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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 March, 2025



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ORAL DEFENSE RECOMMENDATION SHEET

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

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

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38

ABSTRACT

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

53
54

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



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ABBREVIATIONS

189	AC	Alternating Current	13
190	CNN	Convolution Neural Network	14
191	DC	Direct Current	24
192	GUI	Graphical User Interface	43
193	LED	Light Emitting Diode	38
194	UI	User Interface	43



195

NOTATION

196	$B(P)$	Bruises Priority	60
197	$b(p)$	Bruises Prediction	60
198	$R(P)$	Ripeness Priority	60
199	$r(p)$	Ripeness Prediction	60
200	$S(P)$	Size Priority	60
201	$s(p)$	Size Prediction	60



202 GLOSSARY

203	accuracy score	A performance metric that measures the overall proportion of correct predictions made by a machine learning model.
204	bruises	The black or brown area of the mango that is visible on the skin of the mango.
205	Carabao mango	A popular variety of mango grown in the Philippines, known for its sweet and juicy flesh.
206	CNN	A type of deep neural network that is highly effective in analyzing and processing visual data, such as images.
207	computer vision	The use of cameras and algorithms to provide imaging-based inspection and analysis.
208	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.
209	F1-Score	A balanced performance metric that is the harmonic mean of precision and recall, taking both into account.
210	machine learning	A subset of Artificial Intelligence that enables systems to learn and improve from data.
211	microcontroller	A small computing device that controls other parts of a system such as sensors.
212	Precision	A performance metric that reflects the percentage of instances classified as positive that are truly positive.
213	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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Chapter 1

217

INTRODUCTION



218 **1.1 Background of the Study**

219 Mangoes, also known as the *Mangifera indica*, are a member of the cashew family. This
220 fruit can often be seen being farmed by countries such as Myanmar, the Philippines, and
221 India as they have a tropical dry season. Being in a tropical country is an important
222 aspect for mango cultivation as it ensures proper growth for mangoes. If aspects such as
223 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)

224
225 It is known for its sweet signature taste that was recognized sweetest in the world in the
226 Guinness Book of World Records in 1995. The mango was named after the national animal
227 of the Philippines, a native breed of buffalo. On average, it is 12.5 cm in length and 8.5
228 cm in diameter, having a bright yellow color when ripe as seen in Figure 1.1. It is often
229 cultivated during late May to early July (DBpedia, nd).

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



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

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

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

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



258 the MaZda package is the B11 program, which uses Principal Component Analysis, Linear
259 Discriminant Analysis, Nonlinear Discriminant Analysis, and texture classification to
260 extract features from the mango, which in this case are the length, width, and texture. This
261 data is then compared to a database in order to classify any given mango (Abbas et al.,
262 2018).

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

273 1.2 Prior Studies

274 A paper written by Amna et al. (2023), designed an automated fruit sorting machine based
275 on the quality through an image acquisition system and CNN. Furthermore, the results
276 of the paper show that the image processing detection score was 89% while that of the
277 tomatoes was 92% while the CNN model had higher validity of 95% for mangoes and
278 93% for tomatoes. 15%, while the percentage of distinction between the two groups was
279 reported to be 5% respectively (Amna et al., 2023). Despite the high accuracy score in



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

282 Furthermore, the research paper presented by Guillergan et al. (2024) designed an
283 Automated Carabao mango classifier, in which the mango image database is used to extract
284 the features like size, area along with the ratio of the spots for grading using Naïve Bayes
285 Model. For the results, the Naïve Bayes' model recognized large and rejected mangoes with
286 95% accuracy and the large and small/medium difference with a 7% error, suggesting an
287 application for quality differentiation and sorting in the mango business industry. Despite
288 the high accuracy of classifying Carabao mangoes, the researchers used a high quality
289 DSLR camera for the image acquisition system without any microcontroller to control the
290 mangoes (Guillergan et al., 2024).

291 **1.3 Problem Statement**

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



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

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

315 **1.4 Objectives and Deliverables**

316 **1.4.1 General Objective (GO)**

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



320 1.4.2 Specific Objectives (SOs)

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

336 1.4.3 Expected Deliverables

337 Table 1.1 shows the outputs, products, results, achievements, gains, realizations, and/or
338 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.

339

1.5 Significance of the Study

340

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.

341

342

343



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

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

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

359 **1.5.1 Technical Benefit**

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



366 **1.5.2 Social Impact**

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

374 **1.5.3 Environmental Welfare**

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

380 **1.6 Assumptions, Scope, and Delimitations**

381 **1.6.1 Assumptions**

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



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

390 **1.6.2 Scope**

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

399 **1.6.3 Delimitations**

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



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

411 **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

412 As seen above, Table 1.2 shows the Gantt Chart together with the assigned task. For
 413 the first part of the THSCP4A, the group would primarily revise and fine tune Chapters
 414 1 and 2 while also preparing for the defense. After that for THSCP4B, the yellow team
 415 which consists of two members, Hermosura and Salazar, would start buying and collecting



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

424 **1.8 Overview of the Thesis**

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



435

Chapter 2

436

LITERATURE REVIEW



437 **2.1 Existing Work**

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

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



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

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



484 heat units, rainfall, and physical fruit attributes for Haden, Kent, Palmer, and Keitt mango
 485 varieties to establish export and domestic market maturity standards. For the results of
 486 the paper, it shows that temperature, rainfall, and physical characteristics have a reliable,
 487 non-destructive indicators for determining mango maturity (Abu et al., 2021). This shows
 488 that physical characteristics and temperature are important when exporting fruits such as
 489 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%

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



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

501 **2.1.1 Sorting Algorithms**

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

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



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

538 **2.2 Lacking in the Approaches**

539 The majority of past researchers such as Amna et al. (2023) and Guillermo et al. (2019)
540 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

