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

4

5 A Thesis
6 Presented to the Faculty of the
7 Department of Electronics and Computer Engineering
8 Gokongwei College of Engineering
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10

11 In Partial Fulfillment of the
12 Requirements for the Degree of
13 Bachelor of Science in Computer Engineering

14

15 by

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ORAL DEFENSE RECOMMENDATION SHEET

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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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38

ABSTRACT

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

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



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LIST OF TABLES



58 **ABBREVIATIONS**

59	AC	Alternating Current	13
60	CNN	Convolution Neural Network	14



61

NOTATION

62	$D(p, d, f)$	Real World Dimension	27
63	p	Pixel Dimension	27
64	d	Distance from Camera to Object.....	27
65	f	Focal Length	27



66

GLOSSARY

67

accuracy score A performance metric that measures the overall proportion of correct predictions made by a machine learning model.

68

bruises The black or brown area of the mango that is visible on the skin of the mango.

69

Carabao mango A popular variety of mango grown in the Philippines, known for its sweet and juicy flesh.

70

CNN A type of deep neural network that is highly effective in analyzing and processing visual data, such as images.

71

computer vision The use of cameras and algorithms to provide imaging-based inspection and analysis.

72

machine learning A subset of Artificial Intelligence that enables systems to learn and improve from data.

73

microcontroller A small computing device that controls other parts of a system such as sensors.



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LISTINGS



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Chapter 1

76

INTRODUCTION



77 **1.1 Background of the Study**

78 Mangoes, also known as the *Mangifera indica*, are a member of the cashew family. This
79 fruit can often be seen being farmed by countries such as Myanmar, the Philippines, and
80 India as they have a tropical dry season. Being in a tropical country is an important
81 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 (?). Carabao



Fig. 1.1 Carabao Mangoes at Different Ripeness Stages (?)

82
83 mangoes is a variety of a mango that is found and cultivated in the Philippines. It is known
84 for its sweet signature taste that was recognized sweetest in the world in the Guinness
85 Book of World Records in 1995. The mango was named after the national animal of the
86 Philippines, a native breed of buffalo. On average, it is 12.5 cm in length and 8.5 cm in
87 diameter, having a bright yellow color when ripe as seen in Figure 1.1. It is often cultivated
88 during late May to early July (?).

89 As the Philippines is a tropical country, mangoes are a highly valued fruit as it is not
90 only the country's national fruit but also amongst the leading agricultural exports of the
91 country, ranking only third below bananas and pineapples. This gives the country the 9th
92 slot amongst the leading exporters of Mangoes across the world. Attributed to this ranking



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93 is the country's export of both fresh and dried mangoes, as well as low tariff rates. This
94 allows the country to export a large quantity of the fruit in countries such as Singapore,
95 Japan, and the USA as they can enter duty free markets provided by the World Trade
96 Organization and Japan. Due to this, the mangoes have become a major source of income
97 to an estimated 2.5 million farmers in the country (?).

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

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

111 Previous studies have been made to automate the sortation process of the mangoes.
112 Among these is a research done by ?, which focuses on classification of mangoes using their
113 texture and shape features. They do this by, first, acquiring an image of the mango using
114 a digital camera. Then, these images are fed to the MaZda package, which is a software
115 originally developed for magnetic resonance imaging. Within the MaZda package is the
116 B11 program, which uses Principal Component Analysis, Linear Discriminant Analysis,



117 Nonlinear Discriminant Analysis, and texture classification to extract features from the
118 mango, which in this case are the length, width, and texture. This data is then compared to
119 a database in order to classify any given mango (?).

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

129 1.2 Prior Studies

130 A paper written by ?, designed an automated fruit sorting machine based on the quality
131 through an image acquisition system and CNN. Furthermore, the results of the paper show
132 that the image processing detection score was 89% while that of the tomatoes was 92%
133 while the CNN model had higher validity of 95% for mangoes and 93% for tomatoes.
134 15%, while the percentage of distinction between the two groups was reported to be 5%
135 respectively (?). Despite the high accuracy score in detecting mango defects, the fruit
136 sorting system only sorts based on the mango defects and not on ripeness, and weight.

137 Furthermore, the research paper presented by ? designed an Automated Carabao mango
138 classifier, in which the mango image database is used to extract the features like size, area



139 along with the ratio of the spots for grading using Naïve Bayes Model. For the results, the
140 Naïve Bayes' model recognized large and rejected mangoes with 95% accuracy and the
141 large and small/medium difference with a 7% error, suggesting an application for quality
142 differentiation and sorting in the mango business industry. Despite the high accuracy of
143 classifying Carabao mangoes, the researchers used a high quality DSLR camera for the
144 image acquisition system without any microcontroller to control the mangoes (?).

145 1.3 Problem Statement

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

159 With the current advancements in technology, some researchers have already taken steps
160 to automate the process of sorting and grading mangoes. However, these attempts would



161 often only consider some of the aspects pertaining to size, ripeness, and bruises but not all
162 of them at the same time. Lastly, not all research approaches were able to implement a
163 hardware for their algorithm, limiting their output to only a software implementation and not
164 an embedded system. As such the proposed system would assess the export quality of the
165 Carabao mango based on all the mentioned mango traits, namely size, bruises, and ripeness
166 while also taking into consideration being non-destructive. These aspects are important
167 because, as was previously mentioned, there is a need to develop a Carabao mango sorter
168 that takes into account all these aspects at the same time while being non-destructive.

169 **1.4 Objectives and Deliverables**

170 **1.4.1 General Objective (GO)**

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

174 **1.4.2 Specific Objectives (SOs)**

- 175 • SO1: To make an image acquisition system with a conveyor belt for automatic sorting
176 and grading mangoes. ;
- 177 • SO2: To get the precision, recall, F1 score, confusion matrix, and train and test
178 accuracy metrics for classifying the ripeness and bruises with an accuracy score of at
179 least 90%.;



- 180 • SO3: To create a microcontroller-based system to operate the image acquisition
181 system, control the conveyor belt, and process the mango images through machine
182 learning. ;
- 183 • SO4: To grade mangoes based on user priorities for size, ripeness, and bruises. ;
- 184 • SO5: To classify mango ripeness based on image data using machine learning
185 algorithms such as kNN, k-mean, and Naïve Bayes. ;
- 186 • SO6: To classify mango size based on image data by getting its length and width
187 using OpenCV, geometry, and image processing techniques. ;
- 188 • SO7: To classify mango bruises based on image data by employing machine learning
189 algorithms.

190 1.4.3 Expected Deliverables

191 Table 1.1 shows the outputs, products, results, achievements, gains, realizations, and/or
192 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.	<ul style="list-style-type: none"> • 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.

Continued on next page



TABLE 1.1 EXPECTED DELIVERABLES PER OBJECTIVE

Objectives	Expected Deliverables
SO1: To make an image acquisition system with a conveyor belt for automatic sorting and grading mangoes.	<ul style="list-style-type: none"> 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%.	<ul style="list-style-type: none"> 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.	<ul style="list-style-type: none"> 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.	<ul style="list-style-type: none"> 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.
SO5: To classify mango ripeness based on image data using machine learning algorithms such as kNN, k-mean, and Naïve Bayes.	<ul style="list-style-type: none"> 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.	<ul style="list-style-type: none"> 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.

Continued on next page



TABLE 1.1 EXPECTED DELIVERABLES PER OBJECTIVE

Objectives	Expected Deliverables
SO7: To classify mango bruises based on image data by employing machine learning algorithms.	<ul style="list-style-type: none"> • 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. 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 ?.

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



206 ensuring that only marketable fruits are processed further.

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

213 **1.5.1 Technical Benefit**

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

220 **1.5.2 Social Impact**

- 221 1. The reduction in manual labor creates opportunities in maintenance and technologies
222 in the automated Carabao mango sorter.
- 223 2. The automated Carabao mango sorter system improves Carabao mango standards
224 and enhances the satisfaction of the buyers and the customers through guaranteeing
225 consistent Carabao mango grade.



- 226 3. Opportunity to increase sales and profit for the farmers through consistent quality
227 and grade Carabao mangoes while reducing the physical labor to sort it.

228 **1.5.3 Environmental Welfare**

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

234 **1.6 Assumptions, Scope, and Delimitations**

235 **1.6.1 Assumptions**

- 236 1. The Carabao mangoes are from the same source together with the same variation
- 237 2. The Carabao mangoes do not have any fruit borer and diseases
- 238 3. All the components do not have any form of defects
- 239 4. The prototype would have access to constant electricity/power source.
- 240 5. The Carabao mangoes to be tested would be in the post-harvesting stage and in the
241 grading stage.
- 242 6. The image-capturing system would only capture the two sides of the mango which
243 are the two largest surface areas of the skin.

244 **1.6.2 Scope**

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

253 **1.6.3 Delimitations**

- 254 1. The project would only be able to perform sorting and grading on one specific fruit
255 which is the Carabao mango and will not be able to sort other types of mangoes.
- 256 2. Additionally, the project prototype will only be able to capture, sort, and grade one
257 mango subject at a time which means the mangoes have to be placed in the conveyor
258 belt in a single file line for accurate sorting.
- 259 3. For the bruises, the system will only be able to detect external bruises and may not
260 identify the non-visible and internal bruises.
- 261 4. The system does not load the mangoes onto the conveyor belt itself. Assistance is
262 required to put mangoes into the conveyor belt to start the sorting process



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

265 **1.7 Estimated Work Schedule and Budget**

TASKS	THSCP4A				THSCP4B				THSCP4C			
	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				HERMOSURA AND SALAZAR							
Buying and Collecting of Materials												
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

266 As seen above, Table 1.2 shows the Gantt Chart together with the assigned task. For
 267 the first part of the THSCP4A, the group would primarily revise and fine tune Chapters
 268 1 and 2 while also preparing for the defense. After that for THSCP4B, the yellow team
 269 which consists of two members, Hermosura and Salazar, would start buying and collecting
 270 the materials needed for assembling the prototype. While team yellow is doing that,
 271 team purple which consists of Banal and Baustista would start training and validating the
 272 Convolution Neural Network (cnn) model based on the Carabao mango image dataset.
 273 After that integration of the sensors and actuators together with the integration of the cnn
 274 model and beginning of coding of the Application to the Raspberry Pi would be done. Once
 275 that cnn model is deployed and the Application works testing of the Carabao mangoes to
 276 the prototype would be done. During THSCP4C, data gathering would be done together
 277 with polishing and revising of the final paper.



