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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 April, 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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35

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38

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

55	Oral Defense Recommendation Sheet	ii
56	Abstract	iii
57	Table of Contents	iv
58	List of Figures	viii
59	List of Tables	ix
60	Abbreviations and Acronyms	x
61	Notations	xi
62	Glossary	xii
63	Listings	xiv
64	Chapter 1 INTRODUCTION	1
65	1.1 Background of the Study	2
66	1.2 Prior Studies	4
67	1.3 Problem Statement	5
68	1.4 Objectives and Deliverables	6
69	1.4.1 General Objective (GO)	6
70	1.4.2 Specific Objectives (SOs)	7
71	1.4.3 Expected Deliverables	7
72	1.5 Significance of the Study	9
73	1.5.1 Technical Benefit	10
74	1.5.2 Social Impact	11
75	1.5.3 Environmental Welfare	11
76	1.6 Assumptions, Scope, and Delimitations	11
77	1.6.1 Assumptions	11
78	1.6.2 Scope	12
79	1.6.3 Delimitations	12
80	1.7 Estimated Work Schedule and Budget	13
81	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	26
96	3.5.3 Convolutional Neural Network	27
97	3.5.4 Classification Report	27
98	3.5.4.1 Confusion Matrix	27
99	3.5.4.2 Precision	27
100	3.5.4.3 Recall	28
101	3.5.4.4 F1 Score	28
102	3.5.4.5 Accuracy	28
103	3.6 Hardware Concepts	29
104	3.6.1 Camera Module	29
105	3.6.2 4 Channel Relay	29
106	3.6.3 1:3 Pulley Belt	29
107	3.7 Summary	29
108	Chapter 4 DESIGN CONSIDERATIONS	30
109	4.1 Introduction	31
110	4.2 System Architecture	31
111	4.3 Hardware Considerations	33
112	4.3.1 General Prototype Framework	33
113	4.3.2 Prototype Flowchart	34
114	4.3.3 Prototype 3D Model	35
115	4.3.4 Hardware Specifications	36
116	4.3.4.1 Raspberry Pi	36
117	4.3.4.2 Raspberry Pi Camera	37
118	4.3.4.3 DC Motor	39
119	4.3.4.4 MicroSD Card	40
120	4.3.4.5 LED Lights	41



121	4.3.4.6 Power Supply	43
122	4.3.4.7 4 Channel Relay Module	44
123	4.4 Software Considerations	46
124	4.4.1 PyTorch	46
125	4.4.2 OpenCV	46
126	4.4.3 Tkinter	46
127	4.4.4 CustomTkinter	46
128	4.5 Security and Reliability Considerations	46
129	4.6 Scalability and Efficiency Considerations	46
130	4.7 User Interface	47
131	4.8 Constraints and Limitations	47
132	4.9 Technical Standards	47
133	4.10 Prototyping and Simulation	47
134	4.11 Design Validation	48
135	4.12 Summary	48
136	Chapter 5 METHODOLOGY	49
137	5.1 Introduction	52
138	5.2 Research Approach	52
139	5.3 Hardware Design	52
140	5.4 Software Design	53
141	5.5 Data Collection Methods	54
142	5.6 Testing and Evaluation Methods	54
143	5.6.1 Ripeness Training and Testing	55
144	5.6.2 Bruises Training and Testing	55
145	5.6.3 Size Determination	55
146	5.7 Formula for User Priority	55
147	5.8 Ethical Considerations	55
148	5.9 Summary	56
149	Chapter 6 RESULTS AND DISCUSSIONS	57
150	6.1 Training and Testing Results of the Model	62
151	6.1.1 Ripeness Classification Results	62
152	6.1.2 Bruises Classification Results	63
153	6.2 Size Determination Results	64
154	6.3 User Priority Formula	64
155	6.4 Physical Prototype	64
156	6.5 Software Application	64
157	6.6 Summary	64



158	Chapter 7 CONCLUSIONS, RECOMMENDATIONS, AND FUTURE DIRECTIVES	65
159	7.1 Concluding Remarks	66
160	7.2 Contributions	66
161	7.3 Recommendations	66
162	7.4 Future Prospects	66
164	References	68
165	Appendix A STUDENT RESEARCH ETHICS CLEARANCE	70
166	Appendix B ANSWERS TO QUESTIONS TO THIS THESIS	72
167	Appendix C REVISIONS TO THE PROPOSAL	81
168	Appendix D REVISIONS TO THE FINAL	87
169	Appendix E VITA	91
170	Appendix F ARTICLE PAPER(S)	92



171

LIST OF FIGURES

172	1.1	Carabao Mangoes at Different Ripeness Stages (Guillermo et al., 2019)	2
173	1.2	Gantt Chart	13
174	3.1	Theoretical Framework Diagram.	24
175	3.2	Conceptual Framework Diagram.	25
176	4.1	Hardware Schematic	32
177	4.2	Prototype Framework	33
178	4.3	Prototype Main Flowchart	34
179	4.4	Initial 3D Model of the Prototype	35
180	4.5	Raspberry Pi 4 Model B	36
181	4.6	Raspberry Pi Camera Module Version 2	38
182	4.7	12 Volt DC Gear Motor	39
183	4.8	SanDisk Ultra MicroSD Card	41
184	4.9	LED Light Strip	42
185	4.10	Bench Power Supply	43
186	4.11	4 Channel Relay Module	44
187	6.1	Bruises Confusion Matrix	63



188 LIST OF TABLES

189	1.1	Expected Deliverables per Objective	8
190	1.1	Expected Deliverables per Objective	9
191	2.1	Comparison of Existing Studies	18
192	2.2	Comparison of Sorting Algorithm Models	21
193	3.1	Confusion Matrix Example	27
194	5.1	Summary of methods for reaching the objectives	50
195	6.1	Summary of methods for achieving the objectives	58
196	6.2	Performance Metrics for different EfficientNet versions	62
197	6.3	Bruises Classification Report	63
198	6.4	Summarized Classification Report	63
199	D.1	Summary of Revisions to the Thesis	88



200 ABBREVIATIONS

201	AC	Alternating Current	13
202	CNN	Convolution Neural Network	14
203	GUI	Graphical User Interface.....	47
204	LED	Light Emitting Diode.....	41
205	UI	User Interface	47