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

547 2.3 Summary

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



552 On the other hand, although researchers have already taken steps to automate the process
553 of mango sorting and grading, there is still a need for an implementation that takes into
554 account size, ripeness, and bruises altogether whilst being non-destructive and having its
555 own embedded system. The research articles shown above show the different computer
556 vision and CNN approaches for sorting and classifying mangoes. For example, a system
557 created by Adam et al. (2022) was more focused on ripeness detection. Samaniego et al.
558 (2023) considered photonic systems for grading mango fruit based on color and weight.
559 On the other hand, Guillermo et al. (2019) implemented the Naïve Bayes classification
560 model on mangoes with high accuracy, which thereby did not include any microcontroller.
561 There was an attempt to study each of those parameters separately and that is why the
562 multifactorial approach was not used. With this in mind, the system being proposed does
563 exactly what was mentioned, to implement a non-destructive and automated sorting and
564 grading system for Carabao mangoes that takes into account size, ripeness, and bruises
565 altogether using machine learning, as well as having its own embedded system. This system
566 will be mainly composed of a conveyor belt, servo motors, a camera, microcontrollers, and
567 an LCD display for the user interface. By doing so, the system should be able to improve
568 the efficiency and productivity of mango sorting and grading, remove the effect of human
569 error and reduce time consumption. The studies also provided critical insights regarding the
570 effective algorithms that can be used in classification stages in image processing. The use
571 of CNN had the most accuracy with manageable potential challenges. Lastly, by scaling
572 the implementation, the overall export quality of the Carabao mangoes can be improved.



573

Chapter 3

574

THEORETICAL CONSIDERATIONS



575 3.1 Introduction

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

578 3.2 Relevant Theories and Models

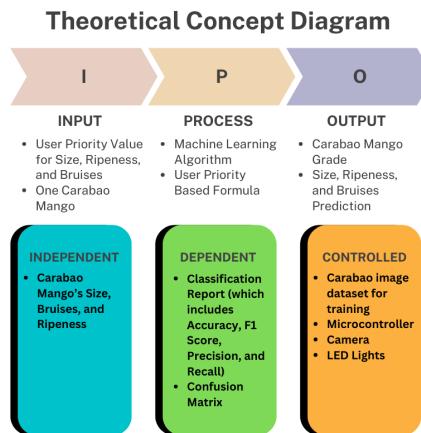


Fig. 3.1 Theoretical Framework Diagram.

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



587 3.3 Technical Background

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

595 3.4 Conceptual Framework Background

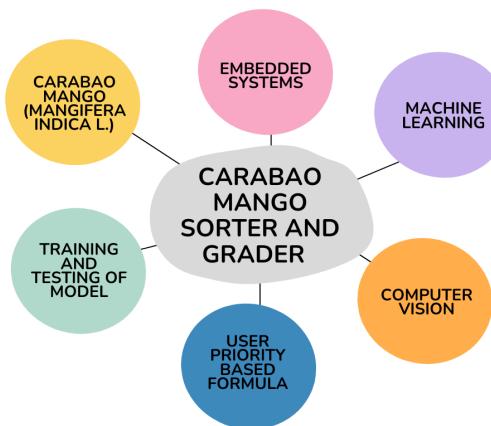


Fig. 3.2 Conceptual Framework Diagram.

596 **3.5 Software Concepts**597 **3.5.1 Thresholding**598 **3.5.2 Object Size Calculation**599 **3.5.3 Convolutional Neural Network**600 **3.6 Hardware Concepts**601 **3.6.1 DC Motor**602 **3.6.2 4 Channel Relay**603 **3.6.3 1:3 Pulley Belt**604 **3.7 Summary**

