



Mobile Phone Application for Measuring Air Parameters in Getting Discomfort Index and  
Amount of Air Pollutants with the Use of a Microcontroller-based System

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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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August, 2016



De La Salle University

## ORAL DEFENSE RECOMMENDATION SHEET

This thesis, entitled **Mobile Phone Application for Measuring Air Parameters in Getting Discomfort Index and Amount of Air Pollutants with the Use of a Microcontroller-based System**, prepared and submitted by thesis group, ESG-04, composed of:

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

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August 13, 2016



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## THESIS APPROVAL SHEET

This thesis entitled **Mobile Phone Application for Measuring Air Parameters in Getting Discomfort Index and Amount of Air Pollutants with the Use of a Microcontroller-based System**, prepared and submitted by:

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with group number ESG-04 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

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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.



67

## ABSTRACT

68

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

69

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



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## ABBREVIATIONS

193	AC	Alternating Current.....	59
194	HTML	Hyper-text Markup Language .....	59
195	CSS	Cascading Style Sheet .....	59
196	XML	eXtensible Markup Language .....	59



197

## NOTATION

198	$\mathcal{S}$	a collection of distinct objects . . . . .	61
199	$\mathcal{U}$	the set containing everything . . . . .	61
200	$\emptyset$	the set with no elements . . . . .	61
201	$ \mathcal{S} $	the number of elements in the set $\mathcal{S}$ . . . . .	61
202	$h(t)$	impulse response . . . . .	51
203	$x(t)$	input signal represented in the time domain . . . . .	51
204	$y(t)$	output signal represented in the time domain . . . . .	51

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



211

## GLOSSARY

212

matrix a concise and useful way of uniquely representing and working with linear transformations; a rectangular table of elements .....61



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## Chapter 1

### INTRODUCTION

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## 1.1 Background of the Study

There has been many reasons why one tries to avoid any outdoor activity but one of these is how the air feels whether it is too hot or too polluted or even both. One undeniable fact is that heat and humidity all play roles in making the weather hot. Both of these weather parameters are involved in the calculation of the heat index and the discomfort index.

Heat index and discomfort index have their similarities because the factors that affect these two are the temperature and the relative humidity. The heat index is the perceived temperature by people when the rising temperature and the relative humidity is combined.

The unit used here is a unit of temperature and the mathematical formula for computing the heat index shows a rather direct square proportionality with the temperature and the humidity. But when it comes to a more human readable scale, reaching 34 degrees Celsius is already a discomfort to some. Reaching at least 46 degrees Celsius is already dangerous to all as this can cause heat stroke and even imminent death to some people. The discomfort index is similar to the heat index but instead, its mathematical formula only indicates a direct proportionality with the temperature and the relative humidity. The scaling is rather similar to that in the heat index. When the discomfort index reaches at least 21 degrees Celsius, it is already a discomfort for some people. Reaching 29 degrees Celsius is already dangerous to all that when it even gets higher, a state of emergency can be declared.

The human body is capable of regulating body temperature because of its abilities as a warm-blooded organism. When the human body detects extreme temperatures, it drastically adjusts the body just to get the internal temperature back to a normal 37 degrees Celsius. When your body detects a lot of heat, it tries to cool itself down by increasing your heart rate and sweating. However, one can sweat too much, he feels drained by the lack of fluids



269 in his body causing discomfort, weakness, loss of stamina, and even muscle pains, leading  
270 to a heat stroke.

271 Other than high temperatures and humidity, the pollutants in the air can be harmful to the  
272 respiratory system. Dust is a particle suspended in the air and it usually comes from the soil  
273 or the pollution. This can cause irritation in the respiratory system because dust entering  
274 the lungs can cause serious complications. This is already bad for those with respiratory  
275 problems such as asthma or emphysema. Carbon monoxide, however, is a colorless and  
276 odorless gas and it usually comes from smoke. When this is inhaled, it can cause serious  
277 complications in the body since this inhibits the delivery of oxygen from the blood to the  
278 other organs in the body which can cause death. Not only do all of this increase the risk of  
279 getting sickness but these also affect the visibility of an area.

280 This study will focus on a mobile application that enables people to have a foresight on  
281 how the outside air feels like. A microcontroller-based system will be used in detecting the  
282 parameters stated above while the mobile application will take note of the visibility with  
283 the use of the phone's camera.

## 284 1.2 Prior Studies

285 Some of the studies that the group has found are about the temperature and humidity  
286 monitoring systems. The temperature system can be constructed by using a simple  
287 microcontroller-based system with an important tool, the LM35 where the output voltage is  
288 directly proportional to the temperature detected. The same procedure can be done with  
289 the humidity sensor but this time, it does not make use of the LM35. Both of these sensors  
290 are good for agricultural applications and getting the air quality. Another study involves



the use of PM10 sensors in order to detect particulate matter that is 10 micrometers wide. An algorithm has been made with the use of the atmospheric reflectance for temporal monitoring. Another study introduces another concept of air monitoring by taking note of the pollutants present which are namely carbon monoxide, PM 2.5 , and ozone which make use of the MQ-7 4 sensor, MQ-131 sensor, and Sharp dust sensor respectively. Another study made use of getting the discomfort index by using temperature, humidity, atmospheric pressure, and carbon dioxide sensors. Finally, a study states the standards set by different parts of the world when it comes to the air quality. These standards all make use of the amount of pollutants present in the air as basis of air quality.

### 1.3 Problem Statement

Though there have been mobile applications that display the weather in real time, none have been able to show the discomfort index given the data. Also, there are no applications that tell the amount of dust or carbon monoxide in the air considering that these are some important factors when people choose to commute by an ordinary jeepney or do any outdoor activity in urban areas.

The aim of this study is to develop a new mobile application that is able to report the condition of the air such as weather parameters and the amount of pollutants present. The system will make use of a microcontroller along with different sensors that will measure the said parameters. Also, the mobile application will make use of computer vision to measure the visibility in an area.

Can a mobile application be developed to report real time conditions of the air and the amount of pollutants present with the used of a sensor-based microcontroller system?



## 1.4 Objectives

### 1.4.1 General Objective(s)

To design and develop an indoor/outdoor system for getting the discomfort index of the air...;

### 1.4.2 Specific Objectives

1. To make use of the temperature, humidity, amount of dust, amount of carbon monoxide, and visibility in calculating discomfort index and measuring pollutants
2. To utilize different sensors for temperature, humidity, dust, and carbon monoxide measurement
3. To gather apparent information on the discomfort regarding heat and air pollution with the use of crowd sourcing
4. To make use of computer vision with the use of a cellphone camera to measure visibility
5. To achieve a social impact on the conditions and quality of the air for the people in urban areas where smoke is present and abundant

## 1.5 Significance of the Study

The significance of this topic is to be able to design and produce a device of checking the air quality and discomfort index for the public health awareness. There are millions of



331 commuters in the Philippines riding jeepneys or light rail transit system. The problem of  
 332 this way of commuting is the air because there are a lot of old vehicles producing smoke and  
 333 most people just breathe in either direct or indirect way. It is very important for the people  
 334 to know the status of the air to secure their respiratory health. Together with this, the group  
 335 aim to the user friendly device that anyone can easily understand how to use the device  
 336 through an android application. Since a lot of people uses android mobile phones, making  
 337 an application for free will be very helpful. The application will display the required data  
 338 in graphics so that it is easy to understand for the public and to make the aware of the effect  
 339 of the environment to their health. This study will surely help a lot of people who still dont  
 340 know about why it is important to know the air we are breathing outside.

## 341 1.6 Assumptions, Scope and Delimitations

- 342 1. The given data will only be determined by the air quality index and the discomfort
- 343 index.
- 344 2. The application will be used only for displaying the data gathered in the device.
- 345 3. People should be able to know the importance of their respiratory system in the body.
- 346 4. Users must aware the connection between air pollution and lung cancer.
- 347 5. The device will only deal with the common factors for discomfort such as temperature,
- 348 humidity, and the amount of dust in the air.



