AUTOMATED EGGPLANT SORTING AND GRADING SYSTEM USING COMPUTER VISION AND MACHINE LEARNING FOR QUALITY CLASSIFICATION

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BACHELOR OF SCIENCE IN COMPUTER ENGINEERING

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ABSTRACT

This study...

Keywords: *computer vision, grading system, eggplant classification*

This piece of work is wholeheartedly dedicated

to my parents

Papang

and

Nanay

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I would like to express my gratitude to the following people and institutions which, in one way or another, greatly contributed towards the completion of this study.

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Above all, to our ***Almighty God***, whose unconditional love infinitely transcends all human comprehensions, provides us with good health, divine protection and bountiful blessings.

Jodie

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

List of Equations

CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Eggplant (*Solanum melongena* L.) has been cultivated for centuries and is now a staple in cuisines worldwide. Also known as aubergine, brinjal, or *talong* in the Philippines, eggplant holds a prominent position in the vegetable sector, with global production of approximately 60.8 million metric tons from an area of over 1.9 million hectares (Food and Agriculture Organization of the United Nations (FAO), 2025). In April to June of 2023, the Philippines produced 102.98 thousand metric tons of eggplant (Philippine Statistics Authority, 2023), making it one of the most important and widely grown vegetable crops in the country.

But before being sold, eggplant is manually categorized by visual inspection to determine their quality (Sun et al., 2025). This includes assessing the fruit's diameter, length, volume, curvature, color homogeneity, calyx area (the green, leaf-like "cap" at the fruit's stem end), calyx color, and surface defects (Lyu et al., 2025; Lalam et al., 2025). Sorting only takes a few hours for small-scale farmers, but it can take a little longer and more workers on large plantations, since the quantity of harvested eggplants is directly proportional to labor and time needed (Khan et al., 2025).

Because most people just use their eyes to judge the quality of eggplant, there is a significant rate of inaccuracy in addition to the time-consuming and expensive nature of manual eggplant sorting (Waghmare et al., 2025). As a result, a number of cutting-edge technologies were combined to increase classification accuracy and decrease inefficiencies, particularly deep learning and computer vision. For instance, the study of

1.2 Statement of the Problem

This study seeks to investigate some properties of decomposable hyper KS-semigroups in the context of strong, weak, quasi- and bi-hyper KS-ideals.

1.3 Objectives of the Study

In view of the above stated problem, we have the following objectives:

1. To introduce the concept of strong, weak, quasi- and bi-hyper KS-ideals;
2. To provide characterizations of strong, weak, quasi- and bi-hyper KS-ideals and investigate their relationships;
3. To introduce the idea of decomposable hyper KS-semigroups and give some characterizations.

1.4 Significance of the Study

The concept of hyperstructures is itself, a powerful mathematical tool since algebraic hyperstructures seem to occur very naturally in many areas of mathematics and even in other disciplines.

1.5 Scope and Limitations

The primary motivation of this study lies within the structural properties of hyper

1.6 Definition of Terms

Data Logger An electronic device that records data over time or in relation to location either with a built-in instrument or sensor or via external instruments and sensors.

GPS Tracking Using the Global Positioning System to determine and track the precise location of a person, vehicle, or other asset.

Real-time Monitoring The process of continuously observing a system or process and immediately reporting any changes or anomalies.

Sensor A device that detects or measures a physical property and records, indicates, or otherwise responds to it.

Telemetry The process of recording and transmitting the readings of an instrument.

Wireless Communication The transfer of information between two or more points that are not connected by an electrical conductor.

CHAPTER 2

REVIEW OF RELATED LITERATURE

This chapter focuses on related studies or projects that have provided additional relevant information to the proponent. Section 2.1 presents the theoretical background related to computer vision, cyber-physical systems, and machine learning. Section 2.2 specifies the concept of how the system will classify the eggplants by class based on surface defects, color homogeneity, and size. Section 2.3 presents a review of literature related to the design of employing computer vision, machine learning, and mechatronic integration in agricultural automation for image-based inspection and mechanical sorting applications. Collectively, these reviewed literatures support the concept presented in this study.

2.1 Theoretical Background

The development of an automated eggplant grading system is fundamentally grounded in the integrated theoretical paradigms of computer vision, deep learning, and mechatronics. The entire process can be conceptualized through a sequential computer vision pipeline, which moves from image acquisition to physical actuation (Szeliski, 2022). This pipeline begins with the digital image formation theory, where a camera sensor captures light reflectance from objects on a conveyor belt, a common setup in food process engineering (Dougherty, 2020). The stability and quality of this initial stage are paramount, as controlled, diffuse illumination is critical to minimize specular reflections and shadows that can obscure critical features like color and surface defects, thereby ensuring consistent input for subsequent algorithmic processing.