278 **1.8 Overview of the Thesis**

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



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Chapter 2

290

LITERATURE REVIEW



291 **2.1 Existing Work**

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

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



314 Furthermore, the research paper presented by ? designed an Automated Carabao
315 mango classifier, in which the mango image database is used to extract the features like
316 weight, size, area along with the ratio of the spots for grading using Naïve Bayes Model.
317 Concerning the quantitative test design, one had to control and experiment with various
318 methods of image processing that would improve the likelihood of improved classification.
319 The paper methodology entailed sample collection from 300 Carabao mangoes, picture
320 taking using a DSLR camera, and feature deconstruction for categorization (?). The
321 system prototype and the software were designed with the programming language C# with
322 integration of Aforge. NET routines. The performance of this model was checked with
323 the help of the dataset containing 250 images, precision, recall, F-score key indicators
324 were used. The investigation discovered that the Naïve Bayes' model recognized large and
325 rejected mangoes with 95% accuracy and the large and small/medium difference with a
326 7% error, suggesting an application for quality differentiation and sorting in the mango
327 business industry. The limitations in the researchers' paper include the researchers were
328 able to achieve high accuracy after using a high quality DSLR camera and the fact that the
329 researchers were not able to incorporate the use of microcontrollers.

330 Another study by ? proposed SVM-based system for classifying the maturity stages of
331 bananas, mangoes, and calamansi. With the use of 1729 images of bananas together with
332 711 mango images and 589 calamansi, the researchers were able to achieve a high accuracy
333 score of above 90% for all fruits. Some pre-processing techniques used to get this high
334 accuracy are the change in hue, saturation, and value channels in the mango image (?). To
335 better understand the harvest time of mangoes, the paper by ? examined the association of
336 the harvest season with seasonal heat units, rainfall, and physical fruit attributes for Haden,
337 Kent, Palmer, and Keitt mango varieties to establish export and domestic market maturity



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338 standards. For the results of the paper, it shows that temperature, rainfall, and physical
 339 characteristics have a reliable, non-destructive indicators for determining mango maturity
 340 (?). This shows that physical characteristics and temperature are important when exporting
 341 fruits such as mangoes.

TABLE 2.1 COMPARISON OF EXISTING STUDIES

Existing Study	Limitations	Accuracy Rating
?	No physical automation, not suitable for large amounts of mangoes, only classifies ripeness and only a sample size of 10 mangoes.	95%
?	Focuses only on color and size.	91.2%
?	Relies on high-quality DSLR cameras, and limited automation due to not integrating microcontrollers.	95%
?	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%

342 Previous studies on mango grading have achieved an accuracy rating of up to 95%, as
 343 shown in Table 2.1. However, these studies either relied on a small sample size, which
 344 limits statistical significance, or utilized expensive equipment, which may be impractical.
 345 In light of this, the researchers have set a target accuracy rating of greater than or equal
 346 to 90%. This target ensures that the system being developed is comparable to, or better
 347 than, existing studies that used larger sample sizes or assessed multiple mango traits at the
 348 same time. Furthermore, this research aims to distinguish itself by not only maintaining or
 349 exceeding the 90% accuracy rating but also incorporating a graphical user interface (GUI)



350 for selective priority-based mango classification. The system will integrate both software
351 and hardware components, and it will evaluate a greater number of mango traits for grading
352 purposes.

353 **2.1.1 Sorting Algorithms**

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

367 In the study done by ?, Simple Linear Regression, Multiple Linear Regression, and
368 Artificial Neural Network models were all studied and compared for the purpose of size-
369 mass estimation for mango fruits. The researchers found that the Artificial Neural Network
370 yielded a high accuracy rating for mass estimation and for mango classification based on
371 size with a success rate of 96.7% (?). This is attributed to the Artificial Neural Network
372 model's ability to learn both linear and nonlinear relationships between the inputs and the



373 outputs. However, a problem can occur with the use of the model, which is overfitting.
374 This issue occurs when the model is overtrained with the data set such that it will start to
375 recognize unnecessary details such as image noise which results in poor generalization
376 when fed with new data. With this in mind, additional steps will be necessary to mitigate the
377 issue. Another research article written by ? implements a method for sorting and grading
378 Carabao mangoes. This research focuses on the use of Probabilistic Neural Network, which
379 is another algorithm that is used for pattern recognition and classification of objects. For
380 this study, the researchers focused on the area, color, and the black spots of the mango
381 for their Probabilistic Neural Network model (?). Their research using the model yielded
382 an accuracy rating of 87.5% for classification of the mangoes which means it is quite
383 accurate for classifying mangoes within the predefined categories. However, problems
384 were encountered with the use of the model when trying to identify mangoes that did not
385 fit the predefined size categories of small, medium, and large. This means that the PNN
386 model may become challenged when presented with a mango with outlying traits or traits
387 that were very different from the data set.

388 2.2 Lacking in the Approaches

389 The majority of past researchers such as ? and ? were able to implement a fruit and
390 mango sorter together with an accurate AI algorithm to detect the ripeness defects. This
391 means that none of the previous research papers were able to integrate an interchangeable
392 user-priority-based grading together with size, ripeness, and bruises using machine learning
393 for Carabao mango sorter and grader. Our research however would implement an automated
394 Carabao mango sorter in terms of size, ripeness, and bruises with its own UI, conveyor



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

395 belt, stepper motors, and bins for collecting the different ripeness and defect grade of the
 396 Carabao mango.

397 2.3 Summary

398 To reiterate, there is an innovative gap that needs to be filled with regards to the process of
 399 sorting and grading Carabao mangoes. The traditional methods for conducting this process
 400 manually by hand, by a porous ruler, by a sugar meter, and by a color palette can be prone
 401 to human error and expensive costs due to the number of laborers required to do the task.
 402 On the other hand, although researchers have already taken steps to automate the process
 403 of mango sorting and grading, there is still a need for an implementation that takes into
 404 account size, ripeness, and bruises altogether whilst being non-destructive and having its
 405 own embedded system. The research articles shown above show the different computer



406 vision and CNN approaches for sorting and classifying mangoes. For example, a system
407 created by ? was more focused on ripeness detection. ? considered photonic systems
408 for grading mango fruit based on color and weight. On the other hand, ? implemented
409 the Naïve Bayes classification model on mangoes with high accuracy, which thereby did
410 not include any microcontroller. There was an attempt to study each of those parameters
411 separately and that is why the multifactorial approach was not used. With this in mind, the
412 system being proposed does exactly what was mentioned, to implement a non-destructive
413 and automated sorting and grading system for Carabao mangoes that takes into account
414 size, ripeness, and bruises altogether using machine learning, as well as having its own
415 embedded system. This system will be mainly composed of a conveyor belt, servo motors,
416 a camera, microcontrollers, and an LCD display for the user interface. By doing so, the
417 system should be able to improve the efficiency and productivity of mango sorting and
418 grading, remove the effect of human error and reduce time consumption. The studies also
419 provided critical insights regarding the effective algorithms that can be used in classification
420 stages in image processing. The use of CNN had the most accuracy with manageable
421 potential challenges. Lastly, by scaling the implementation, the overall export quality of
422 the Carabao mangoes can be improved.



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423

Chapter 3

424

THEORETICAL CONSIDERATIONS



425 3.1 Introduction

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

428 3.2 Relevant Theories and Models

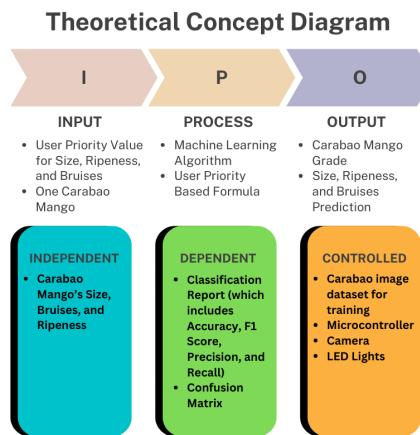


Fig. 3.1 Theoretical Framework Diagram.

429 The theoretical framework seen in figure 3.1 follows the IPO (Input-Process-Output)
 430 Model for a Carabao Mango Sorting System. The Input section includes user-defined
 431 priority values for size, ripeness, and bruises, along with a single mango for analysis. The
 432 Process section highlights the use of a machine learning algorithm and a user-priority-based
 433 formula to classify the mango. The Output consists of the mango's grade, predicted size,
 434 ripeness, and bruises. Below the IPO model, the diagram categorizes variables into three
 435 groups: Independent (mango's size, ripeness, and bruises), Dependent (classification report
 436 with accuracy, precision, recall, and confusion matrix), and Controlled (image dataset,
 437 microcontroller, camera, and LED lights).



438 3.3 Technical Background

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

446 3.4 Conceptual Framework Background

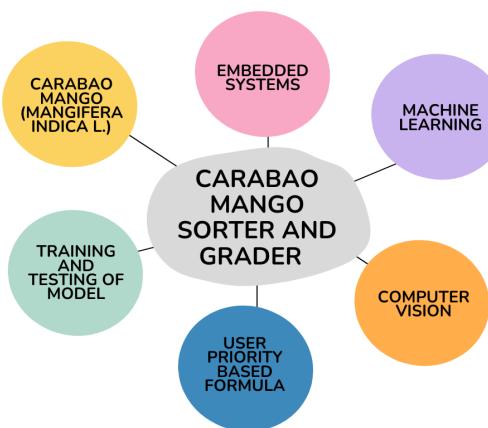


Fig. 3.2 Conceptual Framework Diagram.

447 The conceptual framework seen in figure 3.2 illustrates the key components involved
 448 in the Carabao Mango Sorter and Grader system. At the center, the system is represented
 449 as the core element, surrounded by six interconnected components: Carabao Mango
 450 (*Mangifera indica L.*), Embedded Systems, Machine Learning, Computer Vision, User



451 Priority-Based Formula, and Training and Testing of the Model. These elements represent
452 the different technologies, methodologies, and considerations required for the development
453 and operation of the sorter and grader. The diagram provides an overview of how various
454 disciplines contribute to the project's functionality.

