Non-Destructive Carabao Mango Sorter and Grader based on Physical Characteristics

using Machine Learning

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A Thesis
Presented to the Faculty of the
Department of Electronics and Computer Engineering
Gokongwei College of Engineering
De La Salle University

————————————

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

————————————

by

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ORAL DEFENSE RECOMMENDATION SHEET

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

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

<div align="center">

Dr. Reggie C. Gustillo
Adviser

February 4, 2025

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ABSTRACT

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

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ABBREVIATIONS

NOTATION

Throughout this thesis, mathematical notations conform to ISO 80000-2 standard, e.g., variable names are printed in italics, the only exception being acronyms like, e.g., SNR, which are printed in regular font. Constants are also set in regular font like j. Standard functions and operators are also set in regular font, e.g., in $\sin(\cdot)$, $\max\{\cdot\}$. Commonly used notations are t, f, $\mathrm{j} = \sqrt{-1}$, n and $\exp(\cdot)$, which refer to the time variable, frequency variable, imaginary unit, nth variable, and exponential function, respectively.

130 # **GLOSSARY**

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

132 **LISTINGS**

133 **Chapter 1**

134 **INTRODUCTION**

1.1   Background of the Study

Mangoes, also known as the Mangifera indica, are a member of the cashew family. This fruit can often be seen being farmed by countries such as Myanmar, the Philippines, and India as they have a tropical dry season. Being in a tropical country is an important 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 (Britannica, T. Editors of Encyclopaedia, 2024). Carabao mangoes is a variety of a mango that is found and

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

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

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

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

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

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

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

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the MaZda package is the B11 program, which uses Principal Component Analysis, Linear Discriminant Analysis, Nonlinear Discriminant Analysis, and texture classification to extract features from the mango, which in this case are the length, width, and texture. This data is then compared to a database in order to classify any given mango.

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

1.2 Prior Studies

A paper written by Amana et. al. (2023), designed an automated fruit sorting machine based on the quality through an image acquisition system and CNN. Furthermore, the results of the paper show that the image processing detection score was 89% while that of the tomatoes was 92% while the CNN model had higher validity of 95% for mangoes and 93% for tomatoes. 15%, while the percentage of distinction between the two groups was reported to be 5% respectively (Amna et. al., 2023). Despite the high accuracy in detecting mango defects, the fruit sorting system only sorts based on the mango defects and not on

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ripeness, and weight.

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

1.3   Problem Statement

As mangoes are among the top exports of the Philippines (Centino, et al., 2020), assessing the physical deformities is a necessity. The physical deformities of the Carabao mango can determine the global competitiveness of the country. Having higher quality exports can often lead to gaining competitive edge, increase in demand, increase export revenues, and becoming less susceptible to low-wage competition (Adamo, 2018). In order to increase the quality of mango fruit exports, a key post-harvest process is done, which is sorting and grading. Mango sorting and grading then becomes important to determine which batches are of high quality and can be sold for a higher price, and which batches are of low quality and can only be sold for a low price (Zhengzhou First Industry Co., Ltd, n.d). Traditionally, fruit sorting and grading is inefficient as it is done manually by hand. Some tools are used such as porous ruler to determine fruit size and color palette for color grading (Zhengzhou

First Industry Co., Ltd, n.d). However, among the problems encountered in the process of manually sorting and grading mangoes are susceptibility to human error and requiring a number of laborers to do the task.

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

1.4 Objectives and Deliverables

1.4.1 General Objective (GO)

- 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. ;

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1.4.2 Specific Objectives (SOs)

- SO1: To make an image acquisition system with a conveyor belt for automatic sorting and grading 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%.;

- 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. ;

- SO4: To grade mangoes based on user priorities for size, ripeness, and bruises. ;

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

- SO6: To classify mango size based on image data by getting its length and width using OpenCV, geometry, and image processing techniques. ;

- SO7: To classify mango bruises based on image data by employing machine learning algorithms.

