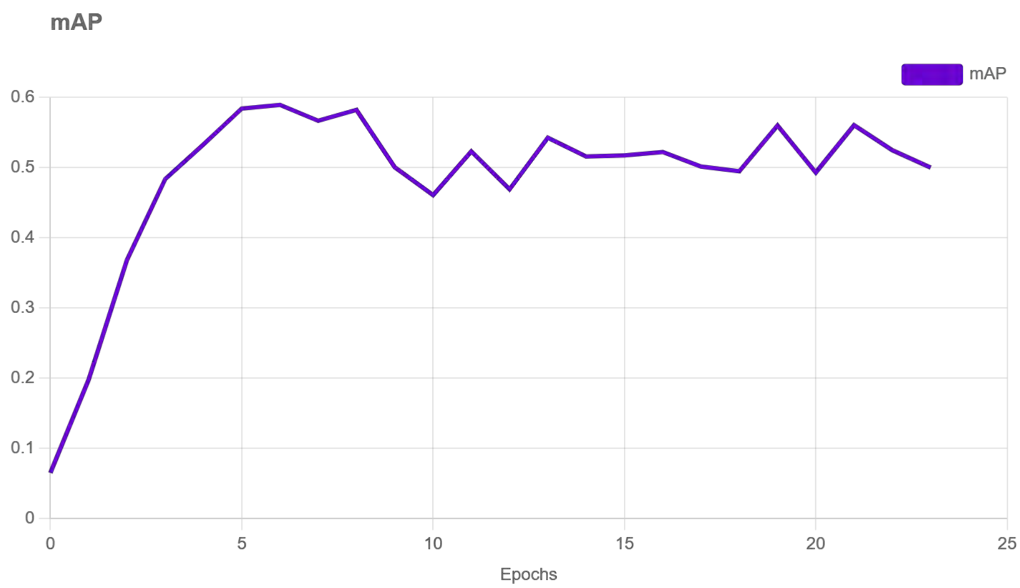

Figure 3.7. The mPA of the third version that was used to annotate the dataset

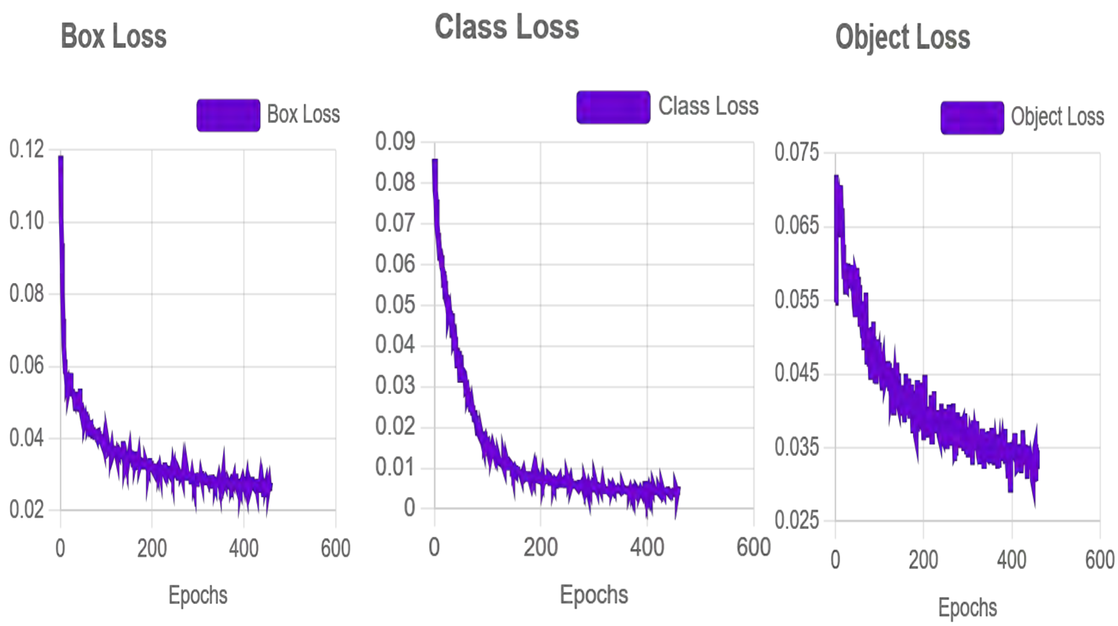

FIGURE 3.8. The evaluation of the third Pre-trained Model used to the annotation of the dataset

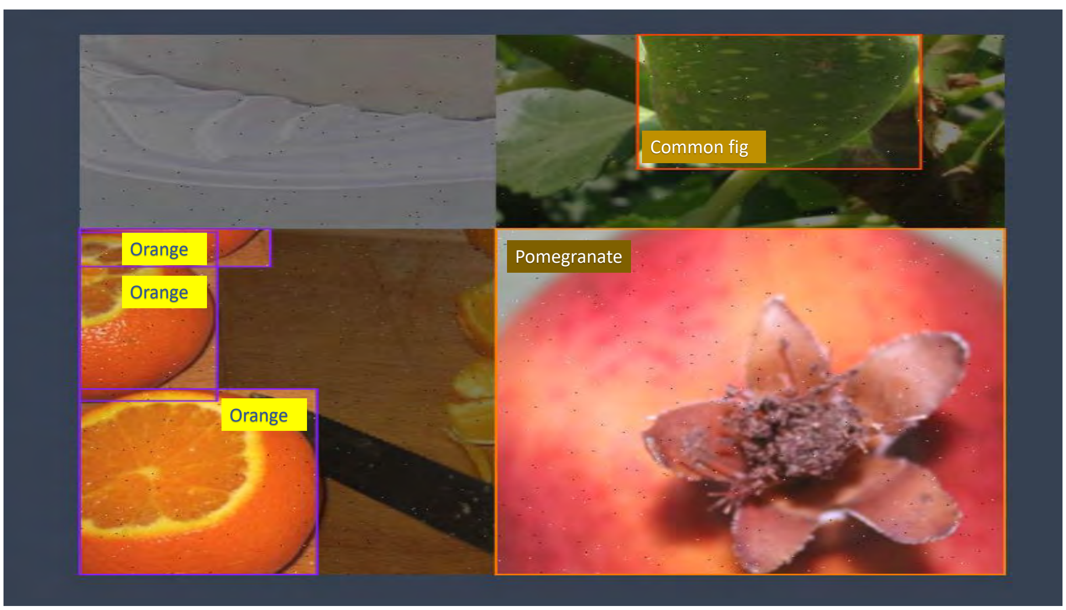

FIGURE 3.9. Samples of Annotated Image

TABLE 3.1. Annotations

Class	**Number of image**	**annotations**
Strawberry	630	3,368
Orange	519	2,957
Lemon	426	1,638
Pear	149	547
Pineapple	212	539
Grapefruit	92	429
Peach	138	1,425
Banana	471	1,401
Common fig	66	356
Apple	188	631
Grape	454	1,546
Mango	105	639
Watermelon	223	660
Pomegranate	131	343
Cantaloupe	85	283
Null	170	0
Total	3,862 without Null images	16,762

Table 3.2. Boundary boxes for each kinds of fruits include training, validation, and testing

Class	**Training**	**Validation**	**Testing**
Strawberry	2,458	592	314
Orange	2,019	607	321
Lemon	958	449	241
Pear	374	122	56
Pineapple	346	135	56
Grapefruit	342	65	29
Peach	888	411	128
Banana	831	416	181
Common fig	66	25	33
Apple	397	122	107
Grape	1118	295	135
Mango	481	85	72
Watermelon	423	122	130
Pomegranate	230	89	29
Cantaloupe	166	71	48

Table 3.3. Evaluation Dataset

Metrics	**YOLOv8m**	**YOLOv5m V6.0**
Precision	86%	90%
Recall	77%	80%
mAP50	84%	87%
mAP50-95	66%	71%
Parameters	25m	

