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

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

————————

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

————————

by

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August, 2016

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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

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

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with group number ESG-04 in partial fulfillment of the requirements for the degree of **Bachelor of Science in Computer Engineering** (**BS-CPE**) has been examined and is recommended for acceptance and approval.

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ACKNOWLEDGMENT

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

ABSTRACT

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

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

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ABBREVIATIONS

NOTATION

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

GLOSSARY

LISTINGS

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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. Discomfort index is a measure of discomfort derived from the temperature and humidity. 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

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rate and sweating. However, one can sweat too much, he feels drained by the lack of fluids in his body causing discomfort, weakness, loss of stamina, and even muscle pains, leading to a heat stroke.

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

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

1.2 Prior Studies

Some of the studies, specifically [Aji Hanggoro and Sari, 2013] and [Chavan and V.Karande, 2014] that the group has found are about the temperature and humidity monitoring systems. The temperature system can be constructed by using a simple microcontroller-based system with an important tool, the LM35 where the output voltage is directly proportional to the temperature detected. The same procedure can be done with the humidity sensor but this

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time, it does not make use of the LM35. Both of these sensors are good for agricultural applications and getting the air quality. Another study which is [Folea and Mois, 2015] 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.

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

1.4 Objectives

1.4.1 General Objective(s)

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

1.4.2 Specific Objectives

1. To make use of the temperature, humidity, amount of dust, amount of carbon monoxide, and visibility in calculating discomfort index and measuring pollutants

2. To utilize different sensors for temperature, humidity, dust, and carbon monoxide measurement

3. To gather apparent information on the discomfort regarding heat and air pollution with the use of crowd sourcing

4. To make use of computer vision with the use of a cellphone camera to measure visibility

5. To achieve a social impact on the conditions and quality of the air for the people in urban areas where smoke is present and abundant

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1.5 Significance of the Study

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

1.6 Assumptions, Scope and Delimitations

1. The given data will only be determined by the air quality index and the discomfort index.

2. The application will be used only for displaying the data gathered in the device.

3. People should be able to know the importance of their respiratory system in the body.

4. Users must be aware the connection between air pollution and lung cancer.

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5. The device will only deal with the common factors for discomfort such as temperature, humidity, and the amount of dust in the air.

1.7   Description and Methodology

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

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1.8 Estimated Work Schedule and Budget

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373 .

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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							

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TABLE 1.2   GANNT CHART PART 2

	W7	W8	W9	W10	W11
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	JC, RN			
Sensor Testing			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
OpenCV Integration	RP	RP	RP	RP	RP
Board design					
Board layout					
Fabrication					
Mounting					
Proofreading and Revisions					
Final documentation					
Defense					

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TABLE 1.3   GANNT CHART PART 3

	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		
Schematic diagram			
Sensor Collection			
Sensor Testing	All		
Arduino programming	NP		
Android programming	JC, RN		
Android layout	RP, RN		
OpenCV Integration			
Board design			
Board layout			
Fabrication			
Mounting			
Proofreading and Revisions		All	All
Final documentation		All	All
Defense			All

TABLE 1.4

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

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TABLE 1.5   ESTIMATED BUDGET

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

1.9   Overview

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

LITERATURE REVIEW

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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, according to [Chavan and V.Karande, 2014]. 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

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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

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447 connection. The system is consists of humidity sensor, Arduino UNO microcontroller,
448 serial communication, wireless connection and a computer. The data from the sensor
449 will be transmitted to the microcontroller and transferred to the computer through serial
450 communication. The computer will transmit the data to the android phone via wireless
451 connection and the android phone can now control the system depending on the commands
452 that will be selected. The android can receive data from the humidity sensor, send data
453 for water sprayer to turn on, send data for stepper motor to work and other commands
454 that the system is capable of doing. This system ensures the condition of the green house
455 environment to be in good condition.

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

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2.3 PM$_{10}$ Temporal Monitoring

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

They developed an algorithm which makes use of the atmospheric reflectance and the concentration of the PM$_{10}$ using regression. The amount of reflectance is measured using a spectroradiometer and the concentration of the particles are determined by the different RGB bands of the camera. The PM$_{10}$ 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.

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491   Another similar study [Hebbar et al., 2014] of an air monitoring device is implemented

492 using a microcontroller where several sensors are placed and data is sent through GSM

493 wirelessly. The design tests the amount of CO_2 levels indoors. It also measures the

494 temperature and humidity of the atmosphere locally. Calibration of the sensors is done by

495 concentrating known amount of a certain gas into a test chamber and determine its offset

496 from the results obtained. The design was tested in a seminar hall and the results obtained

497 showed that the start and end of each class attributed to the increase in CO_2 emission. The

498 design also shows the data through an online GUI.

499   One similar design, called HazeWatch, is done using several sensors and cloud com-

500 puting [Hu et al., 2016]. The design is made compact and portable and can be mounted

501 onto a car or bike. Data is harvested using a mobile phone and records the location in

502 real time. Data is then sent wirelessly to cloud-based servers and is interpolated (Inverse

503 Weighing and Ordinary Kriging interpolation) to generate estimates. The data can then be

504 view visually using contour maps of the pollution or gas concentration levels in the area.

505 The results obtained are compared to similar products (*Node* and *SensorDrone*)

2.5   Discomfort Index Monitoring System

507 A research was made about the importance of monitoring and controlling of atmospheric

508 conditions to the efficiency of the performance of the human beings [Noh et al., 2013]

509 . They designed a wireless sensor module that uses a Zigbee communication and sensor

510 module, which consists of temperature, humidity, CO_2 and atmospheric pressure sensor,

511 that maintains a comfortable environment for human beings or to prevent discomfort.

512 The sensor module is the transmitter which delivers the sensor data to the receiver and

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513 the receiver will transmit the filtered or recovered sensor data to a microcontroller board

514 in monitoring the room environment. The room monitoring system is able to provide a

515 comfortable environment for human beings through the wireless sensor network or WSN

516 for monitoring the room environment.

2.6 Air Quality Standards

518 This review shows the different indoor air quality standards set by different countries across

519 the world. The data is collected from documents from different health and environmental

520 organization. This paper can be set as a tool for evaluating acceptable concentrations of

521 different pollutants within an area. The pollutants included in this study are "carbon dioxide

522 (CO_2), carbon monoxide (CO), formaldehyde (HCHO), nitrogen dioxide (NO_2), sulfur

523 dioxide (SO_2), total volatile organic compounds (TVOCs) and particulate matter ($PM_{2.5}$

524 and PM_{10})." The amount allowable depends on how bad the amount of a certain pollutant

525 exists indoors. The paper also explains different harmful health effects each pollutant has

526 on the human body.

