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Microcontroller-based Fire Sensing and Extinguishing Mobile Robot

3

A Thesis

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Presented to the Faculty of the

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Department of Electronics and Communications Engineering

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Gokongwei College of Engineering

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De La Salle University

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

13

14

by

15

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July, 2016



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ORAL DEFENSE RECOMMENDATION SHEET

21

This thesis, entitled **Microcontroller-based Fire Sensing and Extinguishing Mobile Robot**, prepared and submitted by thesis group, HERBS, composed of:

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

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THESIS APPROVAL SHEET

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Date: July 24, 2016

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2016

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ACKNOWLEDGMENT

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63

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



64

ABSTRACT

65

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

66

Index Terms—microcontroller, fire, sensing, extinguishing, mobile, robot.



TABLE OF CONTENTS

68	Oral Defense Recommendation Sheet	ii
69	Thesis Approval Sheet	iii
70	Acknowledgment	v
71	Abstract	vi
72	Table of Contents	vii
73	List of Figures	xi
74	List of Tables	xii
75	Abbreviations	xiii
76	Notation	xiv
77	Glossary	xv
78	Listings	xvi
79	Chapter 1 INTRODUCTION	1
80	1.1 Background of the Study	2
81	1.2 Prior Studies	2
82	1.3 Problem Statement	4
83	1.4 Objectives	4
84	1.4.1 General Objective(s)	4
85	1.4.2 Specific Objectives	5
86	1.5 Significance of the Study	5
87	1.6 Assumptions, Scope and Delimitations	6
88	1.7 Description and Methodology	7
89	1.8 Estimated Work Schedule and Budget	9
90	1.9 Overview	11
91	Chapter 2 LITERATURE REVIEW	12
92	2.1 Mobile Robots	13



93	2.1.1	Operation of Mobile Robot	13
94	2.1.2	Mobile Robot Controlled with Android Device	13
95	2.1.3	Mobile Robot Navigation	13
96	2.2	Battery Management System	14
97	2.3	Sensor	15
98	2.3.1	Ultrasonic Sensor	15
99	2.3.2	Flame Sensor	16
100	2.3.3	Smoke Sensor	16
101	Chapter 3 THEORETICAL CONSIDERATIONS		18
102	3.1	Summary	20
103	Chapter 4 DESIGN CONSIDERATIONS		22
104	4.1	Summary	24
105	Chapter 5 METHODOLOGY		25
106	5.1	Implementation	26
107	5.2	Evaluation	27
108	5.3	Summary	27
109	Chapter 6 RESULTS AND DISCUSSION		30
110	6.1	Summary	32
111	Chapter 7 CONCLUSIONS, RECOMMENDATIONS, AND FUTURE DIREC-		
112	TIVES		33
113	7.1	Concluding Remarks	34
114	7.2	Contributions	34
115	7.3	Recommendations	34
116	7.4	Future Prospects	36
117	References		37
118	Appendix A ANSWERS TO QUESTIONS TO THIS THESIS		38
119	A1	How important is the problem to practice?	39
120	A2	How will you know if the solution/s that you will achieve would be better than existing ones?	39
121	A2.1	How will you measure the improvement/s?	39
122	A2.1.1	What is/are your basis/bases for the improvement/s?	40
123	A2.1.2	Why did you choose that/those basis/bases?	40
124	A2.1.3	How significant are your measure/s of the improvement/s?	40
125	A3	What is the difference of the solution/s from existing ones?	41



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127	A3.1 How is it different from previous and existing ones?	41
128	A4 What are the assumptions made (that are behind for your proposed solution to work)?	41
130	A4.1 Will your proposed solution/s be sensitive to these assumptions? .	42
131	A4.2 Can your proposed solution/s be applied to more general cases when some of the assumptions are eliminated? If so, how?	42
133	A5 What is the necessity of your approach / proposed solution/s?	42
134	A5.1 What will be the limits of applicability of your proposed solution/s? .	43
135	A5.2 What will be the message of the proposed solution to technical people? How about to non-technical managers and business men? .	43
137	A6 How will you know if your proposed solution/s is/are correct?	43
138	A6.1 Will your results warrant the level of mathematics used (i.e., will the end justify the means)?	44
140	A7 Is/are there an/_ alternative way/s to get to the same solution/s?	44
141	A7.1 Can you come up with illustrating examples, or even better, counter examples to your proposed solution/s?	44
143	A7.2 Is there an approximation that can arrive at the essentially the same proposed solution/s more easily?	45
145	A8 If you were the examiner of your proposal, how would you present the proposal in another way?	45
146	A8.1 What are the weaknesses of your proposal?	45
148	Appendix B USAGE EXAMPLES	47
149	B1 Equations	48
150	B2 Notations	50
151	B3 Abbreviation	56
152	B4 Glossary	58
153	B5 Figure	59
154	B6 Table	65
155	B7 Algorithm or Pseudocode Listing	69
156	B8 Program/Code Listing	71
157	B9 Referencing	73
158	B9.1 A subsection	74
159	B9.1.1 A sub-subsection	75
160	B10 Index	76
161	B11 Adding Relevant PDF Pages (e.g. Standards, Datasheets, Specification Sheets, Application Notes, etc.)	77
163	Appendix C PUBLICATION LIST AND AWARD	81



