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# Deep learning mango fruit recognition based on TensorFlow lite

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ABSTRACT

Agricultural images such as fruits and vegetables have previously been recognized and classified using image analysis and computer vision techniques. Mangoes are currently being classified manually, whereby mango sellers must laboriously identify mangoes by hand. This is time-consuming and tedious. In this work, TensorFlow Lite was used as a transfer learning tool. Transfer learning is a fast approach to resolving classification problems effectively using small datasets. This work involves six categories, where four mango types are classified (Harum Manis, Langra, Dasheri and Sindhri), categories for other types of mangoes, and a non-mango category. Each category dataset comprises 100 images and is split 70/30 between the training and testing set. This work was undertaken with a mobile-based application that can be used to distinguish various types of mangoes based on the proposed transfer learning method. The results obtained from the experiment show that adopted transfer learning can achieve an accuracy of 95% for mango recognition. A preliminary user acceptance survey was also carried out to investigate the user's requirements, the effectiveness of the proposed functionalities, and the ease of use of its proposed interfaces, with promising results.



## 1. Introduction

Mango (*Mangifera indica* L.) is one of the world's most valued tropical and subtropical fruit, particularly in Asia. Its significance can be recognized by the fact that it is known as the "King of Fruits" across the tropical globe [1], [2]. Mango has acquired worldwide popularity over the past two decades due to its nutritious value, wonderful taste, outstanding flavor, appealing scent, and health-promoting properties [3]–[5]. It is cultivated commercially in over 103 countries, which include India, Pakistan, China, Indonesia, Mexico, Egypt, Philippines, Central America, Australia, Brazil, Nigeria, and Thailand [6], [7].

There are many types of mangoes in the world. For this work, some of the primary mangoes will be focused on, such as the Harum Manis, Langra, Dasheri and Sindhri. Harum Manis are all well-loved by Malaysians. For example, the Harum Manis is planted on more than one thousand hectares of land in the state of Perlis alone [8]. Harum Manis mangoes feature a bright green skin with big light-yellow spots. Harum Manis mangoes have a wide, oval form, are slightly larger than the size of a palm, and may weigh up to one kilogram. As for the Langra mango, the base of the fruit is flat, and the apex is curved. For the Langra mango variety, the skin is rougher compared to the Dasheri with black spots, and a medium-thin shape [9]. Dasheri mangoes are small to medium-sized fruits, that range in size from nine to 15 centimeters in length. The Dasheri have an elongated, straight oval form with blunt, curving ends, and they are available in a variety of colors. If the fruit is fully ripe, the skin is semi-thick, smooth, leathery, and mildly waxy, and it ranges in colour from light green to yellow-green, eventually becoming a golden yellow tint [10], [11]. According to Baloch *et al.* [9], the color of the Sindhri mango variety is yellow golden, with a pulp of light yellow with an orange tinge, firm texture, rich flavor, smells like melons, and tastes extremely sweet. The mango variants and its characteristics are shown in Table 1.

**Table 1.** Mango variants and its characteristics

| Mango variants/ Characteristics | Harum Manis | Langra | Dasheri | Sindhri |
|---|---|---|---|---|
| *Colour of mango* |  |  |  |  |
| *Shape of mango* |  |  |  |  |
| *Texture of mango* |  |  |  |  |

Agricultural images such as fruits and vegetables have been analyzed using a variety of image analysis approaches in the past for recognition and classification reasons [12]–[14]. Recognition systems have evolved as a grand challenge for machine learning, with the long-term goal of achieving near-human recognition levels for thousands of categories under a variety of aspects. Deep learning is a type of machine learning that has found use in a wide variety of research domains such as biometrics applications [15], as well as in other fields [16]–[18]. Transfer learning enables the usage of pre-trained networks by fine-tuning them with domain-specific data, hence increasing their effectiveness. In its most basic form, transfer learning is the act of reusing information gained from a previous training exercise, to improve the learning process in a new, or for a much more difficult task [19]. [20], [21] stated that this technique is particularly useful for the difficult challenge of learning classifiers which must function well, when just a small number of training samples are available.

