



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

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

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

by
DELA CRUZ John Carlo Theo S.
PAREL Pierre Justine P.
TABIOLO Jiro Renzo D.
VALENCERINA Ercid Bon B.

February, 2025



De La Salle University

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:

DELA CRUZ, John Carlo Theo S.
PAREL, Pierre Justine P.
TABIOLO, Jiro Renzo D.
VALENCERINA, Ercid Bon B.

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**.

Dr. Francisco D. Baltasar
Adviser

February 5, 2025



ABSTRACT

Keep your abstract short by giving the gist/nutshell of your thesis. Use the following checklist questions to help you in crafting your abstract.

- ☐ Did you briefly state what you intend to do?
- ☐ Did you concisely discuss the problem statement?
- ☐ Did you tersely mention the objectives in general terms?
- ☐ Did you succinctly describe the methodology for the target audience?
- ☐ Did you strongly describe your significant results and your conclusions?

Index Terms—alloy system, characterization, InP, InGaAs (see IEEE Taxonomy and Thesaurus).



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ABBREVIATIONS

151	AC	Alternating Current.....	83
152	HTML	Hyper-text Markup Language	83
153	CSS	Cascading Style Sheet	83
154	XML	eXtensible Markup Language	83



155

NOTATION

156	\mathcal{S}	a collection of distinct objects	85
157	\mathcal{U}	the set containing everything	85
158	\emptyset	the set with no elements	85
159	$ \mathcal{S} $	the number of elements in the set \mathcal{S}	85
160	$h(t)$	impulse response	75
161	$x(t)$	input signal represented in the time domain	75
162	$y(t)$	output signal represented in the time domain	75

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



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GLOSSARY

170

matrix

a concise and useful way of uniquely representing and working with linear transformations; a rectangular table of elements

171

Functional Analysis

the branch of mathematics concerned with the study of spaces of functions



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Chapter 1

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INTRODUCTION



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

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 neighbors (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.



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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Proposed System	Balay, D. D., Cabrera, R. M., Jensen, J. T. B., & 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
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- | | | |
|--|---|--|
| <ul style="list-style-type: none">• 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. | <ul style="list-style-type: none">• Defect sorting using YOLOv8• The study considered only 6 types of defects. | <ul style="list-style-type: none">• 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

Your objectives are the states that you desire to achieve in solving the problem. The general objective is the main state to be achieved whereas the specific ones are sub-states to be achieved.



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))	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • Computer Vision Program • Sorting Mechanism
SO4: To achieve an accuracy of at least 85% in filtering out less-dense green coffee beans	<ul style="list-style-type: none"> • 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 bean 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 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 insufficiency 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 businesses



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

302 **1.6 Assumptions, Scope, and Delimitations**

303 **1.6.1 Assumptions**

- 304 1. There would be a defective coffee bean from the green coffee bean test batch;
- 305 2. Identifying the defective coffee beans using the machine vision and density-based
306 analysis would be much more efficient and accurate than manually sorting them;
- 307 3. During testing, test batches will contain 50% good beans and 50% defective beans,
308 60% good beans and 40% defective beans, 70% good beans and 30% defective beans,
309 80% good beans and 20% defective beans, 90% good beans and 10% defective beans,
310 100% good beans;

311 **1.6.2 Scope**

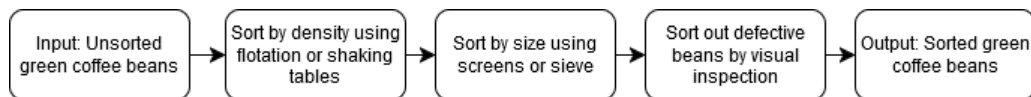
- 312 1. The study only focuses on Arabica green coffee beans;
- 313 2. The study has two stages, the first stage would segregate the defective green coffee
314 beans from the batch, then the second stage would identify the specialty-grade green
315 coffee beans depending on its density;



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;

1.7 Description and Methodology of the Thesis



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

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

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

341 1.8 Estimated Work Schedule and Budget

342 The estimated work schedule can be represented as a Gantt Chart or a combination of
 343 Project Network Diagram, Work Breakdown Structure, and Critical Path. The budget can
 344 be made into a Bill of Materials, financial plan, or if your Thesis is funded and part of
 345 larger project, the cost, and date for reaching each milestone and/or deliverable for your
 346 part of the project.

347 For ECE Department undergraduate theses, the individual Gantt Chart or Work Break-
 348 down Schedule and Bill of Materials will be included in this section and be removed in the
 349 final document.

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359 **1.9 Overview of the Thesis**

360 Provide here a brief summary and what the reader should expect from each succeeding
361 chapter. Show how each chapter is connected with each other.



362

Chapter 2

363

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*.

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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))

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474 **2.3 Summary**

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



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Chapter 3

477

THEORETICAL CONSIDERATIONS



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

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

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Fig. 3.1 A quadrilateral image example.

528

3.1 Summary

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



De La Salle University

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Chapter 4

531

DESIGN CONSIDERATIONS



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

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

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

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4.1 Standards

Standards are essential for successful projects and impactful research. They provide a common framework and ensure consistency, quality, and safety across various disciplines. By adhering to established standards, your work becomes more reliable, interoperable, and valuable in real-world applications. Standards also demonstrate your understanding of industry best practices and enhance the credibility of your research.

 To effectively integrate standards into your project, begin by identifying relevant standards related to your specific field. Thoroughly research and understand the requirements and guidelines outlined within these standards. Align your project objectives and methodologies to meet or exceed these standards. Document your use of standards in this section, including how and why specific standards were chosen. Finally, evaluate your results against the established standards, justifying any deviations from the norm with sound



602 reasoning and evidence.

603 **4.2 Summary**

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



De La Salle University

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Chapter 5

606

METHODOLOGY



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

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

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

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

TABLE 5.1 SUMMARY OF METHODS FOR REACHING THE OBJECTIVES

Objectives	Methods	Locations
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Continued on next page



Continued from previous page

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.	<ol style="list-style-type: none"> 1. First itemtext 2. Second itemtext 3. Last itemtext 4. First itemtext 5. Second itemtext 	Sec. 5.1 on p. 35
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))	<ol style="list-style-type: none"> 1. First itemtext 2. Second itemtext 3. Last itemtext 4. First itemtext 5. Second itemtext 	Sec. 5.1 on p. 35

Continued on next page



Continued from previous page

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	<ol style="list-style-type: none"> 1. First itemtext 2. Second itemtext 3. Last itemtext 4. First itemtext 5. Second itemtext 	Sec. 5.1 on p. 35
SO3: To achieve an accuracy of at least 85% in classifying defective green coffee beans using computer vision	<ol style="list-style-type: none"> 1. First itemtext 2. Second itemtext 3. Last itemtext 4. First itemtext 5. Second itemtext 	Sec. 5.1 on p. 35
SO4: To achieve an accuracy of at least 85% in filtering out less-dense green coffee beans	<ol style="list-style-type: none"> 1. First itemtext 2. Second itemtext 3. Last itemtext 4. First itemtext 5. Second itemtext 	Sec. 5.1 on p. 35

Continued on next page



Continued from previous page

Objectives	Methods	Locations
	1. First itemtext	Sec. 5.1 on p. 35
	2. Second itemtext	
	3. Last itemtext	
	4. First itemtext	
	5. Second itemtext	

5.1 Implementation

Summarize the process used to create/set-up the work with an explanation of such process, instruments, and materials that you used if any. If the description is lengthy, use condensed bullet points.