1.4.3 Expected Deliverables

Table 1.1 and 1.2 shows the outputs, products, results, achievements, gains, realizations, and/or yields of the Thesis.

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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.	• To develop a Carabao mango grading and sorting system • To grade Carabao mangoes into three categories based on ripeness, size, and bruises of the Carabao mangoes using machine learning. • To integrate sensors and actuators to control the conveyor belt and image acquisition system.
SO1: To make an image acquisition system with a conveyor belt for automatic sorting and grading mangoes.	• 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%.	• 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.	• 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.	• 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.	• To train a machine learning model such as kNN, k-mean, naive 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

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TABLE 1.2   EXPECTED DELIVERABLES PER OBJECTIVE CONTINUED

Objectives	Expected Deliverables
SO6: To classify mango size based on image data by getting its length and width using OpenCV, geometry, and image processing techniques.	• To develop an image processing algorithm capable of determining mango size using OpenCV, NumPy, and imutils • To classify mangoes based on size and categories into small, medium, and large based on those measures
SO7: To classify mango bruises based on image data by employing machine learning algorithms.	• 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-mean, 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 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 study concluded by Chakraborty et. al. (2023), 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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ensuring that only marketable fruits are processed further.

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

1.5.1 Technical Benefit

1. The development of an automated Carabao mango sorter would increase the quality control of classifying Carabao mangoes based on ripeness, size, and bruising.

2. The accuracy in sorting Carabao Mangoes will be significantly improved while reducing the errors due to human factors in manual sorting.

3. The automated Carabao Mango sorter carefully sorts the mangoes while ensuring that they remain free from bruising or further damage during the process

1.5.2 Social Impact

1. The reduction in manual labor creates opportunities in maintenance and technologies in the automated Carabao mango sorter.

2. The automated Carabao mango sorter system improves Carabao mango standards and enhances the satisfaction of the buyers and the customers through guaranteeing consistent Carabao mango grade.

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

1.5.3 Environmental Welfare

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

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

1.6 Assumptions, Scope, and Delimitations

1.6.1 Assumptions

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

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

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

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

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

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

1.6.2 Scope

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

2. The mangoes used as the subject will be solely sourced from markets in the Philippines.

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

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

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

1.6.3 Delimitations

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

2. Additionally, the project prototype will only be able to capture, sort, and grade one mango subject at a time which means the mangoes have to be placed in the conveyor belt in a single file line for accurate sorting.

3. For the bruises, the system will only be able to detect external bruises and may not identify the non-visible and internal bruises.

4. The system does not load the mangoes onto the conveyor belt itself. Assistance is required to put mangoes into the conveyor belt to start the sorting process

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5. The prototype will be powered using alternating current (ac) power and will be plugged into a wall socket which is only suitable for indoor use.

1.7 Description and Methodology of the Thesis

A purpose of the description here is to re-steer/remind the panelist/reader again by tersely describing what your thesis is about (i.e. the problem and the main goal you want to achieve) in another way without sounding repetitive.

Your methodology is your means of achieving your stated objectives. What you put here is the summary of your methodology chapter.

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1.8 Estimated Work Schedule and Budget

The estimated work schedule can be represented as a Gantt Chart or a combination of Project Network Diagram, Work Breakdown Structure, and Critical Path. The budget can

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be made into a Bill of Materials, financial plan, or if your Thesis is funded and part of larger project, the cost, and date for reaching each milestone and/or deliverable for your part of the project.

For ECE Department undergraduate theses, the individual Gantt Chart or Work Breakdown Schedule and Bill of Materials will be included in this section and be removed in the final document.

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1.9   Overview of the Thesis

There are seven succeeding chapters. To recall, chapter 1 involves the introduction of the thesis topic containing the background of the study, previous studies, objectives and deliverables, assumptions, scope, and delimitation, significance of the study, description of the project together with the methodology, and Gantt chart and budget. Chapter 2 involves the existing articles, the lacking in their approaches, and the summary of chapter 2. Chapter 3 involves the theoretical considerations of the thesis topic while chapter 4 would

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consist of the design consideration involving the thesis topic. Chapter 5 would involve the research methodology containing the testing procedure and setup. Chapter 6 would involve the results and discussion based on the methodology while chapter 7 would involve the conclusion, recommendations, and future suggestions.