The fruit-recognition system suggested by Hussain *et al.* [22] is based on a transfer learning method. This work was able to expand the author's previous work on automated fruit detection by adding additional classes to an existing model, that had been trained for 15 types of fruits. The model had previously been trained on a large-scale dataset of 44406 images, which was publicly accessible. The experimental findings showed that the proposed CNN framework outperformed the state-of-the-art networks which had been previously created. Precision, recall, and the F1-score were all 0.99, which is taken to be a very good value. This work could be improved further by increasing the number of training epochs.

Saari *et al.* [23] built a web-based system (CamPauh) for visually identifying the Harum Manis, the apple mango, and other mango varieties and fruits not classified as mangoes. The purpose of this study was to develop and evaluate an accurate mango type classification system based on textural features. This article suggests a system which utilizes the TensorFlow and Keras in conjunction with the Mobile Net concept or architecture. Additionally, the system doubled the number of training steps, and added a massive number of images to the dataset to ensure that the result was accurate, to be able to improve the output's accuracy. The system's accuracy was determined by utilizing a confusion matrix approach, and it was found to be 92% accurate. Nonetheless, the system was web-based. It could be extended as a mobile application to enhance the system's efficiency, as well as allowing users to utilize it from their devices.

Bahera *et al.* [24] experimented on various machine learning and transfer learning methods for determining the maturity of the papaya fruits. The authors trained the classifiers across 300 papaya images for three different maturity levels. For the machine learning methods, several feature extraction methods were adopted to generate the required suitable features for the papaya fruits, and the features were fed into various traditional machine learning methods. As for the transfer learning methods, various methods and settings were used. It has been found that the VGG19 transfer learning method outperforms the traditional machine learning method (Histogram of Gradient feature extraction method with a K-Nearest Neighbour classifier).

Kang and Gwak [25] adopted the transfer learning of the ResNet-50 and ResdNet-101 to categorize the fruits and the freshness of these fruits. The transfer learning method allowed the authors to achieve an average accuracy of over 95% with limited training data.

Frutolo is an application which provides a feature that determines the types of fruits and vegetables if users take photos, videos, and browse them from their phone gallery [26]. This application will also display the required information about the fruits and its nutrients. The disadvantage of this application is that it was unable to recognize types of fruits immediately, because it tended to display possible fruits that looked similar first, and the users needed to click the right fruits which matched the photo taken. In addition, this application predictions were not always accurate.

Musang King is a mobile application that is available for free in the Google Play Store, and App Store. The Musang King Application enables users to recognize types of durians if the user takes a photo or browses it from a photo gallery [27]. This application also allows users to take multiple photos of durians from different angles to get better results. The Musang King application will also display the necessary information about the durian and where to find it. The disadvantage of this application was that the recognition mechanism only worked if the photo was taken from the bottom of the durian. Moreover, this application also could not recognize other types of durians other than the musang king, and it required an Internet connection.

FreshThumb is a mobile application that is freely available in the Google Play Store and App Store. FreshThumb detects fruits, vegetables, and spices, based on their visible surfaces [28]. By simply aiming a phone camera at the object, the application will receive detailed information about them, including their ripeness level, professional suggestions for selecting ingredients, and how to store them. One of the disadvantages of this application is that it will only allow users to scan objects, but they are not able to browse from them from the photo gallery. The application is also not very accurate because the system was unable to recognize many types of fruits.

From the literature reviews, it has been found that the mango tree (*Mangifera indica* L.) has a considerable deal of genetic variation, resulting in more than one thousand varieties of the fruit. Currently, the classification of mangoes is usually done manually. As a result, farmers and sellers must spend a significant amount of effort in identifying mangoes. Aside from that, the manual categorization result might be inaccurate. The agriculture industry has made extensive use of image processing technologies. Computer vision is a huge barrier when it comes to achieving human-level recognition of objects. It is possible to use the recognition of fruits and vegetables in computer vision to automatically classify a range of various fruits. The utilization of deep learning methods for the classification means in comparison to the traditional machine learning methods would be beneficial as well, since deep learning methods do not require hand-crafted feature extractions and high domain understanding in comparison to traditional machine learning methods [29], [30]. Learning a new task from the beginning requires the collection of a large quantity of training data. Transfer learning enables one to apply previously acquired knowledge for new situations when less information is accessible, hence enhancing the learning process. This has become the motivation of this work, which is to assist in the automatic recognition of mango types based on transfer learning approaches, when given an unknown mango type as an input.

