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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 September, 2025



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THESIS APPROVAL SHEET

22

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2025

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47

48

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49

ABSTRACT

50 to change *Index Terms*—Machine Learning, Carabao Mangoes, Sorting and Grading
51 Mangoes, Machine Vision, Microcontroller.



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ABBREVIATIONS

213	AC	Alternating Current.....	13
214	GUI	Graphical User Interface	49
215	LED	Light Emitting Diode	43
216	UI	User Interface	49



217

NOTATION

218	$B(P)$	Bruises Priority	61
219	$b(p)$	Bruises Prediction.....	61
220	$R(P)$	Ripeness Priority.....	61
221	$r(p)$	Ripeness Prediction	61
222	$S(P)$	Size Priority	61
223	$s(p)$	Size Prediction	61
224	$D(p, d, f)$	Real World Dimension	26
225	p	Pixel Dimension	26
226	d	Distance from Camera to Object.....	26
227	f	Focal Length	26



228 GLOSSARY

229	bruises	The black or brown area of the mango that is visible on the skin of the mango.
230	Carabao mango	A popular variety of mango grown in the Philippines, known for its sweet and juicy flesh.
231	accuracy score	A performance metric that measures the overall proportion of correct predictions made by a machine learning model.
232	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.
233	CNN	A type of deep neural network that is highly effective in analyzing and processing visual data, such as images.
234	F1-Score	A balanced performance metric that is the harmonic mean of precision and recall, taking both into account.
235	machine learning	A subset of Artificial Intelligence that enables systems to learn and improve from data.
236	computer vision	The use of cameras and algorithms to provide imaging-based inspection and analysis.
237	microcontroller	A small computing device that controls other parts of a system such as sensors.
238	Precision	A performance metric that reflects the percentage of instances classified as positive that are truly positive.
239	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

243

INTRODUCTION



244 **1.1 Background of the Study**

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



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

249
250 mangoes is a variety of a mango that is found and cultivated in the Philippines. It is known
251 for its sweet signature taste that was recognized sweetest in the world in the Guinness
252 Book of World Records in 1995. The mango was named after the national animal of the
253 Philippines, a native breed of buffalo. On average, it is 12.5 cm in length and 8.5 cm in
254 diameter, having a bright yellow color when ripe as seen in Figure 1.1. It is often cultivated
255 during late May to early July (?).

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



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

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

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

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



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

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

296 1.2 Prior Studies

297 A paper written by ?, designed an automated fruit sorting machine based on the quality
298 through an image acquisition system and CNN. Furthermore, the results of the paper show
299 that the image processing detection score was 89% while that of the tomatoes was 92%
300 while the CNN model had higher validity of 95% for mangoes and 93% for tomatoes.
301 15%, while the percentage of distinction between the two groups was reported to be 5%
302 respectively (?). Despite the high accuracy score in detecting mango defects, the fruit
303 sorting system only sorts based on the mango defects and not on ripeness, and weight.

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



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

312 **1.3 Problem Statement**

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

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



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

336 **1.4 Objectives and Deliverables**

337 **1.4.1 General Objective (GO)**

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

341 **1.4.2 Specific Objectives (SOs)**

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



- 347 • SO3: To create a microcontroller-based system to operate the image acquisition
 348 system, control the conveyor belt, and process the mango images through machine
 349 learning. ;
- 350 • SO4: To grade mangoes based on user priorities for size, ripeness, and bruises. ;
- 351 • SO5: To classify mango ripeness based on image data using machine learning
 352 algorithms such as kNN, k-mean, and Naïve Bayes. ;
- 353 • SO6: To classify mango size based on image data by getting its length and width
 354 using OpenCV, geometry, and image processing techniques. ;
- 355 • SO7: To classify mango bruises based on image data by employing machine learning
 356 algorithms.

357 **1.4.3 Expected Deliverables**

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

TABLE 1.1 EXPECTED DELIVERABLES PER OBJECTIVE

Objectives	Expected Deliverables
GO: To develop a user-priority-based grading and sorting system for Carabao mangoes, using machine learning and computer vision techniques to assess ripeness, size, and bruises.	<ul style="list-style-type: none"> • To develop a Carabao mango grading and sorting system. • To grade Carabao mangoes into three categories based on ripeness, size, and bruises using machine learning. • To integrate sensors and actuators to control the conveyor belt and image acquisition system.

Continued on next page



TABLE 1.1 EXPECTED DELIVERABLES PER OBJECTIVE

Objectives	Expected Deliverables
SO1: To make an image acquisition system with a conveyor belt for automatic sorting and grading mangoes.	<ul style="list-style-type: none"> To make an image acquisition system with a camera and LED light source. To build a flat belt conveyor for moving the mangoes.
SO2: To get the precision, recall, F1 score, confusion matrix, and train and test accuracy metrics for classifying the ripeness and bruises with an accuracy score of at least 90%.	<ul style="list-style-type: none"> To use a publicly available dataset of at least 10,000 mango images for classification of ripeness and bruises.
SO3: To create a microcontroller-based system to operate the image acquisition system, control the conveyor belt, and process the mango images through machine learning.	<ul style="list-style-type: none"> To develop an intuitive UI where users can start and stop the system. To implement a priority-based grading system with sliders for ripeness, bruises, and size.
SO4: To grade mangoes based on user priorities for size, ripeness, and bruises.	<ul style="list-style-type: none"> To utilize a linear combination formula as the overall mango score, where each classification level contributes a grade, weighted by the priority assigned to the three properties. To assign score values for each classification level of the mango.
SO5: To classify mango ripeness based on image data using machine learning algorithms such as kNN, k-mean, and Naïve Bayes.	<ul style="list-style-type: none"> To train a machine learning model such as kNN, k-means, or Naïve Bayes capable of classifying mango ripeness based on the image color. To gather a dataset of annotated images with ripeness labels. To obtain an evaluation report of performance metrics of the model.
SO6: To classify mango size based on image data by getting its length and width using OpenCV, geometry, and image processing techniques.	<ul style="list-style-type: none"> To develop an image processing algorithm capable of determining mango size using OpenCV, NumPy, and imutils. To classify mangoes based on size into small, medium, and large based on measurements.

Continued on next page



TABLE 1.1 EXPECTED DELIVERABLES PER OBJECTIVE

Objectives	Expected Deliverables
SO7: To classify mango bruises based on image data by employing machine learning algorithms.	<ul style="list-style-type: none"> • To train a machine learning model such as CNN capable of distinguishing bruised and non-bruised mangoes. • To train a machine learning model such as kNN, k-means, and Naïve Bayes capable of assessing the extent of bruising on the mangoes if it is significant or partial. • To gather a dataset of annotated images based on bruises. • To obtain an evaluation report of performance metrics of both CNN and other machine learning models.

1.5 Significance of the Study

Automating the process of sorting and grading mangoes increases efficiency and productivity for the user which would in effect remove human error in sorting and grading and decrease the human labor and time taken to sort and grade the mangoes. This is especially important for farmers with a large amount of fruit such as mangoes and a lesser labor force. A recent study showed that their automated citrus sorter and grader using computer vision can reduce the human labor cost and time to sort and grade when comparing the automated citrus sorter and grader to manual human labor ?.

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



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373 ensuring that only marketable fruits are processed further.

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

380 **1.5.1 Technical Benefit**

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

387 **1.5.2 Social Impact**

- 388 1. The reduction in manual labor creates opportunities in maintenance and technologies
389 in the automated Carabao mango sorter.
- 390 2. The automated Carabao mango sorter system improves Carabao mango standards
391 and enhances the satisfaction of the buyers and the customers through guaranteeing
392 consistent Carabao mango grade.



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

395 **1.5.3 Environmental Welfare**

- 396 1. With the utilization of non-destruction methods of classifying Carabao mangoes
397 together with an accurate sorting system, overall waste from Carabao mangoes is
398 reduced and the likelihood of improperly sorted mangoes is decreased.

399 2. Automation of sorting and grading Carabao mangoes promotes sustainable farming
400 practices.

