



Development of Remote Controlled Bluetooth Mobile Robot with Live Video Feedback

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

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

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

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## 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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Date: June 13, 2016



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2016

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## ACKNOWLEDGMENT

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



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## ABSTRACT

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

70

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



71

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## ABBREVIATIONS

177	AC	Alternating Current.....	51
178	CSS	Cascading Style Sheet .....	51
179	HTML	Hyper-text Markup Language .....	51
180	XML	eXtensible Markup Language .....	51



## NOTATION

181

182	$ \mathcal{S} $	the number of elements in the set $\mathcal{S}$ .....	53
183	$\emptyset$	the set with no elements .....	53
184	$h(t)$	impulse response .....	43
185	$\mathcal{S}$	a collection of distinct objects .....	53
186	$\mathcal{U}$	the set containing everything .....	53
187	$x(t)$	input signal represented in the time domain .....	43
188	$y(t)$	output signal represented in the time domain .....	43

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



195

## GLOSSARY

196

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



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## Chapter 1

## INTRODUCTION

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## 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 continuous 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**

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### **1.5.1 General Objective(s)**

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### **1.5.2 Specific Objectives**

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2. To ...;

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3. To ...;

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4. To ...;

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5. To ...;

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## **1.6 Significance of the Study**

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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.



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## **1.7 Assumptions, Scope and Delimitations**

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

311

## **1.8 Description and Methodology**

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## **1.9 Overview**



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## Chapter 2

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## LITERATURE REVIEW

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## 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
	<u>Values at nominal voltage</u>		
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
	<u>Characteristics</u>		
10	<i>Terminal Resistance phase to phase</i>	$\Omega$	1.1
11	<i>Terminal Inductance phase to phase</i>	mH	0.50
12	<i>Torque Constant</i>	mNm/A	24.5
13	<i>Speed Constant</i>	rpm/V	35.4
14	Speed/Torque Gradient	rpm/mNm	17.6
15	<i>Mechanical time constant</i>	ms	16.1
16	<i>Rotor Inertia</i>	gcm <sup>2</sup>	82.5
17	<i>Number of phase</i>		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



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## Chapter 3

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# THEORETICAL CONSIDERATIONS

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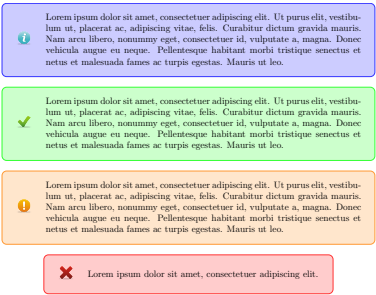


Fig. 3.1 A quadrilateral image example.



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## Chapter 4

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# DESIGN CONSIDERATIONS

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## 481 4.1 Summary



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## Chapter 5

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## METHODOLOGY

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## 5.1 Implementation

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## 5.2 Evaluation

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De La Salle University

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### 5.3 Summary





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## Chapter 6

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# RESULTS AND DISCUSSION

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## 634 6.1 Summary



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## Chapter 7

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## CONCLUSIONS, RECOMMENDATIONS,

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## AND FUTURE DIRECTIVES

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645 **7.1 Concluding Remarks**

646 In this Thesis, . . .

647 **7.2 Contributions**

648 The interrelated contributions and supplements that have been developed in this Thesis are  
649 listed as follows.

- 650 • the ;
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653 **7.3 Recommendations**

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

## 699 7.4 Future Prospects

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

702 1. the ....

703 2. the ....

704 3. the ....



## REFERENCES

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- [Oetiker et al., 2014] Oetiker, T., Partl, H., Hyna, I., and Schlegl, E. (2014). *The Not So Short Introduction to L<sup>A</sup>T<sub>E</sub>X 2<sub>ε</sub> Or L<sup>A</sup>T<sub>E</sub>X 2<sub>ε</sub> in 157 minutes*. n.a.