Furthermore, there is currently no mobile-based application that can be used to identify mangoes in the market. Only web-based mango identification is accessible, so it is not particularly handy for individuals to easily identify the different sorts of mangoes. It would also be difficult to recognize mangoes using a computer. According to the existing applications which have been evaluated, the majority of the applications can produce the necessary desired outcomes. Based on these applications, it was concluded that the output accuracy is low and must be improved. Some of the applications also require an Internet connection to detect the type of fruit, which is not very convenient for the users.

Therefore, this work will focus on achieving three objectives; (1) to construct a transfer learning model based on TensorFlow Lite, which can classify the mango's variant, (2) to develop a mobile-based application that can recognize a mango type, given a mango's image as the input item, and (3) to include a game and necessary information on the mangoes for added value in the mango's mobile application recognition features

## 2. Method

The scope for this work involves developing a mobile application to determine the types of mangoes. The application will be conducted by adopting a transfer learning method that will classify mango variants from their corresponding images to determine the types of mangoes. This research was carried in Universiti Putra Malaysia in the year 2021-2022.

This work starts with preliminary studies on the user requirements for the mango's recognition application. Questionnaires can be a much more cost-effective and time-efficient method of enhancing many respondent's behaviors, opinions, interests, views, and intentions, compared to other methods. Previous related research works and existing applications then investigated what has been done in the field, and identifying the existing research and application gaps. The datasets for the work were also gathered during this step. All the gathered and studied sources are then analyzed to construct the proposed overall framework for the mango's recognition application. The mango's recognition application is then developed based on the proposed framework. This is followed by measuring the effectiveness and functionalities of the proposed framework and application by calculating the recognition rate, as well as performing the user acceptance survey through the use of another questionnaire. The overall framework for the proposed work is shown in Fig. 1.

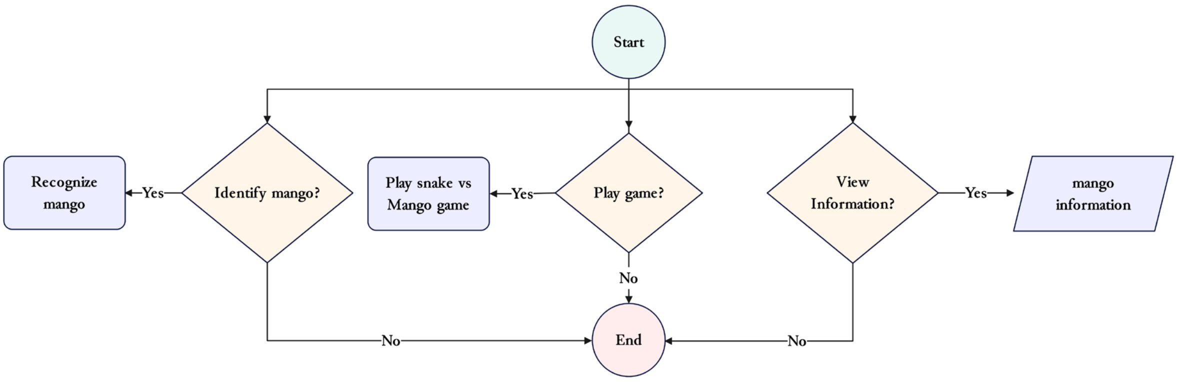



**Fig. 1.** The proposed overall framework

The mango's image and recognition was trained and recognized using TensorFlow Lite. The flowchart for the training process and recognition process is shown in Fig. 2. Transfer learning is a machine learning technique, in which a model created for one task can be used as the basis for another task's model. In order to construct a deep learning-based model with high accuracy in practical applications, it is necessary to gather thousands of training data samples. Collecting thousands of training data samples is tough. Hence, the pre-trained TensorFlow Lite is used as the transfer learning model which needs to be trained using the targeted mango dataset. The Tensorflow Lite is a framework designed for Android applications, that allows for more complex implementations to be done. The pre-trained TensorFlow Lite is used for further training for recognizing the unique characteristics of each mango type, followed by constructing the final model for the given domain. The mangoes are then classified into six categories, where four mango types are considered (Harum Manis, Langra, Dasheri and Sindhri), including a category for other types of mangoes, and a category to categorize then nonmangoes. The parameters used for the constructed model used an epoch= 50, a learning rate= 0.001, and a batch size= 32. A total of 70 images from six categories were utilized for the training.