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



610

Chapter 4

611

DESIGN CONSIDERATIONS



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

618 **4.1 Introduction**

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

623 **4.2 System Architecture**

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



630 4.3 Hardware Considerations

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

635 4.3.1 General Prototype Framework

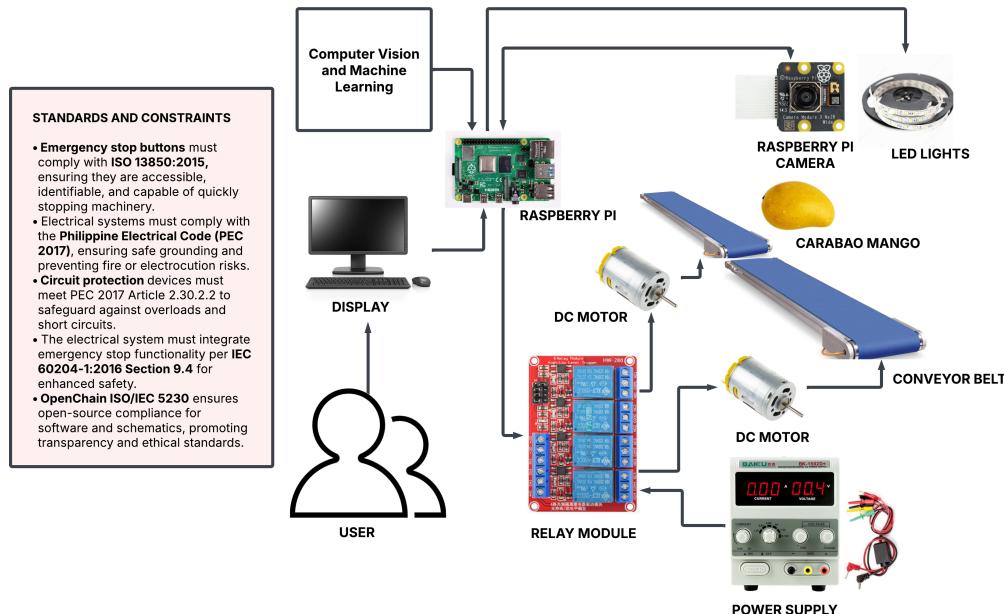


Fig. 4.1 Prototype Framework

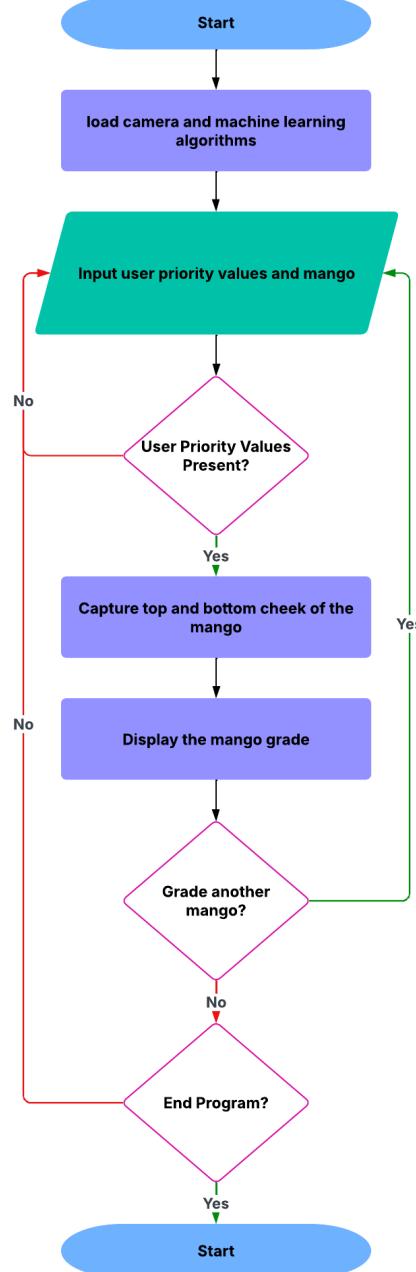


Fig. 4.2 Prototype Main Flowchart



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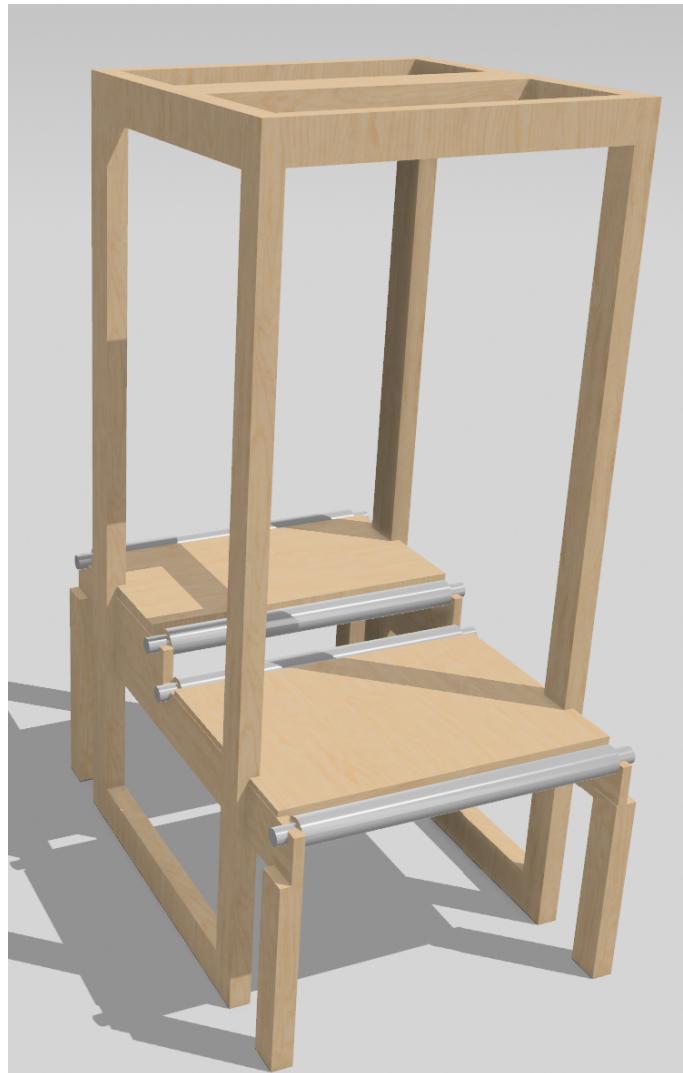


Fig. 4.3 Initial 3D Model of the Prototype



636 **4.3.2 Prototype Flowchart**

637 **4.3.3 Prototype 3D Model**

638 **4.3.4 Hardware Specifications**

639 **4.3.4.1 Raspberry Pi**



Fig. 4.4 Raspberry Pi 4 Model B

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

645

646 **Specifications:**



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- 647 • SoC: Broadcom BCM2711
- 648 • CPU: Quad-core ARM Cortex-A72 (64-bit)
- 649 • Clock Speed: 1.5 GHz (base, overclockable)
- 650 • RAM: 8GB LPDDR4-3200 SDRAM
- 651 • Wireless: Dual-band 2.4 GHz / 5 GHz Wi-Fi (802.11ac)
- 652 • Bluetooth: Bluetooth 5.0 (BLE support)
- 653 • Ethernet: Gigabit Ethernet (full throughput)
- 654 • USB: 2 x USB 3.0 ports and 2 x USB 2.0 ports
- 655 • Video Output: 2 x micro-HDMI ports (supports 4K @ 60Hz, dual 4K display capability)
- 656 • Audio: 3.5mm audio/video composite jack
- 657 • Storage: MicroSD card slot (supports booting via SD card or USB)
- 658 • GPIO: 40-pin GPIO header (backward-compatible with older models)
- 659 • Camera/Display: CSI (camera) and DSI (display) ports
- 660 • Power Input: USB-C (5V/3A recommended)
- 661 • Power Consumption: 3W idle, up to 7.5W under load

