



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

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

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

by

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July, 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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THESIS APPROVAL SHEET

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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

189	AC	Alternating Current.....	58
190	CSS	Cascading Style Sheet	58
191	HTML	Hyper-text Markup Language	58
192	XML	eXtensible Markup Language	58



193

NOTATION

194	$ \mathcal{S} $	the number of elements in the set \mathcal{S}	60
195	\emptyset	the set with no elements	60
196	$h(t)$	impulse response	50
197	\mathcal{S}	a collection of distinct objects	60
198	\mathcal{U}	the set containing everything	60
199	$x(t)$	input signal represented in the time domain	50
200	$y(t)$	output signal represented in the time domain	50

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



207

GLOSSARY

208

matrix a concise and useful way of uniquely representing and working with linear transformations; a rectangular table of elements 60



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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



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

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

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

280 1.2 Prior Studies

281 Some of the studies that the group has found are about the temperature and humidity
282 monitoring systems. The temperature system can be constructed by using a simple
283 microcontroller-based system with an important tool, the LM35 where the output voltage is
284 directly proportional to the temperature detected. The same procedure can be done with
285 the humidity sensor but this time, it does not make use of the LM35. Both of these sensors
286 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?



309 1.4 Objectives

310 1.4.1 General Objective(s)

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

313 1.4.2 Specific Objectives

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

324 1.5 Significance of the Study

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



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

337 **1.6 Assumptions, Scope and Delimitations**

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



345 1.7 Description and Methodology

346 A device for checking air quality and discomfort index can be functional through the use of
347 the electronic sensors attached in the circuit and sensors for dust, humidity, and temperature
348 will provide the data for air quality index and discomfort index. The device will be user
349 friendly so that anyone can easily control and use it for the given purpose. The goal for this
350 project is to come up with a device and android application for air quality and discomfort
351 index which will provide data related to the health of the public. Challenges to this project
352 would be the design of the circuit with indicated sensors and the accuracy of the data
353 gathered by the device. The size of the device matters because it has to be user friendly
354 and this will be designed for the typical citizens like commuters. The prototype test would
355 determine if it has accurate data and user friendly in general. Android application will be
356 supporting the device as a method of health awareness. the application will be able to show
357 the data gathered in the device and show the effect of air quality index and discomfort index
358 for respiratory health. The information is also one of the important part because people
359 must know why it is important to know the air quality and their discomfort level.

360 1.8 Estimated Work Schedule and Budget

361 1.9 Overview

362 In the first chapter, it will be helpful for readers to understand what is the purpose of
363 making the device and android application and why it is important for the society. It also
364 shows how the project will be implemented in the real world from the hypothesis. For the
365 second part of the paper, there will be a lot of helpful literature related to the air quality,



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 ESTIMATED BUDGET

Laptop	30000
Android Phone	6000
Microcontroller	250
Temperature Sensor	85
Humidity Sensor	400
PM2.5 Sensor	1600
Carbon Monoxide Sensor	350
TOTAL COST	38685

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



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Chapter 2

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LITERATURE REVIEW

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2.6	Air Quality Standards	17
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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,



433 serial communication, wireless connection and a computer. The data from the sensor
434 will be transmitted to the microcontroller and transferred to the computer through serial
435 communication. The computer will transmit the data to the android phone via wireless
436 connection and the android phone can now control the system depending on the commands
437 that will be selected. The android can receive data from the humidity sensor, send data
438 for water sprayer to turn on, send data for stepper motor to work and other commands
439 that the system is capable of doing. This system ensures the condition of the green house
440 environment to be in good condition.

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



2.3 PM₁₀ Temporal Monitoring

PM₁₀ 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 PM₁₀ 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 PM₁₀ 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_{2.5}, 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 CO₂ 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 CO₂ 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, CO₂ 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_2), carbon monoxide (CO), formaldehyde (HCHO), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), total volatile organic compounds (TVOCs) and particulate matter ($\text{PM}_{2.5}$ and PM_{10}).” 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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3.3	Bluetooth Technology	20
3.4	Comfortability indicator application at De La Salle university using Android platform	20



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



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

545 **3.3 Bluetooth Technology**

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

555 **3.4 Comfortability indicator application at De La Salle** 556 **university using Android platform**

