Development of Remote Controlled Bluetooth Mobile Robot with Live Video Feedback

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

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

by

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June, 2016

De La Salle University

ORAL DEFENSE RECOMMENDATION SHEET

This thesis, entitled **Development of Remote Controlled Bluetooth Mobile Robot with Live Video Feedback**, prepared and submitted by thesis group, Kevin and Friends, composed of:

CEPRIA, Kevin Jeff T.
ECO, Lance Randall L.
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,

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

Engr. Melvin K. Cabatuan
Adviser

June 13, 2016

De La Salle University

THESIS APPROVAL SHEET

This thesis entitled **Development of Remote Controlled Bluetooth Mobile Robot with Live Video Feedback**, prepared and submitted by:

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with group number Kevin and Friends 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.

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ACKNOWLEDGMENT

Write this prior to hard binding if you have submitted all requirements and are told by your adviser that you have passed.

ABSTRACT

Keep your abstract short by giving the gist/nutshell of your thesis.

Index Terms—alloy system, characterization, InP, InGaAs.

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ABBREVIATIONS

AC	Alternating Current	51
CSS	Cascading Style Sheet	51
HTML	Hyper-text Markup Language	51
XML	eXtensible Markup Language	51

NOTATION

$\lvert\mathcal{S}\rvert$	the number of elements in the set $\mathcal{S}$	53
$\emptyset$	the set with no elements	53
$h\left(t\right)$	impulse response	43
$\mathcal{S}$	a collection of distinct objects	53
$\mathcal{U}$	the set containing everything	53
$x\left(t\right)$	input signal represented in the time domain	43
$y\left(t\right)$	output signal represented in the time domain	43

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

GLOSSARY

matrix a concise and useful way of uniquely representing and working with linear transformations; a rectangular table of elements 53

LISTINGS

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Chapter 1

INTRODUCTION

Contents

1.1 Background of the Study

Search and rescue mobile robots have been widely used in different situations mostly pertaining to disasters such as earthquakes, fire, and, urban accidents, mining accidents, and etc. The main purpose of these robots is to locate the victims or survivors in unreachable or dangerous areas. Once the survivors are located, rescue teams can now start the process of rescuing the survivor with more efficiency due to the know location of the said survivor. These mobile bots are either controlled through a remove device or self-operated through a programmed algorithm. Some search and rescue mobile bots have the capability of rescuing the survivor themselves but due to their large size, they are at a disadvantage in rescue operations where in survivors are under a pile of rubble and are fragile and need careful handling. Small mobile bots are more used than larger ones. The advantages of using these small search and rescue mobile bots are reduced fatigue, less man power, efficiency, and access to unreachable locations.

Mobile robots include components such as a DC motor or a servomotor, motor driver to supply the required power the motor needs, a microcontroller such as the Arduino to serve as its core unit, and a battery. Components such as lights, sensors, and signal modules are added to make the mobile bot more convenient to certain operations. The most important part of a mobile bot is the microcontroller because it serves as the brain of the motor. The microcontroller is programmable using C language. The behavior of the mobile bot depends on the algorithm programmed in the microcontroller. Mobile bots can be controlled by a remote control device such as a smartphone or a laptop. There are different kinds of signals used to transmit signals between the remote control and the mobile bot. These signals can be Bluetooth, RF signal, Wi-Fi signal, ZigBee, and etc. One of the methods in this option

of project is using bluetooth. Bluetooth transmits data through low-power radio waves, communicating at a frequency of around 2.45 gigahertz. The limitation of bluetooth is its low power method of transmitting signals typically 1 milliwatts, this greatly limits the range of bluetooth to around 10m. Another option for wireless communication aside from bluetooth, is the radio frequency (RF) which are electromagnetic wave frequencies that lie in the range of 3 khz to 300 Ghz. The problem our group has in using rf is its limitation in bandwidth, in our project we also need to stream a live video feedback from the robot. As for wireless communication we settled for wifi. The reason for choosing wifi is because of its ability to satisfy our need for continous video feedback with controls and all this could be done with wifi.