# Appendix A ANSWERS TO QUESTIONS TO THIS THESIS

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

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

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 789 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec  
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797 **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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839 **A4.1 Will your proposed solution/s be sensitive to these as-**  
 840 **sumptions?**

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

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862 **A5 What is the necessity of your approach / pro-**  
 863 **posed solution/s?**

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873 **A5.1 What will be the limits of applicability of your proposed so-**  
874 **lution/s?**

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

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

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

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

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

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910 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec  
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918 **A7 Is/are there an/\_ alternative way/s to get to the**  
919 **same solution/s?**

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

929 **A7.1 Can you come up with illustrating examples, or even bet-**  
930 **ter, counter examples to your proposed solution/s?**

931 Lorem ipsum dolor sit amet, consectetur adipiscing elit. Etiam lobortis facilisis sem.  
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 939 amet ipsum. Nunc quis urna dictum turpis accumsan semper.

## 940 **A7.2 Is there an approximation that can arrive at the essen-** 941 **tially the same proposed solution/s more easily?**

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## 951 **A8 If you were the examiner of your proposal, how** 952 **would you present the proposal in another way?**

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

## 962 **A8.1 What are the weaknesses of your proposal?**

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





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



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972

973

## **Appendix B**

### **USAGE EXAMPLES**



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

## 977 B1 Equations

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

984 In (B.1), the output signal  $y(t)$  is the result of the convolution of the input signal  $x(t)$   
 985 and the impulse response  $h(t)$  .

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

986 Other example equations are as follows.

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

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

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



987

The verbatim L<sup>A</sup>T<sub>E</sub>X code of Sec. B1 is in List. B.1.Listing B.1: Sample L<sup>A</sup>T<sub>E</sub>X code for equations and notations usage

```

1 The following examples show how to typeset equations in \LaTeX.
2
3 In~\eqref{eq:conv}, the output signal \gls{not:output_sigt} is the
  result of the convolution of the input signal \gls{not:input_sigt}
  and the impulse response \gls{not:ir}.
4
5 \begin{eqnarray}
6   y\left( t \right) = h\left( t \right) * x\left( t \right)=\int_{-\infty}^{+\infty}h\left( t-\tau \right)x\left( \tau \right) \mathrm{d}\tau
7   \label{eq:conv}
8 \end{eqnarray}
9
10 Other example equations are as follows.
11
12 \begin{eqnarray}
13   \left[ \dfrac{V_{1}}{I_{1}} \right] =
14   \begin{bmatrix}
15     A & B \\
16     C & D
17   \end{bmatrix}
18   \left[ \dfrac{V_{2}}{I_{2}} \right]
19   \label{eq:ABCD}
20 \end{eqnarray}
21
22 \begin{eqnarray}
23   {1\over 2} < \left\lfloor \mathrm{mod}\right\left(\left\lfloor {y \over 17} \right\rfloor 2^{-17} \lfloor x \rfloor - \mathrm{mod}(\lfloor y \rfloor, 17)\right)\right\rfloor, 2\right)\right\rfloor,
24 \end{eqnarray}
25
26 \begin{eqnarray}
27   | \zeta(x)^3 \zeta(x+iy)^4 \zeta(x+2iy) | =
28   \exp\sum_{n,p}\frac{3+4\cos(ny\log p) +\cos(2ny\log p)}{np^{nx}}\geq 1
29 \end{eqnarray}

```



## 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.

<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>	$A, B, \Gamma, \Delta, \Theta, \Lambda, \Xi, \Pi, \Sigma, \Phi, \Psi, \Omega, \textit{ff}, \textit{fi}, \beta, ^\circ, !, v, w, 0, 1, 9$
<code>mathrm</code>	$A, B, \Gamma, \Delta, \Theta, \Lambda, \Xi, \Pi, \Sigma, \Phi, \Psi, \Omega, \text{ff}, \text{fi}, \beta, ^\circ, !, v, w, 0, 1, 9$
<code>mathbf</code>	$\mathbf{A, B, \Gamma, \Delta, \Theta, \Lambda, \Xi, \Pi, \Sigma, \Phi, \Psi, \Omega, ff, fi, \beta, ^\circ, !, v, w, 0, 1, 9}$
<code>mathsf</code>	$A, B, \Gamma, \Delta, \Theta, \Lambda, \Xi, \Pi, \Sigma, \Phi, \Psi, \Omega, \text{ff}, \text{fi}, \beta, ^\circ, !, v, w, 0, 1, 9$
<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>	$\mathbf{A, B, \Gamma, \Delta, \Theta, \Lambda, \Xi, \Pi, \Sigma, \Phi, \Psi, \Omega, \alpha, \beta, \pi, \nu, \omega, v, w, 0, 1, 9}$
<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>mathsfbfit</code>	$\mathbf{A, B, \Gamma, \Delta, \Theta, \Lambda, \Xi, \Pi, \Sigma, \Phi, \Psi, \Omega, \alpha, \beta, \pi, \nu, \omega, v, w, 0, 1, 9}$

Do the math alphabets match?