401 **1.6 Assumptions, Scope, and Delimitations**

402 **1.6.1 Assumptions**

- 403 1. The Carabao mangoes are from the same source together with the same variation

404 2. The Carabao mangoes do not have any fruit borer and diseases

405 3. All the components do not have any form of defects

406 4. The prototype would have access to constant electricity/power source.

407 5. The Carabao mangoes to be tested would be in the post-harvesting stage and in the
408 grading stage.

409 6. The image-capturing system would only capture the two sides of the mango which
410 are the two largest surface areas of the skin.



411 **1.6.2 Scope**

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

420 **1.6.3 Delimitations**

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



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

432 **1.7 Overview of the Thesis**

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



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Chapter 2

444

LITERATURE REVIEW



445 **2.1 Existing Work**

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

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



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

484 Another study by ? proposed SVM-based system for classifying the maturity stages of
485 bananas, mangoes, and calamansi. With the use of 1729 images of bananas together with
486 711 mango images and 589 calamansi, the researchers were able to achieve a high accuracy
487 score of above 90% for all fruits. Some pre-processing techniques used to get this high
488 accuracy are the change in hue, saturation, and value channels in the mango image (?). To
489 better understand the harvest time of mangoes, the paper by ? examined the association of
490 the harvest season with seasonal heat units, rainfall, and physical fruit attributes for Haden,
491 Kent, Palmer, and Keitt mango varieties to establish export and domestic market maturity



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

TABLE 2.1 COMPARISON OF EXISTING STUDIES

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

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



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

507 **2.1.1 Sorting Algorithms**

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

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



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

542 **2.2 Lacking in the Approaches**

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



TABLE 2.2 COMPARISON OF SORTING ALGORITHM MODELS

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

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

2.3 Summary

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



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



577

Chapter 3

578

THEORETICAL CONSIDERATIONS



579 3.1 Introduction

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

582 3.2 Relevant Theories and Models

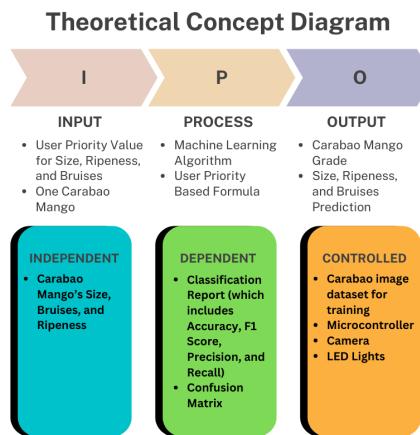


Fig. 3.1 Theoretical Framework Diagram.

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



592 **3.3 Technical Background**

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

600 **3.4 Conceptual Framework Background**

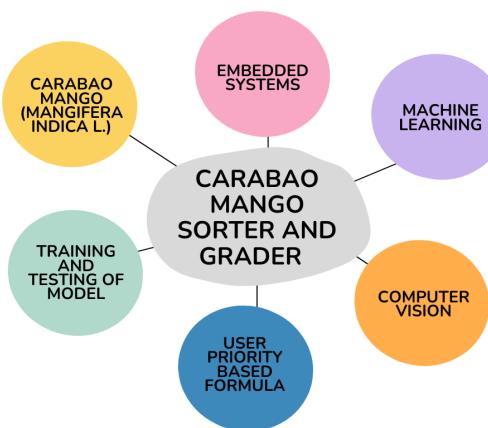


Fig. 3.2 Conceptual Framework Diagram.

