Two-Stage Automated Coffee Bean Sorter: A Precise System for Green Coffee Beans Using Machine Vision and Density-Based Analysis

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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

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by

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March, 2025

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ORAL DEFENSE RECOMMENDATION SHEET

This thesis, entitled **Two-Stage Automated Coffee Bean Sorter: A Precise System for Green Coffee Beans Using Machine Vision and Density-Based Analysis**, prepared and submitted by thesis group, ESG-04, composed of:

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

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ABSTRACT

The study proposes to develop a two-stage automated coffee bean sorter that identifies the good beans, less-dense beans and at the same time segregating the defective coffee bean using machine vision and density-based analysis. In the first stage, the defective beans will be detected through the use of machine vision, parameters such as size and defects are taken into account. The second stage is used to categorize each bean by its density, which is calculated by its mass and volume. Thus, beans with relatively low density and not within the size threshold, are sorted out. The system aims to incorporate machine vision and density analysis to reduce human labor and provide an alternative to manual sorting methods for the farmers and coffee bean producers.

Index Terms—computer vision, deep learning, density-based analysis, Arabica, green coffee beans, sorting.

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ABBREVIATIONS

AC	Alternating Current	95
CSS	Cascading Style Sheet	95
HTML	Hyper-text Markup Language	95
XML	eXtensible Markup Language	95

NOTATION

$\lvert\mathcal{S}\rvert$	the number of elements in the set $\mathcal{S}$	97
$\emptyset$	the set with no elements	97
$h\left(t\right)$	impulse response	87
$\mathcal{S}$	a collection of distinct objects	97
$\mathcal{U}$	the set containing everything	97
$x\left(t\right)$	input signal represented in the time domain	87
$y\left(t\right)$	output signal represented in the time domain	87

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 $\sin\left(\cdot\right)$, $\max\{\cdot\}$. Commonly used notations are t, f, $\mathrm{j} = \sqrt{-1}$, n and $\exp\left(\cdot\right)$, which refer to the time variable, frequency variable, imaginary unit, nth variable, and exponential function, respectively.

GLOSSARY

217	Functional Analysis	the branch of mathematics concerned with the study of spaces of functions
218	matrix	a concise and useful way of uniquely representing and working with linear transformations; a rectangular table of elements

LISTINGS

Chapter 1

INTRODUCTION

De La Salle University

1.1 Background of the Study

Coffee is one of the most globally consumed beverages. It is a vital product in the global market, with production reaching 168.2 million bags in 2022-2023. The coffee industry is expected to grow even more in the coming years, with output projected to rise by 5.8% in 2023-2024 (International Coffee Organization, 2023). In the Philippines, coffee holds a strong cultural significance, with the local industry continuously expanding. The country is the 14th largest coffee producer in the world. Locally, the industry is expected to grow at a compound annual growth rate (CAGR) of 3.5% from 2021 to 2025, driven by small-scale farm households (Santos & Baltazar, 2022). With a growing popularity among coffee enthusiasts, the demand for specialty coffee is increasing as well. Consumers are becoming more selective about the quality of their coffee beans (Tampon, 2023).

To stay competitive in the rapidly evolving coffee industry, farmers carefully select high-quality coffee beans for production. Grading green coffee beans is a crucial part of coffee production, as it is directly associated with the quality of the cup quality of coffee brews (Barbosa et al., 2019). Coffee grading is a process in the industry that determines the quality of coffee beans, using various parameters such as size, density, color, and defects, ensuring that only high quality beans are selected for consumption (Córdoba et al., 2021). The size of coffee beans is determined using a screen size and sorting procedure, where the coffee beans are categorized into different screen sizes, with larger beans considered higher quality (González et al., 2019). The density of a bean can be calculated by the ratio of its mass and volume, which greatly influences the roasting process and overall quality of the coffee (Datov & Lin, 2019). Color is also another indicator for quality, with darker beans being preferred for their richer flavor profile. On the other hand, defects are classified

among 3 categories: Category 1 includes the most severe issues such as foreign matter and black beans, Category 2 includes less severe defects like broken beans, and Category 3 includes minor defects like slight discoloration. Determining the quality of the coffee beans in relation to their defect values is based on quality standards and grading systems such as SCAA protocols guidance or the Philippine National Standard on Green Coffee Bean.

Traditionally, this stage of assessing and categorizing coffee beans relies on visual evaluation, which is time-consuming and labor-intensive, making it prone to human error. One of the biggest challenges in coffee bean production is ensuring consistency in quality. As the demand for specialty coffee continues to grow, there has also been an increase for the need of more efficient and accurate sorting methods. The application of modern technology can help reduce the labor costs and minimize human errors in these tasks. In recent years, computer vision was used alongside various machine learning models and techniques, such as convolutional neural networks (CNNs), support vector machines (SVMs), or K-nearest neighors (KNN) models, where the models were trained on labeled data to classify images of coffee beans into different quality categories. The proposed aims to utilize this technology to develop a two-stage automated coffee bean sorting system using machine vision and density-based analysis to categorize and identify and segregate specialty-grade green coffee beans from non-specialty and defective coffee beans.

1.2 Prior Studies

Identifying and sorting specialty-grade coffee beans can be strenuous since the traditional way of classifying a specialty-grade coffee is by manually sorting the coffee bean batch and classifying them according to the set of standards of the SCAA. The existing work aims

to solve these problems through image processing and implementing deep learning-based models to automatically sort the coffee beans while achieving high accuracy. However, these solutions only automate detecting either one of the parameters such as defects, color, and size, while the proposed system considers density, size, color and defects all in one system. Hence, eliminating human intervention or labor. The table below shows the comparison of existing solutions to the researcher's proposal aligning with the traditional way of sorting coffee beans.

TABLE 1.1 SUMMARY OF THE LITERATURE REVIEW

Existing Literature	Description
Defect Detection	The existing literature focuses on using various machine learning models such as YOLO, KNN, and CNN to detect defects in green coffee beans, through identifying visible defects like black spots, broken beans, discoloration, and more. These existing approaches heavily rely on visual characteristics and do not consider other key factors that affect green coffee bean quality like density, which can enhance classification accuracy. The proposed system integrates density and size analysis alongside the defecting various levels of defects on the coffee bean for a more holistic detection and classification.

Coffee Bean Grading and Quality Assessment	The existing literature utilize algorithms such as artificial neural networks, support vector machine, and random forest to grade and classify coffee beans according to the specified grading system. These methods primarily focus on visual features of the beans, which do not account the bean's density and size, which are both essential factors for classifying specialty-grade coffee beans. Additionally, there is a lack of practical implementation of automated sorting systems, as these focus on simply classifying the beans. Through a two-stage process, the proposed system will take into consideration both the visual inspection and the density measurement, which leads to a more complete classification of coffee beans.

Automated Sorting and Classification System	Research has been conducted on developing that automate the process of sorting coffee beans according to various parameters. Some studies focus on sorting defectives against non-defective, while others focus on other visual parameters like defects and roast profiles. These systems focus only on visual characteristics, without considering the actual size of the bean and its density as parameters for better classification accuracy. The proposed system will integrate the use of visual, density, and size parameters to enable a comprehensive automated sorting solution for classifying specialty-grade coffee beans.

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TABLE 1.2 COMPARISON TABLE ON EXISTING STUDIES

Proposed System	Balay, D. D., Cabrera, R. M., Jensen, J. T. B., and Mayuga, K. E. L. (2024). Automatic sorting of defective coffee beans through computer vision	A. J. N. Lualhati, J. B. Mariano, A. E. L. Torres, and S. D. Fenol, "Development and Testing of Green Coffee Bean Quality Sorter using Image Processing and Artificial Neural Network

• Defect sorting using EfficientNetV2. • Considers classification of 10 defect types. • The system considers density parameters to sort out less-dense beans. • The system includes a graphical user interface for farmers to visualize the cumulative data of the defects present in the batch. • The system also includes AI-generated recommendations on the possible interventions for the farmers based on the data gathered from the sorting system.	• Defect sorting using YOLOv8 • The study considered only 6 types of defects.	• Defect sorting using YOLOv2 and InceptionV3. • The study considered only 2 types of defects.

1.3 Problem Statement

The Philippine coffee industry is a growing market, however it is stuck with using traditional methods in sorting green coffee beans. Often relying on manually sorting the beans, it exposes a number of problems that are apparent in the industry. Relying on manual sorting increases production cost which results in higher prices for quality coffee beans. To make the Philippine coffee beans more competitive to the exported beans, reducing the price is crucial. Another problem that is encountered in manual sorting heavily focuses only on the physical attributes of the bean like size and appearance. There are standards that need to be met, which forces the farmers to resort to manual sorting to comply with the standards of the SCAA. The SCAA standards require a 300g batch of green coffee beans must not contain any defects and the size consistency of the beans must not exceed 5% variance. Another reason why coffee processors still opt to do manual sorting is because there are no commercially available and reliable GCB sorting machines (Lualhati et al., 2022). There is a need for a coffee sorter that is able to efficiently and accurately sort GCB. Coffee bean selection is carried out either manually, which is a costly and unreliable process (Santos, 2020). The manual sorting process limits scalability and quality control, putting the strain on farmers as coffee shop owners' demands for high-quality coffee continue to rise (Lualhati et al., 2022).

1.4 Objectives and Deliverables

1.4.1 General Objective (GO)

GO: To develop an automated (Arabica) green coffee bean sorter that identifies good, less-dense and defective beans from an unsorted batch of coffee beans. The system will utilize machine vision and density-based analysis for defect detection and classification of the coffee beans, ensuring efficient coffee bean sorting.;

1.4.2 Specific Objectives (SOs)

- SO1: To gather and create a dataset consisting of 500 high-resolution images per classification of Arabica green coffee beans (dense, less-dense, defective (category 1 & 2));
- SO2: To improve the synchronization between the machine vision system and the embedded sorting mechanism, ensuring defect sorting of at least 20 beans per minute, solving issues such as non-synchronization of the system;
- SO3: To achieve an accuracy of at least 85% in classifying defective green coffee beans using computer vision;
- SO4: To achieve an accuracy of at least 85% in filtering out less-dense green coffee beans;

1.4.3 Expected Deliverables

Table 1.3 shows the outputs, products, results, achievements, gains, realizations, and/or yields of the Thesis.

TABLE 1.3 EXPECTED DELIVERABLES PER OBJECTIVE

Objectives	Expected Deliverables
GO: To develop an automated (Arabica) green coffee bean sorter that identifies good, less-dense and defective beans from an unsorted batch of coffee beans. The system will utilize machine vision and density-based analysis for defect detection and classification of the coffee beans, ensuring efficient coffee bean sorting.	A Two-Stage Automated Coffee Bean Sorter System that identifies defective, good beans, and less-dense green coffee bean using machine vision and density-based analysis.
SO1: To gather and create a dataset consisting of 500 high-resolution images per classification of Arabica green coffee beans (dense, less-dense, defective (category 1 & 2))	• Data Gathering • Image Collection through High Quality Camera
SO2: To improve the synchronization between the machine vision system and the embedded sorting mechanism, ensuring defect sorting of at least 20 beans per minute, solving issues such as non-synchronization of the system	• Improving the synchronization of machine vision and embedded sorting mechanism of the system.
SO3: To achieve an accuracy of at least 85% in classifying defective green coffee beans using computer vision	• Computer Vision Program • Sorting Mechanism
SO4: To achieve an accuracy of at least 85% in filtering out less-dense green coffee beans	• Density-based Analysis • Sorting Mechanism

1.5 Significance of the Study

The study explores the implementation of machine Vision and density analysis of an automated coffee been sorter that can identify and sort out the defective, less-dense and good green coffee beans. This said system would aid coffee sorters to mitigate manual labor and to ensure that the sorting process of the GCB are accurate. In order to test the effectiveness of the system, the study would gather data and compare the time efficiency and accuracy of the manual sorting by a an expert sorter to be compared with the proposed system. The system proposes significance to specific parts of society as follows:

1.5.1 Technical Benefit

This study would benefit the academe as this introduces a significant advancement in coffee bean sorting technology by implementing both machine vision and density-based analysis to detect and sort good coffee beans, less-dense and separating defective ones. The proposed system would mitigate manual sorting that leads into insufficency like human error and fatigue. The system would improve the overall efficiency by operating at a faster rate compared to manual labor. As a result, it would serve as a proof of concept for the implementation of machine vision and density-based analysis in agricultural industries specifically in the Philippine coffee industry.

1.5.2 Impact to the Coffee Industry

The study would aid coffee farmers and producers, by providing an automated system that ensures accurate sorting of Arabica green coffee beans, the system aims to have an accurate output to help maintain to yield higher quality coffee beans and allows coffee bussinesses

to scale up their operations, increase the competitiveness of exporting those beans, and meet demand more efficiently. The productivity given from the system would potentially strengthen the foundation of local coffee producers.