Following acquisition, image pre-processing theories are applied to enhance data quality and standardize inputs. This involves digital signal processing techniques such as noise reduction using Gaussian or median filters (Kumar and Sodhi, 2020) and, crucially, color space transformation. Converting images from the default Red-Green-Blue (RGB) space to Hue-Saturation-Value (HSV) or CIEL*a*b* is a well-established step in agricultural product inspection (Khan and AlGhamdi, 2024). The theoretical underpinning for this conversion lies in the decoupling of color information (chrominance) from intensity (luminance) in these spaces, making the extracted color features more robust to minor variations in lighting conditions, which is essential for accurate color-based grading.

The core of the system resides in the theoretical distinction between traditional machine learning and deep learning for feature extraction. Traditional approaches are based on manual feature engineering, drawing from image processing and pattern recognition theory to hand-craft descriptors for color (e.g., histograms, mean values), shape (e.g., aspect ratio, roundness, area), and texture (e.g., using Gray-Level Co-occurrence Matrix (GLCM) or Local Binary Patterns (LBP)) (Haralick et al., 2007; Ojala et al., 2002). In contrast, deep learning, specifically Convolutional Neural Network (CNN) theory, posits that models can automatically learn a hierarchical representation of features directly from raw pixel data (LeCun et al., 2015; Goodfellow et al., 2016). The lower layers of a CNN learn generic features like edges and corners, while deeper layers synthesize these into complex, task-specific features relevant to defect identification, thereby eliminating the need for manual feature design.

For the classification task itself, the theoretical models diverge. Machine learning classifiers operate on the principles of statistical learning theory, finding optimal hyperplanes to separate classes or constructing ensembles of decision trees, respectively, based on the handcrafted features (Hearst et al., 1998; Breiman, 2001). Conversely, an end-to-end deep learning model uses a fully connected output layer with a normalized exponential function (also known as *Softmax*) to perform classification based on the high-level features it learned itself. The theoretical advantage of CNNs is their superior ability to model complex, non-linear relationships in visual data, a capability that has been demonstrated to outperform traditional methods in numerous agricultural applications (Bharman et al., 2022).

The integrity of any supervised learning system is dependent upon the quality of its labeled dataset. The establishment of a reliable ground truth is a theoretical problem rooted in psychometrics and expert systems. The grading labels for the eggplant images must be derived from standardized agricultural protocols, such as those provided by the United States Department of Agriculture (USDA) or equivalent bodies, which define quality classes based on size, color uniformity, and defect tolerances (USDA, 2013). Locally, the project will utilize the criteria defined by the Philippine National Standard (PNS), and Bureau of Agricultural and Fisheries Product Standards (BAFPS) (specifically the PNS/BAFPS 52:2007), which classifies eggplants into Extra Class, Class I, and Class II based on visual quality, size, and defect tolerances (BAFPS, 2007; PNS, 2019). To ensure scientific rigor, the concept of inter-rater reliability, often measured by Cohen's Kappa statistic (κ), must be applied to quantify the agreement between human experts who label the dataset, thereby validating the consistency of the training labels (McHugh, 2012; He et al., 2022).

The closed-loop system theory integrates the digital classification with physical actuation. The decision output from the classification model (e.g., a specific grade) is transmitted via a software-to-hardware interface to a Programmable Logic Controller (PLC) or microcontroller (Bolton, 2015). This triggers a mechatronic actuator, such as a pneumatic pusher or a servo-controlled diverter, which physically sorts the eggplant into its designated bin on the conveyor line. This final stage embodies the principle of cyber-physical systems, where computational intelligence directly controls a physical process to achieve full automation, replicating and potentially surpassing human grading efficiency (Lee, 2008; Zhang et al., 2022).

CHAPTER 3

METHODOLOGY

This chapter details the design and development of the automated eggplant sorting and grading system, following the Modified Waterfall SDLC model. Section 3.1 discusses the research design and procedural framework. Section 3.2 focuses on the hardware development, describing the design, architecture, and components essential of the conveyor and sorting mechanism. Section 3.3 explains the software development process, detailing the algorithms, tools, and models used for image processing, feature extraction, and classification. Section 3.4 elaborates on the system integration, illustrating how the hardware and software components interact to achieve seamless automation. Collectively, this chapter provides a comprehensive overview of the methods used to ensure the system's accuracy and reliability.