## 1.7 Description and Methodology

A device for checking air quality and discomfort index can be functional through the use of the electronic sensors attached in the circuit and sensors for dust, humidity, and temperature will provide the data for air quality index and discomfort index. The device will be user friendly so that anyone can easily control and use it for the given purpose. The goal for this project is to come up with a device and android application for air quality and discomfort index which will provide data related to the health of the public. Challenges to this project would be the design of the circuit with indicated sensors and the accuracy of the data gathered by the device. The size of the device matters because it has to be user friendly and this will be designed for the typical citizens like commuters. The prototype test would determine if it has accurate data and user friendly in general. Android application will be supporting the device as a method of health awareness. the application will be able to show the data gathered in the device and show the effect of air quality index and discomfort index for respiratory health. The information is also one of the important part because people must know why it is important to know the air quality and their discomfort level. The information from the Arduino will be passed on to the HC-06 Bluetooth module in order to relay the information to an Android phone. With the use of crowd sourcing, any Android phone can update the discomfort index and other information from the sensors that will be stored in a firebase database and another phone can access these data.



TABLE 1.1 GANNT CHART PART 1

	W1	W2	W3	W4	W5	W6	W7
Research for a topic	All						
Submission of proposed topic		All					
Background of the study			NP				
Statement of the problem			NP				
Objectives			NP, JC				
Scope and delimitation			JC				
Review of related literature			RN, RP				
Methodology				All	All		
Individual Research				All	All	All	All
Schematic diagram				NP	NP	NP	
Sensor Collection						JC, RN	JC, RN
Sensor Testing							
Arduino programming						NP	NP
Android programming						JC, RN	JC, RN
Android layout							
OpenCV Integration						RP	RP
Board design							
Board layout							
Fabrication							
Mounting							
Proofreading and Revisions							
Final documentation							
Defense							





TABLE 1.2 GANNT CHART PART 2

	W8	W9	W10	W11	W12	W13	W14
Research for a topic							
Submission of proposed topic							
Background of the study							
Statement of the problem							
Objectives							
Scope and delimitation							
Review of related literature							
Methodology							
Individual Research	All	All	All	All	All		
Schematic diagram							
Sensor Collection	JC, RN						
Sensor Testing		All	All	All	All		
Arduino programming	NP	NP	NP	NP	NP		
Android programming	JC, RN	JC, RN	JC, RN	JC, RN	JC, RN		
Android layout			RP, RN	RP, RN	RP, RN		
OpenCV Integration	RP	RP	RP	RP			
Board design							
Board layout							
Fabrication							
Mounting							
Proofreading and Revisions						All	All
Final documentation						All	All
Defense							All

TABLE 1.3 GANNT CHART LEGEND

LEGEND:	
JC	Junlae Cheong
RN	Rohit Nihalani
NP	Noel Paulino
RP	Ryback Po



TABLE 1.4 ESTIMATED BUDGET

Laptop	30000
Android Phone	6000
Arduino Kit	2500
DHT-11	105
PM2.5 Sensor	1600
Carbon Monoxide Sensor	350
TOTAL COST	41055

## 1.8 Estimated Work Schedule and Budget

## 1.9 Overview

In the first chapter, it will be helpful for readers to understand what is the purpose of making the device and android application and why it is important for the society. It also shows how the project will be implemented in the real world from the hypothesis. For the second part of the paper, there will be a lot of helpful literature related to the air quality, discomfort index, respiratory health, prevention of lung cancer, effect of dust to the human body, circuit design for humidity, dust, and temperature sensors. These literature will guide the group what is the right way to develop a project and make it functional in order to fulfill the standard of the public. Theoretical considerations will be the key part to determine the data gathered from the device because there are theoretical standards in other research to know what are the air quality and discomfort index. Considering the design, it will be fully electronic design because the implementation in the hardware will be using electronic circuits. methodology will introduce how the data is gathered in the device and represented to the users. result and discussion will be providing the user feedback and the actual data given by the device in real situation. The value of this project will be determined in the



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384 conclusion based on all the provided data and actual simulation. It is the most important  
385 part to prove how this project fulfilled its purpose for the public health awareness.



## Chapter 2

# LITERATURE REVIEW

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2.6	Air Quality Standards . . . . .	18



There are several existing studies or researches about different kinds of applications of air parameters. Most of the studies found relating to these parameters are temperature, humidity, temporal, wireless air quality and discomfort index monitoring systems and air quality standards.

## 2.1 Temperature Monitoring System

An important parameter, not only in the air but also in everything, is the temperature. It is very important to monitor temperature of objects because most objects are sensitive to changes in the temperature such as products and some machines. Some existing researches of temperature monitoring system are found in the field of agriculture. Recent studies [Chavan and V.Karande, 2014] shows how important data-acquisition systems in the agriculture through environmental monitoring. Environmental monitoring refers to the gathering of data of some parameters in the environment that may affect the products. Automated measurements are beneficial because gathering of data and measurements are made several times. Chavan and Karande have developed a system for wireless monitoring of soil moisture, temperature and humidity in the field of agriculture. The system uses a temperature sensor, humidity sensor and soil moisture sensor that are connected to an AVR microcontroller. It also uses GSM-Zigbee based remote monitoring and control system. The application of Zigbee to the monitoring system in the agriculture reduces human power and enables to evaluate some accurate changes that will happen.

Aside from the agricultural implementation of temperature monitoring, there are also existing studies that involves its application to automated systems for electronic devices or appliances. [Mohamed Abd El-Latif Mowad, 2014] designed a smart home automated



control system. The system uses a microcontroller for sensors and android application for the transmission of data and the receiving of data. One of the four major fields of the smart home system or SHS is the environmental monitoring, which includes the monitoring of the humidity and the temperature. The main components used in the system are microcontroller, adruino board, android and a bluetooth module. Wireless internet services are also used for several monitoring and controlling processes. The passive infrared sensors are capable off detecing movements of a human being through sensing the changes in the temperature over the scene. The SHS also uses LM35 temperature sensor for the Temperature sensing system for Air Conditioner. The system can transfer data from the sensors to the android phone. On the same way, it can transmit data or commands from the android to the appliances. The wireless monitoring of temperature allows the user to control electronic devices or appliances from anywhere in the world.

## 2.2 Humidity Monitoring System

Humidity is always associated with temperature. It plays an important role to human due to the skin being sensitive to the changes in humidity. This is also the reason why humans sweat. Not only humans are affected by the changes in the humidity in the air but also applies to the things related to the field of agriculture.

A group of researchers [Aji Hanggoro and Sari, 2013] designed a green house monitoring and controlling system using an android mobile application. The system can control the humidity inside a green house, based on the readings of the humidity sensor through the microcontroller which is connected to the central server and can be accessed through Wi-Fi connection. The system is consists of humidity sensor, Arduino UNO microcontroller,



441 serial communication, wireless connection and a computer. The data from the sensor  
442 will be transmitted to the microcontroller and transferred to the computer through serial  
443 communication. The computer will transmit the data to the android phone via wireless  
444 connection and the android phone can now control the system depending on the commands  
445 that will be selected. The android can receive data from the humidity sensor, send data  
446 for water sprayer to turn on, send data for stepper motor to work and other commands  
447 that the system is capable of doing. This system ensures the condition of the green house  
448 environment to be in good condition.

449 Other than agricultural applications, studies also shows how air quality such as tem-  
450 perature and humidity affects the health of a human being. Indoor air quality or IAQ is  
451 an important factor that may affect the level of comfort and the health of the people. This  
452 may increase the discomfort index of a human being which may result to difficulties in con-  
453 centration or even headaches. [Folea and Mois, 2015] develop a wireless battery-powered  
454 system for online ambient monitoring. The system has the ability to monitor temperature,  
455 humidity, carbon dioxide level, absolute pressure and intensity of light in the indoor spaces.  
456 The data gathered can be sent through a computer for visualization and can send SMS for  
457 alarms. The system has sensors such as ambient, temperature, humidity and many more  
458 sensors to evaluate the indoor air quality. Wi-Fi connection is used as a data transmission,  
459 from the sensors to the computer, due to the fact that Wi-Fi can be found in almost every  
460 home. The study of indoor air quality will help prevent or solve issues that may affect the  
461 health and the performance of the people.