1.6 Assumptions, Scope, and Delimitations

1.6.1 Assumptions

1. There would be a defective coffee bean from the green coffee bean test batch;
2. Identifying the defective coffee beans using the machine vision and density-based analysis would be much more efficient and accurate than manually sorting them;
3. During testing, test batches will contain 50% good beans and 50% defective beans, 60% good beans and 40% defective beans, 70% good beans and 30% defective beans, 80% good beans and 20% defective beans, 90% good beans and 10% defective beans, 100% good beans;

1.6.2 Scope

1. The study only focuses on Arabica green coffee beans;
2. The study has two stages, the first stage would segregate the defective green coffee beans from the batch, then the second stage would identify the specialty-grade green coffee beans depending on its density;

1.6.3 Delimitations

1. The batch of coffee beans to be used for testing and dataset collection will consist solely of Arabica beans from the same origin, farmer, and processed in the same way;
2. The system is only limited to unroasted green coffee beans;
3. The batch of coffee beans to be used should only be dehulled and not sorted visually and by density;
4. Since the system is considering several types of defects and density parameter, sorting time is compromised;
5. The system is designed to perform individual scanning of each coffee bean;

Chapter 2

LITERATURE REVIEW

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*.

2.2 Lacking in the Approaches

You can summarize the weaknesses of existing approaches by a tabular comparison of the literature. Your focus here is what has *not been done*, i.e. what features were missed, what solutions were not considered, what the demerits are, etc. Through these items, you then can introduce the necessity for doing your proposed solution.

It is to be noted that the degree of novelty for undergraduate thesis is lower than those for graduate school. If a Ph.D. dissertation/thesis has a high degree of novelty and that for an undergraduate is low, then a master's thesis is somewhere between the two.

Briefly include here the following in order to remind the reader why you are highlighting the weaknesses of the solutions of existing literature.

- mentioning the problem
- showing how your solution is better (can be better (for proposals))

2.3 Summary

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

Chapter 3

THEORETICAL CONSIDERATIONS

3.1 Theoretical Framework

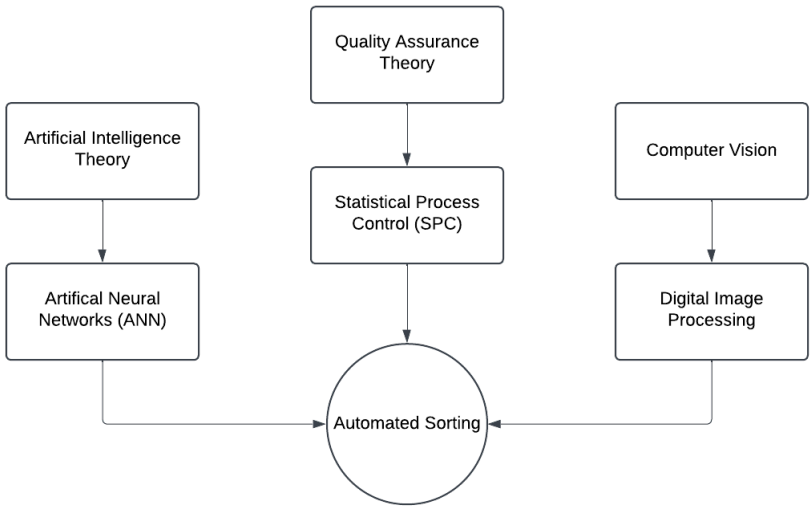

Fig. 3.1 Theoretical Framework

The theoretical framework discusses the multiple concepts that are involved in this study. These key concepts are crucial to ensuring the success of the thesis. There are three main concepts that are key to this study, the Artificial Intelligence Theory, the Quality Assurance Theory and lastly, Computer Vision.

3.2 Conceptual Framework

The conceptual framework shows the implementation of two systems which consists of machine vision and embedded systems. The framework describes the thought process of both systems with the end goal of integrating both systems. The machine vision handles the defect classification of the system, whereas the embedded system handles the sorting of

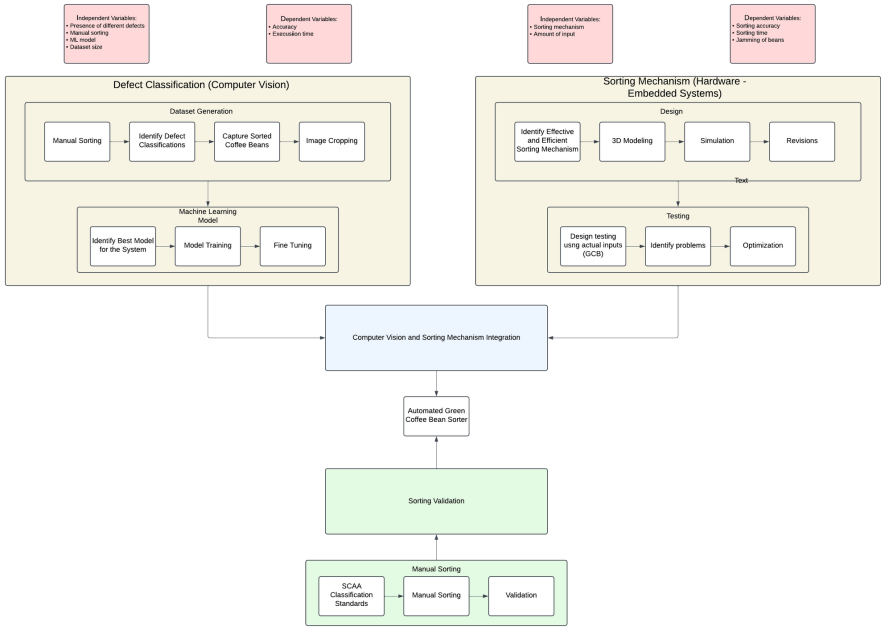

Fig. 3.2 Conceptual Framework

the beans. By integrating both systems together, creates an automated green coffee bean sorter. The data validation is done by sorting through the tested coffee beans by the system following the standards of the SCAA.

3.3 Summary

Chapter 4

DESIGN CONSIDERATIONS

4.1 Mechanical Design

4.1.1 Screw Feeder

Fig. 4.1 Screw Feeder Diagram

Figure4.1 shows the diagram of a screw feeder. Screw feeders are usually used in industrial fields like agriculture, chemicals, plastics, cements, poultry and food processing. According to Mingalani et al. (2020), screw feeders are specifically used to transport or move granular materials at a controlled rate like corn and wheat. It consists of a rotating screw and small feeding section or the hopper. Despite having big batches of a certain material, screw feeders can control the rate of which these materials are dispensed. With this concept, the group decided to utilize a screw feeder as the input mechanism for the system. This mechanism allows a controlled rate of coffee bean dispensing, which is a significant factor to avoid overcrowding in the rotating conveyor table causing the beans to jam. In addition, batches of coffee beans can be put at once instead of just adding a certain amount of beans at a time.

4.1.2 Rotating Conveyor Table

Fig. 4.2 Rotating Conveyor Table 3D Design (32-inch Rotary Table Accumulator (RTA))

After the inputted beans comes out from the screw feeder, the coffee beans would then be placed in the rotating conveyor table. According to the study of Dabek (2022). The conveyor table is used as a transportation systems for all forms of bulk materials to a

certain machine or destination. The system utilizes the rotating conveyor table to have a controlled movement of coffee beans towards the first stage of the system. The improvised linearization system, consisting of metal guide rails and dividers ensures that beans align in a single path, reducing random movement, and improving the flow of the input beans. An infrared sensor would detect each bean as it passes, to control the movement of the bean preventing clogging and ensuring efficient operation.

4.1.3 Inspection Tray (1st Stage)

Fig. 4.3 Inspector Tray 3D Design

The inspection tray serves as the platform for the machine vision based analysis of coffee beans. It is designed with 8 holes, allowing uniform placements and optimal camera positioning for the system. The system utilizes a two-layer structure: a stationary acrylic platform and a rotating 3D-printed platform with holes. The rotating mechanism sequentially positions each bean between two webcams, which captures and analyzes its physical characteristics from top and bottom perspective. This design captures both sides of the bean, ensuring a better classification of the bean. After inspection, the bean moves onto a slide, where it is either directed to the second stage for density analysis (Good) or sorted out as a defect.

4.1.4 Density Sorter (2nd Stage)

4.2 Embedded Systems

4.2.1 Microcontroller

Fig. 4.4 Arduino Nano Microcontroller

Since the system is composed of two stages of sorting: defect sorting through computer vision and density-based analysis–the group decided to utilize two Arduino Nano microcontrollers to modularize the control process. The first Arduino Nano microcontroller is tasked to handle the computer vision-based defect sorting through serial communication with OpenCv operating in Python. In addition, it handles the operation of defect sorting consisting of a stepper motor for the rotation of the inspection tray and a servo motor for the slider, which directs the beans to the designated bin (defect or good bin). On the other hand, the second Arduino Nano microcontroller manages the density-based analysis and sorting, which consists of another stepper motor to direct the beans to its respective bin (dense and less-dense bin), the precision scale which is interfaced through RS232, and the top feeder where the input beans are poured. The use of separate Arduino microcontrollers is advantageous when it comes to the computer vision-based sorting of beans. This is because serial communication is much faster when code complexity is significantly reduced. With this, a designated microcontroller handles the computer vision part and two-way serial communication between the microcontroller and the computer vision algorithm running in Python. Most importantly, the use of two microcontrollers allowed the system to not rely solely on a sequential approach. This means that the two stages of sorting are not relying

on the timing of each other, allowing the inspection tray and the top feeder to operate independently. Thus, resulting in a much faster and efficient sorting process.

4.2.2 Sensors

Fig. 4.5 Infrared Sensor

To ensure that the beans are falling in a one-by-one manner onto the inspection tray, the group placed an IR sensor at the edge of the top feeder. This IR sensor triggers the DC motor that runs the feeder to stop, and runs small steps until the bean is dropped. The addition of the IR sensor at the edge of the feeder allows the motor to run continuously until another bean is detected. With this, the waiting time for the next bean at the inspection tray is significantly lessened.

Fig. 4.6 TOF10120

TOF10120 or Time of Flight sensor is utilized in the system due to its high precision, non-contact measurement capability. This sensor is used to estimate the volume of each bean, which is essential for computing the density. In the second stage of sorting, where beans are classified based on density, the sensor plays a crucial role in determining the approximate volume of each bean by measuring its height or dimensions as it passes through the system.

Fig. 4.7 12V NEMA 17 Stepper Motor

4.2.3 Motor control

Two NEMA 17 12V stepper motors, paired with L298N motor drivers were used to control the movement of the inspection tray in the first stage and the density-based sorting mechanisms in the second stage. In these mechanisms, the group decided to use stepper motors to ensure precise and accurate movements. Precise and accurate movements are needed for the inspection tray to make sure every movement of the hole is perfectly aligned to the camera. Thus, allowing a more uniform and consistent angle for each bean to be inspected through the computer vision. In addition, NEMA 17 stepper motors were the best choice for these mechanisms due to its high torque, which is essential because it will be moving weighted objects.

Fig. 4.8 6V DC Motor

For the rotating conveyor table (top feeder), where the beans are initially poured, a 6V DC motor is used. The group decided to use this motor due to its high RPM, which is needed for a fast rotation of the rotating conveyor table. The speed of the feeder is regulated to prevent clogging and ensure that the beans are evenly spaced before they enter the inspection tray. The motor speed is fine-tuned through pulse-width modulation (PWM) to synchronize with the stepper motor-driven inspection tray, ensuring a steady input without overwhelming the system.

Fig. 4.9 TB6612FNG Motor Driver

To drive the 6V DC motor, the group utilized TB6612FNG, a motor driver module. This module also allowed PWM control for the motor, which is essential for reducing the speed of the motor when needed.

4.2.4 Operating Voltage

Fig. 4.10 12V Power Supply

The main power supply comes from a 12V external power supply, which provides enough voltage for all the components and keeps the voltage from dropping and interfering with system performance. The Arduino microcontroller is powered via its VIN pin, so it can function without the need for a USB connection and maintains a stable 5V logic output for sensor and actuator control. The NEMA 17 stepper motors that operate the inspection tray and density sorter are directly powered from the 12V supply and fed into L298N motor drivers to adjust voltage and monitor current flow. Operating these motors at 12V provides best torque output, which is vital in ensuring consistent movement during the sorting process.

Fig. 4.11 MT3608 Step-Up Module

For the top feeder mechanism, a step-up module is needed to supply the sufficient voltage needed for the motor–6V. From the 5V output of the Arduino, the step-up module will be utilized to convert it into 6V.

4.3 Computer Vision System

4.3.1 Image Processing

4.3.2 Image Detection and Classification Models

4.4 Serial Communication

Serial communication is used for sensors and motors for arduino due to the simplicity, reliability and efficient transfer of data between different devices. The precision scale uses a RS232 and a MAX TTL converter to send the data from the precision to the arduino to get the weight values of each green coffee bean. To sort out the good from defective beans the system utilizes a servo motor. The data from python is received by the arduino through serial communication. The python side is responsible for the decision and defect classification while the arduino is responsible for controlling the servo motor.