Chapter 2

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LITERATURE REVIEW

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It is to be noted that each subsection in this chapter should discuss in narrative form each table that is presented in order to point out to the reader what the author(s) intend to convey.

2.1 Existing Work

Cite and summarize here relevant and significant literature (dissertations, theses, journals, patents, notable conference papers) through a table and descriptions to prove that no one has done your work yet and/or that your work is not a duplication of existing ones. Your focus here is what has *been done*.

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2.2   Lacking in the Approaches

428   You can summarize the weaknesses of existing approaches by a tabular comparison of the

429   literature. Your focus here is what has *not been done*, i.e. what features were missed, what

430   solutions were not considered, what the demerits are, etc. Through these items, you then

431   can introduce the necessity for doing your proposed solution.

432   It is to be noted that the degree of novelty for undergraduate thesis is lower than those

433   for graduate school. If a Ph.D. dissertation/thesis has a high degree of novelty and that for

434   an undergraduate is low, then a master's thesis is somewhere between the two.

435   Briefly include here the following in order to remind the reader why you are highlighting

436   the weaknesses of the solutions of existing literature.

437   • mentioning the problem

438   • showing how your solution is better (can be better (for proposals))

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484 ## 2.3 Summary

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

486 **Chapter 3**

487 **THEORETICAL CONSIDERATIONS**

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Before starting the first section, provide an overview of the purpose of this chapter and its contents, and how they are relevant to your methodology. Discuss in this chapter the relevant theories and concepts that should support your proposed solutions.

This chapter is for providing the context to your panelist/reader. It is actually an expanded form of the Background of the Study that you have put in Chapter 1.

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Fig. 3.1   A quadrilateral image example.

3.1 Summary

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

540 **Chapter 4**

541 **DESIGN CONSIDERATIONS**

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Before starting the first section, provide an overview of the purpose of this chapter and its contents, and how they are relevant to your methodology.

Your primary goal in the Design Considerations chapter is to describe to your panelist/readers the key topics that fall further under Theoretical Considerations, but should be placed here instead since they are geared towards your Methodology. These key topics are those that you have directly adopted in making your solution/methodology. You can think of the connection of the Design Considerations chapter to the Theoretical Considerations chapter in this way: if your Theoretical Considerations chapter serves as the main foundation of a building, then the Design Considerations chapter functions as the columns.

The Design Considerations chapter is an avenue for explaining why you considered the topics here for your proposed methodology. This chapter is different from your methodology, because topics you discuss here are already accepted as part of the body of knowledge, and may have not been developed by you.

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4.1   Standards

601   Standards are essential for successful projects and impactful research. They provide a

602   common framework and ensure consistency, quality, and safety across various disciplines.

603   By adhering to established standards, your work becomes more reliable, interoperable, and

604   valuable in real-world applications. Standards also demonstrate your understanding of

605   industry best practices and enhance the credibility of your research.

606   To effectively integrate standards into your project, begin by identifying relevant stan-

607   dards related to your specific field. Thoroughly research and understand the requirements

608   and guidelines outlined within these standards. Align your project objectives and method-

609   ologies to meet or exceed these standards. Document your use of standards in this section,

610   including how and why specific standards were chosen. Finally, evaluate your results

611   against the established standards, justifying any deviations from the norm with sound

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612   reasoning and evidence.

4.2   Summary

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

615 **Chapter 5**

616 **METHODOLOGY**

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Put an overview of the contents of chapter. Mention here your methodology flow through a figure and provide an overview of it and how your methodology achieves your objectives. How your methodology achieves each of your specific objectives is what your panelists/examiners will be looking for. Specify how your methodology achieves your general objective and specific objectives. A point-by-point comparison how your methodology achieves each of your specific objectives is expected in the final Thesis.