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



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

609 **3.5 Software Concepts**

610 **3.5.1 Thresholding**

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

618

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

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



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

630 **3.5.2 Object Size Calculation**

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

635 The size of the mango can be determined given:

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

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

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

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



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

646 **3.5.3 Convolutional Neural Network**

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

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

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

659 **3.6 Hardware Concepts**

660 **3.6.1 Camera Module**

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



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

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

674 **3.6.2 4 Channel Relay**

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

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

**684 3.6.3 Gear Ratio**

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

693 3.7 Summary

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



699

Chapter 4

700

DESIGN CONSIDERATIONS



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

707 **4.1 Introduction**

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

712 **4.2 System Architecture**

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

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

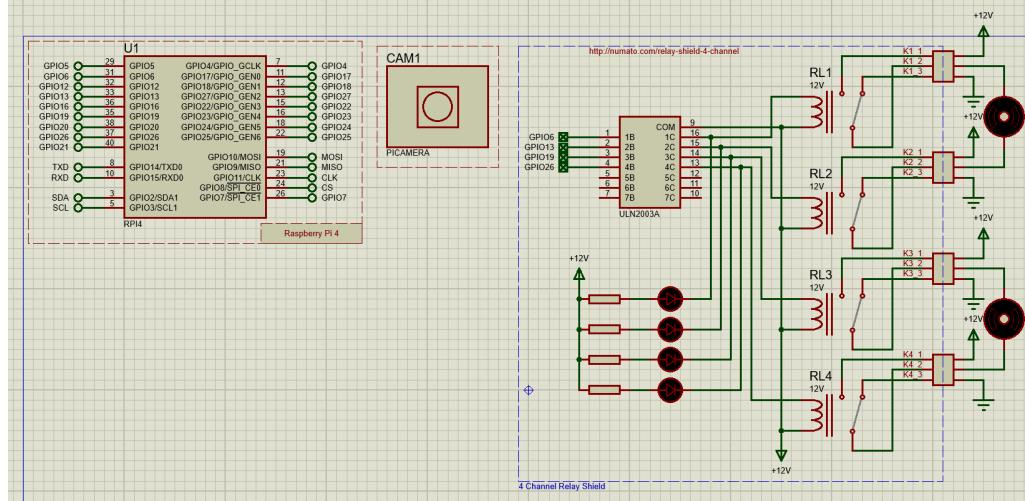


Fig. 4.1 Hardware Schematic

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

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

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



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

738 4.3 Hardware Considerations

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

743 4.3.1 General Prototype Framework

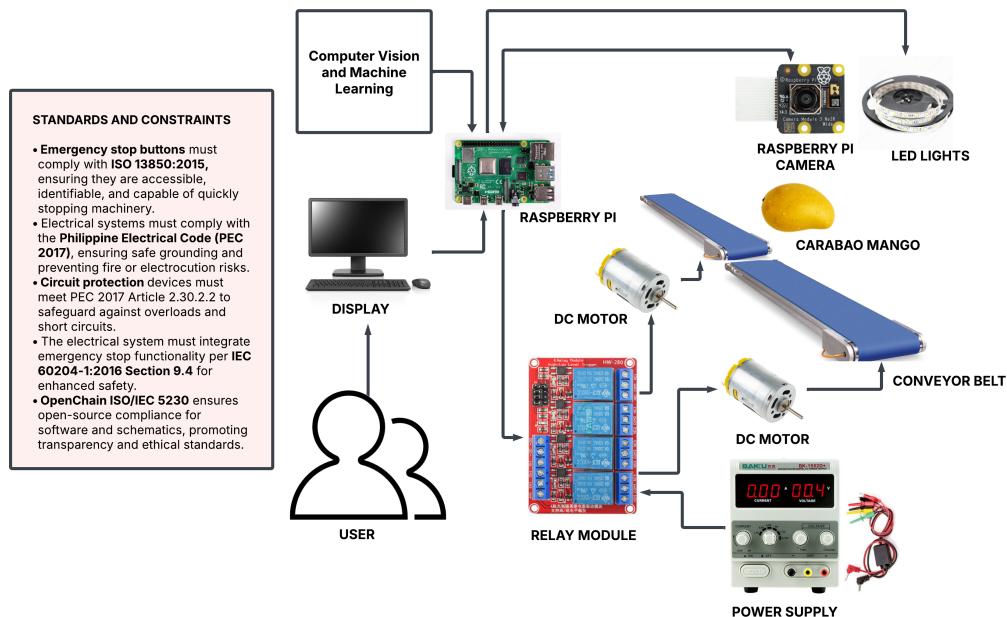


Fig. 4.2 Prototype Framework



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

752 **4.3.2 Prototype Flowchart**

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

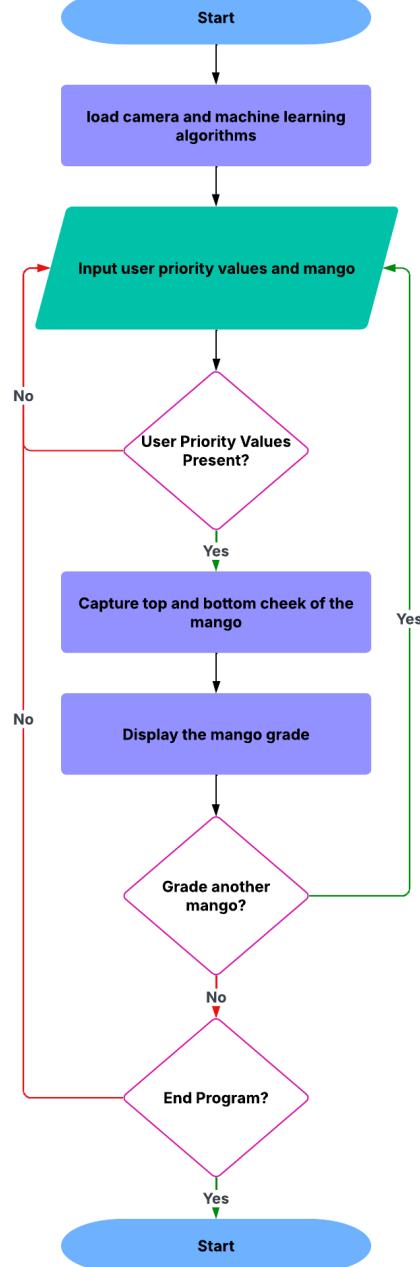


Fig. 4.3 Prototype Main Flowchart



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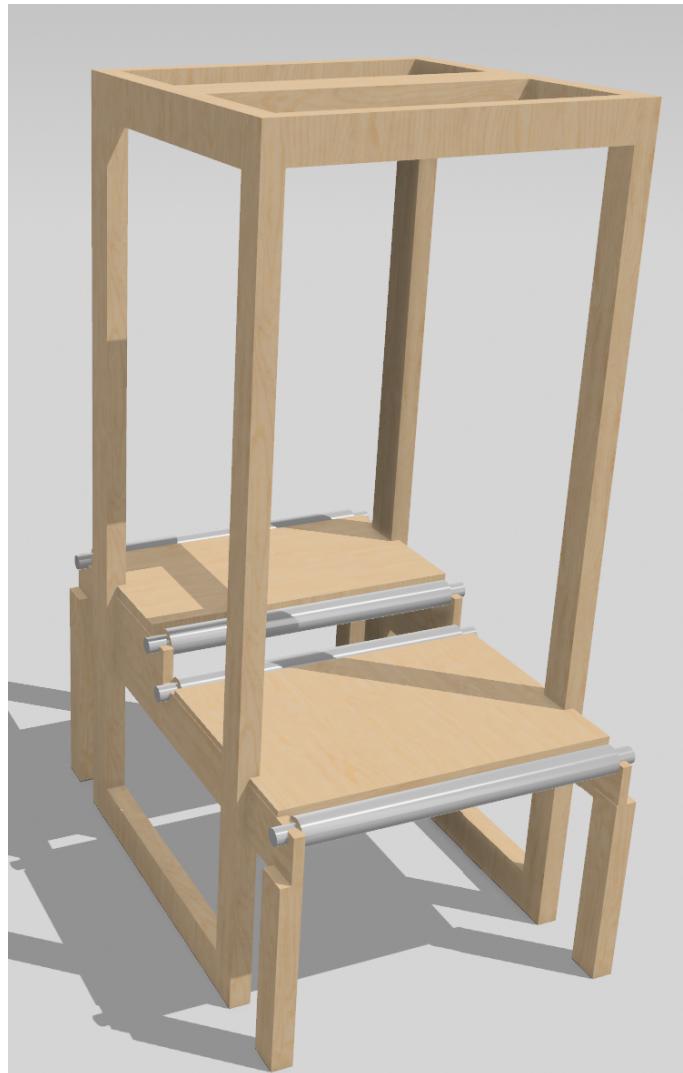


Fig. 4.4 Initial 3D Model of the Prototype



763 4.3.3 Prototype 3D Model

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

771 4.3.4 Hardware Specifications

772 4.3.4.1 Raspberry Pi



Fig. 4.5 Raspberry Pi 4 Model B

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



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

780 **Specifications:**

- 781 • SoC: Broadcom BCM2711
- 782 • CPU: Quad-core ARM Cortex-A72 (64-bit)
- 783 • Clock Speed: 1.5 GHz (base, overclockable)
- 784 • RAM: 8GB LPDDR4-3200 SDRAM
- 785 • Wireless: Dual-band 2.4 GHz / 5 GHz Wi-Fi (802.11ac)
- 786 • Bluetooth: Bluetooth 5.0 (BLE support)
- 787 • Ethernet: Gigabit Ethernet (full throughput)
- 788 • USB: 2 x USB 3.0 ports and 2 x USB 2.0 ports
- 789 • Video Output: 2 x micro-HDMI ports (supports 4K @ 60Hz, dual 4K display
790 capability)
- 791 • Audio: 3.5mm audio/video composite jack
- 792 • Storage: MicroSD card slot (supports booting via SD card or USB)



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

797 **4.3.4.2 Raspberry Pi Camera**

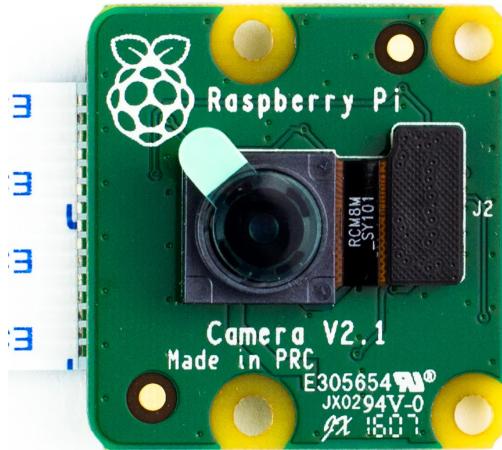


Fig. 4.6 Raspberry Pi Camera Module Version 2

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



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

805

806 **Specifications:**

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

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

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

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

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

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

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

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

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

819 **4.3.4.3 DC Motor**

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



Fig. 4.7 12 Volt DC Gear Motor

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

Specifications:

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



- 835 • Torque Output: 18 kg-cm (rated)
836 • Stall Torque: 60 kg-cm (maximum)
837 • Power Rating: 50W (maximum)
838 • Unit Weight: 350 grams

839 **4.3.4.4 MicroSD Card**



Fig. 4.8 SanDisk Ultra MicroSD Card

840 The SanDisk Ultra MicroSD Card is a compact, high-capacity, and secure digital
841 memory card that is suitable for a wide range of applications, including digital cameras,
842 smartphones, and tablets. It features a high-speed data transfer rate, making it ideal for
843 storing large files such as images and videos. This card was selected for its high capacity, se-
844 cure data protection, and ease of use, making it ideal for the storage system for the prototype.
845

846 **Specifications:**



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

851 **4.3.4.5 LED Lights**



Fig. 4.9 LED Light Strip

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

856

857 **Specifications:**



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

867 **4.3.4.6 Power Supply**

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

873

874 **Specifications:**

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



Fig. 4.10 Bench Power Supply

- 877 • Output Range: 0-30V DC / 0-5A DC
- 878 • Voltage Precision: $\pm 0.010V$ (10 mV) resolution
- 879 • Current Precision: $\pm 0.001A$ (1 mA) resolution
- 880 • Power Precision: $\pm 0.1W$ resolution
- 881 • Weight: 5 lbs (2.27 kg)
- 882 • Dimensions: 11.1" x 4.92" x 6.14" (28.2 cm x 12.5 cm x 15.6 cm)
- 883 • Maximum Power: 195W
- 884 • Power Source: AC input only