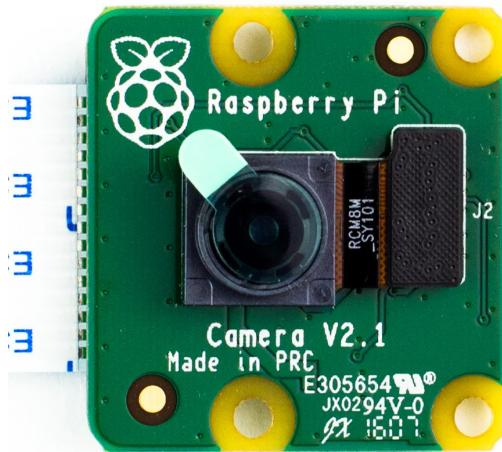


Fig. 4.5 Raspberry Pi Camera Module Version 2

663 **4.3.4.2 Raspberry Pi Camera**

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

671

672 **Specifications:**

- 673 • Sensor: Sony IMX219PQ 8-megapixel CMOS sensor.
674 • Still Images Resolution: 8 MP (3280 x 2464 pixels).



- 675 • Video Resolution: Supports up to 1080p @ 30fps, 720p @ 60fps, and 480p @ 90fps.
- 676 • Focus: Fixed-focus lens (manual focus adjustment not supported without physical
677 modification).
- 678 • Lens Size: 1/4-inch optical format.
- 679 • Field of View (FoV): Diagonal 62.2 degrees.
- 680 • Interface: Connected via 15-pin ribbon cable to the Raspberry Pi's CSI (Camera
681 Serial Interface) port.
- 682 • APIs/Libraries: Supports Python libraries such as Picamera and OpenCV for image
683 capture and processing.
- 684 • Dimensions: 25 mm x 24 mm x 9 mm.

685 **4.3.4.3 DC Motor**

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

693
694 **Specifications:**



Fig. 4.6 12 Volt DC Gear Motor

- 695 • Gearbox Type: Spur gear design
- 696 • Operating Voltage: 12V (operational range: 6-12V)
- 697 • No-load Current Consumption: 0.8A
- 698 • Rated Current Draw: 3A (under standard load)
- 699 • No-load Speed: 282 RPM (maximum)
- 700 • Operating Speed: 248 RPM (under rated load)
- 701 • Torque Output: 18 kg-cm (rated)
- 702 • Stall Torque: 60 kg-cm (maximum)
- 703 • Power Rating: 50W (maximum)
- 704 • Unit Weight: 350 grams



705

4.3.4.4 MicroSD Card



Fig. 4.7 SanDisk Ultra MicroSD Card

706

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

711

Specifications:

713

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

714

715

716



717

4.3.4.5 LED Lights



Fig. 4.8 LED Light Strip

718

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

722

Specifications:

724

- Power Input: 5V DC (USB-powered, compatible with laptops, power banks, or USB adapters).
- Waterproof Design: Suitable for indoor/outdoor use.
- LED Type: SMD 2835 (surface-mount diodes for high brightness and efficiency).

725

726

727



- 728 • Color Type: White (cool white)
- 729 • Length: 1m
- 730 • Beam Angle: 120°
- 731 • Operating Temperature: -25°C to 60°C.
- 732 • Storage Temperature: -40°C to 80°C.

733 **4.3.4.6 Power Supply**



Fig. 4.9 Bench Power Supply

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



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738 control for the prototype.

739

740 **Specifications:**

- 741 • Type: SMPS (Switch-Mode Power Supply)
- 742 • Input: 110V AC, 50/60Hz (U.S. Standard)
- 743 • Output Range: 0-30V DC / 0-5A DC
- 744 • Voltage Precision: $\pm 0.010V$ (10 mV) resolution
- 745 • Current Precision: $\pm 0.001A$ (1 mA) resolution
- 746 • Power Precision: $\pm 0.1W$ resolution
- 747 • Weight: 5 lbs (2.27 kg)
- 748 • Dimensions: 11.1" x 4.92" x 6.14" (28.2 cm x 12.5 cm x 15.6 cm)
- 749 • Maximum Power: 195W
- 750 • Power Source: AC input only

751 **4.3.4.7 4 Channel Relay Module**

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



Fig. 4.10 4 Channel Relay Module

757

758

Specifications:

759

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

760

- Number of Relays: 4 independent channels.

761

- Relay Type: Electromechanical (mechanical switching).

762

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

763

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

764

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

765

- Dimensions: 50mm x 70mm x 20mm

766

767



- 768 • Weight: 50-80 grams.
- 769 • Status LEDs: Individual LEDs for each relay (indicates ON/OFF state).
- 770 • Input Pins: 4 digital control pins (one per relay).
- 771 • Output Terminals: Screw terminals for connecting loads (NO/NC/COM).

772

4.4 Software Considerations

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

776

4.4.1 PyTorch

777

4.4.2 OpenCV

778

4.4.3 Tkinter

779

4.4.4 CustomTkinter

780

4.5 Security and Reliability Considerations

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



4.6 Scalability and Efficiency Considerations

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

4.7 User Interface

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

4.8 Constraints and Limitations

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

4.9 Technical Standards

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



799 **4.10 Prototyping and Simulation**

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

803 **4.11 Design Validation**

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

807 **4.12 Summary**

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



811

Chapter 5

812

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. 48
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. 48
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. 50

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. 48
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. 52
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. 52
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. 52
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. 52



813 5.1 Introduction

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

821 5.2 Research Approach

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

828 5.3 Hardware Design

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



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

837 **5.4 Software Design**

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

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



852 **5.5 Data Collection Methods**

853 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.