Rule of thumb: Implementation is how you made your work; (keywords: implemented, created, made, soldered, programmed, etc.).

If you wrote a program or made a simulation, you must state how the program or simulation functions in this section. An algorithm or a pseudocode as shown in Table E.2 is a good example.

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674 5.2 Evaluation

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

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

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724 **5.3 Summary**

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Chapter 6

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RESULTS AND DISCUSSIONS



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

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

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

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

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

TABLE 6.1 SUMMARY OF RESULTS FOR ACHIEVING THE OBJECTIVES

Objectives	Results	Locations
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Continued on next page



Continued from previous page

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.	<ol style="list-style-type: none"> 1. First itemtext 2. Second itemtext 3. Last itemtext 4. First itemtext 5. Second itemtext 	Sec. 5.1 on p. 35
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))	<ol style="list-style-type: none"> 1. First itemtext 2. Second itemtext 3. Last itemtext 4. First itemtext 5. Second itemtext 	Sec. 5.1 on p. 35

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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	<ol style="list-style-type: none"> 1. First itemtext 2. Second itemtext 3. Last itemtext 4. First itemtext 5. Second itemtext 	Sec. 5.1 on p. 35
SO3: To achieve an accuracy of at least 85% in classifying defective green coffee beans using computer vision	<ol style="list-style-type: none"> 1. First itemtext 2. Second itemtext 3. Last itemtext 4. First itemtext 5. Second itemtext 	Sec. 5.1 on p. 35
SO4: To achieve an accuracy of at least 85% in filtering out less-dense green coffee beans	<ol style="list-style-type: none"> 1. First itemtext 2. Second itemtext 3. Last itemtext 4. First itemtext 5. Second itemtext 	Sec. 5.1 on p. 35

Continued on next page



Continued from previous page

Objectives	Results	Locations
	1. First itemtext	Sec. 5.1 on p. 35
	2. Second itemtext	
	3. Last itemtext	
	4. First itemtext	
	5. Second itemtext	

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791 **6.1 Summary**

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



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Chapter 7

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CONCLUSIONS, RECOMMENDATIONS, AND

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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.

- the ;
- the ;
- the ;

7.3 Recommendations

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7. Conclusions, Recommendations, and Future Directives



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854 7.4 Future Prospects

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

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7. Conclusions, Recommendations, and Future Directives



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861 Recommendations and Future Directives will be removed for the hardbound copy but will
862 be retained for database storage.



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



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Appendix A

STUDENT RESEARCH ETHICS CLEARANCE



875

RESEARCH ETHICS CLEARANCE FORM¹
For Thesis Proposals

Names of Student Researcher(s):

Dela Cruz, Juan Z.

College: **Gokongwei College of Engineering**Department: **Electronics and Communications Engineering**Course: **PhD-ECE**Expected Duration of the Project: from: **April 2015**to: **April 2017**

Ethical considerations

None

(The [Ethics Checklists](#) may be used as guides in determining areas for ethical concern/consideration)

To the best of my knowledge, the ethical issues listed above have been addressed in the research.

Dr. Francisco D. Baltasar

Name and Signature of Adviser/Mentor:

Date: **April 8, 2017**

Noted by:

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.



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Appendix B

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ANSWERS TO QUESTIONS TO THIS THESIS



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

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

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

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



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

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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 business people?

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

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1041 **B6.1 Will your results warrant the level of mathematics used**
1042 **(i.e., will the end justify the means)?**

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1052 **B7 Is/are there an/_ alternative way/s to get to the**
1053 **same solution/s?**

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1063 **B7.1 Can you come up with illustrating examples, or even**
1064 **better, counterexamples to your proposed solution/s?**

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 1073 amet ipsum. Nunc quis urna dictum turpis accumsan semper.

1074 **B7.2 Is there an approximation that can arrive at essentially**
 1075 **the same proposed solution/s more easily?**

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1085 **B8 If you were the examiner of your Thesis, how**
 1086 **would you present the Thesis in another way? Give**
 1087 **your remarks, especially for your methodology and**
 1088 **the results and discussions.**

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1098 **B8.1 What are the weaknesses of your Thesis, specifically your**
 1099 **methodology and the results and discussions?**

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De La Salle University

1109

Appendix C

1110

REVISIONS TO THE PROPOSAL



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, consectetur adipiscing elit. Etiam lobortis facilisis sem. Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec ullamcorper, felis non sodales commodo, lectus velit ultrices augue, a dignissim nibh lectus placerat pede. Vivamus nunc nunc, molestie ut, ultricies vel, semper in, velit. Ut porttitor. Praesent in sapien. Lorem ipsum dolor sit amet, consectetur adipiscing elit. Duis fringilla tristique neque. Sed interdum libero ut metus. Pellentesque placerat. Nam rutrum augue a leo. Morbi sed elit sit amet ante lobortis sollicitudin. Praesent blandit blandit mauris. Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit amet ipsum. Nunc quis urna dictum turpis accumsan semper.	<p>Lorem ipsum dolor sit amet, consectetur adipiscing elit. Etiam lobortis facilisis sem. Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec ullamcorper, felis non sodales commodo, lectus velit ultrices augue, a dignissim nibh lectus placerat pede. Vivamus nunc nunc, molestie ut, ultricies vel, semper in, velit. Ut porttitor. Praesent in sapien. Lorem ipsum dolor sit amet, consectetur adipiscing elit. Duis fringilla tristique neque. Sed interdum libero ut metus. Pellentesque placerat. Nam rutrum augue a leo. Morbi sed elit sit amet ante lobortis sollicitudin. Praesent blandit blandit mauris. Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit amet ipsum. Nunc quis urna dictum turpis accumsan semper.</p> <p>First itemtext</p> <p>Second itemtext</p> <p>Last itemtext</p> <p>First itemtext</p> <p>Second itemtext</p>	<p>Sec. 5.1 on p. 35, Sec. 5.2 on p. 37, Fig. 3.1 on p. 25</p>