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164	Appendix D VITA	83
165	Index	85



166 LIST OF FIGURES

167	3.1 A quadrilateral image example.	21
168	5.1 Target Mobile Robot Design	26
169	5.2 Current Mobile Robot Design	26
170	5.3 Room Handling Algorithm	28
171	5.4 Navigation Algorithm	29
172	B.1 A quadrilateral image example.	59
173	B.2 Figures on top of each other. See List. B.6 for the corresponding L ^A T _E X code.	61
174	B.3 Four figures in each corner. See List. B.7 for the corresponding L ^A T _E X code. .	63



175

LIST OF TABLES

176

B.1 Feasible triples for highly variable grid 65

177

B.2 Calculation of $y = x^n$ 69



178

ABBREVIATIONS

179	AC	Alternating Current.....	56
180	HTML	Hyper-text Markup Language	56
181	CSS	Cascading Style Sheet.....	56
182	XML	eXtensible Markup Language	56



183

NOTATION

184	\mathcal{S}	a collection of distinct objects	58
185	\mathcal{U}	the set containing everything	58
186	\emptyset	the set with no elements	58
187	$ \mathcal{S} $	the number of elements in the set \mathcal{S}	58
188	$h(t)$	impulse response	48
189	$x(t)$	input signal represented in the time domain	48
190	$y(t)$	output signal represented in the time domain	48

191 Throughout this thesis, mathematical notations conform to ISO 80000-2 standard, e.g.
192 variable names are printed in italics, the only exception being acronyms like e.g. SNR,
193 which are printed in regular font. Constants are also set in regular font like j . Functions are
194 also set in regular font, e.g. in $\sin(\cdot)$. Commonly used notations are t , f , $j = \sqrt{-1}$, n and
195 $\exp(\cdot)$, which refer to the time variable, frequency variable, imaginary unit, n th variable,
196 and exponential function, respectively.



197

GLOSSARY

198

matrix a concise and useful way of uniquely representing and working with linear transformations; a rectangular table of elements 58



199

LISTINGS

200	B.1 Sample L ^A T _E X code for equations and notations usage	49
201	B.2 Sample L ^A T _E X code for notations usage	53
202	B.3 Sample L ^A T _E X code for abbreviations usage	57
203	B.4 Sample L ^A T _E X code for glossary and notations usage	58
204	B.5 Sample L ^A T _E X code for a single figure	60
205	B.6 Sample L ^A T _E X code for three figures on top of each other	62
206	B.7 Sample L ^A T _E X code for the four figures	64
207	B.8 Sample L ^A T _E X code for making typical table environment	67
208	B.9 Sample L ^A T _E X code for algorithm or pseudocode listing usage	70
209	B.10 Computing Fibonacci numbers	71
210	B.11 Sample L ^A T _E X code for program listing	72
211	B.12 Sample L ^A T _E X code for referencing sections	73
212	B.13 Sample L ^A T _E X code for referencing subsections	74
213	B.14 Sample L ^A T _E X code for referencing sub-subsections	75
214	B.15 Sample L ^A T _E X code for Index usage	76
215	B.16 Sample L ^A T _E X code for including PDF pages	77



216

Chapter 1

217

INTRODUCTION

218

Contents

219

220

1.1	Background of the Study	2
1.2	Prior Studies	2
1.3	Problem Statement	4
1.4	Objectives	4
1.4.1	General Objective(s)	4
1.4.2	Specific Objectives	5
1.5	Significance of the Study	5
1.6	Assumptions, Scope and Delimitations	6
1.7	Description and Methodology	7
1.8	Estimated Work Schedule and Budget	9
1.9	Overview	11

221

222

223

224

225

226

227

228

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232 **1.1 Background of the Study**

233 A mobile robot is an automatic machine that is fast evolving and has a significant role in
234 the industry. It is capable of moving from one place to another or to execute the program it
235 was given. Some mobile robots have the capability to navigate without the user controlling
236 it, while there are also mobile robots that can be controlled through controllers. Some of its
237 application in the industry includes, manufacturing, agriculture, medical, aerospace and
238 etc. Mobile robots are made up of software, controller, actuators and sensor. Its controller
239 can be made using embedded microcontroller, microprocessor or a computer. Its controller
240 is programmed using assembly language, C, C++ and etc. The kind of sensor that will
241 be equipped in the mobile robot depends on the application. Some application can be for
242 proximity sensing, collision avoidance, positioning, distance calculator and etc.