## 2.3 PM<sub>10</sub> Temporal Monitoring

PM<sub>10</sub> or particulate matter that have a diameter of 10 micrometers wide which are classified under fine particles. One study [Wong et al., 2007] used an internet protocol camera to observe real time changes in the amount of particles found in the air. The camera points to a reference location and the still images were divided into the RGB bands.

They developed an algorithm which makes use of the atmospheric reflectance and the concentration of the PM<sub>10</sub> using regression. The amount of reflectance is measured using a spectroradiometer and the concentration of the particles are determined by the different RGB bands of the camera. The PM<sub>10</sub> and the atmospheric reflectance are found to be linearly related through using the skylight parameter model, which utilizes the sun's radiation. The results produced were compared to a DustTrak meter and provide a high correlation coefficient of .78.

## 2.4 Wireless Air Quality Monitoring System

A study [Reilly et al., 2015] monitored the amount of different air pollutants using Arduino. The pollutants that are measured are carbon monoxide, PM<sub>2.5</sub>, and ozone which make use of the MQ-7 sensor, MQ-131 sensor, and Sharp dust sensor respectively. The sensors are mounted onto a redboard as well as GSM shield to send data wirelessly. The sensors are calibrated using a co-located ADEQ (Air Quality Division) sensor and were validated. The device is placed around the metro area and the data collected will be compared to a monitoring station. Data was collected for a period of time and a trend was found in CO and ozone levels. However, the use of the Sharp dust sensor was not very effective but could find slight differences at high pollution times with low pollution times.





Another similar study [Hebbar et al., 2014] of an air monitoring device is implemented using a microcontroller where several sensors are placed and data is sent through GSM wirelessly. The design tests the amount of CO<sub>2</sub> levels indoors. It also measures the temperature and humidity of the atmosphere locally. Calibration of the sensors is done by concentrating known amount of a certain gas into a test chamber and determine its offset from the results obtained. The design was tested in a seminar hall and the results obtained showed that the start and end of each class attributed to the increase in CO<sub>2</sub> emission. The design also shows the data through an online GUI.

One similar design, called HazeWatch, is done using several sensors and cloud computing [Hu et al., 2016]. The design is made compact and portable and can be mounted onto a car or bike. Data is harvested using a mobile phone and records the location in real time. Data is then sent wirelessly to cloud-based servers and is interpolated (Inverse Weighing and Ordinary Kriging interpolation) to generate estimates. The data can then be view visually using contour maps of the pollution or gas concentration levels in the area. The results obtained are compared to similar products (*Node* and *SensorDrone*)

## 2.5 Discomfort Index Monitoring System

A research was made about the importance of monitoring and controlling of atmospheric conditions to the efficiency of the performance of the human beings [Noh et al., 2013]. They designed a wireless sensor module that uses a Zigbee communication and sensor module, which consists of temperature, humidity, CO<sub>2</sub> and atmospheric pressure sensor, that maintains a comfortable environment for human beings or to prevent discomfort. The sensor module is the transmitter which delivers the sensor data to the receiver and



the receiver will transmit the filtered or recovered sensor data to a microcontroller board in monitoring the room environment. The room monitoring system is able to provide a comfortable environment for human beings through the wireless sensor network or WSN for monitoring the room environment.

## 2.6 Air Quality Standards

This review shows the different indoor air quality standards set by different countries across the world. The data is collected from documents from different health and environmental organization. This paper can be set as a tool for evaluating acceptable concentrations of different pollutants within an area. The pollutants included in this study are "carbon dioxide (CO<sub>2</sub>), carbon monoxide (CO), formaldehyde (HCHO), nitrogen dioxide (NO<sub>2</sub>), sulfur dioxide (SO<sub>2</sub>), total volatile organic compounds (TVOCs) and particulate matter (PM<sub>2.5</sub> and PM<sub>10</sub>).” The amount allowable depends on how bad the amount of a certain pollutant exists indoors. The paper also explains different harmful health effects each pollutant has on the human body.



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## Chapter 3

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## THEORETICAL CONSIDERATIONS

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### 3.1 Microcontroller based temperature humidity meter using Arduino Platform

Arduino is one of the many micro-controller based systems that can be utilized to measure temperature and humidity level. It is a combination of hardware and software computer architecture system that has already made into several versions of small size chipsets. Both of these versions can be used along with the humidity and temperature sensors to detect temperature and humidity in the environment. Temperature and humidity level may vary depends on the locations since every different location are affected by various environments. Different time also affects the result due to the weather change and location of the sun in the sky. The Arduino microcontroller system implemented together with the sensor on a device like a portable temperature and humidity meter. The device used and temperature and humidity sensor must have a physical connection and battery for the power supply. The Arduino device will present the data into a LCD display, in order to make it easier for users to read the humidity and temperature levels.

### 3.2 Discomfort Index

Discomfort index refer to impact of heat and stress on the individual taking account the combined effect of temperature and humidity. This index is used as a standard to inform the user whether their respective places are not comfortable or good enough for an activity. Several temperature and humidity levels will be gathered in order to give a more accurate discomfort index as a result. Proper gathering of temperature and humidity level data is necessary to fulfill the purpose of the discomfort index. It is important for student to know



551 which location at the campus is uncomfortable because stress caused by the environments  
552 affects the welfare of the students at school.

### 553 **3.3 Bluetooth Technology**

554 Bluetooth is a wireless communication technology. This technology deals with the regula-  
555 tion of the flow of data. Data transmission is done through the wireless communication in  
556 this technology there are paired two devices and these devices can communicate to each  
557 other through Bluetooth. After the pairing of devices, there is a process of data transfer.  
558 It is a bidirectional technology since it is capable of sending and receiving data. It has a  
559 limited transmission distance between the two devices and it cannot transmit data in far  
560 distances. The temperature and humidity data from the Arduino device can be transferred  
561 into the android application in terms of wireless Bluetooth communication as indicated  
562 above information.

### 563 **3.4 Comfortability indicator application at De La Salle** 564 **university using Android platform**

565 Android is one of the operating system programs that can be used in various purposes. This  
566 operating system already has several versions such as Ginger Bread, Ice Cream Sandwich,  
567 Jelly Bean, KitKat and Marshmallow. All these versions are compatible with the android  
568 operating system to show the comfortability indicator. Marshmallow is the latest version  
569 and it has the more functions than the older versions but most phones do not support this  
570 version yet. older version of android will be used since it is the version where a lot of



571 students are using it right now. The Comfortability Indicator application will based it on  
572 the temperature and humidity data gathered in the Arduino device and it will display the  
573 heat map to indicate which area is comfortable and which are not. The students will have  
574 information about the discomfort index and the effect of heat and stress to their health and  
575 welfare.