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



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



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Chapter 4

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DESIGN CONSIDERATIONS

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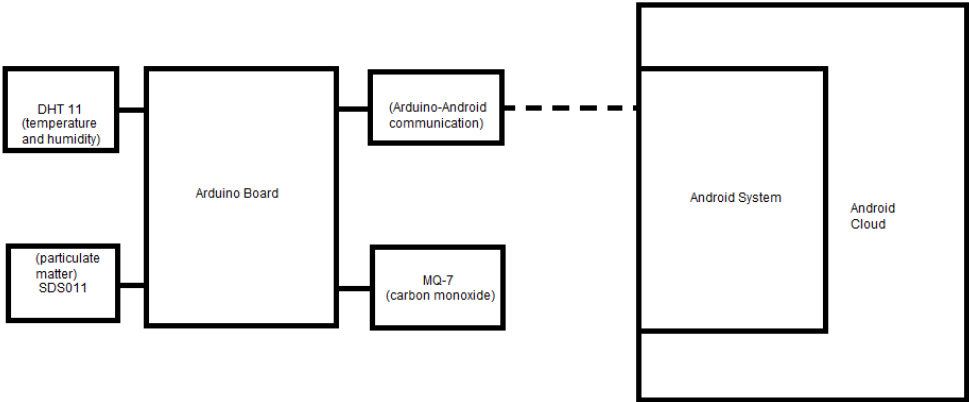