Also make sure that you refer clearly to the chapters on the Literature Review, Theoretical Considerations, and Design Considerations showing how your methodology ties with those that you have discussed in those chapters.

Make an overview of the contents of the chapter. Put here your methodology flow through a figure and provide an overview of it.

In summative form, Table 5.1 indicates the approaches, designs, modes, processes, programs, techniques, and/or ways that the Thesisreaches the objectives.

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.	1. First itemtext 2. Second itemtext 3. Last itemtext 4. First itemtext 5. Second itemtext	Sec. 5.1 on p. 34

Continued on next page

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Objectives	Methods	Locations
SO1: To make an image acquisition system with a conveyor belt for automatic sorting and grading mangoes.	1. First itemtext 2. Second itemtext 3. Last itemtext 4. First itemtext 5. Second itemtext	Sec. 5.1 on p. 34
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%.	1. First itemtext 2. Second itemtext 3. Last itemtext 4. First itemtext 5. Second itemtext	Sec. 5.1 on p. 34
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. First itemtext 2. Second itemtext 3. Last itemtext 4. First itemtext 5. Second itemtext	Sec. 5.1 on p. 34

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Continued from previous page

Objectives	Methods	Locations
SO4: To grade mangoes based on user priorities for size, ripeness, and bruises.	1. First itemtext 2. Second itemtext 3. Last itemtext 4. First itemtext 5. Second itemtext	Sec. 5.1 on p. 34
SO5: To classify mango ripeness based on image data using machine learning algorithms such as kNN, k-mean, and Naïve Bayes.	1. First itemtext 2. Second itemtext 3. Last itemtext 4. First itemtext 5. Second itemtext	Sec. 5.1 on p. 34

5.1 Implementation

630

631 Summarize the process used to create/set-up the work with an explanation of such process,

632 instruments, and materials that you used if any. If the description is lengthy, use condensed

633 bullet points.

634 *Rule of thumb*: Implementation is how you made your work; (keywords: implemented,

635 created, made, soldered, programmed, etc.).

636   If you wrote a program or made a simulation, you must state how the program or

637 simulation functions in this section. An algorithm or a pseudocode as shown in Table **??** is

638 a good example.

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684 ## 5.2   Evaluation

685 Describe the procedures for evaluating the correct behavior and outcome of your work,
686 including what information you need to gather and how you will obtain or measure it.

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687 *Rule of thumb*: Evaluation is how you tested your work; (keywords: measured, tested,
688 compared, simulated, etc.).

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5.3   Summary

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736 **Chapter 6**

737 **RESULTS AND DISCUSSIONS**

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Show in this chapter proofs why your proposed solution works. However, presenting results ("It worked") without an appropriate explanation does not show thorough understanding. Aside from the data and results that you have obtained, and their explanation, the discussion includes why components of your proposed solution work did or did not work in accordance to what you described in the evaluation process, and how the proposed solution performed and faired. Interpret the results and the reasons why they were obtained. If your results are incorrect, apparent discrepancies from theory should be pointed out and explained. In essence, what do the results mean? Citing existing publication can help you compare your results and your explanations.

The next items below is not related to the description of this results and discussions chapter, but serves as an opener for the LaTeX portion of this template.

Here is an example of a citation for ISO 80000-2 standard [**?**]. Another one is [**?**] and [**?**].

In using this template, the user is expected to have a working knowledge of LaTeX. A good introduction is in [**?**]. Its latest version can be accessed at `http://www.ctan.org/tex-archive/info/lshort`. See the Appendix of `document_guide.pdf` for examples.

In aggregate form, Table 6.1 shows the outcomes and completions in applying the methodology of the Thesisper objective.

