Non-Destructive Carabao Mango Sorter and Grader based on Physical Characteristics using Machine Learning

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In Partial Fulfillment of the
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Bachelor of Science in Computer Engineering

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ORAL DEFENSE RECOMMENDATION SHEET

This thesis, entitled **Non-Destructive Carabao Mango Sorter and Grader based on Physical Characteristics using Machine Learning**, prepared and submitted by thesis group, AISL-1-2425-C5, composed of:

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in partial fulfillment of the requirements for the degree of **Bachelor of Science in Computer Engineering** (**BS-CPE**) has been examined and is recommended for acceptance and approval for **ORAL DEFENSE**.

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ABSTRACT

Carabao Mangoes are one of the sweetest mangoes in the world and one of the major producers of this is the Philippines. However, mangoes go through many screening processes, one of them being sorting and grading during post harvesting which is labor intensive, prone to human error, and can be inefficient if done manually. Previous researchers have taken steps to automate the process, however, their works often focus on only specific traits, and do not try to encapsulate all the physical traits of the mangoes altogether. Furthermore, previous researchers made the grading system static or unchangeable to the user. In this study, the researchers will develop an automated Carabao mango grader and sorter based on ripeness, size, and bruises with an interchangeable mango attribute priority through non-destructive means. Using machine vision, image processing, Machine Learning, microcontrollers and sensors the mangoes will be physically sorted into designated bins via a conveyor belt system which can be controlled and monitored via a graphical user interface. The approach will streamline the post-harvest process and cut down on human errors and labor costs, helping maintain the high quality of Carabao mango exports.

Index Terms—Machine Learning, Carabao Mangoes, Sorting and Grading Mangoes, Machine Vision, Microcontroller.

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ABBREVIATIONS

AC	Alternating Current	13
DC	Direct Current	24
CNN	Convolution Neural Network	14
GUI	Graphical User Interface	45
LED	Light Emitting Diode	41
UI	User Interface	45

NOTATION

214 # GLOSSARY

215	bruises	The black or brown area of the mango that is visible on the skin of the mango.
216	Carabao mango	A popular variety of mango grown in the Philippines, known for its sweet and juicy flesh.
217	accuracy score	A performance metric that measures the overall proportion of correct predictions made by a machine learning model.
218	confusion matrix	A table that summarizes the performance of a classification model, showing the number of true positives, true negatives, false positives, and false negatives.
219	CNN	A type of deep neural network that is highly effective in analyzing and processing visual data, such as images.
220	F1-Score	A balanced performance metric that is the harmonic mean of precision and recall, taking both into account.
221	machine learning	A subset of Artificial Intelligence that enables systems to learn and improve from data.
222	computer vision	The use of cameras and algorithms to provide imaging-based inspection and analysis.
223	microcontroller	A small computing device that controls other parts of a system such as sensors.
224	Precision	A performance metric that reflects the percentage of instances classified as positive that are truly positive.
225	recall	A performance metric that measures the proportion of actual positive instances that the model correctly identified.

226 User Priority-Based Grading	A customizable grading system where users can assign weights to grading factors.

Chapter 1

INTRODUCTION

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1.1 Background of the Study

Mangoes, also known as the Mangifera indica, are a member of the cashew family. This fruit can often be seen being farmed by countries such as Myanmar, the Philippines, and India as they have a tropical dry season. Being in a tropical country is an important aspect for mango cultivation as it ensures proper growth for mangoes. If aspects such as temperature and rainfall are not ideal, it may affect the quality of the mango (Britannica, nd). Carabao mangoes is a variety of a mango that is found and cultivated in the Philippines.

Fig. 1.1 Carabao Mangoes at Different Ripeness Stages (Guillermo et al., 2019)

It is known for its sweet signature taste that was recognized sweetest in the world in the Guinness Book of World Records in 1995. The mango was named after the national animal of the Philippines, a native breed of buffalo. On average, it is 12.5 cm in length and 8.5 cm in diameter, having a bright yellow color when ripe as seen in Figure 1.1. It is often cultivated during late May to early July (DBpedia, nd).

As the Philippines is a tropical country, mangoes are a highly valued fruit as it is not only the country's national fruit but also amongst the leading agricultural exports of the country, ranking only third below bananas and pineapples. This gives the country the 9th slot amongst the leading exporters of Mangoes across the world. Attributed to this ranking is the country's export of both fresh and dried mangoes, as well as low tariff rates. This allows the country to export a large quantity of the fruit in countries such as Singapore, Japan, and the USA as they can enter duty free markets provided by the World Trade Organization and Japan. Due to this, the mangoes have become a major source of income to an estimated 2.5 million farmers in the country (Centino et al., 2020).

Before mangoes are sold in markets, they first undergo multiple post-harvest processes. This is to ensure that the mangoes that arrive in markets are utmost quality before being sold to consumers. Moreover, it ensures that mangoes are contained and preserved properly such that they do not incur damages and/or get spoiled on its transportation to the market. Processing of the mango involves pre-cooling, cleaning, waxing, classification, grading, ripening, packaging, preservation, storage, packing, and transportation (Patel et al., 2019) (Rizwan Iqbal and Hakim, 2022).

Among the processes that mangoes undergo, classification and grading is important as it allows the manufacturer to separate mangoes with good qualities versus mangoes with poor qualities. According to a study by (Lacap et al., 2021), size, length, width, volume, density, indention, and grooves are aspects that determine the maturity of mangoes. These traits are being checked along with the ripeness of the mango, sightings of bruise injury, and cracks on the fruit (Lacap et al., 2021) as these aspects affect the sellability of the fruit as well as the chances of it getting spoiled sooner.

Previous studies have been made to automate the sortation process of the mangoes. Among these is a research done by Abbas et al. (2018), which focuses on classification of mangoes using their texture and shape features. They do this by, first, acquiring an image of the mango using a digital camera. Then, these images are fed to the MaZda package, which is a software originally developed for magnetic resonance imaging. Within the MaZda package is the B11 program, which uses Principal Component Analysis, Linear Discriminant Analysis, Nonlinear Discriminant Analysis, and texture classification to extract features from the mango, which in this case are the length, width, and texture. This data is then compared to a database in order to classify any given mango (Abbas et al., 2018).

Another study is done by Rizwan Iqbal and Hakim (2022), which classifies mangoes based on their color, volume, size, and shape This is done by making use of Charge Coupled Devices, Complementary Metal-Oxide Semiconductor sensors, and 3-layer Convolutional Neural Network. To classify the mangoes, images are first captured and preprocessed to be used as a data set (Rizwan Iqbal and Hakim, 2022). This data set is then augmented to be used as a model for the 3-layer Convolutional Neural Network. After extracting the features of the mango, the 3-layer Convolutional Neural Network is used as a method for their classification as it can mimic the human brain in pattern recognition, and process data for decision making. This is important as some mangoes have very subtle differences which make it difficult to differentiate them.

1.2 Prior Studies

A paper written by Amna et al. (2023), designed an automated fruit sorting machine based on the quality through an image acquisition system and CNN. Furthermore, the results of the paper show that the image processing detection score was 89% while that of the tomatoes was 92% while the CNN model had higher validity of 95% for mangoes and 93% for tomatoes. 15%, while the percentage of distinction between the two groups was reported to be 5% respectively (Amna et al., 2023). Despite the high accuracy score in detecting mango defects, the fruit sorting system only sorts based on the mango defects and not on ripeness, and weight.

Furthermore, the research paper presented by Guillergan et al. (2024) designed an Automated Carabao mango classifier, in which the mango image database is used to extract the features like size, area along with the ratio of the spots for grading using Naïve Bayes Model. For the results, the Naïve Bayes' model recognized large and rejected mangoes with 95% accuracy and the large and small/medium difference with a 7% error, suggesting an application for quality differentiation and sorting in the mango business industry. Despite the high accuracy of classifying Carabao mangoes, the researchers used a high quality DSLR camera for the image acquisition system without any microcontroller to control the mangoes (Guillergan et al., 2024).

1.3 Problem Statement

As mangoes are among the top exports of the Philippines (Centino et al., 2020), assessing the physical deformities is a necessity. The physical deformities of the Carabao mango can determine the global competitiveness of the country. Having higher quality exports can often lead to gaining competitive edge, increase in demand, increase export revenues, and becoming less susceptible to low-wage competition (D'Adamo, 2018). In order to increase the quality of mango fruit exports, a key post-harvest process is done, which is sorting and grading. Mango sorting and grading then becomes important to determine which batches are of high quality and can be sold for a higher price, and which batches are of low quality and can only be sold for a low price (Co., nd). Traditionally, fruit sorting and grading is inefficient as it is done manually by hand. Some tools are used such as porous ruler to determine fruit size and color palette for color grading (Co., nd). However, among the problems encountered in the process of manually sorting and grading mangoes are susceptibility to human error and requiring a number of laborers to do the task.

With the current advancements in technology, some researchers have already taken steps to automate the process of sorting and grading mangoes. However, these attempts would often only consider some of the aspects pertaining to size, ripeness, and bruises but not all of them at the same time. Lastly, not all research approaches were able to implement a hardware for their algorithm, limiting their output to only a software implementation and not an embedded system. As such the proposed system would assess the export quality of the Carabao mango based on all the mentioned mango traits, namely size, bruises, and ripeness while also taking into consideration being non-destructive. These aspects are important because, as was previously mentioned, there is a need to develop a Carabao mango sorter that takes into account all these aspects at the same time while being non-destructive.

1.4 Objectives and Deliverables

1.4.1 General Objective (GO)

- GO: To develop a user-priority-based grading and sorting system for Carabao mangoes, using machine learning and computer vision techniques to assess ripeness, size, and bruises. ;

1.4.2 Specific Objectives (SOs)

- SO1: To make an image acquisition system with a conveyor belt for automatic sorting and grading mangoes. ;
- SO2: To get the precision, recall, F1 score, confusion matrix, and train and test accuracy metrics for classifying the ripeness and bruises with an accuracy score of at least 90%.;
- SO3: To create a microcontroller-based system to operate the image acquisition system, control the conveyor belt, and process the mango images through machine learning. ;
- SO4: To grade mangoes based on user priorities for size, ripeness, and bruises. ;
- SO5: To classify mango ripeness based on image data using machine learning algorithms such as kNN, k-mean, and Naïve Bayes. ;
- SO6: To classify mango size based on image data by getting its length and width using OpenCV, geometry, and image processing techniques. ;
- SO7: To classify mango bruises based on image data by employing machine learning algorithms.

1.4.3 Expected Deliverables

Table 1.1 shows the outputs, products, results, achievements, gains, realizations, and/or yields of the Thesis.