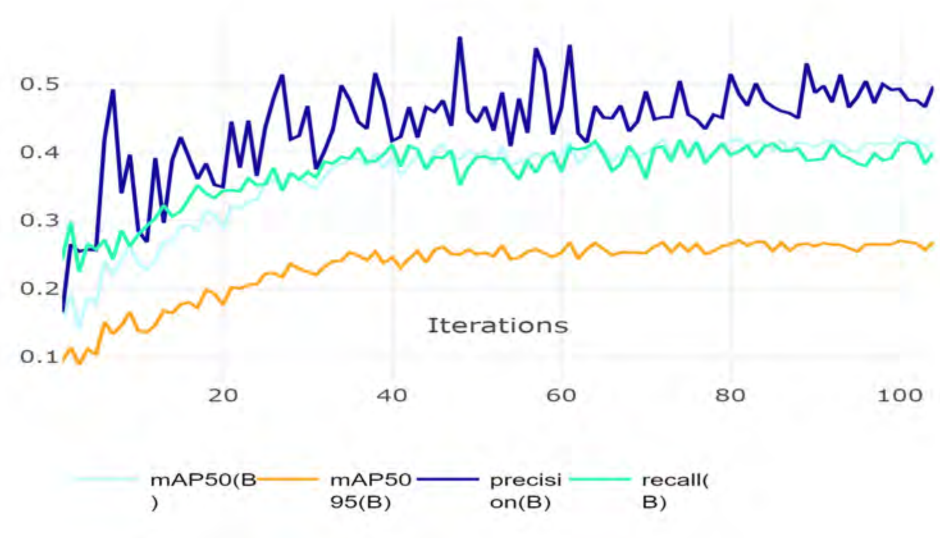

FIGURE 3.10. Evaluation of the Dataset Without Augmentation

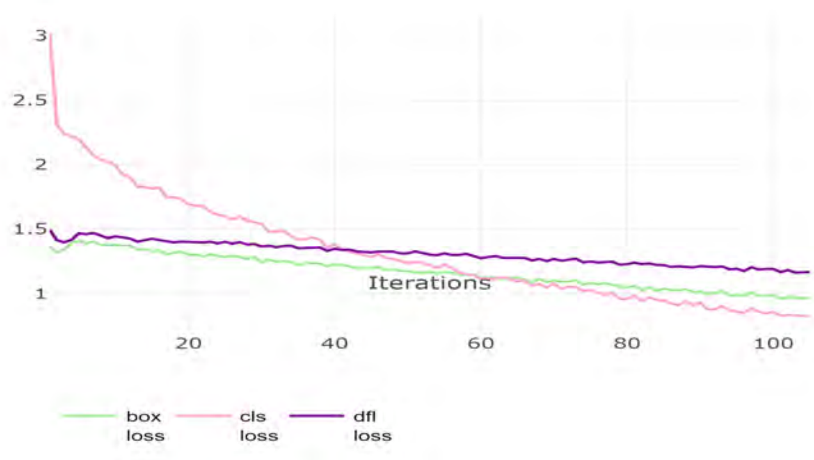

FIGURE 3.11. Box Loss, Class Loss, and Difi Loss on Training Without Augmentation

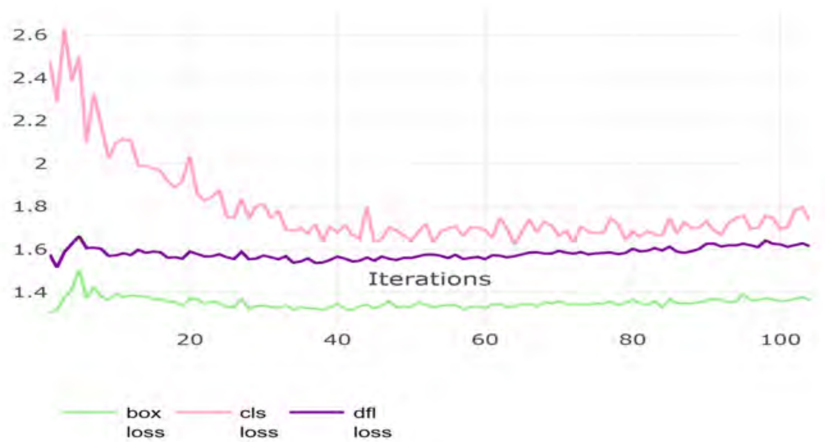

FIGURE 3.12. Box Loss, Class Loss, and Difi Loss on Validations Without Augmentation

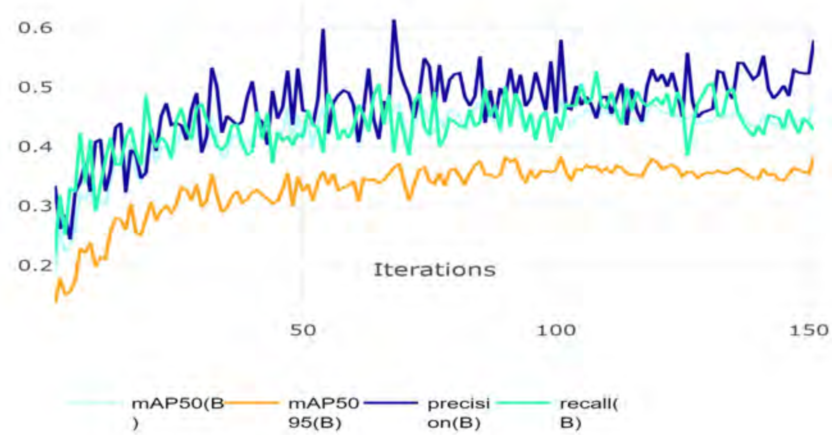

FIGURE 3.13. Evaluation of the Second set of Image Augmentation

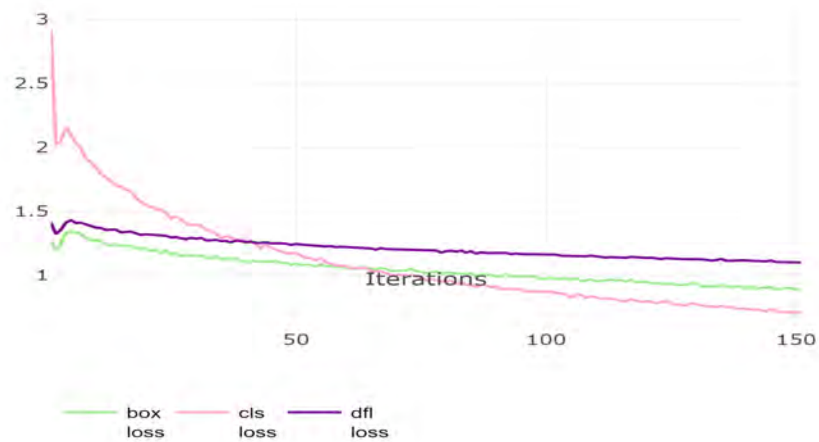

FIGURE 3.14. Box Loss, Class Loss, and Difi Loss on Training of the Second set of Image Augmentation

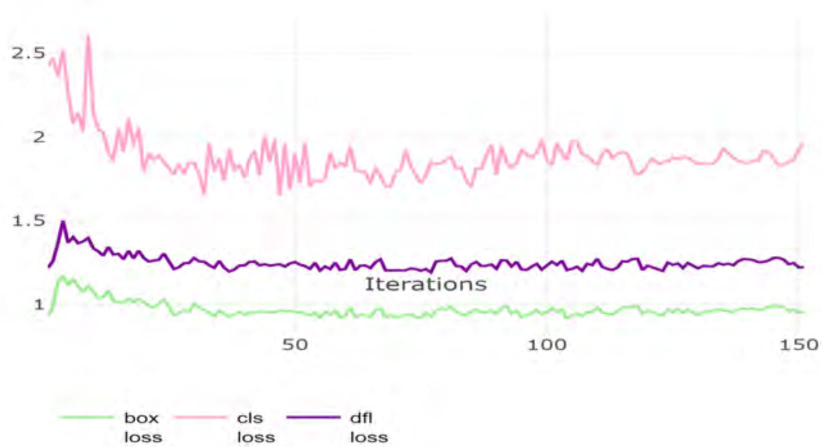

FIGURE 3.15. Box Loss, Class Loss, and Difi Loss on Validations of the Second set of Image Augmentation