TABLE 6.1   SUMMARY OF RESULTS FOR ACHIEVING THE OBJECTIVES

Objectives	Results	Locations

Continued on next page

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Objectives	Results	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.	1. First itemtext 2. Second itemtext 3. Last itemtext 4. First itemtext 5. Second itemtext	Sec. 5.1 on p. 34
SO1: To make an image acquisition system with a conveyor belt for automatic sorting and grading mangoes.	1. First itemtext 2. Second itemtext 3. Last itemtext 4. First itemtext 5. Second itemtext	Sec. 5.1 on p. 34
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%.	1. First itemtext 2. Second itemtext 3. Last itemtext 4. First itemtext 5. Second itemtext	Sec. 5.1 on p. 34

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Continued from previous page

Objectives	Results	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. First itemtext 2. Second itemtext 3. Last itemtext 4. First itemtext 5. Second itemtext	Sec. 5.1 on p. 34
SO4: To grade mangoes based on user priorities for size, ripeness, and bruises.	1. First itemtext 2. Second itemtext 3. Last itemtext 4. First itemtext 5. Second itemtext	Sec. 5.1 on p. 34
SO5: To classify mango ripeness based on image data using machine learning algorithms such as kNN, k-mean, and Naïve Bayes.	1. First itemtext 2. Second itemtext 3. Last itemtext 4. First itemtext 5. Second itemtext	Sec. 5.1 on p. 34

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6.1 Summary

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Chapter 7

CONCLUSIONS, RECOMMENDATIONS, AND FUTURE DIRECTIVES

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7.1 Concluding Remarks

In this Thesis, . . .

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

7.2 Contributions

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

- the ;

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- the ;

7.3 Recommendations

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7.4 Future Prospects

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

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3. the . . . .

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1. IEEE Citation Reference: www.ieee.org/documents/ieeecitationref.pdf

2. IEEE Editorial Style manual: www.ieee.org/documents/style_manual.pdf

3. IEEE Abbreviations for Transactions, Journals, Letters, and Magazines: www.ieee.org/documents/trans_journal_names.pdf

Also in your BibTeX file, enclose letters or words that should all be in uppercase in curly brackets. Example: IBM, Philippines, eXtensible Markup Language.

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Appendix A
STUDENT RESEARCH ETHICS CLEARANCE

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RESEARCH ETHICS CLEARANCE FORM[1]
For Thesis Proposals

Names of Student Researcher(s):

SAMPLE ONLY

Dela Cruz, Juan Z.

College: Gokongwei College of Engineering
Department: Electronics and Communications Engineering
Course: PhD-ECE
Expected Duration of the Project: from: **April 2015**   to: **April 2017**
Ethical considerations **None** *(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. *Baltasar* **Dr. Francisco D. Baltasar** **_____** **Name and Signature of Adviser/Mentor:** **Date: April 8, 2017**
Noted by: *R Sison* **Dr. Rafael W. Sison** **_____** **Name and Signature of the Department Chairperson:** **Date: April 8, 2017**

---

[1] The same form can be used for the reports of completed projects. The appropriate heading need only be used.

Appendix B

ANSWERS TO QUESTIONS TO THIS THESIS

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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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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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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?

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

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

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

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

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

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B5.1 What will be the limits of applicability of your proposed solution/s?

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

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

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

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1072 amet ipsum. Nunc quis urna dictum turpis accumsan semper.

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

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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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1119 **Appendix C**

1120 **REVISIONS TO THE PROPOSAL**

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1121 Make a table with the following columns for showing the summary of revisions to the
1122 proposal based on the comments of the panel of examiners.