243 The plan is to create a firefighting robot that will be able to extinguish fire and draw the
244 smoke in. It is capable of detecting fire and smoke using a flame sensor and smoke sensor.
245 It can also extinguish the flames by using the small fire extinguisher equipped on it. The
246 mobile robot will be Arduino-based. It will consist of several DC motors.

247 The constants will be the battery, the fan, and the room to be used. The goal is to design
248 a system that will allow all components of the robot to function harmoniously. The flame
249 sensor will be integrated with the Arduino to be able to sense the flame and alarm the
250 vehicle. It will approach it and extinguish it using the canister equipped with it.

251 **1.2 Prior Studies**

252 There are many ways to detect fire. As technology improves, ways to detect fire became
253 more and more reliable and accurate. The most reliable fire detectors are still humans



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254 because they can see the fire and smell the smoke the moment they appear, which allows
255 them to respond quickly. However, at times when people are not home, electronic fire
256 detectors are needed to keep a house or building safe. One such sensor is the heat detector.
257 According to Science Learning Hub, most heat-detecting sprinklers used these days utilize
258 a fragile glass bulb containing fluid that expands with heat. The glass breaks, spraying
259 water down from the sprinkler. Heat detectors do not cost much and are relatively reliable.
260 They operate completely without electricity as well, which makes them very popular in
261 large establishments. They are, however, slow to respond as the heat needs to reach the
262 ceiling to activate the sprinklers.

263 Another way to detect fire is through the use of smoke detectors. Smoke detectors
264 respond faster than heat detectors. They are more sensitive and can respond the moment it
265 detects the smoke from the fire. One drawback of the smoke detector is its complex design
266 and its price. Another drawback is its sensitivity. Sometimes the smoke detector cannot
267 differentiate fire smoke from normal steam or dust.

268 Other ways to sense fire include optical flame detectors. These detectors work using
269 ultraviolet or infrared light. Infrared flame detectors sense fire through the infrared spectral
270 band for unique patterns emitted by the hot gas of the flame. However, accuracy of the
271 infrared flame detectors is largely affected when exposed to direct sunlight. Ultraviolet
272 detectors, on the other hand, operate by sensing the UV radiation given off by the flame.
273 These sensors are capable of detecting flames in three to four milliseconds. Between these
274 two optical flame detectors, the UV detector is much more accurate and reliable.



275 **1.3 Problem Statement**

276 According to the Philippine Statistics Authority, at least 2,000 fire incidents happen on
277 the months of April to May each year. Fire incidents is one of the major setbacks to the
278 growth of the Philippines economy because it does not only do damage to properties,
279 but also result to a sizable number of casualties. With the joint efforts of the Bureau of
280 Fire Prevention (BFP), Red Cross, and other Non-Government Organizations (NGOs), the
281 amount of destruction caused by fires decreased.

282 However, due to the recent incidents of heavy traffic in Metro Manila, fire and medical
283 volunteers are having a hard time arriving at their destinations. Because of the delayed
284 response of the volunteers, about 2.5 billion pesos worth of property are destroyed, 5,000
285 civilians left homeless, and 90 persons killed (58 civilians and 32 firefighters) in Metro
286 Manila only. Lack of proper fire response equipment in local barangays also play a part in
287 the destruction caused by the fire.

288 In response to this problem, The researchers study proposes to create a microcontroller-
289 based mobile robot that can sense and extinguish fire. The said robot can be deployed
290 manually (by a technician) or automatically (by using its flame sensor) to the concerned
291 location. Because the robot will already be placed in the building, the immediate response
292 time to treat the fire will be fairly shorter as compared as to calling the fire department.

293 **1.4 Objectives**

294 **1.4.1 General Objective(s)**

295 To design and to develop a wheeled mobile robot that is capable of detecting fire using an



296 infrared-based flame sensor, and extinguish fire with the use of a small fire extinguisher
297 mounted onto the robot.