3.1 Research Design and Procedure

This study adopts the Modified Waterfall System Development Life Cycle (SDLC) model as the primary framework for the systematic development of the project. The Modified Waterfall model follows a structured and sequential design process, allowing limited feedback between phases when nec-

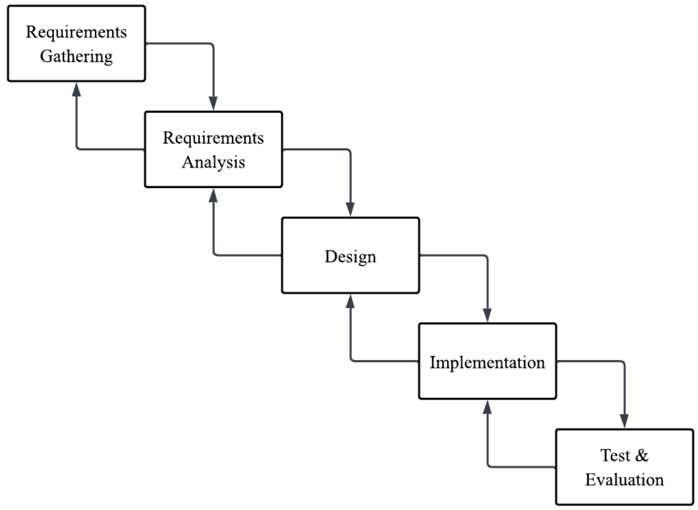


Figure 1: Modified Waterfall Model of SDLC

essary. This approach ensures that each stage is properly analyzed and refined before proceeding to the next, promoting accuracy, consistency, and efficiency throughout system development. The research design of the study follows these distinct phases, as represented in Figure 1.

The development will begin with requirements gathering, where the researchers will collect relevant information from local farmers and agricultural experts to determine the necessity and specifications for automating eggplant sorting and disease detection. This will be followed by requirements analysis, where the system's functional requirements and non-functional requirements will be formally defined.

During the design phase, the overall system architecture will be planned.

This includes the hardware setup, featuring camera modules for image capture and conveyors with actuators for sorting. The software framework will also be designed to manage image processing, feature extraction, and machine learning-based classification for grading.

In the implementation phase, the designed hardware and software components will be developed and integrated. The program will be coded and linked to the physical components such as cameras, motors, actuators, and controllers to perform automated grading and sorting. Finally, the testing and evaluation phase will assess the prototype's grading accuracy. The results will be analyzed to identify errors or limitations, guiding refinements to improve the system's accuracy, and reliability.

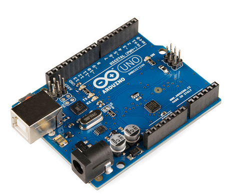
3.2 Hardware Development

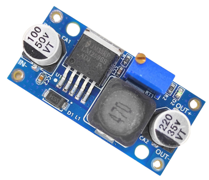
This section presents the design and integration of the system's mechanical and electronic components. The hardware consists of a conveyor system, camera modules, actuators, and a microcontroller that operate together to transport, classify, and sort eggplants. Each component is configured to function in coordination with the software, ensuring synchronized operation and accurate sorting based on the detected quality of the eggplant.

3.2.1 Hardware Requirements

The hardware requirements include all the physical components essential for constructing the system. Each component is selected based on its purpose and function in the automated eggplant grading and sorting system, ensuring effective integration and reliable operation to achieve accurate grading and sorting performance.

Table 1: Hardware Requirements

Component	Image	Function
DC Motor		This component powers the conveyor belt by converting electrical energy into mechanical motion.
Power Supply Adapter		This component supplies the necessary electrical power for the Arduino to operate effectively.
Arduino		Functions as the control unit for the conveyor belt and actuators, managing the movement and sorting operations of the system based on the classification results.

Buck Converter		Regulates the 12 V input into required voltages: 6 V for the servos and 5 V for the relay and control circuits.
NPN Transistor		Serves as a relay driver that amplifies the Arduino's control signal to energize the relay coil.
Flyback Diode		Protects the transistor and other components from voltage spikes generated by inductive loads.
Servo Motor		Controls the sorting gates that direct eggplants into Grades Extra Class, Class I, Class II, or Rejected bins after classification.
Ball Bearings		This part enables the smooth rotation of the conveyors rollers by minimizing friction. It supports the conveyor belt's movement, allowing efficient loading and consistent operation of the rollers.
Bolts & Nuts		This component is used to firmly attach and hold together parts of the conveyor system, such as the motors, frame, and rollers, to keep everything stable and properly aligned.