455 **3.5 Software Concepts**

456 **3.5.1 Thresholding**

457 Thresholding is a computer vision image segmentation technique that is used to separate
458 objects from their surroundings by converting a grayscale image to binary. The conversion
459 is done by choosing a certain threshold intensity value. It is usually done by assigning pixels
460 with an intensity higher than the threshold are mapped to one value (commonly white),
461 and pixels with an intensity lower than the threshold are mapped to another (commonly
462 black). The result of this technique is in a high-contrast image that makes it easy to detect
463 the object's boundary and shape in the image.

464

465 In this project, two types of thresholding were applied:

- 466 • Absolute Difference Thresholding – This method involves computing the absolute
467 difference between two images. The first image is one of the object, and the other
468 of the same background without the object. The result isolates only the pixels that
469 have changed between the two images, thus isolating the mango from its background
470 successfully.
- 471 • Binary Thresholding – Once the difference image has been created, binary threshold-



472 ing is used. A threshold value is employed to threshold the difference image into a
 473 binary image. Values greater than the threshold are made white (foreground), and
 474 values less than that are made black (background). This creates a clear silhouette of
 475 the mango, which is appropriate for size estimation and contour detection.

476 **3.5.2 Object Size Calculation**

477 Object size calculation is the calculation of a certain object's true size from image data. This
 478 is essential in computer vision systems to efficiently process object features in real-time.
 479 In this research, the size of the Carabao mango is estimated through image measurement
 480 techniques based on geometric principles and camera calibration.

481 The size of the mango can be determined given:

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

$$D(p, d, f) = \frac{p \cdot d}{f} \quad (3.2)$$

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

485 After capture and preprocessing of the image, the binary image so obtained is processed
 486 with contour detection to find the largest object, which is assumed to be the mango. The
 487 contour is then bounded with a minimum-area bounding box, and pixel-based length and
 488 width are calculated using Euclidean distance between the corner points.



489 This size estimation method offers a consistent and efficient way of taking the mea-
490 surements with only standard camera input, providing consistency in classification and
491 reducing the necessity for physical measuring devices.

492 **3.5.3 Convolutional Neural Network**

493 Convolutional Neural Networks are a class of deep learning models commonly used in
494 analyzing visual data. CNNs are particularly effective in image classification tasks due to
495 their ability to automatically extract and effectively learn the spatial hierarchies of features
496 directly from the pixels of a given image. This makes it highly suitable for functions such
497 as object detection and, in the case of this study, image classification.

498 CNN usually applies filters to input images. These filters are designed to detect local
499 patterns such as edges, textures, and color gradients. The network is able to learn more
500 patterns as the data goes through the layers. This enables it to recognize effectively the
501 characteristics that it is looking for.

502 The use of CNNs in this study allows for accurate, automated classification of mango
503 images which contributes to the development of a reliable, non-destructive grading system
504 that minimizes human error and ensures consistent quality assessment

505 **3.5.4 Classification Report**

506 **3.5.4.1 Confusion Matrix**

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

509



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

TABLE 3.1 CONFUSION MATRIX EXAMPLE

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

514 **3.5.4.2 Precision**

$$\text{Precision} = \frac{TP}{TP + FP} \quad (3.3)$$

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

518 **3.5.4.3 Recall**

$$\text{Recall} = \frac{TP}{TP + FN} \quad (3.4)$$

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

522 **3.5.4.4 F1 Score**

$$F_1 = 2 \times \frac{\text{Precision} \times \text{Recall}}{\text{Precision} + \text{Recall}} \quad (3.5)$$

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

526 **3.5.4.5 Accuracy**

$$\text{Accuracy} = \frac{TP + TN}{TP + TN + FP + FN} \quad (3.6)$$

527 Accuracy measures the proportion of correct predictions (both true positives and true
 528 negatives) among the total cases. While intuitive, accuracy can be misleading with imbal-
 529 anced datasets.

530

3.6 Hardware Concepts

531

3.6.1 Camera Module

532 The camera module serves as the main image acquisition tool in the mango sorter and
 533 grader system. Its role is to capture clear, high-resolution images of each mango as it moves
 534 along the conveyor. These images are critical for analyzing physical traits like ripeness,
 535 bruising, and size through computer vision and machine learning techniques.

536 The camera is directly connected to the Raspberry Pi, which manages both image
 537 capture and processing. It is fixed in position to ensure consistent distance and angle for
 538 all images. It is also paired with a lighting system to provide a consistent lighting for the



539 images. The system captures images of both the top and bottom sides of each mango to
540 ensure a more accurate grading. The prototype integrates the Raspberry Pi Camera Module
541 Version 2. This camera is chosen for its 8MP resolution which is critical in capturing
542 real-time images. Another reason for integrating this camera is because of its compatibility
543 with the Raspberry Pi 4, and reliability in capturing detailed images needed for accurate
544 classification. It is also cost effective and lightweight which is important for the prototype.

545 **3.6.2 4 Channel Relay**

546 The relay module in this project is used to control the direction and movement of the
547 motors that operate the conveyor system and mango sorting mechanism. As an electrically
548 operated switch, the relay allows the low-power signals from the Raspberry Pi to safely
549 manage the higher voltage and current required by the DC motors.

550 For the prototype, the relay module is responsible for changing the polarity of motor
551 connections which enables the motors to rotate in both forward and reverse directions.
552 This will drive the conveyor belt system. This is essential for moving mangoes along the
553 conveyor, rotating them for the top and bottom image capture, and directing them to the
554 appropriate bin based on their grade.

555 **3.6.3 1:3 Pulley Belt**

556 **3.7 Summary**

557 Overall, chapter 3 establishes key concepts and theoretical considerations that form the
558 foundation of the Carabao mango sorter and grading system. It discusses and connects



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559 each component together, explaining how each component such as the RaspberryPi and
560 DC motors work together to create a system that utilizes machine learning and computer
561 vision techniques to classify mangoes based on user priority.



562

Chapter 4

563

DESIGN CONSIDERATIONS



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

570 **4.1 Introduction**

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

575 **4.2 System Architecture**

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

582 In figure ?? presents the electronic circuit diagram, designed using Proteus. The
583 diagram illustrates a system where a Raspberry Pi 4 serves as the central control unit,

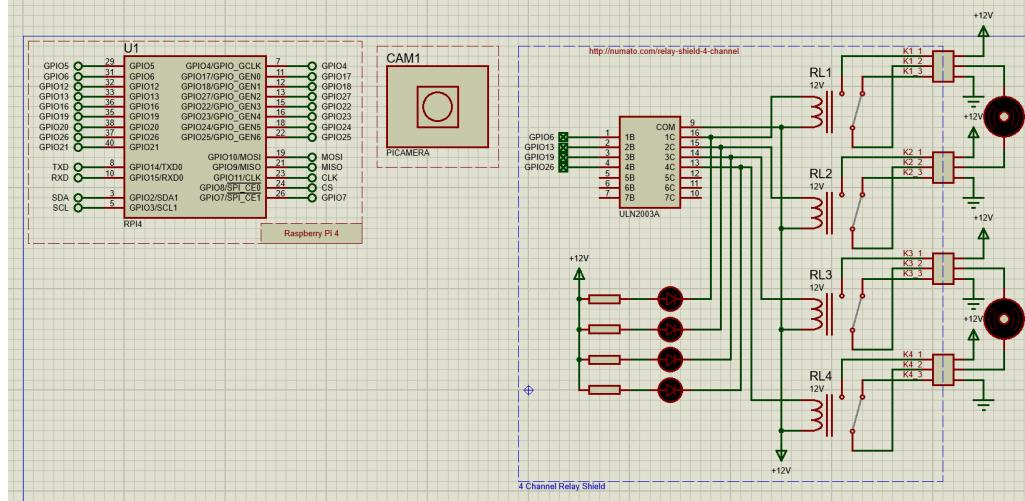


Fig. 4.1 Hardware Schematic

584 managing four motors through a relay mechanism. The Raspberry Pi 4, represented by
 585 a rectangular box on the left, showcases various pin connections, including GPIO pins,
 586 power supply pins (5V and 3V3), ground pins (GND), and communication pins (TXD,
 587 RXD, SDA, SCL).

588 In the center of the diagram, an 18-pin integrated circuit labeled "ULN2803A" is
 589 depicted. This component, a Darlington transistor array, likely functions as a buffer,
 590 providing the necessary current to drive the relays. Four relays, designated as RL1, RL2,
 591 RL3, and RL4, are positioned on the right side of the diagram, each connected to a motor
 592 (represented by a circle with an "M" inside) and a +12V power source. Additionally, four
 593 resistors are placed between the ULN2803A and the relays, serving to limit current. The
 594 circuit section containing these resistors is labeled "4 Channel Relay Driver," indicating its
 595 purpose.

596 The camera module is labeled "PICAMERA" is located in the top center of the diagram.
 597 It is represented by a square with a circle inside, symbolizing the camera lens. The camera



598 module is connected to the Raspberry Pi 4 through the CSI (Camera Serial Interface) pins.
 599 The overall circuit is designed for a 12V system, with the +12V power supply indicated at
 600 various points. The Raspberry Pi 4's GPIO pins are used to control the relays.