Chapter 3

THEORETICAL CONSIDERATIONS

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3.1 Microcontroller based temperature humidity meter using Arduino Platform

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

3.2 Discomfort Index

[Poupkou, 2011] states that discomfort index refers 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

558 important for student to know which location at the campus is uncomfortable because stress
559 caused by the environments affects the welfare of the students at school.

3.3 Bluetooth Technology

561 Bluetooth is a wireless communication technology. This technology deals with the regula-
562 tion of the flow of data. Data transmission is done though the wireless communication in
563 this technology there are paired two devices and these devices can communicate to each
564 other through Bluetooth. After the paring of devices, there is a process of data transfer.
565 It is a bidirection technology since it is capable of sending and receiving data. It has a
566 limited transmission distance between the two devices and it cannot transmit data in far
567 distances. The temperature and humidity data from the Arduino device can be transferred
568 into the android application in terms of wireless Bluetooth communication as indicated
569 above information.

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

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

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578 students are using it right now. The Comfortability Indicator application will based it on

579 the temperature and humidity data gathered in the Arduino device and it will display the

580 heat map to indicate which area is comfortable and which are not. The students will have

581 information about the discomfort index and the effect of heat and stress to their health and

582 welfare.

Chapter 4

DESIGN CONSIDERATIONS

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589
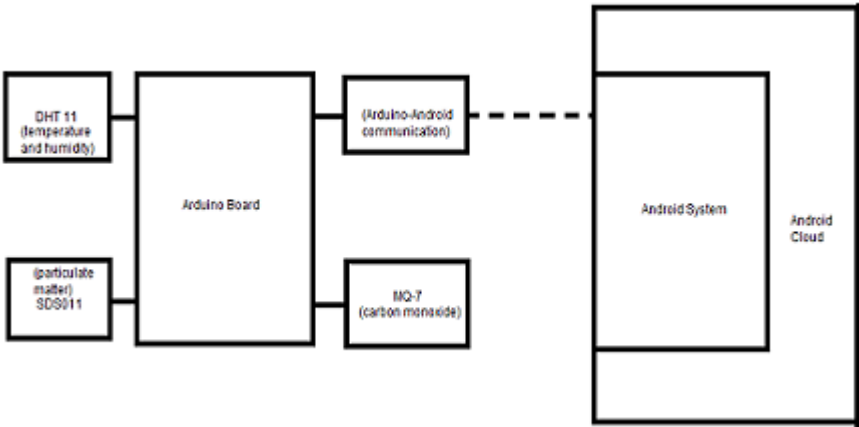
590   Figure 4.1. System Model of the Project

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591
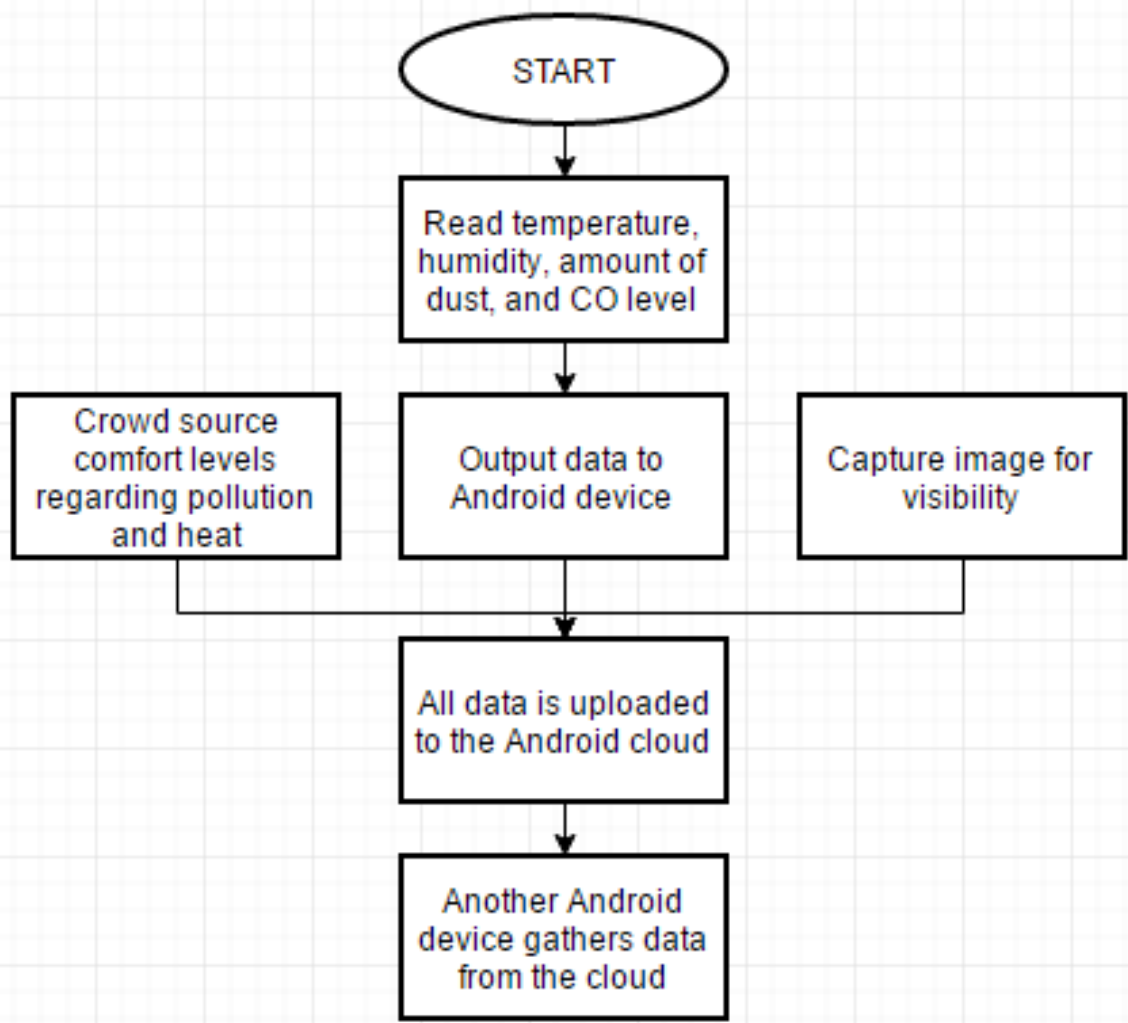
592   Figure 4.2. System Flowchart