4.5 Graphical User Interface (GUI)

Fig. 4.12 Graphical User Interface

The proposed system would be integrating a graphical user interface developed using PyGui and ChatGPT API. The GUI would serve as the control center platform for the system. This would provide real-time feedback and insights for users. As shown in Figure 8, a concept of how the GUI would interact with the system would be a start button, once the button is executed the system would then be expecting inputs and start sorting. There would

be real-time feedback during the sorting process, then some visual markers to indicate their classification, and an elapsed time so the user would be aware of the time of the sorting process. Once the system is done, the user can click the end button and the summary report would generate in an orderly manner, providing tables of classification that was detected through the process. In the bottom part of the GUI, ChatGPT API would be integrated and would offer recommendations based on the detected quality and classification of the coffee beans.

4.6 Density Based Analysis

4.7 Summary

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Chapter 5

METHODOLOGY

De La Salle University

TABLE 5.1 SUMMARY OF METHODS FOR REACHING THE OBJECTIVES

Objectives	Methods	Locations
GO: To develop an automated (Arabica) green coffee bean sorter that identifies good, less-dense and defective beans from an unsorted batch of coffee beans. The system will utilize machine vision and density-based analysis for defect detection and classification of the coffee beans, ensuring efficient coffee bean sorting.	1. First itemtext 2. Second itemtext 3. Last itemtext 4. First itemtext 5. Second itemtext	Sec. **??** on p. **??**
SO1: To gather and create a dataset consisting of 500 high-resolution images per classification of Arabica green coffee beans (dense, less-dense, defective (category 1 & 2))	1. First itemtext 2. Second itemtext 3. Last itemtext 4. First itemtext 5. Second itemtext	Sec. **??** on p. **??**

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Objectives	Methods	Locations
SO2: To improve the synchronization between the machine vision system and the embedded sorting mechanism, ensuring defect sorting of at least 20 beans per minute, solving issues such as non-synchronization of the system	1. First itemtext 2. Second itemtext 3. Last itemtext 4. First itemtext 5. Second itemtext	Sec. **??** on p. **??**
SO3: To achieve an accuracy of at least 85% in classifying defective green coffee beans using computer vision	1. First itemtext 2. Second itemtext 3. Last itemtext 4. First itemtext 5. Second itemtext	Sec. **??** on p. **??**
SO4: To achieve an accuracy of at least 85% in filtering out less-dense green coffee beans	1. First itemtext 2. Second itemtext 3. Last itemtext 4. First itemtext 5. Second itemtext	Sec. **??** on p. **??**

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Objectives	Methods	Locations
	1. First itemtext 2. Second itemtext 3. Last itemtext 4. First itemtext 5. Second itemtext	Sec. ?? on p. ??

5.1 Research Design

5.2 Data Collection

5.2.1 Utilization of Open-Source Databases

To establish a foundation for the system's model, the group initially referenced an open-source dataset from Kaggle [x]. This dataset provides an original 500x500px images of Arabica green coffee beans categorize as defective or good. This dataset also provided insights into how individual beans were captured, including factors such as lighting, camera positioning, focus, and resolution. By analyzing the dataset, the group gained a better understanding of how to achieve a high-quality data collection, ensuring that the collected dataset would contribute to high model accuracy when it is fed into the system.

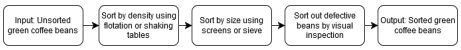

Fig. 5.1 Manual Sorting Process

5.2.2 Manual Sorting

The diagram in Figure 5.1 depicts the representation of the process of manual sorting of unsorted green coffee beans through a series of steps. First, the beans are sorted by density using methods such as floatation or shaking tables. This helps in separating the denser beans, usually pertaining to a more developed and higher quality bean. Then, the beans are sorted by size using screens and sieves with specific dimensions depending on the variety of the beans. After this, a thorough visual inspection is performed by the sorters to identify and remove the defective beans from the batch. To ensure consistency and accuracy, the group follows the Specialty Coffee Association of America (SCAA) Standards Defect Handbook, which provide documentation and guidelines for identifying and classifying defective beans [x]. Finally, the process results in the output of sorted green coffee beans, ready for further processing or sale. To ensure the dataset reflects real-world conditions, the group acquired Arabica green coffee beans from Davao. These beans were manually sorted to properly classify defective characteristics before capturing images for dataset creation. This step was crucial for improving the efficiency of batch image capture and ensuring accurate model training, making the system more applicable to Philippine coffee producers.

5.2.3 1st Iteration: Controlled Setup

The first iteration of data collection utilized a Sony A6300 camera with its Kit Lens, set at 1/200 Shutter Speed, 1000 ISO, and a Distance of 50mm. The beans were captured in batches of nine, carefully arranged within the camera's field of view following the rule of

Fig. 5.2 Data Collection Setup

thirds. The rule of thirds is a photographic composition principle where an image is divided into a 3x3 grid, creating nine equal grid lines to create balance to the photo. By aligning the coffee beans with the rule of thirds, the group ensured a structured and even distribution of the beans within the frame. This setup also made it easier to automate the cropping process, as the predefined positions of the beans allowed a Python script to accurately extract individual images.

5.2.4 2nd Iteration: Ideal Conditions

The second iteration focused on real-world implementation, using the system's built-in webcam to capture images directly from the inspection tray. This setup represents the ideal condition, as it replicates the actual environment where the model will operate. The images captured in this iteration directly reflect what the system will process in a practical application, allowing for better generalization and real-time adaptability.

5.3 Description of the System

The proposed system is a two-staged automated green coffeee bean sorting machine, integrating both machine vision and density analysis. Firstly, the coffee beans are introduced into the system through a funnel, which directs them to a conveyor belt mechanism. In the first stage, the green coffee beans will be sorted depending on their visual characteristics. In this stage, the physical qualities of the bean is analyzed such as size, color, and defect. If the bean is defective, the system will automatically sort it out. Then, all the non-defective beans will go through the second stage of the system. In the second stage, there will be an IR sensor and a weighing scale. The IR sensor will help the system to calculate for the estimated volume of the bean. The volume and mass of the bean in hand, the density of the bean can be calculated. Depending on the density threshold and size threshold set by the user, the bean will be classified whether it is good or not.

Figure 5.4 shows the schematic diagram of the proposed system. Arduino Uno microcontroller makes all the mechanical components such as the servo motor, stepper motors, and the conveyor belt. The servo motor controls the rotating mechanism for bean sorting. On the other hand, the stepper motors operate a slide mechanism to direct the beans. Two cameras, integrated with OpenCV via Python, handle machine vision algorithms, and image processing for defect detection of the beans. A ToF10120 sensor provides precise distance measurement. A precision weighing scale measures the density of each bean for classification. The Arduino communicates with the OpenCV system through serial communication, ensuring smooth coordination.

Figure 5.5 shows the design overview of the system. Beans are first arranged through a hopper and a conveyor belt. On top of the conveyor belt, a 3D-printed guide is attached for

the beans to maintain a linear formation. Then, the beans are expected to fall into another funnel attached to a tube. The tube is directly attached to a rotating mechanism that allows the beans to be inspected and sorted one-by-one. In this stage, defective beans are sorted out. Then, the non-defective beans are transferred onto the precision scale to analyze the density. The less-dense beans are sorted out of the batch.

5.4 Dataset and Model Training

For dataset collection, Arabica green beans from a farm will be used. Each bean will be captured by a high-resolution camera under sufficient and consistent lighting. Proper lighting is crucial, as it directly affects the visibility of the bean's physical features, minimizing shadows, grain, and other noise that could result from inconsistent illumination. The top and bottom side pictures of the beans are to be collected. In addition, defective beans of the same type and origin will be gathered to identify the different classification of defects (primary and secondary). This study focuses on defects such as Broken, Dried Cherry, Floater, Full Black, Full Sour, Fungus Damage, and Insect Damage. The dataset will include at least 500 images of good beans and a minimum of 200 images for each defect category. To expand the dataset and enhance model training, augmentation techniques such as scaling, rotation, and mirroring will be applied.

The models to be used in this study are Convolutional Neural Network (CNN) and Random Forest. The CNN model is mostly compatible for image classification and feature extraction as it is composed of several different layers resulting in a better representation of image data (Wang et al., 2021). Thus, this model is the most ideal for green bean defect detection by identifying its texture, color, size, volume, deformations, and cracks in the

first stage of sorting. Then, for the second stage where density parameter is added, Random Forest will be used. Since mixed data types are being considered (visual features extracted by CNN and density values), Random Forest is the best fit for this classification (Rigatti, 2017). In addition, the model is robust to overfitting, which means that it can handle noisy data.

5.5 Testing

For the testing procedures, processed but unsorted green coffee beans will be acquired from a local farmer. These coffee beans will be sorted manually based on their different defects and quality, and also will be fed into the automated system to compare accuracy and performance. In line with the Philippine National Standard or PNS (2022) for testing green coffee bean sorters, three test trials will be conducted. These trials will be conducted under similar operational settinsg to ensure consistency. The duration of each trial begins when the beans are fed into the system's hopper and endsd after no beans remain in the system. During these trials, the system's ability to sort defective beans and categorize the good beans by density will be monitored. To create the dataset, coffee beans will be arranged on a sheet of paper and photo of the entire sheet will be taken. A program using YOLOv8 will then be used to process this image, detecting each bean, creating bounding boxes, and crop them into separate image files for labeling. Additionally, an alternative method involves using the system itself to collect data, with cameras capturing the top and bottom of the beans as they pass through the system. These approaches aim to ensure to create a diverse dataset that will be used for training the machine learning model.

In evaluating the system's performance, various metrics, as dictated by the PNS for

Green Coffee Bean Sorters, will be considered:

- **Sorting Accuracy**. The system's sorting accuracy will be verified by comparing the output of the system to the manually sorted output of the same batch of beans.
- **Duration of Tests**. The total operating time for each trial will be recorded.
- **Sorting Yield**. The quantity and quality of the beans sorted in each trial will be measured to assess the system.

The desired accuracy of the system for its defect sorting is an accuracy of at least 85%. The paper of Lualhati et al. (2022) was able to achieve an accuracy score of 85% for sorting out good beans and 95% for defect sorting, with an average score of 90% for sorting out both. However, their paper only included two types of defects (black and deformed), and good quality beans as its data set. This study aims to target 10 types of defects along with the good green coffee beans ensuring that the system can cover a wider range of defects while also matching the accuracy of the previous study.

To validate the performance of the system, the results will be compared with those obtained during the manual sorting. This comparison will focus on determining the accuracy of the defect detection and bean classification. The manual sorting process will serve as the reference for evaluating the system's ability to enhance sorting efficiency and accuracy.

5.6 Data Analysis

5.7 System/Prototype Development

5.8 Evaluation

5.9 Summary

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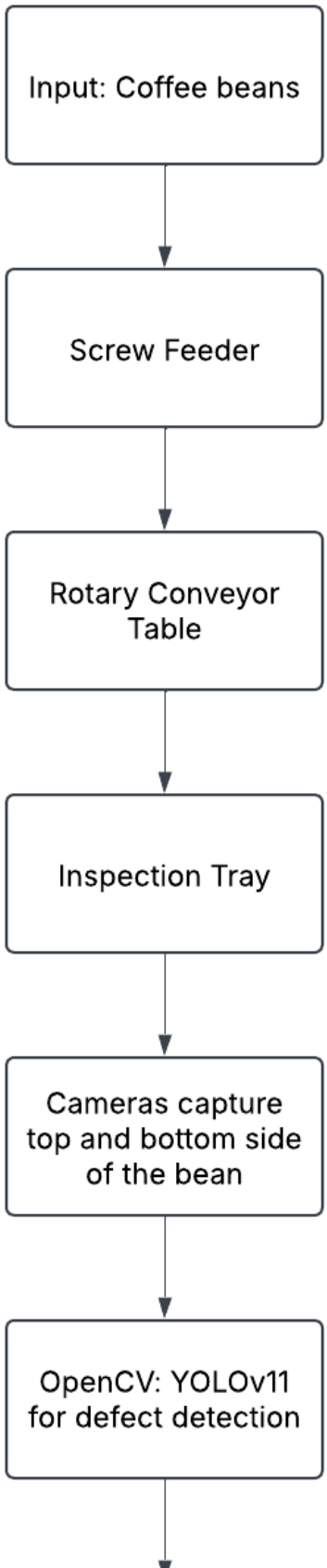
Input: Coffee beans
Screw Feeder
Rotary Conveyor Table
Inspection Tray
Cameras capture top and bottom side of the bean
OpenCV: YOLOv11 for defect detection

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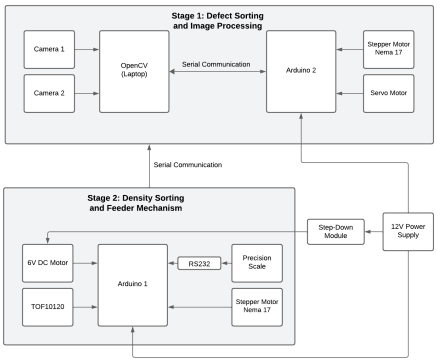

Fig. 5.4 Schematic Diagram of the System

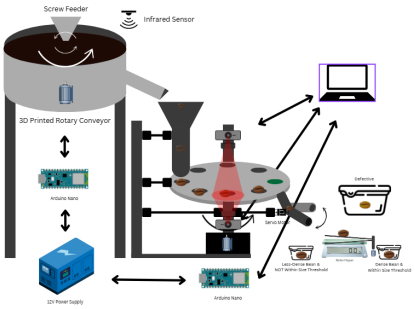

Fig. 5.5 Design Overview of the System

Chapter 6

RESULTS AND DISCUSSIONS

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 LaTeXportion of this template.