601 4.3 Hardware Considerations

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

606 4.3.1 General Prototype Framework

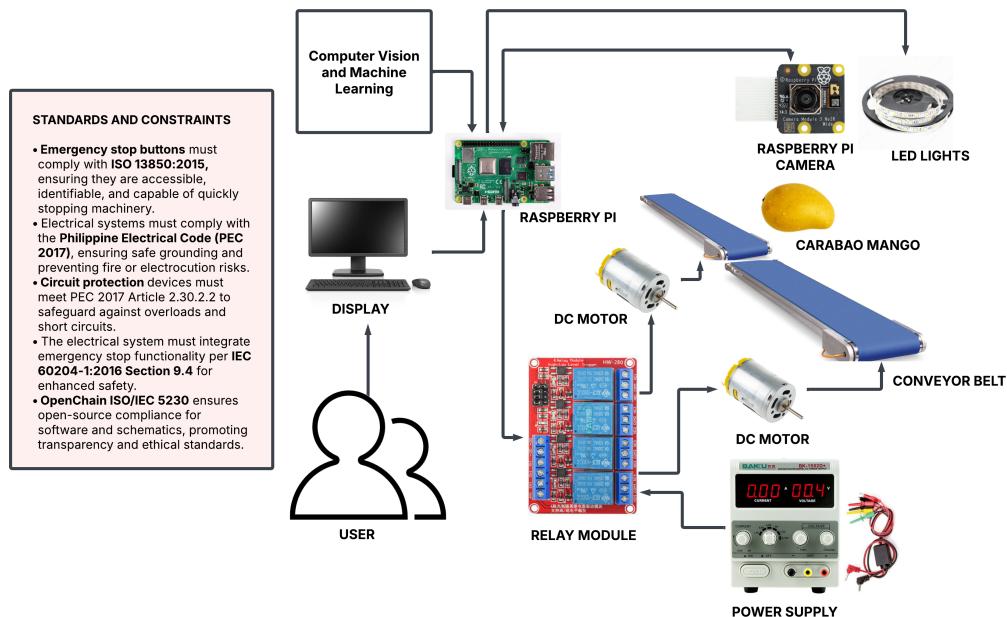


Fig. 4.2 Prototype Framework



607 The Figure 4.2 presents the overall prototype layout of the automated Carabao mango
608 sorter and grader. The diagram illustrates the flow of operations from mango loading onto
609 the conveyor belt to sorting them. It illustrates the major elements of the system, that is,
610 the image acquisition area, lighting system, camera module, Raspberry Pi controller, and
611 mechanical actuators. The layout illustrates how all the subsystems work together to ensure
612 mangoes are scanned, processed, sorted based on ripeness, size, and bruises, and eventually
613 sorted based on the calculated priority score. The layout served as the basis for actual
614 prototype development.

615 **4.3.2 Prototype Flowchart**

616 The flowchart in Figure 4.3 represents the overall operational logic of the mango grading
617 and sorting system. The process starts with system initialization, where the camera and
618 lighting modules are switched on and the machine learning algorithms are initialised. The
619 input of the user priority values as well as the detection of the mango on the conveyor
620 belt triggers the capture of both the top and bottom cheek of the mango. The captured
621 image is processed using machine learning algorithms to determine its ripeness, size, and
622 bruises. Depending on these classifications along with priority weights given by the user,
623 the system calculates an overall score. Once this calculation is done, the mango is routed to
624 the respective bin through the respective actuator. Having this logical sequence is important
625 to know the system's decision-making and automation process.

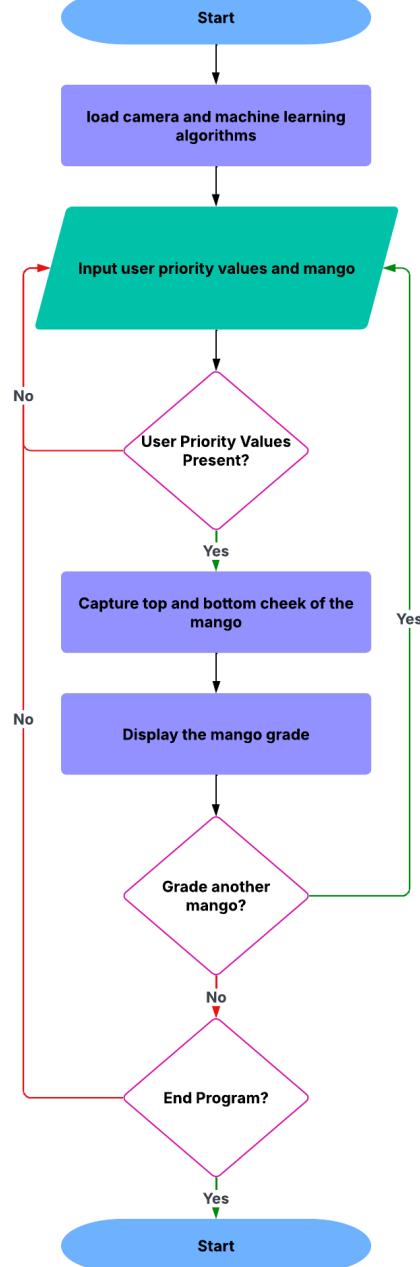


Fig. 4.3 Prototype Main Flowchart



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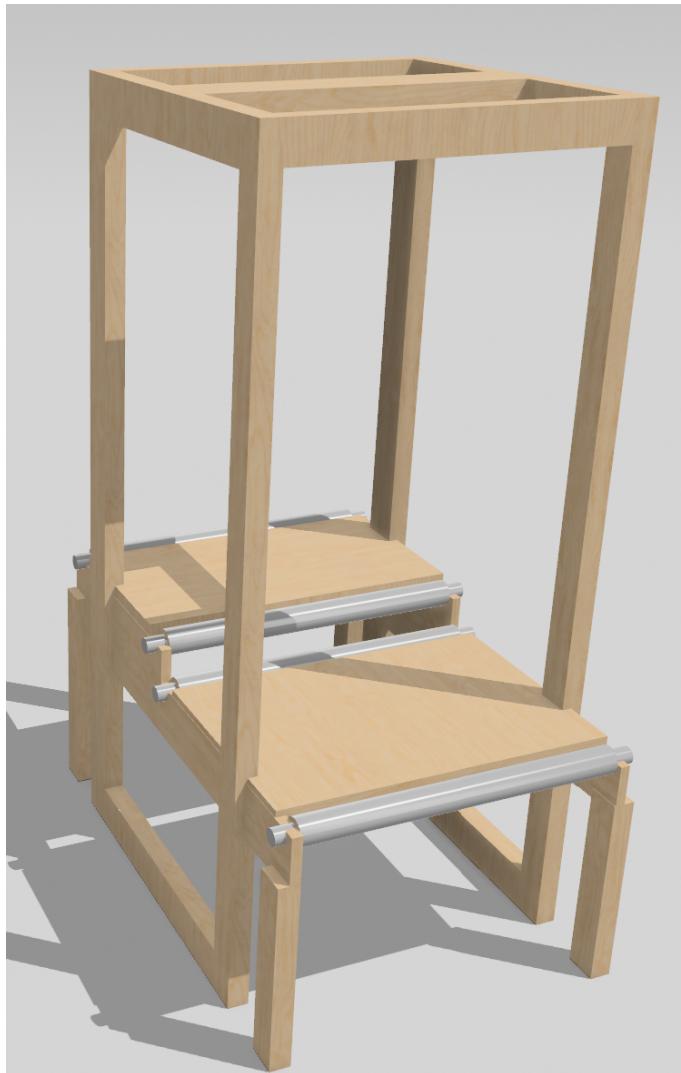


Fig. 4.4 Initial 3D Model of the Prototype



626 4.3.3 Prototype 3D Model

627 Figure 4.4 shows the first 3D model of the initial physical prototype developed for the
628 sorting and grading system. This model shows the skeleton of the system and where
629 the conveyor system is going to be placed strategically in order to flip the mango for
630 image acquisition. It is useful for where the hardware components would be arranged
631 and assembled. This 3D model helped the researchers visualize the spacing, alignment,
632 and where to mount parts before assembling the prototype making sure all electronic and
633 mechanical components are effectively integrated.

634 4.3.4 Hardware Specifications

635 4.3.4.1 Raspberry Pi



Fig. 4.5 Raspberry Pi 4 Model B

636 Figure 4.5 depicts the Raspberry Pi 4 Model B which is the core of the processing unit



637 of the prototype. It was selected due to its small size, low cost, and high computing power
638 for image processing and machine learning. The image depicts the most critical aspects
639 of the board, such as the GPIO (General Purpose Input/Output) pins for sensor, actuator,
640 and relay connections, and the USB and HDMI ports for other device connections. Its
641 capability to support a full operating system makes it suitable for supporting both the user
642 interface and the control logic of the mango grading system.

643 **Specifications:**

- 644 • SoC: Broadcom BCM2711
- 645 • CPU: Quad-core ARM Cortex-A72 (64-bit)
- 646 • Clock Speed: 1.5 GHz (base, overclockable)
- 647 • RAM: 8GB LPDDR4-3200 SDRAM
- 648 • Wireless: Dual-band 2.4 GHz / 5 GHz Wi-Fi (802.11ac)
- 649 • Bluetooth: Bluetooth 5.0 (BLE support)
- 650 • Ethernet: Gigabit Ethernet (full throughput)
- 651 • USB: 2 x USB 3.0 ports and 2 x USB 2.0 ports
- 652 • Video Output: 2 x micro-HDMI ports (supports 4K @ 60Hz, dual 4K display
653 capability)
- 654 • Audio: 3.5mm audio/video composite jack
- 655 • Storage: MicroSD card slot (supports booting via SD card or USB)



- 656 • GPIO: 40-pin GPIO header (backward-compatible with older models)
- 657 • Camera/Display: CSI (camera) and DSI (display) ports
- 658 • Power Input: USB-C (5V/3A recommended)
- 659 • Power Consumption: 3W idle, up to 7.5W under load

660 **4.3.4.2 Raspberry Pi Camera**

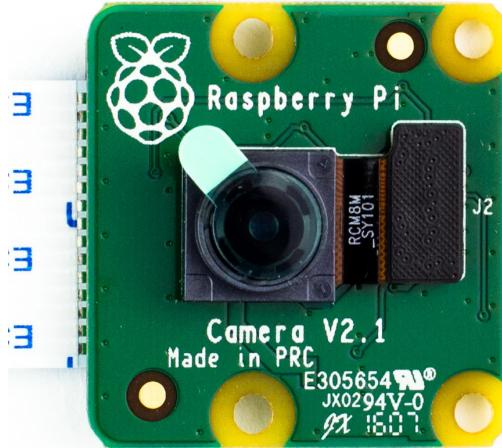


Fig. 4.6 Raspberry Pi Camera Module Version 2

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



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667 compact size, ease of integration, and ability to capture high-resolution images.

668

669 **Specifications:**

670 • Sensor: Sony IMX219PQ 8-megapixel CMOS sensor.