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## Chapter 4

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# DESIGN CONSIDERATIONS

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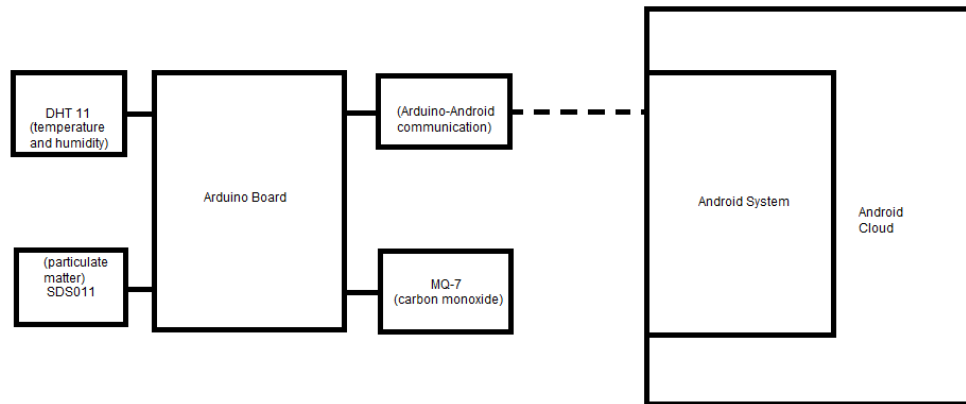


Figure 4.1. System Model of the Project

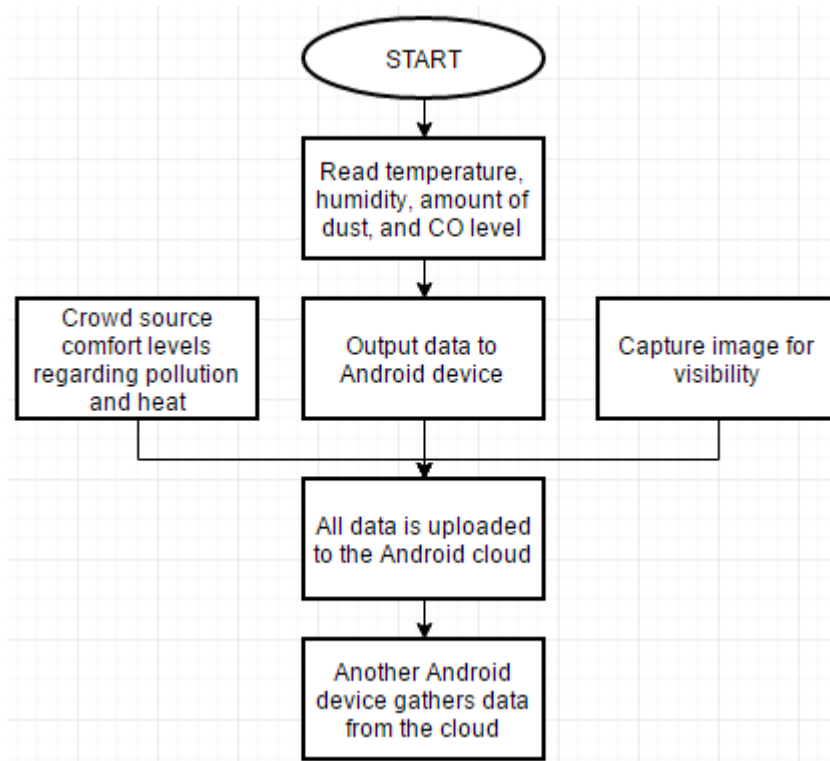


Figure 4.2. System Flowchart



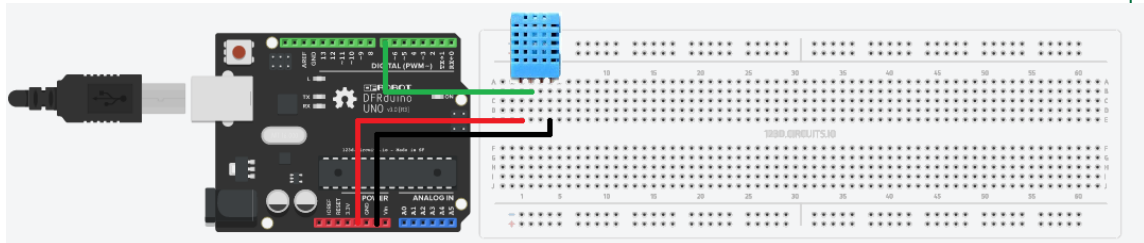


Figure 4.3. Circuit Configuration for Testing the DHT-11

```

1  #include <dht.h>
2
3  dht DHT;
4
5  #define DHT11_PIN 7
6
7  void setup(){
8      Serial.begin(9600);
9  }
10
11 void loop()
12 {
13     int chk = DHT.read11(DHT11_PIN);
14     Serial.print("Temperature = ");
15     Serial.println(DHT.temperature);
16     Serial.print("Humidity = ");
17     Serial.println(DHT.humidity);
18     delay(1000);
19 }

```

Figure 4.4. Code for Temperature and Humidity Gathering

$$DI = T - 0.55(1 - 0.01H)(T - 14.5) \quad (4.1)$$



Figure 4.5. Formula for Discomfort Index

## 4.1 Summary

According to the system model, the project will make use of an Arduino microcontroller system that will handle tasks of gathering inputs which are the temperature, humidity, amount of dust, and amount of carbon monoxide. These data will be transmitted an Android system. Afterwards, this data can be submitted to the Android cloud in real time. Each individual Android system in the cloud can make use of the camera to capture the image of the surroundings in order to get the visibility with the aid of computer vision. A crowdsourcing element is considered to be added in each system where the user can rank the amount of discomfort he feels in terms of the heat and air pollution. This information will be utilized in the cloud.

The current accomplishments for the group is the successful gathering of the temperature and humidity with the use of the Arduino system and the DHT-11 sensor. These values are rounded to the nearest units value.



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## Chapter 5

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## METHODOLOGY

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## 5.1 Implementation

The group has chosen system prototyping as the primary methodology of the study Fig. 5.1. It is effective to use this because Arduino is quick to learn and would be useful in creating prototypes easily. It will also be advantageous to follow this methodology because of the time constraint and weekly updates. This would, however, not be very effective in terms of developing an Android application with a crowdsourcing element and bluetooth communications due to its unfamiliarity to the group.

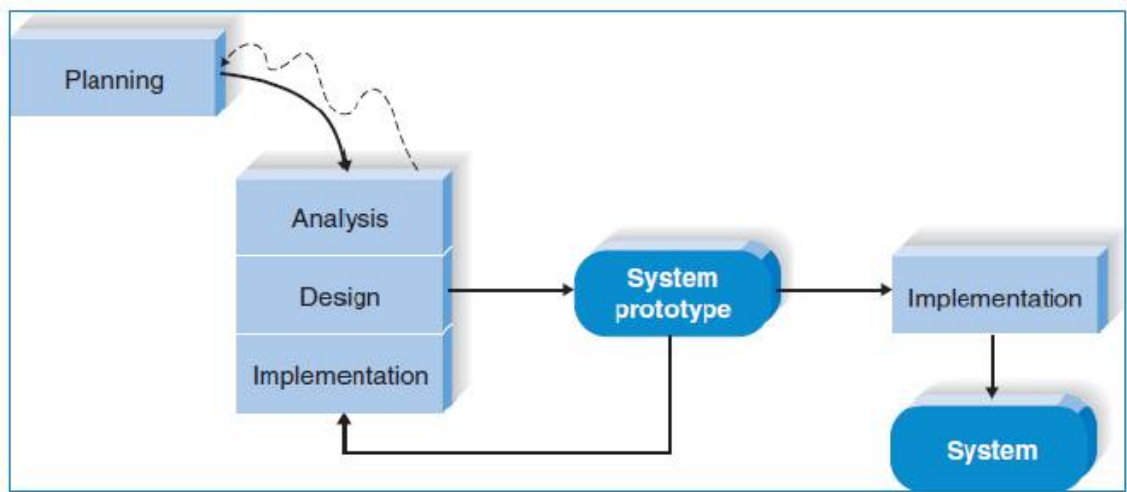


Fig. 5.1 System Prototyping Diagram

### 5.1.1 Planning

The planning stage took around four weeks. In the planning stage, several factors of air quality was taken into consideration. Among these factors are temperature, humidity, dust, and amount of Carbon Monoxide. In creating this design, few more considerations must be accounted for. Among these are portability, Android compatibility, and real time. Different



649 stages must take place in creating the proposed system. These stages will consist of the  
650 integration of the different sensors to our design, testing and evaluating these sensors, and  
651 integrating them in the Android application.