TABLE 1.1 EXPECTED DELIVERABLES PER OBJECTIVE

Objectives	Expected Deliverables
GO: To develop a user-priority-based grading and sorting system for Carabao mangoes, using machine learning and computer vision techniques to assess ripeness, size, and bruises.	• To develop a Carabao mango grading and sorting system. • To grade Carabao mangoes into three categories based on ripeness, size, and bruises using machine learning. • To integrate sensors and actuators to control the conveyor belt and image acquisition system.
SO1: To make an image acquisition system with a conveyor belt for automatic sorting and grading mangoes.	• To make an image acquisition system with a camera and LED light source. • To build a flat belt conveyor for moving the mangoes.
SO2: To get the precision, recall, F1 score, confusion matrix, and train and test accuracy metrics for classifying the ripeness and bruises with an accuracy score of at least 90%.	• To use a publicly available dataset of at least 10,000 mango images for classification of ripeness and bruises.
SO3: To create a microcontroller-based system to operate the image acquisition system, control the conveyor belt, and process the mango images through machine learning.	• To develop an intuitive UI where users can start and stop the system. • To implement a priority-based grading system with sliders for ripeness, bruises, and size.
SO4: To grade mangoes based on user priorities for size, ripeness, and bruises.	• To utilize a linear combination formula as the overall mango score, where each classification level contributes a grade, weighted by the priority assigned to the three properties. • To assign score values for each classification level of the mango.

Continued on next page

TABLE 1.1 EXPECTED DELIVERABLES PER OBJECTIVE

Objectives	**Expected Deliverables**
SO5: To classify mango ripeness based on image data using machine learning algorithms such as kNN, k-mean, and Naïve Bayes.	• To train a machine learning model such as kNN, k-means, or Naïve Bayes capable of classifying mango ripeness based on the image color. • To gather a dataset of annotated images with ripeness labels. • To obtain an evaluation report of performance metrics of the model.
SO6: To classify mango size based on image data by getting its length and width using OpenCV, geometry, and image processing techniques.	• To develop an image processing algorithm capable of determining mango size using OpenCV, NumPy, and imutils. • To classify mangoes based on size into small, medium, and large based on measurements.
SO7: To classify mango bruises based on image data by employing machine learning algorithms.	• To train a machine learning model such as CNN capable of distinguishing bruised and non-bruised mangoes. • To train a machine learning model such as kNN, k-means, and Naïve Bayes capable of assessing the extent of bruising on the mangoes if it is significant or partial. • To gather a dataset of annotated images based on bruises. • To obtain an evaluation report of performance metrics of both CNN and other machine learning models.

1.5 Significance of the Study

Automating the process of sorting and grading mangoes increases efficiency and productivity for the user which would in effect remove human error in sorting and grading and decrease the human labor and time taken to sort and grade the mangoes. This is especially important for farmers with a large amount of fruit such as mangoes and a lesser labor force.

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A recent study showed that their automated citrus sorter and grader using computer vision can reduce the human labor cost and time to sort and grade when comparing the automated citrus sorter and grader to manual human labor Chakraborty et al. (2023).

Another benefit to automating sorting and grading mangoes is the improvement in quality control. This implies that compared to human labor, automating sorting and grading mangoes can uniformly assess the quality of mangoes based on size, color, and bruises, ensuring that the expected grade and high-quality mangoes reach the consumer. By accurately identifying substandard mangoes, the system helps in reducing waste and ensuring that only marketable fruits are processed further.

Likewise, the scalability of automating sorting and grading mangoes is simpler, especially for lower labor force farmers with large volumes of mangoes. Because of the possibility of large-scale operations by automating sorting and grading mangoes, farmers can now handle large volumes of mangoes, making them suitable for commercial farms and processing plants. Moreover, it can be adapted to different varieties of mangoes and potentially other fruits with minor modifications.

1.5.1 Technical Benefit

1. The development of an automated Carabao mango sorter would increase the quality control of classifying Carabao mango based on ripeness, size, and bruising.
2. The accuracy in sorting Carabao mangoes will be significantly improved while reducing the errors due to human factors in manual sorting.
3. The automated Carabao mango sorter carefully sorts the mangoes while ensuring that they remain free from bruising or further damage during the process

1.5.2 Social Impact

1. The reduction in manual labor creates opportunities in maintenance and technologies in the automated Carabao mango sorter.
2. The automated Carabao mango sorter system improves Carabao mango standards and enhances the satisfaction of the buyers and the customers through guaranteeing consistent Carabao mango grade.
3. Opportunity to increase sales and profit for the farmers through consistent quality and grade Carabao mangoes while reducing the physical labor to sort it.

1.5.3 Environmental Welfare

1. With the utilization of non-destruction methods of classifying Carabao mangoes together with an accurate sorting system, overall waste from Carabao mangoes is reduced and the likelihood of improperly sorted mangoes is decreased.
2. Automation of sorting and grading Carabao mangoes promotes sustainable farming practices.

1.6 Assumptions, Scope, and Delimitations

1.6.1 Assumptions

1. The Carabao mangoes are from the same source together with the same variation
2. The Carabao mangoes do not have any fruit borer and diseases

3. All the components do not have any form of defects
4. The prototype would have access to constant electricity/power source.
5. The Carabao mangoes to be tested would be in the post-harvesting stage and in the grading stage.
6. The image-capturing system would only capture the two sides of the mango which are the two largest surface areas of the skin.

1.6.2 Scope

1. The prototype would be specifically designed to grade and sort Carabao Mangoes based on only ripeness, size, and visible skin bruises.
2. The mangoes used as the subject will be solely sourced from markets in the Philippines.
3. The Carabao mangoes would be graded into three levels.
4. The prototype will be using a microcontroller-based system locally stored on the device itself to handle user interaction.
5. Computer vision algorithms to be used will include image classification.

1.6.3 Delimitations

1. The project would only be able to perform sorting and grading on one specific fruit which is the Carabao mango and will not be able to sort other types of mangoes.

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2. Additionally, the project prototype will only be able to capture, sort, and grade one mango subject at a time which means the mangoes have to be placed in the conveyor belt in a single file line for accurate sorting.

3. For the bruises, the system will only be able to detect external bruises and may not identify the non-visible and internal bruises.

4. The system does not load the mangoes onto the conveyor belt itself. Assistance is required to put mangoes into the conveyor belt to start the sorting process

5. The prototype will be powered using Alternating Current (AC) power and will be plugged into a wall socket which is only suitable for indoor use.

1.7 Estimated Work Schedule and Budget

	THSCP4A				THSCP4B				THSCP4C			
TASKS	Week 1-3	Week 4-6	Week 7-9	Week 10-13	Week 1-3	Week 4-6	Week 7-9	Week 10-13	Week 1-3	Week 4-6	Week 7-9	Week 10-13
Topic Proposal and Defense	BANAL, BAUTISTA, HERMOSURA, SALAZAR											
Buying and Collecting of Materials					HERMOSURA AND SALAZAR							
Training and Testing the CNN model					BANAL AND BAUTISTA							
Integrating the sensors and actuators to the Arduino Uno						HERMOSURA AND SALAZAR						
Coding of the Application with CNN model to the Raspberry Pi and connecting it to the Arduino Uno						BANAL AND BAUTISTA						
Polishing and Revising the UI App							BANAL AND BAUTISTA					
Testing and Surveying of the System with the Carabao Mangoes							BANAL, BAUTISTA, HERMOSURA, SALAZAR					
Data Gathering									BANAL, BAUTISTA, HERMOSURA, SALAZAR			

Fig. 1.2 Gantt Chart

As seen above, Table 1.2 shows the Gantt Chart together with the assigned task. For the first part of the THSCP4A, the group would primarily revise and fine tune Chapters 1 and 2 while also preparing for the defense. After that for THSCP4B, the yellow team which consists of two members, Hermosura and Salazar, would start buying and collecting the materials needed for assembling the prototype. While team yellow is doing that, team purple which consists of Banal and Baustista would start training and validating the Convolution Neural Network (cnn) model based on the Carabao mango image dataset. After that integration of the sensors and actuators together with the integration of the cnn model and beginning of coding of the Application to the Raspberry Pi would be done. Once that cnn model is deployed and the Application works testing of the Carabao mangoes to the prototype would be done. During THSCP4C, data gathering would be done together with polishing and revising of the final paper.

1.8 Overview of the Thesis

There are seven succeeding chapters. To recall, chapter 1 involves the introduction of the thesis topic containing the background of the study, previous studies, objectives and deliverables, assumptions, scope, and delimitation, significance of the study, description of the project together with the methodology, and Gantt chart and budget. Chapter 2 involves the existing articles, the lacking in their approaches, and the summary of chapter 2. Chapter 3 involves the theoretical considerations of the thesis topic while chapter 4 would consist of the design consideration involving the thesis topic. Chapter 5 would involve the research methodology containing the testing procedure and setup. Chapter 6 would involve the results and discussion based on the methodology while Chapter 7 would involve the conclusion, recommendations, and future suggestions.

Chapter 2

LITERATURE REVIEW

2.1 Existing Work

The research paper written by Adam et al. (2022) developed a ripeness grader for Carabao mangoes. The Carabao mango ripeness grade calculated based on object and color detection which were written in microcontroller. These are the systems designed by the researchers that consists of Raspberry Pi 4, Arduino Uno, camera, touch screen LCD, MQ3 gas sensor, ventilation system. The proposed system was able to ascertain an overall reliability of 95%: therefore, the specified objective of ascertaining the ripeness level of the mangoes was met with success. However, accuracy and reliability of the software system are there since the hardware design does not seem to be workable when one must deal with the scores of mangoes (Adam et al., 2022). In addition, the design of the hardware does not integrate any form of physical automating, say like the conveyor belt. Besides, the hardware system only works efficiently when deciding the ripeness grade of mangoes separately.

A study done by Samaniego et al. (2023) is another research paper that supports and has relevant information concerning the topic. The researchers proposed a fully-perovskite photonic system which has the capability to identify and sort or grade mango based on features such as color, weight and, conversely, signs of damages (Samaniego et al., 2023). Some of the techniques in image processing that the researchers used included image enhancement, image deblurring, edge detection using MATLAB and Arduino as well as color image segmentation. By carrying out the multiple trials on the device they achieved a classification speed of 8.132 seconds and an accuracy of 91.2%. The proponents' metrics used for the ratings were speed wherein the results were rated "excellent" while the accuracy rating given was "good". One of the limitations of the paper is that the researchers were only limited to the color, texture, and size of the Carabao mango

Furthermore, the research paper presented by Guillergan et al. (2024) designed an Automated Carabao mango classifier, in which the mango image database is used to extract the features like weight, size, area along with the ratio of the spots for grading using Naïve Bayes Model. Concerning the quantitative test design, one had to control and experiment with various methods of image processing that would improve the likelihood of improved classification. The paper methodology entailed sample collection from 300 Carabao mangoes, picture taking using a DSLR camera, and feature deconstruction for categorization (Guillergan et al., 2024). The system prototype and the software were designed with the programming language C# with integration of Aforge. NET routines. The performance of this model was checked with the help of the dataset containing 250 images, precision, recall, F-score key indicators were used. The investigation discovered that the Naïve Bayes' model recognized large and rejected mangoes with 95% accuracy and the large and small/medium difference with a 7% error, suggesting an application for quality differentiation and sorting in the mango business industry. The limitations in the researchers' paper include the researchers were able to achieve high accuracy after using a high quality DSLR camera and the fact that the researchers were not able to incorporate the use of microcontrollers.