Figure 4.1. System Model of the Project

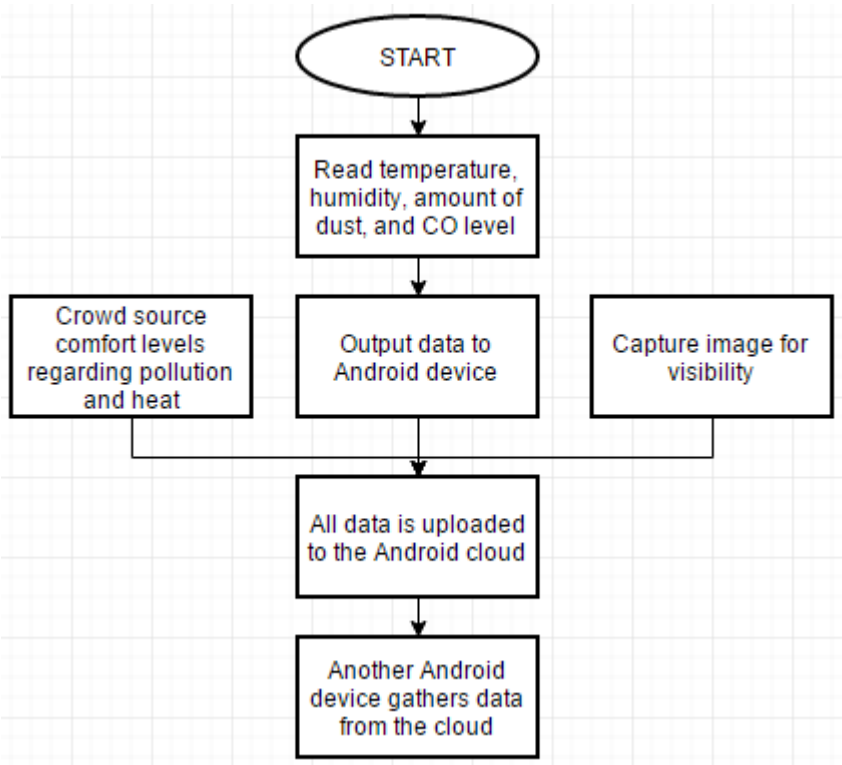


Figure 4.2. System Flowchart

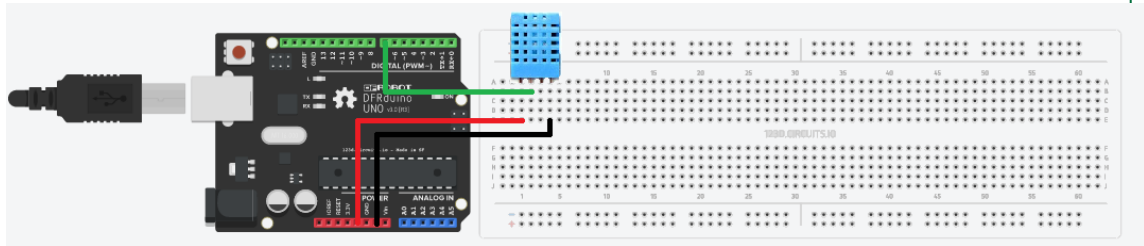


Figure 4.3. Circuit Configuration for Testing the DHT-11

```

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.

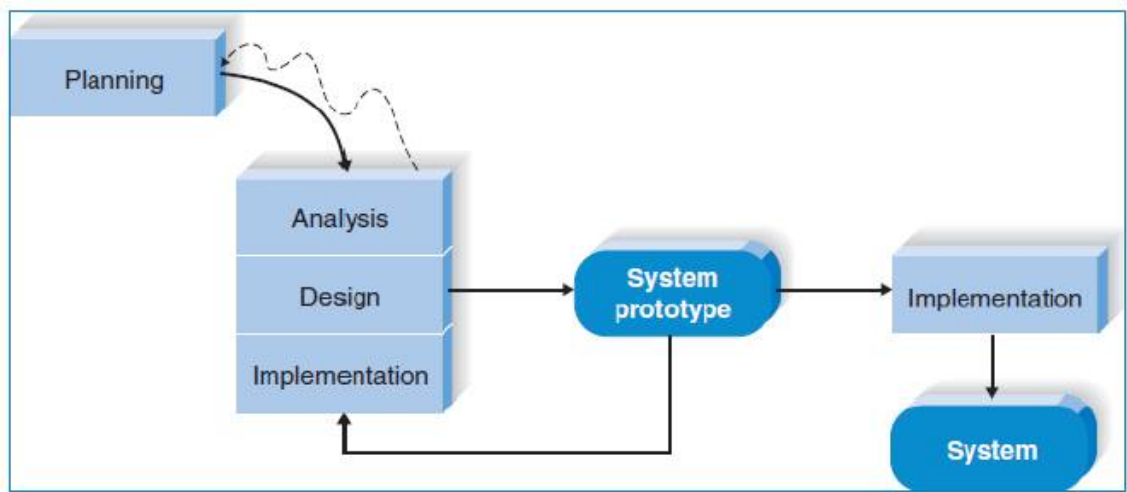


Fig. 5.1 System Prototyping Diagram

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



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

644 **5.1.2 Initial Prototype**

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

653 **5.1.3 Second Prototype**

654 More features are added in the initial prototype. These will include bluetooth communica-
655 tions with the Android app as well as integrating crowdsourcing using FireBase. This will
656 also include the SDS011 particulate matter laser sensor which measures the concentration
657 of dust present locally. The use of this sensor will have a relative error of 10% . This error
658 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



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

703 **5.3 Summary**

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

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



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Chapter 6

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RESULTS AND DISCUSSION

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770 6.1 Summary



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Chapter 7

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CONCLUSIONS, RECOMMENDATIONS,

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AND FUTURE DIRECTIVES

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781 **7.1 Concluding Remarks**

782 In this Thesis, . . .

783 **7.2 Contributions**

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

- 786 • the ;
- 787 • the ;
- 788 • the ;

789 **7.3 Recommendations**

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835 7.4 Future Prospects

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

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Appendix A

ANSWERS TO QUESTIONS TO THIS THESIS

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908

A1 How important is the problem to practice?

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

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

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

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

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

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

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

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

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

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1035 **A5.1 What will be the limits of applicability of your proposed so-**
1036 **lution/s?**

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1045 amet ipsum. Nunc quis urna dictum turpis accumsan semper.

1046 **A5.2 What will be the message of the proposed solution to**
1047 **technical people? How about to non-technical managers**
1048 **and business men?**

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1057 amet ipsum. Nunc quis urna dictum turpis accumsan semper.

1058 **A6 How will you know if your proposed solution/s**
1059 **is/are correct?**

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1068 amet ipsum. Nunc quis urna dictum turpis accumsan semper.

1069 **A6.1 Will your results warrant the level of mathematics used**
1070 **(i.e., will the end justify the means)?**

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1080 **A7 Is/are there an/_ alternative way/s to get to the**
1081 **same solution/s?**

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1091 **A7.1 Can you come up with illustrating examples, or even bet-**
1092 **ter, counter examples to your proposed solution/s?**

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1101 amet ipsum. Nunc quis urna dictum turpis accumsan semper.

1102 **A7.2 Is there an approximation that can arrive at the essen-** 1103 **tially the same proposed solution/s more easily?**

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1112 amet ipsum. Nunc quis urna dictum turpis accumsan semper.

1113 **A8 If you were the examiner of your proposal, how** 1114 **would you present the proposal in another way?**

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1116 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec
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1124 **A8.1 What are the weaknesses of your proposal?**

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De La Salle University

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Appendix B

1135

USAGE EXAMPLES



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

B1 Equations

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

In (B.1), the output signal $y(t)$ 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.

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

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

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



1149

The verbatim L^AT_EX code of Sec. B1 is in List. B.1.

Listing B.1: Sample L^AT_EX code for equations and notations usage