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593
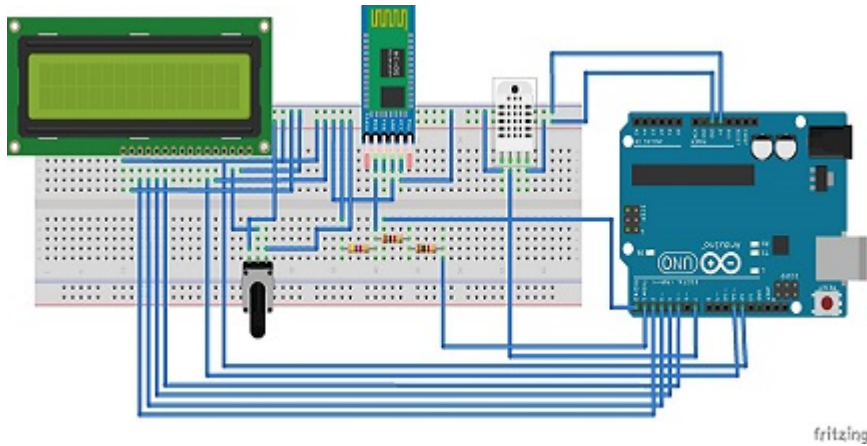
Figure 4.3. Circuit Configuration for Testing the DHT-11

594

```
1   #include "DHT.h"
2   #include <LiquidCrystal.h>
3   LiquidCrystal lcd(12, 11, 5, 4, 3, 2);
4
5   const int analogInPin0 = A0;// Analog input pins
6
7   #define DHT11_PIN 7
8
9   float sensorValue0,sensorValue1 = 0;
10  float voltageValue0, voltageValue1 = 0;
11
12  char inbyte = 0;
13
14  DHT dht(7,DHT11);
15  void setup(){
16    lcd.begin(16, 2);
17      Serial.begin(9600);
18  }
19  void loop()
20  {
21  //  int chk = DHT.read11(DHT11_PIN);
```

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```
616   22     lcd.setCursor(0,0);
617   23     lcd.print("Temp: ");
618   24     float t = dht.readTemperature();
619   25  //   Serial.print("Temp: ");
620   26  //   Serial.println(t);
621   27
622   28     lcd.print(t);
623   29     lcd.print((char)223);
624   30     lcd.print("C");
625   31     lcd.setCursor(0,1);
626   32     float h = dht.readHumidity();
627   33
628   34  //   Serial.print("Hum: ");
629   35  //   Serial.println(h);
630   36
631   37     lcd.print("Humidity: ");
632   38     lcd.print(h);
633   39     lcd.print("%");
634   40     delay(5000);
635   41     float di = t - 0.55* (1-0.01*h)*(t-14.5);
636   42
637   43  //   Serial.print("DI: ");
638   44  //   Serial.println(di);
639   45
640   46     lcd.clear();
641   47     lcd.setCursor(0,0);
642   48     lcd.print("Discomfort Index");
643   49     lcd.setCursor(0,1);
644   50     lcd.print(di);
645   51
646   52     delay(2000);
647   53
648   54     sendAndroidValues(t,h,di);
649   55         lcd.clear();
```

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```
650   56  }
651   57
652   58  void sendAndroidValues(float t, float h, float di)
653   59   {
654   60    //puts # before the values so our app knows what to do with the data
655   61    Serial.print('#');
656   62    //for loop cycles through 4 sensors and sends values via serial
657   63
658   64      Serial.print(t);
659   65      Serial.print('+');
660   66      Serial.print(h);
661   67      Serial.print('+');
662   68      Serial.print(di);
663   69      Serial.print('~');
664   70      //technically not needed but I prefer to break up data values
665   71      //so they are easier to see when debugging
666   72    Serial.println();
667   73    delay(10);          //added a delay to eliminate missed transmissions
```

Figure 4.4. Code for Temperature and Humidity Gathering with Bluetooth Transmission

This code is to be utilized in using the DHT-11 sensor in getting the humidity and temperature. This code is file that is part of the DHT library for Arduino systems.

$$DI = T - 0.55(1 - 0.01H)(T - 14.5) \tag{4.1}$$

Figure 4.5. Formula for Discomfort Index

This is the formula from [Cal,] that is used to calculate the discomfort index where DI is the discomfort index, T is the temperature, and H is the humidity.

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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, the use of the Bluetooth module for transmission, and the development of the Android application.

Chapter 5

METHODOLOGY

Contents

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5.1 Implementation

The group has chosen system prototyping as the primary methodology of the study Fig. 5.1 which comes from [Dennis, 2014]. 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.
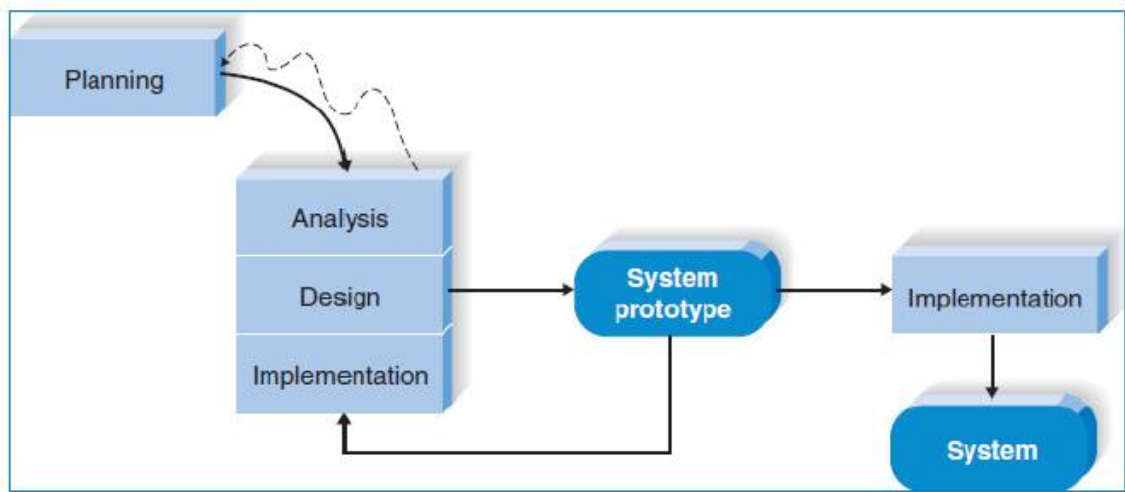
Fig. 5.1   System Prototyping Diagram

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

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

5.1.2 Initial Prototype

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

5.1.3 Second Prototype

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

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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.