Another study by Tomas et al. (2022) proposed SVM-based system for classifying the maturity stages of bananas, mangoes, and calamansi. With the use of 1729 images of bananas together with 711 mango images and 589 calamansi, the researchers were able to achieve a high accuracy score of above 90% for all fruits. Some pre-processing techniques used to get this high accuracy are the change in hue, saturation, and value channels in the mango image (Tomas et al., 2022). To better understand the harvest time of mangoes, the paper by Abu et al. (2021) examined the association of the harvest season with seasonal heat units, rainfall, and physical fruit attributes for Haden, Kent, Palmer, and Keitt mango varieties to establish export and domestic market maturity standards. For the results of the paper, it shows that temperature, rainfall, and physical characteristics have a reliable, non-destructive indicators for determining mango maturity (Abu et al., 2021). This shows that physical characteristics and temperature are important when exporting fruits such as mangoes.

TABLE 2.1 COMPARISON OF EXISTING STUDIES

Existing Study	**Limitations**	**Accuracy Rating**
Adam et al. (2022)	No physical automation, not suitable for large amounts of mangoes, only classifies ripeness and only a sample size of 10 mangoes.	95%
Samaniego et al. (2023)	Focuses only on color and size.	91.2%
Guillergan et al. (2024)	Relies on high-quality DSLR cameras, and limited automation due to not integrating microcontrollers.	95%
Supekar and Wakode (2020)	No physical automation implemented. Ripeness, size, and shape-based classification achieved 100%, 98.19%, and 99.20% accuracy respectively on their own. However, errors occurred when taking into account all these aspects together for grading mangoes, causing an accuracy rating deduction.	88.88%

Previous studies on mango grading have achieved an accuracy rating of up to 95%, as shown in Table 2.1. However, these studies either relied on a small sample size, which limits statistical significance, or utilized expensive equipment, which may be impractical. In light of this, the researchers have set a target accuracy rating of greater than or equal to 90%. This target ensures that the system being developed is comparable to, or better than, existing studies that used larger sample sizes or assessed multiple mango traits at the same time. Furthermore, this research aims to distinguish itself by not only maintaining or exceeding the 90% accuracy rating but also incorporating a graphical user interface (GUI) for selective priority-based mango classification. The system will integrate both software and hardware components, and it will evaluate a greater number of mango traits for grading purposes.

2.1.1 Sorting Algorithms

In previous studies, researchers have implemented various artificial intelligence algorithms in order to determine the optimal and most effective method for sorting mangoes. One of the algorithms that was used in the classification of mangoes was the CNN or Convolutional Neural Networks. A study done by Zheng and Huang (2021) explored the effectiveness of CNN, specifically in classifying mangoes through image processing. The system that the researchers developed graded mangoes into four groups which was based on the Chinese National Standard (Zheng and Huang, 2021). These mangoes were examined by their shape, color uniformity, and external defects. The system that was developed had an impressive accuracy of 97.37% in correctly classifying the mangoes into these grading categories Support Vector Machine was also one of the classification algorithms that was implemented to detect flaws in mangoes. In that study by Veling (2019), SVM was used in the classification of diseases from mangoes. The study used 4 different diseases/defects for testing (Veling, 2019). The diseases were Anthracnose, Powdery Mildew, Black Banded, and Red Rust. and provided 90% accuracy for both the leaves and the fruit

In the study done by Schulze et al. (2015), Simple Linear Regression, Multiple Linear Regression, and Artificial Neural Network models were all studied and compared for the purpose of size-mass estimation for mango fruits. The researchers found that the

Artificial Neural Network yielded a high accuracy rating for mass estimation and for mango classification based on size with a success rate of 96.7% (Schulze et al., 2015). This is attributed to the Artificial Neural Network model's ability to learn both linear and nonlinear relationships between the inputs and the outputs. However, a problem can occur with the use of the model, which is overfitting. This issue occurs when the model is overtrained with the data set such that it will start to recognize unnecessary details such as image noise which results in poor generalization when fed with new data. With this in mind, additional steps will be necessary to mitigate the issue. Another research article written by Alejandro et al. (2018) implements a method for sorting and grading Carabao mangoes. This research focuses on the use of Probabilistic Neural Network, which is another algorithm that is used for pattern recognition and classification of objects. For this study, the researchers focused on the area, color, and the black spots of the mango for their Probabilistic Neural Network model (Alejandro et al., 2018). Their research using the model yielded an accuracy rating of 87.5% for classification of the mangoes which means it is quite accurate for classifying mangoes within the predefined categories. However, problems were encountered with the use of the model when trying to identify mangoes that did not fit the predefined size categories of small, medium, and large. This means that the PNN model may become challenged when presented with a mango with outlying traits or traits that were very different from the data set.

2.2 Lacking in the Approaches

The majority of past researchers such as Amna et al. (2023) and Guillermo et al. (2019) were able to implement a fruit and mango sorter together with an accurate AI algorithm

TABLE 2.2 COMPARISON OF SORTING ALGORITHM MODELS

Sorting Algorithm Model	Accuracy Rating	Criteria	Problems Encountered
Convolution Neural Network	97.37%	shape, color, defects	Minor blemishes affected the accuracy.
Support Vector Machine	90%	mango defects and diseases	The model is sensitive to noise, which requires intensive image preprocessing.
Artificial Neural Network	96.7%	for mango size and mass	Overfitting
Probabilistic Neural Network	87.5%	for mango area, color, and black spots	Difficulty in identifying mangoes that have outlying features or did not fit the predefined categories

to detect the ripeness defects. This means that none of the previous research papers were able to integrate an interchangeable user-priority-based grading together with size, ripeness, and bruises using machine learning for Carabao mango sorter and grader. Our research however would implement an automated Carabao mango sorter in terms of size, ripeness, and bruises with its own UI, conveyor belt, stepper motors, and bins for collecting the different ripeness and defect grade of the Carabao mango.

2.3 Summary

To reiterate, there is an innovative gap that needs to be filled with regards to the process of sorting and grading Carabao mangoes. The traditional methods for conducting this process manually by hand, by a porous ruler, by a sugar meter, and by a color palette can be prone to human error and expensive costs due to the number of laborers required to do the task.

On the other hand, although researchers have already taken steps to automate the process of mango sorting and grading, there is still a need for an implementation that takes into account size, ripeness, and bruises altogether whilst being non-destructive and having its own embedded system. The research articles shown above show the different computer vision and CNN approaches for sorting and classifying mangoes. For example, a system created by Adam et al. (2022) was more focused on ripeness detection. Samaniego et al. (2023) considered photonic systems for grading mango fruit based on color and weight. On the other hand, Guillermo et al. (2019) implemented the Naïve Bayes classification model on mangoes with high accuracy, which thereby did not include any microcontroller. There was an attempt to study each of those parameters separately and that is why the multifactorial approach was not used. With this in mind, the system being proposed does exactly what was mentioned, to implement a non-destructive and automated sorting and grading system for Carabao mangoes that takes into account size, ripeness, and bruises altogether using machine learning, as well as having its own embedded system. This system will be mainly composed of a conveyor belt, servo motors, a camera, microcontrollers, and an LCD display for the user interface. By doing so, the system should be able to improve the efficiency and productivity of mango sorting and grading, remove the effect of human error and reduce time consumption. The studies also provided critical insights regarding the effective algorithms that can be used in classification stages in image processing. The use of CNN had the most accuracy with manageable potential challenges. Lastly, by scaling the implementation, the overall export quality of the Carabao mangoes can be improved.

Chapter 3

THEORETICAL CONSIDERATIONS

3.1 Introduction

Likewise, the purpose of this chapter is to go through the important theories in developing the prototype together with training and testing the machine learning model.

3.2 Relevant Theories and Models

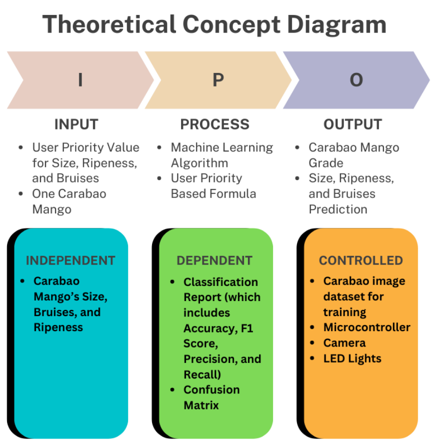

Fig. 3.1 Theoretical Framework Diagram.

The theoretical framework seen in figure x revolves around the concepts that revolve around the research topic. Embedded systems include the Raspberry Pi, which is the microcontroller that will be the brain of the system, Direct Current (DC) motors, 4 channel relays, and the conveyor belt. The machine learning portion includes a neural network model, namely the Convolutional Neural Network, which will use computer vision as a method of seeing and classifying the mangoes based on their physical traits. The image processing will include methods such as size calculation and background removal using OpenCV. Lastly, the Carabao mango will be the test subject of the system.

3.3 Technical Background

At its core, the system will be using machine learning concepts pertaining to CNN and OpenCV, and may use other algorithms such as Naive Bayes and k-Nearest Neighbors to supplement the classification tasks, particularly for assessing mango ripeness, bruise detection, and size determination. The system will be built on an embedded framework, integrating a Raspberry Pi microcontroller to control the RaspberryPi camera, actuators, LED lights, and motors. A user-friendly GUI will also be utilized to ensure users can customize the prioritization of the mango sorting system.

3.4 Conceptual Framework Background

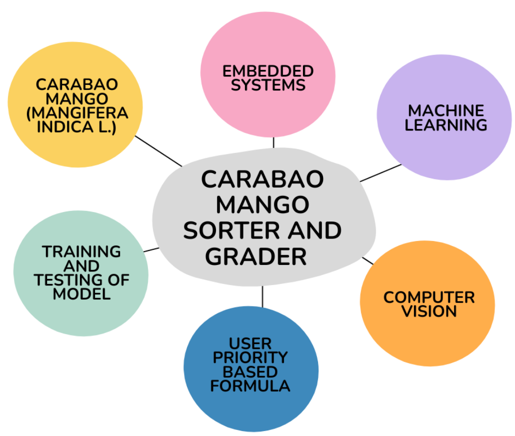

Fig. 3.2 Conceptual Framework Diagram.

3.5 Software Concepts

3.5.1 Thresholding

3.5.2 Object Size Calculation

The size of the mango can be determined given:

$$\text{Real World Dimension} = \frac{\text{Pixel Dimension} \times \text{Distance from Camera to Object}}{\text{Focal Length}} \tag{3.1}$$

$$D\left(p, d, f\right) = \frac{p \cdot d}{f} \tag{3.2}$$

where $D\left(p, d, f\right)$ is the real world dimension of the object, p is the pixel dimension of the object, d is the distance from the camera to the object, and f is the focal length of the camera.

3.5.3 Convolutional Neural Network

3.5.4 Classification Report

3.5.4.1 Confusion Matrix

	Predicted Positive	**Predicted Negative**
Actual Positive	TP	FN
Actual Negative	FP	TN

TABLE 3.1 CONFUSION MATRIX EXAMPLE

A confusion matrix is a table that visualizes the performance of a classification model. For a binary classification problem, it has four components:

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- True Positives (TP): Cases correctly predicted as positive
- True Negatives (TN): Cases correctly predicted as negative
- False Positives (FP): Cases incorrectly predicted as positive. (Type I error)
- False Negatives (FN): Cases incorrectly predicted as negative (Type II error)

3.5.4.2 Precision

$$\text{Precision} = \frac{TP}{TP + FP} \tag{3.3}$$

Precision measures how many of the predicted positives are actually positive. It answers the question: ”When the model predicts the positive class, how often is it correct?” High precision means low false positives.