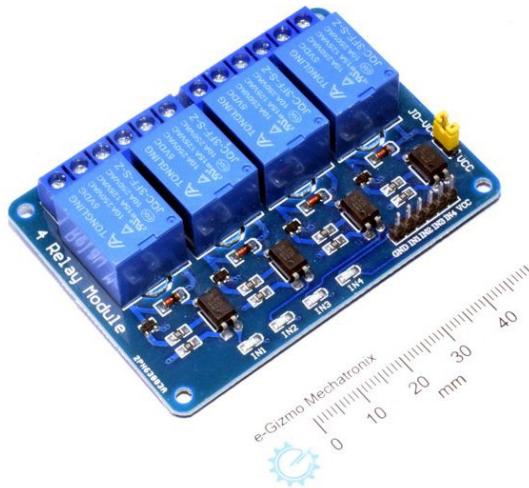


Fig. 4.11 4 Channel Relay Module

885 **4.3.4.7 4 Channel Relay Module**

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

891

892 **Specifications:**

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



- 897 • Max AC Load: 10A @ 250V AC (resistive).
- 898 • Max DC Load: 10A @ 30V DC (resistive).
- 899 • Contact Type: SPDT (Single Pole Double Throw) - NO (Normally Open), NC
900 (Normally Closed), COM (Common).
- 901 • Dimensions: 50mm x 70mm x 20mm
- 902 • Weight: 50-80 grams.
- 903 • Status LEDs: Individual LEDs for each relay (indicates ON/OFF state).
- 904 • Input Pins: 4 digital control pins (one per relay).
- 905 • Output Terminals: Screw terminals for connecting loads (NO/NC/COM).

906 **4.4 Software Considerations**

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

910 **4.4.1 PyTorch**

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



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

917 **4.4.2 OpenCV**

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

924 **4.4.3 CustomTkinter**

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

931 **4.5 Security and Reliability Considerations**

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



935 **4.6 Scalability and Efficiency Considerations**

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

939 **4.7 User Interface**

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

943 **4.8 Constraints and Limitations**

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

947 **4.9 Technical Standards**

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



4.10 Prototyping and Simulation

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

4.11 Design Validation

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

4.12 Summary

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



962

Chapter 5

963

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. 54
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. 54
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. 56

Continued on next page



Continued from previous page

Objectives	Methods	Locations
SO3: To create a microcontroller-based system to operate the image acquisition system, control the conveyor belt, and process the mango images through machine learning.	1. Algorithm development: To develop a code for the image acquisition system 2. Hardware design: To design a schematic for the microcontroller based system	Sec. 5.3 on p. 54
SO4: To grade mangoes based on user priorities for size, ripeness, and bruises.	1. Formula development: Formulated an equation based on the inputted user priority and the predicted mango classification	Sec. 5.7 on p. 61
SO5: To classify mango ripeness based on image data using machine learning algorithms such as kNN, k-mean, and Naïve Bayes.	1. Performance testing: Train and test the machine learning algorithm for classifying bruises	Sec. 5.6.3 on p. 60
SO6: To classify mango size based on image data by getting its length and width using OpenCV, geometry, and image processing techniques.	1. Performance testing: Train and test the machine learning algorithm for classifying ripeness	Sec. 5.6.2 on p. 59
SO7: To classify mango bruises based on image data by employing machine learning algorithms.	1. Accuracy testing: Get the percent accuracy testing for getting the length and width of the Carabao mango	Sec. 5.6.4 on p. 61



964 **5.1 Introduction**

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

972 **5.2 Research Approach**

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

979 **5.3 Hardware Design**

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



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

988 **5.4 Software Design**

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

995 Furthermore, the rest of the software components are of utmost importance to mango
996 classification. Image processing algorithms in OpenCV and CNN models extract features
997 such as color, size, and bruises that are known to determine quality parameters of mangoes.
998 Mangoes are classified based on ripeness and defects by using machine learning algorithms,
999 which further enhances accuracy using deep learning techniques. A user interface (UI) is
1000 designed for users to control and observe the system in real time. Finally, the interface
1001 programming of the microcontroller provides the necessary synchronization between
1002 sensors, actuators, and motors throughout the sorting operation scenario.



5.5 Data Collection Methods

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



Fig. 5.1 Carabao Mango Image Data Collection

5.6 Testing and Evaluation Methods

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



1014 each of the components works as expected when operating separately. After component
 1015 testing on an individual basis, integration testing is conducted to ensure communication
 1016 between hardware and software is correct to ensure the image processing system, motors,
 1017 and sorting actuators work in concert as required. System testing is conducted to con-
 1018 duct overall system performance testing in real-world conditions to ensure mangoes are
 1019 accurately and efficiently sorted and graded.

5.6.1 Classification Report

5.6.1.1 Confusion Matrix

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

TABLE 5.2 CONFUSION MATRIX EXAMPLE

1022 A confusion matrix is a table that visualizes the performance of a classification model.
 1023 For a binary classification problem, it has four components:

- 1025 • True Positives (TP): Cases correctly predicted as positive
- 1026 • True Negatives (TN): Cases correctly predicted as negative
- 1027 • False Positives (FP): Cases incorrectly predicted as positive. (Type I error)
- 1028 • False Negatives (FN): Cases incorrectly predicted as negative (Type II error)



1029

5.6.1.2 Precision

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

1030

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

1033

5.6.1.3 Recall

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

1034

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

1037

5.6.1.4 F1 Score

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

1038

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

1041

5.6.1.5 Accuracy

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



1042 Accuracy measures the proportion of correct predictions (both true positives and true
1043 negatives) among the total cases. While intuitive, accuracy can be misleading with imbal-
1044 anced datasets.

1045 To test system performance, various measures of performance are used to evaluate.
1046 As seen on equation 5.4, accuracy score is used to measure the percentage of correctly
1047 classified mangoes to ensure the system maintains high precision levels. Precision as seen
1048 on equation 5.1 and recall as seen on equation 5.2 are used to measure consistency of
1049 classification to determine if the system classifies different ripeness levels and defects
1050 correctly. Furthermore, the F1 score formula as seen on equation 5.3 is used to evaluate the
1051 performance of the model's classification.

1052 A confusion matrix is used to measure correct and incorrect classification to ensure the
1053 machine learning model is optimized and that minimum errors are achieved. Throughput
1054 analysis is also used to determine the rate and efficiency of sorting to ensure that the
1055 system maintains high capacity without bottlenecks to sort mangoes. Using these methods
1056 of testing, the system is constantly optimized to ensure high-quality and reliable mango
1057 classification.

1058 **5.6.2 Ripeness Training and Testing**

1059 For the testing of the ripeness classification, the Carabao mangoes are classified into three
1060 ripeness stages which are Green, green yellow, and yellow. Likewise, The green would
1061 represent the ripe mangoes while the green yellow would represent the semi ripe while the
1062 yellow would represent the ripe mangoes. As reference, Figure 5.3 shows the different
1063 ripeness stages for Carabao/Pico mangoes.



Annex A

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

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

Fig. 5.2 Carabao Mango Ripeness Stages

5.6.3 Bruises Training and Testing

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

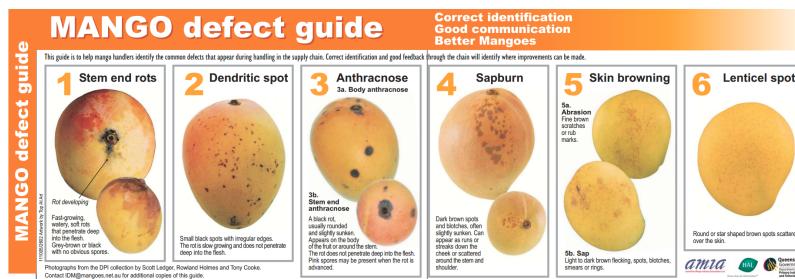


Fig. 5.3 Different Kinds of Mango Defects



1069 5.6.4 Size Determination

1070 To get the size of the mangoes, computer vision techniques such as Gaussian Blur and
 1071 Thresholding are used to get the length and width of the mangoes.