671 • Still Images Resolution: 8 MP (3280 x 2464 pixels).

672 • Video Resolution: Supports up to 1080p @ 30fps, 720p @ 60fps, and 480p @ 90fps.

673 • Focus: Fixed-focus lens (manual focus adjustment not supported without physical
674 modification).

675 • Lens Size: 1/4-inch optical format.

676 • Field of View (FoV): Diagonal 62.2 degrees.

677 • Interface: Connected via 15-pin ribbon cable to the Raspberry Pi's CSI (Camera
678 Serial Interface) port.

679 • APIs/Libraries: Supports Python libraries such as Picamera and OpenCV for image
680 capture and processing.

681 • Dimensions: 25 mm x 24 mm x 9 mm.

682 **4.3.4.3 DC Motor**

683 The 12 Volt DC Gear Motor is a compact, high-torque, and low-noise motor suitable for a
684 wide range of applications, including robotics, automation, and industrial control systems.

685 It features a spur gear design, which provides a high reduction ratio for increased torque
686 output. The motor is designed for continuous operation and has a low power consumption



Fig. 4.7 12 Volt DC Gear Motor

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.

691 **Specifications:**

- 692 • Gearbox Type: Spur gear design
- 693 • Operating Voltage: 12V (operational range: 6-12V)
- 694 • No-load Current Consumption: 0.8A
- 695 • Rated Current Draw: 3A (under standard load)
- 696 • No-load Speed: 282 RPM (maximum)
- 697 • Operating Speed: 248 RPM (under rated load)



- 698 • Torque Output: 18 kg-cm (rated)
- 699 • Stall Torque: 60 kg-cm (maximum)
- 700 • Power Rating: 50W (maximum)
- 701 • Unit Weight: 350 grams

702 **4.3.4.4 MicroSD Card**



Fig. 4.8 SanDisk Ultra MicroSD Card

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

708
709 **Specifications:**



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

714 **4.3.4.5 LED Lights**



Fig. 4.9 LED Light Strip

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

719

720 **Specifications:**



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

730 4.3.4.6 Power Supply

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

737 Specifications:

- 738 • Type: SMPS (Switch-Mode Power Supply)
- 739 • Input: 110V AC, 50/60Hz (U.S. Standard)



Fig. 4.10 Bench Power Supply

- 740 • Output Range: 0-30V DC / 0-5A DC
- 741 • Voltage Precision: $\pm 0.010\text{V}$ (10 mV) resolution
- 742 • Current Precision: $\pm 0.001\text{A}$ (1 mA) resolution
- 743 • Power Precision: $\pm 0.1\text{W}$ resolution
- 744 • Weight: 5 lbs (2.27 kg)
- 745 • Dimensions: 11.1" x 4.92" x 6.14" (28.2 cm x 12.5 cm x 15.6 cm)
- 746 • Maximum Power: 195W
- 747 • Power Source: AC input only



Fig. 4.11 4 Channel Relay Module

748 **4.3.4.7 4 Channel Relay Module**

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

754

755 **Specifications:**

- 756 • Operating Voltage: 5V DC (compatible with Arduino, Raspberry Pi, and other
757 microcontrollers).
- 758 • Number of Relays: 4 independent channels.
- 759 • Relay Type: Electromechanical (mechanical switching).



- 760 • Max AC Load: 10A @ 250V AC (resistive).
- 761 • Max DC Load: 10A @ 30V DC (resistive).
- 762 • Contact Type: SPDT (Single Pole Double Throw) - NO (Normally Open), NC
763 (Normally Closed), COM (Common).
- 764 • Dimensions: 50mm x 70mm x 20mm
- 765 • Weight: 50-80 grams.
- 766 • Status LEDs: Individual LEDs for each relay (indicates ON/OFF state).
- 767 • Input Pins: 4 digital control pins (one per relay).
- 768 • Output Terminals: Screw terminals for connecting loads (NO/NC/COM).

769 **4.4 Software Considerations**

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

773 **4.4.1 PyTorch**

774 PyTorch is an open-source deep-learning framework used in this project for implementing
775 and running the convolutional neural networks responsible for classifying mango ripeness
776 and detecting bruises. Its dynamic computational graph and GPU acceleration support
777 made it an ideal choice for real-time image classification. Its simplicity and flexibility also



778 allowed for easy integration with the Raspberry Pi which is important as it is the main
779 processing unit for the system.

780 **4.4.2 OpenCV**

781 Open Source Computer Vision Library or OpenCV is utilized in the system for all image
782 processing tasks, particularly in preprocessing steps such as background subtraction, thresh-
783 olding, edge detection, and contour analysis. These operations are essential for calculating
784 the real-world dimensions of the mango. OpenCV was utilized primarily because of its
785 diverse set of functions, performance optimization, and ease of use making it a core tool
786 for enabling accurate and fast computer vision processing within the prototype.

787 **4.4.3 CustomTkinter**

788 CustomTkinter is a modern alternative to the standard Tkinter library, and is used to
789 build the graphical user interface (GUI) of the system. It provides a more polished and
790 customizable visual appearance while retaining the simplicity of Tkinter. With features
791 such as styled buttons, frames, and labels, CustomTkinter allowed for the creation of
792 a user-friendly interface that supports real-time display of classification results, priority
793 scoring inputs, and system status updates.

794 **4.5 Security and Reliability Considerations**

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



798 **4.6 Scalability and Efficiency Considerations**

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

802 **4.7 User Interface**

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

806 **4.8 Constraints and Limitations**

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

810 **4.9 Technical Standards**

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



813 **4.10 Prototyping and Simulation**

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

817 **4.11 Design Validation**

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

821 **4.12 Summary**

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



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825

Chapter 5

826

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.	<ol style="list-style-type: none"> 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. ?? on p. ??
SO1: To make an image acquisition system with a conveyor belt for automatic sorting and grading mangoes.	<ol style="list-style-type: none"> 1. Hardware implementation: Design and build an image acquisition system prototype 	Sec. ?? on p. ??
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%.	<ol style="list-style-type: none"> 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. ?? on p. ??

Continued on next page



Continued from previous page

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. ?? on p. ??
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. ?? on p. ??
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. ?? on p. ??
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. ?? on p. ??
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. ?? on p. ??



827 5.1 Introduction

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

835 5.2 Research Approach

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

842 5.3 Hardware Design

843 The prototype consists of hardware and software components for automated mango sorting
844 and grading purposes. The hardware includes the conveyor belt system used to transfer
845 mangoes from scanning to sorting smoothly. A camera and lighting system are able
846 to collect high-resolution images for analysis. The DC motors and stepper motors are



847 responsible for driving the conveyor belt and sorting actuators. The entire system is
848 controlled by a microcontroller (Raspberry Pi 4b), coordinating actions of all components.
849 Sorting actuators then direct mangoes into selected bins based on their classification to
850 make sorting efficient.

851 **5.4 Software Design**

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

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



866 **5.5 Data Collection Methods**

867 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.

877 **5.6 Testing and Evaluation Methods**

878 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

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



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

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

901 **5.6.1 Ripeness Training and Testing**

902 **5.6.2 Bruises Training and Testing**

903 **5.6.3 Size Determination**

904 **5.7 Formula for User Priority**

905 **5.8 Ethical Considerations**

906 Ethical considerations ensure that the system is operated safely and responsibly. Data
907 privacy is ensured by securely storing and anonymizing extracted images and classification



908 data so that unauthorized access becomes impossible. The system is also eco-friendly
909 through non-destructive testing, saving mangoes while also ensuring that they are of good
910 quality. Safety in operations is also ensured by protecting moving parts to prevent mechan-
911 ical harm and incorporating fail-safes to securely stop operation in case of malfunction.
912 Addressing these concerns, the system is not only accurate and efficient but also secure,
913 eco-friendly, and safe for operators, thus a sustainable solution to automated mango sorting
914 and grading.

915 **5.9 Summary**

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



924

Chapter 6

925

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.	<p>Expected Results:</p> <ul style="list-style-type: none"> 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. <p>Actual Results:</p> <ul style="list-style-type: none"> 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. ?? on p. ??
SO1: To make an image acquisition system with a conveyor belt for automatic sorting and grading mangoes.	<p>Expected Results:</p> <ul style="list-style-type: none"> 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 <p>Actual Results:</p> <ul style="list-style-type: none"> 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. ?? on p. ??

Continued on next page

6. Results and Discussions



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Objectives	Methods	Locations
<p>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%.</p>	<p>Expected Results:</p> <ul style="list-style-type: none"> 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 <p>Actual Results:</p> <ul style="list-style-type: none"> 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 	<p>Sec. ?? on p. ??</p>
<p>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.</p>	<p>Expected Results:</p> <ul style="list-style-type: none"> 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 prototype 3. Successfully made the frame for the conveyor belt and image acquisition system to sit on <p>Actual Results:</p> <ul style="list-style-type: none"> 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 prototype 3. Successfully made the frame for the conveyor belt and image acquisition system to sit on 	<p>Sec. ?? on p. ??</p>

Continued on next page

6. Results and Discussions



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Objectives	Methods	Locations
SO4: To grade mangoes based on user priorities for size, ripeness, and bruises.	<p>Expected Results:</p> <ul style="list-style-type: none"> 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 <p>Actual Results:</p> <ul style="list-style-type: none"> 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. ?? on p. ???

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6. Results and Discussions



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Continued from previous page

Objectives	Methods	Locations
<p>SO5: To classify mango ripeness based on image data using machine learning algorithms such as kNN, k-mean, and Naïve Bayes.</p>	<p>Expected Results:</p> <ul style="list-style-type: none"> 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 <p>Actual Results:</p> <ul style="list-style-type: none"> 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. ?? on p. ??
<p>SO6: To classify mango size based on image data by getting its length and width using OpenCV, geometry, and image processing techniques.</p>	<p>Expected Results:</p> <ul style="list-style-type: none"> 1. Successfully classified mango size using computer vision techniques 2. Successfully tuned to have an accurate size with an 80 percent accuracy rating <p>Actual Results:</p> <ul style="list-style-type: none"> 1. Successfully classified mango size using computer vision techniques 2. Calculation of mango size is somewhat inaccurate and needs more fine tuning 	Sec. ?? on p. ??