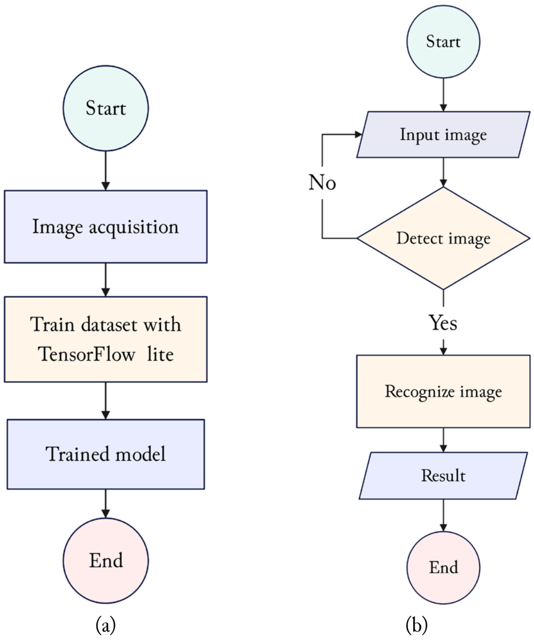



**Fig. 2.** Flowchart for (a) training process (b) mango recognition

The main objective of this application is to provide a system for users to recognize mangoes with a single click on their phone, whenever they open the application. Users can also play games, as such, the users will be more interested in using the application. The application will display the information of the mangoes so that the users can gain information about the fruit.

The functionalities that apply to a system are referred to as functional requirements. The Mango Recognition Mobile Application has the following functional requirements: (1) The user needs to take a photo of mango to get to know the type of mango, (2) The user needs to browse it from their photo gallery to get to know the types of mangoes, (3) The application will provide information about the mangoes, (4) The users will be able to play games, and (5) The application will be able to display scores when the users play games. As for the non-functional requirements, we focused on the following: (1) The application must allow users to browse it from their photo gallery, (2) The application must allow users to use their phone camera, (3) The application must be able to save scores after the users play games, and (4) The application must support android devices. The flowchart for the snake Vs. mango game is shown in Fig. 3, while the interfaces for the proposed mango recognition is also shown in Fig. 4 [31].