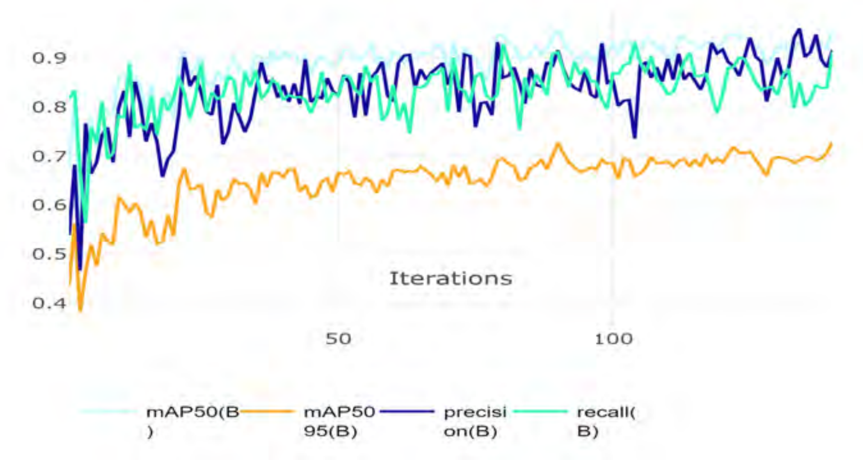

FIGURE 3.16. Evaluation of the third set of Image Augmentation

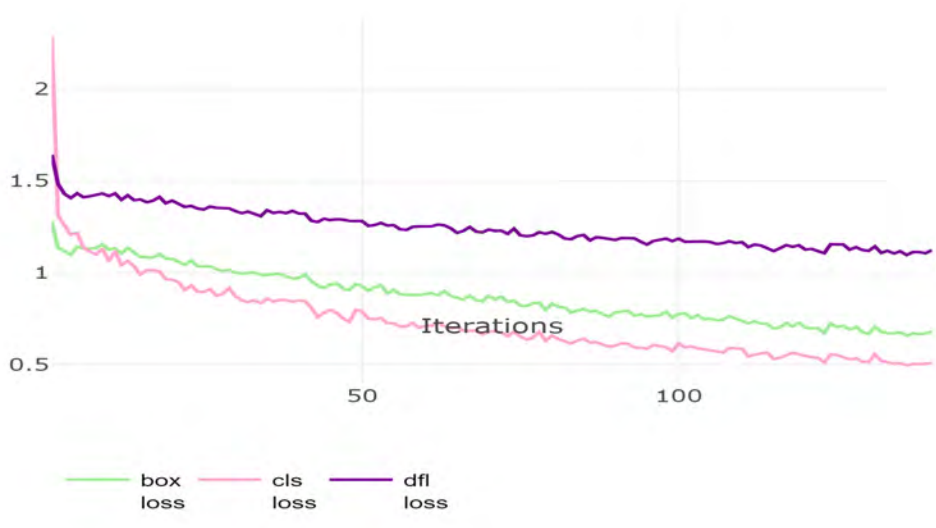

FIGURE 3.17. Box Loss, Class Loss, and Difi Loss on Training of the third set of Image Augmentation

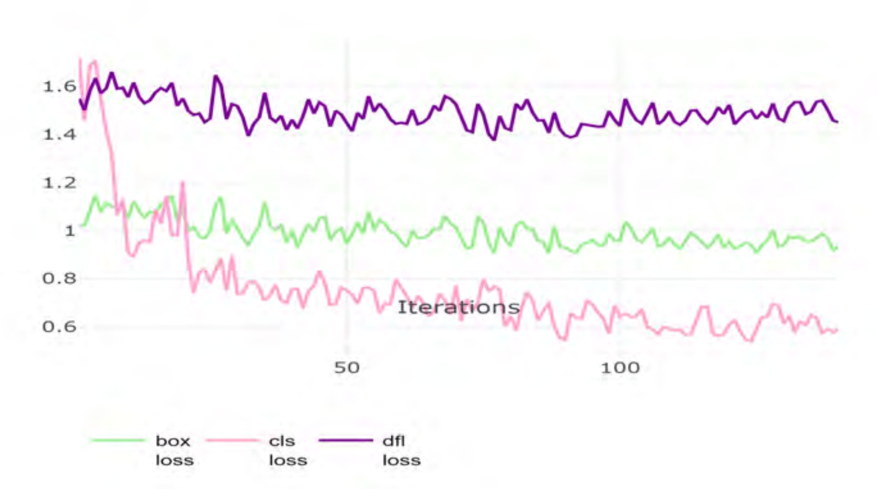

FIGURE 3.18. Box Loss, Class Loss, and Difi Loss on Validations of the third set of Image Augmentation

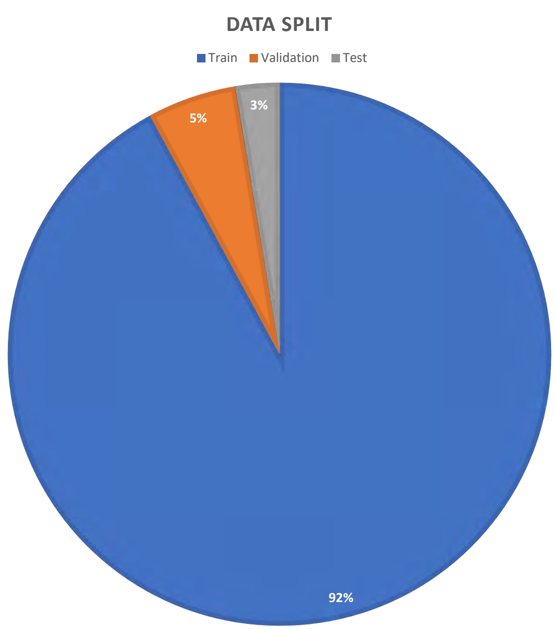

FIGURE 3.19. Data Split

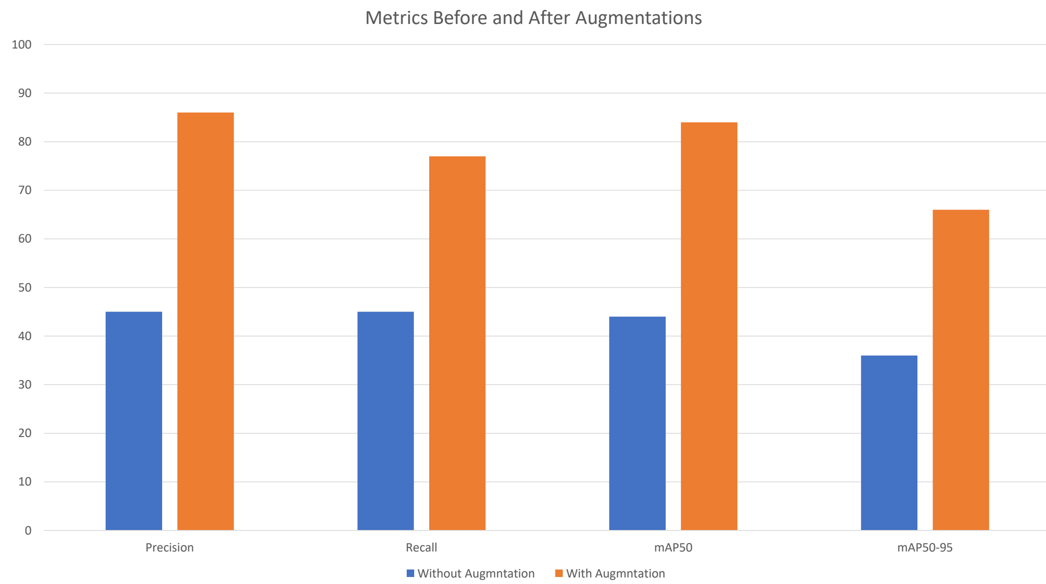

FIGURE 3.20. Metrics Before and After Augmentations

Table 3.4. mAP50 for Each Class on Allergic-fruit dataset

Class	**YOLOv8**	**YOLOv5m V6.0**
Strawberry	87.5%	89.6%
Orange	81.6%	82.2%
Lemon	78.8%	83.0%
Pear	88.0%	91.6%
Pineapple	85.5%	88.7%
Grapefruit	82.1%	81.5%
Peach	94.1%	95.8%
Banana	76.3%	77.0%
Common fig	89.7%	90.6%
Apple	59.1%	64.2%
Grape	76.2%	82.7%
Mango	94.8%	96.3%
Watermelon	93.6%	94.4%
Pomegranate	94.1%	98.0%
Cantaloupe	92.5%	91.4%
mAP50	84.9%	87.1%

CHAPTER 4

FRUITPAL: A SMART HEALTHCARE FRAMEWORK FOR AUTOMATIC DETECTION OF FRUIT ALLERGENS

[1] This chapter provides a detailed view of a smart healthcare framework for automatic detection of fruit allergens [**13**, **14**].

4.1. Overview

Consumption of certain fruits has the potential to cause allergic reactions, which can manifest rapidly. FruitPAL assists caregivers in monitoring people who have allergies to identify specific fruits that may trigger allergic reactions. The caregiver is notified upon detection of danger by FruitPAL. FruitPAL is a real time device that can generate the results in real time. The device is capable of detecting suspect fruit and notifying the caregiver without the need for human intervention. The YOLOv8 model is utilized in the FruitPAL device, enabling FruitPAL to achieve a high level of accuracy in fruit detection.