$\alpha x \alpha \omega \mathbf{a x} \alpha \omega \mathbf{a x} \alpha \omega \quad T C \Theta \Gamma T C \Theta \Gamma T C \Theta \Gamma$

### Vector symbols

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

### Matrix symbols

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

<sup>1</sup>However, 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  $\mathbf{E}$ .



1002 **Tensor symbols**

1003 Symbols for tensors are sans-serif bold italic,

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

1004 The permittivity tensor describes the coupling of electric field and displacement:

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



## 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>	$A, B, \Gamma, \Delta, \Theta, \Lambda, \Xi, \Pi, \Sigma, \Phi, \Psi, \Omega, \textit{ff}, \textit{fi}, \beta, ^\circ, !, v, w, 0, 1, 9$
<code>mathrm</code>	$A, B, \Gamma, \Delta, \Theta, \Lambda, \Xi, \Pi, \Sigma, \Phi, \Psi, \Omega, \text{ff}, \text{fi}, \beta, ^\circ, !, v, w, 0, 1, 9$
<code>mathbf</code>	$A, B, \Gamma, \Delta, \Theta, \Lambda, \Xi, \Pi, \Sigma, \Phi, \Psi, \Omega, \text{ff}, \text{fi}, \beta, ^\circ, !, v, w, 0, 1, 9$
<code>mathsf</code>	$\mathbf{A}, \mathbf{B}, \mathbf{\Gamma}, \mathbf{\Delta}, \mathbf{\Theta}, \mathbf{\Lambda}, \mathbf{\Xi}, \mathbf{\Pi}, \mathbf{\Sigma}, \mathbf{\Phi}, \mathbf{\Psi}, \mathbf{\Omega}, \text{ff}, \text{fi}, \beta, ^\circ, !, v, w, 0, 1, 9$
<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>	$A, B, \Gamma, \Delta, \Theta, \Lambda, \Xi, \Pi, \Sigma, \Phi, \Psi, \Omega, \alpha, \beta, \pi, \nu, \omega, v, w, 0, 1, 9$
<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?

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

## 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,  $a + 0 = a$ .

## Matrix symbols

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

## Tensor symbols

Symbols for tensors are sans-serif bold italic,

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

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

$$D = \epsilon_0 \epsilon_r E$$

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



1019 The verbatim  $\text{\LaTeX}$  code of Sec. B2 is in List. B.2.

Listing B.2: Sample  $\text{\LaTeX}$  code for notations usage

```

1020 1 % A teststring with Latin and Greek letters::
1021 2 \newcommand{\teststring}{%
1022 3 % capital Latin letters
1023 4 % A,B,C,
1024 5 A,B,
1025 6 % capital Greek letters
1026 7 %\Gamma,\Delta,\Theta,\Lambda,\Xi,\Pi,\Sigma,\Upsilon,\Phi,\Psi,
1027 8 \Gamma,\Delta,\Theta,\Lambda,\Xi,\Pi,\Sigma,\Phi,\Psi,\Omega,
1028 9 % small Greek letters
1029 10 \alpha,\beta,\pi,\nu,\omega,
1030 11 % small Latin letters:
1031 12 % compare \nu, \omega, v, and w
1032 13 v,w,
1033 14 % digits
1034 15 0,1,9
1035 16 }
1036 17
1037 18
1038 19 \subsection*{Math alphabets}
1039 20
1040 21 If there are other symbols in place of Greek letters in a math
1041 22 alphabet, it uses T1 or OT1 font encoding instead of OML.
1042 23
1043 24 \begin{eqnarray*}
1044 25 \mbox{\mathnormal} & & \mbox{\teststring} \\
1045 26 \mbox{\mathit} & & \mbox{\mathit{\teststring}} \\
1046 27 \mbox{\mathrm} & & \mbox{\mathrm{\teststring}} \\
1047 28 \mbox{\mathbf} & & \mbox{\mathbf{\teststring}} \\
1048 29 \mbox{\mathsf} & & \mbox{\mathsf{\teststring}} \\
1049 30 \mbox{\mathtt} & & \mbox{\mathtt{\teststring}} \\
1050 31 \end{eqnarray*}
1051 32 New alphabets bold-italic, sans-serif-italic, and sans-serif-bold-
1052 33 italic.
1053 34 \begin{eqnarray*}
1054 35 \mbox{\mathbfit} & & \mbox{\mathbfit{\teststring}} \\
1055 36 \mbox{\mathsfit} & & \mbox{\mathsfit{\teststring}} \\
1056 37 \mbox{\mathsfbfit} & & \mbox{\mathsfbfit{\teststring}} \\
1057 38 \end{eqnarray*}
1058 39 %
1059 40 Do the math alphabets match?
1060 41 $
1061 42 \mathnormal {a x \alpha \omega}
1062 43 \mathbfit {a x \alpha \omega}
1063 44 \mathsfbfit{a x \alpha \omega}
1064 45 \quad
1065 46 \mathsfbfit{T C \Theta \Gamma}
1066 47 \mathbfit {T C \Theta \Gamma}
1067 48 \mathnormal {T C \Theta \Gamma}
1068 49 $
1069 50
1070 51 \subsection*{Vector symbols}
1071 52