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Examiner	Comment	Summary of how the comment was addressed	Locations
Dr. Amado Z. Hernandez	<p>Lorem ipsum dolor sit amet, consectetur adipiscing elit. Etiam lobortis facilisis sem. Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec ullamcorper, felis non sodales commodo, lectus velit ultrices augue, a dignissim nibh lectus placerat pede. Vivamus nunc nunc, molestie ut, ultricies vel, semper in, velit. Ut porttitor. Praesent in sapien. Lorem ipsum dolor sit amet, consectetur adipiscing elit. Duis fringilla tristique neque. Sed interdum libero ut metus. Pellentesque placerat. Nam rutrum augue a leo. Morbi sed elit sit amet ante lobortis sollicitudin. Praesent blandit blandit mauris. Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit amet ipsum. Nunc quis urna dictum turpis accumsan semper.</p>	<p>Lorem ipsum dolor sit amet, consectetur adipiscing elit. Etiam lobortis facilisis sem. Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec ullamcorper, felis non sodales commodo, lectus velit ultrices augue, a dignissim nibh lectus placerat pede. Vivamus nunc nunc, molestie ut, ultricies vel, semper in, velit. Ut porttitor. Praesent in sapien. Lorem ipsum dolor sit amet, consectetur adipiscing elit. Duis fringilla tristique neque. Sed interdum libero ut metus. Pellentesque placerat. Nam rutrum augue a leo. Morbi sed elit sit amet ante lobortis sollicitudin. Praesent blandit blandit mauris. Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit amet ipsum. Nunc quis urna dictum turpis accumsan semper.</p> <p>First itemtext</p> <p>Second itemtext</p> <p>Last itemtext</p> <p>First itemtext</p> <p>Second itemtext</p>	<p>Sec. 5.1 on p. 35, Sec. 5.2 on p. 37, Fig. 3.1 on p. 25</p>

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Examiner	Comment	Summary of how the comment was addressed	Locations
Dr. Jose Y. Alonzo	<p>Lorem ipsum dolor sit amet, consectetur adipiscing elit. Etiam lobortis facilisis sem. Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec ullamcorper, felis non sodales commodo, lectus velit ultrices augue, a dignissim nibh lectus placerat pede. Vivamus nunc nunc, molestie ut, ultricies vel, semper in, velit. Ut porttitor. Praesent in sapien. Lorem ipsum dolor sit amet, consectetur adipiscing elit. Duis fringilla tristique neque. Sed interdum libero ut metus. Pellentesque placerat. Nam rutrum augue a leo. Morbi sed elit sit amet ante lobortis sollicitudin. Praesent blandit blandit mauris. Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit amet ipsum. Nunc quis urna dictum turpis accumsan semper.</p>	<p>Lorem ipsum dolor sit amet, consectetur adipiscing elit. Etiam lobortis facilisis sem. Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec ullamcorper, felis non sodales commodo, lectus velit ultrices augue, a dignissim nibh lectus placerat pede. Vivamus nunc nunc, molestie ut, ultricies vel, semper in, velit. Ut porttitor. Praesent in sapien. Lorem ipsum dolor sit amet, consectetur adipiscing elit. Duis fringilla tristique neque. Sed interdum libero ut metus. Pellentesque placerat. Nam rutrum augue a leo. Morbi sed elit sit amet ante lobortis sollicitudin. Praesent blandit blandit mauris. Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit amet ipsum. Nunc quis urna dictum turpis accumsan semper.</p> <ul style="list-style-type: none"> • First itemtext • Second itemtext • Last itemtext • First itemtext • Second itemtext 	<p>Sec. 5.1 on p. 35, Sec. 5.2 on p. 37, Fig. 3.1 on p. 25</p>

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Examiner	Comment	Summary of how the comment was addressed	Locations
Dr. Mariana X. Mercado	<p>Lorem ipsum dolor sit amet, consectetur adipiscing elit. Etiam lobortis facilisis sem. Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec ullamcorper, felis non sodales commodo, lectus velit ultrices augue, a dignissim nibh lectus placerat pede. Vivamus nunc nunc, molestie ut, ultricies vel, semper in, velit. Ut porttitor. Praesent in sapien. Lorem ipsum dolor sit amet, consectetur adipiscing elit. Duis fringilla tristique neque. Sed interdum libero ut metus. Pellentesque placerat. Nam rutrum augue a leo. Morbi sed elit sit amet ante lobortis sollicitudin. Praesent blandit blandit mauris. Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit amet ipsum. Nunc quis urna dictum turpis accumsan semper.</p>	<p>Lorem ipsum dolor sit amet, consectetur adipiscing elit. Etiam lobortis facilisis sem. Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec ullamcorper, felis non sodales commodo, lectus velit ultrices augue, a dignissim nibh lectus placerat pede. Vivamus nunc nunc, molestie ut, ultricies vel, semper in, velit. Ut porttitor. Praesent in sapien. Lorem ipsum dolor sit amet, consectetur adipiscing elit. Duis fringilla tristique neque. Sed interdum libero ut metus. Pellentesque placerat. Nam rutrum augue a leo. Morbi sed elit sit amet ante lobortis sollicitudin. Praesent blandit blandit mauris. Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit amet ipsum. Nunc quis urna dictum turpis accumsan semper.</p> <ol style="list-style-type: none"> 1. First itemtext 2. Second itemtext 3. Last itemtext 4. First itemtext 5. Second itemtext 	<p>Sec. 5.1 on p. 35, Sec. 5.2 on p. 37, Fig. 3.1 on p. 25</p>

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Continued from previous page

Examiner	Comment	Summary of how the comment was addressed	Locations
Dr. Rafael W. Sison	<p>Lorem ipsum dolor sit amet, consectetur adipiscing elit. Etiam lobortis facilisis sem. Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec ullamcorper, felis non sodales commodo, lectus velit ultrices augue, a dignissim nibh lectus placerat pede. Vivamus nunc nunc, molestie ut, ultricies vel, semper in, velit. Ut porttitor. Praesent in sapien. Lorem ipsum dolor sit amet, consectetur adipiscing elit. Duis fringilla tristique neque. Sed interdum libero ut metus. Pellentesque placerat. Nam rutrum augue a leo. Morbi sed elit sit amet ante lobortis sollicitudin. Praesent blandit blandit mauris. Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit amet ipsum. Nunc quis urna dictum turpis accumsan semper.</p>	<p>Lorem ipsum dolor sit amet, consectetur adipiscing elit. Etiam lobortis facilisis sem. Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec ullamcorper, felis non sodales commodo, lectus velit ultrices augue, a dignissim nibh lectus placerat pede. Vivamus nunc nunc, molestie ut, ultricies vel, semper in, velit. Ut porttitor. Praesent in sapien. Lorem ipsum dolor sit amet, consectetur adipiscing elit. Duis fringilla tristique neque. Sed interdum libero ut metus. Pellentesque placerat. Nam rutrum augue a leo. Morbi sed elit sit amet ante lobortis sollicitudin. Praesent blandit blandit mauris. Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit amet ipsum. Nunc quis urna dictum turpis accumsan semper.</p>	<p>Sec. 5.1 on p. 35, Sec. 5.2 on p. 37, Fig. 3.1 on p. 25</p>



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Appendix D

1118

REVISIONS TO THE FINAL



1119 Make a table with the following columns for showing the summary of revisions to the
1120 proposal based on the comments of the panel of examiners.