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5.2.1 Quantitative Approach

Data were gathered four nonconsecutive trials on twenty different locations along De La Salle University. The data collected is 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 varies 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 users of the application. The crowdsourcing application is very dependent on the users data and it would be most effective when more people uses the application. This approach allows the user to gather information and at the same time, contributes to the cloud-based system of

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

5.3 Summary

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

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

Chapter 6

RESULTS AND DISCUSSION

Contents

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798   The goal of this research is to be able to provide a system that makes use of an Arduino-

799   based measuring device that can pass on data with a Bluetooth module to an Android phone

800   that can be able to relay this data to a firebase database that can be accessed by another

801   Android phone.

802   In order to be able to verify the temperature-humidity sensor being used, another device

803   will serve as the basis for true data. Measurements coming from the TH-65, a digital

804   temperature and humidity measuring device, will be established as ground truth.

805   The following graphs show the accuracy testing of the DHT-11 with the TH-65 as the

806   basis for ground truth. The blue data represents the temperature measured by the DHT-11

807   while the orange represents data coming from the TH-65. Temperature, humidity, and

808   discomfort index are to be considered in this set of data. From the results, it has been shown

809   that in measuring temperature, the DHT-11 sensor shows 98.91% accuracy and in humidity,

810   the sensor is 89.66% accurate in terms of measuring humidity and in discomfort index, the

811   sensor is 97.79% accurate.
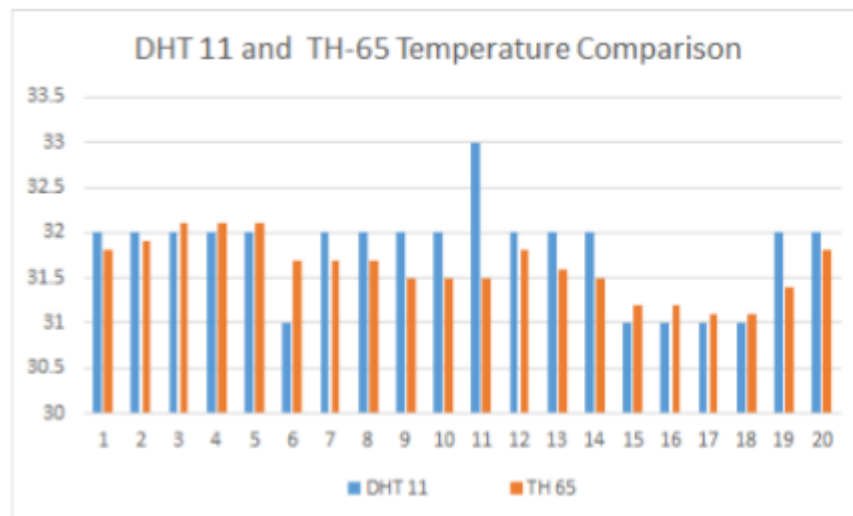
Fig. 6.1   Accuracy Testing of Temperature from DHT-11 sensor

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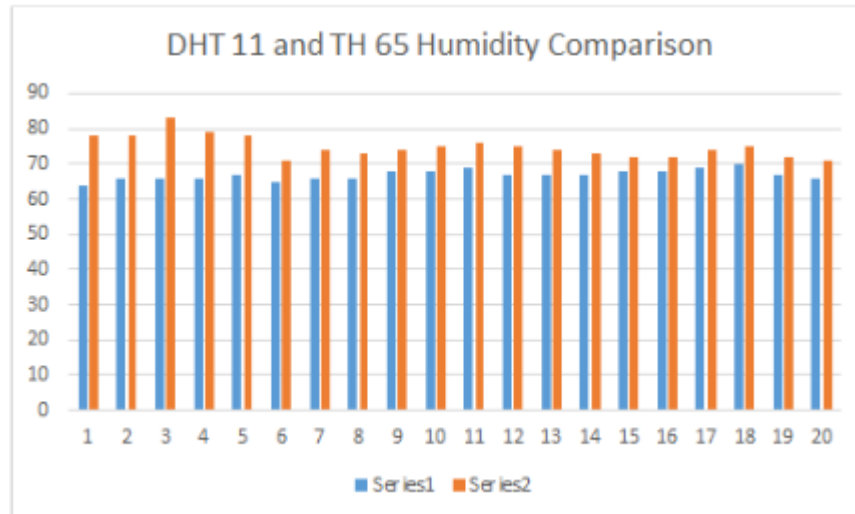
Fig. 6.2   Accuracy Testing of Humidity from DHT-11 sensor
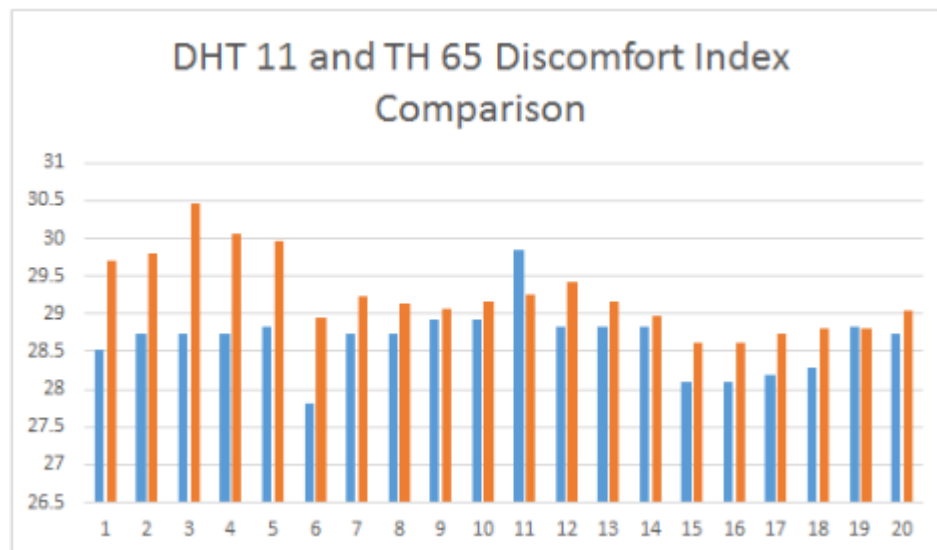
Fig. 6.3   Accuracy Testing of Discomfort Index from DHT-11 sensor