4.2. Proposed Method: FruitPAL

The proposed method of FruitPAL is illustrated in Fig. 4.1. The system begins with the End Platform once human movement is detected by the PIR sensor. The YOLOv8 algorithm is employed to detect fruit after the camera captures the image. The analysis of the object detection result will be then

[1]Significant portions of this chapter are reproduced from Abdulrahman Alkinani, Alakananda Mitra, Saraju P Mohanty, and Elias Kougianos, FruitPAL: A smart healthcare framework for automatic detection of fruit allergens, 2023 IEEE International Symposium on Smart Electronic Systems (iSES) (IEEE-iSES-2023) (Ahmedabad, India), December 2023, with permission from IEEE.

conducted. The alarm will be sent to the Cloud Platform based on the result. The alarm is processed by the cloud and subsequently transmitted to the caregiver.

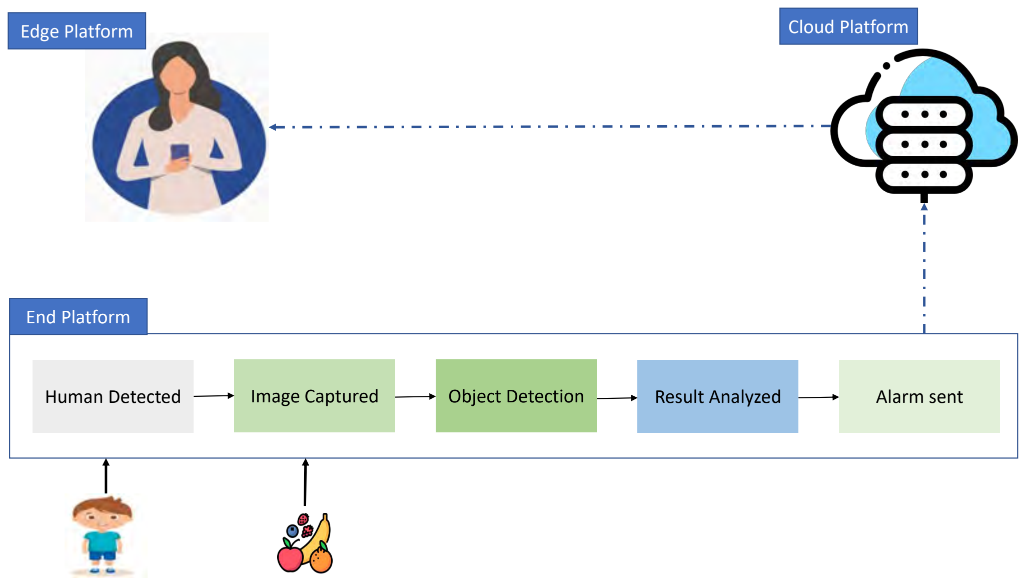

FIGURE 4.1. FruitPAL Method.

4.3. Computing Platforms

Fig. 4.2 illustrates the system level description of the concept proposed in FruitPAL. Both components, "Passive Infrared Sensor (PIR) and Smart Camera" are on the same level, so the benefit of this platform is to predict the dangers earlier and accurately. Once the power supply is activated, the camera captures a series of consecutive images. The captured images undergo automated processing and the resulting data is stored within the system. The data obtained will not be transmitted to a platform that sends notifications to the caregivers unless the PIR sensor detects movement by humans. The notifications will be delivered to the caregivers via their mobile devices, and they will have the ability to withdraw the notification as necessary. The system is distributed across different computing platforms. All those computing platforms are connected to each other by wireless communications. The objectives of the end platform are image acquisition, motion detection, and image processing. The main purpose of cloud platform is to communicate with the other platforms of the system. The other platform is the edge platform, and its feature is to receive notifications from and send the caregiver's decision to the cloud.

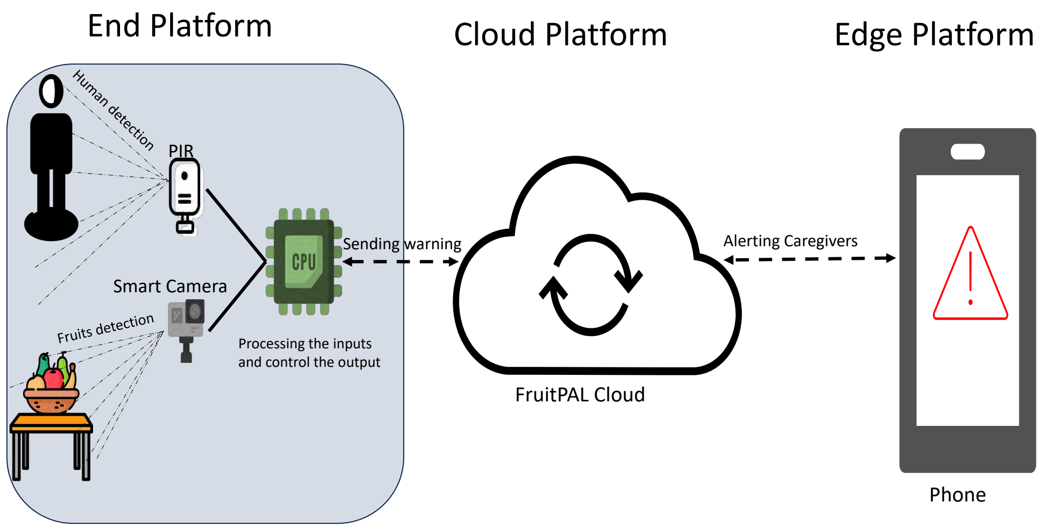

FIGURE 4.2. Three Different Computing Platforms Visible in FruitPAL's Architecture: End Platform, Cloud Platform, and Edge Platform [**13**].

4.3.1. End Platform

In this stage, FruitPAL detects the fruit that causes allergies and sends the collected data to the next stage. Fig. 4.3 shows the end platform components, PIR and smart camera. The PIR sensor and smart camera work synchronously to provide a faster response. PIR is a movement sensor that detects humans and animals via their bodies' temperature [**30**]. The PIR sensor should be positioned in a wide area that can detect the motion of the allergic person easily.

For the second component of the first level, the "smart camera" is able to detect fruit that cause allergies. Excellent visual capabilities are required to acquire a high result accuracy.

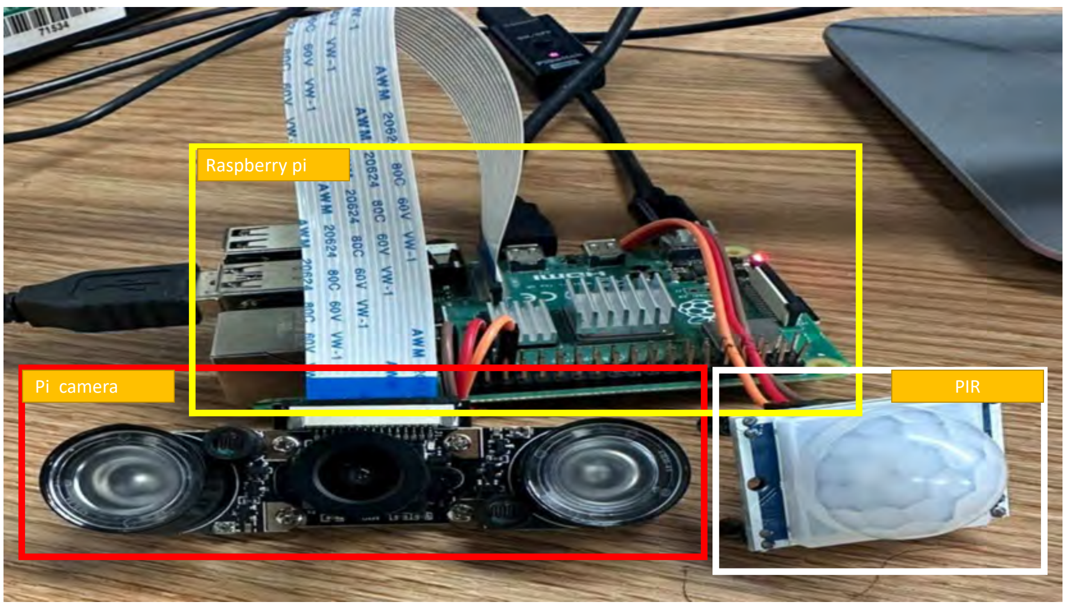

FIGURE 4.3. End Platform in FruitPAL [**13**].