1121 1. Examiner

1122 2. Comment

1123 3. Summary of how the comment has been addressed

1124 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	1. First itemtext	Sec. 5.1 on p. 35, Sec. 5.2 on p. 37, Fig. 3.1 on p. 25
	2. Second itemtext	2. Second itemtext	
	3. Last itemtext	3. Last itemtext	
	4. First itemtext	4. First itemtext	
	5. Second itemtext	5. Second itemtext	
		First itemtext	
		Second itemtext	
		Last itemtext	
		First itemtext	
		Second itemtext	

Continued on next page



Continued from previous page

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. 5.1 on p. 35, Sec. 5.2 on p. 37, Fig. 3.1 on p. 25
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. 5.1 on p. 35, Sec. 5.2 on p. 37, Fig. 3.1 on p. 25

Continued on next page



Continued from previous page

Examiner	Comment	Summary of how the comment has been addressed	Locations
Dr. Mariana X. Mercado	1. First itemtext	1. First itemtext	Sec. 5.1 on p. 35, Sec. 5.2 on p. 37, Fig. 3.1 on p. 25
	2. Second itemtext	2. Second itemtext	
	3. Last itemtext	3. Last itemtext	
	4. First itemtext	4. First itemtext	
	5. Second itemtext	5. Second itemtext	
Dr. Rafael W. Sison	1. First itemtext	1. First itemtext	Sec. 5.1 on p. 35, Sec. 5.2 on p. 37, Fig. 3.1 on p. 25
	2. Second itemtext	2. Second itemtext	
	3. Last itemtext	3. Last itemtext	
	4. First itemtext	4. First itemtext	
	5. Second itemtext	5. Second itemtext	



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Appendix E

1126

USAGE EXAMPLES



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

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 $y(t)$ is the result of the convolution of the input signal $x(t)$ and the impulse response $h(t)$.

$$y(t) = h(t) * x(t) = \int_{-\infty}^{+\infty} h(t - \tau) x(\tau) d\tau \quad (\text{E.1})$$

Other example equations are as follows.

$$\begin{bmatrix} V_1 \\ I_1 \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} V_2 \\ I_2 \end{bmatrix} \quad (\text{E.2})$$

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

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



The verbatim L^AT_EX code of Sec. E1 is in List. E.1.

```

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[ \begin{matrix} \dfrac{V_{1}}{I_{1}} \end{matrix} \right] =
14   \begin{bmatrix} A & B \\ C & D \end{bmatrix}
15   \label{eq:ABCD}
16 \end{eqnarray}
17
18 \begin{eqnarray}
19   \dfrac{1}{2} < \left\lfloor \mathrm{mod} \left( \left\lfloor \dfrac{y}{17} \right\rfloor \right. \right.
20   \left. \left. \right\rfloor 2^{-17} \left\lfloor x \right\rfloor - \mathrm{mod} \left( \left\lfloor y \right\rfloor \right. \right.
21   \left. \left. \right\rfloor 2 \right) \right\rfloor,
22 \end{eqnarray}
23
24 \begin{eqnarray}
25   | \zeta(x)^3 \zeta(x + iy)^4 \zeta(x + 2iy) | =
26   \exp \sum_{n,p} \frac{3 + 4 \cos( ny \log p) + \cos( 2ny \log p)}{n^p}
27   \geq 1
28 \end{eqnarray}
29

```




E2 Notations

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

See https://en.wikipedia.org/wiki/Help:Displaying_a_formula and https://en.wikipedia.org/wiki/List_of_mathematical_symbols for L^AT_EX 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.

<code>mathnormal</code>	$A, B, \Gamma, \Delta, \Theta, \Lambda, \Xi, \Pi, \Sigma, \Phi, \Psi, \Omega, \alpha, \beta, \pi, \nu, \omega, v, w, 0, 1, 9$
<code>mathit</code>	$A, B, \Gamma, \Delta, \Theta, \Lambda, \Xi, \Pi, \Sigma, \Phi, \Psi, \Omega, \mathfrak{f}, \mathfrak{f}, \beta, ^\circ, !, v, w, 0, 1, 9$
<code>mathrm</code>	$A, B, \Gamma, \Delta, \Theta, \Lambda, \Xi, \Pi, \Sigma, \Phi, \Psi, \Omega, \mathfrak{f}, \mathfrak{f}, \beta, ^\circ, !, v, w, 0, 1, 9$
<code>mathbf</code>	$\mathbf{A}, \mathbf{B}, \mathbf{\Gamma}, \mathbf{\Delta}, \mathbf{\Theta}, \mathbf{\Lambda}, \mathbf{\Xi}, \mathbf{\Pi}, \mathbf{\Sigma}, \mathbf{\Phi}, \mathbf{\Psi}, \mathbf{\Omega}, \mathbf{f}, \mathbf{f}, \mathbf{\beta}, ^\circ, !, v, w, 0, 1, 9$
<code>mathsf</code>	$A, B, \Gamma, \Delta, \Theta, \Lambda, \Xi, \Pi, \Sigma, \Phi, \Psi, \Omega, \mathfrak{f}, \mathfrak{f}, \beta, ^\circ, !, v, w, 0, 1, 9$
<code>mathtt</code>	$A, B, \Gamma, \Delta, \Theta, \Lambda, \Xi, \Pi, \Sigma, \Phi, \Psi, \Omega, \uparrow, \downarrow, \beta, ^\circ, !, v, w, 0, 1, 9$

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

<code>mathbfit</code>	$\mathbf{A}, \mathbf{B}, \mathbf{\Gamma}, \mathbf{\Delta}, \mathbf{\Theta}, \mathbf{\Lambda}, \mathbf{\Xi}, \mathbf{\Pi}, \mathbf{\Sigma}, \mathbf{\Phi}, \mathbf{\Psi}, \mathbf{\Omega}, \alpha, \beta, \pi, \nu, \omega, v, w, 0, 1, 9$
<code>mathsf</code>	$A, B, \Gamma, \Delta, \Theta, \Lambda, \Xi, \Pi, \Sigma, \Phi, \Psi, \Omega, \alpha, \beta, \pi, \nu, \omega, v, w, 0, 1, 9$
<code>mathsfbit</code>	$\mathbf{A}, \mathbf{B}, \mathbf{\Gamma}, \mathbf{\Delta}, \mathbf{\Theta}, \mathbf{\Lambda}, \mathbf{\Xi}, \mathbf{\Pi}, \mathbf{\Sigma}, \mathbf{\Phi}, \mathbf{\Psi}, \mathbf{\Omega}, \alpha, \beta, \pi, \nu, \omega, v, w, 0, 1, 9$

Do the math alphabets match?

$\alpha x \alpha \omega \alpha x \alpha \omega \alpha x \alpha \omega \quad TC\Theta\Gamma TC\Theta\Gamma TC\Theta\Gamma$

E2.2 Vector symbols

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

E2.3 Matrix symbols

Symbols for matrices are boldface italic, too:¹ $\mathbf{A} = \mathbf{E} \cdot \mathbf{A}$.

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



1157

E2.4 Tensor symbols

1158

Symbols for tensors are sans-serif bold italic,

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

1159

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

$$\boldsymbol{D} = \epsilon_0 \boldsymbol{\epsilon}_r \boldsymbol{E}$$



E2.5 Bold math version

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

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

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

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

Do the math alphabets match?

$\alpha x \alpha \omega \alpha x \alpha \omega \alpha x \alpha \omega \quad TC\Theta\Gamma TC\Theta\Gamma TC\Theta\Gamma$

E2.5.1 Vector symbols

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

E2.5.2 Matrix symbols

Symbols for matrices are boldface italic, too:² $\Lambda = E \cdot A$.

E2.5.3 Tensor symbols

Symbols for tensors are sans-serif bold italic,

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

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

$$D = \epsilon_0 \epsilon_r E$$

²However, matrix symbols are usually capital letters whereas vectors are small ones. Exceptions are physical quantities like the force vector F or the electrical field E .