```

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

```



B2 Notations

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

Math alphabets

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

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

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

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

Do the math alphabets match?

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

Vector symbols

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

Matrix symbols

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

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



1164

Tensor symbols

1165

Symbols for tensors are sans-serif bold italic,

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

1166

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:² $\Lambda = E \cdot A$.

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:

$$D = \epsilon_0 \epsilon_r E$$

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



1181 The verbatim \LaTeX code of Sec. B2 is in List. B.2.

Listing B.2: Sample \LaTeX code for notations usage

```

1182 1 % A teststring with Latin and Greek letters::
1183 2 \newcommand{\teststring}{%
1184 3 % capital Latin letters
1185 4 % A,B,C,
1186 5 A,B,
1187 6 % capital Greek letters
1188 7 %\Gamma,\Delta,\Theta,\Lambda,\Xi,\Pi,\Sigma,\Upsilon,\Phi,\Psi,
1189 8 \Gamma,\Delta,\Theta,\Lambda,\Xi,\Pi,\Sigma,\Phi,\Psi,\Omega,
1190 9 % small Greek letters
1191 10 \alpha,\beta,\pi,\nu,\omega,
1192 11 % small Latin letters:
1193 12 % compare \nu, \omega, v, and w
1194 13 v,w,
1195 14 % digits
1196 15 0,1,9
1197 16 }
1198 17
1199 18
1200 19 \subsection*{Math alphabets}
1201 20
1202 21 If there are other symbols in place of Greek letters in a math
1203 22 alphabet, it uses T1 or OT1 font encoding instead of OML.
1204 23
1205 24 \begin{eqnarray*}
1206 25 \mbox{\mathnormal} & & \mbox{\teststring} \\
1207 26 \mbox{\mathit} & & \mbox{\mathit{\teststring}} \\
1208 27 \mbox{\mathrm} & & \mbox{\mathrm{\teststring}} \\
1209 28 \mbox{\mathbf} & & \mbox{\mathbf{\teststring}} \\
1210 29 \mbox{\mathsf} & & \mbox{\mathsf{\teststring}} \\
1211 30 \mbox{\mathtt} & & \mbox{\mathtt{\teststring}} \\
1212 31 \end{eqnarray*}
1213 32 New alphabets bold-italic, sans-serif-italic, and sans-serif-bold-
1214 33 italic.
1215 34 \begin{eqnarray*}
1216 35 \mbox{\mathbfit} & & \mbox{\mathbfit{\teststring}} \\
1217 36 \mbox{\mathsfit} & & \mbox{\mathsfit{\teststring}} \\
1218 37 \mbox{\mathsfbfit} & & \mbox{\mathsfbfit{\teststring}} \\
1219 38 \end{eqnarray*}
1220 39 %
1221 40 Do the math alphabets match?
1222 41 $
1223 42 \mathnormal {a x \alpha \omega}
1224 43 \mathbfit {a x \alpha \omega}
1225 44 \mathsfbfit{a x \alpha \omega}
1226 45 \quad
1227 46 \mathsfbfit{T C \Theta \Gamma}
1228 47 \mathbfit {T C \Theta \Gamma}
1229 48 \mathnormal {T C \Theta \Gamma}
1230 49 $
1231 50
1232 51 \subsection*{Vector symbols}
1233 52
1234
1235

```