3.5.4.3 Recall

$$\text{Recall} = \frac{TP}{TP + FN} \tag{3.4}$$

Recall, which is also called sensitivity, measures how many of the actual positives were correctly identified. It answers the question: ”Of all the actual positive cases, how many did the model catch?” High recall means low false negatives.

3.5.4.4 F1 Score

$$F_1 = 2 \times \frac{\text{Precision} \times \text{Recall}}{\text{Precision} + \text{Recall}} \tag{3.5}$$

The F1 score is the harmonic mean of precision and recall. It provides a single metric that balances both concerns. This is particularly useful when you need to find a balance between precision and recall, as optimizing for one often decreases the other.

3.5.4.5 Accuracy

$$\text{Accuracy} = \frac{TP + TN}{TP + TN + FP + FN} \tag{3.6}$$

Accuracy measures the proportion of correct predictions (both true positives and true negatives) among the total cases. While intuitive, accuracy can be misleading with imbalanced datasets.

3.6 Hardware Concepts

3.6.1 Camera Module

3.6.2 4 Channel Relay

3.6.3 1:3 Pulley Belt

3.7 Summary

Overall, chapter 3 establishes key concepts and theoretical considerations that form the foundation of the Carabao mango sorter and grading system. It discusses and connects each component together, explaining how each component such as the RaspberryPi and DC motors work together to create a system that utilizes machine learning and computer vision techniques to classify mangoes based on user priority.

Chapter 4

DESIGN CONSIDERATIONS

Likewise, the objective of chapter 4 is to describe the researcher's design consideration when developing and testing the prototype. For an overview of the design of the prototype, the researchers considered different computer vision models in classifying the ripeness and bruises together with other algorithms to determine the size of the mango. Likewise, the hardware design was also taken into consideration where the physical design of the conveyor belt was taken into account.

4.1 Introduction

This chapter discusses the design considerations for the mango sorting and grading system, focusing on the technical and engineering decisions required for its development. The design process aims to create a scalable, efficient, and user-friendly system that leverages machine learning for accurate mango classification.

4.2 System Architecture

The system architecture is represented through a block diagram, showcasing modules such as image acquisition, preprocessing, feature extraction, machine learning model, and grading output. Each module is described in detail, emphasizing its role in the overall system. For instance, the image acquisition module uses high-resolution cameras to capture mango images, while the preprocessing module enhances image quality for better feature extraction.

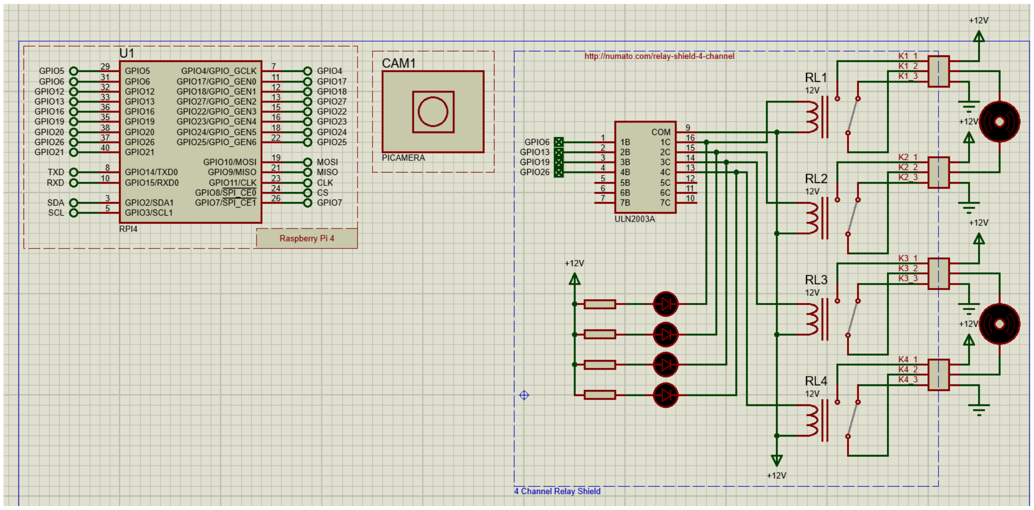

Fig. 4.1 Hardware Schematic

4.3 Hardware Considerations

The hardware components include high-resolution cameras, lighting systems for consistent image capture, and microcontrollers like Raspberry Pi or Arduino for system control, actuators like DC and stepper motors to move the mangoes. The choice of hardware is justified based on cost, performance, and compatibility with the software framework.

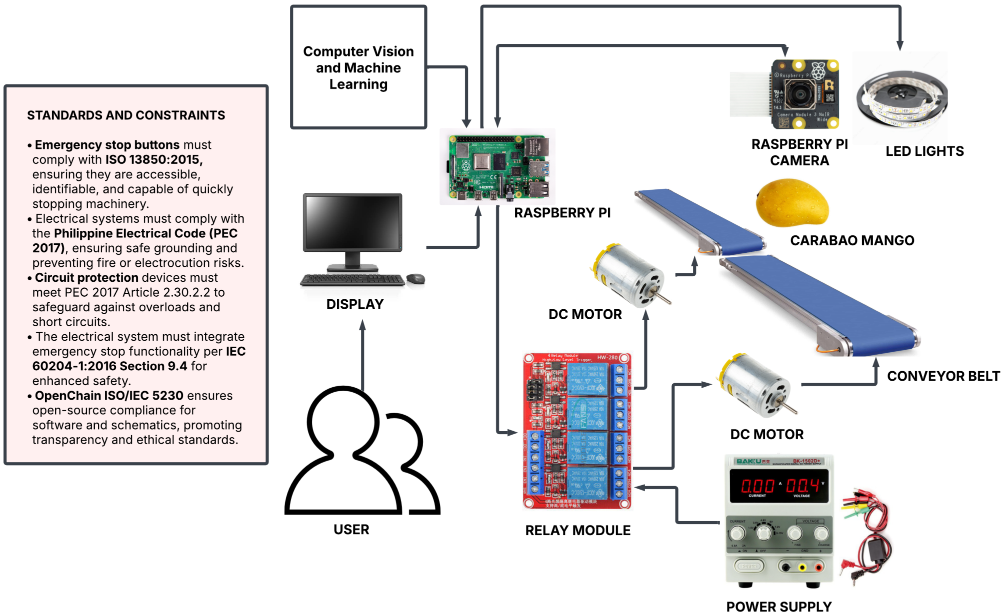

Fig. 4.2 Prototype Framework

4.3.1 General Prototype Framework

4.3.2 Prototype Flowchart

4.3.3 Prototype 3D Model

4.3.4 Hardware Specifications

4.3.4.1 Raspberry Pi

The Raspberry Pi 4 Model B is a compact, low-cost computer that serves as the system's main processing unit. It was chosen for its balance of performance and affordability, making it suitable for image processing tasks. Furthermore, it was selected for its compatibility with various peripherals through the GPIO pins and USB-A ports together with its ease of integration into the prototype.

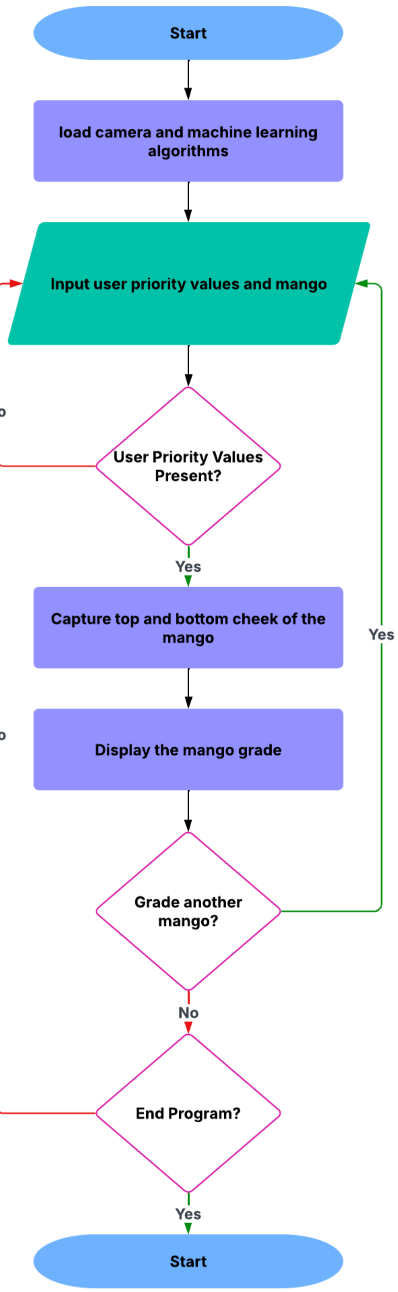

Fig. 4.3 Prototype Main Flowchart

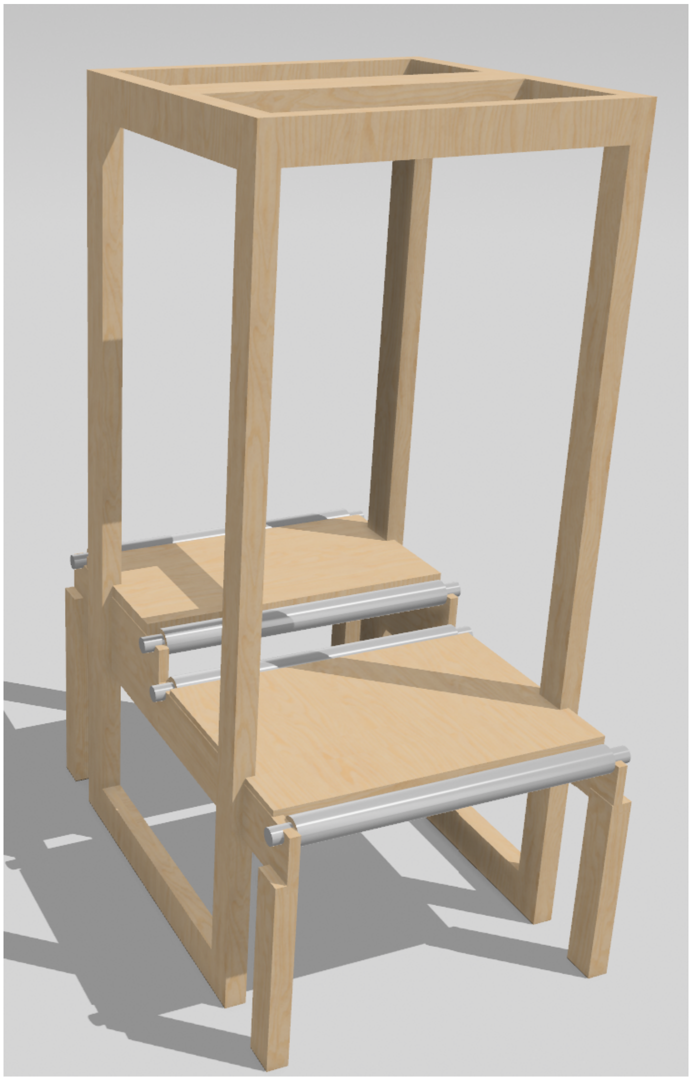

Fig. 4.4 Initial 3D Model of the Prototype

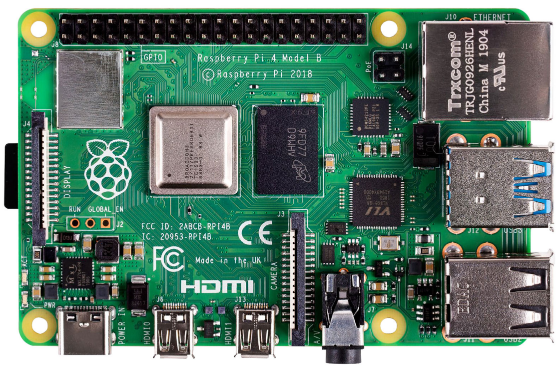

Fig. 4.5 Raspberry Pi 4 Model B

Specifications:

- SoC: Broadcom BCM2711
- CPU: Quad-core ARM Cortex-A72 (64-bit)
- Clock Speed: 1.5 GHz (base, overclockable)
- RAM: 8GB LPDDR4-3200 SDRAM
- Wireless: Dual-band 2.4 GHz / 5 GHz Wi-Fi (802.11ac)
- Bluetooth: Bluetooth 5.0 (BLE support)
- Ethernet: Gigabit Ethernet (full throughput)
- USB: 2 x USB 3.0 ports and 2 x USB 2.0 ports

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- Video Output: 2 x micro-HDMI ports (supports 4K @ 60Hz, dual 4K display capability)
- Audio: 3.5mm audio/video composite jack
- Storage: MicroSD card slot (supports booting via SD card or USB)
- GPIO: 40-pin GPIO header (backward-compatible with older models)
- Camera/Display: CSI (camera) and DSI (display) ports
- Power Input: USB-C (5V/3A recommended)
- Power Consumption: 3W idle, up to 7.5W under load

4.3.4.2 Raspberry Pi Camera

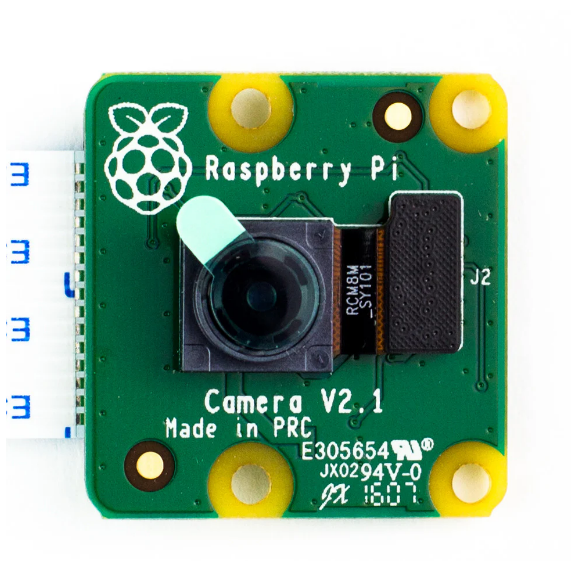

Fig. 4.6 Raspberry Pi Camera Module Version 2

The Raspberry Pi Camera Module Version 2 is a high-quality camera module designed for the Raspberry Pi platform. Likewise, it is capable of capturing still images at 8 megapixels, and supports video recording at 1080p @ 30fps, 720p @ 60fps, and 480p @ 90fps. Moreover, it has a fixed-focus lens with a diagonal field of view of 62.2 degrees, and an optical format of 1/4 inch. Furthermore, it supports various Python libraries such as Picamera and OpenCV for image capture and processing. As such, it was selected for its compact size, ease of integration, and ability to capture high-resolution images.

Specifications:

- Sensor: Sony IMX219PQ 8-megapixel CMOS sensor.
- Still Images Resolution: 8 MP (3280 x 2464 pixels).
- Video Resolution: Supports up to 1080p @ 30fps, 720p @ 60fps, and 480p @ 90fps.
- Focus: Fixed-focus lens (manual focus adjustment not supported without physical modification).
- Lens Size: 1/4-inch optical format.
- Field of View (FoV): Diagonal 62.2 degrees.
- Interface: Connected via 15-pin ribbon cable to the Raspberry Pi's CSI (Camera Serial Interface) port.
- APIs/Libraries: Supports Python libraries such as Picamera and OpenCV for image capture and processing.
- Dimensions: 25 mm x 24 mm x 9 mm.

4.3.4.3 DC Motor

Fig. 4.7 12 Volt DC Gear Motor

The 12 Volt DC Gear Motor is a compact, high-torque, and low-noise motor suitable for a wide range of applications, including robotics, automation, and industrial control systems. It features a spur gear design, which provides a high reduction ratio for increased torque output. The motor is designed for continuous operation and has a low power consumption under standard load conditions. Likewise, it is also capable of withstanding high temperatures and has a high reliability. This motor was selected for its high torque output, low power consumption, and compact size, making it ideal for the conveyor system.

Specifications:

- Gearbox Type: Spur gear design
- Operating Voltage: 12V (operational range: 6-12V)

- No-load Current Consumption: 0.8A
- Rated Current Draw: 3A (under standard load)
- No-load Speed: 282 RPM (maximum)
- Operating Speed: 248 RPM (under rated load)
- Torque Output: 18 kg-cm (rated)
- Stall Torque: 60 kg-cm (maximum)
- Power Rating: 50W (maximum)
- Unit Weight: 350 grams

4.3.4.4 MicroSD Card

Fig. 4.8 SanDisk Ultra MicroSD Card

The SanDisk Ultra MicroSD Card is a compact, high-capacity, and secure digital memory card that is suitable for a wide range of applications, including digital cameras, smartphones, and tablets. It features a high-speed data transfer rate, making it ideal for storing large files such as images and videos. This card was selected for its high capacity, secure data protection, and ease of use, making it ideal for the storage system for the prototype.

Specifications:

- Capacity: 256GB
- Type: MicroSDXC (Secure Digital eXtended Capacity)
- Form Factor: MicroSD (11mm x 15mm x 1mm)
- File System: Pre-formatted exFAT

4.3.4.5 LED Lights

Fig. 4.9 LED Light Strip

For the Light Emitting Diode (LED), they were used to provide consistent lighting for image capture, ensuring accurate color representation and feature extraction. The LED lights were selected for their energy efficiency, long lifespan, and ability to produce a uniform light output.

Specifications:

- Power Input: 5V DC (USB-powered, compatible with laptops, power banks, or USB adapters).
- Waterproof Design: Suitable for indoor/outdoor use.
- LED Type: SMD 2835 (surface-mount diodes for high brightness and efficiency).
- Color Type: White (cool white)
- Length: 1m
- Beam Angle: 120°
- Operating Temperature: -25°C to 60°C.
- Storage Temperature: -40°C to 80°C.

4.3.4.6 Power Supply

The bench power supply is a versatile and adjustable power source used to provide stable voltage and current for various electronic projects. It is designed for testing applications, allowing users to set specific voltage and current levels. This power supply was selected for its versatility, ease of use, and ability to provide accurate voltage and current control for

Fig. 4.10 Bench Power Supply

the prototype.

Specifications:

- Type: SMPS (Switch-Mode Power Supply)
- Input: 110V AC, 50/60Hz (U.S. Standard)
- Output Range: 0-30V DC / 0-5A DC
- Voltage Precision: ±0.010V (10 mV) resolution
- Current Precision: ±0.001A (1 mA) resolution
- Power Precision: ±0.1W resolution
- Weight: 5 lbs (2.27 kg)

- Dimensions: 11.1” x 4.92” x 6.14” (28.2 cm x 12.5 cm x 15.6 cm)
- Maximum Power: 195W
- Power Source: AC input only

4.3.4.7 4 Channel Relay Module

Fig. 4.11 4 Channel Relay Module

The 4 Channel Relay Module is a compact and versatile relay board that allows for the control of multiple devices using a single microcontroller. This module was selected for its compact size, ease of use, and ability to control multiple devices simultaneously. It is designed to be used with microcontrollers such as Arduino and Raspberry Pi, allowing for easy integration into the prototype.

Specifications:

- Operating Voltage: 5V DC (compatible with Arduino, Raspberry Pi, and other microcontrollers).
- Number of Relays: 4 independent channels.
- Relay Type: Electromechanical (mechanical switching).
- Max AC Load: 10A @ 250V AC (resistive).
- Max DC Load: 10A @ 30V DC (resistive).
- Contact Type: SPDT (Single Pole Double Throw) - NO (Normally Open), NC (Normally Closed), COM (Common).
- Dimensions: 50mm x 70mm x 20mm
- Weight: 50-80 grams.
- Status LEDs: Individual LEDs for each relay (indicates ON/OFF state).
- Input Pins: 4 digital control pins (one per relay).
- Output Terminals: Screw terminals for connecting loads (NO/NC/COM).

4.4 Software Considerations

The software stack includes Python for programming PyTorch for machine learning and OpenCV for image processing. These tools are selected for their robustness, ease of use, and extensive community support, ensuring efficient system development.

4.4.1 PyTorch

4.4.2 OpenCV

4.4.3 Tkinter

4.4.4 CustomTkinter

4.5 Security and Reliability Considerations

Potential vulnerabilities, such as data corruption during image capture, are addressed through redundancy and error-checking mechanisms. Reliability is ensured by implementing fault-tolerant designs and rigorous testing protocols.

4.6 Scalability and Efficiency Considerations

The system is designed to handle large volumes of mangoes by optimizing the machine learning model and using parallel processing techniques. Efficiency is improved through techniques like model quantization and hardware acceleration.

4.7 User Interface

A User Interface (UI) is designed to display grading results, system status. Wireframes illustrate the layout, ensuring usability and accessibility for operators. Likewise, a Graphical User Interface (GUI) is also used to allow users to customize the system's grading priorities.

4.8 Constraints and Limitations

Challenges include variations in mango appearance due to lighting and environmental factors. Trade-offs are made between model complexity and real-time performance to balance accuracy and speed.

4.9 Technical Standards

The system adheres to industry standards for image processing and machine learning, ensuring compatibility and interoperability with other systems.

4.10 Prototyping and Simulation

Prototypes are developed using tools like MATLAB and Simulink to simulate the system's performance. These simulations help identify design flaws and optimize the system before deployment.,

4.11 Design Validation

The design is validated through testing, including unit testing of individual modules and integration testing of the entire system. Peer reviews and iterative improvements ensure the system meets the desired performance metrics.

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4.12 Summary

This chapter outlined the key design considerations, including system architecture, hardware and software choices, and validation methods. These decisions are critical for developing a reliable and efficient mango sorting and grading system.