### 652 **5.1.2 Initial Prototype**

653 For the initial prototype, the temperature and humidity are first taken into consideration. The  
654 design will include the DHT11 humidity sensor and an LED display to provide feedback on  
655 the current temperature and humidity as well as the discomfort index of the area. Several  
656 sets of data are first taken in order to retrieve the temperature and humidity. This is done in  
657 order to check the consistency and accuracy of the measuring devices used for comparing  
658 the data collected from our design. The data is taken from 3 different days with 2 analog  
659 and 1 digital sensor. The prototype will make use of the DHT11 sensor and its accuracy  
660 will be tested using the best thermometer and hygrometer.

### 661 **5.1.3 Second Prototype**

662 More features are added in the initial prototype. These will include bluetooth communica-  
663 tions with the Android app as well as integrating crowdsourcing using FireBase. This will  
664 also include the SDS011 particulate matter laser sensor which measures the concentration  
665 of dust present locally. The use of this sensor will have a relative error of 10% . This error  
666 will be tested by comparing the results to a DustTrak or GRIMM dust monitor.



#### 5.1.4 Final Prototype

Using MQ-7 CO sensor, the prototype will be further extended. The range will be from 10 to 500 ppm which is sufficient to determine how harmful the amount is. This too will be compared to an existing CO meter which will be used to measure the reliability of the sensor. The final prototype will also include the integration of visibility detection. The visibility detection will make use of OpenCV by making use of Canny Edge Detection. The prototype will also finalize the Android application's features and design.

#### 5.1.5 Integration of Communication Devices

The data transferred will not only be transferred to the proposed Android application but also to a cloud. This will involve crowdsourcing which would enable several data to be inputted at real time. To transfer the data from the proposed system to the Android application, the SMiRF Bluetooth module or HC-05 Bluetooth module will be used. The data collected will then be transferred to a Firebase database.

### 5.2 Evaluation

The study is to develop a mobile phone application that utilizes the use of a microcontroller-based system to measure air parameters in getting the discomfort index and amount of air pollutants. The discomfort index is dependent on air parameters measured by the system. In relation to the air parameters, the study uses a quantitative approach of data gathering, through actual measurements of air parameters using analog and digital meters and sensors. A crowdsourcing approach was then applied for better information gathering between the users of the applications across the map.



### 5.2.1 Quantitative Approach

Data were gathered four nonconsecutive trials on twenty different locations along De La Salle University. The data collected consists of the measurements of the available meters, one digital and two analog meters, and the measurements of the actual sensors used on the system. The time and date, when the data were taken, were also recorded due to the fact that the parameters greatly vary on the weather and the time it was measured which also leads to inconsistent recorded data.

The gathered data were used to determine the reliability of the measurements from the sensors used in the system, in resemblance to the measurements from the meters. The use of the meters are for establishing the ground truth of the measurements of air parameters. Also, the data were ranked according to their corresponding computed level of discomfort or discomfort index based on the parameters measured using both the meters and the sensors.

### 5.2.2 Crowdsourcing Approach

Due to the fact that the data can only be collected when the user is at the specified location, the android application used in this study integrates a crowdsourcing approach in gathering of data. In this way, the user can be aware of the conditions of the air parameters around a location on the map based on the data from the other users that are in the location.

The application is capable of sharing or storing information in a cloud for crowdsourcing. The cloud is used to hold the data from all the information stored by each user of the application. The crowdsourcing application is very dependent on the user's data and it would be most effective when more people use the application. This approach allows the user to gather information and at the same time, contributes to the cloud-based system of



710 the application which also contributes to the data gathering of other users.

### 711 **5.3 Summary**

712 The proposed design will contain several sensors that will measure temperature, humidity,  
713 particulate matter amount, and levels of carbon dioxide. There are different stages in  
714 gathering the various data required. The sensors will be calibrated based from its individual  
715 datasheets. The data will be taken in a span of two weeks and at different times throughout  
716 the day. The data taken from our design will be compared with commercial sensors that are  
717 readily available to test the reliability and consistency of the proposed design.

718 The data collected from DHT11 sensor for detecting temperature and humidity will  
719 be measured. The design will also use a SDS011 PM laser sensor to record the amount  
720 of dust present within its range. The MQ-7 CO sensor will record the concentrations of  
721 Carbon Monoxide in its vicinity. The range will be from 10 to 500 ppm which is sufficient  
722 to determine how harmful the amount of Carbon Monoxide is. These will be tested with  
723 their corresponding meters and its accuracy will be determined. The data collected will  
724 be sent to a database in a cloud and transferred to the Android application. The program  
725 within the application will handle the discomfort index calculation and will determine level  
726 of discomfort.





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## Chapter 6

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# RESULTS AND DISCUSSION

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The goal of this research is to be able to provide a system that makes use of an Arduino-based measuring device that can pass on data with a Bluetooth module to an Android phone that can be able to relay this data to a firebase database that can be accessed by another Android phone.

In order to be able to verify the temperature-humidity sensor being used, another device will serve as the basis for true data. Measurements coming from the TH-65, a digital temperature and humidity measuring device, will be established as ground truth.

The following graphs show the accuracy testing of the DHT-11 with the TH-65 as the basis for ground truth. The blue data represents the temperature measured by the DHT-11 while the orange represents data coming from the TH-65. Temperature, humidity, and discomfort index are to be considered in this set of data. From the results, it has been shown that in measuring temperature, the DHT-11 sensor shows 98.91% accuracy and in humidity, the sensor is 89.66% accurate in terms of measuring humidity and in discomfort index, the sensor is 97.79% accurate.

