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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
9 De La Salle University

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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20 August, 2025



De La Salle University

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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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ABSTRACT

39

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

53

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



TABLE OF CONTENTS

56	Oral Defense Recommendation Sheet	ii
57	Abstract	iii
58	Table of Contents	iv
59	List of Figures	v
60	List of Tables	vi
61	Abbreviations and Acronyms	vii
62	Notations	viii
63	Glossary	ix
64	Listings	x
65	Chapter 1 INTRODUCTION	1
66	1.1 Background of the Study	2
67	1.2 Prior Studies	4
68	1.3 Problem Statement	5
69	1.4 Objectives and Deliverables	6
70	1.4.1 General Objective (GO)	6
71	1.4.2 Specific Objectives (SOs)	6
72	1.4.3 Expected Deliverables	7
73	1.5 Significance of the Study	9
74	1.5.1 Technical Benefit	10
75	1.5.2 Social Impact	10
76	1.5.3 Environmental Welfare	11
77	1.6 Assumptions, Scope, and Delimitations	11
78	1.6.1 Assumptions	11
79	1.6.2 Scope	12
80	1.6.3 Delimitations	12
81	1.7 Estimated Work Schedule and Budget	13
82	1.8 Overview of the Thesis	14



83	Chapter 2 LITERATURE REVIEW	15
84	2.1 Existing Work	16
85	2.1.1 Sorting Algorithms	19
86	2.2 Lacking in the Approaches	20
87	2.3 Summary	21
88	Chapter 3 THEORETICAL CONSIDERATIONS	23
89	3.1 Introduction	24
90	3.2 Relevant Theories and Models	24
91	3.3 Technical Background	25
92	3.4 Conceptual Framework Background	25
93	3.5 Software Concepts	26
94	3.5.1 Thresholding	26
95	3.5.2 Object Size Calculation	27
96	3.5.3 Convolutional Neural Network	28
97	3.6 Hardware Concepts	28
98	3.6.1 Camera Module	28
99	3.6.2 4 Channel Relay	29
100	3.6.3 Gear Ratio	30
101	3.7 Summary	30
102	Chapter 4 DESIGN CONSIDERATIONS	31
103	4.1 Introduction	32
104	4.2 System Architecture	32
105	4.3 Hardware Considerations	34
106	4.3.1 General Prototype Framework	34
107	4.3.2 Prototype Flowchart	35
108	4.3.3 Prototype 3D Model	38
109	4.3.4 Hardware Specifications	38
110	4.3.4.1 Raspberry Pi	38
111	4.3.4.2 Raspberry Pi Camera	40
112	4.3.4.3 DC Motor	41
113	4.3.4.4 MicroSD Card	43
114	4.3.4.5 LED Lights	44
115	4.3.4.6 Power Supply	45
116	4.3.4.7 4 Channel Relay Module	47
117	4.4 Software Considerations	48
118	4.4.1 PyTorch	48
119	4.4.2 OpenCV	49
120	4.4.3 CustomTkinter	49



121	4.5 Security and Reliability Considerations	49
122	4.6 Scalability and Efficiency Considerations	50
123	4.7 User Interface	50
124	4.8 Constraints and Limitations	50
125	4.9 Technical Standards	50
126	4.10 Prototyping and Simulation	51
127	4.11 Design Validation	51
128	4.12 Summary	51
129	Chapter 5 METHODOLOGY	52
130	5.1 Introduction	55
131	5.2 Research Approach	55
132	5.3 Hardware Design	55
133	5.4 Software Design	56
134	5.5 Data Collection Methods	57
135	5.6 Testing and Evaluation Methods	57
136	5.6.1 Classification Report	58
137	5.6.1.1 Confusion Matrix	58
138	5.6.1.2 Precision	59
139	5.6.1.3 Recall	59
140	5.6.1.4 F1 Score	59
141	5.6.1.5 Accuracy	59
142	5.6.2 Ripeness Training and Testing	60
143	5.6.3 Bruises Training and Testing	61
144	5.6.4 Size Determination	62
145	5.7 Formula for User Priority	62
146	5.8 Ethical Considerations	62
147	5.9 Summary	62
148	Chapter 6 RESULTS AND DISCUSSIONS	64
149	6.1 Training and Testing Results of the Model	69
150	6.1.1 Ripeness Classification Results	69
151	6.1.2 Bruises Classification Results	72
152	6.2 Size Determination Results	72
153	6.3 User Priority Formula	72
154	6.4 Physical Prototype	72
155	6.5 Software Application	72
156	6.6 Summary	77



157	Chapter 7 CONCLUSIONS, RECOMMENDATIONS, AND FUTURE DIRECTIVES	78
159	7.1 Concluding Remarks	79
160	7.2 Contributions	79
161	7.3 Recommendations	79
162	7.4 Future Prospects	80
163	References	81
164	Appendix A STUDENT RESEARCH ETHICS CLEARANCE	83
165	Appendix B ANSWERS TO QUESTIONS TO THIS THESIS	85
166	Appendix C REVISIONS TO THE PROPOSAL	94
167	Appendix D REVISIONS TO THE FINAL	100
168	Appendix E ARTICLE PAPER(S)	104



LIST OF FIGURES

169	1.1	Carabao Mangoes at Different Ripeness Stages (Guillermo et al., 2019)	2
	1.2	Gantt Chart	13
170	3.1	Theoretical Framework Diagram.	24
171	3.2	Conceptual Framework Diagram.	25
172	4.1	Hardware Schematic	33
173	4.2	Prototype Framework	34
174	4.3	Prototype Main Flowchart	36
175	4.4	Initial 3D Model of the Prototype	37
176	4.5	Raspberry Pi 4 Model B	38
177	4.6	Raspberry Pi Camera Module Version 2	40
178	4.7	12 Volt DC Gear Motor	42
179	4.8	SanDisk Ultra MicroSD Card	43
180	4.9	LED Light Strip	44
181	4.10	Bench Power Supply	46
182	4.11	4 Channel Relay Module	47
183	5.1	Carabao Mango Image Data Collection	57
184	5.2	Carabao Mango Ripeness Stages	61
185	5.3	Different Kinds of Mango Defects	61
186	6.1	Ripeness Confusion Matrix using kNN	70
187	6.2	Ripeness Confusion Matrix using Naive Bayes	71
188	6.3	Bruises Confusion Matrix using CNN	71
189	6.4	Prototype Top View	73
190	6.5	Entrance Conveyor Belt View	73
191	6.6	Side Conveyor Belt View	74
192	6.7	Prototype Main Hardware	74
193	6.8	DC Motor and Pulley	75
194	6.9	LED Lights and Camera Module	75
195	6.10	Raspberry Pi App UI Version 1	76
196	6.11	Raspberry Pi App UI Version 2	76
197	6.12	Raspberry Pi App UI Version 3	77



200 LIST OF TABLES

201	1.1 Expected Deliverables per Objective	7
202	1.1 Expected Deliverables per Objective	8
203	1.1 Expected Deliverables per Objective	9
204	2.1 Comparison of Existing Studies	18
205	2.2 Comparison of Sorting Algorithm Models	21
206	5.1 Summary of methods for reaching the objectives	53
207	5.2 Confusion Matrix Example	58
208	6.1 Summary of methods for achieving the objectives	65
209	6.2 Performance Metrics for different EfficientNet versions	69
210	6.3 Ripeness Classification Report using kNN	70
211	6.4 Ripeness Classification Report using Naive Bayes	70
212	6.5 Bruises Classification Report using CNN	71
213	6.6 Summarized Classification Report using CNN	72
214	D.1 Summary of Revisions to the Thesis	101



215 ABBREVIATIONS

216	AC	Alternating Current	13
217	CNN	Convolution Neural Network	13
218	GUI	Graphical User Interface	50
219	LED	Light Emitting Diode	44
220	UI	User Interface	50



221

NOTATION

222	$B(P)$	Bruises Priority	72
223	$b(p)$	Bruises Prediction	72
224	$R(P)$	Ripeness Priority	72
225	$r(p)$	Ripeness Prediction	72
226	$S(P)$	Size Priority	72
227	$s(p)$	Size Prediction	72
228	$D(p, d, f)$	Real World Dimension	27
229	p	Pixel Dimension	27
230	d	Distance from Camera to Object	27
231	f	Focal Length	27



232 GLOSSARY

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



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User Priority-Based Grading

A customizable grading system where users can assign weights to grading factors.



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LISTINGS



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246

Chapter 1

247

INTRODUCTION



248 **1.1 Background of the Study**

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



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

254
255 It is known for its sweet signature taste that was recognized sweetest in the world in the
256 Guinness Book of World Records in 1995. The mango was named after the national animal
257 of the Philippines, a native breed of buffalo. On average, it is 12.5 cm in length and 8.5
258 cm in diameter, having a bright yellow color when ripe as seen in Figure 1.1. It is often
259 cultivated during late May to early July (DBpedia, nd).