```

1236 53 Alphabetic symbols for vectors are boldface italic,
1237 54  $\vec{\lambda} = \vec{e}_1 \cdot \vec{a}$ ,
1238 55 while numeric ones (e.g. the zero vector) are bold upright,
1239 56  $\vec{a} + \vec{0} = \vec{a}$ .
1240 57
1241 58 \subsection*{Matrix symbols}
1242 59
1243 60 Symbols for matrices are boldface italic, too:%
1244 61 \footnote{However, matrix symbols are usually capital letters whereas
1245 62 vectors
1246 62 are small ones. Exceptions are physical quantities like the force
1247 63 vector  $\vec{F}$  or the electrical field  $\vec{E}$ .%
1248 64 }
1249 65  $\Lambda = E \cdot A$ .
1250 66
1251 67
1252 68 \subsection*{Tensor symbols}
1253 69
1254 70 Symbols for tensors are sans-serif bold italic,
1255 71
1256 72 \[
1257 73 \quad \text{\texttt{\textbf{tensorsym}\{alpha\}}} = \text{\texttt{\textbf{tensorsym}\{e\}}} \cdot \text{\texttt{\textbf{tensorsym}\{a\}}}
1258 74 \quad \quad \quad \text{\texttt{\textbf{quad}}} \quad \text{\texttt{\textbf{Longleftarrow}}} \quad \text{\texttt{\textbf{quad}}}
1259 75 \quad \text{\texttt{\textbf{alpha}\{ijl\}}} = \text{\texttt{\textbf{e}\{ijk\}}} \cdot \text{\texttt{\textbf{a}\{kl\}}}.
1260 76 \]
1261 77
1262 78
1263 79 The permittivity tensor describes the coupling of electric field and
1264 80 displacement: \[
1265 81 \vec{D} = \epsilon_0 \text{\texttt{\textbf{tensorsym}\{\epsilon\}\{\mathrm{r}\}}} \vec{E} \]
1266 82
1267 83
1268 84
1269 85 \newpage
1270 86 \subsection*{Bold math version}
1271 87
1272 88 The ‘‘bold’’ math version is selected with the commands
1273 89 \verb+\boldmath+ or \verb+\mathversion{bold}+
1274 90
1275 91 {\boldmath
1276 92 \begin{eqnarray*}
1277 93 \quad \text{\texttt{\textbf{mbox}\{mathnormal\}}} & & \text{\texttt{\textbf{teststring}}} \\
1278 94 \quad \text{\texttt{\textbf{mbox}\{mathit\}}} & & \text{\texttt{\textbf{mathit}\{teststring\}}} \\
1279 95 \quad \text{\texttt{\textbf{mbox}\{mathrm\}}} & & \text{\texttt{\textbf{mathrm}\{teststring\}}} \\
1280 96 \quad \text{\texttt{\textbf{mbox}\{mathbf\}}} & & \text{\texttt{\textbf{mathbf}\{teststring\}}} \\
1281 97 \quad \text{\texttt{\textbf{mbox}\{mathsf\}}} & & \text{\texttt{\textbf{mathsf}\{teststring\}}} \\
1282 98 \quad \text{\texttt{\textbf{mbox}\{mathtt\}}} & & \text{\texttt{\textbf{mathtt}\{teststring\}}} \\
1283 99 \end{eqnarray*}
1284 100 \quad \text{New alphabets bold-italic, sans-serif-italic, and sans-serif-bold-}
1285 101 \quad \text{italic.}
1286 102 \begin{eqnarray*}
1287 102 \quad \text{\texttt{\textbf{mbox}\{mathbfit\}}} & & \text{\texttt{\textbf{mathbfit}\{teststring\}}} \\
1288 103 \quad \text{\texttt{\textbf{mbox}\{mathsf fit\}}} & & \text{\texttt{\textbf{mathsf fit}\{teststring\}}} \\
1289 104 \quad \text{\texttt{\textbf{mbox}\{mathsf bfit\}}} & & \text{\texttt{\textbf{mathsf bfit}\{teststring\}}} \\
1290 105 \end{eqnarray*}
1291 106 \%
1292 107 Do the math alphabets match?

```