```





```

53 Alphabetic symbols for vectors are boldface italic,
1075 54  $\vec{\lambda} = \vec{e}_1 \cdot \vec{a}$ ,
1076 55 while numeric ones (e.g. the zero vector) are bold upright,
1077 56  $\vec{a} + \vec{0} = \vec{a}$ .
1078 57
1079 58 \subsection*{Matrix symbols}
1080 59
1081 60 Symbols for matrices are boldface italic, too:%
1082 61 \footnote{However, matrix symbols are usually capital letters whereas
1083 62 vectors
1084 62 are small ones. Exceptions are physical quantities like the force
1085 63 vector  $\vec{F}$  or the electrical field  $\vec{E}$ .%
1086 64 }
1087 65  $\Lambda = E \cdot A$ .
1088 66
1089 67
1090 68 \subsection*{Tensor symbols}
1091 69
1092 70 Symbols for tensors are sans-serif bold italic,
1093 71
1094 72 [
1095 73   \tensorsym{\alpha} = \tensorsym{e} \cdot \tensorsym{a}
1096 74   \quad \Longleftrightarrow \quad
1097 75   \alpha_{ijl} = e_{ijk} \cdot a_{kl}.
1098 76 ]
1099 77
1100 78
1101 79 The permittivity tensor describes the coupling of electric field and
1102 80 displacement: [
1103 81  $D = \epsilon_0 \text{\tensorsym{\epsilon}}_{\text{\mathrm{r}}} \vec{E}$ ]
1104 82
1105 83
1106 84
1107 85 \newpage
1108 86 \subsection*{Bold math version}
1109 87
1110 88 The ‘‘bold’’ math version is selected with the commands
1111 89 \verb+\boldmath+ or \verb+\mathversion{bold}+
1112 90
1113 91 {\boldmath
1114 92   \begin{eqnarray*}
1115 93     \mbox{\mathnormal} & & \teststring \\
1116 94     \mbox{\mathit} & & \mathit{\teststring} \\
1117 95     \mbox{\mathrm} & & \mathrm{\teststring} \\
1118 96     \mbox{\mathbf} & & \mathbf{\teststring} \\
1119 97     \mbox{\mathsf} & & \mathsf{\teststring} \\
1120 98     \mbox{\mathtt} & & \mathtt{\teststring}
1121 99   \end{eqnarray*}
1122 100   New alphabets bold-italic, sans-serif-italic, and sans-serif-bold-
1123 101   italic.
1124 102   \begin{eqnarray*}
1125 103     \mbox{\mathbfit} & & \mathbfit{\teststring} \\
1126 104     \mbox{\mathsfit} & & \mathsfit{\teststring} \\
1127 105     \mbox{\mathsfbfit} & & \mathsfbfit{\teststring}
1128 106   \end{eqnarray*}
1129 107   %
1130 108   Do the math alphabets match?