1173 The verbatim L^AT_EX code of Sec. E2 is in List. E.2.

Listing E.2: Sample L^AT_EX code for notations usage

```

1174 1 % A teststring with Latin and Greek letters::
1175 2 \newcommand{\teststring}{%
1176 3 % capital Latin letters
1177 4 % A,B,C,
1178 5 A,B,
1179 6 % capital Greek letters
1180 7 %\Gamma,\Delta,\Theta,\Lambda,\Xi,\Pi,\Sigma,\Upsilon,\Phi,\Psi,
1181 8 \Gamma,\Delta,\Theta,\Lambda,\Xi,\Pi,\Sigma,\Phi,\Psi,\Omega,
1182 9 % small Greek letters
1183 10 \alpha,\beta,\pi,\nu,\omega,
1184 11 % small Latin letters:
1185 12 % compare \nu, \omega, v, and w
1186 13 v,w,
1187 14 % digits
1188 15 0,1,9
1189 16 }
1190 17
1191 18
1192 19 \subsection{Math alphabets}
1193 20
1194 21 If there are other symbols in place of Greek letters in a math
1195 22 alphabet, it uses T1 or OT1 font encoding instead of OML.
1196 23
1197 24 \begin{eqnarray*}
1198 25 \mbox{\mathnormal} & & \mbox{\teststring} \\
1199 26 \mbox{\mathit} & & \mbox{\mathit{\teststring}} \\
1200 27 \mbox{\mathrm} & & \mbox{\mathrm{\teststring}} \\
1201 28 \mbox{\mathbf} & & \mbox{\mathbf{\teststring}} \\
1202 29 \mbox{\mathsf} & & \mbox{\mathsf{\teststring}} \\
1203 30 \mbox{\mathtt} & & \mbox{\mathtt{\teststring}} \\
1204 31 \end{eqnarray*}
1205 32 New alphabets bold-italic, sans-serif-italic, and sans-serif-bold-
1206 33 italic.
1207 34 \begin{eqnarray*}
1208 35 \mbox{\mathbfit} & & \mbox{\mathbfit{\teststring}} \\
1209 36 \mbox{\mathsf fit} & & \mbox{\mathsf fit{\teststring}} \\
1210 37 \mbox{\mathsfbfit} & & \mbox{\mathsfbfit{\teststring}} \\
1211 38 \end{eqnarray*}
1212 39 %
1213 40 Do the math alphabets match?
1214 41 $
1215 42 \mathnormal {a x \alpha \omega}
1216 43 \mathbfit {a x \alpha \omega}
1217 44 \mathsfbfit{a x \alpha \omega}
1218 45 \quad
1219 46 \mathsfbfit{T C \Theta \Gamma}
1220 47 \mathbfit {T C \Theta \Gamma}
1221 48 \mathnormal {T C \Theta \Gamma}
1222 49 $
1223 50
1224 51 \subsection{Vector symbols}
1225 52

```



```

1228 53 Alphabetic symbols for vectors are boldface italic,
1229 54  $\vec{\lambda} = \vec{e}_1 \cdot \vec{a}$ ,
1230 55 while numeric ones (e.g. the zero vector) are bold upright,
1231 56  $\vec{a} + \vec{0} = \vec{a}$ .
1232 57
1233 58 \subsection{Matrix symbols}
1234 59
1235 60 Symbols for matrices are boldface italic, too:%
1236 61 \footnote{However, matrix symbols are usually capital letters whereas
1237 62 vectors
1238 62 are small ones. Exceptions are physical quantities like the force
1239 63 vector  $\vec{F}$  or the electrical field  $\vec{E}$ .%
1240 64 }
1241 65  $\Lambda = E \cdot A$ .
1242 66
1243 67
1244 68 \subsection{Tensor symbols}
1245 69
1246 70 Symbols for tensors are sans-serif bold italic,
1247 71
1248 72 \[
1249 73 \quad \text{\textbf{\textit{tensorsym{\alpha} = tensorsym{e} \cdot tensorsym{a}}}}
1250 74 \quad \text{\textbf{\textit{quad \Longleftarrow \rightarrow quad}}}
1251 75 \quad \text{\textbf{\textit{\alpha_{ijl} = e_{ijk} \cdot a_{kl}}}}
1252 76 \]
1253 77
1254 78
1255 79 The permittivity tensor describes the coupling of electric field and
1256 80 displacement: \[
1257 81 \vec{D} = \epsilon_0 \text{\textbf{\textit{tensorsym{\epsilon}_{\mathrm{r}}}}} \vec{E} \]
1258 82
1259 83
1260 84
1261 85 \newpage
1262 86 \subsection{Bold math version}
1263 87
1264 88 The ‘‘bold’’ math version is selected with the commands
1265 89 \verb+\boldmath+ or \verb+\mathversion{bold}+
1266 90
1267 91 {\boldmath
1268 92 \begin{eqnarray*}
1269 93 \quad \text{\textbf{\textit{mbox{mathnormal}} & & \text{\textbf{\textit{teststring}}}} \\
1270 94 \quad \text{\textbf{\textit{mbox{mathit}} & & \text{\textbf{\textit{mathit{teststring}}}}}} \\
1271 95 \quad \text{\textbf{\textit{mbox{mathrm}} & & \text{\textbf{\textit{mathrm{teststring}}}}}} \\
1272 96 \quad \text{\textbf{\textit{mbox{mathbf}} & & \text{\textbf{\textit{mathbf{teststring}}}}}} \\
1273 97 \quad \text{\textbf{\textit{mbox{mathsf}} & & \text{\textbf{\textit{mathsf{teststring}}}}}} \\
1274 98 \quad \text{\textbf{\textit{mbox{mathtt}} & & \text{\textbf{\textit{mathtt{teststring}}}}}} \\
1275 99 \end{eqnarray*}
1276 100 \quad \text{New alphabets bold-italic, sans-serif-italic, and sans-serif-bold-}
1277 101 \quad \text{italic.}
1278 102 \begin{eqnarray*}
1279 103 \quad \text{\textbf{\textit{mbox{mathbfit}} & & \text{\textbf{\textit{mathbfit{teststring}}}}}} \\
1280 104 \quad \text{\textbf{\textit{mbox{mathsf} & & \text{\textbf{\textit{mathsf{teststring}}}}}} \\
1281 105 \quad \text{\textbf{\textit{mbox{mathsfbfit}} & & \text{\textbf{\textit{mathsfbfit{teststring}}}}}} \\
1282 106 \end{eqnarray*}
1283 107 \%
1284 108 Do the math alphabets match?