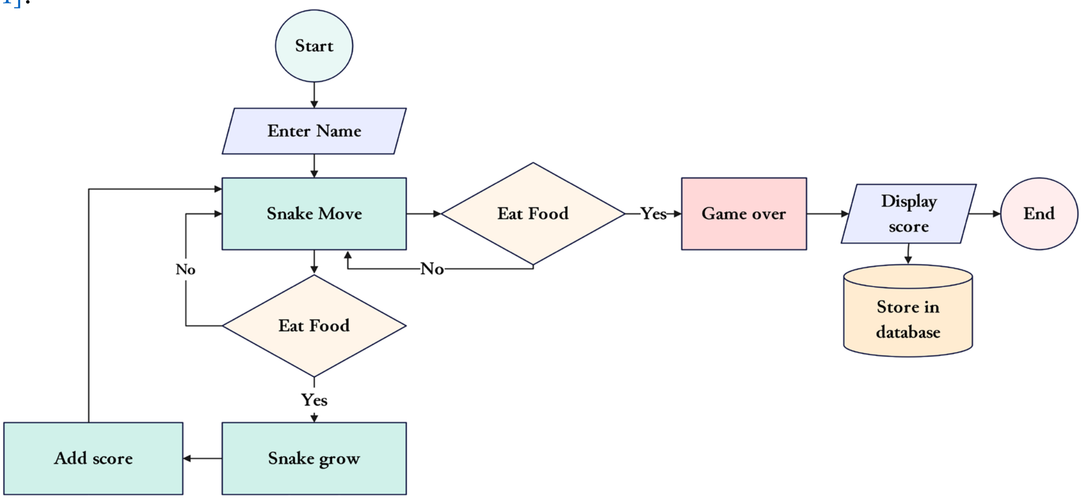



**Fig. 3.** Flowchart for snake Vs. mango game

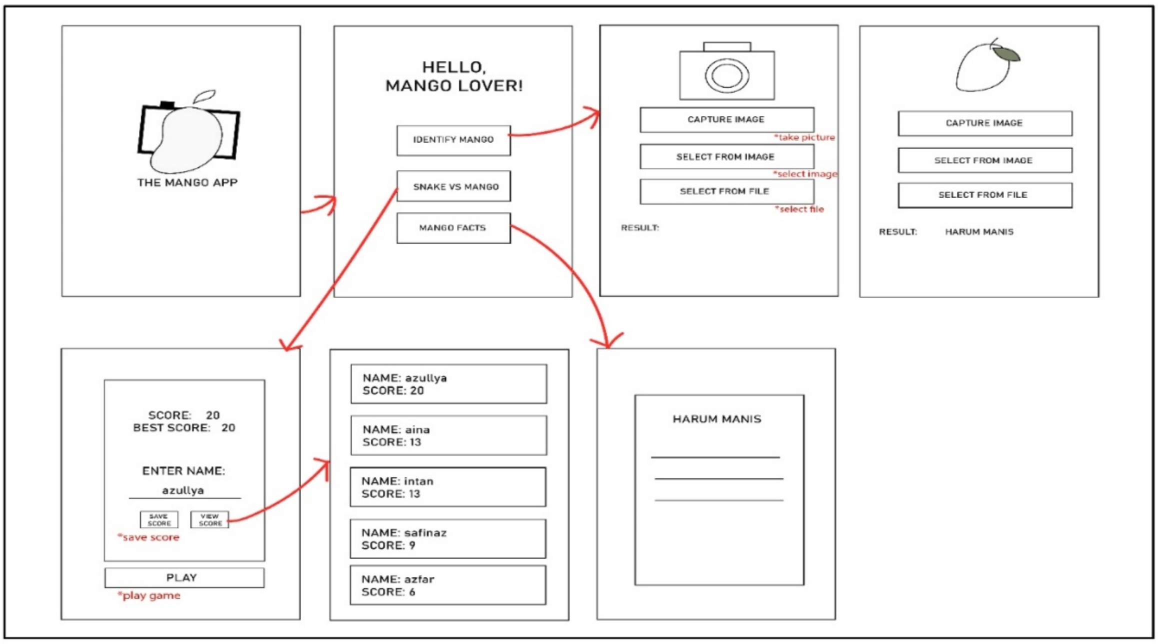



**Fig. 4.** Interface design

## 3. Results and Discussion

Extensive experiments were carried out to evaluate the proposed work. This study consisted of three parts of evaluations. The first experiment was to perform a preliminary study to investigate the user requirements. From the preliminary study analysis and research gap findings, the framework was then proposed. The second experiment was to evaluate the effectiveness of the proposed TensorFlow Lite framework for the mango recognition. The third experiment was to evaluate the user acceptance towards the developed mango recognition mobile application.

### 3.1. Hardware and Software Specifications

All the experiments mentioned in this work have been conducted on a desktop running on a Microsoft Windows 10 Professional operating system, with an Intel ® Core ™ i5–3470 CPU, 3.20GHz, and a 8 GB Random Access Memory.

TensorFlow Lite, a machine learning framework developed by Google, allows machine learning models to be deployed on a variety of devices and interfaces, which are adopted to generate learnt features, and classify the mango types accordingly. Android Studio, an integrated development environment, was used as the main software for developing the mobile application, with Java as the main programming language. Firebase, a Not only Structured Query Language (NoSQL) database that saves data in the JavaScript Object Notation (JSON)-like documents, was used as the database.

### 3.2. Dataset Collection

The iPhone 11 camera was used to capture some of the Harum Manis images. Some of the images of the Harum Manis were taken by Harum Manis sellers who originated from Perlis, Malaysia. Datasets on other mangoes apart from the Harum Manis such as the Langra, Dasheri and Sindhri were obtained from the "Mango Variety, Grading Dataset," Mendeley Data [31]. There were also other mangoes and not mango datasets involved in this project. [32], "Mango Dataset Studio Setup," Mendeley Data provided these other mango datasets. Not mango datasets were collected from Kaggle; [33] "Fruit and Vegetable Image Recognition Dataset" which covered other fruits. Each kind of fruit had 100 images, which were then categorized as training or testing. The training percentage was 70% of the image datasets, and the testing was 30% of the image datasets. Some of the datasets according to the respective categories are shown in Fig. 5.