206

NOTATION

207	$B(P)$	Bruises Priority	64
208	$b(p)$	Bruises Prediction	64
209	$R(P)$	Ripeness Priority	64
210	$r(p)$	Ripeness Prediction	64
211	$S(P)$	Size Priority	64
212	$s(p)$	Size Prediction	64
213	$D(p, d, f)$	Real World Dimension	26
214	p	Pixel Dimension	26
215	d	Distance from Camera to Object	26
216	f	Focal Length	26



217 GLOSSARY

218	bruises	The black or brown area of the mango that is visible on the skin of the mango.
219	Carabao mango	A popular variety of mango grown in the Philippines, known for its sweet and juicy flesh.
220	accuracy score	A performance metric that measures the overall proportion of correct predictions made by a machine learning model.
221	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.
222	CNN	A type of deep neural network that is highly effective in analyzing and processing visual data, such as images.
223	F1-Score	A balanced performance metric that is the harmonic mean of precision and recall, taking both into account.
224	machine learning	A subset of Artificial Intelligence that enables systems to learn and improve from data.
225	computer vision	The use of cameras and algorithms to provide imaging-based inspection and analysis.
226	microcontroller	A small computing device that controls other parts of a system such as sensors.
227	Precision	A performance metric that reflects the percentage of instances classified as positive that are truly positive.
228	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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231

Chapter 1

232

INTRODUCTION



233 **1.1 Background of the Study**

234 Mangoes, also known as the *Mangifera indica*, are a member of the cashew family. This
235 fruit can often be seen being farmed by countries such as Myanmar, the Philippines, and
236 India as they have a tropical dry season. Being in a tropical country is an important
237 aspect for mango cultivation as it ensures proper growth for mangoes. If aspects such as
238 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)

239
240 It is known for its sweet signature taste that was recognized sweetest in the world in the
241 Guinness Book of World Records in 1995. The mango was named after the national animal
242 of the Philippines, a native breed of buffalo. On average, it is 12.5 cm in length and 8.5
243 cm in diameter, having a bright yellow color when ripe as seen in Figure 1.1. It is often
244 cultivated during late May to early July (DBpedia, nd).

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



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

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

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

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



273 the MaZda package is the B11 program, which uses Principal Component Analysis, Linear
274 Discriminant Analysis, Nonlinear Discriminant Analysis, and texture classification to
275 extract features from the mango, which in this case are the length, width, and texture. This
276 data is then compared to a database in order to classify any given mango (Abbas et al.,
277 2018).

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

288 1.2 Prior Studies

289 A paper written by Amna et al. (2023), designed an automated fruit sorting machine based
290 on the quality through an image acquisition system and CNN. Furthermore, the results
291 of the paper show that the image processing detection score was 89% while that of the
292 tomatoes was 92% while the CNN model had higher validity of 95% for mangoes and
293 93% for tomatoes. 15%, while the percentage of distinction between the two groups was
294 reported to be 5% respectively (Amna et al., 2023). Despite the high accuracy score in



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

297 Furthermore, the research paper presented by Guillergan et al. (2024) designed an
298 Automated Carabao mango classifier, in which the mango image database is used to extract
299 the features like size, area along with the ratio of the spots for grading using Naïve Bayes
300 Model. For the results, the Naïve Bayes' model recognized large and rejected mangoes with
301 95% accuracy and the large and small/medium difference with a 7% error, suggesting an
302 application for quality differentiation and sorting in the mango business industry. Despite
303 the high accuracy of classifying Carabao mangoes, the researchers used a high quality
304 DSLR camera for the image acquisition system without any microcontroller to control the
305 mangoes (Guillergan et al., 2024).

306 **1.3 Problem Statement**

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



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

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

330 **1.4 Objectives and Deliverables**

331 **1.4.1 General Objective (GO)**

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



335 **1.4.2 Specific Objectives (SOs)**

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

351 **1.4.3 Expected Deliverables**

352 Table 1.1 shows the outputs, products, results, achievements, gains, realizations, and/or
353 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.

354

1.5 Significance of the Study

355

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.

356

357

358



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

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

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

374 **1.5.1 Technical Benefit**

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



381 **1.5.2 Social Impact**

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

389 **1.5.3 Environmental Welfare**

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

395 **1.6 Assumptions, Scope, and Delimitations**

396 **1.6.1 Assumptions**

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



1.6.2 Scope

- 406 1. The prototype would be specifically designed to grade and sort Carabao Mangoes
407 based on only ripeness, size, and visible skin bruises.

408 2. The mangoes used as the subject will be solely sourced from markets in the Philip-
409 pines.

410 3. The Carabao mangoes would be graded into three levels.

411 4. The prototype will be using a microcontroller-based system locally stored on the
412 device itself to handle user interaction.

413 5. Computer vision algorithms to be used will include image classification.

1.6.3 Delimitations



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

426 **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

427 As seen above, Table 1.2 shows the Gantt Chart together with the assigned task. For
 428 the first part of the THSCP4A, the group would primarily revise and fine tune Chapters
 429 1 and 2 while also preparing for the defense. After that for THSCP4B, the yellow team
 430 which consists of two members, Hermosura and Salazar, would start buying and collecting



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

439 **1.8 Overview of the Thesis**

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



450

Chapter 2

451

LITERATURE REVIEW



452 **2.1 Existing Work**

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

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



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

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



499 heat units, rainfall, and physical fruit attributes for Haden, Kent, Palmer, and Keitt mango
 500 varieties to establish export and domestic market maturity standards. For the results of
 501 the paper, it shows that temperature, rainfall, and physical characteristics have a reliable,
 502 non-destructive indicators for determining mango maturity (Abu et al., 2021). This shows
 503 that physical characteristics and temperature are important when exporting fruits such as
 504 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%

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



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

516 **2.1.1 Sorting Algorithms**

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

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



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

553 2.2 Lacking in the Approaches

554 The majority of past researchers such as Amna et al. (2023) and Guillermo et al. (2019)
555 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