812   The Android application consists of viewing the database, checking the map, and

813   updating the database. In updating the database, the data would simply come from the

814   Arduino system transmitted via Bluetooth. The database is able to view the updated list

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of temperature, humidity, and discomfort index. The map shows the areas within DLSU that are color coded based on their discomfort indices. If the value shown is less than 21, the marker becomes blue. If it is between 21 to 24, the marker becomes cyan. If it is 24 to 27, the marker becomes azure. If it is between 27 to 29, the marker becomes orange. If it is between 29 to 32, the marker becomes rose. And if it is greater than 32, the marker becomes red.
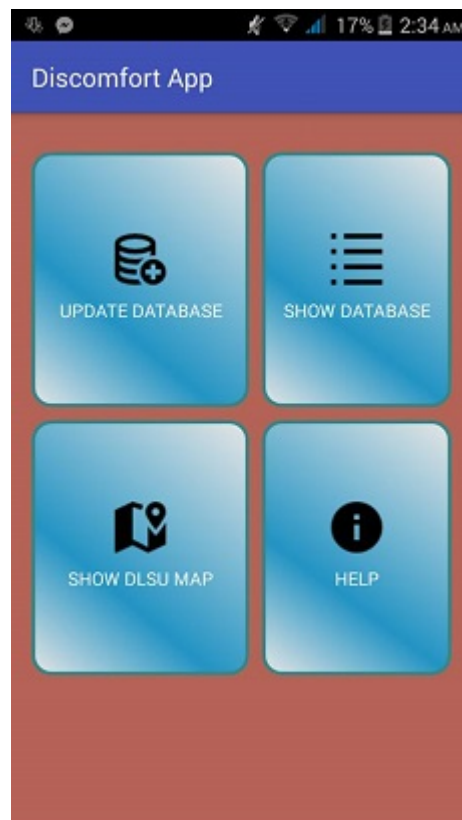
Fig. 6.4   Interface for the Android Application

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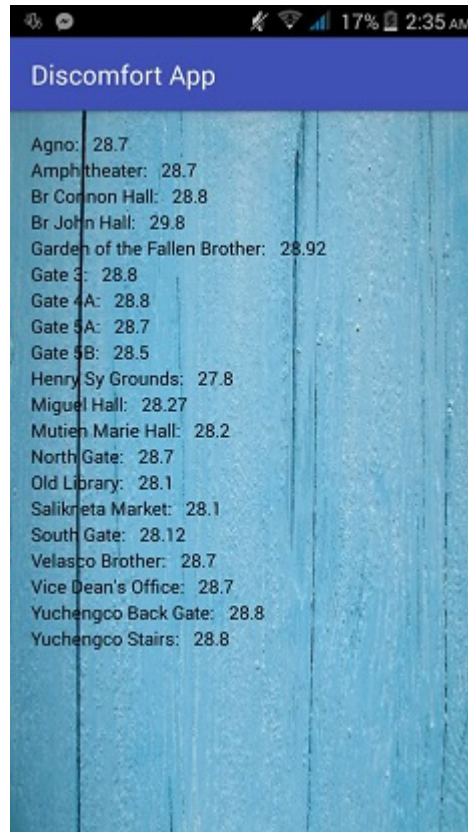
Fig. 6.5   The Updated List of Discomfort Indices Viewed from the Map

6.1 Summary

The group has successfully developed an Arduino-based measuring device that takes note of temperature and humidity which can be transmitted via Bluetooth to an Android device and into an Android application. These data can be relayed onto the firebase database which will be accessible by all who has downloaded the application. The map inside is a handy feature that instantly tells the discomfort level of a certain area inside the university.

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Fig. 6.6   Map of DLSU with Color Coded Markers Dictating the Discomfort Index

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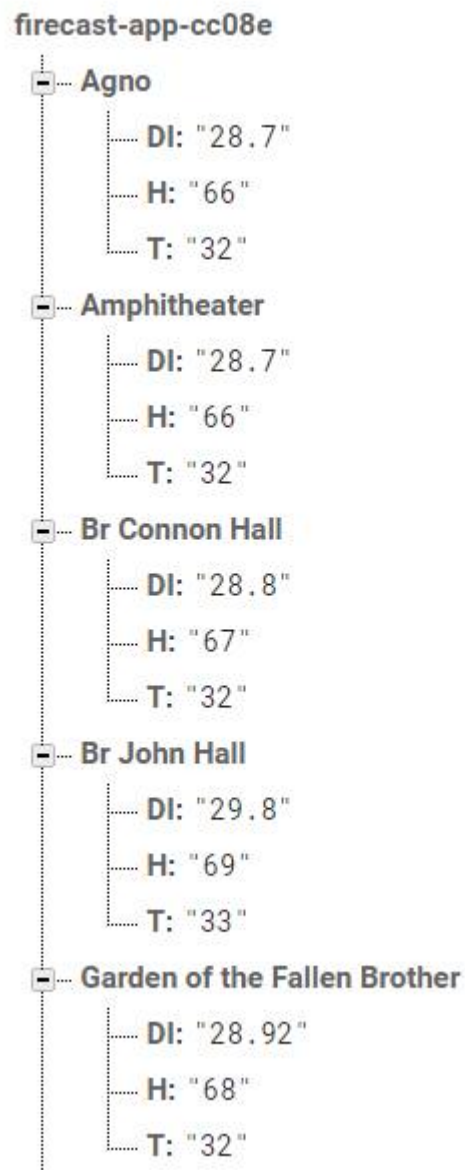
Fig. 6.7   A Part of the Firebase Database

Chapter 7

CONCLUSIONS, RECOMMENDATIONS, AND FUTURE DIRECTIVES

Contents

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7.1 Concluding Remarks

The common function of the Arduino base temperature and humidity meter is to detect the temperature and humidity in any places in order to come up with discomfort index value. This discomfort computation feature of the Arduino base machine would be a new way of giving information on how students feel inside the university campus. In this thesis, the group discussed the process and algorithms to detect temperature and humidity and come up with discomfort index value. The problem that was faced during the development of this research was how to gather the ground truth data and compare it with the data gathered in order to know that it is accurate. The first method used is analog and digital temperature and humidity meter data gathering. In comparison, analog and digital humidity and temperature meters showed similar results but digital showed a more accurate data which is nearer to the data gathered in the Arduino temperature and humidity detector machine. The ground truth was set as data from digital temperature and humidity meter to come up with a more accurate discomfort index result. On the other hand, the android based application for discomfort index indication used firebase technology for displaying and uploading the humidity, temperature, and discomfort index data. The data is uploaded in the firebase and displays the data from various locations. The advantage of this application is that the crowd can easily upload their humidity and temperature data so that everyone application users will know which places are comfortable and which places are not. When this data is transferred into a google map, it will be a heat map of the campus to graphically indicate the discomfort index of different locations. The project came up with several problems for the temperature and humidity meter machine. There was a challenge that how this machine will get accurate data from the sensor before the ground truth was set as reference. Spreading