Chapter 5

METHODOLOGY

TABLE 5.1 SUMMARY OF METHODS FOR REACHING THE OBJECTIVES

Objectives	Methods	Locations
GO: To develop a user-priority-based grading and sorting system for Carabao mangoes, using machine learning and computer vision techniques to assess ripeness, size, and bruises.	1. Hardware design: Build an image acquisition system with a conveyor belt, LED lights, and Raspberry Pi Camera 2. Software design: Coded a Raspberry Pi application to grade and sort the Carabao mangoes	Sec. 5.2 on p. 51
SO1: To make an image acquisition system with a conveyor belt for automatic sorting and grading mangoes.	1. Hardware implementation: Design and build an image acquisition system prototype	Sec. 5.3 on p. 51
SO2: To get the precision, recall, F1 score, confusion matrix, and train and test accuracy metrics for classifying the ripeness and bruises with an accuracy score of at least 90%.	1. Performance testing: Train and test the machine learning algorithm for classifying bruises and ripeness 2. Data collection: Gather our own Carabao mango dataset together with an online dataset	Sec. 5.5 on p. 53

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Objectives	Methods	Locations
SO3: To create a microcontroller-based system to operate the image acquisition system, control the conveyor belt, and process the mango images through machine learning.	1. Algorithm development: To develop a code for the image acquisition system 2. Hardware design: To design a schematic for the microcontroller based system	Sec. 5.3 on p. 51
SO4: To grade mangoes based on user priorities for size, ripeness, and bruises.	1. Formula development: Formulated an equation based on the inputted user priority and the predicted mango classification	Sec. 5.7 on p. 54
SO5: To classify mango ripeness based on image data using machine learning algorithms such as kNN, k-mean, and Naïve Bayes.	1. Performance testing: Train and test the machine learning algorithm for classifying bruises	Sec. 5.6.2 on p. 54
SO6: To classify mango size based on image data by getting its length and width using OpenCV, geometry, and image processing techniques.	1. Performance testing: Train and test the machine learning algorithm for classifying ripeness	Sec. 5.6.1 on p. 54
SO7: To classify mango bruises based on image data by employing machine learning algorithms.	1. Accuracy testing: Get the percent accuracy testing for getting the length and width of the Carabao mango	Sec. 5.6.3 on p. 54

5.1 Introduction

The methodology for this research outlines the development of the Carabao Mango sorter using machine learning and computer vision. The sorting system uses a conveyor belt system which delivers the mangoes into the image acquisition system. This system captures the image of the mangoes which will then be going through the various stages of image processing and classification into grades which will depend on the priority of the user. This methodology ensures that the grading of the mangoes will be accurate while being non-destructive.

5.2 Research Approach

This study applies the experimental approach for research in order to develop and properly test the proposed system. The experimental approach of the methodology will allow the researchers to fine-tune the parameters and other factors in the classification of mangoes in order to get optimal results with high accuracy scores while maintaining the quality of the mangoes. This approach will also allow for real-time data processing and classification which will improve the previous static grading systems.

5.3 Hardware Design

The prototype consists of hardware and software components for automated mango sorting and grading purposes. The hardware includes the conveyor belt system used to transfer mangoes from scanning to sorting smoothly. A camera and lighting system are able to collect high-resolution images for analysis. The DC motors and stepper motors are responsible for driving the conveyor belt and sorting actuators. The entire system is controlled by a microcontroller (Raspberry Pi 4b), coordinating actions of all components. Sorting actuators then direct mangoes into selected bins based on their classification to make sorting efficient.

5.4 Software Design

For the programming language used for the prototype and training and testing the CNN model, Python was used for training and testing the CNN model and it was also used in the microcontroller to run the application containing the UI and CNN model. PyTorch was the main library used in using the EfficientNet model that is used in classifying the ripeness and bruises of the mango. Likewise, tkinter is the used library when designing the UI in Python.

Furthermore, the rest of the software components are of utmost importance to mango classification. Image processing algorithms in OpenCV and CNN models extract features such as color, size, and bruises that are known to determine quality parameters of mangoes. Mangoes are classified based on ripeness and defects by using machine learning algorithms, which further enhances accuracy using deep learning techniques. A user interface (UI) is designed for users to control and observe the system in real time. Finally, the interface programming of the microcontroller provides the necessary synchronization between sensors, actuators, and motors throughout the sorting operation scenario.

5.5 Data Collection Methods

The system acquires high-resolution images of mangoes under pre-specified lighting conditions through systematic acquisition. Apart from that, this corpus of data is based on the real-time images acquired from the camera system, where classification operations are carried out based on real-time data. Pre-processing image operations such as flipping, rotating, resizing, normalization, and Gaussian blur are also carried out in order to enhance image clarity and feature detection. Then, the feature extraction process is carried out, where the intensity of color, shape, and texture are analyzed for the detection of characteristic features in terms of the mango. All these aspects lead to the creation of a reliable dataset for the machine learning algorithm that will allow the system to classify and grade mangoes more accurately.

5.6 Testing and Evaluation Methods

In a bid to ensure the mango sorting and grading system is accurate and reliable, there is intensive testing conducted at different levels. Unit testing is initially conducted on each component separately, for instance, the conveyor belt, sensors, and cameras, to ensure that each of the components works as expected when operating separately. After component testing on an individual basis, integration testing is conducted to ensure communication between hardware and software is correct to ensure the image processing system, motors, and sorting actuators work in concert as required. System testing is conducted to conduct overall system performance

testing in real-world conditions to ensure mangoes are accurately and efficiently sorted and graded.

To test system performance, various measures of performance are used to evaluate. As seen on equation 3.6, accuracy score is used to measure the percentage of correctly classified mangoes to ensure the system maintains high precision levels. Precision as seen on equation 3.3 and recall as seen on equation 3.4 are used to measure consistency of classification to determine if the system classifies different ripeness levels and defects correctly. Furthermore, the F1 score formula as seen on equation 3.5 is used to evaluate the performance of the model's classification.

A confusion matrix is used to measure correct and incorrect classification to ensure the machine learning model is optimized and that minimum errors are achieved. Throughput analysis is also used to determine the rate and efficiency of sorting to ensure that the system maintains high capacity without bottlenecks to sort mangoes. Using these methods of testing, the system is constantly optimized to ensure high-quality and reliable mango classification.

5.6.1 Ripeness Training and Testing

5.6.2 Bruises Training and Testing

5.6.3 Size Determination

5.7 Formula for User Priority

5.8 Ethical Considerations

Ethical considerations ensure that the system is operated safely and responsibly. Data privacy is ensured by securely storing and anonymizing extracted images and classification data so that unauthorized access becomes impossible. The system is also eco-friendly through non-destructive testing, saving mangoes while also ensuring that they are of good quality. Safety in operations is also ensured by protecting moving parts to prevent mechanical harm and incorporating fail-safes to securely stop operation in case of malfunction. Addressing these concerns, the system is not only accurate and efficient but also secure, eco-friendly, and safe for operators, thus a sustainable solution to automated mango sorting and grading.

5.9 Summary

This chapter explained how to create an automatic Carabao mango sorter and grader using machine learning and computer vision. The system integrates hardware and software resources, including a conveyor belt, cameras, sensors, and actuators, to offer accurate, real-time sorting by ripeness, size, and bruises. Various testing and evaluation processes ensure its performance to offer reliability. Ethical issues are data privacy, environmental sustainability, and operation safety. With enhanced efficiency, reduced human error, and enhanced quality, this system provides an affordable, scalable, and non-destructive solution to post-harvest mango classification in agricultural industries.

Chapter 6

RESULTS AND DISCUSSIONS

TABLE 6.1 SUMMARY OF METHODS FOR ACHIEVING THE OBJECTIVES

Objectives	**Methods**	**Locations**
GO: To develop a user-priority-based grading and sorting system for Carabao mangoes, using machine learning and computer vision techniques to assess ripeness, size, and bruises.	Expected Results: 1. Successfully developed a user-priority-based grading and sorting system using machine learning and computer vision which can assess the mangoes' ripeness, size and bruises. Actual Results: 1. More work needs to be done to fine tune the software components to achieve higher accuracy such as changing hyperparameters or using a newer version of EfficientNet 2. More work needs to be done to make the hardware component more robust such as by fixing the camera and LED lights in place	Sec. 6.6 on p. 62
SO1: To make an image acquisition system with a conveyor belt for automatic sorting and grading mangoes.	Expected Results: 1. Successfully integrated a conveyor belt with the image acquisition in order to achieve efficient flow of automated sorting and grading of the mangoes. 2. Successfully integrated LED strips to provide optimal lighting for image capturing of the mangoes. 3. Successfully fixed the hardware components in place Actual Results: 1. Successfully integrated a conveyor belt with the image acquisition in order to achieve efficient flow of automated sorting and grading of the mangoes. 2. Successfully integrated LED strips to provide optimal lighting for image capturing of the mangoes. 3. Need to fix the hardware components in place	Sec. 6.4 on p. 62

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Objectives	Methods	Locations
SO2: To get the precision, recall, F1 score, confusion matrix, and train and test accuracy metrics for classifying the ripeness and bruises with an accuracy score of at least 90%.	Expected Results: 1. Successfully achieved at least 90 percent accuracy, precision, recall, f1 score for ripeness classification of Carabao mangoes 2. Successfully achieved at least 90 percent accuracy, precision, recall, f1 score for bruises classification of Carabao mangoes Actual Results: 1. Successfully achieved at least 93% accuracy for ripeness classification of Carabao mangoes 2. Successfully achieved at least 73% accuracy for bruise classification of Carabao Mangoes	Sec. 6.1 on p. 61
SO3: To create a microcontroller-based system to operate the image acquisition system, control the conveyor belt, and process the mango images through machine learning.	Expected Results: 1. Successfully made a conveyor belt system to move the mangoes through the image acquisition system to the sorting system 2. Successfully mounted the image acquisition system on the the prototype 3. Successfully made the frame for the conveyor belt and image acquisition system to sit on Actual Results: 1. Successfully made a conveyor belt system to move the mangoes through the image acquisition system to the sorting system 2. Temporarily mounted the image acquisition system on the the prototype 3. Successfully made the frame for the conveyor belt and image acquisition system to sit on	Sec. 6.4 on p. 62

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Objectives	Methods	Locations
SO4: To grade mangoes based on user priorities for size, ripeness, and bruises.	Expected Results: 1. Successfully grade mangoes based on the user priorities on the physical characteristics of the mango 2. Successfully verified with qualified individual the results 3. Successfully utilize the weighted equation to evaluate mango grade based on user priorities Actual Results: 1. Successfully grade mangoes based on the user priorities on the physical characteristics of the mango 2. Successfully utilize the weighted equation to evaluate mango grade based on user priorities 3. Need to look for a qualified person to evaluate the graded mango for ground truth	Sec. 6.3 on p. 62

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Objectives	Methods	Locations
SO5: To classify mango ripeness based on image data using machine learning algorithms such as kNN, k-mean, and Naïve Bayes.	Expected Results: 1. Achieve at least 90% accuracy on performance metrics 2. Obtain performance metrics for kNN, k-mean, and Naive Bayes methods for comparison and show the superior performance of using CNN 3. Successfully fine tuned the CNN model to achieve the highest accuracy possible, choosing the best performing among EfficientNet b0-b7, and testing other CNN hyperparameters Actual Results: 1. Successfully trained a CNN model using EfficientNet-b0 and Adam Optimizer to detect ripeness based on color 2. Successfully achieved at least 90 percent accuracy, precision, recall, f1 score for ripeness classification of Carabao mangoes	Sec. 6.1.1 on p. 61
SO6: To classify mango size based on image data by getting its length and width using OpenCV, geometry, and image processing techniques.	Expected Results: 1. Successfully classified mango size using computer vision techniques 2. Successfully tuned to have an accurate size with an 80 percent accuracy rating Actual Results: 1. Successfully classified mango size using computer vision techniques 2. Calculation of mango size is somewhat inaccurate and needs more fine tuning	Sec. 6.2 on p. 62