```



```

1285 108
1286 109 $
1287 110 \mathnormal {a x \alpha \omega}
1288 111 \mathbfit {a x \alpha \omega}
1289 112 \mathsfbfit{a x \alpha \omega}
1290 113 \quad
1291 114 \mathsfbfit{T C \Theta \Gamma}
1292 115 \mathbfit {T C \Theta \Gamma}
1293 116 \mathnormal {T C \Theta \Gamma}
1294 117 $
1295 118
1296 119 \subsection{Vector symbols}
1297 120
1298 121 Alphabetic symbols for vectors are boldface italic,
1299 122 $\vec{\lambda}=\vec{e}_{1}\cdot\vec{a}$,
1300 123 while numeric ones (e.g. the zero vector) are bold upright,
1301 124 $\vec{a} + \vec{0} = \vec{a}$.
1302 125
1303 126
1304 127
1305 128
1306 129 \subsection{Matrix symbols}
1307 130
1308 131 Symbols for matrices are boldface italic, too:%
1309 132 \footnote{However, matrix symbols are usually capital letters whereas
1310 133 vectors
1311 133 are small ones. Exceptions are physical quantities like the force
1312 134 vector $\vec{F}$ or the electrical field $\vec{E}$.%
1313 135 }
1314 136 $\matrixsym{\Lambda}=\matrixsym{E}\cdot\matrixsym{A}$.
1315 137
1316 138
1317 139 \subsection{Tensor symbols}
1318 140
1319 141 Symbols for tensors are sans-serif bold italic,
1320 142
1321 143 \[
1322 144 \tensorsym{\alpha} = \tensorsym{e}\cdot\tensorsym{a}
1323 145 \quad \Longleftarrow \quad
1324 146 \alpha_{ijl} = e_{ijk}\cdot a_{kl}.
1325 147 \]
1326 148
1327 149 The permittivity tensor describes the coupling of electric field and
1328 150 displacement: \[
1329 151 \vec{D}=\epsilon_{0}\tensorsym{\epsilon}_{\mathrm{r}}\vec{E}\]
1330 152 }

```



E3 Abbreviation

This section shows examples of the use of \LaTeX commands 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).



- 1361 • Provide your own link text: style sheet.

1362 The verbatim \LaTeX code of Sec. E3 is in List. E.3.

Listing E.3: Sample \LaTeX code for abbreviations usage

```

1 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:
2
3 \begin{itemize}
4
5   \item \acr{xml} and \acr{css}.
6
7   \item Next use: \acr{xml} and \acr{css}.
8
9   \item Full form: \gls{xml} and \gls{css}.
10
11  \item Reset again. \glsresetall{abbreviation}
12
13  \item Start with a capital. \Acr{html}.
14
15  \item Next: \Acr{html}. Full: \Gls{html}.
16
17  \item Prefer capitals? \renewcommand{\acronymfont}[1]{\
    MakeTextUppercase{#1}} \Acr{xml}. Next: \acr{xml}. Full: \gls{xml}
    }.
18
19  \item Prefer small-caps? \renewcommand{\acronymfont}[1]{\textsc{#1}}
    \Acr{css}. Next: \acr{css}. Full: \gls{css}.
20
21  \item Resetting all acronyms.\glsresetall{abbreviation}
22
23  \item Here are the acronyms again:
24
25  \item \Acr{html}, \acr{xml} and \acr{css}.
26
27  \item Next use: \Acr{html}, \acr{xml} and \acr{css}.
28
29  \item Full form: \Gls{html}, \gls{xml} and \gls{css}.
30
31  \item Provide your own link text: \glslink[[textbf]css]{style}
32
33 \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 \mathbf{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

```

1 \begin{itemize}
2
3   \item \Glspl{matrix} are usually denoted by a bold capital letter,
      such as  $\mathbf{A}$ . The  $\mathbf{A}$ 's  $(i,j)$ th element is
      usually denoted  $a_{ij}$ .  $\mathbf{I}$  is the
      identity  $\mathbf{I}$ .
4
5   \item A set, denoted as  $\mathbf{S}$ , is a collection of objects.
6
7   \item The universal set, denoted as  $\mathbf{U}$ , is the
      set of everything.
8
9   \item The empty set, denoted as  $\emptyset$ , contains no
      elements.
10
11  \item  $\mathbf{FA}$  is seen as the study of complete
      normed vector spaces, i.e., Banach spaces.
12
13  \item The cardinality of a set, denoted as  $\mathbf{C}$ , is
      the number of elements in the set.
14
15 \end{itemize}

```



E5 Figure

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



Fig. E.1 A quadrilateral image example.



1382 Fig. E.1 is a gray box enclosed by a dark border. List. E.5 shows the corresponding
1383 \LaTeX code.

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

```
1 \begin{figure}[!htbp]
2   \centering
3   \includegraphics[width=0.5\textwidth]{example}
4   \caption{A quadrilateral image example.}
5   \label{fig:example}
6 \end{figure}
7 \cleardoublepage
8
9 Fig.~\ref{fig:example} is a gray box enclosed by a dark border. List.~\ref{lst:onefig} shows the corresponding  $\text{\LaTeX}$  \ code.
10 \end{figure}
```



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



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

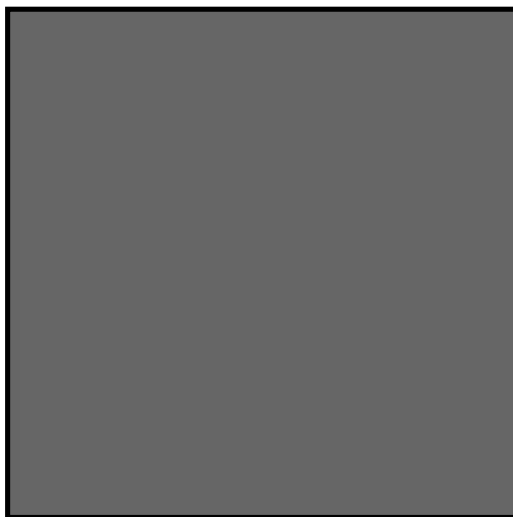


(c) A sub-figure in the bottom row.

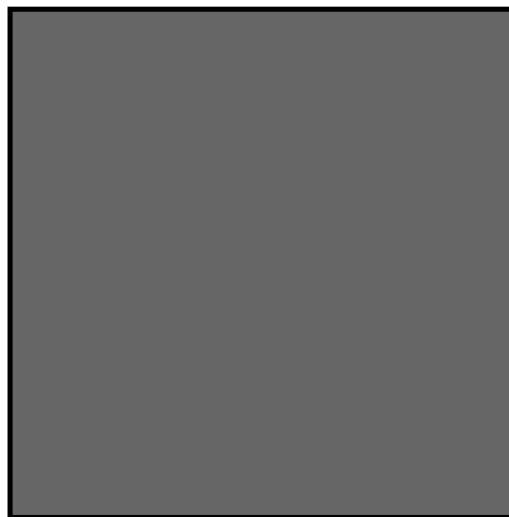
Fig. E.2 Figures on top of each other. See List. E.6 for the corresponding \LaTeX code.

Listing E.6: Sample L^AT_EX code for three figures on top of each other

```
1 \begin{figure}[!htbp]
2 \centering
3 \subbottom[A sub-figure in the top row.]{
4 \includegraphics[width=0.35\textwidth]{example_gray_box}
5 \label{fig:top}
6 }
7 \vfill
8 \subbottom[A sub-figure in the middle row.]{
9 \includegraphics[width=0.35\textwidth]{example_gray_box}
10 \label{fig:mid}
11 }
12 \vfill
13 \subbottom[A sub-figure in the bottom row.]{
14 \includegraphics[width=0.35\textwidth]{example_gray_box}
15 \label{fig:botm}
16 }
17 \caption{Figures on top of each other}
18 \label{fig:tmb}
19 \end{figure}
```



(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