Continued on next page



Continued from previous page

Objectives	Methods	Locations
SO7: To classify mango bruises based on image data by employing machine learning algorithms.	<p>Expected Results:</p> <ul style="list-style-type: none"> 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 <p>Actual Results:</p> <ul style="list-style-type: none"> 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. ?? on p. ??

926

6.1 Training and Testing Results of the Model

927

6.1.1 Ripeness Classification Results

928

Add the F1-Score and etc here

EfficientNet Version	Precision	Recall	F1	Test Accuracy
b0	0.9841	0.9838	0.9838	0.98
b1	0.9876	0.9876	0.9876	0.99
b2	0.9802	0.9801	0.9801	0.98
b3	0.9709	0.968	0.9684	0.97
b4	0.9716	0.9699	0.9699	0.97
b5	0.93	0.93	0.93	0.93

TABLE 6.2 PERFORMANCE METRICS FOR DIFFERENT EFFICIENTNET VERSIONS



	Precision	Recall	F1	Support
Green	0.95	0.94	0.95	135
Green Yellow	0.77	0.78	0.77	81
Yellow	0.70	0.71	0.71	80
Accuracy			0.83	296
Macro Avg	0.81	0.81	0.81	296
Weighted Avg	0.84	0.83	0.84	296

TABLE 6.3 RIPENESS CLASSIFICATION REPORT USING KNN

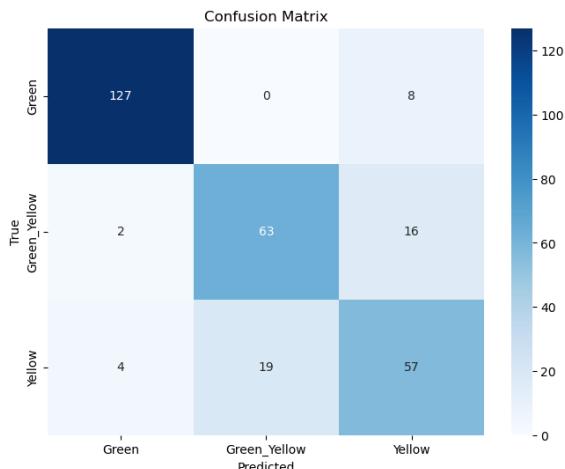


Fig. 6.1 Ripeness Confusion Matrix using kNN

	Precision	Recall	F1	Support
Green	0.96	0.76	0.85	135
Yellow Green	0.75	0.30	0.42	81
Yellow	0.45	0.88	0.59	80
Accuracy			0.67	296
Macro Avg	0.72	0.64	0.62	296
Weighted Avg	0.76	0.67	0.66	296

TABLE 6.4 RIPENESS CLASSIFICATION REPORT USING NAIVE BAYES

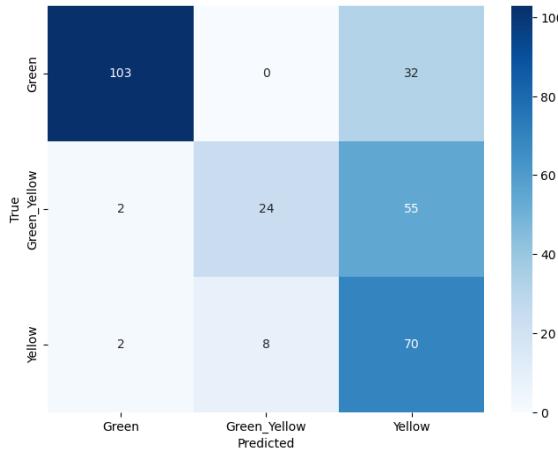


Fig. 6.2 Ripeness Confusion Matrix using Naive Bayes

929

6.1.2 Bruises Classification Results

	Precision	Recall	F1	Support
Bruised	0.97	0.90	0.93	1515
Not Bruised	0.88	0.97	0.92	1146
Accuracy			0.93	2661
Macro Avg	0.93	0.93	0.93	2661
Weighted Avg	0.93	0.93	0.93	2661

TABLE 6.5 BRUISES CLASSIFICATION REPORT USING CNN

Metrics	Results
Precision	0.9318
Recall	0.9275
F1 Score	0.9278

TABLE 6.6 SUMMARIZED CLASSIFICATION REPORT USING CNN

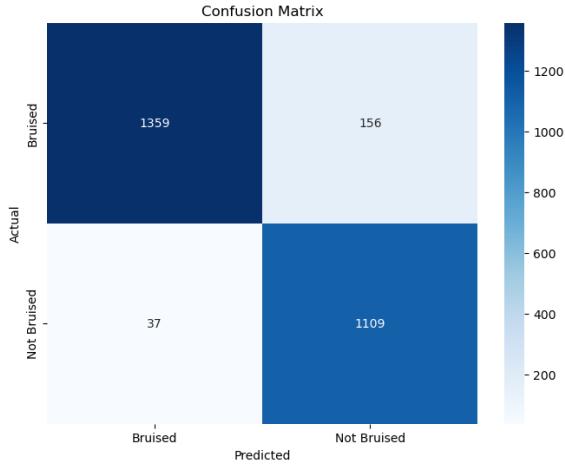


Fig. 6.3 Bruises Confusion Matrix using CNN

930 6.2 Size Determination Results

931 6.3 User Priority Formula

932 $B(P)$ and $R(P)$ and $S(P)$ are the User Priority-Based Grading for bruises, ripeness,
 933 and size of the Carabao mango. Furthermore, $b(p)$ and $r(p)$ and $s(p)$ are the machine
 934 learning's predictions for bruises, ripeness, and size of the Carabao mango. The formula
 935 for the user priority is given by:

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

936 6.4 Physical Prototype

937 Add pictures of the hardware prototype here with description



Fig. 6.4 Prototype Top View



Fig. 6.5 Entrance Conveyor Belt View

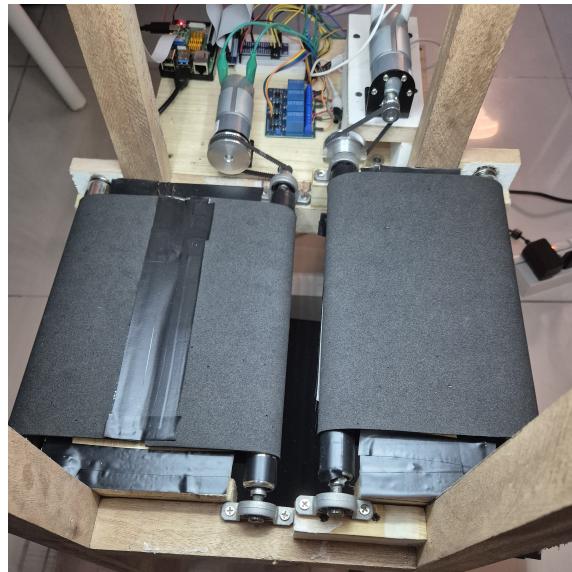


Fig. 6.6 Side Conveyor Belt View



Fig. 6.7 Prototype Main Hardware

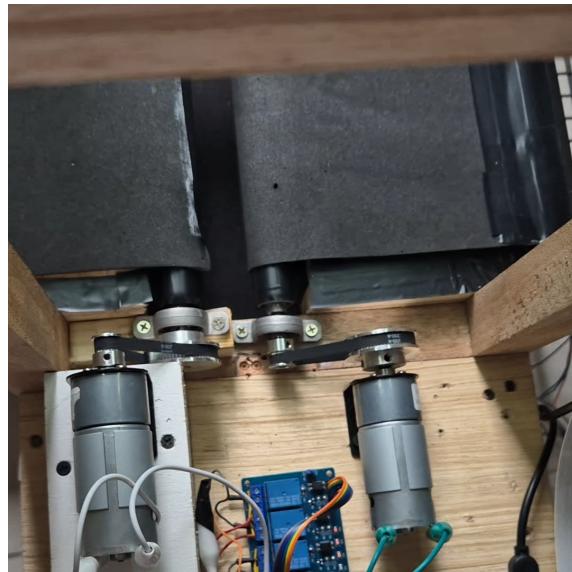


Fig. 6.8 DC Motor and Pulley

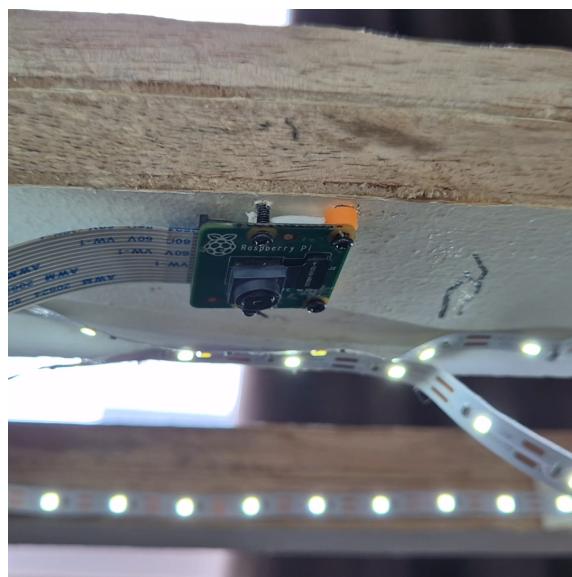


Fig. 6.9 LED Lights and Camera Module



938 6.5 Software Application

939 Show the raspberry pi app UI and demonstrate it here

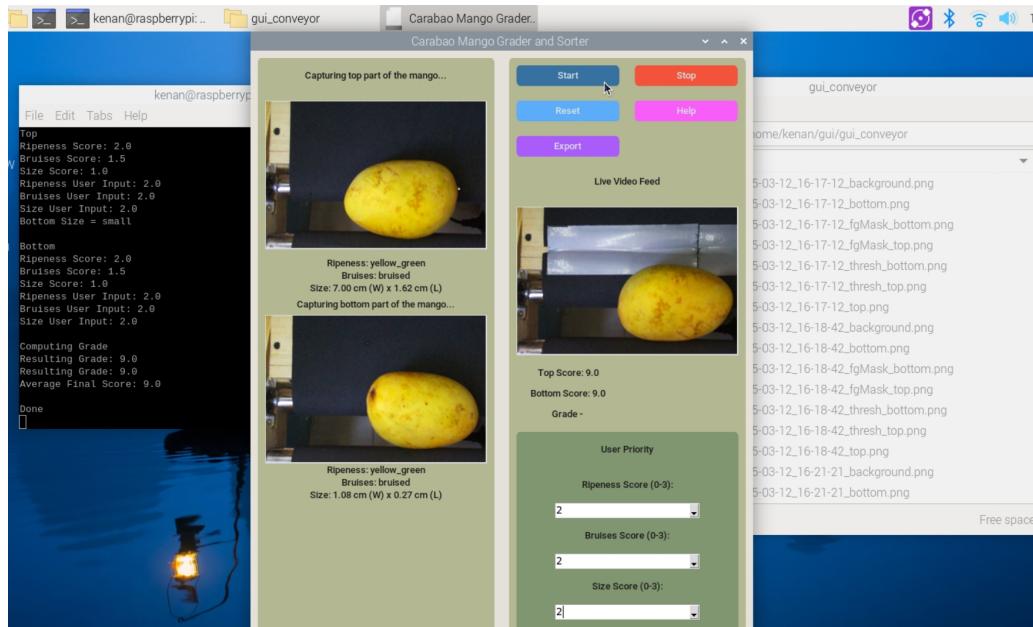


Fig. 6.10 Raspberry Pi App UI Version 1

940 6.6 Summary

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

6. Results and Discussions

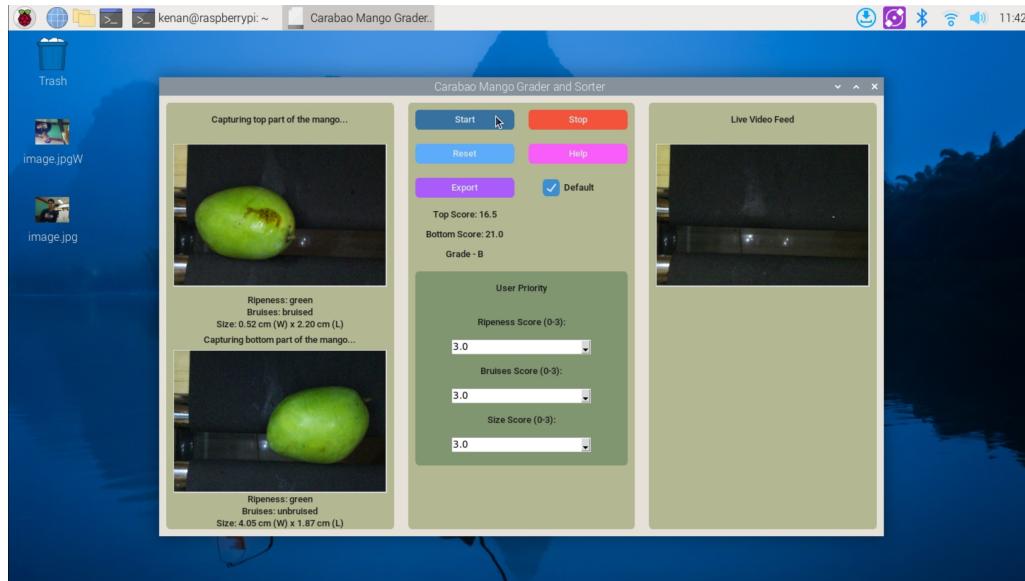


Fig. 6.11 Raspberry Pi App UI Version 2

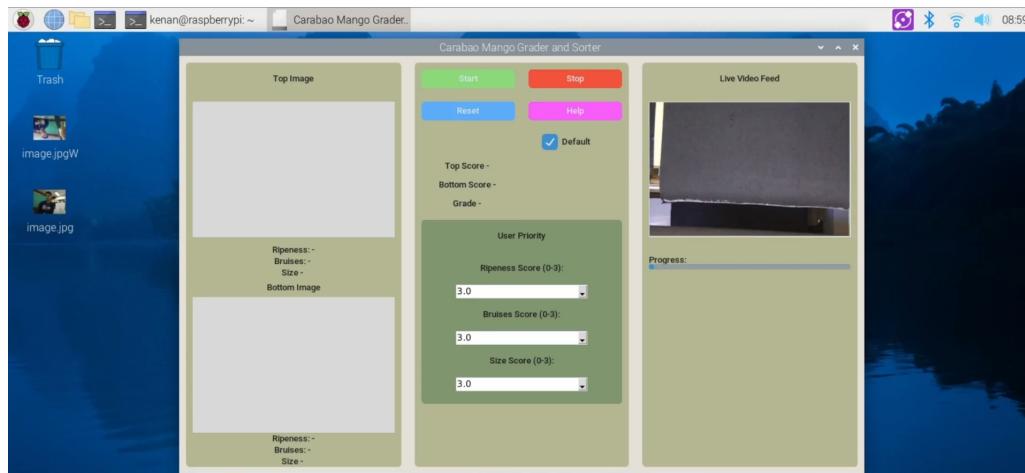


Fig. 6.12 Raspberry Pi App UI Version 3



942

Chapter 7

943

CONCLUSIONS, RECOMMENDATIONS, AND FUTURE DIRECTIVES

944



945 **7.1 Concluding Remarks**

946 In this Thesis, ...

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

950 **7.2 Contributions**

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

- 954 • the ;
- 955 • the ;
- 956 • the ;

957 **7.3 Recommendations**

958 The researchers recommend...

959 **7.4 Future Prospects**

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



962 1. the

963 2. the

964 3. the

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



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Produced: April 1, 2025, 21:24



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Appendix A STUDENT RESEARCH ETHICS CLEARANCE

1022

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.



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Appendix B ANSWERS TO QUESTIONS TO THIS THESIS

1025



1026	<h2>B1 How important is the problem to practice?</h2>
1027	A possible answer to this question is the summary of your Significance of the Study, and
1028	that portion of the Problem Statement where you describe the ideal scenario for your
1029	intended audience.
1030	
1031	
1032	
1033	
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1038	
1039	<h2>B2 How will you know if the solution/s that you will achieve would be better than existing ones?</h2>
1040	
1041	
1042	
1043	
1044	
1045	
1046	
1047	
1048	
1049	
1050	<h3>B2.1 How will you measure the improvement/s?</h3>
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1052	
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1057	



1058 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit
 1059 amet ipsum. Nunc quis urna dictum turpis accumsan semper.

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

1061 Lorem ipsum dolor sit amet, consectetur adipiscing elit. Etiam lobortis facilisis sem.
 1062 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec
 1063 ullamcorper, felis non sodales commodo, lectus velit ultrices augue, a dignissim nibh lectus
 1064 placerat pede. Vivamus nunc nunc, molestie ut, ultricies vel, semper in, velit. Ut porttitor.
 1065 Praesent in sapien. Lorem ipsum dolor sit amet, consectetur adipiscing elit. Duis fringilla
 1066 tristique neque. Sed interdum libero ut metus. Pellentesque placerat. Nam rutrum augue
 1067 a leo. Morbi sed elit sit amet ante lobortis sollicitudin. Praesent blandit blandit mauris.
 1068 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit
 1069 amet ipsum. Nunc quis urna dictum turpis accumsan semper.

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

1071 Lorem ipsum dolor sit amet, consectetur adipiscing elit. Etiam lobortis facilisis sem.
 1072 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec
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 1078 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit
 1079 amet ipsum. Nunc quis urna dictum turpis accumsan semper.

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

1081 Lorem ipsum dolor sit amet, consectetur adipiscing elit. Etiam lobortis facilisis sem.
 1082 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec
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 1085 Praesent in sapien. Lorem ipsum dolor sit amet, consectetur adipiscing elit. Duis fringilla
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 1088 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit
 1089 amet ipsum. Nunc quis urna dictum turpis accumsan semper.



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

1090 Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Etiam lobortis facilisis sem.
 1091 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec
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 1094 Praesent in sapien. Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Duis fringilla
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 1097 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit
 1098 amet ipsum. Nunc quis urna dictum turpis accumsan semper.
 1099
 1100

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

1101 Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Etiam lobortis facilisis sem.
 1102 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec
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 1107 a leo. Morbi sed elit sit amet ante lobortis sollicitudin. Praesent blandit blandit mauris.
 1108 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit
 1109 amet ipsum. Nunc quis urna dictum turpis accumsan semper.
 1110

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

1111 Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Etiam lobortis facilisis sem.
 1112 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec
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 1117 a leo. Morbi sed elit sit amet ante lobortis sollicitudin. Praesent blandit blandit mauris.
 1118 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit
 1119 amet ipsum. Nunc quis urna dictum turpis accumsan semper.
 1120
 1121



1122 **B4.1 Will your proposed solution/s be sensitive to these as-**
 1123 **sump tions?**

1124 Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Etiam lobortis facilisis sem.
 1125 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec
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 1129 tristique neque. Sed interdum libero ut metus. Pellentesque placerat. Nam rutrum augue
 1130 a leo. Morbi sed elit sit amet ante lobortis sollicitudin. Praesent blandit blandit mauris.
 1131 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit
 1132 amet ipsum. Nunc quis urna dictum turpis accumsan semper.

1133 **B4.2 Can your proposed solution/s be applied to more general**
 1134 **cases when some assumptions are eliminated? If so, how?**

1135 Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Etiam lobortis facilisis sem.
 1136 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec
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 1142 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit
 1143 amet ipsum. Nunc quis urna dictum turpis accumsan semper.

1144 **B5 What is the necessity of your approach / pro-**
 1145 **posed solution/s?**

1146 Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Etiam lobortis facilisis sem.
 1147 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec
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 1152 a leo. Morbi sed elit sit amet ante lobortis sollicitudin. Praesent blandit blandit mauris.
 1153 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit
 1154 amet ipsum. Nunc quis urna dictum turpis accumsan semper.



1155 **B5.1 What will be the limits of applicability of your proposed so-**
 1156 **lution/s?**

1157 Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Etiam lobortis facilisis sem.
 1158 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec
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 1164 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit
 1165 amet ipsum. Nunc quis urna dictum turpis accumsan semper.