1123 1. Examiner

1124 2. Comment

1125 3. Summary of how the comment was addressed

1126 4. Locations in the document where the changes have been reflected

TABLE C.1   SUMMARY OF REVISIONS TO THE PROPOSAL

Examiner	Comment	Summary of how the comment was addressed	Locations
Dr. Reggie C. Gustillo	Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Etiam lobortis facilisis sem. Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec ullamcorper, felis non sodales commodo, lectus velit ultrices augue, a dignissim nibh lectus placerat pede. Vivamus nunc nunc, molestie ut, ultricies vel, semper in, velit. Ut porttitor. Praesent in sapien. Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Duis fringilla tristique neque. Sed interdum libero ut metus. Pellentesque placerat. Nam rutrum augue a leo. Morbi sed elit sit amet ante lobortis sollicitudin. Praesent blandit blandit mauris. Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit amet ipsum. Nunc quis urna dictum turpis accumsan semper.	Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Etiam lobortis facilisis sem. Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec ullamcorper, felis non sodales commodo, lectus velit ultrices augue, a dignissim nibh lectus placerat pede. Vivamus nunc nunc, molestie ut, ultricies vel, semper in, velit. Ut porttitor. Praesent in sapien. Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Duis fringilla tristique neque. Sed interdum libero ut metus. Pellentesque placerat. Nam rutrum augue a leo. Morbi sed elit sit amet ante lobortis sollicitudin. Praesent blandit blandit mauris. Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit amet ipsum. Nunc quis urna dictum turpis accumsan semper. **First** itemtext **Second** itemtext **Last** itemtext **First** itemtext **Second** itemtext	Sec. 5.1 on p. 34, Sec. 5.2 on p. 36, Fig. 3.1 on p. 25

Continued on next page

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Examiner	Comment	Summary of how the comment was addressed	Locations
Dr. Donable de Veas Abuan	Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Etiam lobortis facilisis sem. Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec ullamcorper, felis non sodales commodo, lectus velit ultrices augue, a dignissim nibh lectus placerat pede. Vivamus nunc nunc, molestie ut, ultricies vel, semper in, velit. Ut porttitor. Praesent in sapien. Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Duis fringilla tristique neque. Sed interdum libero ut metus. Pellentesque placerat. Nam rutrum augue a leo. Morbi sed elit sit amet ante lobortis sollicitudin. Praesent blandit blandit mauris. Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit amet ipsum. Nunc quis urna dictum turpis accumsan semper.	Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Etiam lobortis facilisis sem. Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec ullamcorper, felis non sodales commodo, lectus velit ultrices augue, a dignissim nibh lectus placerat pede. Vivamus nunc nunc, molestie ut, ultricies vel, semper in, velit. Ut porttitor. Praesent in sapien. Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Duis fringilla tristique neque. Sed interdum libero ut metus. Pellentesque placerat. Nam rutrum augue a leo. Morbi sed elit sit amet ante lobortis sollicitudin. Praesent blandit blandit mauris. Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit amet ipsum. Nunc quis urna dictum turpis accumsan semper. **First** itemtext **Second** itemtext **Last** itemtext **First** itemtext **Second** itemtext	Sec. 5.1 on p. 34, Sec. 5.2 on p. 36, Fig. 3.1 on p. 25

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Examiner	Comment	Summary of how the comment was addressed	Locations
Engr. Jose Martin Maningo	Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Etiam lobortis facilisis sem. Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec ullamcorper, felis non sodales commodo, lectus velit ultrices augue, a dignissim nibh lectus placerat pede. Vivamus nunc nunc, molestie ut, ultricies vel, semper in, velit. Ut porttitor. Praesent in sapien. Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Duis fringilla tristique neque. Sed interdum libero ut metus. Pellentesque placerat. Nam rutrum augue a leo. Morbi sed elit sit amet ante lobortis sollicitudin. Praesent blandit blandit mauris. Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit amet ipsum. Nunc quis urna dictum turpis accumsan semper.	Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Etiam lobortis facilisis sem. Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec ullamcorper, felis non sodales commodo, lectus velit ultrices augue, a dignissim nibh lectus placerat pede. Vivamus nunc nunc, molestie ut, ultricies vel, semper in, velit. Ut porttitor. Praesent in sapien. Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Duis fringilla tristique neque. Sed interdum libero ut metus. Pellentesque placerat. Nam rutrum augue a leo. Morbi sed elit sit amet ante lobortis sollicitudin. Praesent blandit blandit mauris. Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit amet ipsum. Nunc quis urna dictum turpis accumsan semper. • First itemtext • Second itemtext • Last itemtext • First itemtext • Second itemtext	Sec. 5.1 on p. 34, Sec. 5.2 on p. 36, Fig. 3.1 on p. 25