4.3.2. Cloud Platform & Edge Platform

The cloud platform connects the end platform with the edge platform. The communication between those two platforms is done by Wi-Fi connection. The cloud platform receives requests from the end platform and warns the caregivers in the edge platform. The caregiver must respond to the warning that comes from the detection platform to ensure the danger is addressed. The warning comes to the caregiver as a phone call with voice messages that are “there is a allergen danger”. The warning stops when the takes the required action. FruitPAL can play a crucial role in saving human lives.

4.4. Training Protocol

FruitPAL is a real-time system that accurately predicts the risk of fruit allergens. Real-time object detection applications can have different algorithms, such as Faster-RCNN, DPM, or YOLO’s family. The dataset 3 of the proposed device was trained by YOLOV8 (YOLOv8 is one of the YOLO family). The reason for using YOLOv8 is the high accuracy results and fast detection of the objects. The YOLO family has made a significant impact in the field of object detection due to its single-stage architecture [**48**]. The distinction between the YOLO family of algorithms and other algorithms is that the YOLO family does not have Region Proposal Network (RPN) [**49**]. The training mode has done by weight YOLOv8s (weight refers to small parameters). The small weight has 11.2M parameters, and it is appropriate for the end edge [**51**].

4.5. Experiment

FruitPAL is a portable electronic device that can be positioned in any location. The computational performance of the model was assessed on a computing system equipped with an Intel Core i7-7700 processor operating at a clock speed of 3.60 GHz and 16 GB of RAM. For the implementation process, we use a Raspberry Pi 4 with 4GB RAM in the end platform, as shown in Fig. 4.3. The model was trained on an A100 GPU (a Google Colab GPU) with high RAM (40GB), and it has consumed around 3 hours to complete 100 epochs. Fig. 4.4 displays the model evaluation for the object detection model and interpreting train box loss, class loss, and DFL loss. Also, Fig. 4.5 illustrates the validations as val box loss, class loss, DFL loss. Precision, recall, and mAP50 and 50-95 are metrics that are considered in our research work. The data is presented in two distinct formats, in Fig. 5.5 and in Table 4.1. The confusion matrix in Fig. 4.7 presents the synopsis performance for each class of the model. As a summary of FruitPAL model, we see how FruitPAL detects the fruit among the other objects in Fig. 4.8 while the FruitPAL device can detect the danger accurately. ONNX is used to convert the YOLOv8 model to TensorFlow Lite. By combining the FruitPAL model part with the FruitPAL device, the allergic person has the possibility to avoid the fruit that jeopardizes their life.

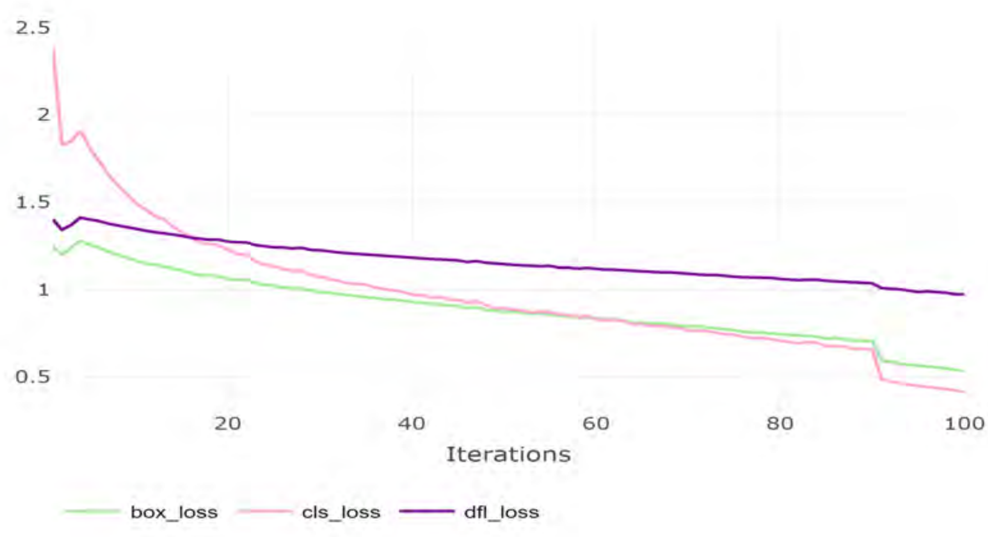

Figure 4.4. FruitPAL Training Model.

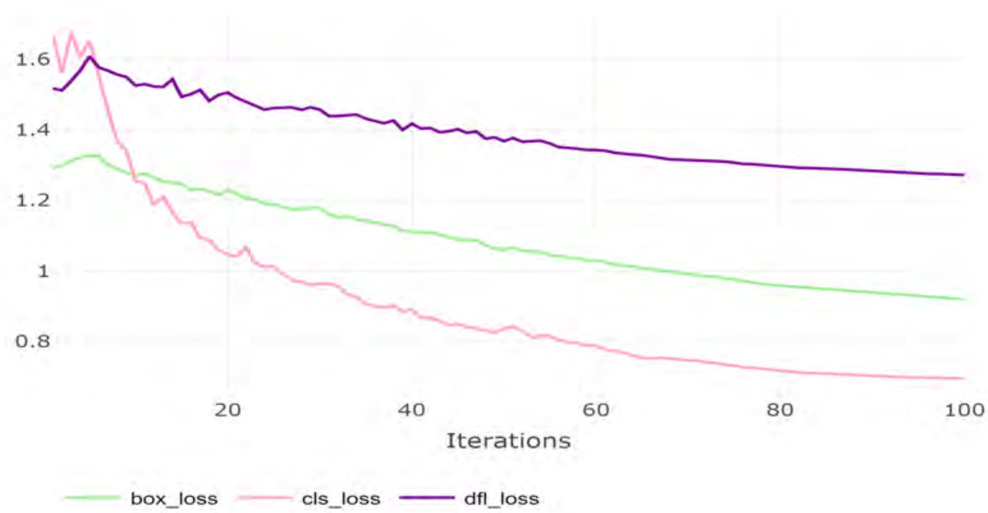

FIGURE 4.5. FruitPAL Validation Model.

TABLE 4.1. FruitPAL Metrics [**13**]

Metrics	**Value**
Precision	86%
Recall	77%
mAP50	84%
mAP50-95	66%
Parameters	25m

4.6. Hardware for Prototyping

The hardware components within the FruitPAL system exhibit high levels of effectiveness and efficiency. Nevertheless, it is possible to modify the PIR sensitivity as required. The calculation of the sensitivity of PIR sensor is

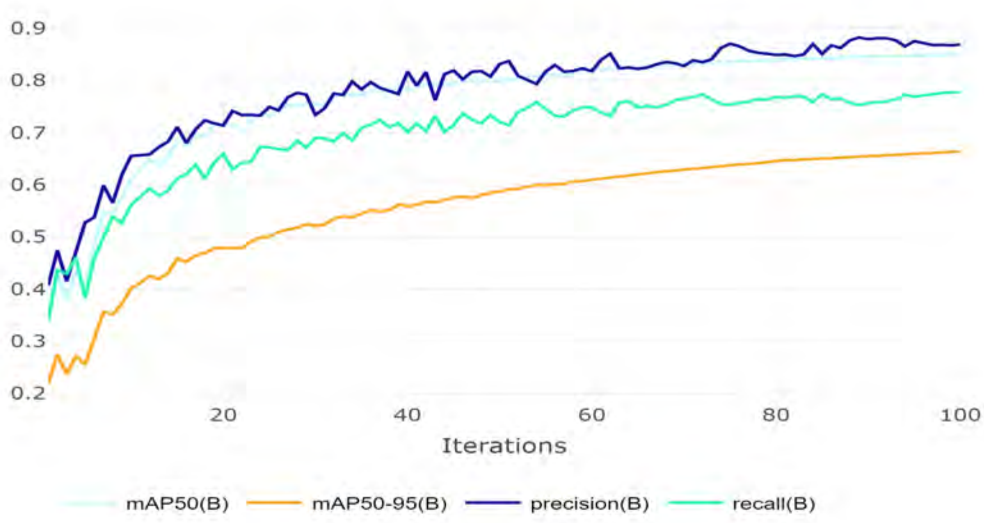

FIGURE 4.6. FruitPAL Metrics Model.