1.2 Prior Studies

On other studies that revolve and focus as well on remote controlled mobile robots, internet connection is being used so that it can be controlled for any given location. On this study, the remote controlled mobile robot is going to be developed alongside the use of Bluetooth connection. This is to enable controlling the mobile robot even without the use of internet connection. A rotating camera as well is being implemented on this study to enable surveying and scouting of areas that the robot would be going into.

1.3 Problem Statement

The problem that our thesis will address is that it usually takes a lot of time for and effort to conduct search and rescue operations if it would be done physically and it will consume

a lot of energy from the rescue team. It is because of this problem that we are suggesting the use of an android controlled wifi mobile robot with an attached camera to conduct this search and rescue operations because it would ease the work for the rescue team that will conduct the operations. They would already have a head start on the area where they will concentrate their search which means that the chances of finding and rescuing the people are greater because the area to conduct the search has been minimized. Also, through the camera of the mobile robot, the rescue team are able to have a live view of what is actually taking place on the site where the robot is conducting the operations.

1.4 Problem Statement

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1.5 Objectives

1.5.1 General Objective(s)

To . . . ;

1.5.2 Specific Objectives

1. To . . . ;
2. To . . . ;
3. To . . . ;
4. To . . . ;
5. To . . . ;

1.6 Significance of the Study

The significance of this study is that it caters to the safety of the public because the rescue process is expedited and the time it takes for them to be rescued will be lesser compared to conducting the operations without the use of the mobile robot. In addition, the study will also enhance the rescue operation process since it has the technology in order to map out the geographical conditions of the area through the use of its attached camera. It will be able to see if there are survivors that are perhaps trapped or still in distress and the rescue team will be able to take the immediate action thereafter.

1.7 Assumptions, Scope and Delimitations

Bulletize your scope in one group, and then bulletize the delimitations in another. Bulletize your assumptions as well.

1.8 Description and Methodology

1.9 Overview

Chapter 2

LITERATURE REVIEW

Contents

2.1 Modeling and Performance Analysis of PID Controlled BLDC Motor and Different Schemes of PWM Controlled BLDC Motor

Brushless DC motors are continuously earning reputation in the electronics side of things preferably in motion control applications. This DC motor has a low maintenance factor as well as it has a higher efficiency rate. On this paper of Singh Patel and Pandey presents the modeling and performance analysis of a brushless DC motors which are PID controlled. The paper also contains different schemes of brushless DC motors that are PWM controlled. According to them one of the key differences of DC motor and brushless one is that the brushless DC motor has brushes attached on its stator.

	Maxon Motor Data	Unit	Value
	Values at nominal voltage		
1	Nominal Voltage	V	12.0
2	No load Speed	rpm	4370
3	No load Current	mA	151
4	Nominal Speed	rpm	2860
5	Nominal Torque (max. continuous torque)	mNm	59.0
6	Nominal Current (max. continuous current)	A	2.14
7	Stall Torque	mNm	255
8	Starting Current	A	10.0
9	Maximum Efficiency	%	77
	Characteristics		
10	***Terminal Resistance phase to phase***	Ω	1.1
11	***Terminal Inductance phase to phase***	mH	0.50
12	***Torque Constant***	mNm/A	24.5
13	***Speed Constant***	rpm/V	35.4
14	Speed/Torque Gradient	rpm/mNm	17.6
15	***Mechanical time constant***	ms	16.1
16	***Rotor Inertia***	gcm^2	82.5
17	*Number of phase*		3

Table 1: BLDC Motor Parameters Used

2.2 Autonomous Machine Vision for Off-Road Vehicles in Unstructured Fields

Some issues that are tackled with a study relating to the machine vision are camera installation pose automatic calibration, vehicle heading estimation and field edge detection. On the research conducted by Wang, a stereo color camera was used to address the three issues mentioned. These cameras are used as sensors for perception for agricultural vehicle navigation. A problem rises whenever this camera is used and it is the difficulty of determining the cameras pose corresponding to the vehicle frame. On the research, Wang implemented a machine vision algorithm which detects static feature points on the ground. It also tracks the three dimensional motions with regards to the vehicle. The main goal of the research is to determine the feasibility of the machine vision to find clues based on the natural visual references in an open agricultural field. To achieve this goal, a binocular stereo camera was selected, because it could provide both color information and 3D space information about a scene. (Wang, 2009).