```

1 \begin{figure}[!htbp]
2 \centering
3 \subbottom[A sub-figure in the upper-left corner.]{
4 \includegraphics[width=0.45\textwidth]{example_gray_box}
5 \label{fig:upprleft}
6 }
7 \hfill
8 \subbottom[A sub-figure in the upper-right corner.]{
9 \includegraphics[width=0.45\textwidth]{example_gray_box}
10 \label{fig:uppright}
11 }
12 \vfill
13 \subbottom[A sub-figure in the lower-left corner.]{
14 \includegraphics[width=0.45\textwidth]{example_gray_box}
15 \label{fig:lowerleft}
16 }
17 \hfill
18 \subbottom[A sub-figure in the lower-right corner]{
19 \includegraphics[width=0.45\textwidth]{example_gray_box}
20 \label{fig:lowright}
21 }
22 \caption{Four figures in each corner. See List.\ref{lst:fourfigs} for
23 the corresponding \LaTeX \ code.}
24 \label{fig:fourfig}
25 \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)



1387

List. E.8 shows the corresponding \LaTeX code.Listing E.8: Sample \LaTeX code for making typical table environment

```

1388 1 \begin{center}
1389 2 {\scriptsize
1390 3 \begin{tabularx}{\textwidth}{p{0.1\textwidth}|p{0.2\textwidth}|p{0.5\textwidth}}
1392 4 \caption{Feasible triples for highly variable grid} \label{tab:triple_
1393 5 grid} \\
1394 6 \hline
1395 7 \textbf{Time (s)} &
1396 8 \textbf{Triple chosen} &
1397 9 \textbf{Other feasible triples} \\
1398 10 \hline
1399 11 \endfirsthead
1400 12 \multicolumn{3}{c}{\textit{Continued from previous page}} \\
1401 13 \hline
1402 14 \hline
1403 15 \textbf{Time (s)} &
1404 16 \textbf{Triple chosen} &
1405 17 \textbf{Other feasible triples} \\
1406 18 \hline
1407 19 \endhead
1408 20 \hline
1409 21 \multicolumn{3}{r}{\textit{Continued on next page}} \\
1410 22 \endfoot
1411 23 \hline
1412 24 \endlastfoot
1413 25 \hline
1414 26
1415 27
1416 28 0 & (1, 11, 13725) & (1, 12, 10980), (1, 13, 8235), (2, 2, 0), (3, 1, 0) \\
1417 29 & \\
1418 30 2745 & (1, 12, 10980) & (1, 13, 8235), (2, 2, 0), (2, 3, 0), (3, 1, 0) \\
1419 31 & \\
1420 32 5490 & (1, 12, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1421 33 8235 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1422 34 10980 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1423 35 13725 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1424 36 16470 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1425 37 19215 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1426 38 21960 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1427 39 24705 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1428 40 27450 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1429 41 30195 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
1430 42 32940 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1431 43 35685 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1432 44 38430 & (1, 13, 10980) & (2, 2, 2745), (2, 3, 0), (3, 1, 0)

```



```

1442 43 41175 & (1, 12, 13725) & (1, 13, 10980), (2, 2, 2745), (2, 3, 0), (3, 1,
1443      0) \\
1444 44 43920 & (1, 13, 10980) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1445 45 46665 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
1446 46 49410 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
1447 47 52155 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1,
1448      0) \\
1449 48 54900 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1450 49 57645 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1451 50 60390 & (1, 12, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1452 51 63135 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1453 52 65880 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1454 53 68625 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
1455 54 71370 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1456 55 74115 & (1, 12, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1457 56 76860 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1458 57 79605 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1459 58 82350 & (1, 12, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1460 59 85095 & (1, 12, 13725) & (1, 13, 10980), (2, 2, 2745), (2, 3, 0), (3, 1,
1461      0) \\
1462 60 87840 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1463 61 90585 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1464 62 93330 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1465 63 96075 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1466 64 98820 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1467 65 101565 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1468 66 104310 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1469 67 107055 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1470 68 109800 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1471 69 112545 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3,
1472      1, 0) \\
1473 70 115290 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1474 71 118035 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1475 72 120780 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1476 73 123525 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1477 74 126270 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3,
1478      1, 0) \\
1479 75 129015 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
1480 76 131760 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
1481 77 134505 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1482 78 137250 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1483 79 139995 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
1484 80 142740 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
1485 81 145485 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3,
1486      1, 0) \\
1487 82 148230 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
1488 83 150975 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1489 84 153720 & (1, 12, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1490 85 156465 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1491 86 159210 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1492 87 161955 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1493 88 164700 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1494 89 \end{tabularx}
1495 90 }
1496 91 \end{center}

```



1498

E7 Algorithm or Pseudocode Listing

1499

1500

1501

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 L^AT_EX code.

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

Input(s):	
n	: n th 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 L^AT_EX code for algorithm or pseudocode listing usage

```

1 \begin{table}[!htbp]
2   \caption{Calculation of  $y = x^n$ }
3   \label{tab:calcxn}
4   {\footnotesize
5     \begin{tabular}{lll}
6       \hline
7       \hline
8       {\bfseries Input(s):} & & \\
9       $n$ & : & $n$th power; $n$ \in \mathbb{Z}^{+}$ \\
10      $x$ & : & base value; $x$ \in \mathbb{R}^{+}$ \\
11      \hline
12      {\bfseries Output(s):} & & \\
13      $y$ & : & result; $y$ \in \mathbb{R}^{+}$ \\
14      \hline
15      \hline
16      \\
17    \end{tabular}
18  }
19  \begin{algorithmic}[1]
20    {\footnotesize
21      \REQUIRE $n \geq 0$ \vee $x \neq 0$
22      \ENSURE $y = x^n$
23      \STATE $y \leftarrow 1$
24      \IF{$n < 0$}
25        \STATE $X \leftarrow 1 / x$
26        \STATE $N \leftarrow -n$
27      \ELSE
28        \STATE $X \leftarrow x$
29        \STATE $N \leftarrow n$
30      \ENDIF
31      \WHILE{$N \neq 0$}
32        \IF{$N$ is even}
33          \STATE $X \leftarrow X \times X$
34          \STATE $N \leftarrow N / 2$
35        \ELSE[$N$ is odd]
36          \STATE $y \leftarrow y \times X$
37          \STATE $N \leftarrow N - 1$
38        \ENDIF
39      \ENDWHILE
40    }
41  \end{algorithmic}
42 \end{table}

```



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)

```

1  /* fibo.c -- It prints out the first N Fibonacci
2  *           numbers.
3  */
4
5  #include <stdio.h>
6
7  int main(void) {
8      int n;           /* Number of fibonacci numbers we will print */
9      int i;           /* Index of fibonacci number to be printed next */
10     int current;      /* Value of the (i)th fibonacci number */
11     int next;         /* Value of the (i+1)th fibonacci number */
12     int twoaway;      /* Value of the (i+2)th fibonacci number */
13
14     printf("How many Fibonacci numbers do you want to compute? ");
15     scanf("%d", &n);
16     if (n<=0)
17         printf("The number should be positive.\n");
18     else {
19         printf("\n\n\tI\t\tFibonacci(I)\t\n\t=====\n");
20         next = current = 1;
21         for (i=1; i<=n; i++) {
22             printf("\t%d\t\t\t%d\n", i, current);
23             twoaway = current+next;
24             current = next;
25             next = twoaway;
26         }
27     }
28 }
29
30 /* The output from a run of this program was:
31
32 How many Fibonacci numbers do you want to compute? 9
33
34 I      Fibonacci(I)
35 =====
36 1      1
37 2      1
38 3      2
39 4      3
40 5      5
41 6      8
42 7      13
43 8      21
44 9      34
45
46 */

```



1505

List. E.11 shows the corresponding \LaTeX code.