```

1293 108
1294 109 $
1295 110 \mathnormal {a x \alpha \omega}
1296 111 \mathbfit {a x \alpha \omega}
1297 112 \mathsfbfit{a x \alpha \omega}
1298 113 \quad
1299 114 \mathsfbfit{T C \Theta \Gamma}
1300 115 \mathbfit {T C \Theta \Gamma}
1301 116 \mathnormal {T C \Theta \Gamma}
1302 117 $
1303 118
1304 119 \subsection*{Vector symbols}
1305 120
1306 121 Alphabetic symbols for vectors are boldface italic,
1307 122 $\vec{\lambda}=\vec{e}_{1}\cdot\vec{a}$,
1308 123 while numeric ones (e.g. the zero vector) are bold upright,
1309 124 $\vec{a} + \vec{0} = \vec{a}$.
1310 125
1311 126
1312 127
1313 128
1314 129 \subsection*{Matrix symbols}
1315 130
1316 131 Symbols for matrices are boldface italic, too:%
1317 132 \footnote{However, matrix symbols are usually capital letters whereas
1318 133 vectors
1319 134 are small ones. Exceptions are physical quantities like the force
1320 135 vector $\vec{F}$ or the electrical field $\vec{E}$.%
1321 136 }
1322 137 $\matrixsym{\Lambda}=\matrixsym{E}\cdot\matrixsym{A}$.
1323 138
1324 139
1325 140 \subsection*{Tensor symbols}
1326 141
1327 142 Symbols for tensors are sans-serif bold italic,
1328 143
1329 144 \[
1330 145 \quad \tensorsym{\alpha} = \tensorsym{e}\cdot\tensorsym{a}
1331 146 \quad \Longleftarrow \quad
1332 147 \quad \alpha_{ijl} = e_{ijk}\cdot a_{kl}.
1333 148 \]
1334 149
1335 150 The permittivity tensor describes the coupling of electric field and
1336 151 displacement: \[
1337 152 \vec{D}=\epsilon_{0}\tensorsym{\epsilon}_{\mathrm{r}}\vec{E}\]
1338 153 }

```



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).



- 1369 • Provide your own link text: style sheet.

1370 The verbatim \LaTeX code of Sec. B3 is in List. B.3.

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

```

1 Again please see List.~\ref{lst:abbrv}. Here is an example of first use:
  \acr{ac}. Next use: \acr{ac}. Full: \gls{ac}. Here's an acronym
  referenced using \verb| \acr |: \acr{html}. And here it is again: \
  acr{html}. If you are used to the \texttt{glossaries} package, note
  the difference in using \verb| \gls |: \gls{html}. And again (no
  difference): \gls{html}. Here are some more entries:
2
3 \begin{itemize}
4
5   \item \acr{xml} and \acr{css}.
6
7   \item Next use: \acr{xml} and \acr{css}.
8
9   \item Full form: \gls{xml} and \gls{css}.
10
11  \item Reset again. \glsresetall{abbreviation}
12
13  \item Start with a capital. \Acr{html}.
14
15  \item Next: \Acr{html}. Full: \Gls{html}.
16
17  \item Prefer capitals? \renewcommand{\acronymfont}[1]{\
    MakeTextUppercase{#1}} \Acr{xml}. Next: \acr{xml}. Full: \gls{xml}
    }.
18
19  \item Prefer small-caps? \renewcommand{\acronymfont}[1]{\textsc{#1}}
    \Acr{css}. Next: \acr{css}. Full: \gls{css}.
20
21  \item Resetting all acronyms.\glsresetall{abbreviation}
22
23  \item Here are the acronyms again:
24
25  \item \Acr{html}, \acr{xml} and \acr{css}.
26
27  \item Next use: \Acr{html}, \acr{xml} and \acr{css}.
28
29  \item Full form: \Gls{html}, \gls{xml} and \gls{css}.
30
31  \item Provide your own link text: \glslink{[textbf]css}{style}
32
33 \end{itemize}

```



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}
```



1385

B5 Figure

1386

1387

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

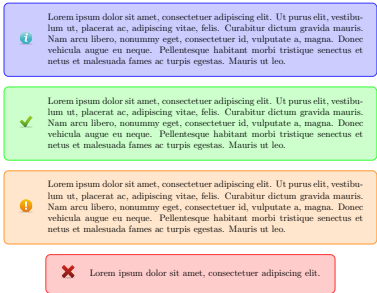


Fig. B.1 A quadrilateral image example.