De La Salle University

Examiner	Comment	Summary of how the comment was addressed	Locations
Dr. Alexander Co Abad	Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Etiam lobortis facilisis sem. Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec ullamcorper, felis non sodales commodo, lectus velit ultrices augue, a dignissim nibh lectus placerat pede. Vivamus nunc nunc, molestie ut, ultricies vel, semper in, velit. Ut porttitor. Praesent in sapien. Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Duis fringilla tristique neque. Sed interdum libero ut metus. Pellentesque placerat. Nam rutrum augue a leo. Morbi sed elit sit amet ante lobortis sollicitudin. Praesent blandit blandit mauris. Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit amet ipsum. Nunc quis urna dictum turpis accumsan semper.	Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Etiam lobortis facilisis sem. Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec ullamcorper, felis non sodales commodo, lectus velit ultrices augue, a dignissim nibh lectus placerat pede. Vivamus nunc nunc, molestie ut, ultricies vel, semper in, velit. Ut porttitor. Praesent in sapien. Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Duis fringilla tristique neque. Sed interdum libero ut metus. Pellentesque placerat. Nam rutrum augue a leo. Morbi sed elit sit amet ante lobortis sollicitudin. Praesent blandit blandit mauris. Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit amet ipsum. Nunc quis urna dictum turpis accumsan semper. 1. First itemtext 2. Second itemtext 3. Last itemtext 4. First itemtext 5. Second itemtext	Sec. 5.1 on p. 34, Sec. 5.2 on p. 36, Fig. 3.1 on p. 25

De La Salle University

Examiner	Comment	Summary of how the comment was addressed	Locations
Dr. Rafael W. Sison	Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Etiam lobortis facilisis sem. Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec ullamcorper, felis non sodales commodo, lectus velit ultrices augue, a dignissim nibh lectus placerat pede. Vivamus nunc nunc, molestie ut, ultricies vel, semper in, velit. Ut porttitor. Praesent in sapien. Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Duis fringilla tristique neque. Sed interdum libero ut metus. Pellentesque placerat. Nam rutrum augue a leo. Morbi sed elit sit amet ante lobortis sollicitudin. Praesent blandit blandit mauris. Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit amet ipsum. Nunc quis urna dictum turpis accumsan semper.	Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Etiam lobortis facilisis sem. Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec ullamcorper, felis non sodales commodo, lectus velit ultrices augue, a dignissim nibh lectus placerat pede. Vivamus nunc nunc, molestie ut, ultricies vel, semper in, velit. Ut porttitor. Praesent in sapien. Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Duis fringilla tristique neque. Sed interdum libero ut metus. Pellentesque placerat. Nam rutrum augue a leo. Morbi sed elit sit amet ante lobortis sollicitudin. Praesent blandit blandit mauris. Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit amet ipsum. Nunc quis urna dictum turpis accumsan semper.	Sec. 5.1 on p. 34, Sec. 5.2 on p. 36, Fig. 3.1 on p. 25

1127 **Appendix D**

1128 **REVISIONS TO THE FINAL**

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1129   Make a table with the following columns for showing the summary of revisions to the
1130 proposal based on the comments of the panel of examiners.

1131   1. Examiner

1132   2. Comment

1133   3. Summary of how the comment has been addressed

1134   4. Locations in the document where the changes have been reflected

TABLE D.1   SUMMARY OF REVISIONS TO THE THESIS

Examiner	Comment	Summary of how the comment has been addressed	Locations
Dr. Reggie C. Gustillo	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. 5.1 on p. 34, Sec. 5.2 on p. 36, Fig. 3.1 on p. 25

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| Examiner	Comment	Summary of how the comment has been addressed	Locations
Dr. Donable de Veas Abuan	1. First itemtext 2. Second itemtext 3. Last itemtext 4. First itemtext 5. Second itemtext	1. First itemtext 2. Second itemtext 3. Last itemtext 4. First itemtext 5. Second itemtext **First** itemtext **Second** itemtext **Last** itemtext **First** itemtext **Second** itemtext	Sec. 5.1 on p. 34, Sec. 5.2 on p. 36, Fig. 3.1 on p. 25
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. 5.1 on p. 34, Sec. 5.2 on p. 36, Fig. 3.1 on p. 25