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



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264 is the country's export of both fresh and dried mangoes, as well as low tariff rates. This
265 allows the country to export a large quantity of the fruit in countries such as Singapore,
266 Japan, and the USA as they can enter duty free markets provided by the World Trade
267 Organization and Japan. Due to this, the mangoes have become a major source of income
268 to an estimated 2.5 million farmers in the country (Centino et al., 2020).

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

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

283 Previous studies have been made to automate the sortation process of the mangoes.
284 Among these is a research done by Abbas et al. (2018), which focuses on classification
285 of mangoes using their texture and shape features. They do this by, first, acquiring an
286 image of the mango using a digital camera. Then, these images are fed to the MaZda
287 package, which is a software originally developed for magnetic resonance imaging. Within



288 the MaZda package is the B11 program, which uses Principal Component Analysis, Linear
289 Discriminant Analysis, Nonlinear Discriminant Analysis, and texture classification to
290 extract features from the mango, which in this case are the length, width, and texture. This
291 data is then compared to a database in order to classify any given mango (Abbas et al.,
292 2018).

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

303 1.2 Prior Studies

304 A paper written by Amna et al. (2023), designed an automated fruit sorting machine based
305 on the quality through an image acquisition system and CNN. Furthermore, the results
306 of the paper show that the image processing detection score was 89% while that of the
307 tomatoes was 92% while the CNN model had higher validity of 95% for mangoes and
308 93% for tomatoes. 15%, while the percentage of distinction between the two groups was
309 reported to be 5% respectively (Amna et al., 2023). Despite the high accuracy score in



310 detecting mango defects, the fruit sorting system only sorts based on the mango defects
311 and not on ripeness, and weight.

312 Furthermore, the research paper presented by Guillergan et al. (2024) designed an
313 Automated Carabao mango classifier, in which the mango image database is used to extract
314 the features like size, area along with the ratio of the spots for grading using Naïve Bayes
315 Model. For the results, the Naïve Bayes' model recognized large and rejected mangoes with
316 95% accuracy and the large and small/medium difference with a 7% error, suggesting an
317 application for quality differentiation and sorting in the mango business industry. Despite
318 the high accuracy of classifying Carabao mangoes, the researchers used a high quality
319 DSLR camera for the image acquisition system without any microcontroller to control the
320 mangoes (Guillergan et al., 2024).

321 **1.3 Problem Statement**

322 As mangoes are among the top exports of the Philippines (Centino et al., 2020), assessing
323 the physical deformities is a necessity. The physical deformities of the Carabao mango
324 can determine the global competitiveness of the country. Having higher quality exports
325 can often lead to gaining competitive edge, increase in demand, increase export revenues,
326 and becoming less susceptible to low-wage competition (D'Adamo, 2018). In order to
327 increase the quality of mango fruit exports, a key post-harvest process is done, which is
328 sorting and grading. Mango sorting and grading then becomes important to determine
329 which batches are of high quality and can be sold for a higher price, and which batches are
330 of low quality and can only be sold for a low price (Co., nd). Traditionally, fruit sorting
331 and grading is inefficient as it is done manually by hand. Some tools are used such as



332 porous ruler to determine fruit size and color palette for color grading (Co., nd). However,
333 among the problems encountered in the process of manually sorting and grading mangoes
334 are susceptibility to human error and requiring a number of laborers to do the task.

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

345 **1.4 Objectives and Deliverables**

346 **1.4.1 General Objective (GO)**

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



350 **1.4.2 Specific Objectives (SOs)**

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

366 **1.4.3 Expected Deliverables**

367 Table 1.1 shows the outputs, products, results, achievements, gains, realizations, and/or
368 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.
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.

Continued on next page



TABLE 1.1 EXPECTED DELIVERABLES PER OBJECTIVE

Objectives	Expected Deliverables
SO5: To classify mango ripeness based on image data using machine learning algorithms such as kNN, k-mean, and Naïve Bayes.	<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.
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.

369

1.5 Significance of the Study

370

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.

371

372

373



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

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

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

389 **1.5.1 Technical Benefit**

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



- 396 **1.5.2 Social Impact**
- 397 1. The reduction in manual labor creates opportunities in maintenance and technologies
398 in the automated Carabao mango sorter.
- 399 2. The automated Carabao mango sorter system improves Carabao mango standards
400 and enhances the satisfaction of the buyers and the customers through guaranteeing
401 consistent Carabao mango grade.
- 402 3. Opportunity to increase sales and profit for the farmers through consistent quality
403 and grade Carabao mangoes while reducing the physical labor to sort it.
- 404 **1.5.3 Environmental Welfare**
- 405 1. With the utilization of non-destruction methods of classifying Carabao mangoes
406 together with an accurate sorting system, overall waste from Carabao mangoes is
407 reduced and the likelihood of improperly sorted mangoes is decreased.
- 408 2. Automation of sorting and grading Carabao mangoes promotes sustainable farming
409 practices.
- 410 **1.6 Assumptions, Scope, and Delimitations**
- 411 **1.6.1 Assumptions**
- 412 1. The Carabao mangoes are from the same source together with the same variation
- 413 2. The Carabao mangoes do not have any fruit borer and diseases



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

420 **1.6.2 Scope**

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

429 **1.6.3 Delimitations**

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



- 432 2. Additionally, the project prototype will only be able to capture, sort, and grade one
 433 mango subject at a time which means the mangoes have to be placed in the conveyor
 434 belt in a single file line for accurate sorting.
- 435 3. For the bruises, the system will only be able to detect external bruises and may not
 436 identify the non-visible and internal bruises.
- 437 4. The system does not load the mangoes onto the conveyor belt itself. Assistance is
 438 required to put mangoes into the conveyor belt to start the sorting process
- 439 5. The prototype will be powered using Alternating Current (AC) power and will be
 440 plugged into a wall socket which is only suitable for indoor use.

441 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					BANAL AND BAUTISTA							
Training and Testing the CNN model						HERMOSURA AND SALAZAR						
Integrating the sensors and actuators to the Arduino Uno						BANAL AND BAUTISTA						
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 Surviving of the System with the Carabao Mangoes							BANAL, BAUTISTA, HERMOSURA, SALAZAR					
Data Gathering								BANAL, BAUTISTA, HERMOSURA, SALAZAR				

Fig. 1.2 Gantt Chart

442 As seen above, Table 1.2 shows the Gantt Chart together with the assigned task. For
 443 the first part of the THSCP4A, the group would primarily revise and fine tune Chapters
 444 1 and 2 while also preparing for the defense. After that for THSCP4B, the yellow team
 445 which consists of two members, Hermosura and Salazar, would start buying and collecting



446 the materials needed for assembling the prototype. While team yellow is doing that,
447 team purple which consists of Banal and Baustista would start training and validating the
448 Convolution Neural Network (cnn) model based on the Carabao mango image dataset.
449 After that integration of the sensors and actuators together with the integration of the cnn
450 model and beginning of coding of the Application to the Raspberry Pi would be done. Once
451 that cnn model is deployed and the Application works testing of the Carabao mangoes to
452 the prototype would be done. During THSCP4C, data gathering would be done together
453 with polishing and revising of the final paper.

454 **1.8 Overview of the Thesis**

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



465

Chapter 2

466

LITERATURE REVIEW



467 2.1 Existing Work

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

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



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

507 Another study by Tomas et al. (2022) proposed SVM-based system for classifying
508 the maturity stages of bananas, mangoes, and calamansi. With the use of 1729 images of
509 bananas together with 711 mango images and 589 calamansi, the researchers were able to
510 achieve a high accuracy score of above 90% for all fruits. Some pre-processing techniques
511 used to get this high accuracy are the change in hue, saturation, and value channels in the
512 mango image (Tomas et al., 2022). To better understand the harvest time of mangoes, the
513 paper by Abu et al. (2021) examined the association of the harvest season with seasonal



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514 heat units, rainfall, and physical fruit attributes for Haden, Kent, Palmer, and Keitt mango
 515 varieties to establish export and domestic market maturity standards. For the results of
 516 the paper, it shows that temperature, rainfall, and physical characteristics have a reliable,
 517 non-destructive indicators for determining mango maturity (Abu et al., 2021). This shows
 518 that physical characteristics and temperature are important when exporting fruits such as
 519 mangoes.

TABLE 2.1 COMPARISON OF EXISTING STUDIES

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

520 Previous studies on mango grading have achieved an accuracy rating of up to 95%, as
 521 shown in Table 2.1. However, these studies either relied on a small sample size, which
 522 limits statistical significance, or utilized expensive equipment, which may be impractical.
 523 In light of this, the researchers have set a target accuracy rating of greater than or equal
 524 to 90%. This target ensures that the system being developed is comparable to, or better
 525 than, existing studies that used larger sample sizes or assessed multiple mango traits at the



526 same time. Furthermore, this research aims to distinguish itself by not only maintaining or
527 exceeding the 90% accuracy rating but also incorporating a graphical user interface (GUI)
528 for selective priority-based mango classification. The system will integrate both software
529 and hardware components, and it will evaluate a greater number of mango traits for grading
530 purposes.