Here is an example of a citation for ISO 80000-2 standard [ISO, 2009]. Another one is [Einstein, 1905] and [Croft, 1978].

In using this template, the user is expected to have a working knowledge of LaTeX. A good introduction is in [Oetiker et al., 2014]. 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

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Objectives	Results	Locations
GO: To develop an automated (Arabica) green coffee bean sorter that identifies good, less-dense and defective beans from an unsorted batch of coffee beans. The system will utilize machine vision and density-based analysis for defect detection and classification of the coffee beans, ensuring efficient coffee bean sorting.	1. First itemtext 2. Second itemtext 3. Last itemtext 4. First itemtext 5. Second itemtext	Sec. **??** on p. **??**
SO1: To gather and create a dataset consisting of 500 high-resolution images per classification of Arabica green coffee beans (dense, less-dense, defective (category 1 & 2))	1. First itemtext 2. Second itemtext 3. Last itemtext 4. First itemtext 5. Second itemtext	Sec. **??** on p. **??**

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Objectives	Results	Locations
SO2: To improve the synchronization between the machine vision system and the embedded sorting mechanism, ensuring defect sorting of at least 20 beans per minute, solving issues such as non-synchronization of the system	1. First itemtext 2. Second itemtext 3. Last itemtext 4. First itemtext 5. Second itemtext	Sec. **??** on p. **??**
SO3: To achieve an accuracy of at least 85% in classifying defective green coffee beans using computer vision	1. First itemtext 2. Second itemtext 3. Last itemtext 4. First itemtext 5. Second itemtext	Sec. **??** on p. **??**
SO4: To achieve an accuracy of at least 85% in filtering out less-dense green coffee beans	1. First itemtext 2. Second itemtext 3. Last itemtext 4. First itemtext 5. Second itemtext	Sec. **??** on p. **??**

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Objectives	Results	Locations
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6.1 Summary

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Chapter 7

CONCLUSIONS, RECOMMENDATIONS, AND FUTURE DIRECTIVES

7.1 Concluding Remarks

In this Thesis, . . .

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

7.2 Contributions

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

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

REFERENCES

[Aamport, 1986a] Aamport, L. A. (1986a). The gnats and gnus document preparation system. *G-Animal's Journal*, 41(7):73+. This is a full ARTICLE entry.

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

Produced: March 16, 2025, 15:20

Appendix A
STUDENT RESEARCH ETHICS CLEARANCE

De La Salle University

1175

RESEARCH ETHICS CLEARANCE FORM[1]
For Thesis Proposals

Names of Student Researcher(s):

Dela Cruz, Juan Z.

SAMPLE ONLY

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

De La Salle University

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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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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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.

1. Examiner
2. Comment
3. Summary of how the comment was addressed
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. Francisco D. Baltasar	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. **??** on p. **??**, Sec. **??** on p. **??**, Fig. **??** on p. **??**

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Examiner	Comment	Summary of how the comment was addressed	Locations
Dr. Amado Z. Hernandez	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. **??** on p. **??**, Sec. **??** on p. **??**, Fig. **??** on p. **??**

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Examiner	Comment	Summary of how the comment was addressed	Locations
Dr. Jose Y. Alonzo	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. **??** on p. **??**, Sec. **??** on p. **??**, Fig. **??** on p. **??**

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Examiner	Comment	Summary of how the comment was addressed	Locations
Dr. Mariana X. Mercado	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. **??** on p. **??**, Sec. **??** on p. **??**, Fig. **??** on p. **??**

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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. **??** on p. **??**, Sec. **??** on p. **??**, Fig. **??** on p. **??**

Appendix D
REVISIONS TO THE FINAL

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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.

1. Examiner
2. Comment
3. Summary of how the comment has been addressed
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. Francisco D. Baltasar	1. First itemtext 2. Second itemtext 3. Last itemtext 4. First itemtext 5. Second itemtext	1. First itemtext 2. Second itemtext 3. Last itemtext 4. First itemtext 5. Second itemtext **First** itemtext **Second** itemtext **Last** itemtext **First** itemtext **Second** itemtext	Sec. **??** on p. **??**, Sec. **??** on p. **??**, Fig. **??** on p. **??**

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Examiner	Comment	Summary of how the comment has been addressed	Locations
Dr. Amado Z. Hernandez	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. **??**
Dr. Jose Y. Alonzo	1. First itemtext 2. Second itemtext 3. Last itemtext 4. First itemtext 5. Second itemtext	1. First itemtext 2. Second itemtext 3. Last itemtext 4. First itemtext 5. Second itemtext • First itemtext • Second itemtext • Last itemtext • First itemtext • Second itemtext	Sec. **??** on p. **??**, Sec. **??** on p. **??**, Fig. **??** on p. **??**

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

Appendix E
USAGE EXAMPLES

The user is expected to have a working knowledge of LaTeX. A good introduction is in [Oetiker et al., 2014]. Its latest version can be accessed at http://www.ctan.org/tex-archive/info/lshort.

E1 Equations

The following examples show how to typeset equations in LaTeX. This section also shows examples of the use of `\gls{ }` commands in conjunction with the items that are in the `notation.tex` file. **Please make sure that the entries in `notation.tex` are those that are referenced in the LaTeX document files used by this Thesis. Please comment out unused notations and be careful with the commas and brackets in `notation.tex` .**

In (E.1), the output signal $y\left(t\right)$ is the result of the convolution of the input signal $x\left(t\right)$ and the impulse response $h\left(t\right)$.

$$y\left(t\right) = h\left(t\right) * x\left(t\right) = \int_{-\infty}^{+\infty} h\left(t-\tau\right) x\left(\tau\right) \mathrm{d}\tau \tag{E.1}$$

Other example equations are as follows.

$$\begin{bmatrix} \frac{V_1}{I_1} \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} \frac{V_2}{I_2} \end{bmatrix} \tag{E.2}$$

$$\frac{1}{2} < \left\lfloor \mathrm{mod}\left(\left\lfloor \frac{y}{17} \right\rfloor 2^{-17\lfloor x \rfloor - \mathrm{mod}(\lfloor y \rfloor, 17)}, 2 \right) \right\rfloor, \tag{E.3}$$

$$|\zeta(x)^3 \zeta(x+iy)^4 \zeta(x+2iy)| = \exp \sum_{n,p} \frac{3 + 4\cos(ny \log p) + \cos(2ny \log p)}{np^{nx}} \geq 1 \tag{E.4}$$

1440 The verbatim LaTeX code of Sec. E1 is in List. E.1.

Listing E.1: Sample LaTeX code for equations and notations usage

```
1  The following examples show how to typeset equations in \LaTeX.  This
       section also shows examples of the use of \verb| \gls{ } | commands
       in conjunction with the items that are in the \verb| notation.tex |
       file. \textbf{Please make sure that the entries in} \verb| notation.
       tex |\textbf{  are those that are referenced in the \LaTeX \
       document files used by this \documentType.  Please comment out
       unused notations and be careful with the commas and brackets  in} \
       verb| notation.tex |.
2
3  In~\eqref{eq:conv}, the output signal \gls{not:output_sigt} is the
       result of the convolution of the input signal \gls{not:input_sigt}
       and the impulse response \gls{not:ir}.
4
5  \begin{eqnarray}
6       y\left( t \right) = h\left( t \right) * x\left( t \right)=\int_{-\
            infty}^{+\infty}h\left( t-\tau \right)x\left( \tau \right) \
            mathrm{d}\tau
7     \label{eq:conv}
8  \end{eqnarray}
9
10 Other example equations are as follows.
11
12 \begin{eqnarray}
13    \left[ \dfrac{ V_{1} }{ I_{1} } \right] =
14    \begin{bmatrix}
15       A & B \\
16       C & D
17    \end{bmatrix}
18    \left[ \dfrac{ V_{2} }{ I_{2} } \right]
19    \label{eq:ABCD}
20 \end{eqnarray}
21
22 \begin{eqnarray}
23 \dfrac{1}{2} < \left\lfloor \mathrm{mod}\left(\left\lfloor \dfrac{y}{17}
       \right\rfloor 2^{-17 \lfloor x \rfloor - \mathrm{mod}(\lfloor y\
       rfloor, 17)},2\right)\right\rfloor,
24 \end{eqnarray}
25
26 \begin{eqnarray}
27 | \zeta(x)^3 \zeta(x + iy)^4 \zeta(x + 2iy) | =
28 \exp\sum_{n,p} \frac{3 + 4 \cos( ny \log p) + \cos (2ny \log p)}{np^{nx
       }} \ge 1
29 \end{eqnarray}
```

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E2 Notations

In order to use the standardized notation, the user is highly suggested to see the ISO 80000-2 standard [ISO, 2009].

See https://en.wikipedia.org/wiki/Help:Displaying_a_formula and https://en.wikipedia.org/wiki/List_of_mathematical_symbols for LaTeX maths and other notations, respectively.

The following were taken from `isomath-test.tex` .

E2.1 Math alphabets

If there are other symbols in place of Greek letters in a math alphabet, it uses T1 or OT1 font encoding instead of OML.

mathnormal	$A, B, \Gamma, \Delta, \Theta, \Lambda, \Xi, \Pi, \Sigma, \Phi, \Psi, \Omega, \alpha, \beta, \pi, \nu, \omega, v, w, 0, 1, 9$
mathit	$A, B, \Gamma, \Delta, \Theta, \Lambda, \Xi, \Pi, \Sigma, \Phi, \Psi, \Omega, ff, fi, ß, \text{˚}, !, v, w, 0, 1, 9$
mathrm	$\mathrm{A, B, \Gamma, \Delta, \Theta, \Lambda, \Xi, \Pi, \Sigma, \Phi, \Psi, \Omega, ff, fi, ß, \text{˚}, !, v, w, 0, 1, 9}$
mathbf	$\mathbf{A, B, \Gamma, \Delta, \Theta, \Lambda, \Xi, \Pi, \Sigma, \Phi, \Psi, \Omega, ff, fi, ß, \text{˚}, !, v, w, 0, 1, 9}$
mathsf	$\mathsf{A, B, \Gamma, \Delta, \Theta, \Lambda, \Xi, \Pi, \Sigma, \Phi, \Psi, \Omega, ff, fi, ß, \text{˚}, !, v, w, 0, 1, 9}$
mathtt	$\mathtt{A, B, \Gamma, \Delta, \Theta, \Lambda, \Xi, \Pi, \Sigma, \Phi, \Psi, \Omega, \uparrow, \downarrow, ß, \text{˚}, !, v, w, 0, 1, 9}$

New alphabets bold-italic, sans-serif-italic, and sans-serif-bold-italic.

mathbfit	$\boldsymbol{A, B, \Gamma, \Delta, \Theta, \Lambda, \Xi, \Pi, \Sigma, \Phi, \Psi, \Omega, \alpha, \beta, \pi, \nu, \omega, v, w, 0, 1, 9}$
mathsfit	$\mathit{A, B, \Gamma, \Delta, \Theta, \Lambda, \Xi, \Pi, \Sigma, \Phi, \Psi, \Omega, \alpha, \beta, \pi, \nu, \omega, v, w, 0, 1, 9}$
mathsfbfit	$\boldsymbol{\mathit{A, B, \Gamma, \Delta, \Theta, \Lambda, \Xi, \Pi, \Sigma, \Phi, \Psi, \Omega, \alpha, \beta, \pi, \nu, \omega, v, w, 0, 1, 9}}$

Do the math alphabets match?

$ax\alpha\omega\boldsymbol{ax\alpha\omega}\mathit{ax\alpha\omega}\boldsymbol{\mathit{ax\alpha\omega}}$ $TC\Theta\Gamma\boldsymbol{TC\Theta\Gamma}\mathit{TC\Theta\Gamma}\boldsymbol{\mathit{TC\Theta\Gamma}}$

E2.2 Vector symbols

Alphabetic symbols for vectors are boldface italic, $\boldsymbol{\lambda} = \boldsymbol{e}_1 \cdot \boldsymbol{a}$, while numeric ones (e.g. the zero vector) are bold upright, $\boldsymbol{a} + \mathbf{0} = \boldsymbol{a}$.