Continued on next page

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Objectives	**Methods**	**Locations**
SO7: To classify mango bruises based on image data by employing machine learning algorithms.	Expected Results: 1. Achieve at least 90% accuracy on performance metrics 2. Successfully fine tuned the CNN model to achieve the highest accuracy possible, choosing the best performing among EfficientNet b0-b7, and testing other CNN hyperparameters Actual Results: 1. Successfully trained a CNN model using EfficientNet-b0 and Adam Optimizer to bruises 2. Successfully achieved at least 90 percent accuracy, precision, recall, f1 score for bruise classification of Carabao mangoes	Sec. 6.1.2 on p. 62

6.1 Training and Testing Results of the Model

6.1.1 Ripeness Classification Results

Add the F1-Score and etc here

6.1.2 Bruises Classification Results

6.2 Size Determination Results

6.3 User Priority Formula

$B(P)$ and $R(P)$ and $S(P)$ are the User Priority-Based Grading for bruises, ripeness, and size of the Carabao mango. Furthermore, $b(p)$ and $r(p)$ and $s(p)$ are the machine learning's predictions for bruises, ripeness, and size of the Carabao mango. The formula for the user priority is given by:

$$\text{User Priority} = b(P)\,B(P) + r(P)\,R(P) + s(P)\,S(P) \tag{6.1}$$

6.4 Physical Prototype

Add pictures of the hardware prototype here with description

6.5 Software Application

Show the raspberry pi app UI and demonstrate it here

6.6 Summary

Provide the gist of this chapter such that it reflects the contents and the message.

Chapter 7

CONCLUSIONS, RECOMMENDATIONS, AND FUTURE DIRECTIVES

7.1 Concluding Remarks

In this Thesis, . . .

Put here the main points that should be known and learned about the work topic. Summarize or give the gist of the essential principles and inferences drawn from your results.

7.2 Contributions

The interrelated contributions and supplements that have been developed by the author(s) in this Thesis are listed as follows. Only those that are unique to the authors' work are included.

- the ;
- the ;
- the ;

7.3 Recommendations

The researchers recommend...

7.4 Future Prospects

There are several prospects that may be extended for further studies. . . . So the suggested topics are listed in the following.

1. the . . . .

2. the . . . .

3. the . . . .

Note that for ECE undergraduate theses, as per the directions of the thesis adviser, Recommendations and Future Directives will be removed for the hardbound copy but will be retained for database storage.

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Appendix A
STUDENT RESEARCH ETHICS CLEARANCE

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RESEARCH ETHICS CLEARANCE FORM[1] For Thesis Proposals
Names of Student Researcher(s): BANAL, Kenan A. BAUTISTA, Francis Robert Miguel F. HERMOSURA, Don Humphrey L. SALAZAR, Daniel G
College: GCOE
Department: ECE
Course: Computer Engineering
Expected Duration of the Project: from: January 4 2025 to: January 4 2026
Ethical considerations *(The Ethics Checklists may be used as guides in determining areas for ethical concern/consideration)*
To the best of my knowledge, the ethical issues listed above have been addressed in the research. Dr. Reggie C. Gustilo **Name and Signature of Adviser/Mentor:** **Date:** February 5, 2025
Noted by: Dr. Argel Bandala **Name and Signature of the Department Chairperson:** **Date:** February 6, 2025

[1] The same form can be used for the reports of completed projects. The appropriate heading need only be used.

Appendix B
ANSWERS TO QUESTIONS TO THIS THESIS

B1 How important is the problem to practice?

A possible answer to this question is the summary of your Significance of the Study, and that portion of the Problem Statement where you describe the ideal scenario for your intended audience.

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B2 How will you know if the solution/s that you will achieve would be better than existing ones?

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B2.1 How will you measure the improvement/s?

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B2.1.1 What is/are your basis/bases for the improvement/s?

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B2.1.2 Why did you choose that/those basis/bases?

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B2.1.3 How significant are your measure/s of the improvement/s?

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B3 What is the difference of the solution/s from existing ones?

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B3.1 How is it different from previous and existing ones?

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B4 What are the assumptions made (that are behind for your proposed solution to work)?

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B4.1 Will your proposed solution/s be sensitive to these assumptions?

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B4.2 Can your proposed solution/s be applied to more general cases when some assumptions are eliminated? If so, how?

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B5 What is the necessity of your approach / proposed solution/s?

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B5.1 What will be the limits of applicability of your proposed solution/s?

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B5.2 What will be the message of the proposed solution to technical people? How about to non-technical managers and busines people?

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B6 How will you know if your proposed solution/s is/are correct?

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B6.1 Will your results warrant the level of mathematics used (i.e., will the end justify the means)?

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B7 Is/are there an/_ alternative way/s to get to the same solution/s?

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B7.1 Can you come up with illustrating examples, or even better, counterexamples to your proposed solution/s?

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B7.2 Is there an approximation that can arrive at essentially the same proposed solution/s more easily?

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B8 If you were the examiner of your Thesis, how would you present the Thesis in another way? Give your remarks, especially for your methodology and the results and discussions.

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B8.1 What are the weaknesses of your Thesis, specifically your methodology and the results and discussions?

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Appendix C
REVISIONS TO THE PROPOSAL

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PRO1 Panel Comments and Revisions – Appendix Z

PRO1 Panel Comments and Revisions

Zoom Recording:
https://zoom.us/rec/share/mrn9zBtPz3bJ5laVcy2E8-iBno8A6fBRgOCacMrhmzLPCNO0lDxXBHiK_xzdicEb.MzbHGzrD7rL3tVgJ?startTime=1731326444000
Passcode: +?qL6DZE

Panelist's Comments and Revisions	Action Taken	Page Number
Capture both two sides of the mango and not just one to remove error	The image capturing system would only capture the two sides of the mango which are the two largest surface areas of the skin.	18
How will you get large dataset with sweetness and how will you classify it?	Remove Sweetness in the SO	13
Size and weight are not the same.	Remove Weight in objectives but retained size in the SO4 and SO6	
Specify in the specific objectives that it will be automatic sorting	SO1: To make an image acquisition system with a conveyor belt for automatic sorting and grading mangoes.	13
Add what process will be used to get the size classification	SO6: To classify mango size by gettings its length and width using OpenCV, geometry, and image processing techniques	13
Add what process the ripeness classification will be	SO5: To classify mango ripeness using kNN or nearest neighbors algorithm	13
Get rid of texture in the general objectives	Texture is removed in the SOs	13
Get rid of CNN in general objectives and replace with machine learning	CNN is removed and replaced with machine learning GO: To develop a user-priority-based grading and sorting system for Carabao mangoes, using machine learning to assess ripeness, size, and bruises.	13
Remove Raspberry Pi on the SO's and generalize to "to create a microcontroller based application"	SO3: To create a microcontroller application to operate and control the prototype.	13
Remove SO4. No need for user testing	Removed user test and the new SO4 is SO4: To grade mangoes based on user priorities for size, ripeness, and bruises.	13
Fix IPO to the correct input and output	Input: Two side image of the Carabao Mango and the User Priority Attributes Process: Machine Learning Algorithm, Grading Formula, and CNN model using a microcontroller Output: Size, Ripeness, and Bruises	20

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PRO1 Panel Comments and Revisions – Appendix Z

	Classification with its Overall Grade	
Define bruises	The black or brown area of the mango that is visible on the skin of the mango.	6
Dataset should use at least 10,000 images	Added to expected deliverables SO2: To use a publicly available dataset of at least 10,000 mango images for classification of ripeness, and bruises.	14
Add to specific objectives the percentage accuracy	SO2: To get the precision, recall, F1 score, confusion matrix, and train and test accuracy metrics for classifying the ripeness and bruises with an accuracy score of at least 90%.	14
Weight sensor just adds complexity	removed all mention of load sensor, load cell. removed load cell methodology	39,40,41,42,43,44 previously

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PRO1 Panel Comments and Revisions – Appendix Z

PRO1 Panel Comments and Revisions

Zoom Recording:
https://zoom.us/rec/share/mrn9zBtPz3bJ5laVcy2E8-iBno8A6fBRgOCacMrhmzLPCNO0lDxXBHiK_xzdicEb.MzbHGzrD7rL3tVgJ?startTime=1731326444000
Passcode: +?qL6DZE

Summary:
● Specific Objectives
○ Add:
■ what process will be used to get the sweetness classification
■ what process the ripeness classification will be
■ what process will be used to get the size classification
■ Specify in the specific objectives that it will be automatic sorting
○ Remove:
■ get rid of texture in the general objectives
■ get rid of cnn in general objectives and replace with machine learning
■ remove Raspberry Pi on the SO's and generalize to "to create a microcontroller based application"
■ remove SO4. No need for user testing

Comments:
*[00-00] time stamps from recording
○ [15:00] Why only the top side of the mango? Isn't the point of automation to reduce human error? Then what about the bottom side wouldn't that just introduce another error if the mango happens to have defects on the bottom?
○ [16:09] What is the load cell for? Size is not the same as weight. if size is taken from the weight wouldn't size be also taken from the image. if size then adding a load cell would just introduce more complexity, if weight then load cell is fine. reminder that size is not the same as weight.
○ [17:36] When computer vision, state input and output parameters. Output parameters in this case would be sweetness, ripeness, size and bruising. Input parameters would be images.
○ [18:12] No mention of how the dataset would be gathered. Would you be gather your own dataset or using a publicly available dataset
○ [21:38] Fix IPO based on mention input and output parameters.
○ [21:50] Dataset is lacking. Usually in machine learning at least 10,000 images. can take more than one image per mango. after taking an image of mango can make more out of the image using data augmentations.
○ [22:48] Add to specific Objectives the mentioned 80%
○ [23:09] Consultant that would grade the mangoes as a third party to remove biases. For both the testing and the training
○ [24:55] How do you detect the sweetness of mangoes? Add these to the specific objectives. What are the categories of sweetness? Add these to specific objectives. How do

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PRO1 Panel Comments and Revisions – Appendix Z

you detect the correct categorization of sweetness? How to automate the classification of the sweetness.

○ [33:10] Why is the dataset destructive but the testing non destructive? Clarify this further to avoid confusion.

○ [35:09] What is the basis of sweetness using images? Clarify this further.

○ [35:35] How would you know if the classifier is correct or not? What is your ground truth (for the sweetness)?

○ [38:55] When can you say you are getting the top side of the mango? How would you know if the mango images showing the top side or the bottom side of both cheeks of the mango can be captured? If it doesn't matter then any side can be captured so why is it in the limitations that only the top side can be captured. Clarify the limitations.

○ [48:10] What classifier would you use here? What features would you extract from the images?

○ [52:07] Does it explain what process will be used to get the sweetness classification? Add it to the specific objectives

○ [54:00] How will ripeness be classified? Will it use the same dataset as the sweetness classification did? How was ground truth obtained?