863 **5.6 Testing and Evaluation Methods**

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



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

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

873 To test system performance, various measures of performance are used to evaluate.
 874 As seen on equation 5.4, accuracy score is used to measure the percentage of correctly
 875 classified mangoes to ensure the system maintains high precision levels. Precision as seen
 876 on equation 5.1 and recall as seen on equation 5.2 are used to measure consistency of
 877 classification to determine if the system classifies different ripeness levels and defects
 878 correctly. Furthermore, the F1 score formula as seen on equation 5.3 is used to evaluate the
 879 performance of the model's classification.

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

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

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

**886 5.6.1 Ripeness Training and Testing****887 5.6.2 Bruises Training and Testing****888 5.6.3 Size Determination****889 5.7 Formula for User Priority****890 5.8 Ethical Considerations**

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

900 5.9 Summary

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



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



909

Chapter 6

910

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. 60
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. 60

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. 59</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. 60</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. 60

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. 59</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. 60</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. 60

911

6.1 Training and Testing Results of the Model

912

6.1.1 Ripeness Classification Results

913

Add the F1-Score and etc here



914 **6.1.2 Bruises Classification Results**

915 **6.2 Size Determination Results**

916 **6.3 User Priority Formula**

917 $B(P)$ and $R(P)$ and $S(P)$ are the User Priority-Based Grading for bruises, ripeness,
918 and size of the Carabao mango. Furthermore, $b(p)$ and $r(p)$ and $s(p)$ are the machine
919 learning's predictions for bruises, ripeness, and size of the Carabao mango. The formula
920 for the user priority is given by:

$$\text{User Priority} = \frac{b(P) + r(P) + s(P)}{3} \quad (6.1)$$

922 **6.4 Physical Prototype**

923 Add pictures of the hardware prototype here with description

924 **6.5 Software Application**

925 Show the raspberry pi app UI and demonstrate it here

926 **6.6 Summary**

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



928

Chapter 7

929

CONCLUSIONS, RECOMMENDATIONS, AND FUTURE DIRECTIVES

930



931 **7.1 Concluding Remarks**

932 In this Thesis, ...

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

936 **7.2 Contributions**

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

- 940 • the ;
- 941 • the ;
- 942 • the ;

943 **7.3 Recommendations**

944 The researchers recommend...

945 **7.4 Future Prospects**

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



948 1. the

949 2. the

950 3. the

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



954

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Appendix A STUDENT RESEARCH ETHICS CLEARANCE

1008

A. Student Research Ethics Clearance



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1009

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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1011

Appendix B ANSWERS TO QUESTIONS TO THIS THESIS



1012	<h2>B1 How important is the problem to practice?</h2>
1013	A possible answer to this question is the summary of your Significance of the Study, and
1014	that portion of the Problem Statement where you describe the ideal scenario for your
1015	intended audience.
1016	Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Etiam lobortis facilisis sem.
1017	Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec
1018	ullamcorper, felis non sodales commodo, lectus velit ultrices augue, a dignissim nibh lectus
1019	placerat pede. Vivamus nunc nunc, molestie ut, ultricies vel, semper in, velit. Ut porttitor.
1020	Praesent in sapien. Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Duis fringilla
1021	tristique neque. Sed interdum libero ut metus. Pellentesque placerat. Nam rutrum augue
1022	a leo. Morbi sed elit sit amet ante lobortis sollicitudin. Praesent blandit blandit mauris.
1023	Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit
1024	amet ipsum. Nunc quis urna dictum turpis accumsan semper.
1025	<h2>B2 How will you know if the solution/s that you will</h2>
1026	<h2>achieve would be better than existing ones?</h2>
1027	Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Etiam lobortis facilisis sem.
1028	Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec
1029	ullamcorper, felis non sodales commodo, lectus velit ultrices augue, a dignissim nibh lectus
1030	placerat pede. Vivamus nunc nunc, molestie ut, ultricies vel, semper in, velit. Ut porttitor.
1031	Praesent in sapien. Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Duis fringilla
1032	tristique neque. Sed interdum libero ut metus. Pellentesque placerat. Nam rutrum augue
1033	a leo. Morbi sed elit sit amet ante lobortis sollicitudin. Praesent blandit blandit mauris.
1034	Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit
1035	amet ipsum. Nunc quis urna dictum turpis accumsan semper.
1036	<h3>B2.1 How will you measure the improvement/s?</h3>
1037	Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Etiam lobortis facilisis sem.
1038	Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec
1039	ullamcorper, felis non sodales commodo, lectus velit ultrices augue, a dignissim nibh lectus
1040	placerat pede. Vivamus nunc nunc, molestie ut, ultricies vel, semper in, velit. Ut porttitor.
1041	Praesent in sapien. Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Duis fringilla
1042	tristique neque. Sed interdum libero ut metus. Pellentesque placerat. Nam rutrum augue
1043	a leo. Morbi sed elit sit amet ante lobortis sollicitudin. Praesent blandit blandit mauris.



1044 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit
 1045 amet ipsum. Nunc quis urna dictum turpis accumsan semper.

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

1047 Lorem ipsum dolor sit amet, consectetur adipiscing elit. Etiam lobortis facilisis sem.
 1048 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec
 1049 ullamcorper, felis non sodales commodo, lectus velit ultrices augue, a dignissim nibh lectus
 1050 placerat pede. Vivamus nunc nunc, molestie ut, ultricies vel, semper in, velit. Ut porttitor.
 1051 Praesent in sapien. Lorem ipsum dolor sit amet, consectetur adipiscing elit. Duis fringilla
 1052 tristique neque. Sed interdum libero ut metus. Pellentesque placerat. Nam rutrum augue
 1053 a leo. Morbi sed elit sit amet ante lobortis sollicitudin. Praesent blandit blandit mauris.
 1054 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit
 1055 amet ipsum. Nunc quis urna dictum turpis accumsan semper.