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the informative data to the student was also a problem but the firebase crowd sourcing technology solved the issue. The Android platform application was a better option for the discomfort indicator due to its versatility and expandability, compared to other mobile development platforms. The hardware presented in this thesis can be further developed into smaller size and come up with more sensors. It can be innovated with the use of dust sensor and carbon monoxide sensors to perform such functionality. This Arduino temperature and humidity meter machine can be of use not only in the campus, but also in any places outside of the university. This application can further touch the area of health awareness and medical information regarding the discomfort index and data gathered.

7.2 Contributions

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

- The construction of an accurate device that measures temperature and humidity

- The development of an Android application to increase social awareness

7.3 Recommendations

There is more to air pollution than measuring particulate matter and carbon monoxide. It is highly recommended that the measurements of air pollutants be improved by the addition of more sensors to the Arduino system so that more air pollutants and parameters can be measured such as sulfur dioxide and nitrogen dioxide. The system's setting so far is within the campus and the values shown are nearly consistent with one another. It is also

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880 recommended to further expand the coverage of taking down the discomfort index in order
881 for more areas to be involved. Since Google Map API was used to take note of the location,
882 another recommended study is to make use of the GPS location to mark that certain area's
883 discomfort levels.

7.4 Future Prospects

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

887 1. The addition of more air pollutants to be measured.

888 2. The expansion of areas that take note of temperature, humidity, and amount of air
889   pollution.

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Produced: August 23, 2016, 15:58

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Appendix A
ANSWERS TO QUESTIONS TO THIS THESIS

Contents

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A1 How important is the problem to practice?

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

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

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

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

Improvements could be measured by providing different ground truths (other thermometers/hygrometers) to test the accuracy of the system as well as surveys to confirm the level of discomfort felt by the user. Also, integrating the system to the phone is a way to retrieve data easily and it would occupy less space instead of having two separate systems communicating.

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

The accuracy of the system will be the basis of improvement as well as the apparent level of discomfort felt by the user.

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

These data would not only test the accuracy of the Arduino system but also validate the data with the user's perceived level of discomfort.

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

They are significant because the measures of improvement will be more expensive than our system and will determine if a low cost system can be viable alternative to the existing systems.

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

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

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

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

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

For this research, it is assumed that almost every person in the community owns an Android phone because with this phone, one can access the information from the firebase database.

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

Yes. The entire system designed so far is made for Android phones that are able to access this firebase database.

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

In the case of this study, the proposed solution cannot be applied to more general cases. The main backbone of the thesis is the Android system since it gathers the data from the Arduino system and it enables access to the different discomfort indices within the university.

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

Our solution aims towards the convenience of anyone that has the Android application. This gives the user a foresight of how the conditions would be outside.

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

As of now, the whole crowdsourcing system is implemented to provide data such as temperature and humidity for various locations within the university only.

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

For the technical people, the message would be that it is possible to create an application that uses crowdsourcing to take note of air pollution and discomfort index by the construction of an Arduino system that can transmit data via Bluetooth to an Android device which can pass on the data to the firebase database accessible by anyone who has the application. For the non-technical managers, we would say that an application that takes note of real-time updates of the amount of discomfort based on heat and air pollution has been developed.

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

The sensors for temperature, humidity, amount of particulate matter, and carbon monoxide content will be tested based on the accuracy in terms of a ground truth. All group members that own Android phones can be able to verify the data.

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

Yes. A mathematical formula in computing the discomfort index that makes use of temperature and humidity was used.

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

Other microcontroller systems can be considered as alternatives since they also can be able to retrieve values of temperature and humidity with the sensors and transmit the data via Bluetooth or even another method of data transmission.

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

In terms of data gathering, the data would vary based on the time the measurements were taken and weather conditions. There are different stations and air quality devices present today such as Netatmo and CubeSensor however these are very expensive to implement.

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

Integrating the system to the smartphone is a way to retrieve data easily and it would occupy less space instead of having two separate systems communicating.

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

It seems that it would be better if there would be a live system and app demonstration instead of the usual Powerpoint presentation in order to better understand how the system works.

A8.1 What are the weaknesses of your proposal?

The system implemented within the university would yield nearly the same results from different locations.

1053 **Appendix B**

1054 **USAGE EXAMPLES**

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

B1   Equations

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

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

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

Other example equations are as follows.

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

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

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

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1067   The verbatim LaTeX code of Sec. B1 is in List. B.1.

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

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

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B2 Notations

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

Math alphabets

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

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

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

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

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

Vector symbols

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

Matrix symbols

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

---

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

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Tensor symbols

Symbols for tensors are sans-serif bold italic,

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

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

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

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Bold math version

1085

1086 The "bold" math version is selected with the commands `\boldmath` or `\mathversion{bold}`

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

1087 New alphabets bold-italic, sans-serif-italic, and sans-serif-bold-italic.

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

1088 Do the math alphabets match?

1089 $ax\alpha\omega ax\alpha\omega ax\alpha\omega \quad TC\Theta\Gamma TC\Theta\Gamma TC\Theta\Gamma$

Vector symbols

1091 Alphabetic symbols for vectors are boldface italic, $\boldsymbol{\lambda} = \boldsymbol{e_1} \cdot \boldsymbol{a}$, while numeric ones (e.g.
1092 the zero vector) are bold upright, $\boldsymbol{a} + \mathbf{0} = \boldsymbol{a}$.

Matrix symbols

1094 Symbols for matrices are boldface italic, too:[2] $\boldsymbol{\Lambda} = \boldsymbol{E} \cdot \boldsymbol{A}$.

Tensor symbols

1096 Symbols for tensors are sans-serif bold italic,

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

1097 The permittivity tensor describes the coupling of electric field and displacement:

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

1098

---

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

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1099   The verbatim LaTeX code of Sec. B2 is in List. B.2.