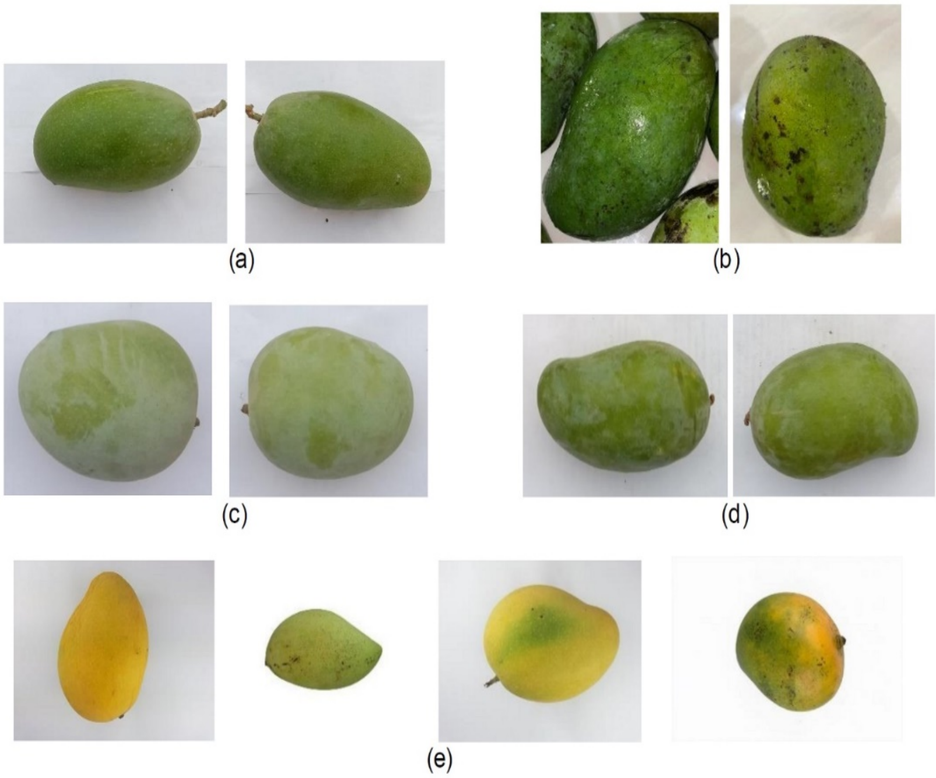



**Fig. 5.** Samples of the mango datasets (a) *Dasheri*, (b) *Harum Manis*, (c) *Langra*, (d) *Sindhri*, and (e) Other mangoes

### 3.3. Evaluation Measurement

For the preliminary study and user acceptance experiment, a different set of questionnaires were distributed to the public. The preliminary study consisted of five questions intended to investigate the needs of an automatic mango recognition framework. As for the user acceptance experiment, there were two general questions on the respondent's background (age and status; consumer or seller), and 11 questions related to the mango's recognition application.

For evaluating the effectiveness of the proposed mango recognition framework, the accuracy measurement was used. This can be computed through a confusion matrix, where one may acquire a clearer understanding of which portions of the categorization model are accurate, and which are inaccurate. The predicted value and actual value of the system are shown in tabulated form to illustrate four different combinations of the predicted value and actual values. Table 2 illustrates the confusion matrix for the two-class categories. The term "true positive" (TP) refers to a system's ability to recognize a positive image. The term "true negative" (TN) refers to a system's capacity to determine if an image is negative. The term "false positive" (FP) refers to a scenario in which the system erroneously classifies a negative image as positive, whereas the "false negative" (FN) refers to a situation in which the system classifies a positive image as negative.

**Table 2.** Confusion matrix

| Predicted Values | Actual Class | |
|---|---|---|
| | *Positive* | *Negative* |
| *Positive* | True Positive (TP) | False Positive (FP) |
| *Negative* | False Negative (FN) | True Negative (TN) |

Accuracy is the ratio of the correctly predicted observation versus the sum of observations. Accuracy can be calculated based on Equation (1).

$$Accuracy = \frac{True\ Positive + True\ Negative}{(True\ Positive + False\ Positive + False\ Negative + True\ Negative)} \quad (1)$$

### 3.4. Preliminary Study

Based on the preliminary survey conducted for this project, the data from 32 respondents were sorted. The first question was about investigating the respondent's awareness on the availability of various mango types. 90.6% of the respondents knew that there were many types of mangoes, and only 9.4% were unaware of this fact.