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

562 2.3 Summary

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



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567 On the other hand, although researchers have already taken steps to automate the process
568 of mango sorting and grading, there is still a need for an implementation that takes into
569 account size, ripeness, and bruises altogether whilst being non-destructive and having its
570 own embedded system. The research articles shown above show the different computer
571 vision and CNN approaches for sorting and classifying mangoes. For example, a system
572 created by Adam et al. (2022) was more focused on ripeness detection. Samaniego et al.
573 (2023) considered photonic systems for grading mango fruit based on color and weight.
574 On the other hand, Guillermo et al. (2019) implemented the Naïve Bayes classification
575 model on mangoes with high accuracy, which thereby did not include any microcontroller.
576 There was an attempt to study each of those parameters separately and that is why the
577 multifactorial approach was not used. With this in mind, the system being proposed does
578 exactly what was mentioned, to implement a non-destructive and automated sorting and
579 grading system for Carabao mangoes that takes into account size, ripeness, and bruises
580 altogether using machine learning, as well as having its own embedded system. This system
581 will be mainly composed of a conveyor belt, servo motors, a camera, microcontrollers, and
582 an LCD display for the user interface. By doing so, the system should be able to improve
583 the efficiency and productivity of mango sorting and grading, remove the effect of human
584 error and reduce time consumption. The studies also provided critical insights regarding the
585 effective algorithms that can be used in classification stages in image processing. The use
586 of CNN had the most accuracy with manageable potential challenges. Lastly, by scaling
587 the implementation, the overall export quality of the Carabao mangoes can be improved.



588

Chapter 3

589

THEORETICAL CONSIDERATIONS



590 3.1 Introduction

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

593 3.2 Relevant Theories and Models

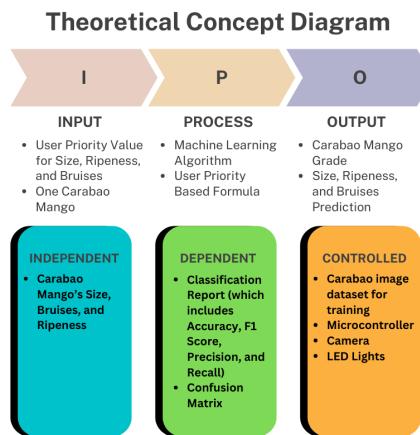


Fig. 3.1 Theoretical Framework Diagram.

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



3.3 Technical Background

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

3.4 Conceptual Framework Background

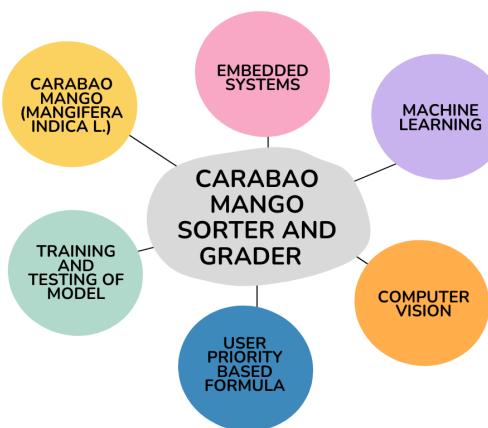


Fig. 3.2 Conceptual Framework Diagram.

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



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

620 **3.5 Software Concepts**

621 **3.5.1 Thresholding**

622 **3.5.2 Object Size Calculation**

623 The size of the mango can be determined given:

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

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

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



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

TABLE 3.1 CONFUSION MATRIX EXAMPLE

627 **3.5.3 Convolutional Neural Network**628 **3.5.4 Classification Report**629 **3.5.4.1 Confusion Matrix**