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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. 5.1 on p. 34, Sec. 5.2 on p. 36, Fig. 3.1 on p. 25
Dr. Rafael W. Sison	1. First itemtext 2. Second itemtext 3. Last itemtext 4. First itemtext 5. Second itemtext	1. First itemtext 2. Second itemtext 3. Last itemtext 4. First itemtext 5. Second itemtext	Sec. 5.1 on p. 34, Sec. 5.2 on p. 36, Fig. 3.1 on p. 25

Appendix E
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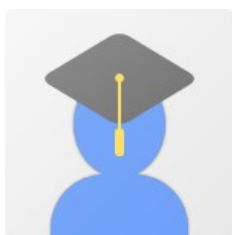
Kenan A. Banal received the B.Sc., M.Sc., and Ph.D. degrees in chemistry all from the Pamantasan ng Pilipinas, San Juan, Metro Manila, Philippines, in 2020, 2022 and 2025 respectively. He is currently taking up his B.Sc. Computer Engineering studies. He has developed several high-speed packet-switched network systems and node modules. His research interests include high-speed packet-switched networks, high speed radio interface design, discrete simulation and statistical models for packet switches.
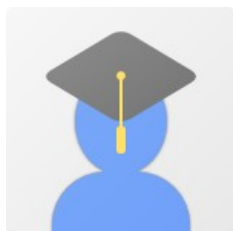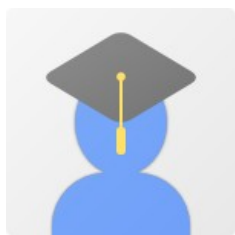
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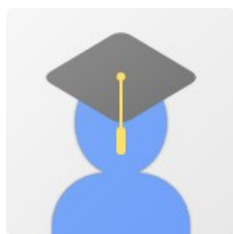
Don Humphrey L. HERMOSURA received the B.Sc., M.Sc., and Ph.D. degrees in chemistry all from the Pamantasan ng Pilipinas, San Juan, Metro Manila, Philippines, in 2020, 2022 and 2025 respectively. He is currently taking up his B.Sc. Computer Engineering studies. He has developed several high-speed packet-switched

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network systems and node modules. His research interests include high-speed packet-switched networks, high speed radio interface design, discrete simulation and statistical models for packet switches.

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1165 **Appendix F**

1166 **ARTICLE PAPER(S)**

Article/Forum Paper Format
(IEEE LaTeX format)

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

1167

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

Index Terms—**Computer Society, IEEE, IEEEtran, journal, LaTeX, paper, template.**

I. INTRODUCTION

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

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M. Shell was with the Department of Electrical and Computer Engineering, Georgia Institute of Technology, Atlanta, GA, 30332.
E-mail: see http://www.michaelshell.org/contact.html
J. Doe and J. Doe are with Anonymous University.
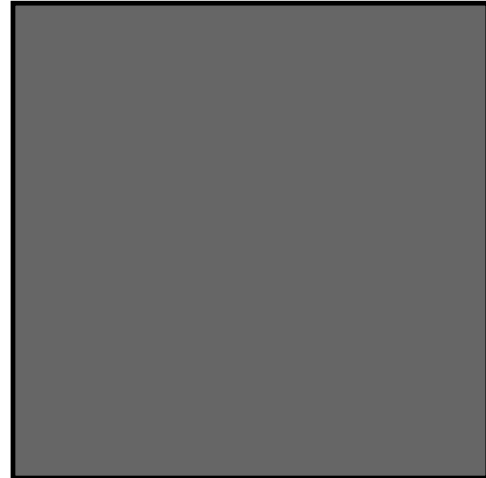
Fig. 1. Simulation results for the network.

TABLE I
AN EXAMPLE OF A TABLE

One	Two
Three	Four

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II. CONCLUSION

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(a) Case I

(b) Case II

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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