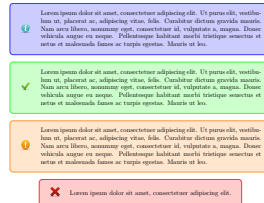
1388 Fig. B.1 is a gray box enclosed by a dark border. List. B.5 shows the corresponding
1389 L^AT_EX code.

Listing B.5: Sample L^AT_EX code for a single figure

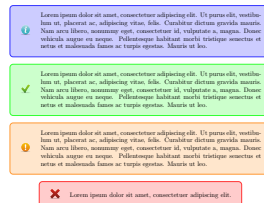
```
1 \begin{figure}[!htbp]
2   \centering
3   \includegraphics[width=0.5\textwidth]{example}
4   \caption{A quadrilateral image example.}
5   \label{fig:example}
6 \end{figure}
7 \cleardoublepage
8
9 Fig.~\ref{fig:example} is a gray box enclosed by a dark border. List.~\
  ref{lst:onefig} shows the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



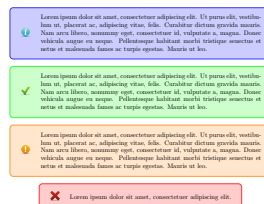
De La Salle University



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



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



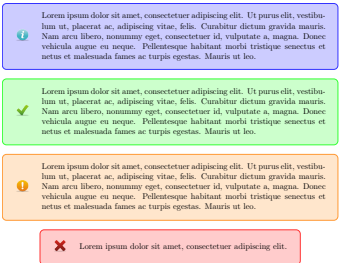
(c) A sub figure in the bottom row

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

```
1 \begin{figure}[!htbp]
2 \centering
3 \subbottom[A sub-figure in the top row.]{
4 \includegraphics[width=0.35\textwidth]{example}
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}
```



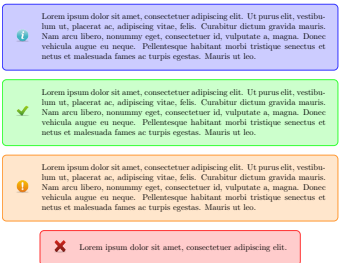

(a) A sub-figure in the upper-left corner.



(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 \LaTeX code.

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

```

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

```



B6 Table

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

TABLE B.1 FEASIBLE TRIPLES FOR HIGHLY VARIABLE GRID

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

Continued on next page



Continued from previous page

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



1393 List. B.8 shows the corresponding \LaTeX code.

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

```

1394 1 \begin{center}
1395 2 {\scriptsize
1396 3 \begin{tabularx}{\textwidth}{p{0.1\textwidth}|p{0.2\textwidth}|p{0.5\textwidth}}
1398 4 \caption{Feasible triples for highly variable grid} \label{tab:triple_
1400 5 grid} \\
1401 6 \hline
1402 7 \textbf{Time (s)} &
1403 8 \textbf{Triple chosen} &
1404 9 \textbf{Other feasible triples} \\
1406 10 \hline
1407 11 \endfirsthead
1408 12 \multicolumn{3}{c}{\textit{Continued from previous page}} \\
1409 13 \hline
1410 14 \hline
1411 15 \textbf{Time (s)} &
1412 16 \textbf{Triple chosen} &
1413 17 \textbf{Other feasible triples} \\
1414 18 \hline
1415 19 \endhead
1416 20 \hline
1417 21 \multicolumn{3}{r}{\textit{Continued on next page}} \\
1418 22 \endfoot
1419 23 \hline
1420 24 \endlastfoot
1421 25 \hline
1422 26
1423 27
1424 28 0 & (1, 11, 13725) & (1, 12, 10980), (1, 13, 8235), (2, 2, 0), (3, 1, 0) \\
1425 29 & \\
1426 30 2745 & (1, 12, 10980) & (1, 13, 8235), (2, 2, 0), (2, 3, 0), (3, 1, 0) \\
1427 31 & \\
1428 32 5490 & (1, 12, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1429 33 8235 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1430 34 & \\
1431 35 10980 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1432 36 & \\
1433 37 13725 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1434 38 & \\
1435 39 16470 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1436 40 19215 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1437 41 & \\
1438 42 21960 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1439 43 & \\
1440 44 24705 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1441 45 & \\
1442 46 27450 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1443 47 & \\
1444 48 30195 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
1445 49 32940 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1446 50 35685 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1447 51 38430 & (1, 13, 10980) & (2, 2, 2745), (2, 3, 0), (3, 1, 0)

```