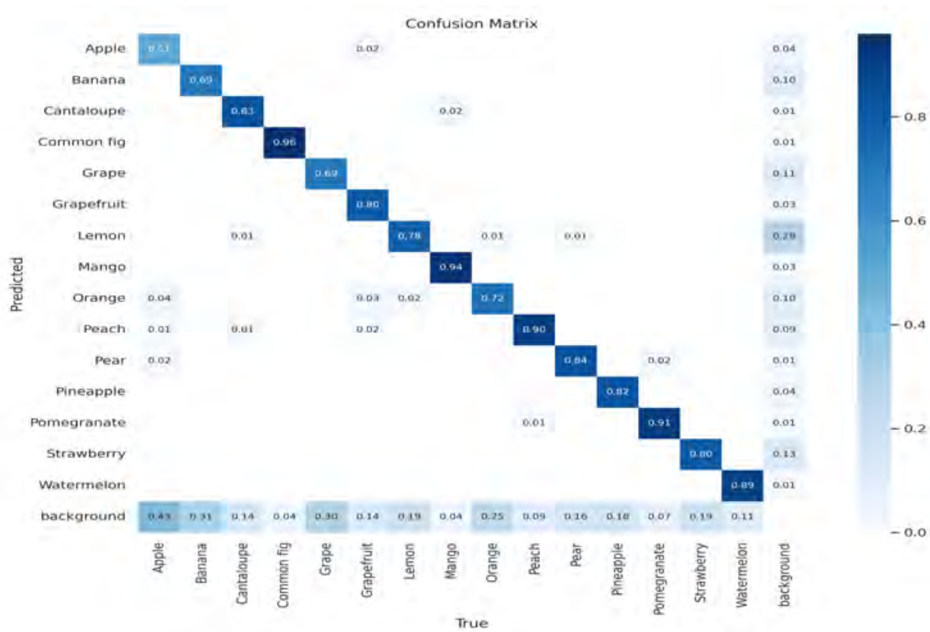

FIGURE 4.7. FruitPAL Confusion Matrix [**13**].

FIGURE 4.8. Object detection by FruitPAL [13].

imperative in order to effectively detect human motion [30]. The sensitivity of PIR can be adjust using the equation:

$$T_i = 24 * R9 * C7,$$

where T_i is the sensitivity. Adjusting the values of the resistor (R9) or capacitor (C7) change of the value of the sensitivity.

The higher and lower limits of responsiveness can be established based on the given equation. The highest point of responsiveness is

$$T_i = 24 * 1m * 0.01uF = 2.4 \quad seconds,$$

and the lowest point of responsiveness is:

$$T_i = 24 * 1m * 0.05uF = 12 \quad seconds.$$

4.7. Discussion

People who are unable to recognize the risks require assistance. A caretaker's error could have disastrous consequences. By monitoring fruit allergies, FruitPAL helps caregivers. It is essential to use object detection to support caregivers. FruitPAL uses the YOLOv8 efficiency model for object detection.

CHAPTER 5

FRUITPAL 2.0: A SMART HEALTHCARE FRAMEWORK FOR AUTOMATIC MONITORING OF FRUIT CONSUMPTION

[1]This chapter discusses a framework for smart healthcare that automatically monitors fruit consumption [**13**, **14**].

5.1. Overview

Vitamins can be obtained from a wide variety of sources. Because fruit contain a high concentration of vitamin content, it should be consumed on a daily basis. However, a lot of people forget to include eating enough fruits in their daily diet. The purpose of FruitPAL 2.0 is to encourage people to consume more fruit. The FruitPAL 2.0 system has the capability to identify and analyze a total of 15 different types of fruit. Subsequently, a daily message will be transmitted to the participants to motivate them.

5.2. Proposed Method

Fig. 5.1 illustrates how each Level works to identify the fruit being consumed and deliver a text message. All functions are fully automatic. Capturing images, detecting images, and analyzing the results is done at the device level. Once the message is issued, it is sent to User Level by the Cloud Level. The message is sent everyday at a specific time to avoid annoying the users. Restarting the system can be done by the User Level when new fruits are

[1]Significant portions of this chapter are reproduced from Abdulrahman Alkinani, Saraju P Mohanty, Alakananda Mitra, and Elias Kougianos, FruitPAL 2.0: A smart healthcare framework for automatic monitoring of fruit consumption, 21st OITS International Conference on Information Technology (OCIT) (OCIT-2023) (Raipur, India), December 2023, with permission from IEEE.

added to the plate. The users may get a boost in motivation by receiving a daily message.

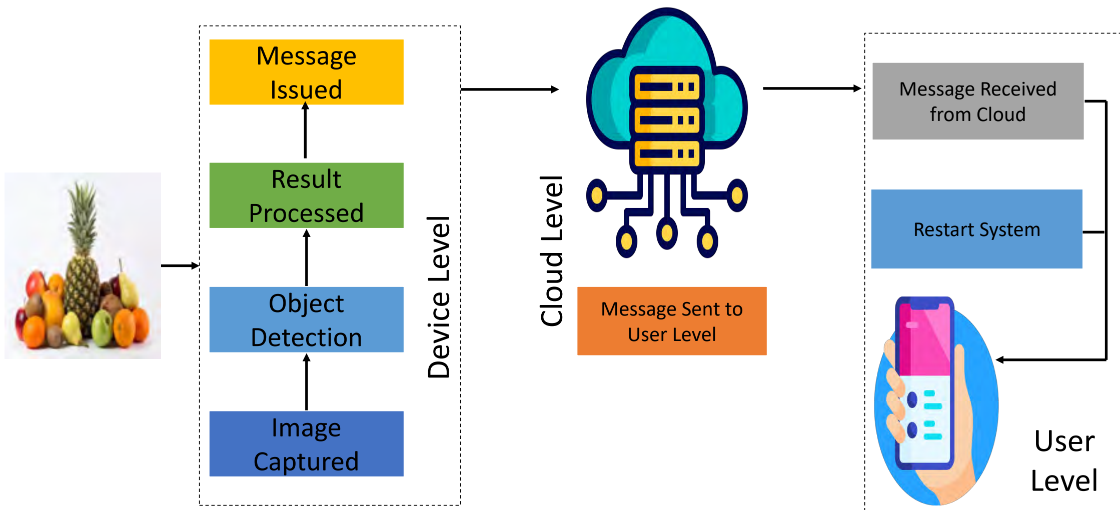

FIGURE 5.1. Workflow for Levels in FruitPAL 2.0.

5.3. Computing Platforms

Three levels are illustrated in Fig 5.2 to explain FruitPAL 2.0's architecture. The camera captures a photo when the power supply is turned on. The photo will be detected by the YOLOv5m V6.0 model. The results can be analyzed and sent to the next level, which is the Cloud Level. The feature of the Cloud Level is to send a text message to the phone on the User Level at a specific time. The text message contains a list of all the vitamins in the fruit that was eaten. Wireless communication is applied between Levels. The majority of work will be done at the Device Level to reduce the cloud cost.

The Cloud Level is a communication station between the Device Level and User Level.