1072 5.7 Mango Formula with User Priority

1073 The linear equation used to calculate the Carabao mango grade is shown below. Likewise,
 1074 the variables $B(P)$, $R(P)$, and $S(P)$ represent the user-defined priority weightings for
 1075 bruising, ripeness, and size characteristics in the User Priority-Based Grading system.
 1076 Additionally, $b(p)$, $r(p)$, and $s(p)$ correspond to the machine learning model's predicted
 1077 values for the bruising, ripeness, and size attributes of the Carabao mango.

$$\text{Mango Grade} = b(P)B(P) + r(P)R(P) + s(P)S(P) \quad (5.5)$$

1078 The machine learning predictions are assigned the following numerical values:

1079 Ripeness Scores:

$$r(\text{yellow}) = 1.0 \quad (5.6)$$

$$r(\text{yellow-green}) = 2.0 \quad (5.7)$$

$$r(\text{green}) = 3.0 \quad (5.8)$$

1080 Bruises Scores:

$$b(\text{bruised}) = 1.0 \quad (5.9)$$

$$b(\text{unbruised}) = 2.0 \quad (5.10)$$

1081 **Size Scores:**

$$s(\text{small}) = 1.0 \quad (5.11)$$

$$s(\text{medium}) = 2.0 \quad (5.12)$$

$$s(\text{large}) = 3.0 \quad (5.13)$$

1082 **5.8 Ethical Considerations**

1083 Ethical considerations ensure that the system is operated safely and responsibly. Data
1084 privacy is ensured by securely storing and anonymizing extracted images and classification
1085 data so that unauthorized access becomes impossible. The system is also eco-friendly
1086 through non-destructive testing, saving mangoes while also ensuring that they are of good
1087 quality. Safety in operations is also ensured by protecting moving parts to prevent mechani-
1088 cal harm and incorporating fail-safes to securely stop operation in case of malfunction.
1089 Addressing these concerns, the system is not only accurate and efficient but also secure,
1090 eco-friendly, and safe for operators, thus a sustainable solution to automated mango sorting
1091 and grading.

1092 **5.9 Summary**

1093 This chapter explained how to create an automatic Carabao mango sorter and grader using
1094 machine learning and computer vision. The system integrates hardware and software
1095 resources, including a conveyor belt, cameras, sensors, and actuators, to offer accurate,
1096 real-time sorting by ripeness, size, and bruises. Various testing and evaluation processes
1097 ensure its performance to offer reliability. Ethical issues are data privacy, environmental



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1098 sustainability, and operation safety. With enhanced efficiency, reduced human error, and
1099 enhanced quality, this system provides an affordable, scalable, and non-destructive solution
1100 to post-harvest mango classification in agricultural industries.



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1101

Chapter 6

1102

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. 76
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. 73

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6. Results and Discussions



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Objectives	Methods	Locations
<p>SO2: To get the precision, recall, F1 score, confusion matrix, and train and test accuracy metrics for classifying the ripeness and bruises with an accuracy score of at least 90%.</p>	<p>Expected Results:</p> <ul style="list-style-type: none"> 1. Successfully achieved at least 90 percent accuracy, precision, recall, f1 score for ripeness classification of Carabao mangoes 2. Successfully achieved at least 90 percent accuracy, precision, recall, f1 score for bruises classification of Carabao mangoes <p>Actual Results:</p> <ul style="list-style-type: none"> 1. Successfully achieved at least 93% accuracy for ripeness classification of Carabao mangoes 2. Successfully achieved at least 73% accuracy for bruise classification of Carabao Mangoes 	<p>Sec. 6.1 on p. 69</p>
<p>SO3: To create a microcontroller-based system to operate the image acquisition system, control the conveyor belt, and process the mango images through machine learning.</p>	<p>Expected Results:</p> <ul style="list-style-type: none"> 1. Successfully made a conveyor belt system to move the mangoes through the image acquisition system to the sorting system 2. Successfully mounted the image acquisition system on the prototype 3. Successfully made the frame for the conveyor belt and image acquisition system to sit on <p>Actual Results:</p> <ul style="list-style-type: none"> 1. Successfully made a conveyor belt system to move the mangoes through the image acquisition system to the sorting system 2. Temporarily mounted the image acquisition system on the prototype 3. Successfully made the frame for the conveyor belt and image acquisition system to sit on 	<p>Sec. 6.4 on p. 73</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> <ol style="list-style-type: none">1. Successfully grade mangoes based on the user priorities on the physical characteristics of the mango2. Successfully verified with qualified individual the results3. Successfully utilize the weighted equation to evaluate mango grade based on user priorities <p>Actual Results:</p> <ol style="list-style-type: none">1. Successfully grade mangoes based on the user priorities on the physical characteristics of the mango2. Successfully utilize the weighted equation to evaluate mango grade based on user priorities3. Need to look for a qualified person to evaluate the graded mango for ground truth	Sec. 6.3 on p. 72

Continued on next page

6. Results and Discussions



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Continued from previous page

Objectives	Methods	Locations
<p>SO5: To classify mango ripeness based on image data using machine learning algorithms such as kNN, k-mean, and Naïve Bayes.</p>	<p>Expected Results:</p> <ul style="list-style-type: none"> 1. Achieve at least 90% accuracy on performance metrics 2. Obtain performance metrics for kNN, k-mean, and Naive Bayes methods for comparison and show the superior performance of using CNN 3. Successfully fine tuned the CNN model to achieve the highest accuracy possible, choosing the best performing among EfficientNet b0-b7, and testing other CNN hyperparameters <p>Actual Results:</p> <ul style="list-style-type: none"> 1. Successfully trained a CNN model using EfficientNet-b0 and Adam Optimizer to detect ripeness based on color 2. Successfully achieved at least 90 percent accuracy, precision, recall, f1 score for ripeness classification of Carabao mangoes 	<p>Sec. 6.1.1 on p. 69</p>
<p>SO6: To classify mango size based on image data by getting its length and width using OpenCV, geometry, and image processing techniques.</p>	<p>Expected Results:</p> <ul style="list-style-type: none"> 1. Successfully classified mango size using computer vision techniques 2. Successfully tuned to have an accurate size with an 80 percent accuracy rating <p>Actual Results:</p> <ul style="list-style-type: none"> 1. Successfully classified mango size using computer vision techniques 2. Calculation of mango size is somewhat inaccurate and needs more fine tuning 	<p>Sec. 6.2 on p. 72</p>

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Objectives	Methods	Locations
SO7: To classify mango bruises based on image data by employing machine learning algorithms.	<p>Expected Results:</p> <ul style="list-style-type: none"> 1. Achieve at least 90% accuracy on performance metrics 2. Successfully fine tuned the CNN model to achieve the highest accuracy possible, choosing the best performing among EfficientNet b0-b7, and testing other CNN hyperparameters <p>Actual Results:</p> <ul style="list-style-type: none"> 1. Successfully trained a CNN model using EfficientNet-b0 and Adam Optimizer to bruises 2. Successfully achieved at least 90 percent accuracy, precision, recall, f1 score for bruise classification of Carabao mangoes 	Sec. 6.1.2 on p. 72