Listing B.2: Sample LaTeX code for notations usage

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

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```
1154   53   Alphabetic symbols for vectors are boldface italic,
1155   54   $\vec{\lambda}=\vec{e}_{1}\cdot\vec{a}$,
1156   55   while numeric ones (e.g. the zero vector) are bold upright,
1157   56   $\vec{a} + \vec{0} = \vec{a}$.
1158   57
1159   58   \subsection*{Matrix symbols}
1160   59
1161   60   Symbols for matrices are boldface italic, too:%
1162   61   \footnote{However, matrix symbols are usually capital letters whereas
1163        vectors
1164   62   are small ones. Exceptions are physical quantities like the force
1165   63   vector $\vec{F}$ or the electrical field $\vec{E}$.%
1166   64   }
1167   65   $\matrixsym{\Lambda}=\matrixsym{E}\cdot\matrixsym{A}.$
1168   66
1169   67
1170   68   \subsection*{Tensor symbols}
1171   69
1172   70   Symbols for tensors are sans-serif bold italic,
1173   71
1174   72   \[
1175   73      \tensorsym{\alpha}  =  \tensorsym{e}\cdot\tensorsym{a}
1176   74      \quad \Longleftrightarrow \quad
1177   75      \alpha_{ijl}  =  e_{ijk}\cdot a_{kl}.
1178   76   \]
1179   77
1180   78
1181   79   The permittivity tensor describes the coupling of electric field and
1182   80   displacement: \[
1183   81   \vec{D}=\epsilon_{0}\tensorsym{\epsilon}_{\mathrm{r}}\vec{E}\]
1184   82
1185   83
1186   84
1187   85   \newpage
1188   86   \subsection*{Bold math version}
1189   87
1190   88   The ''bold'' math version is selected with the commands
1191   89   \verb+\boldmath+ or \verb+\mathversion{bold}+
1192   90
1193   91   {\boldmath
1194   92      \begin{eqnarray*}
1195   93      \mbox{mathnormal} &  & \teststring \\
1196   94      \mbox{mathit} &  & \mathit{\teststring}\\
1197   95      \mbox{mathrm} &  & \mathrm{\teststring}\\
1198   96      \mbox{mathbf} &  & \mathbf{\teststring}\\
1199   97      \mbox{mathsf} &  & \mathsf{\teststring}\\
1200   98      \mbox{mathtt} &  & \mathtt{\teststring}
1201   99      \end{eqnarray*}
1202  100       New alphabets bold-italic, sans-serif-italic, and sans-serif-bold-
1203            italic.
1204  101      \begin{eqnarray*}
1205  102      \mbox{mathbfit}    &  & \mathbfit{\teststring}\\
1206  103      \mbox{mathsfit}    &  & \mathsfit{\teststring}\\
1207  104      \mbox{mathsfbfit} &  & \mathsfbfit{\teststring}
1208  105      \end{eqnarray*}
1209  106      %
1210  107      Do the math alphabets match?
```

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```
1211   108
1212   109       $
1213   110       \mathnormal  {a x \alpha \omega}
1214   111       \mathbfit    {a x \alpha \omega}
1215   112       \mathsfbfit{a x \alpha \omega}
1216   113       \quad
1217   114       \mathsfbfit{T C \Theta \Gamma}
1218   115       \mathbfit    {T C \Theta \Gamma}
1219   116       \mathnormal  {T C \Theta \Gamma}
1220   117       $
1221   118
1222   119       \subsection*{Vector symbols}
1223   120
1224   121       Alphabetic symbols for vectors are boldface italic,
1225   122       $\vec{\lambda}=\vec{e}_{1}\cdot\vec{a}$,
1226   123       while numeric ones (e.g. the zero vector) are bold upright,
1227   124       $\vec{a} + \vec{0} = \vec{a}$.
1228   125
1229   126
1230   127
1231   128
1232   129       \subsection*{Matrix symbols}
1233   130
1234   131       Symbols for matrices are boldface italic, too:%
1235   132       \footnote{However, matrix symbols are usually capital letters whereas
1236               vectors
1237   133       are small ones. Exceptions are physical quantities like the force
1238   134       vector $\vec{F}$ or the electrical field $\vec{E}$.%
1239   135       }
1240   136       $\matrixsym{\Lambda}=\matrixsym{E}\cdot\matrixsym{A}.$
1241   137
1242   138
1243   139       \subsection*{Tensor symbols}
1244   140
1245   141       Symbols for tensors are sans-serif bold italic,
1246   142
1247   143       \[
1248   144           \tensorsym{\alpha}  =  \tensorsym{e}\cdot\tensorsym{a}
1249   145           \quad \Longleftrightarrow \quad
1250   146           \alpha_{ijl}  =  e_{ijk}\cdot a_{kl}.
1251   147       \]
1252   148
1253   149       The permittivity tensor describes the coupling of electric field and
1254   150       displacement: \[
1255   151       \vec{D}=\epsilon_{0}\tensorsym{\epsilon}_{\mathrm{r}}\vec{E}\]
1256   152   }
1257
```

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B3 Abbreviation

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

Again please see List. B.3. Here is an example of first use: alternating current (ac). Next use: ac. Full: alternating current (ac). Here's an acronym referenced using `\acr` : hyper-text markup language (html). And here it is again: html. If you are used to the `glossaries` package, note the difference in using `\gls` : hyper-text markup language (html). And again (no difference): hyper-text markup language (html). Here are some more entries:

- extensible markup language (xml) and cascading style sheet (css).

- Next use: xml and css.

- Full form: extensible markup language (xml) and cascading style sheet (css).

- Reset again.

- Start with a capital. Hyper-text markup language (html).

- Next: Html. Full: Hyper-text markup language (html).

- Prefer capitals? Extensible markup language (XML). Next: XML. Full: extensible markup language (XML).

- Prefer small-caps? Cascading style sheet (CSS). Next: CSS. Full: cascading style sheet (CSS).

- Resetting all acronyms.

- Here are the acronyms again:

- Hyper-text markup language (HTML), extensible markup language (XML) and cascading style sheet (CSS).

- Next use: HTML, XML and CSS.

- Full form: Hyper-text markup language (HTML), extensible markup language (XML) and cascading style sheet (CSS).

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1287   • Provide your own link text: style sheet.