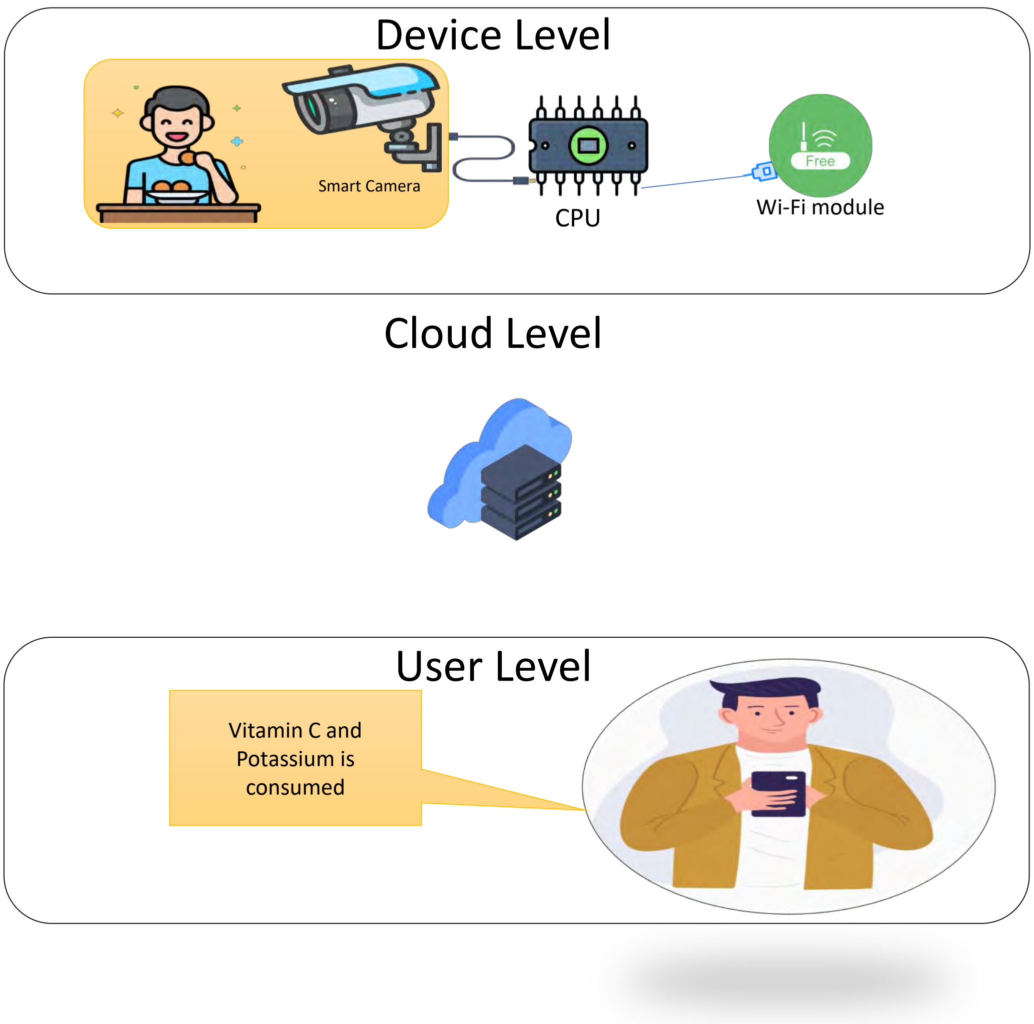

Figure 5.2. FruitPAL 2.0's architecture shows three different computing Levels: Device Level, Cloud Level, and User Level [**14**].

5.3.1. Device Level

The image is taken by a smart camera once the device is active. YOLOv5m V6.0 mode is applied on the captured image. The initial fruit list will be stored after the fruit has been identified. Every hour, the fruit in the dish will be photographed and detected. A new list will be created and compared with the original list to show the consumed fruits. The nutrient value from each eaten fruit will be provided based on the information in Table 5.1. The consumed nutrients will be written on a text message, and it will be provided at a specific time. Table 5.1 shows some of the nutritional information for each fruit group [**46**]. The message provides a summary of the nutritional content that was consumed throughout the day. Furthermore, the system automatically restarts every morning to update the original list.

TABLE 5.1. Fruits Nutritional [**14**].

Group	**Value**	**Fruit**
Citrus Fruits	Vitamin C and Potassium	Grapefruit, Lemon, and Orange.
Tropical Fruits	Vitamin B6 and C	Banana, Mango, and Pineapple.
Pome Fruits	vitamin C and Manganese	Apple, Common fig, and Pomegranate.
Stone Fruits	vitamins A, C, and E	Peach and Pear.
Melons Fruits	Vitamins A and C	Cantaloupe and Watermelon.
Berries Fruits	Vitamin K and Folate	Grape and Strawberry.

5.3.2. Cloud Level & User Level

The link between Device Level and User Level is the Cloud Level. The text message is created by the Device Level. It is sent to User Level by Cloud Level. Users do not need Internet connection to receive the message due to

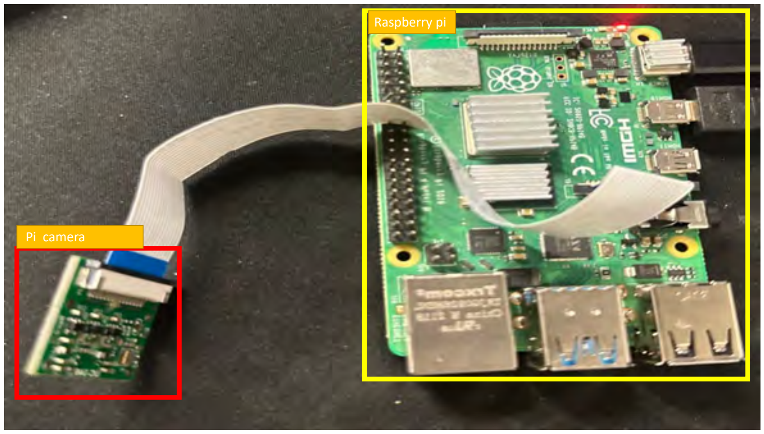

FIGURE 5.3. Device Level in FruitPAL 2.0 [**14**].

GSM.

5.4. Training Protocol

FruitPAL 2.0 is a mobile electronic device that should be placed in a dinning room to monitor the fruit consumption. YOLOv5m V6.0 has been utilized as the object detector in “FruitPAL 2.00”. Fast time response and accuracy is achieved due to the high quality dataset 3. A T4 GPU, a Google Colab GPU, was used for training the model, and it has 40GB of RAM. The model was evaluated on a Microsoft Surface Pro 7 that has Intel I5-1035G4 CPU, 8GB RAM, and 256GB SSD. Fig. 5.4 illustrates the model evaluation process for the object detection model, specifically focusing on the analysis of train box loss, class loss, and DFL loss. Likewise, the above-mentioned figure serves to exemplify many forms of validation, such as val box loss, class loss, and DFL loss. The metrics of precision, recall, mAP50, and mAP50-95 are displayed in Fig. 4.1. The performance for each class of the model is illustrated in Fig 5.6. Open Neural Network Exchange (ONNX) is involved to exchange Yolov5 model from PyTorch to TensorFlow lite. TensorFlow lite is suitable for end devices [**4**].

5.5. Experiment

A Raspberry pi 4 with 8GB RAM and pi camera is used at Device Level, as shown in Fig. 5.1. In evaluating the FruitPAL 2.0 model, its ability is shown in Fig. 5.7. With a high performance model and fast end device, FruitPAL 2.0 can encourage users to increase their fruit consumption.

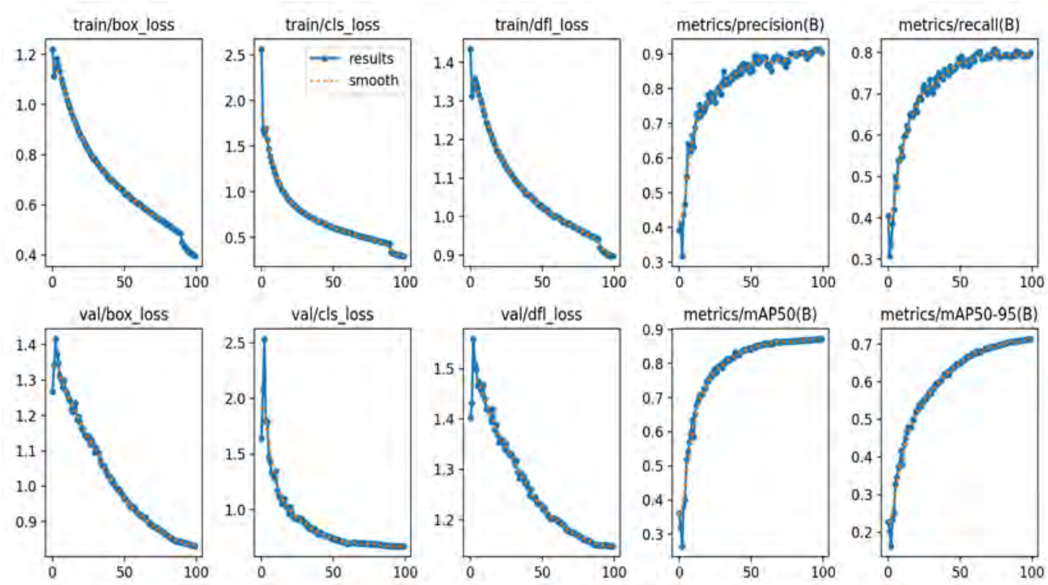

FIGURE 5.4. FruitPAL 2.0 Model Evaluation [**14**].