1103 6.1 Training and Testing Results of the Model

1104 6.1.1 Ripeness Classification Results

1105 Add the F1-Score and etc here

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

TABLE 6.2 PERFORMANCE METRICS FOR DIFFERENT EFFICIENTNET VERSIONS



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

TABLE 6.3 RIPENESS CLASSIFICATION REPORT USING KNN

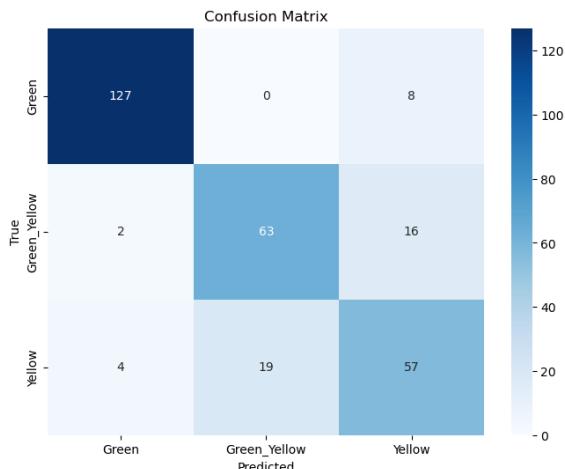


Fig. 6.1 Ripeness Confusion Matrix using kNN

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

TABLE 6.4 RIPENESS CLASSIFICATION REPORT USING NAIVE BAYES

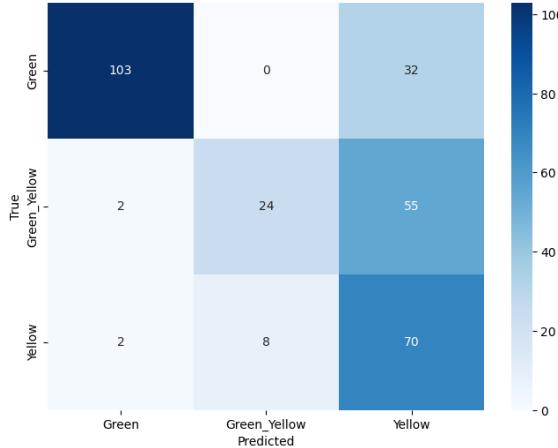


Fig. 6.2 Ripeness Confusion Matrix using Naive Bayes

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

TABLE 6.5 BRUISES CLASSIFICATION REPORT USING CNN

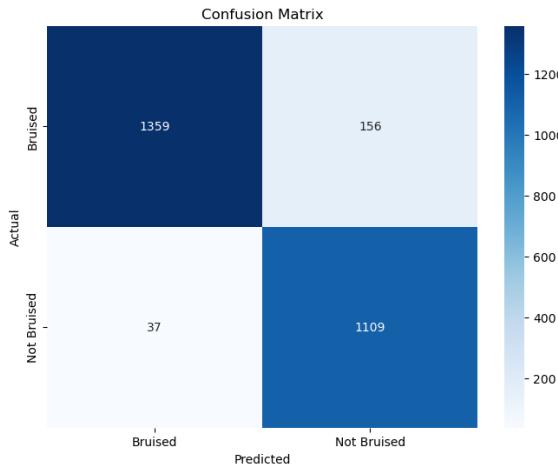


Fig. 6.3 Bruises Confusion Matrix using CNN



Metrics	Results
Precision	0.9318
Recall	0.9275
F1 Score	0.9278

TABLE 6.6 SUMMARIZED CLASSIFICATION REPORT USING CNN

6.1.2 Bruises Classification Results

6.2 Size Determination Results

6.3 Formula with User Priority

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

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

The machine learning predictions are assigned the following numerical values:

Ripeness Scores:

$$r(\text{yellow}) = 1.0 \quad (6.2)$$

$$r(\text{yellow_green}) = 2.0 \quad (6.3)$$

$$r(\text{green}) = 3.0 \quad (6.4)$$



1115

Bruises Scores:

$$b(\text{bruised}) = 1.0 \quad (6.5)$$

$$b(\text{unbruised}) = 2.0 \quad (6.6)$$

1116

Size Scores:

$$s(\text{small}) = 1.0 \quad (6.7)$$

$$s(\text{medium}) = 2.0 \quad (6.8)$$

$$s(\text{large}) = 3.0 \quad (6.9)$$

1117

6.4 Physical Prototype

1118

Add pictures of the hardware prototype here with description



Fig. 6.4 Prototype Top View



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Fig. 6.5 Entrance Conveyor Belt View

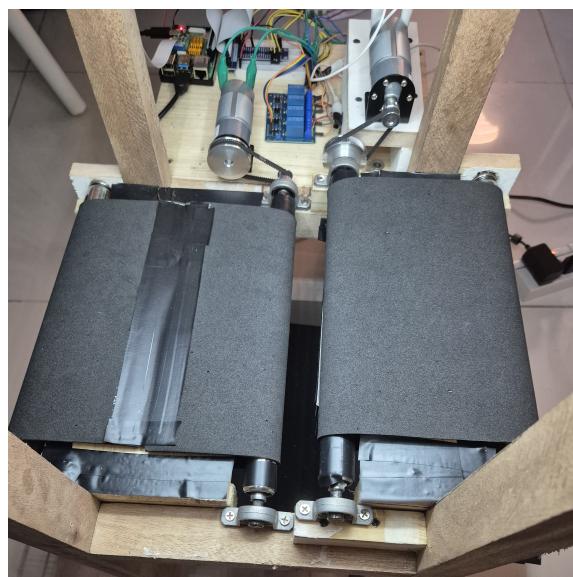


Fig. 6.6 Side Conveyor Belt View

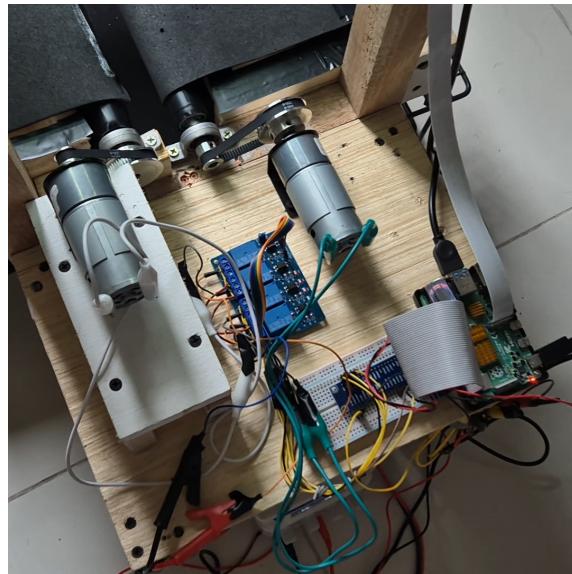


Fig. 6.7 Prototype Main Hardware



Fig. 6.8 DC Motor and Pulley

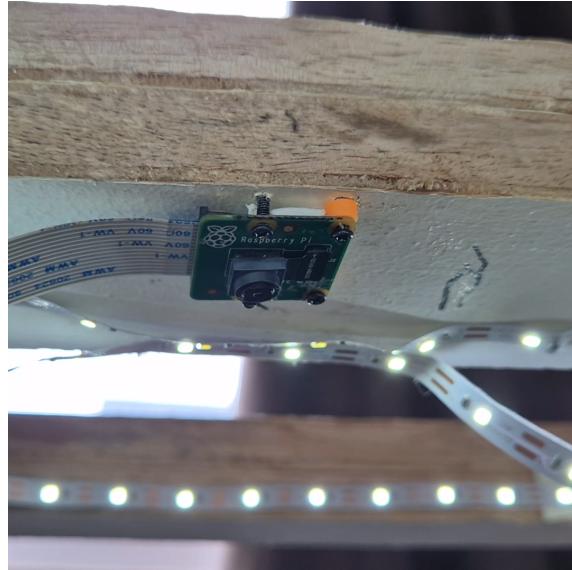


Fig. 6.9 LED Lights and Camera Module

6.5 Software Application

Show the raspberry pi app UI and demonstrate it here

6.6 Summary

Provide the gist of this chapter such that it reflects the contents and the message. This is a compile test