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

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

636 **3.5.4.2 Precision**

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

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



640

3.5.4.3 Recall

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

641

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

644

3.5.4.4 F1 Score

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

645

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

648

3.5.4.5 Accuracy

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

649

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



652 **3.6 Hardware Concepts**

653 **3.6.1 Camera Module**

654 **3.6.2 4 Channel Relay**

655 **3.6.3 1:3 Pulley Belt**

656 **3.7 Summary**

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



662

Chapter 4

663

DESIGN CONSIDERATIONS



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

670 **4.1 Introduction**

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

675 **4.2 System Architecture**

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

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

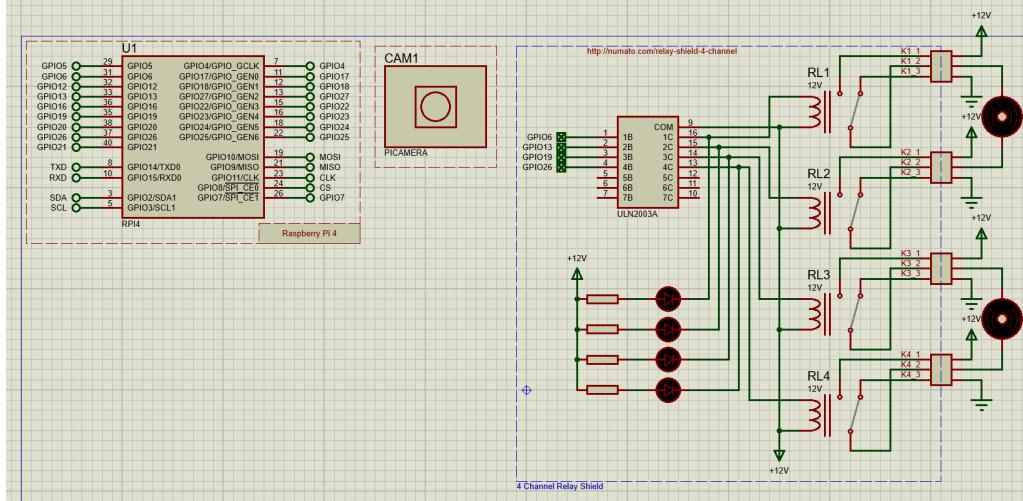


Fig. 4.1 Hardware Schematic

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

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

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



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

701 4.3 Hardware Considerations

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

706 4.3.1 General Prototype Framework

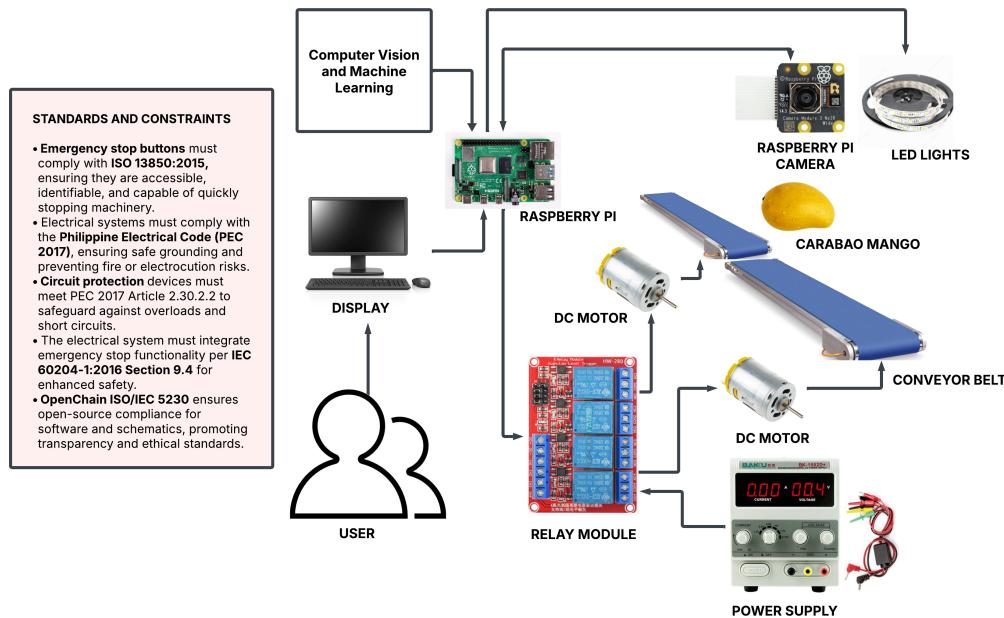


Fig. 4.2 Prototype Framework



707

4.3.2 Prototype Flowchart

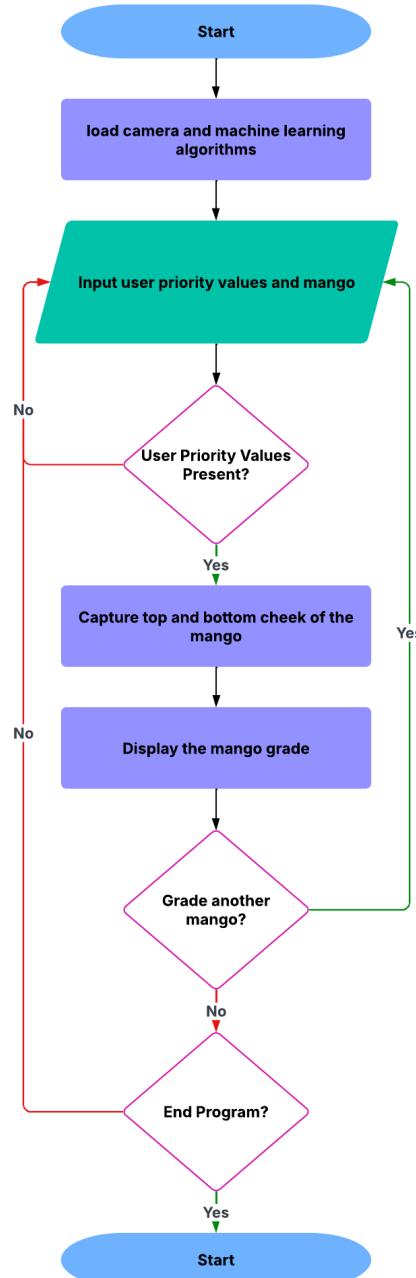


Fig. 4.3 Prototype Main Flowchart



708

4.3.3 Prototype 3D Model

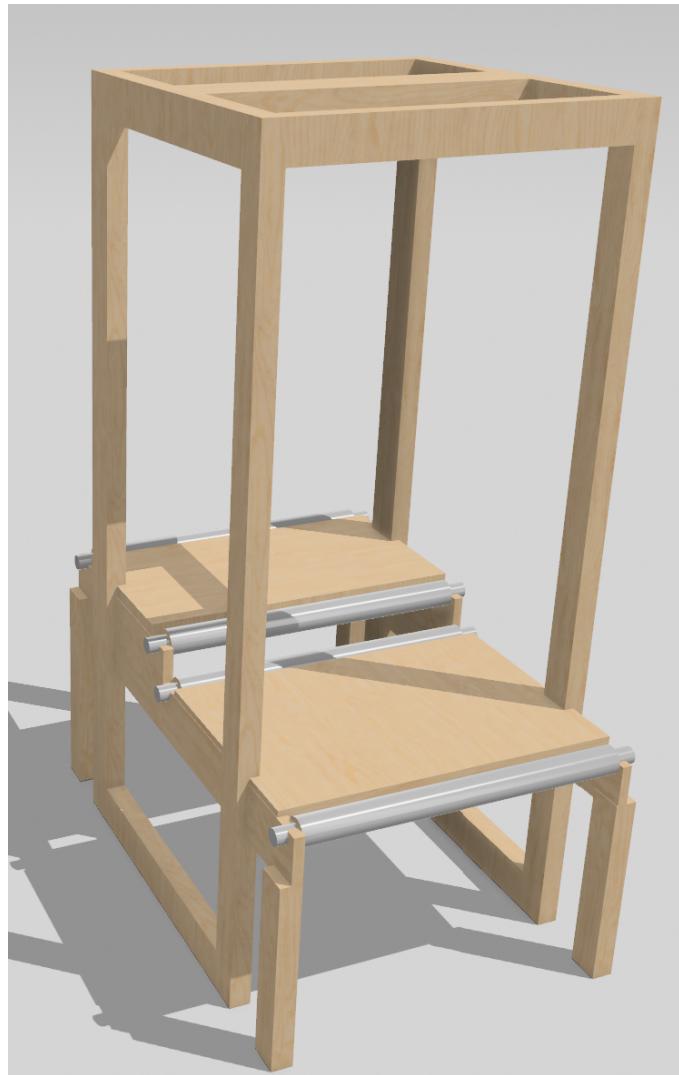


Fig. 4.4 Initial 3D Model of the Prototype

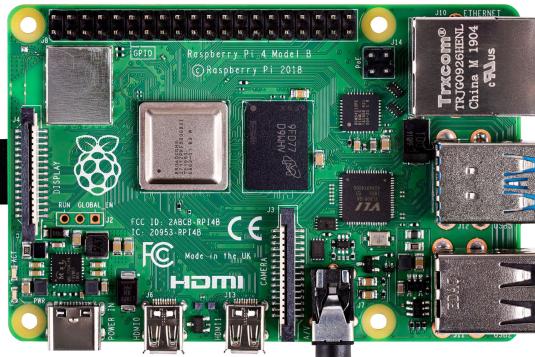


Fig. 4.5 Raspberry Pi 4 Model B

709 **4.3.4 Hardware Specifications**710 **4.3.4.1 Raspberry Pi**711 The Raspberry Pi 4 Model B is a compact, low-cost computer that serves as the system's
712 main processing unit. It was chosen for its balance of performance and affordability, making
713 it suitable for image processing tasks. Furthermore, it was selected for its compatibility
714 with various peripherals through the GPIO pins and USB-A ports together with its ease of
715 integration into the prototype.

716

717 **Specifications:**

- 718
- SoC: Broadcom BCM2711
 - CPU: Quad-core ARM Cortex-A72 (64-bit)



- 720 • Clock Speed: 1.5 GHz (base, overclockable)
- 721 • RAM: 8GB LPDDR4-3200 SDRAM
- 722 • Wireless: Dual-band 2.4 GHz / 5 GHz Wi-Fi (802.11ac)
- 723 • Bluetooth: Bluetooth 5.0 (BLE support)
- 724 • Ethernet: Gigabit Ethernet (full throughput)
- 725 • USB: 2 x USB 3.0 ports and 2 x USB 2.0 ports
- 726 • Video Output: 2 x micro-HDMI ports (supports 4K @ 60Hz, dual 4K display capability)
- 727 • Audio: 3.5mm audio/video composite jack
- 728 • Storage: MicroSD card slot (supports booting via SD card or USB)
- 729 • GPIO: 40-pin GPIO header (backward-compatible with older models)
- 730 • Camera/Display: CSI (camera) and DSI (display) ports
- 731 • Power Input: USB-C (5V/3A recommended)