The second question investigated the respondent's awareness of the image recognition application. Most respondents (85%) had heard about the image recognition application, and only 12.5% answered contrary to it. The response to question 3, which is on the capabilities of the respondents in recognizing different types of mangoes manually, showed that the percentage of people who could not recognize the mango types was 59.4%. Meanwhile, 34.4% of them knew how to recognize mangoes, and the remainder were unsure. For question 4 on the possibility of sellers selling common mangoes at a premium price, more than half (71.9%) of the respondents agreed that there exists the possibility of sellers who sell common mangoes at a premium price, while the others (28.1%) answered no. Lastly, the answer to question 5 (If there is an application to detect types of mangoes automatically, will you use it?) showed that all the respondents agreed that they would use the application to detect the types of mangoes if it is available.

Based on the preliminary study's results, it was concluded that the proposed work would benefit most people because the percentage of people who do not know how to distinguish mangoes, which is high. Most of the respondents were unable to detect the types of mangoes and agreed that some of the sellers are selling common mangoes at a premium price. With this approach, it will be much more convenient for people in guiding them and obtaining information about the mangoes

### 3.5. Classification Performance based on the Mango's Image Dataset

Table 3 displays the proposed method's testing results in the form of a confusion matrix. The algorithm successfully predicted 30 testing images for each of the six mango categories and obtained their recognition rate. A total of 30 images (100%) for the Langra, Dasheri and other mangoes were successfully recognized by the system. The recognition rate reached 100% because the training datasets were good enough to distinguish between the mango types. Meanwhile for the Harum Manis this was slightly lower, with 27 images (90%), where one image (3.33%) was recognized as not a mango, and two images (6.66%) as another mango. This could be due to the reason that the Harum Manis datasets have a colorful background. The same goes with Sindhri where the system recognized 27 images (90%), and the remaining testing images of the Sindhri were detected as Harum Manis. The results showed some of Sindhri as Harum Manis because of the shape of the Sindhri, which is similar to the Harum Manis. For the not-mango testing images, it achieved a 90% recognition rate with 27 images which were recognized as not-mango. In comparison, the remaining datasets of the not-mango were detected as another mango (6.66%), and the Harum Manis (3.33%).

**Table 3.** Accuracy of the proposed framework

| | *Mango Species* | Predicted *Harum Manis* | Predicted *Langra* | Predicted *Dasheri* | Predicted *Sindhri* | Predicted *Not Mango* | Predicted *Other Mango* |
|---|---|---|---|---|---|---|---|
| Actual | Harum Manis | 27<br>90% | | | | 1<br>3.33% | 2<br>6.66% |
| Actual | Langra | | 30<br>100% | | | | |
| Actual | Dasheri | | | 30<br>100% | | | |
| Actual | Sindhri | 3<br>10% | | | 27<br>90% | | |
| Actual | Not Mango | 1<br>3.33% | | | | 27<br>90% | 2<br>6.66% |
| Actual | Other Mango | | | | | | 30<br>100% |

The accuracy results are shown in Table 4, which clearly demonstrates that the accuracy was 95%. The results showed that the proposed framework could definitely assist users in recognizing the mango types effectively, based on the following equations (2) and (3).

$$Total\ number\ of\ predictions = \frac{Total\ of\ correct\ prediction}{Total\ of\ incorrect\ prediction} \quad (2)$$

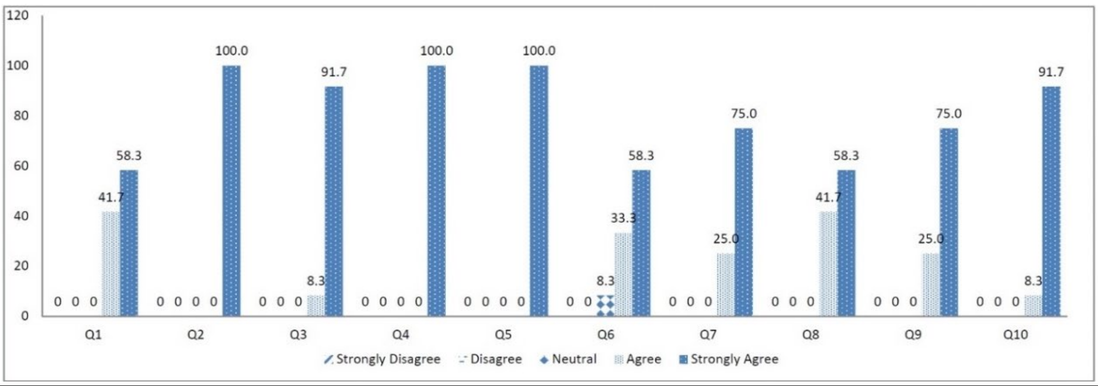
$$Accuracy = \frac{Total\ of\ correct\ prediction}{Total\ number\ of\ predictions} \quad (3)$$