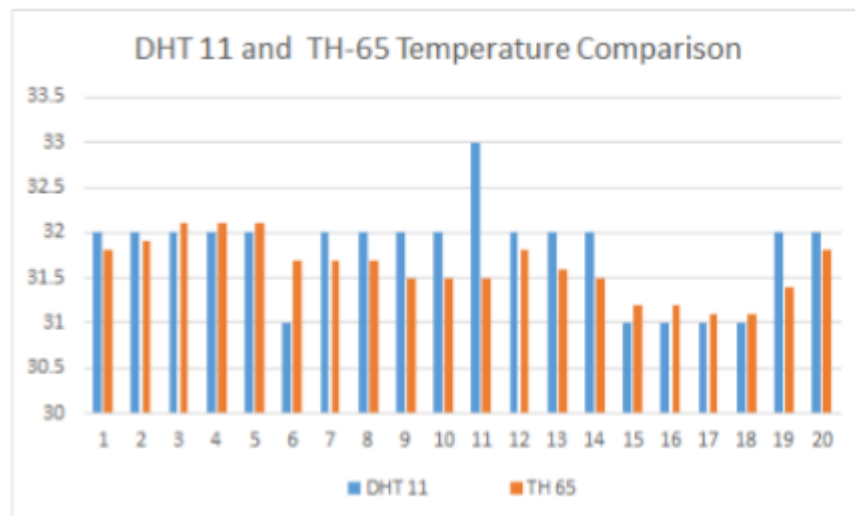


Fig. 6.1 Accuracy Testing of Temperature from DHT-11 sensor

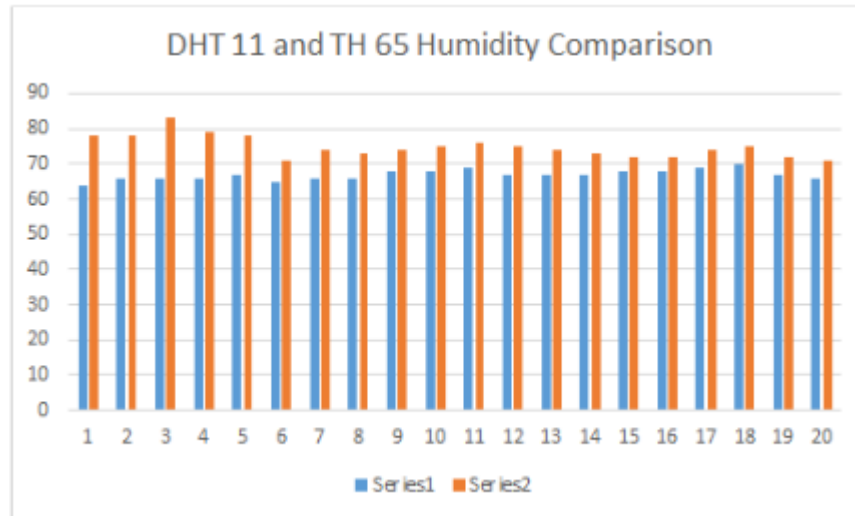


Fig. 6.2 Accuracy Testing of Humidity from DHT-11 sensor

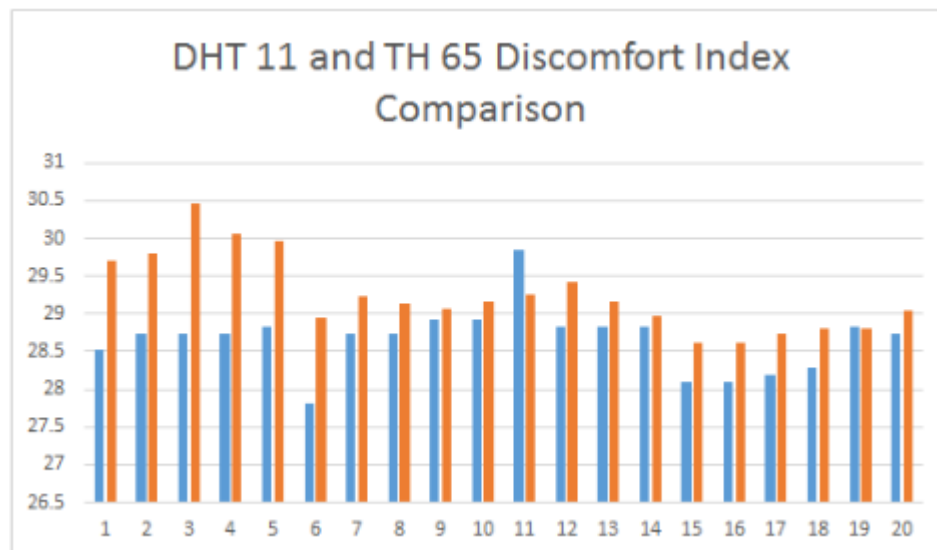


Fig. 6.3 Accuracy Testing of Discomfort Index from DHT-11 sensor



## Chapter 7

# CONCLUSIONS, RECOMMENDATIONS, AND FUTURE DIRECTIVES

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## 7.1 Concluding Remarks

In this Thesis, . . .

## 7.2 Contributions

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

- the ;
- the ;
- the ;

## 7.3 Recommendations

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## 812 7.4 Future Prospects

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

815 1. the ....

816 2. the ....

817 3. the ....



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# Appendix A ANSWERS TO QUESTIONS TO THIS THESIS

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## 885 **A1 How important is the problem to practice?**

886 The Philippines is a country that is prone to discomfort due to the inevitable elements of air  
887 pollution and rising heat levels. An Android application for awareness can be able to alert  
888 the locals about these issues.

## 889 **A2 How will you know if the solution/s that you will** 890 **achieve would be better than existing ones?**

891 Currently, there are no Android applications that provide real-time updates on discomfort  
892 index and amount of dust and carbon monoxide in a Philippine implementation.

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

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

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

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



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

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

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

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

933 **A3 What is the difference of the solution/s from ex-**  
 934 **isting ones?**

935 Weather reports provide temperature and humidity in different parts of the world but our  
 936 solution combines them both into a discomfort index derived from heat which is an essential  
 937 factor in the levels of comfort of an individual.

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

939 Weather stations provide measurements pertaining to temperature and humidity but in this  
 940 solution, the measurements can be accurately measured with an Arduino-based system.  
 941 The crowd sourcing element in the research enables these data to be updated time and time  
 942 again, faster than an selecting an interval of a daily update.



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

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

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

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

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



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

## 977 **A5 What is the necessity of your approach / pro-** 978 **posed solution/s?**

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

### 988 **A5.1 What will be the limits of applicability of your proposed so-** 989 **lution/s?**

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

### 999 **A5.2 What will be the message of the proposed solution to** 1000 **technical people? How about to non-technical managers** 1001 **and business men?**

1002 Lorem ipsum dolor sit amet, consectetur adipiscing elit. Etiam lobortis facilisis sem.  
1003 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec  
1004 ullamcorper, felis non sodales commodo, lectus velit ultrices augue, a dignissim nibh lectus  
1005 placerat pede. Vivamus nunc nunc, molestie ut, ultricies vel, semper in, velit. Ut porttitor.  
1006 Praesent in sapien. Lorem ipsum dolor sit amet, consectetur adipiscing elit. Duis fringilla



1007 tristique neque. Sed interdum libero ut metus. Pellentesque placerat. Nam rutrum augue  
1008 a leo. Morbi sed elit sit amet ante lobortis sollicitudin. Praesent blandit blandit mauris.  
1009 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit  
1010 amet ipsum. Nunc quis urna dictum turpis accumsan semper.

## 1011 **A6 How will you know if your proposed solution/s** 1012 **is/are correct?**

1013 Lorem ipsum dolor sit amet, consectetur adipiscing elit. Etiam lobortis facilisis sem.  
1014 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec  
1015 ullamcorper, felis non sodales commodo, lectus velit ultrices augue, a dignissim nibh lectus  
1016 placerat pede. Vivamus nunc nunc, molestie ut, ultricies vel, semper in, velit. Ut porttitor.  
1017 Praesent in sapien. Lorem ipsum dolor sit amet, consectetur adipiscing elit. Duis fringilla  
1018 tristique neque. Sed interdum libero ut metus. Pellentesque placerat. Nam rutrum augue  
1019 a leo. Morbi sed elit sit amet ante lobortis sollicitudin. Praesent blandit blandit mauris.  
1020 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit  
1021 amet ipsum. Nunc quis urna dictum turpis accumsan semper.

### 1022 **A6.1 Will your results warrant the level of mathematics used** 1023 **(i.e., will the end justify the means)?**

1024 Lorem ipsum dolor sit amet, consectetur adipiscing elit. Etiam lobortis facilisis sem.  
1025 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec  
1026 ullamcorper, felis non sodales commodo, lectus velit ultrices augue, a dignissim nibh lectus  
1027 placerat pede. Vivamus nunc nunc, molestie ut, ultricies vel, semper in, velit. Ut porttitor.  
1028 Praesent in sapien. Lorem ipsum dolor sit amet, consectetur adipiscing elit. Duis fringilla  
1029 tristique neque. Sed interdum libero ut metus. Pellentesque placerat. Nam rutrum augue  
1030 a leo. Morbi sed elit sit amet ante lobortis sollicitudin. Praesent blandit blandit mauris.  
1031 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit  
1032 amet ipsum. Nunc quis urna dictum turpis accumsan semper.

## 1033 **A7 Is/are there an/\_ alternative way/s to get to the** 1034 **same solution/s?**

1035 Lorem ipsum dolor sit amet, consectetur adipiscing elit. Etiam lobortis facilisis sem.  
1036 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec  
1037 ullamcorper, felis non sodales commodo, lectus velit ultrices augue, a dignissim nibh lectus



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

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

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

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

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

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

Lorem ipsum dolor sit amet, consectetur adipiscing elit. Etiam lobortis facilisis sem. Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec





1070 ullamcorper, felis non sodales commodo, lectus velit ultrices augue, a dignissim nibh lectus  
 1071 placerat pede. Vivamus nunc nunc, molestie ut, ultricies vel, semper in, velit. Ut porttitor.  
 1072 Praesent in sapien. Lorem ipsum dolor sit amet, consectetur adipiscing elit. Duis fringilla  
 1073 tristique neque. Sed interdum libero ut metus. Pellentesque placerat. Nam rutrum augue  
 1074 a leo. Morbi sed elit sit amet ante lobortis sollicitudin. Praesent blandit blandit mauris.  
 1075 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit  
 1076 amet ipsum. Nunc quis urna dictum turpis accumsan semper.