2.3 Arduino Based Photovore Robot

The main goal of this research is to create a design of a robot which can be controlled by using light. A light sensor is going to be used so that the robot would be able to follow the light that is to be emitted. An Arduino board would also be used to implement and program the robot. The analog pins of the Arduino board are going to be used to be able to read the analog data that is acquired from the sensors. A specific set of codes as well are going to be used so that the robot would move accordingly and properly. If both sensors read about

the same value, meaning the both get the same amount of light, then robot should drive straight. (Singh, 2013)

2.4 Wi-Fi Remote Control Car via Mobile Device

This project is centered on designing a Wi-Fi remote controlled car using a mobile device. In order to do this, we need a remote control that using wirelessly transmits that used RF technology, and data to the vehicle to move in any way (Hoong, 2013). The research contains an automatic mode in which the car follows the input direction of the user on the controls. The device screen of the mobile is located on the remote control so it can display the direction, distance and mode to plan on the distance and by a button. Although there would be such problems that can occur including the absence of accelerometer on this research by Hoong.

2.5 The Wireless Remote Control Car Based on Arm9

Wi-Fi based Wireless remote control has the features of high bandwidth and rate, non-line-transmission ability, large-scale data collection and high cost-effective, and it has the capability of video monitoring, which cannot be realized with RF (Joginaidu Marudi, 2013). This research of the group has a high significance to the development of the electronics industry. The research if more focused on controlling the car through the use of Wi-Fi module. The remote controlled car is then going to be monitored through remote PC or Laptop which also supports the Wi-Fi technology.

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2.6 Summary

Chapter 3

THEORETICAL CONSIDERATIONS

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3.1 Summary

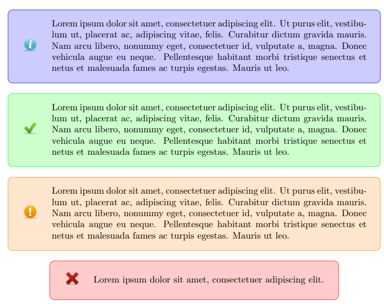

Fig. 3.1 A quadrilateral image example.

Chapter 4

DESIGN CONSIDERATIONS

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4.1 Summary

Chapter 5

METHODOLOGY

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5.1 Implementation

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5.2 Evaluation

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5.3 Summary

Chapter 6

RESULTS AND DISCUSSION

Contents

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6.1 Summary

Chapter 7

CONCLUSIONS, RECOMMENDATIONS, AND FUTURE DIRECTIVES

Contents

7.1 Concluding Remarks

In this Thesis, . . .

7.2 Contributions

The interrelated contributions and supplements that have been developed in this Thesisare listed as follows.

- the ;
- the ;
- the ;

7.3 Recommendations

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7.4 Future Prospects

There are several prospect related in this research that may be extended for further studies. . . . So the suggested topics are listed in the following.

1. the . . . .
2. the . . . .
3. the . . . .

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

Produced: June 13, 2016, 00:00

De La Salle University

Appendix A
ANSWERS TO QUESTIONS TO THIS THESIS

Contents

De La Salle University

A1 How important is the problem to practice?

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A2 How will you know if the solution/s that you will achieve would be better than existing ones?

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A2.1 How will you measure the improvement/s?

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A2.1.1 What is/are your basis/bases for the improvement/s?

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A2.1.2 Why did you choose that/those basis/bases?

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A2.1.3 How significant are your measure/s of the improvement/s?

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A3 What is the difference of the solution/s from existing ones?

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A3.1 How is it different from previous and existing ones?