E2.3 Matrix symbols

Symbols for matrices are boldface italic, too:[1] $\boldsymbol{\Lambda} = \boldsymbol{E} \cdot \boldsymbol{A}$.

[1] However, matrix symbols are usually capital letters whereas vectors are small ones. Exceptions are physical quantities like the force vector $\boldsymbol{F}$ or the electrical field $\boldsymbol{E}$.

E2.4 Tensor symbols

Symbols for tensors are sans-serif bold italic,

$$\boldsymbol{\alpha} = \boldsymbol{e} \cdot \boldsymbol{a} \quad \Longleftrightarrow \quad \alpha_{ijl} = e_{ijk} \cdot a_{kl}.$$

The permittivity tensor describes the coupling of electric field and displacement:

$$\boldsymbol{D} = \epsilon_0 \boldsymbol{\epsilon}_\mathrm{r} \boldsymbol{E}$$

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E2.5 Bold math version

The "bold" math version is selected with the commands `\boldmath` or `\mathversion{bold}`

mathnormal	$A, B, \Gamma, \Delta, \Theta, \Lambda, \Xi, \Pi, \Sigma, \Phi, \Psi, \Omega, \alpha, \beta, \pi, \nu, \omega, v, w, 0, 1, 9$
mathit	$A, B, \Gamma, \Delta, \Theta, \Lambda, \Xi, \Pi, \Sigma, \Phi, \Psi, \Omega, ff, fi, ß, \circ, !, v, w, 0, 1, 9$
mathrm	$\mathrm{A, B, \Gamma, \Delta, \Theta, \Lambda, \Xi, \Pi, \Sigma, \Phi, \Psi, \Omega, ff, fi, ß, \circ, !, v, w, 0, 1, 9}$
mathbf	$\mathbf{A, B, \Gamma, \Delta, \Theta, \Lambda, \Xi, \Pi, \Sigma, \Phi, \Psi, \Omega, ff, fi, ß, \circ, !, v, w, 0, 1, 9}$
mathsf	$\mathsf{A, B, \Gamma, \Delta, \Theta, \Lambda, \Xi, \Pi, \Sigma, \Phi, \Psi, \Omega, ff, fi, ß, \circ, !, v, w, 0, 1, 9}$
mathtt	$\mathtt{A, B, \Gamma, \Delta, \Theta, \Lambda, \Xi, \Pi, \Sigma, \Phi, \Psi, \Omega, \uparrow, \downarrow, ß, \circ, !, v, w, 0, 1, 9}$

New alphabets bold-italic, sans-serif-italic, and sans-serif-bold-italic.

mathbfit	$\boldsymbol{A, B, \Gamma, \Delta, \Theta, \Lambda, \Xi, \Pi, \Sigma, \Phi, \Psi, \Omega, \alpha, \beta, \pi, \nu, \omega, v, w, 0, 1, 9}$
mathsfit	$\mathsfit{A, B, \Gamma, \Delta, \Theta, \Lambda, \Xi, \Pi, \Sigma, \Phi, \Psi, \Omega, \alpha, \beta, \pi, \nu, \omega, v, w, 0, 1, 9}$
mathsfbfit	$\mathsfbfit{A, B, \Gamma, \Delta, \Theta, \Lambda, \Xi, \Pi, \Sigma, \Phi, \Psi, \Omega, \alpha, \beta, \pi, \nu, \omega, v, w, 0, 1, 9}$

Do the math alphabets match?
$\boldsymbol{ax\alpha\omega ax\alpha\omega ax\alpha\omega \quad TC\Theta\Gamma TC\Theta\Gamma TC\Theta\Gamma}$

E2.5.1 Vector symbols

Alphabetic symbols for vectors are boldface italic, $\boldsymbol{\lambda = e_1 \cdot a}$, while numeric ones (e.g. the zero vector) are bold upright, $\boldsymbol{a + 0 = a}$.

E2.5.2 Matrix symbols

Symbols for matrices are boldface italic, too:[2] $\boldsymbol{\Lambda = E \cdot A}$.

E2.5.3 Tensor symbols

Symbols for tensors are sans-serif bold italic,

$$\boldsymbol{\alpha = e \cdot a \quad \Longleftrightarrow \quad \alpha_{ijl} = e_{ijk} \cdot a_{kl}}.$$

The permittivity tensor describes the coupling of electric field and displacement:

$$\boldsymbol{D = \epsilon_0 \epsilon_\mathrm{r} E}$$

[2] However, matrix symbols are usually capital letters whereas vectors are small ones. Exceptions are physical quantities like the force vector $\boldsymbol{F}$ or the electrical field $\boldsymbol{E}$.

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The verbatim LaTeX code of Sec. E2 is in List. E.2.

Listing E.2: Sample LaTeX code for notations usage

```
% A teststring with Latin and Greek letters::
\newcommand{\teststring}{%
% capital Latin letters
% A,B,C,
A,B,
% capital Greek letters
%\Gamma,\Delta,\Theta,\Lambda,\Xi,\Pi,\Sigma,\Upsilon,\Phi,\Psi,
\Gamma,\Delta,\Theta,\Lambda,\Xi,\Pi,\Sigma,\Phi,\Psi,\Omega,
% small Greek letters
\alpha,\beta,\pi,\nu,\omega,
% small Latin letters:
% compare \nu, \omega, v, and w
v,w,
% digits
0,1,9
}


\subsection{Math alphabets}

If there are other symbols in place of Greek letters in a math
alphabet, it uses T1 or OT1 font encoding instead of OML.

\begin{eqnarray*}
\mbox{mathnormal} &  & \teststring \\
\mbox{mathit} &  & \mathit{\teststring}\\
\mbox{mathrm} &  & \mathrm{\teststring}\\
\mbox{mathbf} &  & \mathbf{\teststring}\\
\mbox{mathsf} &  & \mathsf{\teststring}\\
\mbox{mathtt} &  & \mathtt{\teststring}
\end{eqnarray*}
 New alphabets bold-italic, sans-serif-italic, and sans-serif-bold-
    italic.
\begin{eqnarray*}
\mbox{mathbfit}     &  & \mathbfit{\teststring}\\
\mbox{mathsfit}     &  & \mathsfit{\teststring}\\
\mbox{mathsfbfit} &  & \mathsfbfit{\teststring}
\end{eqnarray*}
%
Do the math alphabets match?

$
\mathnormal  {a x \alpha \omega}
\mathbfit    {a x \alpha \omega}
\mathsfbfit{a x \alpha \omega}
\quad
\mathsfbfit{T C \Theta \Gamma}
\mathbfit    {T C \Theta \Gamma}
\mathnormal  {T C \Theta \Gamma}
$

\subsection{Vector symbols}
```

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```
Alphabetic symbols for vectors are boldface italic,
$\vec{\lambda}=\vec{e}_{1}\cdot\vec{a}$,
while numeric ones (e.g. the zero vector) are bold upright,
$\vec{a} + \vec{0} = \vec{a}$.

\subsection{Matrix symbols}

Symbols for matrices are boldface italic, too:%
\footnote{However, matrix symbols are usually capital letters whereas
    vectors
are small ones. Exceptions are physical quantities like the force
vector $\vec{F}$ or the electrical field $\vec{E}$.%
}
$\matrixsym{\Lambda}=\matrixsym{E}\cdot\matrixsym{A}.$


\subsection{Tensor symbols}

Symbols for tensors are sans-serif bold italic,

\[
   \tensorsym{\alpha}  =  \tensorsym{e}\cdot\tensorsym{a}
   \quad \Longleftrightarrow \quad
   \alpha_{ijl}  =  e_{ijk}\cdot a_{kl}.
\]


The permittivity tensor describes the coupling of electric field and
displacement: \[
\vec{D}=\epsilon_{0}\tensorsym{\epsilon}_{\mathrm{r}}\vec{E}\]



\newpage
\subsection{Bold math version}

The ``bold'' math version is selected with the commands
\verb+\boldmath+ or \verb+\mathversion{bold}+

{\boldmath
   \begin{eqnarray*}
   \mbox{mathnormal} &  & \teststring \\
   \mbox{mathit} &  & \mathit{\teststring}\\
   \mbox{mathrm} &  & \mathrm{\teststring}\\
   \mbox{mathbf} &  & \mathbf{\teststring}\\
   \mbox{mathsf} &  & \mathsf{\teststring}\\
   \mbox{mathtt} &  & \mathtt{\teststring}
   \end{eqnarray*}
    New alphabets bold-italic, sans-serif-italic, and sans-serif-bold-
        italic.
   \begin{eqnarray*}
   \mbox{mathbfit}     &  & \mathbfit{\teststring}\\
   \mbox{mathsfit}     &  & \mathsfit{\teststring}\\
   \mbox{mathsfbfit} &  & \mathsfbfit{\teststring}
   \end{eqnarray*}
   %
   Do the math alphabets match?
```

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```
    $
    \mathnormal  {a x \alpha \omega}
    \mathbfit    {a x \alpha \omega}
    \mathsfbfit{a x \alpha \omega}
    \quad
    \mathsfbfit{T C \Theta \Gamma}
    \mathbfit    {T C \Theta \Gamma}
    \mathnormal  {T C \Theta \Gamma}
    $

    \subsection{Vector symbols}

    Alphabetic symbols for vectors are boldface italic,
    $\vec{\lambda}=\vec{e}_{1}\cdot\vec{a}$,
    while numeric ones (e.g. the zero vector) are bold upright,
    $\vec{a} + \vec{0} = \vec{a}$.




    \subsection{Matrix symbols}

    Symbols for matrices are boldface italic, too:%
    \footnote{However, matrix symbols are usually capital letters whereas
        vectors
    are small ones. Exceptions are physical quantities like the force
    vector $\vec{F}$ or the electrical field $\vec{E}$.%
    }
    $\matrixsym{\Lambda}=\matrixsym{E}\cdot\matrixsym{A}.$


    \subsection{Tensor symbols}

    Symbols for tensors are sans-serif bold italic,

    \[
        \tensorsym{\alpha}  =  \tensorsym{e}\cdot\tensorsym{a}
        \quad \Longleftrightarrow \quad
        \alpha_{ijl}  =  e_{ijk}\cdot a_{kl}.
    \]

    The permittivity tensor describes the coupling of electric field and
    displacement: \[
    \vec{D}=\epsilon_{0}\tensorsym{\epsilon}_{\mathrm{r}}\vec{E}\]
}
```

E3 Abbreviation

This section shows examples of the use of LaTeXcommands in conjunction with the items that are in the `abbreviation.tex` and in the `glossary.tex` files. Please see List. E.3. **To lessen the LaTeX parsing time, it is suggested that you use `\acr{ }` only for the first occurrence of the word to be abbreviated.**

Again please see List. E.3. Here is an example of first use: alternating current (ac). Next use: ac. Full: alternating current (ac). Here's an acronym referenced using `\acr` : hyper-text markup language (html). And here it is again: html. If you are used to the `glossaries` package, note the difference in using `\gls` : hyper-text markup language (html). And again (no difference): hyper-text markup language (html). For plural use `\glspl` . Here are some more entries:

- extensible markup language (xml) and cascading style sheet (css).
- Next use: xml and css.
- Full form: extensible markup language (xml) and cascading style sheet (css).
- Reset again.
- Start with a capital. Hyper-text markup language (html).
- Next: Html. Full: Hyper-text markup language (html).
- Prefer capitals? Extensible markup language (XML). Next: XML. Full: extensible markup language (XML).
- Prefer small-caps? Cascading style sheet (CSS). Next: CSS. Full: cascading style sheet (CSS).
- Resetting all acronyms.
- Here are the acronyms again:
- Hyper-text markup language (HTML), extensible markup language (XML) and cascading style sheet (CSS).
- Next use: HTML, XML and CSS.
- Full form: Hyper-text markup language (HTML), extensible markup language (XML) and cascading style sheet (CSS).

- Provide your own link text: style sheet.

The verbatim LaTeX code of Sec. E3 is in List. E.3.