531 **2.1.1 Sorting Algorithms**

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

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



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

568 **2.2 Lacking in the Approaches**

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



TABLE 2.2 COMPARISON OF SORTING ALGORITHM MODELS

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

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

577 2.3 Summary

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



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582 On the other hand, although researchers have already taken steps to automate the process
583 of mango sorting and grading, there is still a need for an implementation that takes into
584 account size, ripeness, and bruises altogether whilst being non-destructive and having its
585 own embedded system. The research articles shown above show the different computer
586 vision and CNN approaches for sorting and classifying mangoes. For example, a system
587 created by Adam et al. (2022) was more focused on ripeness detection. Samaniego et al.
588 (2023) considered photonic systems for grading mango fruit based on color and weight.
589 On the other hand, Guillermo et al. (2019) implemented the Naïve Bayes classification
590 model on mangoes with high accuracy, which thereby did not include any microcontroller.
591 There was an attempt to study each of those parameters separately and that is why the
592 multifactorial approach was not used. With this in mind, the system being proposed does
593 exactly what was mentioned, to implement a non-destructive and automated sorting and
594 grading system for Carabao mangoes that takes into account size, ripeness, and bruises
595 altogether using machine learning, as well as having its own embedded system. This system
596 will be mainly composed of a conveyor belt, servo motors, a camera, microcontrollers, and
597 an LCD display for the user interface. By doing so, the system should be able to improve
598 the efficiency and productivity of mango sorting and grading, remove the effect of human
599 error and reduce time consumption. The studies also provided critical insights regarding the
600 effective algorithms that can be used in classification stages in image processing. The use
601 of CNN had the most accuracy with manageable potential challenges. Lastly, by scaling
602 the implementation, the overall export quality of the Carabao mangoes can be improved.



603

Chapter 3

604

THEORETICAL CONSIDERATIONS



605 3.1 Introduction

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

608 3.2 Relevant Theories and Models

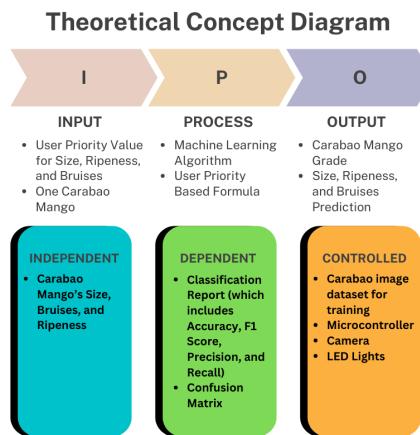


Fig. 3.1 Theoretical Framework Diagram.

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



618 3.3 Technical Background

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

626 3.4 Conceptual Framework Background

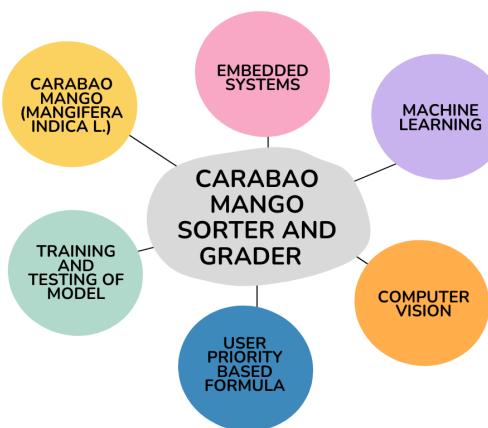


Fig. 3.2 Conceptual Framework Diagram.

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



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

635 **3.5 Software Concepts**

636 **3.5.1 Thresholding**

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

644

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

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



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

656 **3.5.2 Object Size Calculation**

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

661 The size of the mango can be determined given:

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

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

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

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



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

672 **3.5.3 Convolutional Neural Network**

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

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

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

685 **3.6 Hardware Concepts**

686 **3.6.1 Camera Module**

687 The camera module serves as the main image acquisition tool in the mango sorter and
688 grader system. Its role is to capture clear, high-resolution images of each mango as it moves



689 along the conveyor. These images are critical for analyzing physical traits like ripeness,
690 bruising, and size through computer vision and machine learning techniques.

691 The camera is directly connected to the Raspberry Pi, which manages both image
692 capture and processing. It is fixed in position to ensure consistent distance and angle for
693 all images. It is also paired with a lighting system to provide a consistent lighting for the
694 images. The system captures images of both the top and bottom sides of each mango to
695 ensure a more accurate grading. The prototype integrates the Raspberry Pi Camera Module
696 Version 2. This camera is chosen for its 8MP resolution which is critical in capturing
697 real-time images. Another reason for integrating this camera is because of its compatibility
698 with the Raspberry Pi 4, and reliability in capturing detailed images needed for accurate
699 classification. It is also cost effective and lightweight which is important for the prototype.

700 **3.6.2 4 Channel Relay**

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

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



710 **3.6.3 Gear Ratio**

711 In this prototype, gear ratios are used to control the rotational speed of the conveyor belts
712 that move and rotate the mango. A gear ratio of 1:3 was applied, meaning the motor gear
713 completes one full rotation for every three rotations of the driven gear. This is also done in
714 order to avoid overspeeding and make sure that the conveyor belt moves in a controlled
715 manner. This setup slows down one belt relative to the other, creating a differential speed
716 between the left and right belts. As a result, the mango rotates in place while being moved
717 forward. This rotation is essential for capturing both the top and bottom views of the mango
718 for accurate classification and grading.

719 **3.7 Summary**

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



725

Chapter 4

726

DESIGN CONSIDERATIONS



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

733 **4.1 Introduction**

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

738 **4.2 System Architecture**

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

745 In figure 4.1 presents the electronic circuit diagram, designed using Proteus. The
746 diagram illustrates a system where a Raspberry Pi 4 serves as the central control unit,