1166 **B5.2 What will be the message of the proposed solution to**
 1167 **technical people? How about to non-technical managers and**
 1168 **business people?**

1169 Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Etiam lobortis facilisis sem.
 1170 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec
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 1176 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit
 1177 amet ipsum. Nunc quis urna dictum turpis accumsan semper.

1178 **B6 How will you know if your proposed solution/s**
 1179 **is/are correct?**

1180 Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Etiam lobortis facilisis sem.
 1181 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec
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1187 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit
 1188 amet ipsum. Nunc quis urna dictum turpis accumsan semper.

1189 **B6.1 Will your results warrant the level of mathematics used
 1190 (i.e., will the end justify the means)?**

1191 Lorem ipsum dolor sit amet, consectetur adipiscing elit. Etiam lobortis facilisis sem.
 1192 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdier mi nec ante. Donec
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 1198 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit
 1199 amet ipsum. Nunc quis urna dictum turpis accumsan semper.

1200 **B7 Is/are there an/_ alternative way/s to get to the
 1201 same solution/s?**

1202 Lorem ipsum dolor sit amet, consectetur adipiscing elit. Etiam lobortis facilisis sem.
 1203 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdier mi nec ante. Donec
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 1207 tristique neque. Sed interdum libero ut metus. Pellentesque placerat. Nam rutrum augue
 1208 a leo. Morbi sed elit sit amet ante lobortis sollicitudin. Praesent blandit blandit mauris.
 1209 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit
 1210 amet ipsum. Nunc quis urna dictum turpis accumsan semper.

1211 **B7.1 Can you come up with illustrating examples, or even
 1212 better, counterexamples to your proposed solution/s?**

1213 Lorem ipsum dolor sit amet, consectetur adipiscing elit. Etiam lobortis facilisis sem.
 1214 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdier mi nec ante. Donec
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 1220 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit
 1221 amet ipsum. Nunc quis urna dictum turpis accumsan semper.

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

1224 Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Etiam lobortis facilisis sem.
 1225 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec
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 1231 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit
 1232 amet ipsum. Nunc quis urna dictum turpis accumsan semper.

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.

1233 Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Etiam lobortis facilisis sem.
 1234 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec
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 1239 a leo. Morbi sed elit sit amet ante lobortis sollicitudin. Praesent blandit blandit mauris.
 1240 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit
 1241 amet ipsum. Nunc quis urna dictum turpis accumsan semper.

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

1246 Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Etiam lobortis facilisis sem.
 1247 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec



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1252 Praesent in sapien. Lorem ipsum dolor sit amet, consectetur adipiscing elit. Duis fringilla
1253 tristique neque. Sed interdum libero ut metus. Pellentesque placerat. Nam rutrum augue
1254 a leo. Morbi sed elit sit amet ante lobortis sollicitudin. Praesent blandit blandit mauris.
1255 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit
1256 amet ipsum. Nunc quis urna dictum turpis accumsan semper.



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Appendix C REVISIONS TO THE PROPOSAL

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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-iBno8A6fBRgOCacMrhmzLPCNO0IDxXBHiK_xzdicEb.MzbHGzrD7rL3tVgJ?startTIme=1731326444000

Passcode: +7qL6DZE

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 getting 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

C. Revisions to the Proposal



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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 previousl y



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PRO1 Panel Comments and Revisions – Appendix Z

PRO1 Panel Comments and Revisions

Zoom Recording:

https://zoom.us/rec/share/mrn9zBtPz3bJ5laVcy2E8-iBno8A6fBRgOCacMrhmzLPCNO0IDxXBHiK_xzdicEb.MzbHGzrD7rL3tVgJ?startTim=e=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.

C. Revisions to the Proposal



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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.



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Appendix D REVISIONS TO THE FINAL

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- 1266 Make a table with the following columns for showing the summary of revisions to the
1267 proposal based on the comments of the panel of examiners.
- 1268 1. Examiner
- 1269 2. Comment
- 1270 3. Summary of how the comment has been addressed
- 1271 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	<p>1. First itemtext</p> <p>2. Second itemtext</p> <p>3. Last itemtext</p> <p>4. First itemtext</p> <p>5. Second itemtext</p> <p>First itemtext</p> <p>Second itemtext</p> <p>Last itemtext</p> <p>First itemtext</p> <p>Second itemtext</p>	<p>1. First itemtext</p> <p>2. Second itemtext</p> <p>3. Last itemtext</p> <p>4. First itemtext</p> <p>5. Second itemtext</p>	<p>Sec. ?? on p. ??, Sec. ?? on p. ??, Fig. ?? on p. ??</p>

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D. Revisions to the Final



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Examiner	Comment	Summary of how the comment has been addressed	Locations
Dr. Donable de Veas Abuan	<p>1. First itemtext</p> <p>2. Second itemtext</p> <p>3. Last itemtext</p> <p>4. First itemtext</p> <p>5. Second itemtext</p>	<p>1. First itemtext</p> <p>2. Second itemtext</p> <p>3. Last itemtext</p> <p>4. First itemtext</p> <p>5. Second itemtext</p> <p>First itemtext</p> <p>Second itemtext</p> <p>Last itemtext</p> <p>First itemtext</p> <p>Second itemtext</p>	Sec. ?? on p. ??, Sec. ?? on p. ??, Fig. ?? on p. ???
Engr. Jose Martin Maningo	<p>1. First itemtext</p> <p>2. Second itemtext</p> <p>3. Last itemtext</p> <p>4. First itemtext</p> <p>5. Second itemtext</p>	<p>1. First itemtext</p> <p>2. Second itemtext</p> <p>3. Last itemtext</p> <p>4. First itemtext</p> <p>5. Second itemtext</p> <ul style="list-style-type: none"> • First itemtext • Second itemtext • Last itemtext • First itemtext • Second itemtext 	Sec. ?? on p. ??, Sec. ?? on p. ??, Fig. ?? on p. ???

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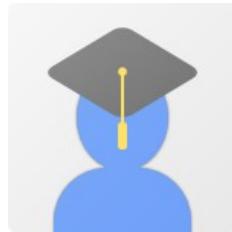
Examiner	Comment	Summary of how the comment has been addressed	Locations
Dr. Alexander Co Abad	1. First itemtext 2. Second itemtext 3. Last itemtext 4. First itemtext 5. Second itemtext	1. First itemtext 2. Second itemtext 3. Last itemtext 4. First itemtext 5. Second itemtext	Sec. ?? on p. ??, Sec. ??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



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Appendix E VITA

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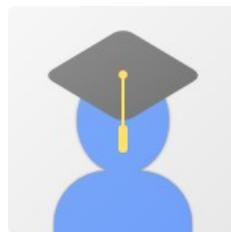


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Kenan A. Banal is currently taking up his B.Sc. Computer Engineering studies. He is passionate about software and hardware systems such as Vivado, Arduino, C, and Python.

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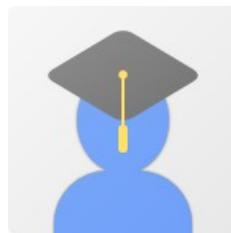


Francis Robert Miguel F. BAUTISTA is currently taking up his B.Sc. Computer Engineering studies. He is passionate about software and hardware systems such as Vivado, Arduino, C, and Python.

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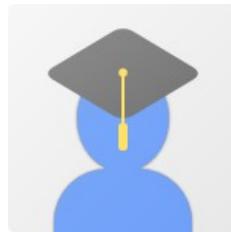


Don Humphrey L. HERMOSURA is currently taking up his B.Sc. Computer Engineering studies. He is passionate about software and hardware systems such as Vivado, Arduino, C, and Python.

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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.

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Appendix F ARTICLE PAPER(S)

1287

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, consectetur 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, consectetur 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, L^AT_EX, paper, template.

I. INTRODUCTION

THIS demo file is intended to serve as a “starter file” for IEEE article papers produced under L^AT_EX using IEEEtran.cls version 1.8b and later. Lorem ipsum dolor sit amet, consectetur 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, consectetur 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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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.



Fig. 1. Simulation results for the network.

TABLE I
AN EXAMPLE OF A TABLE

One	Two
Three	Four

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II. CONCLUSION

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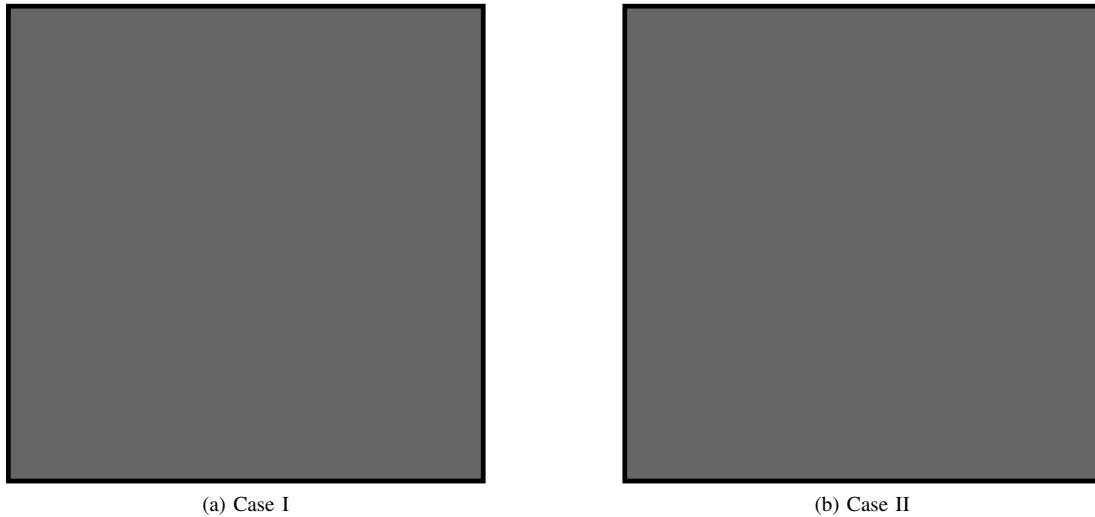


Fig. 2. Simulation results for the network.

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APPENDIX A PROOF OF THE FIRST ZONKLAR EQUATION

Appendix one text goes here.

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APPENDIX B

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ACKNOWLEDGMENT

The authors would like to thank...