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A4 What are the assumptions made (that are behind for your proposed solution to work)?

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A4.1 Will your proposed solution/s be sensitive to these assumptions?

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A4.2 Can your proposed solution/s be applied to more general cases when some of the assumptions are eliminated? If so, how?

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A5 What is the necessity of your approach / proposed solution/s?

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Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit amet ipsum. Nunc quis urna dictum turpis accumsan semper.

A5.1 What will be the limits of applicability of your proposed solution/s?

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

A5.2 What will be the message of the proposed solution to technical people? How about to non-technical managers and business men?

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

A6 How will you know if your proposed solution/s is/are correct?

Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Etiam lobortis facilisis sem. Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec ullamcorper, felis non sodales commodo, lectus velit ultrices augue, a dignissim nibh lectus placerat pede. Vivamus nunc nunc, molestie ut, ultricies vel, semper in, velit. Ut porttitor. Praesent in sapien. Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Duis fringilla

tristique neque. Sed interdum libero ut metus. Pellentesque placerat. Nam rutrum augue a leo. Morbi sed elit sit amet ante lobortis sollicitudin. Praesent blandit blandit mauris. Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit amet ipsum. Nunc quis urna dictum turpis accumsan semper.

A6.1 Will your results warrant the level of mathematics used (i.e., will the end justify the means)?

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

A7 Is/are there an/_ alternative way/s to get to the same solution/s?

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

A7.1 Can you come up with illustrating examples, or even better, counter examples to your proposed solution/s?

Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Etiam lobortis facilisis sem. Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec ullamcorper, felis non sodales commodo, lectus velit ultrices augue, a dignissim nibh lectus placerat pede. Vivamus nunc nunc, molestie ut, ultricies vel, semper in, velit. Ut porttitor.

Praesent in sapien. Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Duis fringilla tristique neque. Sed interdum libero ut metus. Pellentesque placerat. Nam rutrum augue a leo. Morbi sed elit sit amet ante lobortis sollicitudin. Praesent blandit blandit mauris. Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit amet ipsum. Nunc quis urna dictum turpis accumsan semper.

A7.2 Is there an approximation that can arrive at the essentially the same proposed solution/s more easily?

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

A8 If you were the examiner of your proposal, how would you present the proposal in another way?

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

A8.1 What are the weaknesses of your proposal?

Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Etiam lobortis facilisis sem. Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec ullamcorper, felis non sodales commodo, lectus velit ultrices augue, a dignissim nibh lectus placerat pede. Vivamus nunc nunc, molestie ut, ultricies vel, semper in, velit. Ut porttitor.

Praesent in sapien. Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Duis fringilla tristique neque. Sed interdum libero ut metus. Pellentesque placerat. Nam rutrum augue a leo. Morbi sed elit sit amet ante lobortis sollicitudin. Praesent blandit blandit mauris. Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit amet ipsum. Nunc quis urna dictum turpis accumsan semper.

Appendix B
USAGE EXAMPLES

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

B1 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 (B.1), the output signal $y\left(t\right)$ is the result of the convolution of the input signal $x\left(t\right)$ and the impulse response $h\left(t\right)$.

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

Other example equations are as follows.

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

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

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

The verbatim LaTeX code of Sec. B1 is in List. B.1.

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

```
The following examples show how to typeset equations in \LaTeX.

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}.

\begin{eqnarray}
     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
   \label{eq:conv}
\end{eqnarray}

Other example equations are as follows.

\begin{eqnarray}
   \left[ \dfrac{ V_{1} }{ I_{1} } \right] =
   \begin{bmatrix}
      A & B \\
      C & D
   \end{bmatrix}
   \left[ \dfrac{ V_{2} }{ I_{2} } \right]
   \label{eq:ABCD}
\end{eqnarray}

\begin{eqnarray}
{1\over 2} < \left\lfloor \mathrm{mod}\left(\left\lfloor {y \over 17} \
    right\rfloor 2^{-17 \lfloor x \rfloor - \mathrm{mod}(\lfloor y\
    rfloor, 17)},2\right)\right\rfloor,
\end{eqnarray}

\begin{eqnarray}
| \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}}\ge 1
\end{eqnarray}
```

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B2 Notations

In order to use the standardized notation, the user is highly suggested to see the ISO 80000-2 standard [ISO, 2009]. The following were taken from `isomath-test.tex` .