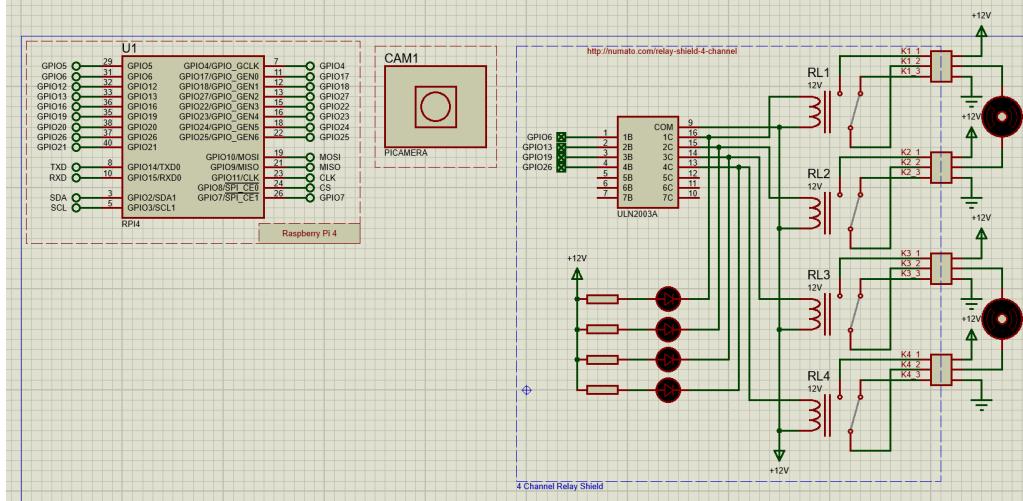


Fig. 4.1 Hardware Schematic

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

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

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



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

764 4.3 Hardware Considerations

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

769 4.3.1 General Prototype Framework

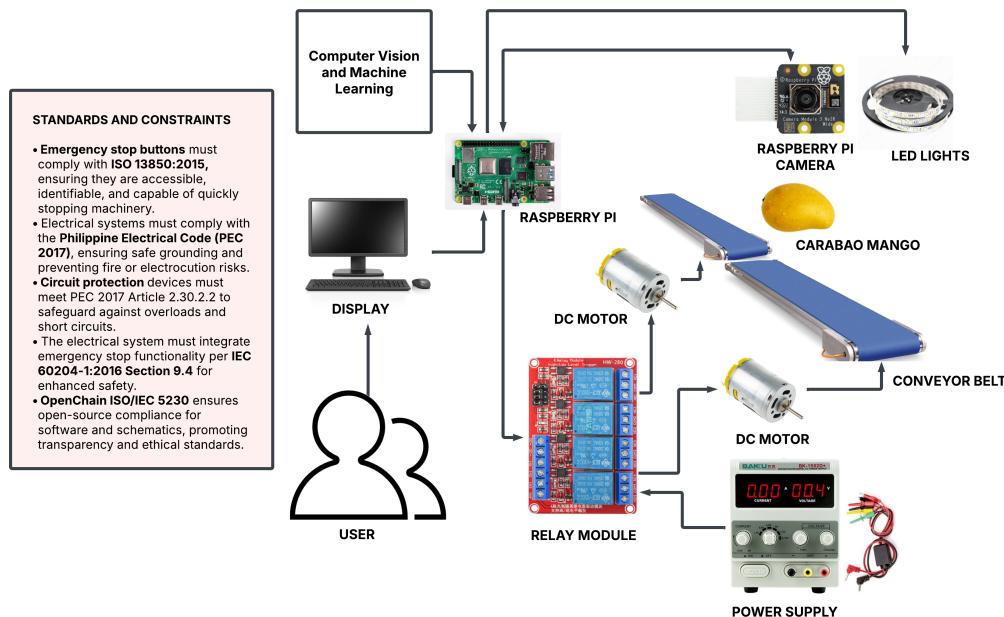


Fig. 4.2 Prototype Framework



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

778 **4.3.2 Prototype Flowchart**

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

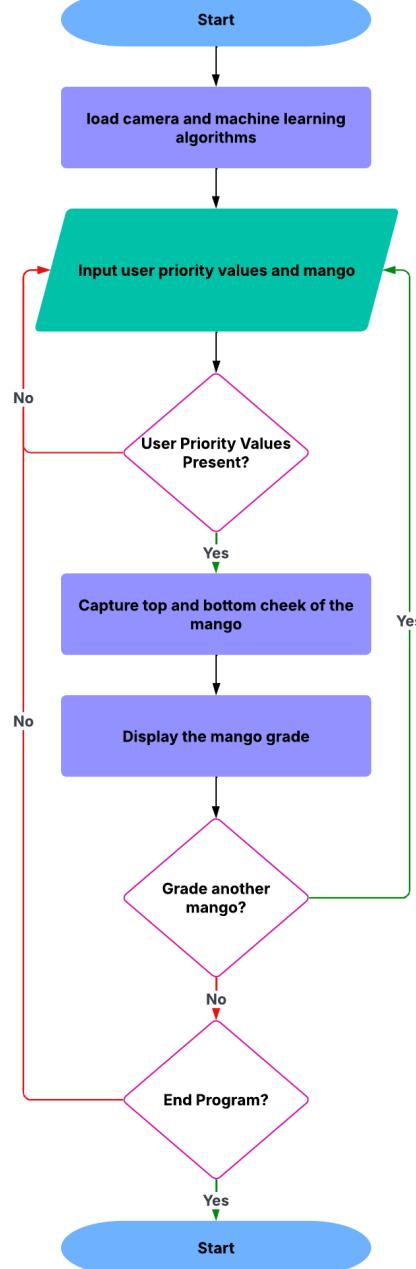


Fig. 4.3 Prototype Main Flowchart



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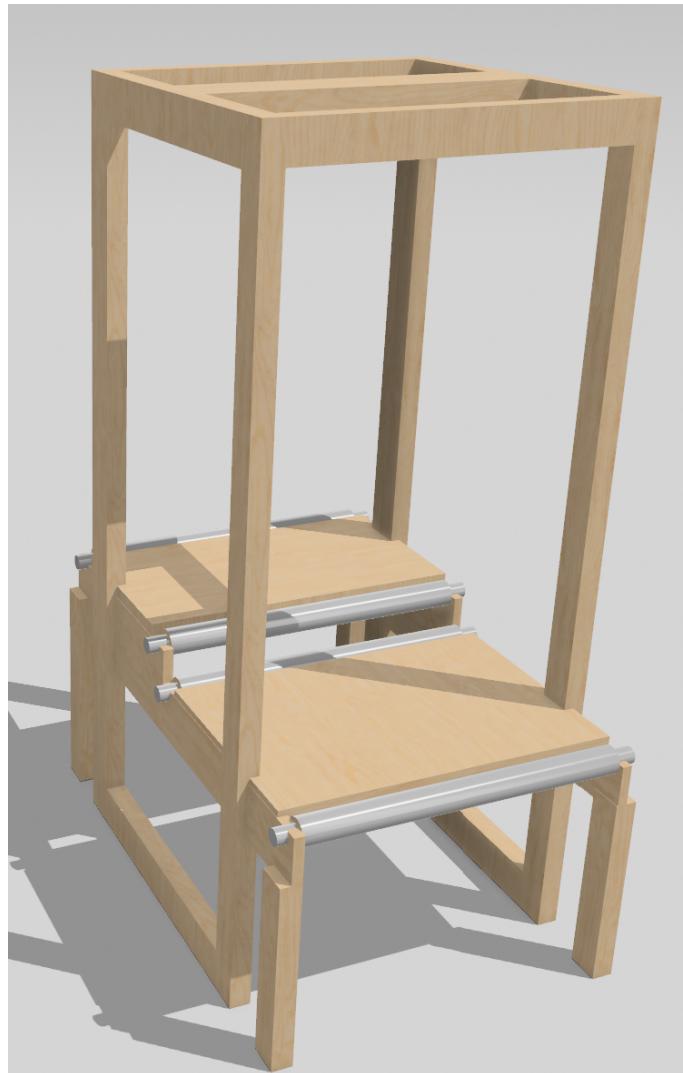


Fig. 4.4 Initial 3D Model of the Prototype



789 4.3.3 Prototype 3D Model

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

797 4.3.4 Hardware Specifications

798 4.3.4.1 Raspberry Pi



Fig. 4.5 Raspberry Pi 4 Model B

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



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

806 **Specifications:**

- 807 • SoC: Broadcom BCM2711
- 808 • CPU: Quad-core ARM Cortex-A72 (64-bit)
- 809 • Clock Speed: 1.5 GHz (base, overclockable)
- 810 • RAM: 8GB LPDDR4-3200 SDRAM
- 811 • Wireless: Dual-band 2.4 GHz / 5 GHz Wi-Fi (802.11ac)
- 812 • Bluetooth: Bluetooth 5.0 (BLE support)
- 813 • Ethernet: Gigabit Ethernet (full throughput)
- 814 • USB: 2 x USB 3.0 ports and 2 x USB 2.0 ports
- 815 • Video Output: 2 x micro-HDMI ports (supports 4K @ 60Hz, dual 4K display
816 capability)
- 817 • Audio: 3.5mm audio/video composite jack
- 818 • Storage: MicroSD card slot (supports booting via SD card or USB)



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

823 **4.3.4.2 Raspberry Pi Camera**

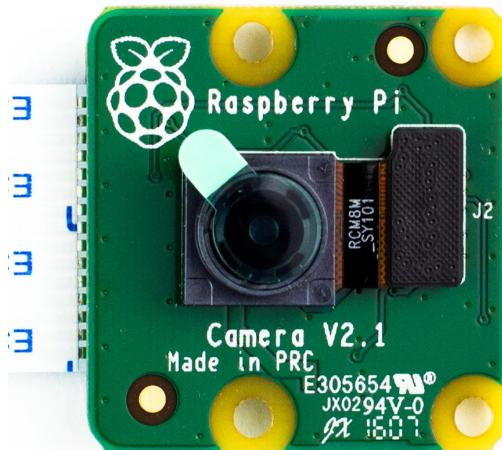


Fig. 4.6 Raspberry Pi Camera Module Version 2

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



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

831

832 **Specifications:**

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

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

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

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

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

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

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

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

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

845 **4.3.4.3 DC Motor**

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

848 It features a spur gear design, which provides a high reduction ratio for increased torque
849 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.

Specifications:

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



- 861 • Torque Output: 18 kg-cm (rated)
862 • Stall Torque: 60 kg-cm (maximum)
863 • Power Rating: 50W (maximum)
864 • Unit Weight: 350 grams

865 **4.3.4.4 MicroSD Card**



Fig. 4.8 SanDisk Ultra MicroSD Card

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

871
872 **Specifications:**



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

877 **4.3.4.5 LED Lights**



Fig. 4.9 LED Light Strip

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

882

883 **Specifications:**



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

893 **4.3.4.6 Power Supply**

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

899

900 **Specifications:**

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



Fig. 4.10 Bench Power Supply

- 903 • Output Range: 0-30V DC / 0-5A DC
- 904 • Voltage Precision: $\pm 0.010V$ (10 mV) resolution
- 905 • Current Precision: $\pm 0.001A$ (1 mA) resolution
- 906 • Power Precision: $\pm 0.1W$ resolution
- 907 • Weight: 5 lbs (2.27 kg)
- 908 • Dimensions: 11.1" x 4.92" x 6.14" (28.2 cm x 12.5 cm x 15.6 cm)
- 909 • Maximum Power: 195W
- 910 • Power Source: AC input only



Fig. 4.11 4 Channel Relay Module

4.3.4.7 4 Channel Relay Module

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

Specifications:

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



- 923 • Max AC Load: 10A @ 250V AC (resistive).
- 924 • Max DC Load: 10A @ 30V DC (resistive).
- 925 • Contact Type: SPDT (Single Pole Double Throw) - NO (Normally Open), NC
926 (Normally Closed), COM (Common).
- 927 • Dimensions: 50mm x 70mm x 20mm
- 928 • Weight: 50-80 grams.
- 929 • Status LEDs: Individual LEDs for each relay (indicates ON/OFF state).
- 930 • Input Pins: 4 digital control pins (one per relay).
- 931 • Output Terminals: Screw terminals for connecting loads (NO/NC/COM).