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

1057 Lorem ipsum dolor sit amet, consectetur adipiscing elit. Etiam lobortis facilisis sem.
 1058 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec
 1059 ullamcorper, felis non sodales commodo, lectus velit ultrices augue, a dignissim nibh lectus
 1060 placerat pede. Vivamus nunc nunc, molestie ut, ultricies vel, semper in, velit. Ut porttitor.
 1061 Praesent in sapien. Lorem ipsum dolor sit amet, consectetur adipiscing elit. Duis fringilla
 1062 tristique neque. Sed interdum libero ut metus. Pellentesque placerat. Nam rutrum augue
 1063 a leo. Morbi sed elit sit amet ante lobortis sollicitudin. Praesent blandit blandit mauris.
 1064 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit
 1065 amet ipsum. Nunc quis urna dictum turpis accumsan semper.

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

1067 Lorem ipsum dolor sit amet, consectetur adipiscing elit. Etiam lobortis facilisis sem.
 1068 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec
 1069 ullamcorper, felis non sodales commodo, lectus velit ultrices augue, a dignissim nibh lectus
 1070 placerat pede. Vivamus nunc nunc, molestie ut, ultricies vel, semper in, velit. Ut porttitor.
 1071 Praesent in sapien. Lorem ipsum dolor sit amet, consectetur adipiscing elit. Duis fringilla
 1072 tristique neque. Sed interdum libero ut metus. Pellentesque placerat. Nam rutrum augue
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 1074 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit
 1075 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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 Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Etiam lobortis facilisis sem. Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec ullamcorper, felis non sodales commodo, lectus velit ultrices augue, a dignissim nibh lectus placerat pede. Vivamus nunc nunc, molestie ut, ultricies vel, semper in, velit. Ut porttitor. Praesent in sapien. Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Duis fringilla tristique neque. Sed interdum libero ut metus. Pellentesque placerat. Nam rutrum augue a leo. Morbi sed elit sit amet ante lobortis sollicitudin. Praesent blandit blandit mauris. Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit amet ipsum. Nunc quis urna dictum turpis accumsan semper.

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

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

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

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



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

1108 Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Etiam lobortis facilisis sem.
 1109 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec
 1110 ullamcorper, felis non sodales commodo, lectus velit ultrices augue, a dignissim nibh lectus
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 1112 Praesent in sapien. Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Duis fringilla
 1113 tristique neque. Sed interdum libero ut metus. Pellentesque placerat. Nam rutrum augue
 1114 a leo. Morbi sed elit sit amet ante lobortis sollicitudin. Praesent blandit blandit mauris.
 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.
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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?

1119 Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Etiam lobortis facilisis sem.
 1120 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec
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 1125 a leo. Morbi sed elit sit amet ante lobortis sollicitudin. Praesent blandit blandit mauris.
 1126 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit
 1127 amet ipsum. Nunc quis urna dictum turpis accumsan semper.
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B5 What is the necessity of your approach / proposed solution/s?

1130 Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Etiam lobortis facilisis sem.
 1131 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec
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 1134 Praesent in sapien. Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Duis fringilla
 1135 tristique neque. Sed interdum libero ut metus. Pellentesque placerat. Nam rutrum augue
 1136 a leo. Morbi sed elit sit amet ante lobortis sollicitudin. Praesent blandit blandit mauris.
 1137 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit
 1138 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?

1143 Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Etiam lobortis facilisis sem.
 1144 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec
 1145 ullamcorper, felis non sodales commodo, lectus velit ultrices augue, a dignissim nibh lectus
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 1147 Praesent in sapien. Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Duis fringilla
 1148 tristique neque. Sed interdum libero ut metus. Pellentesque placerat. Nam rutrum augue
 1149 a leo. Morbi sed elit sit amet ante lobortis sollicitudin. Praesent blandit blandit mauris.
 1150 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit
 1151 amet ipsum. Nunc quis urna dictum turpis accumsan semper.

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

1155 Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Etiam lobortis facilisis sem.
 1156 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec
 1157 ullamcorper, felis non sodales commodo, lectus velit ultrices augue, a dignissim nibh lectus
 1158 placerat pede. Vivamus nunc nunc, molestie ut, ultricies vel, semper in, velit. Ut porttitor.
 1159 Praesent in sapien. Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Duis fringilla
 1160 tristique neque. Sed interdum libero ut metus. Pellentesque placerat. Nam rutrum augue
 1161 a leo. Morbi sed elit sit amet ante lobortis sollicitudin. Praesent blandit blandit mauris.
 1162 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit
 1163 amet ipsum. Nunc quis urna dictum turpis accumsan semper.

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

1166 Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Etiam lobortis facilisis sem.
 1167 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec
 1168 ullamcorper, felis non sodales commodo, lectus velit ultrices augue, a dignissim nibh lectus
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 1170 Praesent in sapien. Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Duis fringilla
 1171 tristique neque. Sed interdum libero ut metus. Pellentesque placerat. Nam rutrum augue
 1172 a leo. Morbi sed elit sit amet ante lobortis sollicitudin. Praesent blandit blandit mauris.



1173 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit
 1174 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)?**

1177 Lorem ipsum dolor sit amet, consectetur adipiscing elit. Etiam lobortis facilisis sem.
 1178 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdier mi nec ante. Donec
 1179 ullamcorper, felis non sodales commodo, lectus velit ultrices augue, a dignissim nibh lectus
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 1181 Praesent in sapien. Lorem ipsum dolor sit amet, consectetur adipiscing elit. Duis fringilla
 1182 tristique neque. Sed interdum libero ut metus. Pellentesque placerat. Nam rutrum augue
 1183 a leo. Morbi sed elit sit amet ante lobortis sollicitudin. Praesent blandit blandit mauris.
 1184 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit
 1185 amet ipsum. Nunc quis urna dictum turpis accumsan semper.