```

1448 43 41175 & (1, 12, 13725) & (1, 13, 10980), (2, 2, 2745), (2, 3, 0), (3, 1,
1449      0) \\
1450 44 43920 & (1, 13, 10980) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1451 45 46665 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
1452 46 49410 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
1453 47 52155 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1,
1454      0) \\
1455 48 54900 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1456 49 57645 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1457 50 60390 & (1, 12, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1458 51 63135 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1459 52 65880 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1460 53 68625 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
1461 54 71370 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1462 55 74115 & (1, 12, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1463 56 76860 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1464 57 79605 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1465 58 82350 & (1, 12, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1466 59 85095 & (1, 12, 13725) & (1, 13, 10980), (2, 2, 2745), (2, 3, 0), (3, 1,
1467      0) \\
1468 60 87840 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1469 61 90585 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1470 62 93330 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1471 63 96075 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1472 64 98820 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1473 65 101565 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1474 66 104310 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1475 67 107055 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1476 68 109800 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1477 69 112545 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3,
1478      1, 0) \\
1479 70 115290 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1480 71 118035 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1481 72 120780 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1482 73 123525 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1483 74 126270 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3,
1484      1, 0) \\
1485 75 129015 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
1486 76 131760 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
1487 77 134505 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1488 78 137250 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1489 79 139995 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
1490 80 142740 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
1491 81 145485 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3,
1492      1, 0) \\
1493 82 148230 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
1494 83 150975 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1495 84 153720 & (1, 12, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1496 85 156465 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1497 86 159210 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1498 87 161955 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1499 88 164700 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1500 89 \end{tabularx}
1501 90 }
1503 91 \end{center}

```



1504

B7 Algorithm or Pseudocode Listing

1505

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1507

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 L^AT_EX code.

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

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

Require: $n \geq 0 \vee x \neq 0$

Ensure: $y = x^n$

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

Listing B.9: Sample L^AT_EX code for algorithm or pseudocode listing usage

```

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

```




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 */

```



1511

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

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

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



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 \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 \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 ⁽¹⁾	468	780	780	780	650	650	1,404
Maximum HR I/Os ⁽²⁾	52	52	52	104	52	52	52
DSP Slices	600	672	768	1,200	1,560	1,800	2,880
System Monitor	1	1	1	2	3	3	3
PCIe Gen3 x8	2	4	4	4	5	6	6
150G Interlaken	3	6	6	6	8	9	0
100G Ethernet	3	4	4	6	9	9	3
GTH 16.3Gb/s Transceivers	20	32	32	40	52	60	48
GTY 30.5Gb/s Transceivers	20	32	32	40	52	60	0

Notes:

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



Virtex UltraScale Device-Package Combinations and Maximum I/Os

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

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

Notes:

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



Virtex UltraScale+ FPGA Feature Summary

Table 8: Virtex UltraScale+ FPGA Feature Summary

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

Notes:

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

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

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

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

Notes:

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



Appendix C

PUBLICATION LIST AND AWARD

Journal

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De La Salle University

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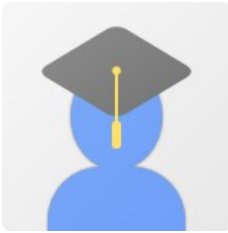
1. ...

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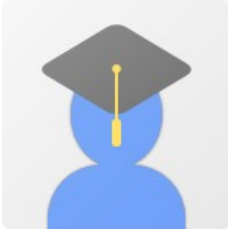
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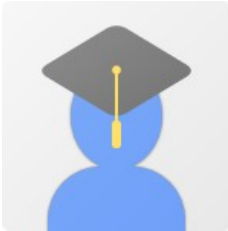
Appendix D VITA



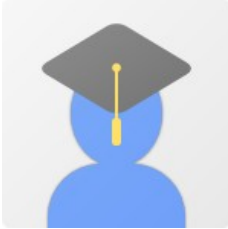
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