- 732 • Power Consumption: 3W idle, up to 7.5W under load

734 **4.3.4.2 Raspberry Pi Camera**

735 The Raspberry Pi Camera Module Version 2 is a high-quality camera module designed for
736 the Raspberry Pi platform. Likewise, it is capable of capturing still images at 8 megapixels,
737 and supports video recording at 1080p @ 30fps, 720p @ 60fps, and 480p @ 90fps. More-
738 over, it has a fixed-focus lens with a diagonal field of view of 62.2 degrees, and an optical

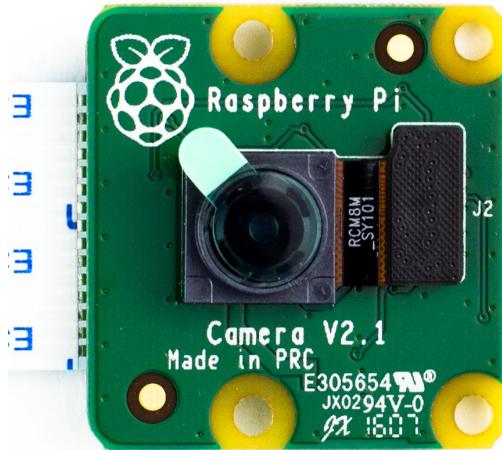


Fig. 4.6 Raspberry Pi Camera Module Version 2

739 format of 1/4 inch. Furthermore, it supports various Python libraries such as Picamera and
740 OpenCV for image capture and processing. As such, it was selected for its compact size,
741 ease of integration, and ability to capture high-resolution images.

742

743 **Specifications:**

- 744 • Sensor: Sony IMX219PQ 8-megapixel CMOS sensor.
- 745 • Still Images Resolution: 8 MP (3280 x 2464 pixels).
- 746 • Video Resolution: Supports up to 1080p @ 30fps, 720p @ 60fps, and 480p @ 90fps.
- 747 • Focus: Fixed-focus lens (manual focus adjustment not supported without physical
748 modification).
- 749 • Lens Size: 1/4-inch optical format.



- 750 • Field of View (FoV): Diagonal 62.2 degrees.
- 751 • Interface: Connected via 15-pin ribbon cable to the Raspberry Pi's CSI (Camera
752 Serial Interface) port.
- 753 • APIs/Libraries: Supports Python libraries such as Picamera and OpenCV for image
754 capture and processing.
- 755 • Dimensions: 25 mm x 24 mm x 9 mm.

756 **4.3.4.3 DC Motor**



Fig. 4.7 12 Volt DC Gear Motor

757 The 12 Volt DC Gear Motor is a compact, high-torque, and low-noise motor suitable for
758 a wide range of applications, including robotics, automation, and industrial control systems.
759 It features a spur gear design, which provides a high reduction ratio for increased torque
760 output. The motor is designed for continuous operation and has a low power consumption



761 under standard load conditions. Likewise, it is also capable of withstanding high temper-
762 atures and has a high reliability. This motor was selected for its high torque output, low
763 power consumption, and compact size, making it ideal for the conveyor system.

764

765 **Specifications:**

- 766 • Gearbox Type: Spur gear design
- 767 • Operating Voltage: 12V (operational range: 6-12V)
- 768 • No-load Current Consumption: 0.8A
- 769 • Rated Current Draw: 3A (under standard load)
- 770 • No-load Speed: 282 RPM (maximum)
- 771 • Operating Speed: 248 RPM (under rated load)
- 772 • Torque Output: 18 kg-cm (rated)
- 773 • Stall Torque: 60 kg-cm (maximum)
- 774 • Power Rating: 50W (maximum)
- 775 • Unit Weight: 350 grams

776 **4.3.4.4 MicroSD Card**

777 The SanDisk Ultra MicroSD Card is a compact, high-capacity, and secure digital memory
778 card that is suitable for a wide range of applications, including digital cameras, smartphones,
779 and tablets. It features a high-speed data transfer rate, making it ideal for storing large



Fig. 4.8 SanDisk Ultra MicroSD Card

files such as images and videos. This card was selected for its high capacity, secure data protection, and ease of use, making it ideal for the storage system for the prototype.