○ [55:44] Why not the nearest neighbor? it is more fit in this scenario. Do not specify CNN in the objectives. The embedded systems as well, do not specify the Raspberry pi unless truly sure

○ [57:30] Table is just image processing. Is there a specific objective that would describe how ripeness classification will be done? Add this to the specific objectives.

○ [59:10] How is the weight obtained? Add it to the specific objectives. Remember that size is not proportional to weight. Size could be obtained from the image as the camera is from a fixed distance. Add to specific objectives how to get the size

○ [1:00:00] get rid of texture in the general objectives. get rid of cnn in general objectives and replace with machine learning. as each parameter will use a different method.

○ [1:04:00] remove Raspberry Pi on the SO's and generalize to "to create a microcontroller based application"

○ [1:04:37] remove SO4. no more user testing

○ [1:05:00] The formula used for grading the mangoes, is this used as industry standard? How do they measure the export quality of mango

○ [1:07:00] Specify in the specific objectives that it will be automatic sorting

Here are my comments on my end :)

1. Ensure seamless integration between hardware (sensors, motors, etc.) and software (CNNs, Raspberry Pi). You can consider using a modular approach for easier troubleshooting.

2. How do you gather a comprehensive and diverse dataset for training your CNN. This will enhance the model's robustness and accuracy.

3. Make sure that the weight sensors are calibrated correctly to avoid measurement errors.

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PRO1 Panel Comments and Revisions – Appendix Z

4. Implement data augmentation techniques to enhance your image dataset, which can improve model generalization and accuracy.

5. Design an intuitive user interface for the Raspberry Pi application.

6. Besides precision, recall, and F1 score, consider incorporating confusion matrices to better understand model performance and error types.

7. Conduct user testing of the application to gather feedback on usability and functionality. This can lead to improvements in design and user experience. Consider how the system can be scaled or adapted for different fruits or larger processing volumes in the future.

Noted by:

Dr. Donabel de Veas Abuan
Chair of Panel

Date: November 11 2024

Note: Keep a copy of this Appendix. It is a requirement that has to be submitted in order to qualify for PRO3 Defense.

Appendix D
REVISIONS TO THE FINAL

Make a table with the following columns for showing the summary of revisions to the proposal based on the comments of the panel of examiners.

1. Examiner
2. Comment
3. Summary of how the comment has been addressed
4. Locations in the document where the changes have been reflected

TABLE D.1 SUMMARY OF REVISIONS TO THE THESIS

Examiner	**Comment**	**Summary of how the comment has been addressed**	**Locations**
Dr. Reggie C. Gustillo	1. First itemtext 2. Second itemtext 3. Last itemtext 4. First itemtext 5. Second itemtext	1. First itemtext 2. Second itemtext 3. Last itemtext 4. First itemtext 5. Second itemtext **First** itemtext **Second** itemtext **Last** itemtext **First** itemtext **Second** itemtext	Sec. **??** on p. **??**, Sec. **??** on p. **??**, Fig. **??** on p. **??**

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Examiner	Comment	Summary of how the comment has been addressed	Locations
Dr. Donable de Veas Abuan	1. First itemtext 2. Second itemtext 3. Last itemtext 4. First itemtext 5. Second itemtext	1. First itemtext 2. Second itemtext 3. Last itemtext 4. First itemtext 5. Second itemtext **First** itemtext **Second** itemtext **Last** itemtext **First** itemtext **Second** itemtext	Sec. **??** on p. **??**, Sec. **??** on p. **??**, Fig. **??** on p. **??**
Engr. Jose Martin Maningo	1. First itemtext 2. Second itemtext 3. Last itemtext 4. First itemtext 5. Second itemtext	1. First itemtext 2. Second itemtext 3. Last itemtext 4. First itemtext 5. Second itemtext • First itemtext • Second itemtext • Last itemtext • First itemtext • Second itemtext	Sec. **??** on p. **??**, Sec. **??** on p. **??**, Fig. **??** on p. **??**

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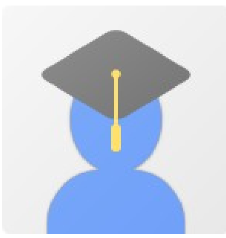
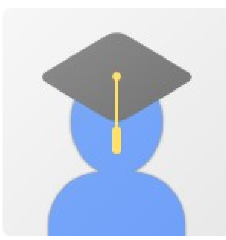
Examiner	Comment	Summary of how the comment has been addressed	Locations
Dr. Alexander Co Abad	1. First itemtext 2. Second itemtext 3. Last itemtext 4. First itemtext 5. Second itemtext	1. First itemtext 2. Second itemtext 3. Last itemtext 4. First itemtext 5. Second itemtext	Sec. **??** on p. **??**, Sec. **??** on p. **??**, Fig. **??** on p. **??**
Dr. Rafael W. Sison	1. First itemtext 2. Second itemtext 3. Last itemtext 4. First itemtext 5. Second itemtext	1. First itemtext 2. Second itemtext 3. Last itemtext 4. First itemtext 5. Second itemtext	Sec. **??** on p. **??**, Sec. **??** on p. **??**, Fig. **??** on p. **??**

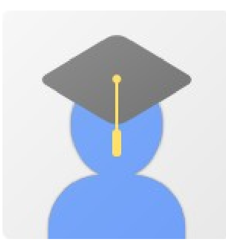
Appendix E
VITA



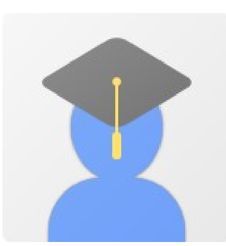
Kenan A. Banal is currently taking up his B.Sc. Computer Engineering studies. He is passionate about software and hardware systems such as Vivado, Arduino, C, and Python.



Francis Robert Miguel F. BAUTISTA is currently taking up his B.Sc. Computer Engineering studies. He is passionate about software and hardware systems such as Vivado, Arduino, C, and Python.



Don Humphrey L. HERMOSURA is currently taking up his B.Sc. Computer Engineering studies. He is passionate about software and hardware systems such as Vivado, Arduino, C, and Python.



Daniel G. SALAZAR is currently taking up his B.Sc. Computer Engineering studies. He is passionate about software and hardware systems such as Vivado, Arduino, C, and Python.

Appendix F
ARTICLE PAPER(S)

Article/Forum Paper Format (IEEE LaTeX format)

Michael Shell, *Member, IEEE,* John Doe, *Fellow, OSA,* and Jane Doe, *Life Fellow, IEEE*

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***Abstract*—The abstract goes here. Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Etiam lobortis facilisis sem. Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec ullamcorper, felis non sodales commodo, lectus velit ultrices augue, a dignissim nibh lectus placerat pede. Vivamus nunc nunc, molestie ut, ultricies vel, semper in, velit. Ut porttitor. Praesent in sapien. Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Duis fringilla tristique neque. Sed interdum libero ut metus. Pellentesque placerat. Nam rutrum augue a leo. Morbi sed elit sit amet ante lobortis sollicitudin. Praesent blandit blandit mauris. Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit amet ipsum. Nunc quis urna dictum turpis accumsan semper.**

***Index Terms*—Computer Society, IEEE, IEEEtran, journal, LaTeX, paper, template.**

I. Introduction

THIS demo file is intended to serve as a "starter file" for IEEE article papers produced under LaTeX using IEEEtran.cls version 1.8b and later. Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Etiam lobortis facilisis sem. Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec ullamcorper, felis non sodales commodo, lectus velit ultrices augue, a dignissim nibh lectus placerat pede. Vivamus nunc nunc, molestie ut, ultricies vel, semper in, velit. Ut porttitor. Praesent in sapien. Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Duis fringilla tristique neque. Sed interdum libero ut metus. Pellentesque placerat. Nam rutrum augue a leo. Morbi sed elit sit amet ante lobortis sollicitudin. Praesent blandit blandit mauris. Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit amet ipsum. Nunc quis urna dictum turpis accumsan semper.

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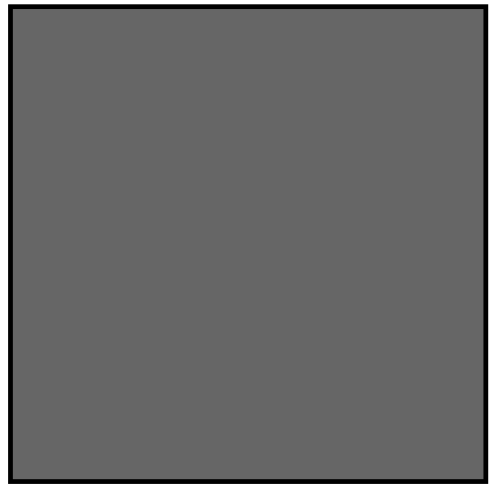

Fig. 1. Simulation results for the network.

TABLE I
AN EXAMPLE OF A TABLE

One	Two
Three	Four

1) Subsubsection Heading Here: Subsubsection text here.

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II. Conclusion

The conclusion goes here.

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M. Shell was with the Department of Electrical and Computer Engineering, Georgia Institute of Technology, Atlanta, GA, 30332.
E-mail: see http://www.michaelshell.org/contact.html
J. Doe and J. Doe are with Anonymous University.

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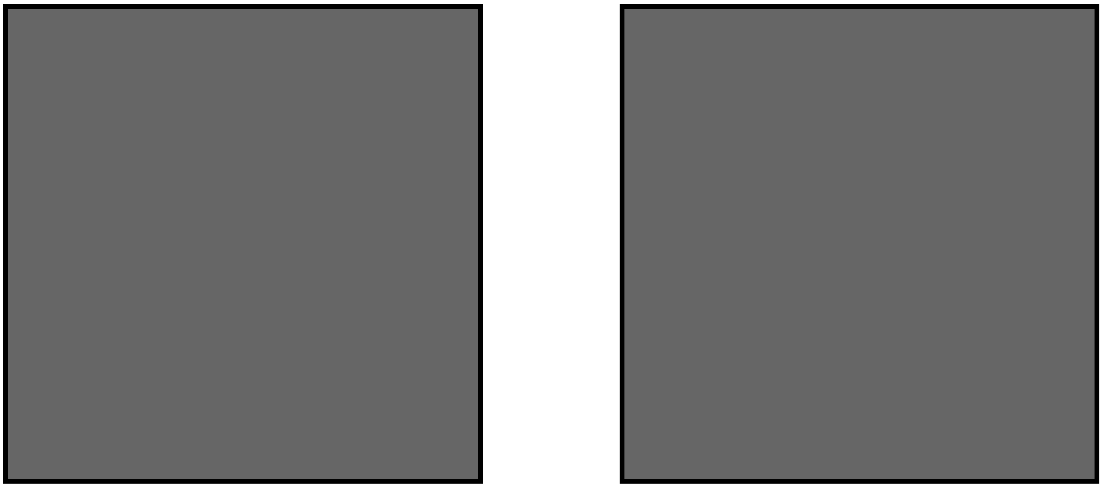

(a) Case I

(b) Case II

Fig. 2. Simulation results for the network.

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Appendix A
Proof of the First Zonklar Equation

Appendix one text goes here.

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Appendix B

Appendix two text goes here. [**?**].

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Acknowledgment

The authors would like to thank...