932 **4.4 Software Considerations**

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

936 **4.4.1 PyTorch**

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



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

943 **4.4.2 OpenCV**

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

950 **4.4.3 CustomTkinter**

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

957 **4.5 Security and Reliability Considerations**

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



961 **4.6 Scalability and Efficiency Considerations**

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

965 **4.7 User Interface**

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

969 **4.8 Constraints and Limitations**

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

973 **4.9 Technical Standards**

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



976 **4.10 Prototyping and Simulation**

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

980 **4.11 Design Validation**

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

984 **4.12 Summary**

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



988

Chapter 5

989

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. 5.2 on p. 55
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. 5.3 on p. 55
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. 5.5 on p. 57

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. 5.3 on p. 55
SO4: To grade mangoes based on user priorities for size, ripeness, and bruises.	1. Formula development: Formulated an equation based on the inputted user priority and the predicted mango classification	Sec. 5.7 on p. 62
SO5: To classify mango ripeness based on image data using machine learning algorithms such as kNN, k-mean, and Naïve Bayes.	1. Performance testing: Train and test the machine learning algorithm for classifying bruises	Sec. 5.6.3 on p. 61
SO6: To classify mango size based on image data by getting its length and width using OpenCV, geometry, and image processing techniques.	1. Performance testing: Train and test the machine learning algorithm for classifying ripeness	Sec. 5.6.2 on p. 60
SO7: To classify mango bruises based on image data by employing machine learning algorithms.	1. Accuracy testing: Get the percent accuracy testing for getting the length and width of the Carabao mango	Sec. 5.6.4 on p. 62



990 5.1 Introduction

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

998 5.2 Research Approach

999 This study applies the experimental approach for research in order to develop and properly
1000 test the proposed system. The experimental approach of the methodology will allow the
1001 researchers to fine-tune the parameters and other factors in the classification of mangoes in
1002 order to get optimal results with high accuracy scores while maintaining the quality of the
1003 mangoes. This approach will also allow for real-time data processing and classification
1004 which will improve the previous static grading systems.

1005 5.3 Hardware Design

1006 The prototype consists of hardware and software components for automated mango sorting
1007 and grading purposes. The hardware includes the conveyor belt system used to transfer
1008 mangoes from scanning to sorting smoothly. A camera and lighting system are able
1009 to collect high-resolution images for analysis. The DC motors and stepper motors are



1010 responsible for driving the conveyor belt and sorting actuators. The entire system is
1011 controlled by a microcontroller (Raspberry Pi 4b), coordinating actions of all components.
1012 Sorting actuators then direct mangoes into selected bins based on their classification to
1013 make sorting efficient.

1014 **5.4 Software Design**

1015 For the programming language used for the prototype and training and testing the CNN
1016 model, Python was used for training and testing the CNN model and it was also used in the
1017 microcontroller to run the application containing the UI and CNN model. PyTorch was the
1018 main library used in using the EfficientNet model that is used in classifying the ripeness
1019 and bruises of the mango. Likewise, tkinter is the used library when designing the UI in
1020 Python.

1021 Furthermore, the rest of the software components are of utmost importance to mango
1022 classification. Image processing algorithms in OpenCV and CNN models extract features
1023 such as color, size, and bruises that are known to determine quality parameters of mangoes.
1024 Mangoes are classified based on ripeness and defects by using machine learning algorithms,
1025 which further enhances accuracy using deep learning techniques. A user interface (UI) is
1026 designed for users to control and observe the system in real time. Finally, the interface
1027 programming of the microcontroller provides the necessary synchronization between
1028 sensors, actuators, and motors throughout the sorting operation scenario.



1029 5.5 Data Collection Methods

1030 For the data collection, online available image datasets with Carabao mangoes were used
1031 together with the captured Carabao mango images. For the setup of the captured Carabao
1032 mangoes, the height of the camera to the white flat surface is 26 cm which can be seen
1033 on Figure 5.1. Furthermore, the S24's camera is used for capturing both cheeks of the
1034 Carabao mango. Initially, the Carabao mangoes would be unripe and green and each day
1035 the Carabao mangoes would be pictured until they are ripe.



Fig. 5.1 Carabao Mango Image Data Collection

1036 5.6 Testing and Evaluation Methods

1037 In a bid to ensure the mango sorting and grading system is accurate and reliable, there is
1038 intensive testing conducted at different levels. Unit testing is initially conducted on each
1039 component separately, for instance, the conveyor belt, sensors, and cameras, to ensure that



1040 each of the components works as expected when operating separately. After component
 1041 testing on an individual basis, integration testing is conducted to ensure communication
 1042 between hardware and software is correct to ensure the image processing system, motors,
 1043 and sorting actuators work in concert as required. System testing is conducted to con-
 1044 duct overall system performance testing in real-world conditions to ensure mangoes are
 1045 accurately and efficiently sorted and graded.

5.6.1 Classification Report

5.6.1.1 Confusion Matrix

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

TABLE 5.2 CONFUSION MATRIX EXAMPLE

1048 A confusion matrix is a table that visualizes the performance of a classification model.
 1049 For a binary classification problem, it has four components:

- 1051 • True Positives (TP): Cases correctly predicted as positive
- 1052 • True Negatives (TN): Cases correctly predicted as negative
- 1053 • False Positives (FP): Cases incorrectly predicted as positive. (Type I error)
- 1054 • False Negatives (FN): Cases incorrectly predicted as negative (Type II error)

1055 **5.6.1.2 Precision**

$$\text{Precision} = \frac{TP}{TP + FP} \quad (5.1)$$

1056 Precision measures how many of the predicted positives are actually positive. It answers
 1057 the question: "When the model predicts the positive class, how often is it correct?" High
 1058 precision means low false positives.

1059 **5.6.1.3 Recall**

$$\text{Recall} = \frac{TP}{TP + FN} \quad (5.2)$$

1060 Recall, which is also called sensitivity, measures how many of the actual positives were
 1061 correctly identified. It answers the question: "Of all the actual positive cases, how many
 1062 did the model catch?" High recall means low false negatives.

1063 **5.6.1.4 F1 Score**

$$F_1 = 2 \times \frac{\text{Precision} \times \text{Recall}}{\text{Precision} + \text{Recall}} \quad (5.3)$$

1064 The F1 score is the harmonic mean of precision and recall. It provides a single metric
 1065 that balances both concerns. This is particularly useful when you need to find a balance
 1066 between precision and recall, as optimizing for one often decreases the other.

1067 **5.6.1.5 Accuracy**

$$\text{Accuracy} = \frac{TP + TN}{TP + TN + FP + FN} \quad (5.4)$$



1068 Accuracy measures the proportion of correct predictions (both true positives and true
1069 negatives) among the total cases. While intuitive, accuracy can be misleading with imbal-
1070 anced datasets.

1071 To test system performance, various measures of performance are used to evaluate.
1072 As seen on equation 5.4, accuracy score is used to measure the percentage of correctly
1073 classified mangoes to ensure the system maintains high precision levels. Precision as seen
1074 on equation 5.1 and recall as seen on equation 5.2 are used to measure consistency of
1075 classification to determine if the system classifies different ripeness levels and defects
1076 correctly. Furthermore, the F1 score formula as seen on equation 5.3 is used to evaluate the
1077 performance of the model's classification.

1078 A confusion matrix is used to measure correct and incorrect classification to ensure the
1079 machine learning model is optimized and that minimum errors are achieved. Throughput
1080 analysis is also used to determine the rate and efficiency of sorting to ensure that the
1081 system maintains high capacity without bottlenecks to sort mangoes. Using these methods
1082 of testing, the system is constantly optimized to ensure high-quality and reliable mango
1083 classification.

1084 **5.6.2 Ripeness Training and Testing**

1085 For the testing of the ripeness classification, the Carabao mangoes are classified into three
1086 ripeness stages which are Green, green yellow, and yellow. Likewise, The green would
1087 represent the ripe mangoes while the green yellow would represent the semi ripe while the
1088 yellow would represent the ripe mangoes. As reference, Figure 5.3 shows the different
1089 ripeness stages for Carabao/Pico mangoes.



Annex A

Stages of ripeness of 'carabao' and 'pico' mango fruits

Stage of ripeness	Peel color	Flesh color
Green	Completely light green	Yellowish white or light yellow green
Breaker	Traces of yellow	Middle area and fruit outline yellowish; other areas, white to yellowish white
Turning	More green than yellow	More yellow than white
Semi-ripe	More yellow than green	Yellow for 'carabao'; yellow orange for 'pico'
Ripe	80-100% yellow ('carabao') or yellow orange ('pico')	Middle area yellow for 'carabao'; yellow orange for 'pico'
Overripe	Yellow for 'carabao'; yellow orange for 'pico'	100% yellow for 'carabao' and yellow orange for 'pico'

Fig. 5.2 Carabao Mango Ripeness Stages

5.6.3 Bruises Training and Testing

For the testing of the bruise classification of the Carabao mangoes, it would classified into two categories which are bruised and not bruised. To define what bruise and not bruise mangoes looked like Figure 5.3 is used as reference to categorize which mangoes are bruised and not bruised.