Specifications:

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

4.3.4.5 LED Lights

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



Fig. 4.9 LED Light Strip

792 uniform light output.

793

794 **Specifications:**

795 • Power Input: 5V DC (USB-powered, compatible with laptops, power banks, or USB
796 adapters).

797 • Waterproof Design: Suitable for indoor/outdoor use.

798 • LED Type: SMD 2835 (surface-mount diodes for high brightness and efficiency).

799 • Color Type: White (cool white)

800 • Length: 1m

801 • Beam Angle: 120°

802 • Operating Temperature: -25°C to 60°C.



- 803 • Storage Temperature: -40°C to 80°C.

804 **4.3.4.6 Power Supply**



Fig. 4.10 Bench Power Supply

805 The bench power supply is a versatile and adjustable power source used to provide
806 stable voltage and current for various electronic projects. It is designed for testing applica-
807 tions, allowing users to set specific voltage and current levels. This power supply was
808 selected for its versatility, ease of use, and ability to provide accurate voltage and current
809 control for the prototype.

810

811 **Specifications:**

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



- 814 • Output Range: 0-30V DC / 0-5A DC
- 815 • Voltage Precision: $\pm 0.010V$ (10 mV) resolution
- 816 • Current Precision: $\pm 0.001A$ (1 mA) resolution
- 817 • Power Precision: $\pm 0.1W$ resolution
- 818 • Weight: 5 lbs (2.27 kg)
- 819 • Dimensions: 11.1" x 4.92" x 6.14" (28.2 cm x 12.5 cm x 15.6 cm)
- 820 • Maximum Power: 195W
- 821 • Power Source: AC input only

822 **4.3.4.7 4 Channel Relay Module**



Fig. 4.11 4 Channel Relay Module



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

828

829 **Specifications:**

830 • Operating Voltage: 5V DC (compatible with Arduino, Raspberry Pi, and other
831 microcontrollers).

832 • Number of Relays: 4 independent channels.

833 • Relay Type: Electromechanical (mechanical switching).

834 • Max AC Load: 10A @ 250V AC (resistive).

835 • Max DC Load: 10A @ 30V DC (resistive).

836 • Contact Type: SPDT (Single Pole Double Throw) - NO (Normally Open), NC
837 (Normally Closed), COM (Common).

838 • Dimensions: 50mm x 70mm x 20mm

839 • Weight: 50-80 grams.

840 • Status LEDs: Individual LEDs for each relay (indicates ON/OFF state).

841 • Input Pins: 4 digital control pins (one per relay).

842 • Output Terminals: Screw terminals for connecting loads (NO/NC/COM).



843 **4.4 Software Considerations**

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

847 **4.4.1 PyTorch**

848 **4.4.2 OpenCV**

849 **4.4.3 Tkinter**

850 **4.4.4 CustomTkinter**

851 **4.5 Security and Reliability Considerations**

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

855 **4.6 Scalability and Efficiency Considerations**

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



859 **4.7 User Interface**

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

863 **4.8 Constraints and Limitations**

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

867 **4.9 Technical Standards**

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

870 **4.10 Prototyping and Simulation**

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



874 **4.11 Design Validation**

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

878 **4.12 Summary**

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



882

Chapter 5

883

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. 52
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. 52
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. 54

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.	<ol style="list-style-type: none"> 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. 52
SO4: To grade mangoes based on user priorities for size, ripeness, and bruises.	<ol style="list-style-type: none"> 1. Formula development: Formulated an equation based on the inputted user priority and the predicted mango classification 	Sec. 5.7 on p. 55
SO5: To classify mango ripeness based on image data using machine learning algorithms such as kNN, k-mean, and Naïve Bayes.	<ol style="list-style-type: none"> 1. Performance testing: Train and test the machine learning algorithm for classifying bruises 	Sec. 5.6.2 on p. 55
SO6: To classify mango size based on image data by getting its length and width using OpenCV, geometry, and image processing techniques.	<ol style="list-style-type: none"> 1. Performance testing: Train and test the machine learning algorithm for classifying ripeness 	Sec. 5.6.1 on p. 55
SO7: To classify mango bruises based on image data by employing machine learning algorithms.	<ol style="list-style-type: none"> 1. Accuracy testing: Get the percent accuracy testing for getting the length and width of the Carabao mango 	Sec. 5.6.3 on p. 55



884 **5.1 Introduction**

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

892 **5.2 Research Approach**

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

899 **5.3 Hardware Design**

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



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

908 **5.4 Software Design**

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

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



923 **5.5 Data Collection Methods**

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

934 **5.6 Testing and Evaluation Methods**

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

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



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

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

958 **5.6.1 Ripeness Training and Testing**

959 **5.6.2 Bruises Training and Testing**

960 **5.6.3 Size Determination**

961 **5.7 Formula for User Priority**

962 **5.8 Ethical Considerations**

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



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

972 **5.9 Summary**

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



981

Chapter 6

982

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. 64
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. 64

Continued on next page

6. Results and Discussions



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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. 62</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. 64</p>

Continued on next page

6. Results and Discussions



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Continued from previous page

Objectives	Methods	Locations
SO4: To grade mangoes based on user priorities for size, ripeness, and bruises.	<p>Expected Results:</p> <ul style="list-style-type: none"> 1. Successfully grade mangoes based on the user priorities on the physical characteristics of the mango 2. Successfully verified with qualified individual the results 3. Successfully utilize the weighted equation to evaluate mango grade based on user priorities <p>Actual Results:</p> <ul style="list-style-type: none"> 1. Successfully grade mangoes based on the user priorities on the physical characteristics of the mango 2. Successfully utilize the weighted equation to evaluate mango grade based on user priorities 3. Need to look for a qualified person to evaluate the graded mango for ground truth 	Sec. 6.3 on p. 64

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. 62</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. 64</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. 63