6. Results and Discussions



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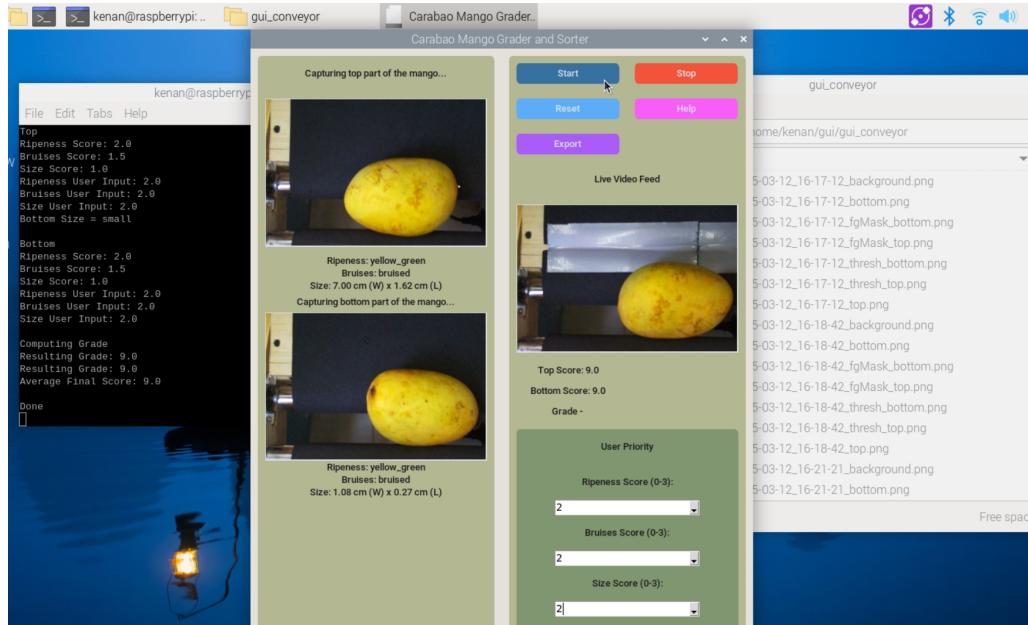


Fig. 6.10 Raspberry Pi App UI Version 1

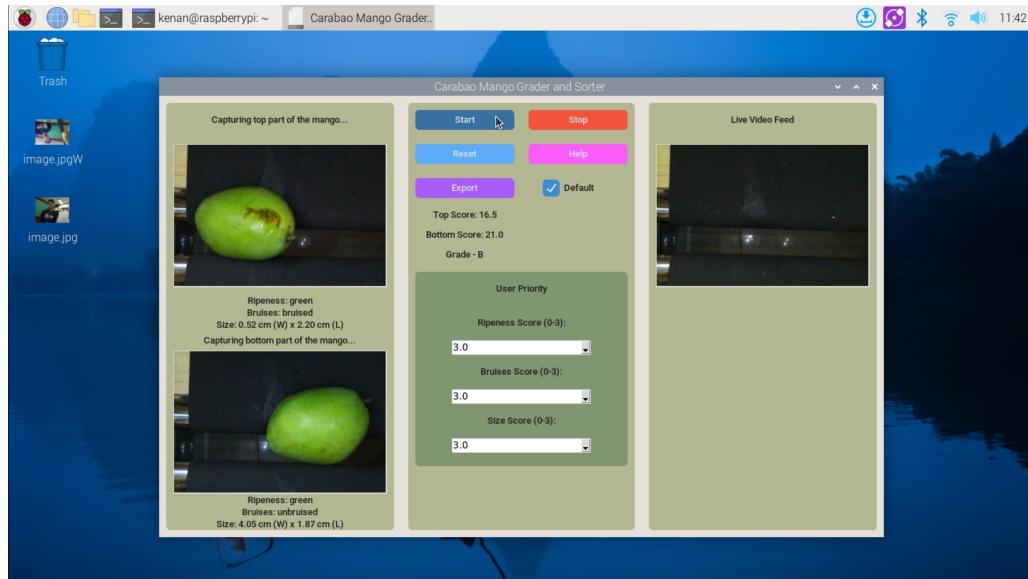


Fig. 6.11 Raspberry Pi App UI Version 2

6. Results and Discussions

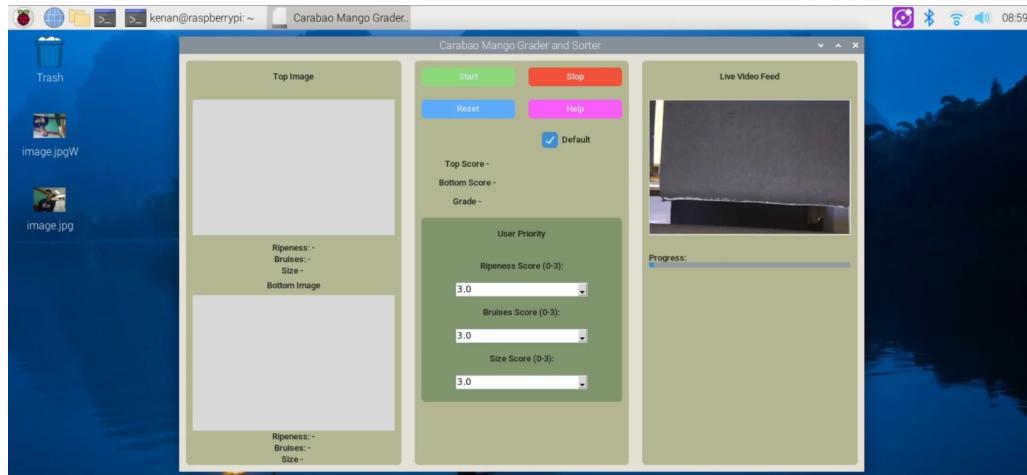


Fig. 6.12 Raspberry Pi App UI Version 3

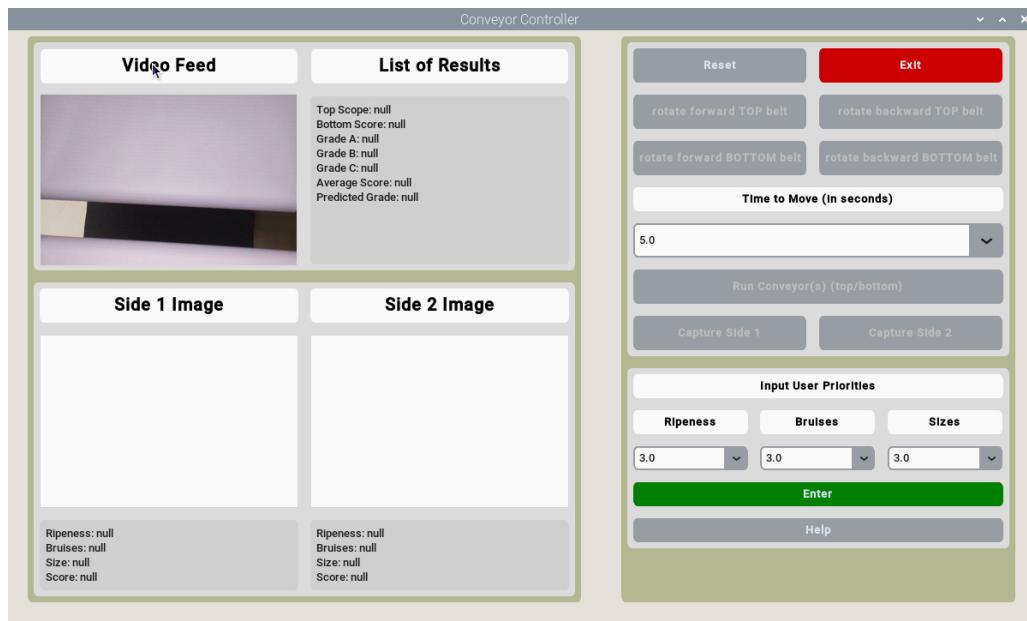


Fig. 6.13 Raspberry Pi App UI Version 4

6. Results and Discussions



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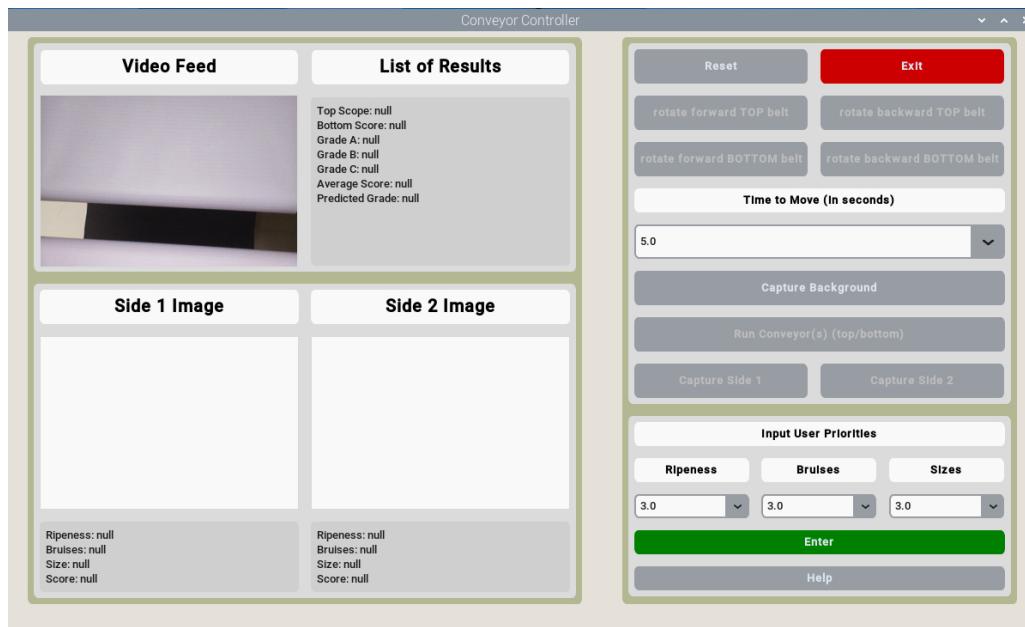