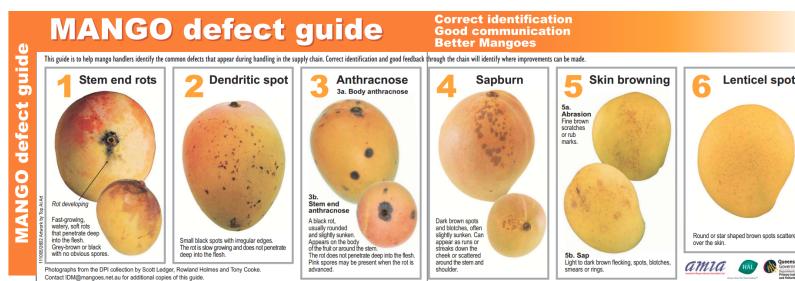


Fig. 5.3 Different Kinds of Mango Defects



1095 **5.6.4 Size Determination**

1096 To get the size of the mangoes, computer vision techniques such as Gaussian Blur and
1097 Thresholding are used to get the length and width of the mangoes.

1098 **5.7 Formula for User Priority**

1099 **5.8 Ethical Considerations**

1100 Ethical considerations ensure that the system is operated safely and responsibly. Data
1101 privacy is ensured by securely storing and anonymizing extracted images and classification
1102 data so that unauthorized access becomes impossible. The system is also eco-friendly
1103 through non-destructive testing, saving mangoes while also ensuring that they are of good
1104 quality. Safety in operations is also ensured by protecting moving parts to prevent mechani-
1105 cal harm and incorporating fail-safes to securely stop operation in case of malfunction.
1106 Addressing these concerns, the system is not only accurate and efficient but also secure,
1107 eco-friendly, and safe for operators, thus a sustainable solution to automated mango sorting
1108 and grading.

1109 **5.9 Summary**

1110 This chapter explained how to create an automatic Carabao mango sorter and grader using
1111 machine learning and computer vision. The system integrates hardware and software
1112 resources, including a conveyor belt, cameras, sensors, and actuators, to offer accurate,
1113 real-time sorting by ripeness, size, and bruises. Various testing and evaluation processes



1114 ensure its performance to offer reliability. Ethical issues are data privacy, environmental
1115 sustainability, and operation safety. With enhanced efficiency, reduced human error, and
1116 enhanced quality, this system provides an affordable, scalable, and non-destructive solution
1117 to post-harvest mango classification in agricultural industries.



1118

Chapter 6

1119

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. 6.6 on p. 77
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. 6.4 on p. 72

Continued on next page

6. Results and Discussions



De La Salle University

Continued from previous page

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. 6.1 on p. 69</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. 6.4 on p. 72</p>

Continued on next page

6. Results and Discussions



De La Salle University

Continued from previous page

Objectives	Methods	Locations
SO4: To grade mangoes based on user priorities for size, ripeness, and bruises.	<p>Expected Results:</p> <ol style="list-style-type: none">1. Successfully grade mangoes based on the user priorities on the physical characteristics of the mango2. Successfully verified with qualified individual the results3. Successfully utilize the weighted equation to evaluate mango grade based on user priorities <p>Actual Results:</p> <ol style="list-style-type: none">1. Successfully grade mangoes based on the user priorities on the physical characteristics of the mango2. Successfully utilize the weighted equation to evaluate mango grade based on user priorities3. Need to look for a qualified person to evaluate the graded mango for ground truth	Sec. 6.3 on p. 72

Continued on next page

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 	<p>Sec. 6.1.1 on p. 69</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 	<p>Sec. 6.2 on p. 72</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. 6.1.2 on p. 72

1120 6.1 Training and Testing Results of the Model

1121 6.1.1 Ripeness Classification Results

1122 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

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

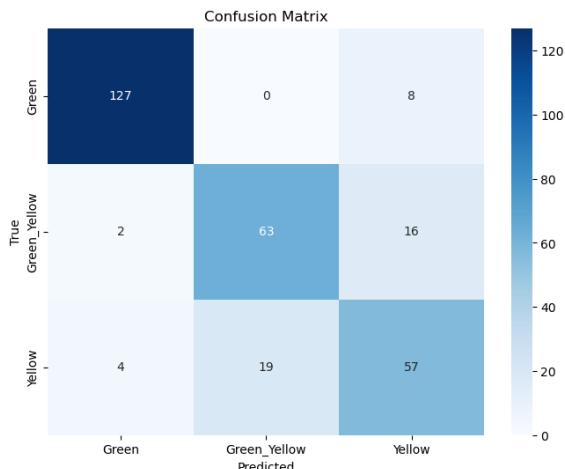


Fig. 6.1 Ripeness Confusion Matrix using kNN

	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

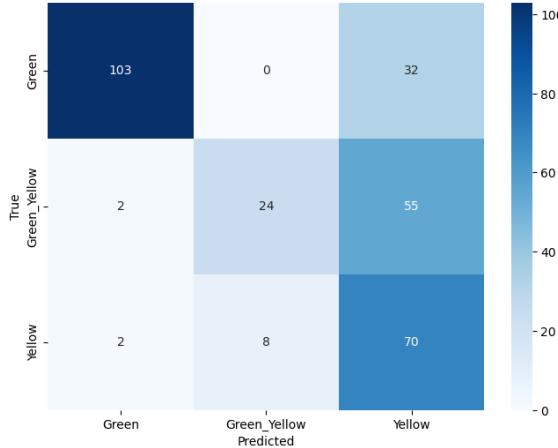


Fig. 6.2 Ripeness Confusion Matrix using Naive Bayes

	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

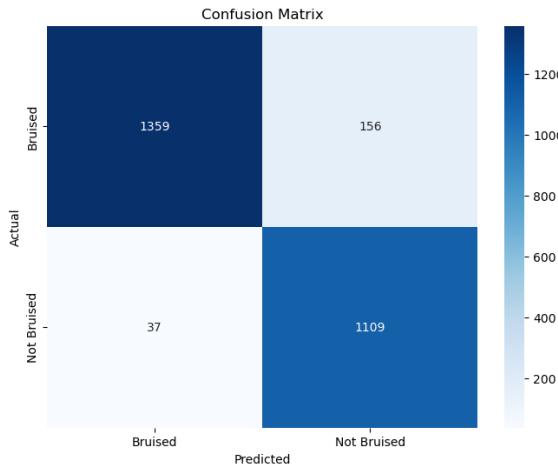


Fig. 6.3 Bruises Confusion Matrix using CNN



Metrics	Results
Precision	0.9318
Recall	0.9275
F1 Score	0.9278

TABLE 6.6 SUMMARIZED CLASSIFICATION REPORT USING CNN

1123 **6.1.2 Bruises Classification Results**

1124 **6.2 Size Determination Results**

1125 **6.3 User Priority Formula**

1126 $B(P)$ and $R(P)$ and $S(P)$ are the User Priority-Based Grading for bruises, ripeness,
 1127 and size of the Carabao mango. Furthermore, $b(p)$ and $r(p)$ and $s(p)$ are the machine
 1128 learning's predictions for bruises, ripeness, and size of the Carabao mango. The formula
 1129 for the user priority is given by:

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

1130 **6.4 Physical Prototype**

1131 Add pictures of the hardware prototype here with description

1132 **6.5 Software Application**

1133 Show the raspberry pi app UI and demonstrate it here



Fig. 6.4 Prototype Top View



Fig. 6.5 Entrance Conveyor Belt View

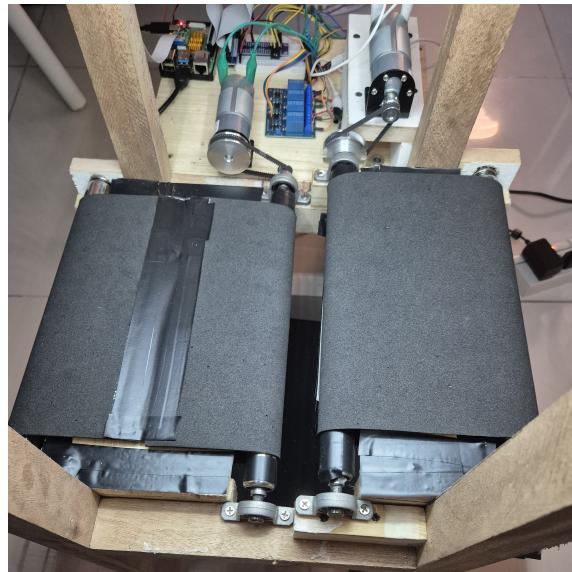


Fig. 6.6 Side Conveyor Belt View



Fig. 6.7 Prototype Main Hardware



Fig. 6.8 DC Motor and Pulley

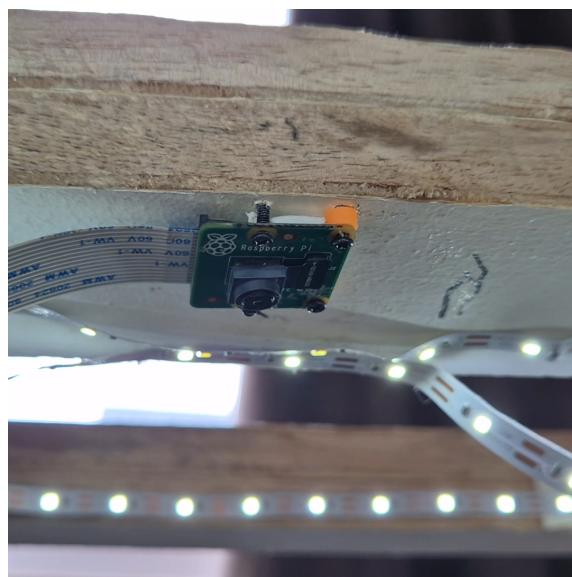


Fig. 6.9 LED Lights and Camera Module

6. Results and Discussions



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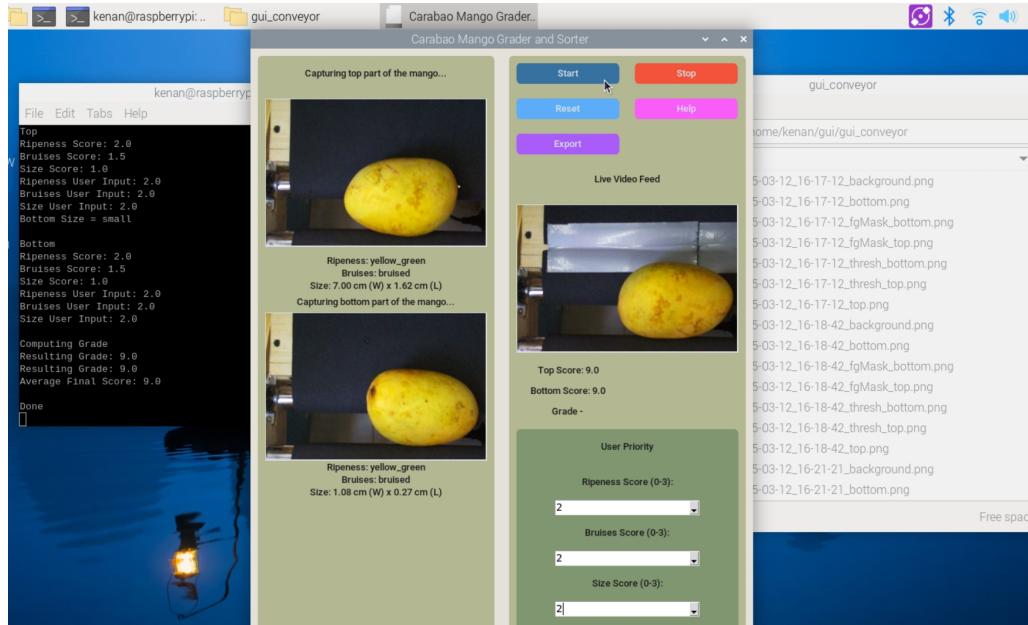


Fig. 6.10 Raspberry Pi App UI Version 1

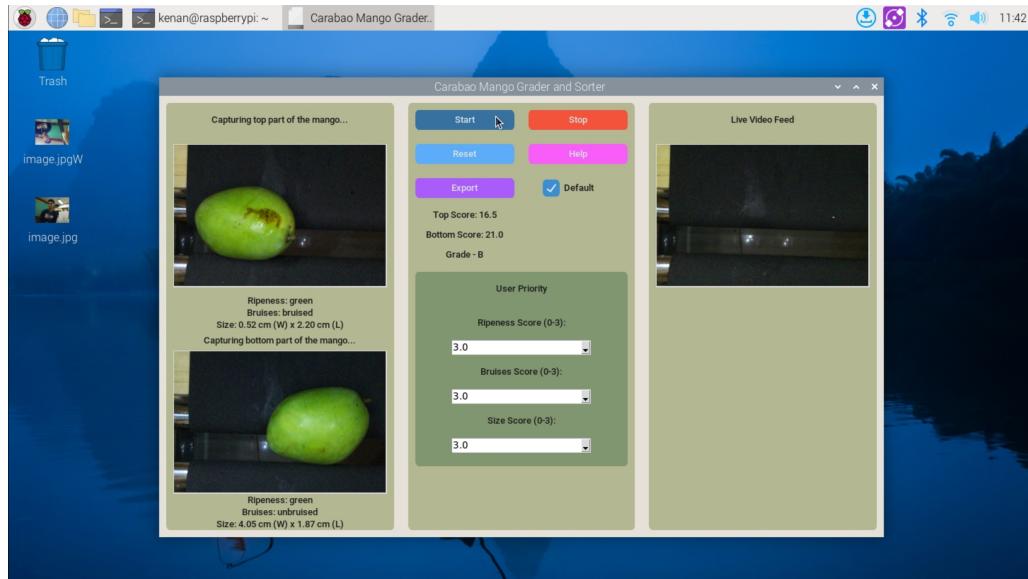


Fig. 6.11 Raspberry Pi App UI Version 2

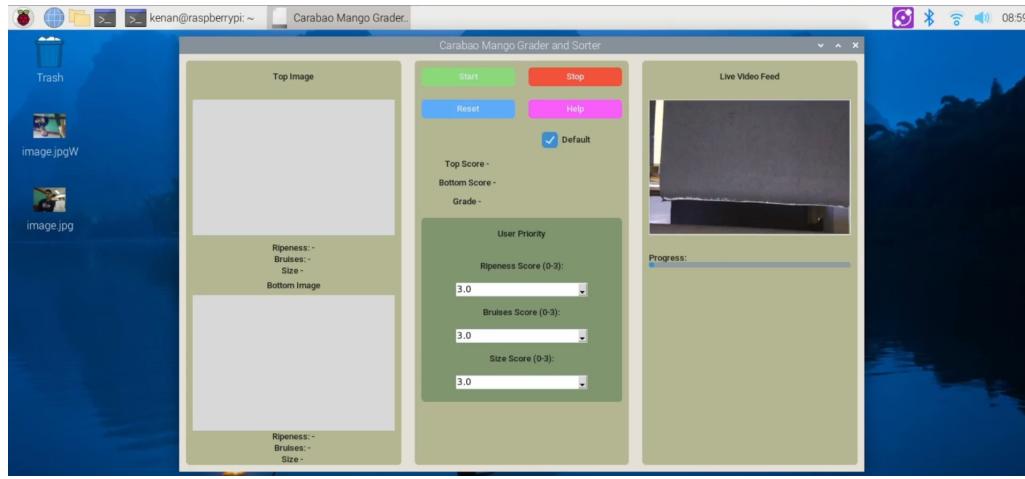


Fig. 6.12 Raspberry Pi App UI Version 3

6.6 Summary

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

1134

1135

1136



1137 **Chapter 7**

1138 **CONCLUSIONS, RECOMMENDATIONS, AND**
1139 **FUTURE DIRECTIVES**



7.1 Concluding Remarks

In this Thesis, the prototype is successful in grading and sorting Carabao mangoes based on the user priority and machine learning algorithm. More specifically, the prototype is successful in automatically classifying Carabao mangoes based on ripeness (Green, Green Yellow, and Yellow), size (Large, Medium, Small), and bruises (bruised and not bruised)

7.2 Contributions

The contributions of each group member are as follows:

- BANAL Kenan A.: Scrum Master (Project manager in charge of the hardware and software integration)
- BAUTISTA Francis Robert Miguel F.: Front End Engineer (UI/UX Designer in charge of software interface and hardware assistant of the Scrum Master)
- HERMOSURA Don Humphrey L. : Back End Engineer (Software Engineer in charge of the machine learning algorithm and software assistant of the Scrum Master)
- SALAZAR Daniel G.: Product Engineer (Software Engineer in charge of training and testing of the machine learning algorithm)

7.3 Recommendations

The researchers recommend that the prototype be improved in the optimization of the machine learning algorithm and the hardware design. The researchers also recommend that



1159 the prototype be tested in the actual grading and sorting of Carabao mangoes in the market.

1160 **7.4 Future Prospects**

1161 Future researchers may consider the following recommendations for future work:

1162 1. User testing of the prototype in the actual grading and sorting of Carabao mangoes
1163 in the Philippine market.

1164 2. Additional of weight measurement to the prototype to improve the grading and
1165 sorting of Carabao mangoes.

1166 3. Integration of a custom PCB to improve the hardware design of the prototype.



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Appendix A STUDENT RESEARCH ETHICS CLEARANCE

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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

1224

ANSWERS TO QUESTIONS TO THIS THESIS



B1 How important is the problem to practice?