Listing E.3: Sample LaTeX code for abbreviations usage

```
Again please see List.~\ref{lst:abbrv}. Here is an example of first use:
    \acr{ac}. Next use: \acr{ac}. Full: \gls{ac}.  Here's an acronym
   referenced using \verb| \acr |: \acr{html}.  And here it is again: \
   acr{html}. If you are used to the \texttt{glossaries} package, note
   the difference in using \verb| \gls |: \gls{html}. And again (no
   difference): \gls{html}. Here are some more entries:

\begin{itemize}

   \item \acr{xml} and \acr{css}.

   \item Next use: \acr{xml} and \acr{css}.

   \item Full form: \gls{xml} and \gls{css}.

   \item Reset again. \glsresetall{abbreviation}

   \item Start with a capital. \Acr{html}.

   \item Next: \Acr{html}. Full: \Gls{html}.

   \item Prefer capitals? \renewcommand{\acronymfont}[1]{\
      MakeTextUppercase{#1}} \Acr{xml}. Next: \acr{xml}. Full: \gls{xml
      }.

   \item Prefer small-caps? \renewcommand{\acronymfont}[1]{\textsc{#1}}
      \Acr{css}. Next: \acr{css}. Full: \gls{css}.

   \item Resetting all acronyms.\glsresetall{abbreviation}

   \item Here are the acronyms again:

   \item \Acr{html}, \acr{xml} and \acr{css}.

   \item Next use: \Acr{html}, \acr{xml} and \acr{css}.

   \item Full form: \Gls{html}, \gls{xml} and \gls{css}.

   \item Provide your own link text: \glslink{[textbf]css}{style}

\end{itemize}
```

E4 Glossary

This section shows examples of the use of `\gls{ }` commands in conjunction with the items that are in the `glossary.tex` and `notation.tex` files. Note that entries in `notation.tex` are prefixed with "`not:`" label (see List. E.4).

Please make sure that the entries in `notation.tex` are those that are referenced in the LaTeX document files used by this Thesis. Please comment out unused notations and be careful with the commas and brackets in `notation.tex` .

- Matrices are usually denoted by a bold capital letter, such as $\boldsymbol{A}$. The matrix's (i, j)th element is usually denoted a_{ij}. Matrix $\mathbf{I}$ is the identity matrix.
- A set, denoted as $\mathcal{S}$, is a collection of objects.
- The universal set, denoted as $\mathcal{U}$, is the set of everything.
- The empty set, denoted as $\emptyset$, contains no elements.
- Functional Analysis is seen as the study of complete normed vector spaces, i.e., Banach spaces.
- The cardinality of a set, denoted as $|\mathcal{S}|$, is the number of elements in the set.

The verbatim LaTeX code for the part of Sec. E4 is in List. E.4.

Listing E.4: Sample LaTeX code for glossary and notations usage

```
\begin{itemize}

   \item \Glspl{matrix} are usually denoted by a bold capital letter,
       such as $\mathbfit{A}$. The \gls{matrix}'s $(i,j)$th element is
       usually denoted $a_{ij}$. \Gls{matrix} $\mathbf{I}$ is the
       identity \gls{matrix}.

   \item A set, denoted as \gls{not:set}, is a collection of objects.

   \item The universal set,  denoted as \gls{not:universalSet}, is the
       set of everything.

   \item The empty set, denoted as \gls{not:emptySet}, contains no
       elements.

   \item \Gls{Functional Analysis} is seen as the study of complete
       normed vector spaces, i.e., Banach spaces.

   \item The cardinality of a set, denoted as \gls{not:cardinality}, is
       the number of elements in the set.

\end{enumerate}
```

E5 Figure

This section shows several ways of placing figures. PDFLaTeX compatible files are PDF, PNG, and JPG. Please see the `figure` subdirectory.

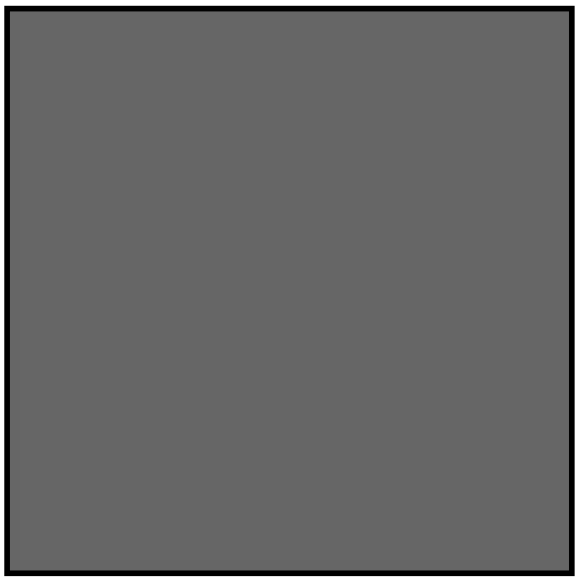
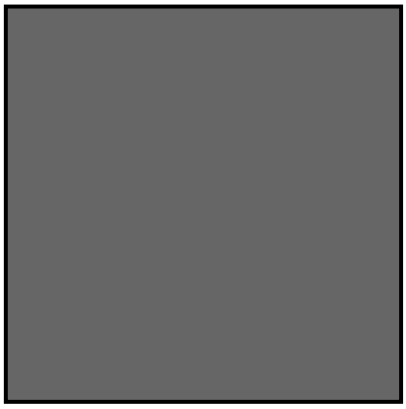


Fig. E.1 A quadrilateral image example.

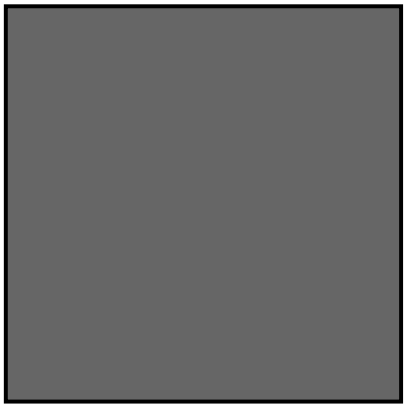
Fig. E.1 is a gray box enclosed by a dark border. List. E.5 shows the corresponding LaTeX code.

Listing E.5: Sample LaTeX code for a single figure

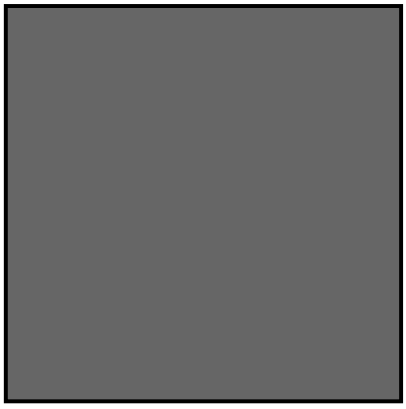
```
\begin{figure}[!htbp]
   \centering
      \includegraphics[width=0.5\textwidth]{example}
   \caption{A quadrilateral image example.}
   \label{fig:example}
\end{figure}
\cleardoublepage

Fig.~\ref{fig:example} is a gray box enclosed by a dark border. List.~\
    ref{lst:onefig} shows the corresponding \LaTeX \ code.
\end{figure}
```



(a) A sub-figure in the top row.



(b) A sub-figure in the middle row.



(c) A sub-figure in the bottom row.

Fig. E.2 Figures on top of each other. See List. E.6 for the corresponding LaTeX code.

Listing E.6: Sample LaTeX code for three figures on top of each other

```
\begin{figure}[!htbp]
\centering
\subbottom[A sub-figure in the top row.]{
\includegraphics[width=0.35\textwidth]{example_gray_box}
\label{fig:top}
}
\vfill
\subbottom[A sub-figure in the middle row.]{
\includegraphics[width=0.35\textwidth]{example_gray_box}
\label{fig:mid}
}
\vfill
\subbottom[A sub-figure in the bottom row.]{
\includegraphics[width=0.35\textwidth]{example_gray_box}
\label{fig:botm}
}
\caption{Figures on top of each other}
\label{fig:tmb}
\end{figure}
```

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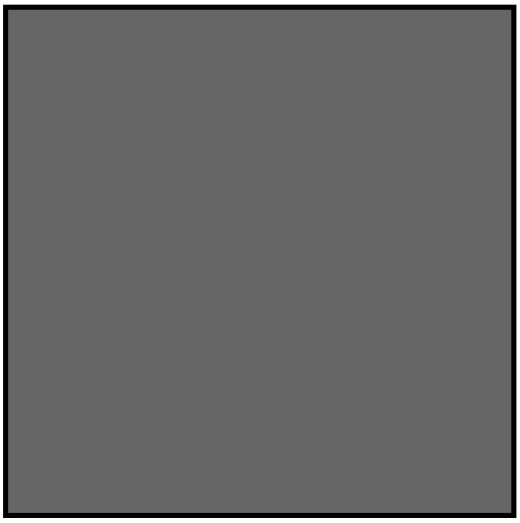
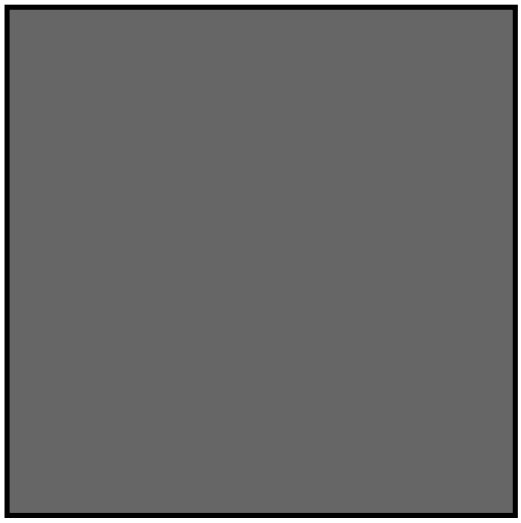
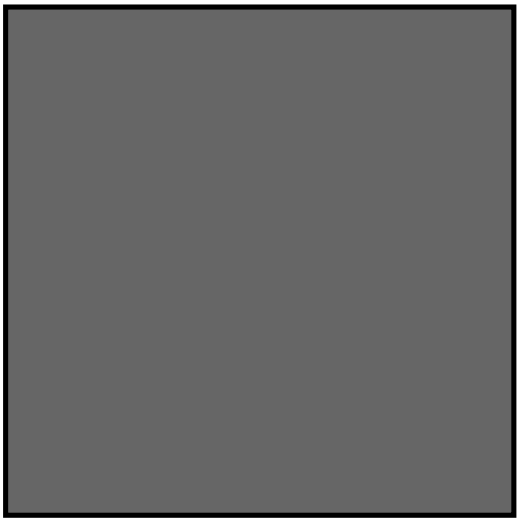


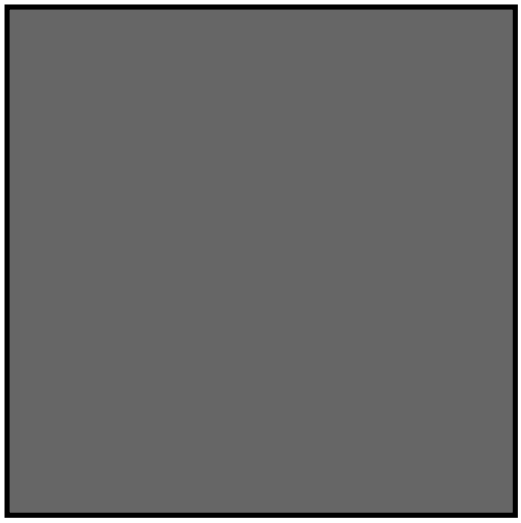
(a) A sub-figure in the upper-left corner.



(b) A sub-figure in the upper-right corner.



(c) A sub-figure in the lower-left corner.



(d) A sub-figure in the lower-right corner

Fig. E.3 Four figures in each corner. See List. E.7 for the corresponding LaTeX code.

Listing E.7: Sample LaTeX code for the four figures

```
\begin{figure}[!htbp]
\centering
\subbottom[A sub-figure in the upper-left corner.]{
\includegraphics[width=0.45\textwidth]{example_gray_box}
\label{fig:upprleft}
}
\hfill
\subbottom[A sub-figure in the upper-right corner.]{
\includegraphics[width=0.45\textwidth]{example_gray_box}
\label{fig:uppright}
}
\vfill
\subbottom[A sub-figure in the lower-left corner.]{
\includegraphics[width=0.45\textwidth]{example_gray_box}
\label{fig:lowerleft}
}
\hfill
\subbottom[A sub-figure in the lower-right corner]{
\includegraphics[width=0.45\textwidth]{example_gray_box}
\label{fig:lowright}
}
\caption{Four figures in each corner. See List.~\ref{lst:fourfigs} for
    the corresponding \LaTeX \ code.}
\label{fig:fourfig}
\end{figure}
```

E6 Table

This section shows an example of placing a table (a long one). Table E.1 are the triples.