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

1188 Lorem ipsum dolor sit amet, consectetur adipiscing elit. Etiam lobortis facilisis sem.
 1189 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdier mi nec ante. Donec
 1190 ullamcorper, felis non sodales commodo, lectus velit ultrices augue, a dignissim nibh lectus
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 1192 Praesent in sapien. Lorem ipsum dolor sit amet, consectetur adipiscing elit. Duis fringilla
 1193 tristique neque. Sed interdum libero ut metus. Pellentesque placerat. Nam rutrum augue
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 1195 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit
 1196 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?**

1199 Lorem ipsum dolor sit amet, consectetur adipiscing elit. Etiam lobortis facilisis sem.
 1200 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdier mi nec ante. Donec
 1201 ullamcorper, felis non sodales commodo, lectus velit ultrices augue, a dignissim nibh lectus
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 1203 Praesent in sapien. Lorem ipsum dolor sit amet, consectetur adipiscing elit. Duis fringilla
 1204 tristique neque. Sed interdum libero ut metus. Pellentesque placerat. Nam rutrum augue



1205 a leo. Morbi sed elit sit amet ante lobortis sollicitudin. Praesent blandit blandit mauris.
 1206 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit
 1207 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?

1210 Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Etiam lobortis facilisis sem.
 1211 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec
 1212 ullamcorper, felis non sodales commodo, lectus velit ultrices augue, a dignissim nibh lectus
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 1214 Praesent in sapien. Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Duis fringilla
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 1216 a leo. Morbi sed elit sit amet ante lobortis sollicitudin. Praesent blandit blandit mauris.
 1217 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit
 1218 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.

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
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 1228 tristique neque. Sed interdum libero ut metus. Pellentesque placerat. Nam rutrum augue
 1229 a leo. Morbi sed elit sit amet ante lobortis sollicitudin. Praesent blandit blandit mauris.
 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.

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

1232 Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Etiam lobortis facilisis sem.
 1233 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec



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- 1236 ullamcorper, felis non sodales commodo, lectus velit ultrices augue, a dignissim nibh lectus
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1238 Praesent in sapien. Lorem ipsum dolor sit amet, consectetur adipiscing elit. Duis fringilla
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1242 amet ipsum. Nunc quis urna dictum turpis accumsan semper.



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Appendix C REVISIONS TO THE PROPOSAL

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C. Revisions to the Proposal



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PRO1 Panel Comments and Revisions – Appendix Z

PRO1 Panel Comments and Revisions

Zoom Recording:

https://zoom.us/rec/share/mrn9zBtPz3bJ5laVcy2E8-iBno8A6fBRgOCacMrhmzLPCNO0IDxXBHiK_xzdicEb.MzbHGzrD7rL3tVgJ?startTIme=1731326444000

Passcode: +7qL6DZE

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

C. Revisions to the Proposal



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PRO1 Panel Comments and Revisions – Appendix Z

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



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PRO1 Panel Comments and Revisions – Appendix Z

PRO1 Panel Comments and Revisions

Zoom Recording:

https://zoom.us/rec/share/mrn9zBtPz3bJ5laVcy2E8-iBno8A6fBRgOCacMrhmzLPCNO0IDxXBHiK_xzdicEb.MzbHGzrD7rL3tVgJ?startTim=e=1731326444000

Passcode: +?qL6DZE

Summary:

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

Comments:

*[00-00] time stamps from recording

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



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PRO1 Panel Comments and Revisions – Appendix Z

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

- [33:10] Why is the dataset destructive but the testing non destructive? Clarify this further to avoid confusion.
- [35:09] What is the basis of sweetness using images? Clarify this further.
- [35:35] How would you know if the classifier is correct or not? What is your ground truth (for the sweetness)?
- [38:55] When can you say you are getting the top side of the mango? How would you know if the mango images showing the top side or the bottom side of both cheeks of the mango can be captured? If it doesn't matter then any side can be captured so why is it in the limitations that only the top side can be captured. Clarify the limitations.
- [48:10] What classifier would you use here? What features would you extract from the images?
- [52:07] Does it explain what process will be used to get the sweetness classification? Add it to the specific objectives
- [54:00] How will ripeness be classified? Will it use the same dataset as the sweetness classification did? How was ground truth obtained?
- [55:44] Why not the nearest neighbor? It is more fit in this scenario. Do not specify CNN in the objectives. The embedded systems as well, do not specify the Raspberry pi unless truly sure
- [57:30] Table is just image processing. Is there a specific objective that would describe how ripeness classification will be done? Add this to the specific objectives.
- [59:10] How is the weight obtained? Add it to the specific objectives. Remember that size is not proportional to weight. Size could be obtained from the image as the camera is from a fixed distance. Add to specific objectives how to get the size
- [1:00:00] get rid of texture in the general objectives. get rid of cnn in general objectives and replace with machine learning. as each parameter will use a different method.
- [1:04:00] remove Raspberry Pi on the SO's and generalize to "to create a microcontroller based application"
- [1:04:37] remove SO4. no more user testing
- [1:05:00] The formula used for grading the mangoes, is this used as industry standard? How do they measure the export quality of mango
- [1:07:00] Specify in the specific objectives that it will be automatic sorting

Here are my comments on my end :)

1. Ensure seamless integration between hardware (sensors, motors, etc.) and software (CNNs, Raspberry Pi). You can consider using a modular approach for easier troubleshooting.
2. How do you gather a comprehensive and diverse dataset for training your CNN. This will enhance the model's robustness and accuracy.
3. Make sure that the weight sensors are calibrated correctly to avoid measurement errors.