```



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--	---	--

1131	108	
1132	109	\$
1133	110	\mathnormal {a x \alpha \omega}
1134	111	\mathbfit {a x \alpha \omega}
1135	112	\mathsfbfit{a x \alpha \omega}
1136	113	\quad
1137	114	\mathsfbfit{T C \Theta \Gamma}
1138	115	\mathbfit {T C \Theta \Gamma}
1139	116	\mathnormal {T C \Theta \Gamma}
1140	117	\$
1141	118	
1142	119	\subsection*{Vector symbols}
1143	120	
1144	121	Alphabetic symbols for vectors are boldface italic,
1145	122	\$\vec{\lambda}=\vec{e}_{1}\cdot\vec{a}\$,
1146	123	while numeric ones (e.g. the zero vector) are bold upright,
1147	124	\$\vec{a} + \vec{0} = \vec{a}\$.
1148	125	
1149	126	
1150	127	
1151	128	
1152	129	\subsection*{Matrix symbols}
1153	130	
1154	131	Symbols for matrices are boldface italic, too:%
1155	132	\footnote{However, matrix symbols are usually capital letters whereas
1156		vectors
1157	133	are small ones. Exceptions are physical quantities like the force
1158	134	vector \$\vec{F}\$ or the electrical field \$\vec{E}\$.%
1159	135	}
1160	136	\$\matrixsym{\Lambda}=\matrixsym{E}\cdot\matrixsym{A}\$.
1161	137	
1162	138	
1163	139	\subsection*{Tensor symbols}
1164	140	
1165	141	Symbols for tensors are sans-serif bold italic,
1166	142	
1167	143	\[
1168	144	\tensorsym{\alpha} = \tensorsym{e}\cdot\tensorsym{a}
1169	145	\quad \Longleftarrow \quad
1170	146	\alpha_{ijl} = e_{ijk}\cdot a_{kl}.
1171	147	\]
1172	148	
1173	149	The permittivity tensor describes the coupling of electric field and
1174	150	displacement: \[
1175	151	\vec{D}=\epsilon_{0}\tensorsym{\epsilon}_{\mathrm{r}}\vec{E}\]
1176	152	}



## B3 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. 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).



- 1207 • Provide your own link text: style sheet.

1208 The verbatim  $\text{\LaTeX}$  code of Sec. B3 is in List. B.3.

### Listing B.3: Sample $\text{\LaTeX}$ 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}

```



## 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  $A$ . The matrix’s  $(i, j)$ th element is usually denoted  $a_{ij}$ . Matrix  $I$  is the identity matrix.
- A set, denoted as  $S$ , 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  $|S|$ , 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

```

1 \begin{itemize}
2
3   \item \Glspl{matrix} are usually denoted by a bold capital letter,
      such as  $\mathbf{A}$ . The  $\gls{matrix}$ ’s  $(i, j)$ th element is
      usually denoted  $a_{ij}$ .  $\gls{matrix}$   $\mathbf{I}$  is the
      identity  $\gls{matrix}$ .
4
5   \item A set, denoted as  $\gls{not:set}$ , is a collection of objects.
6
7   \item The universal set, denoted as  $\gls{not:universalSet}$ , is the
      set of everything.
8
9   \item The empty set, denoted as  $\gls{not:emptySet}$ , contains no
      elements.
10
11   \item The cardinality of a set, denoted as  $\gls{not:cardinality}$ , is
      the number of elements in the set.
12
13 \end{itemize}

```



1223

**B5 Figure**

1224

1225

This section shows several ways of placing figures. PDFL<sup>A</sup>T<sub>E</sub>X compatible files are PDF, PNG, and JPG. Please see the `figure` subdirectory.

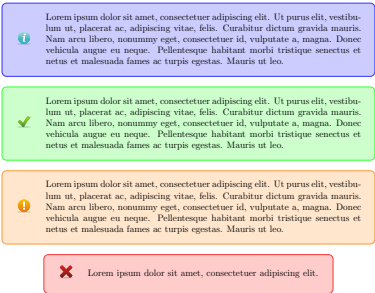


Fig. B.1 A quadrilateral image example.



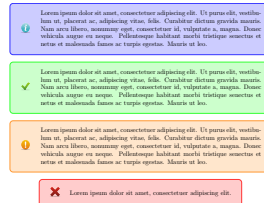
1226 Fig. B.1 is a gray box enclosed by a dark border. List. B.5 shows the corresponding  
1227  $\text{\LaTeX}$  code.

Listing B.5: Sample  $\text{\LaTeX}$  code for a single figure

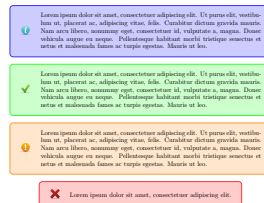
```
1 \begin{figure}[!htbp]
2   \centering
3   \includegraphics[width=0.5\textwidth]{example}
4   \caption{A quadrilateral image example.}
5   \label{fig:example}
6 \end{figure}
7 \cleardoublepage
8
9 Fig.~\ref{fig:example} is a gray box enclosed by a dark border. List.~\ref{lst:onefig} shows the corresponding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