Math alphabets

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

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

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

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

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

Vector symbols

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

Matrix symbols

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

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

Tensor symbols

Symbols for tensors are sans-serif bold italic,

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

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

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

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Bold math version

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

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

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

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

Do the math alphabets match?

$\boldsymbol{axαωaxαωaxαω} \quad \mathsfbfit{TCΘΓTCΘΓTCΘΓ}$

Vector symbols

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

Matrix symbols

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

Tensor symbols

Symbols for tensors are sans-serif bold italic,

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

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

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

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

The verbatim LaTeX code of Sec. B2 is in List. B.2.

Listing B.2: Sample LaTeX code for notations usage

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


\subsection*{Math alphabets}

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

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

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

\subsection*{Vector symbols}
```

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

\subsection*{Matrix symbols}

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


\subsection*{Tensor symbols}

Symbols for tensors are sans-serif bold italic,

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


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



\newpage
\subsection*{Bold math version}

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

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

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

    \subsection*{Vector symbols}

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




    \subsection*{Matrix symbols}

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


    \subsection*{Tensor symbols}

    Symbols for tensors are sans-serif bold italic,

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

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

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B3 Abbreviation

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

Again please see List. B.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). Here are some more entries:

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

- Provide your own link text: style sheet.

The verbatim LaTeX code of Sec. B3 is in List. B.3.

Listing B.3: Sample LaTeX code for abbreviations usage

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

\begin{itemize}

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

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

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

   \item Reset again. \glsresetall{abbreviation}

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

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

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

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

   \item Resetting all acronyms.\glsresetall{abbreviation}

   \item Here are the acronyms again:

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

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

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

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

\end{itemize}
```

B4 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. B.4).

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

- Matrices are usually denoted by a bold capital letter, such as $\boldsymbol{A}$. The matrix's (i, j)th element is usually denoted a_{ij}. Matrix $\mathbf{I}$ is the identity matrix.
- A set, denoted as $\mathcal{S}$, is a collection of objects.
- The universal set, denoted as $\mathcal{U}$, is the set of everything.
- The empty set, denoted as $\emptyset$, contains no elements.
- 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. B4 is in List. B.4.

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

```
\begin{itemize}

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

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

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

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

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

\end{enumerate}
```

B5 Figure

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

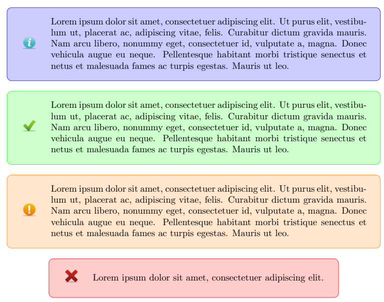
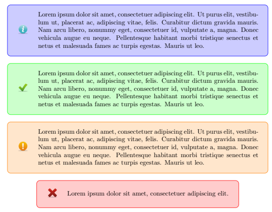


Fig. B.1 A quadrilateral image example.

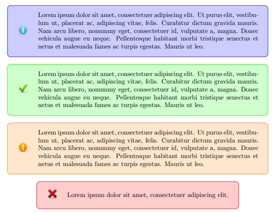
Fig. B.1 is a gray box enclosed by a dark border. List. B.5 shows the corresponding LaTeX code.