### 1077 **A8.1 What are the weaknesses of your proposal?**

1078 Lorem ipsum dolor sit amet, consectetur adipiscing elit. Etiam lobortis facilisis sem.  
 1079 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec  
 1080 ullamcorper, felis non sodales commodo, lectus velit ultrices augue, a dignissim nibh lectus  
 1081 placerat pede. Vivamus nunc nunc, molestie ut, ultricies vel, semper in, velit. Ut porttitor.  
 1082 Praesent in sapien. Lorem ipsum dolor sit amet, consectetur adipiscing elit. Duis fringilla  
 1083 tristique neque. Sed interdum libero ut metus. Pellentesque placerat. Nam rutrum augue  
 1084 a leo. Morbi sed elit sit amet ante lobortis sollicitudin. Praesent blandit blandit mauris.  
 1085 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit  
 1086 amet ipsum. Nunc quis urna dictum turpis accumsan semper.





De La Salle University

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## **Appendix B**

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## **USAGE EXAMPLES**



The user is expected to have a working knowledge of  $\text{\LaTeX}$ . 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  $\text{\LaTeX}$ . 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  $\text{\LaTeX}$  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  $y(t)$  is the result of the convolution of the input signal  $x(t)$  and the impulse response  $h(t)$ .

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

Other example equations are as follows.

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

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

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



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The verbatim  $\text{\LaTeX}$  code of Sec. B1 is in List. B.1.

Listing B.1: Sample  $\text{\LaTeX}$  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\right\right\rfloor 2^{\{-17\lfloor x \rfloor - \mathrm{mod}(\lfloor y \rfloor, 17)\},2\right)\right\rfloor,
24 \end{eqnarray}
25
26 \begin{eqnarray}
27   \left| \zeta(x)^3\zeta(x+iy)^4\zeta(x+2iy) \right| =
28   \exp\sum_{n,p}\frac{3+4\cos(ny\log p) +\cos(2ny\log p)}{n^p}\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  $\mathbf{E}$ .

1117 **Tensor symbols**

1118 Symbols for tensors are sans-serif bold italic,

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

1119 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  $E$ .



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The verbatim  $\text{\LaTeX}$  code of Sec. B2 is in List. B.2.Listing B.2: Sample  $\text{\LaTeX}$  code for notations usage

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```

1 % A teststring with Latin and Greek letters::
2 \newcommand{\teststring}{%
3 % capital Latin letters
4 % A,B,C,
5 A,B,
6 % capital Greek letters
7 %\Gamma,\Delta,\Theta,\Lambda,\Xi,\Pi,\Sigma,\Upsilon,\Phi,\Psi,
8 \Gamma,\Delta,\Theta,\Lambda,\Xi,\Pi,\Sigma,\Phi,\Psi,\Omega,
9 % small Greek letters
10 \alpha,\beta,\pi,\nu,\omega,
11 % small Latin letters:
12 % compare \nu, \omega, v, and w
13 v,w,
14 % digits
15 0,1,9
16 }
17
18
19 \subsection*{Math alphabets}
20
21 If there are other symbols in place of Greek letters in a math
22 alphabet, it uses T1 or OT1 font encoding instead of OML.
23
24 \begin{eqnarray*}
25 \mbox{\mathnormal} & & \mbox{\teststring} \\
26 \mbox{\mathit} & & \mbox{\mathit{\teststring}} \\
27 \mbox{\mathrm} & & \mbox{\mathrm{\teststring}} \\
28 \mbox{\mathbf} & & \mbox{\mathbf{\teststring}} \\
29 \mbox{\mathsf} & & \mbox{\mathsf{\teststring}} \\
30 \mbox{\mathtt} & & \mbox{\mathtt{\teststring}} \\
31 \end{eqnarray*}
32 New alphabets bold-italic, sans-serif-italic, and sans-serif-bold-
33 italic.
34 \begin{eqnarray*}
35 \mbox{\mathbfit} & & \mbox{\mathbfit{\teststring}} \\
36 \mbox{\mathsf fit} & & \mbox{\mathsf fit{\teststring}} \\
37 \mbox{\mathsf bfit} & & \mbox{\mathsf bfit{\teststring}} \\
38 \end{eqnarray*}
39 %
40 Do the math alphabets match?
41 $
42 \mathnormal {a x \alpha \omega}
43 \mathbfit {a x \alpha \omega}
44 \mathsf bfit {a x \alpha \omega}
45 \quad
46 \mathsf bfit {T C \Theta \Gamma}
47 \mathbfit {T C \Theta \Gamma}
48 \mathnormal {T C \Theta \Gamma}
49 $
50
51 \subsection*{Vector symbols}
52

```



```

1189 53 Alphabetic symbols for vectors are boldface italic,
1190 54  $\vec{\lambda} = \vec{e}_1 \cdot \vec{a}$ ,
1191 55 while numeric ones (e.g. the zero vector) are bold upright,
1192 56  $\vec{a} + \vec{0} = \vec{a}$ .
1193 57
1194 58 \subsection*{Matrix symbols}
1195 59
1196 60 Symbols for matrices are boldface italic, too:%
1197 61 \footnote{However, matrix symbols are usually capital letters whereas
1198 62 vectors
1199 62 are small ones. Exceptions are physical quantities like the force
1200 63 vector  $\vec{F}$  or the electrical field  $\vec{E}$ .%
1201 64 }
1202 65  $\Lambda = E \cdot A$ .
1203 66
1204 67
1205 68 \subsection*{Tensor symbols}
1206 69
1207 70 Symbols for tensors are sans-serif bold italic,
1208 71
1209 72 \[
1210 73 \quad \text{\textit{\textbf{tensorsym{\alpha}}}} = \text{\textit{\textbf{tensorsym{e}}}} \cdot \text{\textit{\textbf{tensorsym{a}}}}
1211 74 \quad \quad \quad \Longleftrightarrow \quad \quad \quad
1212 75 \quad \alpha_{ijl} = e_{ijk} \cdot a_{kl}.
1213 76 \]
1214 77
1215 78
1216 79 The permittivity tensor describes the coupling of electric field and
1217 80 displacement: \[
1218 81 \vec{D} = \epsilon_0 \text{\textit{\textbf{tensorsym{\epsilon}}}}_{\text{\textit{\textbf{r}}}} \vec{E} \]
1219 82
1220 83
1221 84
1222 85 \newpage
1223 86 \subsection*{Bold math version}
1224 87
1225 88 The ‘‘bold’’ math version is selected with the commands
1226 89 \verb+\boldmath+ or \verb+\mathversion{bold}+
1227 90
1228 91 {\boldmath
1229 92 \begin{eqnarray*}
1230 93 \quad \text{\textbf{mbox{\mathnormal}}} & & \text{\textbf{\teststring}} \\
1231 94 \quad \text{\textbf{mbox{\mathit}}} & & \text{\textbf{\mathit{\teststring}}} \\
1232 95 \quad \text{\textbf{mbox{\mathrm}}} & & \text{\textbf{\mathrm{\teststring}}} \\
1233 96 \quad \text{\textbf{mbox{\mathbf}}} & & \text{\textbf{\mathbf{\teststring}}} \\
1234 97 \quad \text{\textbf{mbox{\mathsf}}} & & \text{\textbf{\mathsf{\teststring}}} \\
1235 98 \quad \text{\textbf{mbox{\mathtt}}} & & \text{\textbf{\mathtt{\teststring}}} \\
1236 99 \end{eqnarray*}
1237 100 \quad New alphabets bold-italic, sans-serif-italic, and sans-serif-bold-
1238 101 \quad italic.
1239 102 \begin{eqnarray*}
1240 102 \quad \text{\textbf{mbox{\mathbf}}} & & \text{\textbf{\mathbf{\teststring}}} \\
1241 103 \quad \text{\textbf{mbox{\mathsf}}} & & \text{\textbf{\mathsf{\teststring}}} \\
1242 104 \quad \text{\textbf{mbox{\mathsfbf}}} & & \text{\textbf{\mathsfbf{\teststring}}} \\
1243 105 \end{eqnarray*}
1244 106 \quad %
1245 107 Do the math alphabets match?

```