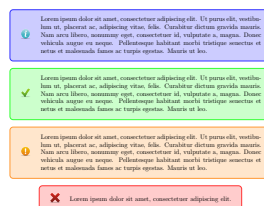
# De La Salle University



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



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



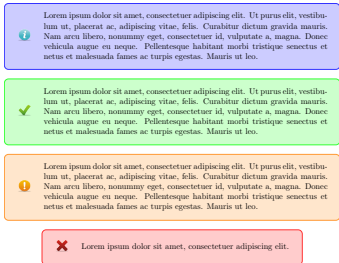
(c) A sub figure in the bottom row



Listing B.6: Sample L<sup>A</sup>T<sub>E</sub>X code for three figures on top of each other

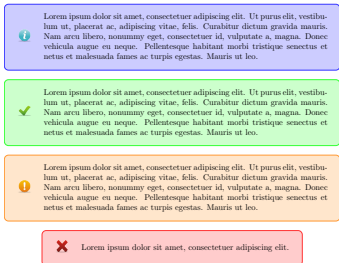
```
1 \begin{figure}[!htbp]
2 \centering
3 \subbottom[A sub-figure in the top row.]{
4 \includegraphics[width=0.35\textwidth]{example}
5 \label{fig:top}
6 }
7 \vfill
8 \subbottom[A sub-figure in the middle row.]{
9 \includegraphics[width=0.35\textwidth]{example}
10 \label{fig:mid}
11 }
12 \vfill
13 \subbottom[A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

B. Usage Examples



(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. B.3 Four figures in each corner. See List. B.7 for the corresponding  $\text{\LaTeX}$  code.

Listing B.7: Sample  $\text{\LaTeX}$  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}
5 \label{fig:upprleft}
6 }
7 \hfill
8 \subbottom[A sub-figure in the upper-right corner.]{
9 \includegraphics[width=0.45\textwidth]{example}
10 \label{fig:uppright}
11 }
12 \vfill
13 \subbottom[A sub-figure in the lower-left corner.]{
14 \includegraphics[width=0.45\textwidth]{example}
15 \label{fig:lowerleft}
16 }
17 \hfill
18 \subbottom[A sub-figure in the lower-right corner]{
19 \includegraphics[width=0.45\textwidth]{example}
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}

```



## 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  $\text{\LaTeX}$  code.

Listing B.8: Sample  $\text{\LaTeX}$  code for making typical table environment

```

1 \begin{center}
2 {\scriptsize
3 \begin{tabularx}{\textwidth}{p{0.1\textwidth}|p{0.2\textwidth}|p{0.5\textwidth}}
4 \caption{Feasible triples for highly variable grid} \label{tab:triple_
   grid} \\
5 \hline
6 \hline
7 \textbf{Time (s)} &
8 \textbf{Triple chosen} &
9 \textbf{Other feasible triples} \\
10 \hline
11 \endfirsthead
12 \multicolumn{3}{c}{\textit{Continued from previous page}} \\
13 \hline
14 \hline
15 \textbf{Time (s)} &
16 \textbf{Triple chosen} &
17 \textbf{Other feasible triples} \\
18 \hline
19 \endhead
20 \hline
21 \hline
22 \multicolumn{3}{r}{\textit{Continued on next page}} \\
23 \endfoot
24 \hline
25 \endlastfoot
26 \hline
27
28 0 & (1, 11, 13725) & (1, 12, 10980), (1, 13, 8235), (2, 2, 0), (3, 1, 0) \\
29 & 2745 & (1, 12, 10980) & (1, 13, 8235), (2, 2, 0), (2, 3, 0), (3, 1, 0) \\
30 & 5490 & (1, 12, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
31 & 8235 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
32 & 10980 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
33 & 13725 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
34 & 16470 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
35 & 19215 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
36 & 21960 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
37 & 24705 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
38 & 27450 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
39 & 30195 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
40 & 32940 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
41 & 35685 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
42 & 38430 & (1, 13, 10980) & (2, 2, 2745), (2, 3, 0), (3, 1, 0)