983

6.1 Training and Testing Results of the Model

984

6.1.1 Ripeness Classification Results

985

Add the F1-Score and etc here

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

TABLE 6.2 PERFORMANCE METRICS FOR DIFFERENT EFFICIENTNET VERSIONS



986

6.1.2 Bruises Classification Results

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

TABLE 6.3 BRUISES CLASSIFICATION REPORT

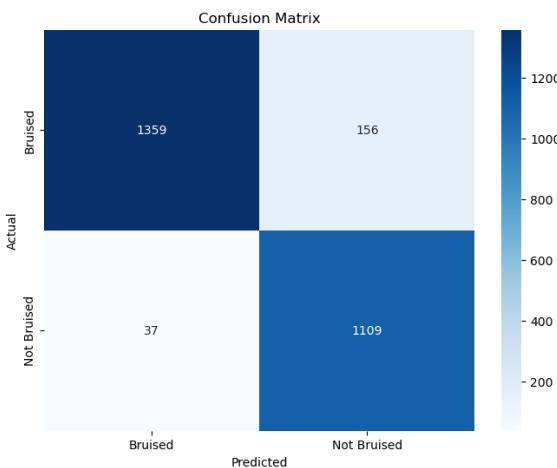


Fig. 6.1 Bruises Confusion Matrix

Metrics	Results
Precision	0.9318
Recall	0.9275
F1 Score	0.9278

TABLE 6.4 SUMMARIZED CLASSIFICATION REPORT



987 **6.2 Size Determination Results**

988 **6.3 User Priority Formula**

989 $B(P)$ and $R(P)$ and $S(P)$ are the User Priority-Based Grading for bruises, ripeness,
990 and size of the Carabao mango. Furthermore, $b(p)$ and $r(p)$ and $s(p)$ are the machine
991 learning's predictions for bruises, ripeness, and size of the Carabao mango. The formula
992 for the user priority is given by:

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

993 **6.4 Physical Prototype**

994 Add pictures of the hardware prototype here with description

995 **6.5 Software Application**

996 Show the raspberry pi app UI and demonstrate it here

997 **6.6 Summary**

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



999 **Chapter 7**

1000 **CONCLUSIONS, RECOMMENDATIONS, AND**
1001 **FUTURE DIRECTIVES**



7.1 Concluding Remarks

In this Thesis, ...

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

7.2 Contributions

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

• the ;

• the ;

• the ;

7.3 Recommendations

The researchers recommend...

7.4 Future Prospects

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



1019 1. the

1020 2. the

1021 3. the

1022 Note that for ECE undergraduate theses, as per the directions of the thesis adviser,
1023 Recommendations and Future Directives will be removed for the hardbound copy but will
1024 be retained for database storage.



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Produced: April 1, 2025, 16:40



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1078

Appendix A STUDENT RESEARCH ETHICS CLEARANCE

1079

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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1081

Appendix B ANSWERS TO QUESTIONS TO THIS THESIS

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1115 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit
 1116 amet ipsum. Nunc quis urna dictum turpis accumsan semper.

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

1118 Lorem ipsum dolor sit amet, consectetur adipiscing elit. Etiam lobortis facilisis sem.
 1119 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec
 1120 ullamcorper, felis non sodales commodo, lectus velit ultrices augue, a dignissim nibh lectus
 1121 placerat pede. Vivamus nunc nunc, molestie ut, ultricies vel, semper in, velit. Ut porttitor.
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 1125 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit
 1126 amet ipsum. Nunc quis urna dictum turpis accumsan semper.

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

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 1129 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec
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 1136 amet ipsum. Nunc quis urna dictum turpis accumsan semper.

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

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 1139 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec
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 1146 amet ipsum. Nunc quis urna dictum turpis accumsan semper.



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

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

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

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

1179 Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Etiam lobortis facilisis sem.
 1180 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec
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 1186 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit
 1187 amet ipsum. Nunc quis urna dictum turpis accumsan semper.
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B4.2 Can your proposed solution/s be applied to more general cases when some assumptions are eliminated? If so, how?

1190 Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Etiam lobortis facilisis sem.
 1191 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec
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 1194 Praesent in sapien. Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Duis fringilla
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 1196 a leo. Morbi sed elit sit amet ante lobortis sollicitudin. Praesent blandit blandit mauris.
 1197 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit
 1198 amet ipsum. Nunc quis urna dictum turpis accumsan semper.
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B5 What is the necessity of your approach / proposed solution/s?

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 1202 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec
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 1208 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit
 1209 amet ipsum. Nunc quis urna dictum turpis accumsan semper.
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B5.1 What will be the limits of applicability of your proposed solution/s?

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 1213 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec
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 1219 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit
 1220 amet ipsum. Nunc quis urna dictum turpis accumsan semper.
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B5.2 What will be the message of the proposed solution to technical people? How about to non-technical managers and business people?

1223 Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Etiam lobortis facilisis sem.
 1224 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec
 1225 ullamcorper, felis non sodales commodo, lectus velit ultrices augue, a dignissim nibh lectus
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 1230 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit
 1231 amet ipsum. Nunc quis urna dictum turpis accumsan semper.
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B6 How will you know if your proposed solution/s is/are correct?

1235 Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Etiam lobortis facilisis sem.
 1236 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec
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 1245 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)?**

1248 Lorem ipsum dolor sit amet, consectetur adipiscing elit. Etiam lobortis facilisis sem.
 1249 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdier mi nec ante. Donec
 1250 ullamcorper, felis non sodales commodo, lectus velit ultrices augue, a dignissim nibh lectus
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 1252 Praesent in sapien. Lorem ipsum dolor sit amet, consectetur adipiscing elit. Duis fringilla
 1253 tristique neque. Sed interdum libero ut metus. Pellentesque placerat. Nam rutrum augue
 1254 a leo. Morbi sed elit sit amet ante lobortis sollicitudin. Praesent blandit blandit mauris.
 1255 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit
 1256 amet ipsum. Nunc quis urna dictum turpis accumsan semper.

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

1259 Lorem ipsum dolor sit amet, consectetur adipiscing elit. Etiam lobortis facilisis sem.
 1260 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdier mi nec ante. Donec
 1261 ullamcorper, felis non sodales commodo, lectus velit ultrices augue, a dignissim nibh lectus
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 1263 Praesent in sapien. Lorem ipsum dolor sit amet, consectetur adipiscing elit. Duis fringilla
 1264 tristique neque. Sed interdum libero ut metus. Pellentesque placerat. Nam rutrum augue
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 1266 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit
 1267 amet ipsum. Nunc quis urna dictum turpis accumsan semper.