Fig. 6.14 Raspberry Pi App UI Version 5



1125 **Chapter 7**

1126 **CONCLUSIONS, RECOMMENDATIONS, AND**
1127 **FUTURE DIRECTIVES**



1128 7.1 Concluding Remarks

1129 In this Thesis, the prototype is successful in grading and sorting Carabao mangoes based
1130 on the user priority and machine learning algorithm. More specifically, the prototype
1131 is successful in automatically classifying Carabao mangoes based on ripeness (Green,
1132 Green Yellow, and Yellow), size (Large, Medium, Small), and bruises (bruised and not
1133 bruised)

1134 7.2 Contributions

1135 The contributions of each group member are as follows:

- 1136 • BANAL Kenan A.: Scrum Master (Project manager in charge of the hardware and
1137 software integration)
- 1138 • BAUTISTA Francis Robert Miguel F.: Front End Engineer (UI/UX Designer in
1139 charge of software interface and hardware assistant of the Scrum Master)
- 1140 • HERMOSURA Don Humphrey L. : Back End Engineer (Software Engineer in
1141 charge of the machine learning algorithm and software assistant of the Scrum Master)
- 1142 • SALAZAR Daniel G.: Product Engineer (Software Engineer in charge of training
1143 and testing of the machine learning algorithm)

1144 7.3 Recommendations

1145 The researchers recommend that the prototype be improved in the optimization of the
1146 machine learning algorithm and the hardware design. The researchers also recommend that



1147 the prototype be tested in the actual grading and sorting of Carabao mangoes in the market.

1148 **7.4 Future Prospects**

1149 Future researchers may consider the following recommendations for future work:

1150 1. User testing of the prototype in the actual grading and sorting of Carabao mangoes
1151 in the Philippine market.

1152 2. Additional of weight measurement to the prototype to improve the grading and
1153 sorting of Carabao mangoes.

1154 3. Integration of a custom PCB to improve the hardware design of the prototype.

7. Conclusions, Recommendations, and Future Directives



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Produced: September 1, 2025, 11:05



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Appendix A STUDENT RESEARCH ETHICS CLEARANCE

1157

A. Student Research Ethics Clearance



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1158

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 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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1159

Appendix B ANSWERS TO QUESTIONS TO THIS THESIS

1160



B1 How important is the problem to practice?

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

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

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

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 1194 amet ipsum. Nunc quis urna dictum turpis accumsan semper.

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

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

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 1213 amet ipsum. Nunc quis urna dictum turpis accumsan semper.

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

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

1225 Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Etiam lobortis facilisis sem.
 1226 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec
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 1233 amet ipsum. Nunc quis urna dictum turpis accumsan semper.

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

1236 Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Etiam lobortis facilisis sem.
 1237 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec
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 1243 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit
 1244 amet ipsum. Nunc quis urna dictum turpis accumsan semper.

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

1246 Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Etiam lobortis facilisis sem.
 1247 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec
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 1254 amet ipsum. Nunc quis urna dictum turpis accumsan semper.



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

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.

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

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.

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

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1290 **B5.1 What will be the limits of applicability of your proposed so-**
 1291 **solution/s?**

1292 Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Etiam lobortis facilisis sem.
 1293 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec
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 1300 amet ipsum. Nunc quis urna dictum turpis accumsan semper.

1301 **B5.2 What will be the message of the proposed solution to**
 1302 **technical people? How about to non-technical managers and**
 1303 **business people?**

1304 Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Etiam lobortis facilisis sem.
 1305 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec
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 1312 amet ipsum. Nunc quis urna dictum turpis accumsan semper.

1313 **B6 How will you know if your proposed solution/s**
 1314 **is/are correct?**

1315 Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Etiam lobortis facilisis sem.
 1316 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec
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1322 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit
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**B6.1 Will your results warrant the level of mathematics used
(i.e., will the end justify the means)?**

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 1327 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdier mi nec ante. Donec
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**B7 Is/are there an/_ alternative way/s to get to the
same solution/s?**

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 1336 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdier mi nec ante. Donec
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**B7.1 Can you come up with illustrating examples, or even
better, counterexamples to your proposed solution/s?**

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

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

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

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Appendix C REVISIONS TO THE PROPOSAL

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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

1400



- 1401 Make a table with the following columns for showing the summary of revisions to the proposal based on the comments of the panel of examiners.
- 1402
- 1403 1. Examiner
- 1404 2. Comment
- 1405 3. Summary of how the comment has been addressed
- 1406 4. Locations in the document where the changes have been reflected

TABLE D.1 SUMMARY OF REVISIONS TO THE THESIS

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

Continued on next page



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Continued from previous page

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

Continued on next page



Continued from previous page

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



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Appendix E ARTICLE PAPER(S)

1408

Article/Forum Paper Format

(IEEE LaTeX format)

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

1409

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

The conclusion goes here.

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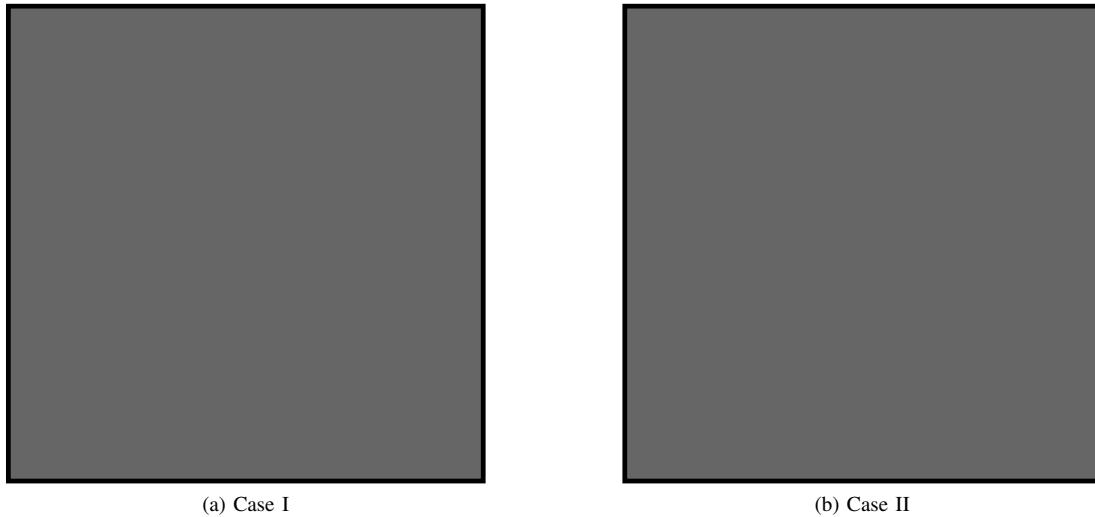


Fig. 2. Simulation results for the network.

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APPENDIX A PROOF OF THE FIRST ZONKLAR EQUATION

Appendix one text goes here.

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APPENDIX B

Appendix two text goes here. [?].

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ACKNOWLEDGMENT

The authors would like to thank...