C. Revisions to the Proposal



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PRO1 Panel Comments and Revisions – Appendix Z

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

Noted by:



Dr. Donabel de Veas Abuan
Chair of Panel

Date: November 11 2024

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



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Appendix D REVISIONS TO THE FINAL

1251



- 1252 Make a table with the following columns for showing the summary of revisions to the
 1253 proposal based on the comments of the panel of examiners.
- 1254 1. Examiner
- 1255 2. Comment
- 1256 3. Summary of how the comment has been addressed
- 1257 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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Examiner	Comment	Summary of how the comment has been addressed	Locations
Dr. Donable de Veas Abuan	1. First itemtext 2. Second itemtext 3. Last itemtext 4. First itemtext 5. Second itemtext	1. First itemtext 2. Second itemtext 3. Last itemtext 4. First itemtext 5. Second itemtext First itemtext Second itemtext Last itemtext First itemtext Second itemtext	Sec. ?? on p. ??, Sec. ?? on p. ??, Fig. ?? on p. ???
Engr. Jose Martin Maningo	1. First itemtext 2. Second itemtext 3. Last itemtext 4. First itemtext 5. Second itemtext	1. First itemtext 2. Second itemtext 3. Last itemtext 4. First itemtext 5. Second itemtext • First itemtext • Second itemtext • Last itemtext • First itemtext • Second itemtext	Sec. ?? on p. ??, Sec. ?? on p. ??, Fig. ?? on p. ???

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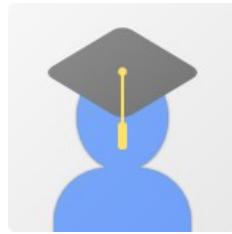
Examiner	Comment	Summary of how the comment has been addressed	Locations
Dr. Alexander Co Abad	1. First itemtext 2. Second itemtext 3. Last itemtext 4. First itemtext 5. Second itemtext	1. First itemtext 2. Second itemtext 3. Last itemtext 4. First itemtext 5. Second itemtext	Sec. ?? on p. ??, Sec. ??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



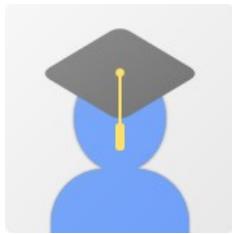
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Appendix E VITA

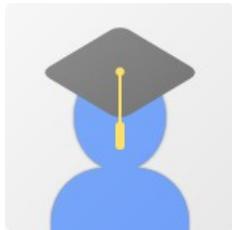
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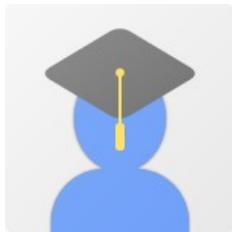
1260 Kenan A. Banal is currently taking up his B.Sc. Computer Engineering
1261 studies. He is passionate about software and hardware systems such as Vivado, Arduino, C,
1262 and Python.



1263 Francis Robert Miguel F. BAUTISTA is currently taking up his B.Sc.
1264 Computer Engineering studies. He is passionate about software and hardware systems such
1265 as Vivado, Arduino, C, and Python.



1266 Don Humphrey L. HERMOSURA is currently taking up his B.Sc.
1267 Computer Engineering studies. He is passionate about software and hardware systems such
1268 as Vivado, Arduino, C, and Python.



1269 Daniel G. SALAZAR is currently taking up his B.Sc. Computer
1270 Engineering studies. He is passionate about software and hardware systems such as Vivado,
1271 Arduino, C, and Python.



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1272

Appendix F ARTICLE PAPER(S)

1273

Article/Forum Paper Format

(IEEE LaTeX format)

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

1274

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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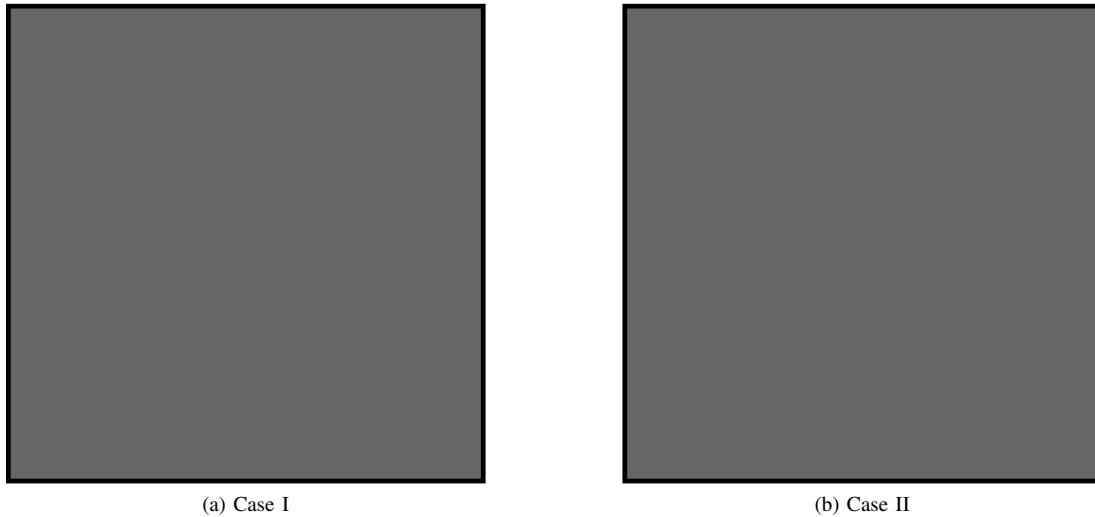


Fig. 2. Simulation results for the network.

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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...