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

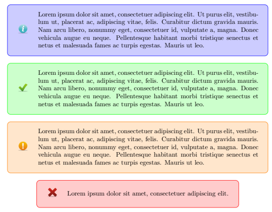
```
\begin{figure}[!htbp]
   \centering
      \includegraphics[width=0.5\textwidth]{example}
   \caption{A quadrilateral image example.}
   \label{fig:example}
\end{figure}
\cleardoublepage

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



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



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



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

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

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

Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Ut purus elit, vestibulum ut, placerat ac, adipiscing vitae, felis. Curabitur dictum gravida mauris. Nam arcu libero, nonummy eget, consectetuer id, vulputate a, magna. Donec vehicula augue eu neque. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Mauris ut leo.

Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Ut purus elit, vestibulum ut, placerat ac, adipiscing vitae, felis. Curabitur dictum gravida mauris. Nam arcu libero, nonummy eget, consectetuer id, vulputate a, magna. Donec vehicula augue eu neque. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Mauris ut leo.

Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Ut purus elit, vestibulum ut, placerat ac, adipiscing vitae, felis. Curabitur dictum gravida mauris. Nam arcu libero, nonummy eget, consectetuer id, vulputate a, magna. Donec vehicula augue eu neque. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Mauris ut leo.

Lorem ipsum dolor sit amet, consectetuer adipiscing elit.

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

Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Ut purus elit, vestibulum ut, placerat ac, adipiscing vitae, felis. Curabitur dictum gravida mauris. Nam arcu libero, nonummy eget, consectetuer id, vulputate a, magna. Donec vehicula augue eu neque. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Mauris ut leo.

Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Ut purus elit, vestibulum ut, placerat ac, adipiscing vitae, felis. Curabitur dictum gravida mauris. Nam arcu libero, nonummy eget, consectetuer id, vulputate a, magna. Donec vehicula augue eu neque. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Mauris ut leo.

Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Ut purus elit, vestibulum ut, placerat ac, adipiscing vitae, felis. Curabitur dictum gravida mauris. Nam arcu libero, nonummy eget, consectetuer id, vulputate a, magna. Donec vehicula augue eu neque. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Mauris ut leo.

Lorem ipsum dolor sit amet, consectetuer adipiscing elit.

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

Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Ut purus elit, vestibulum ut, placerat ac, adipiscing vitae, felis. Curabitur dictum gravida mauris. Nam arcu libero, nonummy eget, consectetuer id, vulputate a, magna. Donec vehicula augue eu neque. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Mauris ut leo.

Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Ut purus elit, vestibulum ut, placerat ac, adipiscing vitae, felis. Curabitur dictum gravida mauris. Nam arcu libero, nonummy eget, consectetuer id, vulputate a, magna. Donec vehicula augue eu neque. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Mauris ut leo.

Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Ut purus elit, vestibulum ut, placerat ac, adipiscing vitae, felis. Curabitur dictum gravida mauris. Nam arcu libero, nonummy eget, consectetuer id, vulputate a, magna. Donec vehicula augue eu neque. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Mauris ut leo.

Lorem ipsum dolor sit amet, consectetuer adipiscing elit.

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

Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Ut purus elit, vestibulum ut, placerat ac, adipiscing vitae, felis. Curabitur dictum gravida mauris. Nam arcu libero, nonummy eget, consectetuer id, vulputate a, magna. Donec vehicula augue eu neque. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Mauris ut leo.

Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Ut purus elit, vestibulum ut, placerat ac, adipiscing vitae, felis. Curabitur dictum gravida mauris. Nam arcu libero, nonummy eget, consectetuer id, vulputate a, magna. Donec vehicula augue eu neque. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Mauris ut leo.

Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Ut purus elit, vestibulum ut, placerat ac, adipiscing vitae, felis. Curabitur dictum gravida mauris. Nam arcu libero, nonummy eget, consectetuer id, vulputate a, magna. Donec vehicula augue eu neque. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Mauris ut leo.

Lorem ipsum dolor sit amet, consectetuer adipiscing elit.

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

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

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

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

De La Salle University

B6 Table

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

TABLE B.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)

List. B.8 shows the corresponding LaTeX code.

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

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

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