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

1225 Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Etiam lobortis facilisis sem.
 1226 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec
 1227 ullamcorper, felis non sodales commodo, lectus velit ultrices augue, a dignissim nibh lectus
 1228 placerat pede. Vivamus nunc nunc, molestie ut, ultricies vel, semper in, velit. Ut porttitor.
 1229 Praesent in sapien. Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Duis fringilla
 1230 tristique neque. Sed interdum libero ut metus. Pellentesque placerat. Nam rutrum augue
 1231 a leo. Morbi sed elit sit amet ante lobortis sollicitudin. Praesent blandit blandit mauris.
 1232 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit
 1233 amet ipsum. Nunc quis urna dictum turpis accumsan semper.

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

1238 Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Etiam lobortis facilisis sem.
 1239 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec
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 1245 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit
 1246 amet ipsum. Nunc quis urna dictum turpis accumsan semper.

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

1249 Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Etiam lobortis facilisis sem.
 1250 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec
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1257 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit
 1258 amet ipsum. Nunc quis urna dictum turpis accumsan semper.

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

1260 Lorem ipsum dolor sit amet, consectetur adipiscing elit. Etiam lobortis facilisis sem.
 1261 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec
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 1267 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit
 1268 amet ipsum. Nunc quis urna dictum turpis accumsan semper.

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

1269 Lorem ipsum dolor sit amet, consectetur adipiscing elit. Etiam lobortis facilisis sem.
 1270 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec
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 1276 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit
 1277 amet ipsum. Nunc quis urna dictum turpis accumsan semper.

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

1278 Lorem ipsum dolor sit amet, consectetur adipiscing elit. Etiam lobortis facilisis sem.
 1279 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec
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 1282 Praesent in sapien. Lorem ipsum dolor sit amet, consectetur adipiscing elit. Duis fringilla
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 1285 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit
 1286 amet ipsum. Nunc quis urna dictum turpis accumsan semper.



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

1289 Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Etiam lobortis facilisis sem.
 1290 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec
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 1296 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit
 1297 amet ipsum. Nunc quis urna dictum turpis accumsan semper.

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

1300 Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Etiam lobortis facilisis sem.
 1301 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec
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 1306 a leo. Morbi sed elit sit amet ante lobortis sollicitudin. Praesent blandit blandit mauris.
 1307 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit
 1308 amet ipsum. Nunc quis urna dictum turpis accumsan semper.

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

1310 Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Etiam lobortis facilisis sem.
 1311 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec
 1312 ullamcorper, felis non sodales commodo, lectus velit ultrices augue, a dignissim nibh lectus
 1313 placerat pede. Vivamus nunc nunc, molestie ut, ultricies vel, semper in, velit. Ut porttitor.
 1314 Praesent in sapien. Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Duis fringilla
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 1317 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit
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1321 **B4.1 Will your proposed solution/s be sensitive to these as-**
 1322 **sump tions?**

1323 Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Etiam lobortis facilisis sem.
 1324 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec
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 1330 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit
 1331 amet ipsum. Nunc quis urna dictum turpis accumsan semper.

1332 **B4.2 Can your proposed solution/s be applied to more general**
 1333 **cases when some assumptions are eliminated? If so, how?**

1334 Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Etiam lobortis facilisis sem.
 1335 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec
 1336 ullamcorper, felis non sodales commodo, lectus velit ultrices augue, a dignissim nibh lectus
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 1338 Praesent in sapien. Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Duis fringilla
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 1340 a leo. Morbi sed elit sit amet ante lobortis sollicitudin. Praesent blandit blandit mauris.
 1341 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit
 1342 amet ipsum. Nunc quis urna dictum turpis accumsan semper.

1343 **B5 What is the necessity of your approach / pro-**
 1344 **posed solution/s?**

1345 Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Etiam lobortis facilisis sem.
 1346 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec
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 1350 tristique neque. Sed interdum libero ut metus. Pellentesque placerat. Nam rutrum augue
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 1352 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit
 1353 amet ipsum. Nunc quis urna dictum turpis accumsan semper.



1354 **B5.1 What will be the limits of applicability of your proposed so-**
 1355 **lution/s?**

1356 Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Etiam lobortis facilisis sem.
 1357 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec
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 1363 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit
 1364 amet ipsum. Nunc quis urna dictum turpis accumsan semper.

1365 **B5.2 What will be the message of the proposed solution to**
 1366 **technical people? How about to non-technical managers and**
 1367 **business people?**

1368 Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Etiam lobortis facilisis sem.
 1369 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec
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 1375 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit
 1376 amet ipsum. Nunc quis urna dictum turpis accumsan semper.

1377 **B6 How will you know if your proposed solution/s**
 1378 **is/are correct?**

1379 Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Etiam lobortis facilisis sem.
 1380 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec
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1386 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit
 1387 amet ipsum. Nunc quis urna dictum turpis accumsan semper.

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

1390 Lorem ipsum dolor sit amet, consectetur adipiscing elit. Etiam lobortis facilisis sem.
 1391 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec
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 1397 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit
 1398 amet ipsum. Nunc quis urna dictum turpis accumsan semper.

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

1401 Lorem ipsum dolor sit amet, consectetur adipiscing elit. Etiam lobortis facilisis sem.
 1402 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec
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**B7.1 Can you come up with illustrating examples, or even
better, counterexamples to your proposed solution/s?**

1412 Lorem ipsum dolor sit amet, consectetur adipiscing elit. Etiam lobortis facilisis sem.
 1413 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec
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 1419 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit
 1420 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?

1423 Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Etiam lobortis facilisis sem.
 1424 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec
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 1430 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit
 1431 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.

1432 Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Etiam lobortis facilisis sem.
 1433 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec
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 1439 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit
 1440 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?

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 1446 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec



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1451 Praesent in sapien. Lorem ipsum dolor sit amet, consectetur adipiscing elit. Duis fringilla
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1454 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit
1455 amet ipsum. Nunc quis urna dictum turpis accumsan semper.



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1456

Appendix C REVISIONS TO THE PROPOSAL

1457

C. Revisions to the Proposal



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1458

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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1459

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



1460

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



1461

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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1462

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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1463

Appendix D REVISIONS TO THE FINAL

1464



- 1465 Make a table with the following columns for showing the summary of revisions to the
 1466 proposal based on the comments of the panel of examiners.
- 1467 1. Examiner
- 1468 2. Comment
- 1469 3. Summary of how the comment has been addressed
- 1470 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. Gustilo	<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>

Continued on next page



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Continued from previous page

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

Continued on next page



Continued from previous page

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. ???



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1471

Appendix E ARTICLE PAPER(S)

1472

Article/Forum Paper Format

(IEEE LaTeX format)

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

1473

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.

A. Subsection Heading Here

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

J. Doe and J. Doe are with Anonymous University.



Fig. 1. Simulation results for the network.

TABLE I
AN EXAMPLE OF A TABLE

One	Two
Three	Four

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1) Subsubsection Heading Here: Subsubsection text here.

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II. CONCLUSION

The conclusion goes here.

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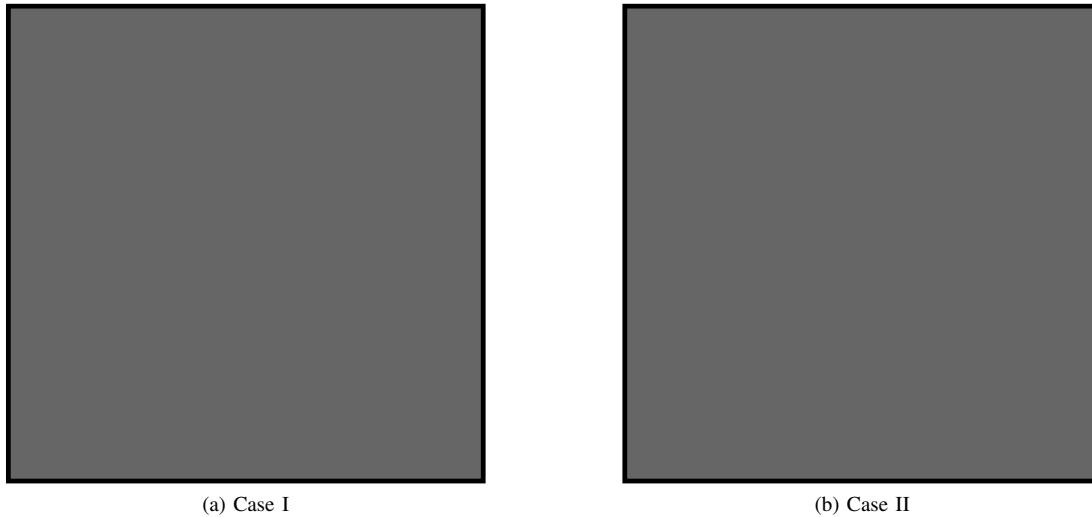


Fig. 2. Simulation results for the network.

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APPENDIX A PROOF OF THE FIRST ZONKLAR EQUATION

Appendix one text goes here.

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APPENDIX B

Appendix two text goes here. [?].

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ACKNOWLEDGMENT

The authors would like to thank...