5.6. Discussion

Demonstrating the health benefits of fruit to people is the most effective kind of motivation. People prefer to look for the good in things. The majority of previous research has been devoted to informing people about food's calorie or sugar content. Focusing only on the negative causes people to make up excuses for the problem. FruitPAL focuses on the positive aspect of motivation

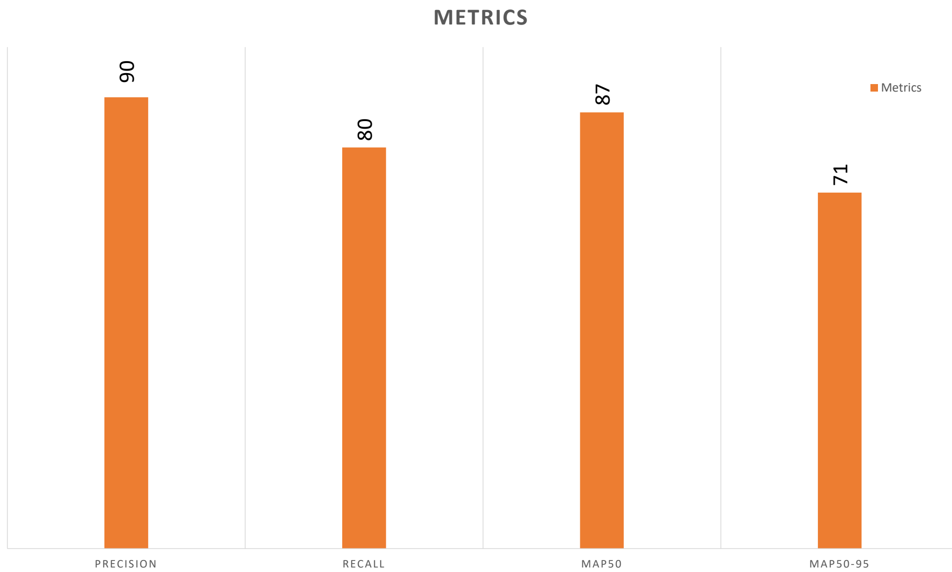

FIGURE 5.5. FruitPAL 2.0 Metrics [**14**].

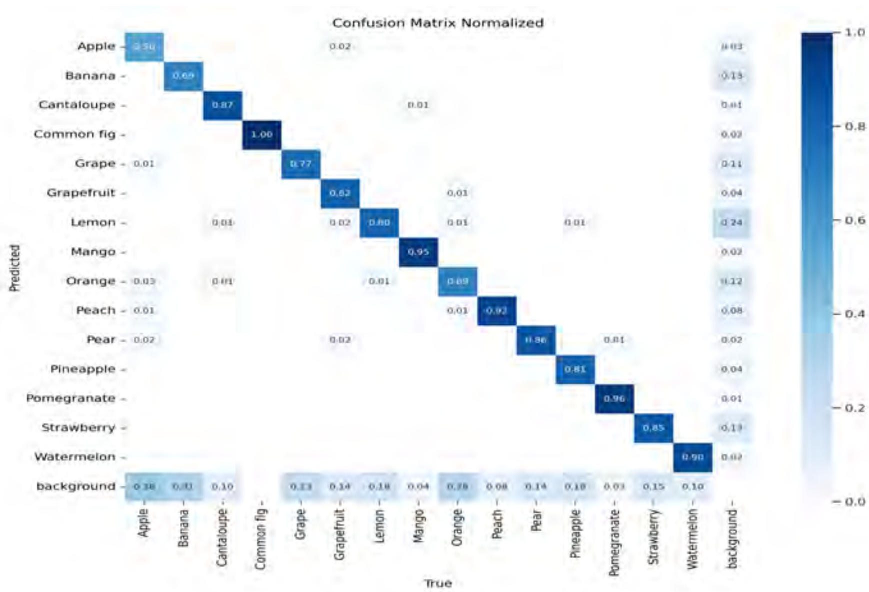

FIGURE 5.6. FruitPAL 2.0 Confusion Matrix [**14**].

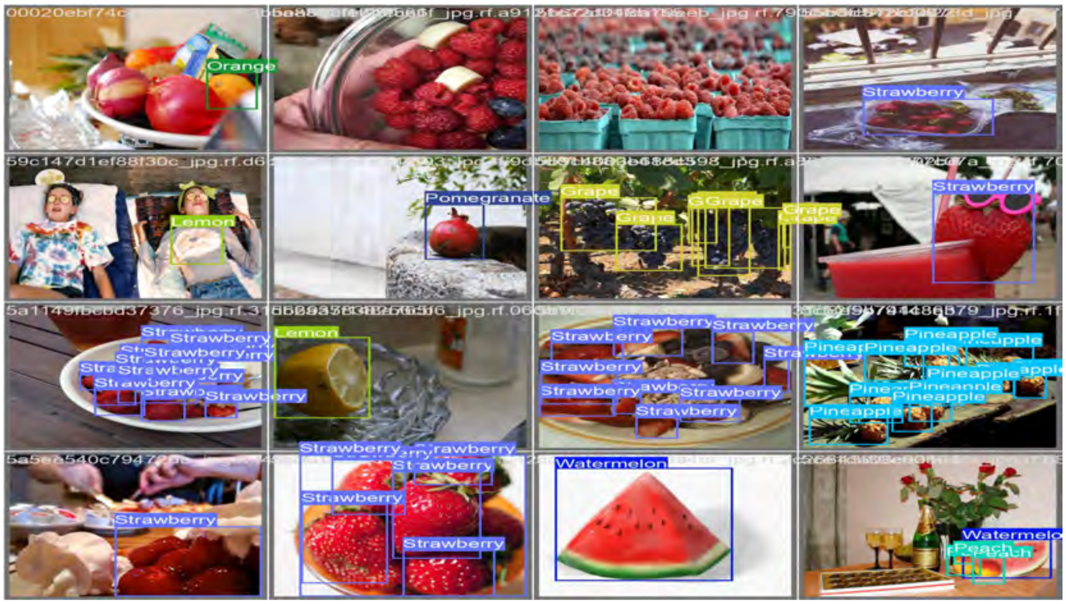

FIGURE 5.7. Fruit detection by FruitPAL 2.0 [**14**].

Algorithm 1 Process of Object Detection employed in FruitPAL 2.0

Time start ▷ the device in on

Image is Captured.

Initial fruit list is created.

for Image is captured **do** every hours

    Compare the new fruit list with initial fruit list.

    if Fruit is eaten **then** Save the eaten fruit in message list.

    else if New fruit add **then** Update the initial fruit list.

    Add a hour in the timer.

    if Timer = 24 hours **then** End For loop.

compare the message list with table 5.1.

Message sends to the user

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to enhance fruit consumption rates. A positive message displays the amount of vitamins consumed during the day.

CHAPTER 6

CONCLUSION

The dataset is the primary asset in boosting the effectiveness of an object detection model. We focus in Chapter 3 on building a high quality dataset. Most available fruit datasets have few kinds of fruit, so we build the Allergic-fruit dataset that consists of fifteen different kinds of fruit. We employed different ways to annotate the dataset. A high efficiency methodology is employed for the annotation of the collection images. We conducted several levels of dataset evaluation. We made changes on different factors. On the annotated images, image augmentation has been applied to improve the accuracy of the dataset. We utilized the fruit object detection dataset to identify fruit allergies in Chapter 4. A novel device for fruit allergen detection has been presented. Fruit allergens could cause significant harm for allergic people. Research discusses different ways to protect the humans from the allergens [**17**, **44**, **47**]. We concentrated on the group of people who lack recognition about fruit allergen. We chose the faster time response and high accuracy model which is YOLOv8. Another use of our dataset is in Chapter 5, a methodology that offers an automated system for monitoring fruit consumption. We focused on an important problem: people who don't eat enough fruit. Consuming fruits contributes to the enhancement of overall health through the provision of essential nutrients [**19**,**20**,**33**,**46**]. Nutritionists encourage the consumption of fruits due to their potential role in preventing diseases [**23**].The proposed work is a fully automatic device that can monitor fruit consumption. Two versions of the YOLO family were used in this thesis to solve two main problems addressed. We also used different models to test our dataset.

As for future research purposes, increasing the number of classes on the dataset can be achieved by collecting additional images. In the event that a caregiver fails to intervene in order to protect an allergic person, it is essential that the system promptly initiates contact with emergency services and transmit the precise location of the affected individual in terms of heath protection. Additionally, the system can provide more security. Furthermore, the inclusion of a speaker and microphone will allow communication between the caregiver and the allergy sufferer. Also, the caregiver can lead the allergic person through out the communication channel to avoid consuming the allergen fruit, so the allergic person can eat other healthier fruits. Creating an application that allows the caregiver to observe the allergic person in real-time is an additional feature to be considered for the future. Future research should concentrate on including face recognition since it can increase efficiency. The implementation of face recognition technology on FruitPAL enables the device to accurately identify individuals and fruit they should not eat. FruitPAL 2.0 can be used by multiple users due to face recognition. Connecting the health record with the FruitPAL 2.0 cloud platform has a chance to enhance the system's ability to encourage users to consume specific fruits that are beneficial to their health. Family doctors can identify the fruits which may affect the allergic patients. One type of food that cause choking is fruits because some fruits are large and solid which may be hard to swallow easily. The device can identify choking situations and alert the physician to protect human lives.

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