Wood Screws		This component is used to join and secure the parts of the conveyor belt system, including the wooden frame, rollers, and other sections, ensuring they are firmly attached and properly assembled.
Conveyor Rollers		The conveyor rollers enable the smooth movement of the conveyor belt, allowing the eggplants placed on top to be transported efficiently. They also help keep the belt properly aligned to ensure stable and consistent motion during operation.
Timing Belt Pulley		The timing belt pulley transfers the motor's rotation to the rollers through a timing belt, ensuring synchronized and slip-free movement. Its toothed design keeps the rollers turning accurately and at the same time, allowing smooth and consistent movement of eggplants along the conveyor.
Acetate Plastic		The acrylic glass platform serves as a transparent base that allows the cameras positioned above and below to capture clear images of both sides of the eggplant.
HD Webcam (Sri home SH003)		This hardware component captures real-time images or video of the eggplants on the conveyor belt. The captured data is then used for image processing and analysis to identify quality and classify the eggplants accordingly.

LED Strips		The LED strips give the camera the right amount of light, helping to improve the accuracy of sorting and classifying eggplants by their quality.
Sorting Plate		Functions to redirect eggplants into their designated bins. Its smooth, durable surface minimizes friction and prevents damage during the sorting process.
Flat Bar		This part will be used as a structural foundation for the camera to mount on top of the conveyor belt.
Wooden Planks		Serves as the base frame that securely holds all components of the conveyor belt, ensuring the entire system remains steady during operation.
Enclosure Box		This will be used to keep the components (Arduino, switch, power supply, relay) arranged in one container.
Conveyor Belt		Serves as the main transport surface for the eggplants, ensuring smooth and hygienic movement along the sorting path. Its non-toxic and easy-to-clean material makes it suitable for handling fresh produce while maintaining consistent motion for accurate image capture and sorting.

Relay Module		Controls the DC motor by switching the 12 V supply line through a transistor-based driver circuit.

3.2.2 Hardware Cost

The estimated prices of the components required to construct the conveyor belt system are shown in Table 2. The cost, which is approximately ₱8,863.00 reflects the parts needed for the construction of the conveyor belt system. The selected components ensure a balance between performance and affordability, making the system cost-effective without compromising functionality or durability using widely available materials.

Table 2: Hardware Cost

Components	**Model**	**Price**
DC Motor	775 DC Motor	₱769.00
Power Supply Adapter		₱118.00
Arduino	Arduino Uno R3	₱540.00
2×	LM2596S DC-DC Step-Down	₱60.00
NPN Transistor	2N2222	₱30.00
Flyback Diode	1N4007	₱14.00
LED Strip Lights		₱199.00
Ball Bearings		₱100.00
Bolts & Nuts		₱200.00

5× Servo Motor	MG946R Full Metal Gear High Torque Servo	₱436.00
5× Sorting Gates	UHMW-PE	₱470.00
Wood Screws		₱80.00
Conveyor Rollers		₱266.00
Timing Belt Pulley	60 teeth - 20 teeth 5mm	₱200.00
Acetate Plastic		₱125.00
2× HD Webcam	SRICAM SriHome SH003	₱2,800
Flat Bar	1” × 1”	₱300.00
Wooden Planks		₱400.00
Enclosure Box	IP65	₱150.00
Conveyor Belt	PVC Food-Grade Conveyor Belt	₱1,900.00
Relay Module	SRD-05VDC-SL-C Power Relay	₱45.00
Total Estimated Cost:		₱8,863.00

3.3 Formula

3.4 Tables

Table 3: A sample long table.