```



```

1286 43 41175 & (1, 12, 13725) & (1, 13, 10980), (2, 2, 2745), (2, 3, 0), (3, 1,
1287 0) \\
1288 44 43920 & (1, 13, 10980) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1289 45 46665 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
1290 46 49410 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
1291 47 52155 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1,
1292 0) \\
1293 48 54900 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1294 49 57645 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1295 50 60390 & (1, 12, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1296 51 63135 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1297 52 65880 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1298 53 68625 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
1299 54 71370 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1300 55 74115 & (1, 12, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1301 56 76860 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1302 57 79605 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1303 58 82350 & (1, 12, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1304 59 85095 & (1, 12, 13725) & (1, 13, 10980), (2, 2, 2745), (2, 3, 0), (3, 1,
1305 0) \\
1306 60 87840 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1307 61 90585 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1308 62 93330 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1309 63 96075 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1310 64 98820 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1311 65 101565 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1312 66 104310 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1313 67 107055 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1314 68 109800 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1315 69 112545 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3,
1316 1, 0) \\
1317 70 115290 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1318 71 118035 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1319 72 120780 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1320 73 123525 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1321 74 126270 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3,
1322 1, 0) \\
1323 75 129015 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
1324 76 131760 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
1325 77 134505 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1326 78 137250 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1327 79 139995 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
1328 80 142740 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
1329 81 145485 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3,
1330 1, 0) \\
1331 82 148230 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
1332 83 150975 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1333 84 153720 & (1, 12, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1334 85 156465 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1335 86 159210 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1336 87 161955 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1337 88 164700 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1338 89 \end{tabularx}
1339 90 }
1340 91 \end{center}

```



1342

**B7    Algorithm or Pseudocode Listing**

1343

1344

1345

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  $\text{\LaTeX}$  code.

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

<b>Input(s):</b>	
$n$	: $n$ th power; $n \in \mathbb{Z}^+$
$x$	: base value; $x \in \mathbb{R}^+$
<b>Output(s):</b>	
$y$	: 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  $\{N \text{ is odd}\}$ 
14:     $y \leftarrow y \times X$ 
15:     $N \leftarrow N - 1$ 
16:  end if
17: end while
```



Listing B.9: Sample L<sup>A</sup>T<sub>E</sub>X 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}

```



## 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)

```

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 */

```



1349

List. B.11 shows the corresponding  $\text{\LaTeX}$  code.

Listing B.11: Sample  $\text{\LaTeX}$  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.
```



## 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

```
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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## 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

```
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.
```

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### 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

```
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.
```

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## 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  $\text{\LaTeX}$  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.
```



## 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  $\text{\LaTeX}$  code for including PDF pages

```
1 \includepdf[pages={8-10},%
2 offset=3.5mm -10mm,%
3 scale=0.73,%
4 frame]
5 {./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 <sup>(1)</sup>	468	780	780	780	650	650	1,404
Maximum HR I/Os <sup>(2)</sup>	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 <sup>(1)(2)(3)</sup>	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 <sup>(1)</sup>	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 <sup>(4)</sup>						832, 52
FLVB2104	47.5x47.5		702, 76	702, 76	702, 76	624, 76	
FHVB2104	52.5x52.5 <sup>(4)</sup>						702, 76
FLVC2104	47.5x47.5		416, 80	416, 80	416, 104	416, 96	
FHVC2104	52.5x52.5 <sup>(4)</sup>						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. ...



# De La Salle University

1414

## Others

1415

1. ...

1416

2. ...

1417

## Award

1418

1. ...

1419

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 knowledgeable about their functions and characteristics. He makes different circuits as a past time.



# De La Salle University



1434 Anfernee Rapio is the teams leader. He is skilled in different fields in  
1435 electrical and eletctronics engineering. He is also skilled in software engineering. He is a  
1436 former member of the DLSU Eco Car Team. One of his favorite circuit designs includes  
1437 relays, operational amplifiers, field programmable gate array, and PIC microcontrollers



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