**Table 4.** Accuracy result

| Mango Type | Correct Prediction | Incorrect prediction |
|---|---|---|
| Harum Manis | 0.9 | 0.1 |
| Langra | 1.0 | 0.0 |
| Dasheri | 1.0 | 0.0 |
| Sindhri | 0.9 | 0.1 |
| Not mango | 0.9 | 0.1 |
| Other mango | 1.0 | 0.0 |
| ***Total*** | ***5.7*** | ***0.3*** |
| ***Accuracy*** | ***0.95*** | |

### 3.6. User Acceptance Experiment

The third experiment involved user acceptance to ensure that the application performed as expected in real-world circumstances. A total of 12 respondents took part in this questionnaire to evaluate the functionality and practicality of the proposed mango recognition mobile application. The first section of the questionnaire was meant to gather the participant's background. Respondents in their 20s and 30s made up the majority of the group. There was just one person in the 41-50 age bracket, and one person in the other category. There was a total of 75% of mango consumers, and 25% mango sellers who participated in this survey. The second section of the questionnaire was with regards to the proposed mango mobile application. Several related questions were included, and the responses were in the form of a five-point Likert scale: 1 – Strongly Disagree, 2 – Disagree, 3 – Neutral, 4 – Agree, and 5 – Strongly Agree. The questions and the findings obtained for each of the questions is shown in Fig. 6. The x-axis represents the question number, while the y-axis represents the percentage of responses.




Q1: I will likely to use the mango recognition mobile application frequently.
Q2: Mango recognition mobile application is easy to use.
Q3: Functions in the mango recognition mobile application are well generated.
Q4: The interfaces (buttons, layout) of mango recognition mobile application is easy to understand and well organized.
Q5: The language used in the mango recognition mobile application is easy to understand.
Q6: Mango recognition mobile application labels the mango type correctly.
Q7: Mango recognition mobile application can recognize different types of mangoes.
Q8: Mango recognition mobile application provide enough information about mangoes.
Q9: Snake Vs. mango game in the mango recognition mobile application is fun to play.
Q10: Mango recognition mobile application is very convenient to use.

**Fig. 6.** Mango recognition mobile application user acceptance survey

The third section of the questionnaire gathered comments and suggestions from the respondents. Some of the suggestions were meant to cater for more mango types, supplement additional information on the mangoes and make the game easier.

Based on the survey, it can be concluded that most responses from the user acceptance survey were good, with practically everyone agreeing that the application is simple to use, and that the language and design are appropriate for the application. Comments and suggestions will be taken into consideration for future improvements.

## 4. Conclusion

In this mango recognition mobile application, the mango varieties were categorized into six, where four mango types were considered (Harum Manis, Langra, Dasheri and Sindhri), and a category for other types of mangoes and a non-mango were also included. The application's simple graphical user interface was created to make it simple for people to understand and utilize it. The proposed work met its objectives, which included displaying the type of recognized mango, providing users with information on the mangoes, and allowing users to play games as an added value for the mobile application. The accuracy for the recognition was evaluated using a confusion matrix approach, with results showing that it had an accuracy of up to 95%. The user acceptance survey also showed that the proposed application was able to recognize the mango types well, when given an unknown mango image as an input. The respondents were also satisfied with the functionalities, interfaces, ease of use, and practicality of the proposed application. With this application, identifying a mango using image classification will be easier for users, as they will not have to spend a large amount of time recognizing the mango. Furthermore, by utilizing the application, users will gain more knowledge about the mango.

There are, however, thousands of varieties of mangoes in the world. The proposed application currently only focuses on recognizing four types of mangoes. To improve the accuracy of this application, more datasets may need to be utilized for future works.

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## Declarations

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