```

1246 108
1247 109 $
1248 110 \mathnormal {a x \alpha \omega}
1249 111 \mathbfit {a x \alpha \omega}
1250 112 \mathsfbfit{a x \alpha \omega}
1251 113 \quad
1252 114 \mathsfbfit{T C \Theta \Gamma}
1253 115 \mathbfit {T C \Theta \Gamma}
1254 116 \mathnormal {T C \Theta \Gamma}
1255 117 $
1256 118
1257 119 \subsection*{Vector symbols}
1258 120
1259 121 Alphabetic symbols for vectors are boldface italic,
1260 122 $\vec{\lambda}=\vec{e}_{1}\cdot\vec{a}$,
1261 123 while numeric ones (e.g. the zero vector) are bold upright,
1262 124 $\vec{a} + \vec{0} = \vec{a}$.
1263 125
1264 126
1265 127
1266 128
1267 129 \subsection*{Matrix symbols}
1268 130
1269 131 Symbols for matrices are boldface italic, too:%
1270 132 \footnote{However, matrix symbols are usually capital letters whereas
1271 133 vectors
1272 134 are small ones. Exceptions are physical quantities like the force
1273 135 vector $\vec{F}$ or the electrical field $\vec{E}$.%
1274 136 }
1275 136 $\matrixsym{\Lambda}=\matrixsym{E}\cdot\matrixsym{A}$.
1276 137
1277 138
1278 139 \subsection*{Tensor symbols}
1279 140
1280 141 Symbols for tensors are sans-serif bold italic,
1281 142
1282 143 \[
1283 144 \quad \tensorsym{\alpha} = \tensorsym{e}\cdot\tensorsym{a}
1284 145 \quad \Longleftarrow \quad
1285 146 \quad \alpha_{ijl} = e_{ijk}\cdot a_{kl}.
1286 147 \]
1287 148
1288 149 The permittivity tensor describes the coupling of electric field and
1289 150 displacement: \[
1290 151 \vec{D}=\epsilon_{0}\tensorsym{\epsilon}_{\mathrm{r}}\vec{E}\]
1291 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).



- 1322 • Provide your own link text: style sheet.

1323 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}

```



1338

**B5 Figure**

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1340

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.

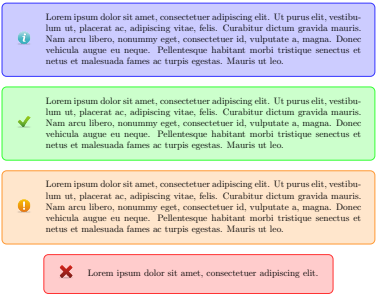


Fig. B.1 A quadrilateral image example.



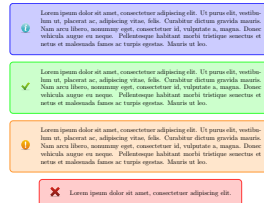
1341 Fig. B.1 is a gray box enclosed by a dark border. List. B.5 shows the corresponding  
1342  $\text{\LaTeX}$  code.

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

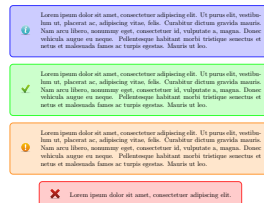
```
1 \begin{figure}[!htbp]
2   \centering
3   \includegraphics[width=0.5\textwidth]{example}
4   \caption{A quadrilateral image example.}
5   \label{fig:example}
6 \end{figure}
7 \cleardoublepage
8
9 Fig.~\ref{fig:example} is a gray box enclosed by a dark border. List.~\ref{lst:onefig} shows the corresponding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



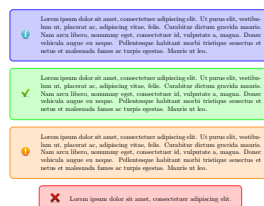
# De La Salle University



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



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

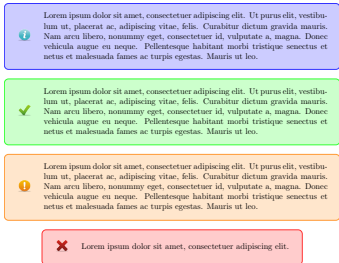


(c) A sub-figure in the bottom row

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

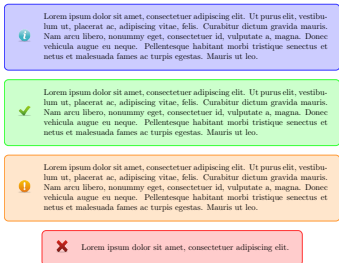
```
1 \begin{figure}[!htbp]
2 \centering
3 \subbottom[A sub-figure in the top row.]{
4 \includegraphics[width=0.35\textwidth]{example}
5 \label{fig:top}
6 }
7 \vfill
8 \subbottom[A sub-figure in the middle row.]{
9 \includegraphics[width=0.35\textwidth]{example}
10 \label{fig:mid}
11 }
12 \vfill
13 \subbottom[A 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}
```





(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}

```



1343

**B6 Table**

1344

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)

```



```

1401 43 41175 & (1, 12, 13725) & (1, 13, 10980), (2, 2, 2745), (2, 3, 0), (3, 1,
1402      0) \\
1403 44 43920 & (1, 13, 10980) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1404 45 46665 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
1405 46 49410 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
1406 47 52155 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1,
1407      0) \\
1408 48 54900 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1409 49 57645 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1410 50 60390 & (1, 12, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1411 51 63135 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1412 52 65880 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1413 53 68625 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
1414 54 71370 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1415 55 74115 & (1, 12, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1416 56 76860 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1417 57 79605 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1418 58 82350 & (1, 12, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1419 59 85095 & (1, 12, 13725) & (1, 13, 10980), (2, 2, 2745), (2, 3, 0), (3, 1,
1420      0) \\
1421 60 87840 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1422 61 90585 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1423 62 93330 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1424 63 96075 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1425 64 98820 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1426 65 101565 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1427 66 104310 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1428 67 107055 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1429 68 109800 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1430 69 112545 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3,
1431      1, 0) \\
1432 70 115290 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1433 71 118035 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1434 72 120780 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1435 73 123525 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1436 74 126270 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3,
1437      1, 0) \\
1438 75 129015 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
1439 76 131760 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
1440 77 134505 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1441 78 137250 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1442 79 139995 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
1443 80 142740 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
1444 81 145485 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3,
1445      1, 0) \\
1446 82 148230 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
1447 83 150975 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1448 84 153720 & (1, 12, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1449 85 156465 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1450 86 159210 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1451 87 161955 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1452 88 164700 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1453 89 \end{tabularx}
1454 90 }
1455 91 \end{center}

```



1457

**B7 Algorithm or Pseudocode Listing**

1458

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.

1459

1460

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 */

```



1464

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.
```

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



## 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.
```

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



### 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.
```

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



## 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

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# De La Salle University

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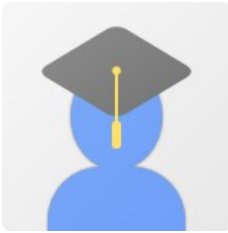
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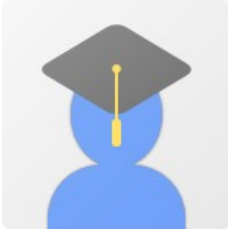
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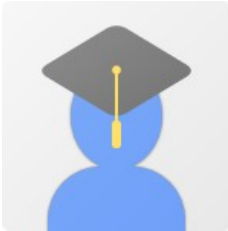
## Appendix D VITA



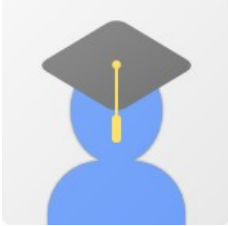
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