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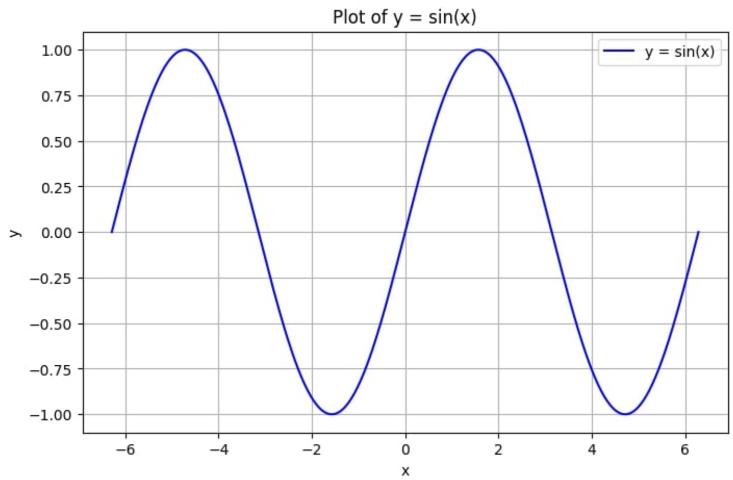

Figure 2

Table 4: Sample Data Table

Item	**Quantity**	**Price ($)**
Apples	10	0.50
Bananas	5	0.30
Cherries	20	1.20
Dates	50	2.50

3.5 Images

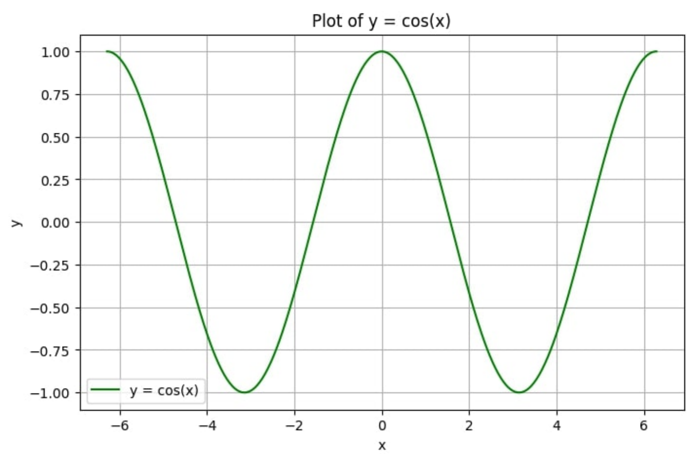

Figure 3: Cosine Graph

CHAPTER 4

RESULTS AND DISCUSSION

This chapter presents the findings from the research conducted and provides a thorough analysis and interpretation of these results.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

This chapter provides the summary of the results obtained in this study and gives some recommendations for further investigation.

5.1 Summary of Findings

The study's findings address the initial research questions by confirming the effectiveness, reliability, and diverse applications of telemetry systems. The "Summary of Findings" section provides a concise overview of the key results from your research. This section should be factual and focus on presenting the data without interpretation. It should include:

Key Results:

Briefly summarize the most significant findings. Use bullet points or numbered lists for clarity if appropriate. Present the data as it was found, highlighting major patterns, relationships, or trends. Data Presentation:

Include tables, graphs, or charts that succinctly summarize the data. Make sure each visual aid is clearly labeled and includes a brief description. Coverage of Research Questions:

Address each of the research questions or hypotheses posed at the beginning of the study. Summarize the results relevant to each question.

5.2 Conclusion

The "Conclusions" section interprets the findings and discusses their implications. This section should:

Interpret Findings:

Provide an interpretation of the data summarized in the previous section. Discuss what the results mean in the context of the research questions or hypotheses. Implications:

Explain the significance of the findings. Discuss how the results contribute to the field of study or practical applications. Limitations:

Acknowledge any limitations in the study that may affect the results or their interpretation.

5.3 Recommendations

The ”Recommendations” section provides actionable suggestions based on the study’s findings and conclusions. This section should:

Practical Applications:

Offer specific recommendations for practitioners, policymakers, or other stakeholders based on the findings. Future Research:

Suggest areas for further investigation that could address the study’s limitations or build on its findings. Implementation:

Provide guidance on how the recommendations can be implemented effectively.

APPENDICES

Type your appendix here.

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CERTIFICATE OF AUTHENTIC AUTHORSHIP

I hereby declare that this submission is my own work and, to the best of my knowledge, it contains no materials previously published or written by another person, nor material which, to a substantial extent, has been accepted for the award of any other degree or diploma at USTP or any other educational institution, except where due acknowledgement is made in the manuscript. Any contribution made to the research by others, with whom I have worked at USTP or elsewhere, is explicitly acknowledged in the manuscript.

I also declare that the intellectual content of this manuscript is the product of my own work, except to the extent that assistance from others in the project design and conception or in style, presentation and linguistic expression is acknowledged.

JODIE REY D. FERNANDEZ

JODIE REY D. FERNANDEZ

JODIE REY D. FERNANDEZ

Date: ”insert date signed