TABLE E.1 FEASIBLE TRIPLES FOR HIGHLY VARIABLE GRID

Time (s)	Triple chosen	Other feasible triples
0	(1, 11, 13725)	(1, 12, 10980), (1, 13, 8235), (2, 2, 0), (3, 1, 0)
2745	(1, 12, 10980)	(1, 13, 8235), (2, 2, 0), (2, 3, 0), (3, 1, 0)
5490	(1, 12, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
8235	(1, 12, 16470)	(1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0)
10980	(1, 12, 16470)	(1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0)
13725	(1, 12, 16470)	(1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0)
16470	(1, 13, 16470)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
19215	(1, 12, 16470)	(1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0)
21960	(1, 12, 16470)	(1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0)
24705	(1, 12, 16470)	(1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0)
27450	(1, 12, 16470)	(1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0)
30195	(2, 2, 2745)	(2, 3, 0), (3, 1, 0)
32940	(1, 13, 16470)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
35685	(1, 13, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
38430	(1, 13, 10980)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
41175	(1, 12, 13725)	(1, 13, 10980), (2, 2, 2745), (2, 3, 0), (3, 1, 0)
43920	(1, 13, 10980)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
46665	(2, 2, 2745)	(2, 3, 0), (3, 1, 0)
49410	(2, 2, 2745)	(2, 3, 0), (3, 1, 0)
52155	(1, 12, 16470)	(1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0)
54900	(1, 13, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
57645	(1, 13, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
60390	(1, 12, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
63135	(1, 13, 16470)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
65880	(1, 13, 16470)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
68625	(2, 2, 2745)	(2, 3, 0), (3, 1, 0)
71370	(1, 13, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
74115	(1, 12, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
76860	(1, 13, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
79605	(1, 13, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
82350	(1, 12, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
85095	(1, 12, 13725)	(1, 13, 10980), (2, 2, 2745), (2, 3, 0), (3, 1, 0)
87840	(1, 13, 16470)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
90585	(1, 13, 16470)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
93330	(1, 13, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
96075	(1, 13, 16470)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
98820	(1, 13, 16470)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
101565	(1, 13, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
104310	(1, 13, 16470)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
107055	(1, 13, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
109800	(1, 13, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
112545	(1, 12, 16470)	(1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0)
115290	(1, 13, 16470)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
118035	(1, 13, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
120780	(1, 13, 16470)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
123525	(1, 13, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)

Continued on next page

Continued from previous page

Time (s)	Triple chosen	Other feasible triples
126270	(1, 12, 16470)	(1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0)
129015	(2, 2, 2745)	(2, 3, 0), (3, 1, 0)
131760	(2, 2, 2745)	(2, 3, 0), (3, 1, 0)
134505	(1, 13, 16470)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
137250	(1, 13, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
139995	(2, 2, 2745)	(2, 3, 0), (3, 1, 0)
142740	(2, 2, 2745)	(2, 3, 0), (3, 1, 0)
145485	(1, 12, 16470)	(1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0)
148230	(2, 2, 2745)	(2, 3, 0), (3, 1, 0)
150975	(1, 13, 16470)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
153720	(1, 12, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
156465	(1, 13, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
159210	(1, 13, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
161955	(1, 13, 16470)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)
164700	(1, 13, 13725)	(2, 2, 2745), (2, 3, 0), (3, 1, 0)

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List. E.8 shows the corresponding LaTeX code.

Listing E.8: Sample LaTeX code for making typical table environment

```
\begin{center}
{\scriptsize
\begin{tabularx}{\textwidth}{p{0.1\textwidth}|p{0.2\textwidth}|p{0.5\textwidth}}
\caption{Feasible triples for highly variable grid} \label{tab:triple_grid} \\
\hline
\hline
\textbf{Time (s)} &
\textbf{Triple chosen} &
\textbf{Other feasible triples} \\
\hline
\endfirsthead
\multicolumn{3}{c}%
{\textit{Continued from previous page}} \\
\hline
\hline
\textbf{Time (s)} &
\textbf{Triple chosen} &
\textbf{Other feasible triples} \\
\hline
\endhead
\hline
\multicolumn{3}{r}{\textit{Continued on next page}} \\
\endfoot
\hline
\endlastfoot
\hline

0 & (1, 11, 13725) & (1, 12, 10980), (1, 13, 8235), (2, 2, 0), (3, 1, 0) \\
2745 & (1, 12, 10980) & (1, 13, 8235), (2, 2, 0), (2, 3, 0), (3, 1, 0) \\
5490 & (1, 12, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
8235 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
10980 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
13725 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
16470 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
19215 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
21960 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
24705 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
27450 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
30195 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
32940 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
35685 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
38430 & (1, 13, 10980) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
```

```
41175 & (1, 12, 13725) & (1, 13, 10980), (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
43920 & (1, 13, 10980) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
46665 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
49410 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
52155 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
54900 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
57645 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
60390 & (1, 12, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
63135 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
65880 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
68625 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
71370 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
74115 & (1, 12, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
76860 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
79605 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
82350 & (1, 12, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
85095 & (1, 12, 13725) & (1, 13, 10980), (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
87840 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
90585 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
93330 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
96075 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
98820 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
101565 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
104310 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
107055 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
109800 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
112545 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
115290 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
118035 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
120780 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
123525 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
126270 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
129015 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
131760 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
134505 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
137250 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
139995 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
142740 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
145485 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
148230 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
150975 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
153720 & (1, 12, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
156465 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
159210 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
161955 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
164700 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
\end{tabularx}
}
\end{center}
```

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E7 Algorithm or Pseudocode Listing

Table E.2 shows an example pseudocode. Note that if the pseudocode exceeds one page, it can mean that its implementation is not modular. List. E.9 shows the corresponding LaTeX code.

TABLE E.2 CALCULATION OF $y = x^n$

Input(s):		
n	:	nth power; $n \in \mathbb{Z}^+$
x	:	base value; $x \in \mathbb{R}^+$
Output(s):		
y	:	result; $y \in \mathbb{R}^+$

Require: $n \geq 0 \vee x \neq 0$
Ensure: $y = x^n$
1: $y \Leftarrow 1$
2: **if** $n < 0$ **then**
3: $X \Leftarrow 1/x$
4: $N \Leftarrow -n$
5: **else**
6: $X \Leftarrow x$
7: $N \Leftarrow n$
8: **end if**
9: **while** $N \neq 0$ **do**
10: **if** N is even **then**
11: $X \Leftarrow X \times X$
12: $N \Leftarrow N/2$
13: **else** $\{N$ is odd$\}$
14: $y \Leftarrow y \times X$
15: $N \Leftarrow N - 1$
16: **end if**
17: **end while**

Listing E.9: Sample LaTeX code for algorithm or pseudocode listing usage

```
\begin{table}[!htbp]
   \caption{Calculation of $y = x^n$}
   \label{tab:calcxn}
   {\footnotesize
   \begin{tabular}{lll}
   \hline
   \hline
   {\bfseries Input(s):} & & \\
   $n$ & : & $n$th power; $n \in \mathbb{Z}^{+}$ \\
   $x$ & : & base value; $x \in \mathbb{R}^{+}$ \\
   \hline
   {\bfseries Output(s):} & & \\
   $y$ & : & result; $y \in \mathbb{R}^{+}$  \\
   \hline
   \hline
   \\
   \end{tabular}
   }
   \begin{algorithmic}[1]
   {\footnotesize
      \REQUIRE $n \geq 0 \vee x \neq 0$
      \ENSURE $y = x^n$
      \STATE $y \Leftarrow 1$
      \IF{$n < 0$}
            \STATE $X \Leftarrow 1 / x$
            \STATE $N \Leftarrow -n$
      \ELSE
            \STATE $X \Leftarrow x$
            \STATE $N \Leftarrow n$
      \ENDIF
      \WHILE{$N \neq 0$}
            \IF{$N$ is even}
                  \STATE $X \Leftarrow X \times X$
                  \STATE $N \Leftarrow N / 2$
            \ELSE[$N$ is odd]
                  \STATE $y \Leftarrow y \times X$
                  \STATE $N \Leftarrow N - 1$
            \ENDIF
      \ENDWHILE
   }
   \end{algorithmic}
\end{table}
```

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E8 Program/Code Listing

List. E.10 is a program listing of a C code for computing Fibonacci numbers by calling the actual code. Please see the `code` subdirectory.

Listing E.10: Computing Fibonacci numbers in C (./code/fibo.c)

```
/* fibo.c -- It prints out the first N Fibonacci
 *           numbers.
 */

#include <stdio.h>

int main(void) {
    int n;        /* Number of fibonacci numbers we will print */
    int i;        /* Index of fibonacci number to be printed next */
    int current;  /* Value of the (i)th fibonacci number */
    int next;     /* Value of the (i+1)th fibonacci number */
    int twoaway;  /* Value of the (i+2)th fibonacci number */

    printf("How many Fibonacci numbers do you want to compute? ");
    scanf("%d", &n);
    if (n<=0)
       printf("The number should be positive.\n");
    else {
      printf("\n\n\tI \t Fibonacci(I) \n\t=====================\n");
      next = current = 1;
      for (i=1; i<=n; i++) {
   printf("\t%d \t\t\t%d\n", i, current);
   twoaway = current+next;
   current = next;
   next    = twoaway;
      }
    }
}

/* The output from a run of this program was:

How many Fibonacci numbers do you want to compute? 9

   I   Fibonacci(I)
   =====================
   1      1
   2      1
   3      2
   4      3
   5      5
   6      8
   7      13
   8      21
   9      34

*/
```

List. E.11 shows the corresponding LaTeX code.

Listing E.11: Sample LaTeX code for program listing

```
List.~\ref{lst:fib_c} is a program listing of a C code for computing
    Fibonacci numbers by calling the actual code. Please see the \verb|
    code | subdirectory.
```

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E9 Referencing

Referencing chapters: This appendix is in Appendix E, which is about examples in using various LaTeX commands.

Referencing sections: This section is Sec. E9, which shows how to refer to the locations of various labels that have been placed in the LaTeX files. List. E.12 shows the corresponding LaTeX code.

Listing E.12: Sample LaTeX code for referencing sections

```
Referencing sections: This section is Sec.~\ref{sec:ref}, which shows
    how to refer to the locations of various labels that have been
    placed in the \LaTeX \ files. List.~\ref{lst:refsec} shows the
    corresponding \LaTeX \ code.
```

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E9.1 A subsection

Referencing subsections: This section is Sec. E9.1, which shows how to refer to a subsection. List. E.13 shows the corresponding LaTeX code.

Listing E.13: Sample LaTeX code for referencing subsections

```
Referencing subsections: This section is Sec.~\ref{sec:subsec}, which
    shows how to refer to a subsection. List.~\ref{lst:refsub} shows the
     corresponding \LaTeX \ code.
```

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E9.1.1 A sub-subsection

Referencing sub-subsections: This section is Sec. E9.1.1, which shows how to refer to a sub-subsection. List. E.14 shows the corresponding LaTeX code.

Listing E.14: Sample LaTeX code for referencing sub-subsections

```
Referencing sub-subsections: This section is Sec.~\ref{sec:subsubsec},
    which shows how to refer to a sub-subsection. List.~\ref{lst:
    refsubsub} shows the corresponding \LaTeX \ code.
```

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.

E10 Citing

Citing bibliography content is done using BibTeX. It requires the creation of a BibTeX file (.bib extension name), and then added in the argument of `\bibliography{ }` . For each .bib file, separate them by a comma in the argument of `\bibliography{ }` without the extension name. Building your BibTeX file (references.bib) can be done easily with a tool called JabRef (www.jabref.org).

The following subsections are examples of citations.