1288   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}
```

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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 $\mathbf{I}$ is the identity matrix.

- A set, denoted as $\mathcal{S}$, is a collection of objects.

- The universal set, denoted as $\mathcal{U}$, is the set of everything.

- The empty set, denoted as $\emptyset$, contains no elements.

- The cardinality of a set, denoted as $|\mathcal{S}|$, is the number of elements in the set.

The verbatim LATEX code for the part of Sec. B4 is in List. B.4.

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

```
1  \begin{itemize}
2
3     \item \Glspl{matrix} are usually denoted by a bold capital letter,
          such as $\mathbfit{A}$. The \gls{matrix}'s $(i,j)$th element is
          usually denoted $a_{ij}$. \Gls{matrix} $\mathbf{I}$ is the
          identity \gls{matrix}.
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{enumerate}
```

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B5 Figure

This section shows several ways of placing figures. PDFLATEX compatible files are PDF, PNG, and JPG. Please see the `figure` subdirectory.
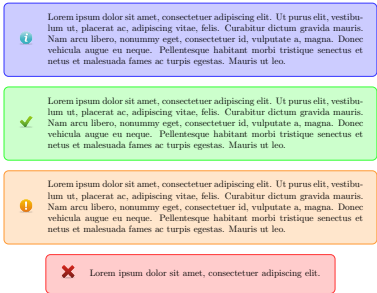
Fig. B.1   A quadrilateral image example.

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1306   Fig. B.1 is a gray box enclosed by a dark border. List. B.5 shows the corresponding
1307   LATEX code.

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

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

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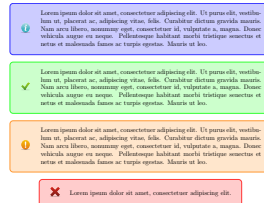
(a) A sub-figure in the top row.
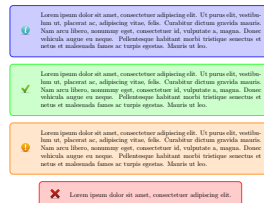
(b) A sub-figure in the middle row.

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

De La Salle University
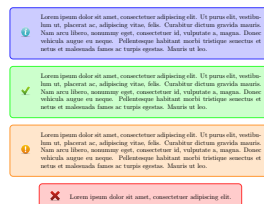
Listing B.6: Sample LATEX code for three figures on top of each other

```
 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}
```

De La Salle University
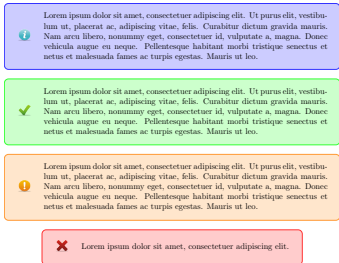
(a) A sub-figure in the upper-left corner.

(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.

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Listing B.7: Sample LATEX code for the four figures
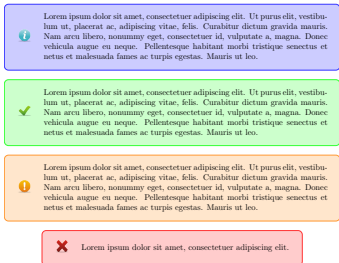
```
1  \begin{figure}[!htbp]
2  \centering
3  \subbottom[A sub-figure in the upper-left corner.]{
4  \includegraphics[width=0.45\textwidth]{example}
5  \label{fig:upprleft}
6  }
7  \hfill
8  \subbottom[A sub-figure in the upper-right corner.]{
9  \includegraphics[width=0.45\textwidth]{example}
10 \label{fig:uppright}
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
       the corresponding \LaTeX \ code.}
23 \label{fig:fourfig}
24 \end{figure}
```

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B6   Table

1308

1309 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

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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)

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List. B.8 shows the corresponding LaTeX code.

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

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

73

```
1366  43  41175 & (1, 12, 13725) & (1, 13, 10980), (2, 2, 2745), (2, 3, 0), (3, 1,
1367         0) \\
1368  44  43920 & (1, 13, 10980) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1369  45  46665 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
1370  46  49410 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
1371  47  52155 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1,
1372         0) \\
1373  48  54900 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1374  49  57645 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1375  50  60390 & (1, 12, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1376  51  63135 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1377  52  65880 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1378  53  68625 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
1379  54  71370 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1380  55  74115 & (1, 12, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1381  56  76860 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1382  57  79605 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1383  58  82350 & (1, 12, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1384  59  85095 & (1, 12, 13725) & (1, 13, 10980), (2, 2, 2745), (2, 3, 0), (3, 1,
1385         0) \\
1386  60  87840 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1387  61  90585 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1388  62  93330 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1389  63  96075 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1390  64  98820 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1391  65  101565 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1392  66  104310 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1393  67  107055 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1394  68  109800 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1395  69  112545 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3,
1396         1, 0) \\
1397  70  115290 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1398  71  118035 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1399  72  120780 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1400  73  123525 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1401  74  126270 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3,
1402         1, 0) \\
1403  75  129015 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
1404  76  131760 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
1405  77  134505 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1406  78  137250 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1407  79  139995 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
1408  80  142740 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
1409  81  145485 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3,
1410         1, 0) \\
1411  82  148230 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
1412  83  150975 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1413  84  153720 & (1, 12, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1414  85  156465 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1415  86  159210 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1416  87  161955 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1417  88  164700 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1418  89  \end{tabularx}
1419  90  }
1420  91  \end{center}
1421
```

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B7 Algorithm or Pseudocode Listing

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

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

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

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

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Listing B.9: Sample LaTeX 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}
```

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B8 Program/Code Listing

1426

1427 List. B.10 is a program listing of a C code for computing Fibonacci numbers by calling the
1428 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 Fibonacci(I) \n\t====================\n");
20        next = current = 1;
21        for (i=1; i<=n; i++) {
22    printf("\t%d \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  */
```

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1429   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.
```

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

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B9.1 A subsection

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

Listing B.13: Sample LaTeX code for referencing subsections

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

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B9.1.1 A sub-subsection

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

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

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

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

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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.
```

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

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

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Virtex UltraScale+ FPGA Feature Summary

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

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

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

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

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

Package [1][2][3]	Package Dimensions (mm)	VU3P HP, GTY	VU5P HP, GTY	VU7P HP, GTY	VU9P HP, GTY	VU11P HP, GTY	VU13P 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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Appendix D
VITA

Junlae Cheong is a sixth year student at De La Salle University. He is currently taking up his B.Sc. Computer Engineering studies. His strengths in the field are electronics circuit design and configuration. His fields of interest are electronics hardware and computer microprocessor.

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Noel B. Paulino is a third year student at De La Salle University. He is currently taking up his B.Sc. Computer Engineering studies. His strengths in the field are microcontroller program design and advanced electronics.

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1515 programmed electronic circuits that includes microcontrollers. His strengths in the field are
1516 microcontroller simulation and programming.

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