Listing E.11: Sample \LaTeX code for program listing

```
1 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.
```




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

```
1 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

```
1 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.
```

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



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

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



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

- [?]

- [?]

- [?]

- [?]

- [?]

- [?]

- [?]

- [?]

- [?]

- [?]

- [?]

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De La Salle University

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1596 • [?]



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E10.2 Booklets

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E10.3 Proceedings

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- [?]

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E10.4 In books

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1623 • [?]

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1628 **E10.5 In proceedings**

1629 • [?]

1630 • [?]

1631 • [?]

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1634 • [?]

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1636 **E10.6 Journals**

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1672 **E10.7 Theses/dissertations**

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1680 **E10.8 Technical Reports and Others**

1681 • [?]

1682 • [?]

1683 • [?]

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		E. Usage Examples	
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1690	• [?]		
1691	• [?]		
1692	• [?]		
1693	• [?]		
1694	• [?]		
1695	• [?]		
1696	E10.9 Miscellaneous		
1697	• [?]		
1698	• [?]		
1699	• [?]		
1700	• [?]		
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1704	• [?]		
1705	• [?]		
1706	• [?]		
1707	• [?]		
1708	• [?]		
1709	• [?]		
		110	



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

```
1 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

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



1723



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.



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UltraScale Architecture and Product Overview

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.



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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

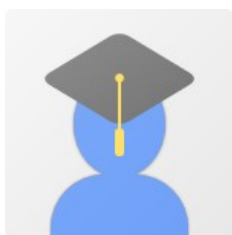
Package (1)(2)(3)	Package Dimensions (mm)	VU3P	VU5P	VU7P	VU9P	VU11P	VU13P
		HP, GTY	HP, GTY	HP, GTY	HP, GTY	HP, GTY	HP, GTY
FFVC1517	40x40	520, 40					
FLVF1924	45x45					624, 64	
FLVA2104	47.5x47.5		832, 52	832, 52	832, 52		
FHVA2104	52.5x52.5 ⁽⁴⁾						832, 52
FLVB2104	47.5x47.5		702, 76	702, 76	702, 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:

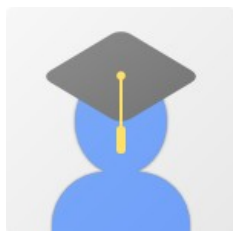
- Go to [Ordering Information](#) for package designation details.
- All packages have 1.0mm ball pitch.
- Packages with the same last letter and number sequence, e.g., A2104, are footprint compatible with all other UltraScale devices with the same sequence. The footprint compatible devices within this family are outlined.
- 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.



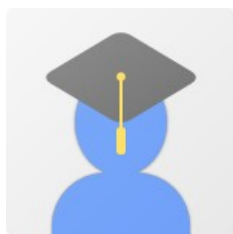
Appendix F VITA



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.



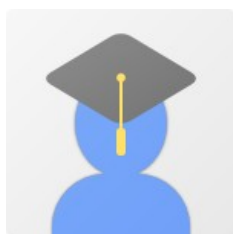
Pierre Justine P. Parel received the B.Sc., M.Sc., and Ph.D. degrees in chemistry all from the Pamantasan ng Pilipinas, San Juan, Metro Manila, Philippines, in 2020, 2022 and 2025 respectively. He is currently taking up his B.Sc. Computer Engineering studies. He has developed several high-speed packet-switched 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.



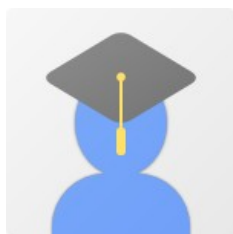
Jiro Renzo D. Tabiolo received the B.Sc., M.Sc., and Ph.D. degrees in chemistry all from the Pamantasan ng Pilipinas, San Juan, Metro Manila, Philippines, in 2020, 2022 and 2025 respectively. He is currently taking up his B.Sc. Computer Engineering studies. He has developed several high-speed packet-switched network systems



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1747 high speed radio interface design, discrete simulation and statistical models for packet
1748 switches.



1749 Ercid Bon B. Valencerina received the B.Sc., M.Sc., and Ph.D.
1750 degrees in chemistry all from the Pamantasan ng Pilipinas, San Juan, Metro Manila,
1751 Philippines, in 2020, 2022 and 2025 respectively. He is currently taking up his B.Sc.
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1753 network systems and node modules. His research interests include high-speed packet-
1754 switched networks, high speed radio interface design, discrete simulation and statistical
1755 models for packet switches.



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1757 the Pamantasan ng Pilipinas, San Juan, Metro Manila, Philippines, in 2020, 2022 and 2025
1758 respectively. He is currently taking up his B.Sc. Computer Engineering studies. He has
1759 developed several high-speed packet-switched network systems and node modules. His
1760 research interests include high-speed packet-switched networks, high speed radio interface
1761 design, discrete simulation and statistical models for packet switches.



De La Salle University

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Appendix G

1763

ARTICLE PAPER(S)

Article/Forum Paper Format (IEEE LaTeX format)

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

1764

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

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

A. Subsection Heading Here

Subsection text here. Lorem ipsum dolor sit amet, consectetur adipiscing elit. Etiam lobortis facilisis sem. Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec ullamcorper, felis non sodales commodo, lectus velit ultrices augue, a dignissim nibh lectus placerat pede. Vivamus nunc nunc, molestie ut, ultricies vel, semper in, velit. Ut porttitor. Praesent in sapien. Lorem ipsum dolor sit amet, consectetur adipiscing elit. Duis fringilla tristique neque. Sed interdum libero ut metus. Pellentesque placerat. Nam rutrum augue a leo. Morbi sed elit sit amet ante lobortis sollicitudin.

M. Shell was with the Department of Electrical and Computer Engineering, Georgia Institute of Technology, Atlanta, GA, 30332.

E-mail: see <http://www.michaelshell.org/contact.html>

J. Doe and J. Doe are with Anonymous University.



Fig. 1. Simulation results for the network.

TABLE I
AN EXAMPLE OF A TABLE

One	Two
Three	Four

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II. CONCLUSION

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(a) Case I



(b) Case II

Fig. 2. Simulation results for the network.

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APPENDIX A

PROOF OF THE FIRST ZONKLAR EQUATION

Appendix one text goes here.

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APPENDIX B

Appendix two text goes here. [1].

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ACKNOWLEDGMENT

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