E10.1 Books

- [‘Chicago’, 1982]
- [Aristotle, 1877]
- [Aristotle, 1907]
- [Aristotle, 1968]
- [Aristotle, 1929]
- [ABCM, 1959]
- [Augustine, 1995]
- [Averroes, 1982]
- [Butcher, 1981]
- [Chapman, 1975]
- [Cicero, 1995]
- [Coleridge, 1983]
- [Cotton et al., 1999]
- [van Gennep, 1909a]
- [van Gennep, 1909b]
- [van Gennep, 1960]
- [Gerhardt, 2000]
- [Gonzalez, 2001]

- [Goossens et al., 1994]
- [Hammond, 1997]
- [Hershkovitz, 1962]
- [Hoel, 1971a]
- [Homer, 2004]
- [Knuth, 1981a]
- [Knuth, 1981b]
- [Knuth, 1973a]
- [Kullback, 1997a]
- [Kullback, 1997b]
- [Kullback, 1959]
- [Malinowski, 1972]
- [Maron, 2000]
- [Massa, 2004]
- [McColvin, 2004]
- [Nietzsche, 1988b]
- [Nietzsche, 1988a]
- [Oetiker et al., 2014]
- [Piccato, 2001]
- [Smart, 1976]
- [Vázques de Parga et al., 1993]
- [Wilde, 1899]
- [Wood, 1961]
- [Worman, 2002]
- [Wright, 1978a]
- [Lipcoll et al., 1977]

E10.2 Booklets

- [Knvth, 1988]

E10.3 Proceedings

- [Oz and Yannakakis, 1983]

E10.4 In books

- [von Brandt and Hoffmann, 1987]
- [BSI, 1973a]
- [Eckstein and Zuckermann, 1960]
- [Feigl, 1958]
- [Gordon, 1975]
- [Hanson, 1967]
- [Hoel, 1971b]
- [Hyman, 1981]
- [Kant, 1968a]
- [Kant, 1968b]
- [Knuth, 1973b]
- [Knuth, 1973c]
- [Lincoll, 1977a]
- [Lincoll, 2004]
- [Lincoll, 1977b]
- [McNeill, 1963]
- [Milton, 1924]
- [Nietzsche, 1988c]

- [Ogilvy, 1965]
- [Pines, 1979]
- [Ramsbottom, 1931]
- [Ranganthan, 1951]
- [Thomson, 1971]
- [Westfahl, 2004]
- [Wright, 1963]
- [Wright, 1978b]

E10.5 In proceedings

- [Chave, 1964]
- [Chomsky, 1973]
- [Moraux, 1979]
- [Oaho et al., 1983a]
- [Oaho et al., 2004]
- [Oaho et al., 1983b]
- [Salam, 1968]

E10.6 Journals

- [Aamport, 2004]
- [Aamport, 1986a]
- [Aamport, 1986b]
- [Aksın et al., 2006]
- [Angenendt, 2002]
- [Aslin, 1949]

- [Baez and Lauda, 2004a]
- [Bertram and Wentworth, 1996]
- [Bry and Afflerbach, 1968]
- [Doody, 1974]
- [Einstein, 1905]
- [Fletcher and Hopkins, 1907]
- [Gillies, 1933]
- [Glashow, 1961]
- [Godfrey, 1959]
- [Hanlon, 1972]
- [Heller and Lederis, 1958]
- [Herrmann et al., 2006]
- [Hostetler et al., 1998]
- [Howells, 1966a]
- [Howells, 1966b]
- [Howells, 1951]
- [ISO, 2009]
- [Jackson, 1979]
- [Johnson, 1974]
- [Moore, 1998]
- [Moore, 1965]
- [Prufer, 1964]
- [Reese, 1958]
- [Sarfraz and Razzak, 2002]

- [Shore, 1991]
- [Sigfridsson and Ryde, 1998]
- [Weinberg, 1967]
- [Yoon et al., 2006]
- [GAJ, 1986]

E10.7 Theses/dissertations

- [Croft, 1978]
- [Maguire, 1976]
- [Mann, 1968]
- [Masterly, 1988a]
- [Masterly, 1988b]
- [Phony-Baloney, 1988a]
- [Phony-Baloney, 1988b]

E10.8 Technical Reports and Others

- [‘Brunswick’, 1985]
- [BSI, 1983]
- [BSI, 1978]
- [BSI, 1976]
- [BSI, 1973b]
- [Ellis and Walton, 1971]
- [Térrific, 1988]
- [Terrific, 1988]
- [Winget Ltd., 1967]

- [Ünderwood et al., 2004]
- [Ünderwood et al., 1988]
- [Downes, 1974]
- [Exchequer, 1639]
- [Pym, 1624]
- [Traquair, 1638]

E10.9 Miscellaneous

- [Almendro et al., 1998]
- [Baez and Lauda, 2004b]
- [Chiu and Chow, 1978]
- [Itzhaki, 1996]
- [Kowalik and Isard, 1995]
- [Laufenberg et al., 2006]
- [Loh, 1992]
- [Markey, 2005]
- [Missilany, 1984]
- [Padhye et al., 1999]
- [Sorace et al., 1997]
- [Wassenberg and Sanders, 2010]
- [Missilany, 2004]

E11 Index

For key words or topics that are expected (or the user would like) to appear in the Index, use `index{key}` , where `key` is an example keyword to appear in the Index. For example, Fredholm integral and Fourier operator of the following paragraph are in the Index.

If we make a very large matrix with complex exponentials in the rows (i.e., cosine real parts and sine imaginary parts), and increase the resolution without bound, we approach the kernel of the Fredholm integral equation of the 2nd kind, namely the Fourier operator that defines the continuous Fourier transform.

List. E.15 is a program listing of the above-mentioned paragraph.

Listing E.15: Sample LaTeX code for Index usage

```
If we make a very large matrix with complex exponentials in the rows (i.
    e., cosine real parts and sine imaginary parts), and increase the
    resolution without bound, we approach the kernel of the \index{
    Fredholm integral} Fredholm integral equation of the 2nd kind,
    namely the \index{Fourier} Fourier operator that defines the
    continuous Fourier transform.
```

E12 Adding Relevant PDF Pages

Examples of such PDF pages are Standards, Datasheets, Specification Sheets, Application Notes, etc. Selected PDF pages can be added (see List. E.16), but note that the options must be tweaked. See the manual of `pdfpages` for other options.

Listing E.16: Sample LaTeX code for including PDF pages

```
\includepdf[pages={8-10},%
offset=3.5mm -10mm,%
scale=0.73,%
frame,%
pagecommand={},]
{./reference/Xilinx2015-UltraScale-Architecture-Overview.pdf}
```

Virtex UltraScale FPGA Feature Summary

Table 6: **Virtex UltraScale FPGA Feature Summary**

	VU065	VU080	VU095	VU125	VU160	VU190	VU440
Logic Cells	626,640	780,000	940,800	1,253,280	1,621,200	1,879,920	4,432,680
CLB Flip-Flops	716,160	891,424	1,075,200	1,432,320	1,852,800	2,148,480	5,065,920
CLB LUTs	358,080	445,712	537,600	716,160	926,400	1,074,240	2,532,960
Maximum Distributed RAM (Mb)	4.8	3.9	4.8	9.7	12.7	14.5	28.7
Block RAM/FIFO w/ECC (36Kb each)	1,260	1,421	1,728	2,520	3,276	3,780	2,520
Total Block RAM (Mb)	44.3	50.0	60.8	88.6	115.2	132.9	88.6
CMT (1 MMCM, 2 PLLs)	10	16	16	20	30	30	30
I/O DLLs	40	64	64	80	120	120	120
Fractional PLLs	5	8	8	10	15	15	0
Maximum HP I/Os(1)	468	780	780	780	650	650	1,404
Maximum HR I/Os(2)	52	52	52	104	52	52	52
DSP Slices	600	672	768	1,200	1,560	1,800	2,880
System Monitor	1	1	1	2	3	3	3
PCIe Gen3 x8	2	4	4	4	5	6	6
150G Interlaken	3	6	6	6	8	9	0
100G Ethernet	3	4	4	6	9	9	3
GTH 16.3Gb/s Transceivers	20	32	32	40	52	60	48
GTY 30.5Gb/s Transceivers	20	32	32	40	52	60	0

Notes:
1. HP = High-performance I/O with support for I/O voltage from 1.0V to 1.8V.
2. HR = High-range I/O with support for I/O voltage from 1.2V to 3.3V.

Virtex UltraScale Device-Package Combinations and Maximum I/Os

Table 7: **Virtex UltraScale Device-Package Combinations and Maximum I/Os**

Package[1][2][3]	Package Dimensions (mm)	VU065	VU080	VU095	VU125	VU160	VU190	VU440
		HR, HP GTH, GTY	HR, HP GTH, GTY	HR, HP GTH, GTY	HR, HP GTH, GTY	HR, HP GTH, GTY	HR, HP GTH, GTY	HR, HP GTH, GTY
FFVC1517	40x40	52, 468 20, 20	52, 468 20, 20	52, 468 20, 20				
FFVD1517	40x40		52, 286 32, 32	52, 286 32, 32				
FLVD1517	40x40				52, 286 40, 32			
FFVB1760	42.5x42.5		52, 650 32, 16	52, 650 32, 16				
FLVB1760	42.5x42.5				52, 650 36, 16			
FFVA2104	47.5x47.5		52, 780 28, 24	52, 780 28, 24				
FLVA2104	47.5x47.5				52, 780 28, 24			
FFVB2104	47.5x47.5		52, 650 32, 32	52, 650 32, 32				
FLVB2104	47.5x47.5				52, 650 40, 36			
FLGB2104	47.5x47.5					52, 650 40, 36	52, 650 40, 36	
FFVC2104	47.5x47.5			52, 364 32, 32				
FLVC2104	47.5x47.5				52, 364 40, 40			
FLGC2104	47.5x47.5					52, 364 52, 52	52, 364 52, 52	
FLGB2377	50x50							52, 1248 36, 0
FLGA2577	52.5x52.5						0, 448 60, 60	
FLGA2892	55x55							52, 1404 48, 0

Notes:

1. Go to Ordering Information for package designation details.
2. All packages have 1.0mm ball pitch.
3. Packages with the same last letter and number sequence, e.g., A2104, are footprint compatible with all other UltraScale architecture-based devices with the same sequence. The footprint compatible devices within this family are outlined. See the UltraScale Architecture Product Selection Guide for details on inter-family migration.

Virtex UltraScale+ FPGA Feature Summary

Table 8: **Virtex UltraScale+ FPGA Feature Summary**

	VU3P	VU5P	VU7P	VU9P	VU11P	VU13P
Logic Cells	689,640	1,051,010	1,379,280	2,068,920	2,147,040	2,862,720
CLB Flip-Flops	788,160	1,201,154	1,576,320	2,364,480	2,453,760	3,271,680
CLB LUTs	394,080	600,577	788,160	1,182,240	1,226,880	1,635,840
Max. Distributed RAM (Mb)	12.0	18.3	24.1	36.1	34.8	46.4
Block RAM/FIFO w/ECC (36Kb each)	720	1,024	1,440	2,160	2,016	2,688
Block RAM (Mb)	25.3	36.0	50.6	75.9	70.9	94.5
UltraRAM Blocks	320	470	640	960	1,152	1,536
UltraRAM (Mb)	90.0	132.2	180.0	270.0	324.0	432.0
CMTs (1 MMCM and 2 PLLs)	10	20	20	30	12	16
Max. HP I/O(1)	520	832	832	832	624	832
DSP Slices	2,280	3,474	4,560	6,840	8,928	11,904
System Monitor	1	2	2	3	3	4
GTY Transceivers 32.75Gb/s	40	80	80	120	96	128
PCIe Gen3 x16 and Gen4 x8	2	4	4	6	3	4
150G Interlaken	3	4	6	9	9	12
100G Ethernet w/RS-FEC	3	4	6	9	6	8

Notes:
1. HP = High-performance I/O with support for I/O voltage from 1.0V to 1.8V.

Virtex UltraScale+ Device-Package Combinations and Maximum I/Os

Table 9: **Virtex UltraScale+ Device-Package Combinations and Maximum I/Os**

Package (1)(2)(3)	Package Dimensions (mm)	VU3P	VU5P	VU7P	VU9P	VU11P	VU13P
		HP, GTY	HP, GTY	HP, GTY	HP, GTY	HP, GTY	HP, GTY
FFVC1517	40x40	520, 40					
FLVF1924	45x45					624, 64	
FLVA2104	47.5x47.5		832, 52	832, 52	832, 52		
FHVA2104	52.5x52.5(4)						832, 52
FLVB2104	47.5x47.5		702, 76	702, 76	702, 76	624, 76	
FHVB2104	52.5x52.5(4)						702, 76
FLVC2104	47.5x47.5		416, 80	416, 80	416, 104	416, 96	
FHVC2104	52.5x52.5(4)						416, 104
FLVA2577	52.5x52.5				448, 120	448, 96	448, 128

Notes:
1. Go to Ordering Information for package designation details.
2. All packages have 1.0mm ball pitch.
3. Packages with the same last letter and number sequence, e.g., A2104, are footprint compatible with all other UltraScale devices with the same sequence. The footprint compatible devices within this family are outlined.
4. These 52.5x52.5mm overhang packages have the same PCB ball footprint as the corresponding 47.5x47.5mm packages (i.e., the same last letter and number sequence) and are footprint compatible.

Appendix F
VITA

John Carlo Theo S. Dela Cruz 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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Appendix G
ARTICLE PAPER(S)

Article/Forum Paper Format (IEEE LaTeX format)

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

2065

***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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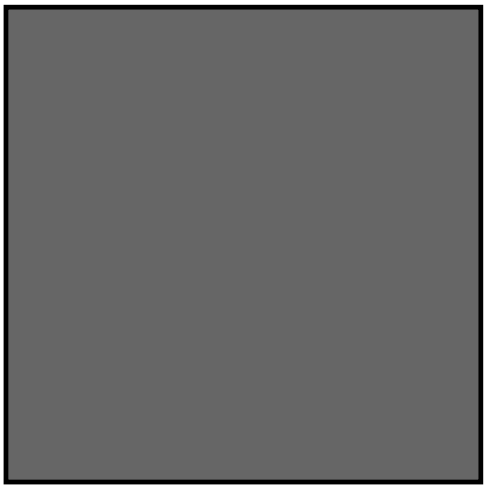

Fig. 1. Simulation results for the network.

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. [1].

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ACKNOWLEDGMENT

The authors would like to thank...

REFERENCES

[1] T. Oetiker, H. Partl, I. Hyna, and E. Schlegl, *The Not So Short Introduction to LaTeX 2ε Or LaTeX 2ε in 157 minutes*. n.a., 2014.