```
43 41175 & (1, 12, 13725) & (1, 13, 10980), (2, 2, 2745), (2, 3, 0), (3, 1,
       0) \\
44 43920 & (1, 13, 10980) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
45 46665 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
46 49410 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
47 52155 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1,
       0) \\
48 54900 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
49 57645 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
50 60390 & (1, 12, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
51 63135 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
52 65880 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
53 68625 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
54 71370 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
55 74115 & (1, 12, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
56 76860 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
57 79605 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
58 82350 & (1, 12, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
59 85095 & (1, 12, 13725) & (1, 13, 10980), (2, 2, 2745), (2, 3, 0), (3, 1,
       0) \\
60 87840 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
61 90585 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
62 93330 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
63 96075 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
64 98820 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
65 101565 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
66 104310 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
67 107055 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
68 109800 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
69 112545 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3,
       1, 0) \\
70 115290 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
71 118035 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
72 120780 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
73 123525 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
74 126270 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3,
       1, 0) \\
75 129015 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
76 131760 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
77 134505 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
78 137250 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
79 139995 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
80 142740 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
81 145485 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3,
       1, 0) \\
82 148230 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
83 150975 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
84 153720 & (1, 12, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
85 156465 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
86 159210 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
87 161955 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
88 164700 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
89 \end{tabularx}
90 }
91 \end{center}
```

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B7 Algorithm or Pseudocode Listing

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

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

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

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

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

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

B8 Program/Code Listing

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

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

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

#include <stdio.h>

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

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

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

How many Fibonacci numbers do you want to compute? 9

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

*/
```

List. B.11 shows the corresponding LaTeX code.

Listing B.11: Sample LaTeX code for program listing

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

B9 Referencing

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

Referencing sections: This section is Sec. B9, which shows how to refer to the locations of various labels that have been placed in the LaTeX files. List. B.12 shows the corresponding LaTeX code.

Listing B.12: Sample LaTeX code for referencing sections

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

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

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B9.1 A subsection

Referencing subsections: This section is Sec. B9.1, which shows how to refer to a subsection. List. B.13 shows the corresponding LaTeX code.

Listing B.13: Sample LaTeX code for referencing subsections

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

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

B9.1.1 A sub-subsection

Referencing sub-subsections: This section is Sec. B9.1.1, which shows how to refer to a sub-subsection. List. B.14 shows the corresponding LaTeX code.

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

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

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

B10 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. B.15 is a program listing of the above-mentioned paragraph.

Listing B.15: Sample LaTeX code for Index usage

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

B11 Adding Relevant PDF Pages (e.g. Standards, Datasheets, Specification Sheets, Application Notes, etc.)

Selected PDF pages can be added (see List. B.16), but note that the options must be tweaked. See the manual of `pdfpages` for other options.

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

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

Virtex UltraScale FPGA Feature Summary

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

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

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

Virtex UltraScale Device-Package Combinations and Maximum I/Os

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

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

Notes:

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

Virtex UltraScale+ FPGA Feature Summary

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

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

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

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

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

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

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

Appendix C
PUBLICATION LIST AND AWARD

Journal

1. ...
2. ...

Conference

1. ...
2. ...

Others

1. ...
2. ...

Award

1. ...
2. ...

Appendix D
VITA

Kevin Jeff T. Cepria is a computer engineering student that has interest in PIC Microcontroller programming and Java programming. He has made different projects at different levels of difficulties. He has experience in developing a mobile application using Android Studio. He is also a new recruit of the DLSU Eco Car Team.

Lance Randall Eco is one of the 4th year computer engineering students. He is skilled in being a domain expert in his team and most often being relied on in terms of the fields characteristics and data. He is interested in C programming and making different hobby circuits.

Ryan Joshuwa Liwag is a member of the DLSU Eco Car Team and also the head of the Motor Controller division of the said team. He is skilled in the PIC microcontroller and is knowledgable about their functions and characteristics. He makes different circuits as a past time.

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Anfernee Rapio is the teams leader. He is skilled in different fields in electrical and eletctronics engineering. He is also skilled in software engineering. He is a former member of the DLSU Eco Car Team. One of his favorite circuit designs includes relays, operational amplifiers, field programmable gate array, and PIC micrcontrollers

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