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

1270 Lorem ipsum dolor sit amet, consectetur adipiscing elit. Etiam lobortis facilisis sem.
 1271 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdier mi nec ante. Donec
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 1277 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit
 1278 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?

1281 Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Etiam lobortis facilisis sem.
 1282 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec
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 1289 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.

1294 Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Etiam lobortis facilisis sem.
 1295 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec
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 1301 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit
 1302 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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 1304 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec



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1311 a leo. Morbi sed elit sit amet ante lobortis sollicitudin. Praesent blandit blandit mauris.
1312 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit
1313 amet ipsum. Nunc quis urna dictum turpis accumsan semper.



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Appendix C REVISIONS TO THE PROPOSAL

C. Revisions to the Proposal



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1316

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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1317

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



1318

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



1319

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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1320

PRO1 Panel Comments and Revisions – Appendix Z

4. Implement data augmentation techniques to enhance your image dataset, which can improve model generalization and accuracy.
5. Design an intuitive user interface for the Raspberry Pi application.
6. Besides precision, recall, and F1 score, consider incorporating confusion matrices to better understand model performance and error types.
7. Conduct user testing of the application to gather feedback on usability and functionality. This can lead to improvements in design and user experience. Consider how the system can be scaled or adapted for different fruits or larger processing volumes in the future.

Noted by:



Dr. Donabel de Veas Abuan
Chair of Panel

Date: November 11 2024

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



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Appendix D REVISIONS TO THE FINAL

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- 1323 Make a table with the following columns for showing the summary of revisions to the
 1324 proposal based on the comments of the panel of examiners.
- 1325 1. Examiner
- 1326 2. Comment
- 1327 3. Summary of how the comment has been addressed
- 1328 4. Locations in the document where the changes have been reflected

TABLE D.1 SUMMARY OF REVISIONS TO THE THESIS

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

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D. Revisions to the Final



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Continued from previous page

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

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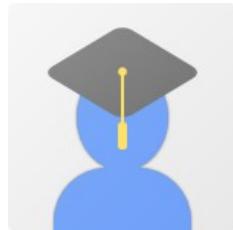
Examiner	Comment	Summary of how the comment has been addressed	Locations
Dr. Alexander Co Abad	1. First itemtext 2. Second itemtext 3. Last itemtext 4. First itemtext 5. Second itemtext	1. First itemtext 2. Second itemtext 3. Last itemtext 4. First itemtext 5. Second itemtext	Sec. ?? on p. ??, Sec. ??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



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Appendix E VITA

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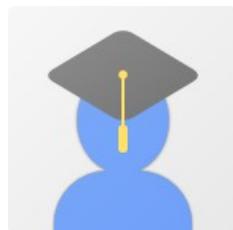


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Kenan A. Banal is currently taking up his B.Sc. Computer Engineering studies. He is passionate about software and hardware systems such as Vivado, Arduino, C, and Python.

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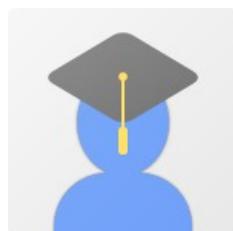


1334

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

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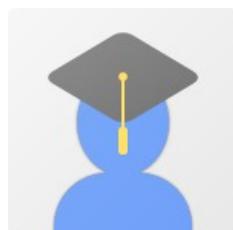


1337

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

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1340

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

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Appendix F ARTICLE PAPER(S)

1344

Article/Forum Paper Format

(IEEE LaTeX format)

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

1345

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

Index Terms—Computer Society, IEEE, IEEEtran, journal, L^AT_EX, paper, template.

I. INTRODUCTION

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

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

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



Fig. 1. Simulation results for the network.

TABLE I
AN EXAMPLE OF A TABLE

One	Two
Three	Four

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II. CONCLUSION

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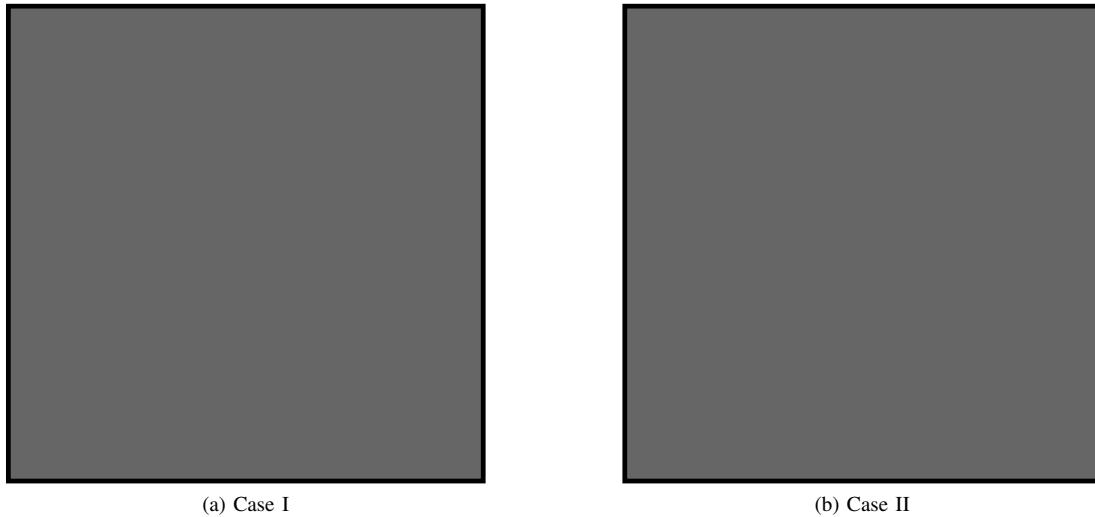


Fig. 2. Simulation results for the network.

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APPENDIX A PROOF OF THE FIRST ZONKLAR EQUATION

Appendix one text goes here.

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APPENDIX B

Appendix two text goes here. [?].

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ACKNOWLEDGMENT

The authors would like to thank...