298 **1.4.2 Specific Objectives**

299 To design and to develop a voltage booster circuit that is capable of powering up a mobile
300 robot carrying a small exhaust fan.;

301 To design and to develop a mobile robot that can detect and locate a flame source.;

302 To develop a mobile robot that is capable of detecting the face of a human within a room
303 with smoke.;

304 **1.5 Significance of the Study**

305 *People working or living in a building*

306 People working or living in buildings that have no complete fire precautions (protection)
307 can use this robot in their daily lives. While the firefighters are still on their way to the
308 rescue, this firefighting robots can clear the smoke from the persons pathway so he or
309 she wont suffocate on his or her way out of the vicinity. It can also help people who are
310 trapped in their rooms by extinguishing the flame on small areas using the fire extinguisher
311 equipped on the mobile robot.

312 *Fire Fighters*

313
314 This robot can be a great help for firefighters because it can start killing some fires to
315 evacuate the people in a room while the firefighters are on their way to the site or when they



316 are stuck in traffic. It can also lessen the number of deaths among firefighters by letting this
317 robot go into the building to check if there are still small fires or if there are things that are
318 on fire. Furthermore, unmanned vehicles are more suitable for dangerous task to reduce the
319 injuries or even deaths of people.

320 *School/University*

321

322 This can also give aid in the universities especially in the laboratories where it is
323 possible to have a fire outbreak like chemistry laboratories, electronic laboratories and etc.

324 *Selling Point*

325

326 The slightest amount of time during a fire outbreak is very crucial which may decide
327 whether the person will live or die. This mobile robot is designed to help the people in
328 case of a fire in buildings, houses or any closed vicinity, while the firefighters get to the
329 burning site. This mobile robot will not only help the people create a smokeless pathway
330 but will also kill small fires with a mini fire extinguisher equipped. It also lessens injuries
331 and deaths to firefighters since it is an unmanned vehicle.

332 **1.6 Assumptions, Scope and Delimitations**

333 This study will focus on using flame sensors in locating the fire approximately 1 foot away.;

334 The study will also use an ultrasonic sensors to avoid obstacle and navigate through the
335 room.;

336 The researchers will use a camera to implement face detection in order to locate victims.;



- 337 This study will only cover extinguishing of small scale of fire that have started from
338 non-electrical things.;
- 339 The researchers will use an Arduino board as means of communication between the sensors
340 and the motors.;
- 341 The researchers will design a battery management module for the robot so the input power
342 will be distributed among the components without making one part of the robot fail or
343 breakdown.;
- 344 The mobile robot will not cover fire proofing.;

345 **1.7 Description and Methodology**

346 The project aims to extinguish fire using a wheeled mobile robot equipped with an Arduino,
347 a fire extinguisher, fans, flame sensors, and ultrasonic sensors. The Arduino board acts as
348 the controller of the mobile robot that loads the program that controls the movement of the
349 robot, fans, and sensors which control the fire extinguisher. The board interprets the data
350 sent by the sensors to the microcontroller and loads a specific program which triggers the
351 movement of the robot, the fans, and the fire extinguisher. Since the robot is controlled
352 by sensors, a camera will be mounted in front of the robot to allow the user to see the
353 surroundings and objects in front of it, and detect a human face inside a smokey room.

354 The research project allows the use of different devices such as fans, camera, sensors,
355 fire extinguisher and a wheeled mobile robot. The researchers would use an algorithm
356 that would allow the mobile robot to navigate through an area and search for fire which it
357 will extinguish while its fans are absorbing the smoke. The research project will then take



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358 inputs from the sensor whether the robot should move or not and whether the fan should
359 rotate or not. The camera equipped on the mobile robot will also detect victims of the fire.

360 The mobile robot will consist of an Arduino board connected to a motor driver which
361 controls the DC motors. The sensors connected on the mobile robot will consist of the
362 following: ultrasonic sensors, flame sensors, and smoke sensor. The ultrasonic sensor is
363 used by the mobile robot to navigate through the room. The flame sensor is used to locate
364 the flame about a foot apart. The smoke sensor will dictate when the fans will operate in
365 sucking the smoke. The mobile robot will also be equipped with a fire extinguisher which
366 the mobile robot will use in killing the fire. Lastly, the camera will be used in detecting
367 victims of the fire.

368 The accuracy of the flame sensor can be verified by testing the sensor on set distances
369 from the flame. The flame sensor will first be tested 10 times while placed 3 feet away from
370 the flame; followed by another 10 times, 2 feet away; and finally another 10 times, 1 foot
371 away.



372

1.8 Estimated Work Schedule and Budget

373

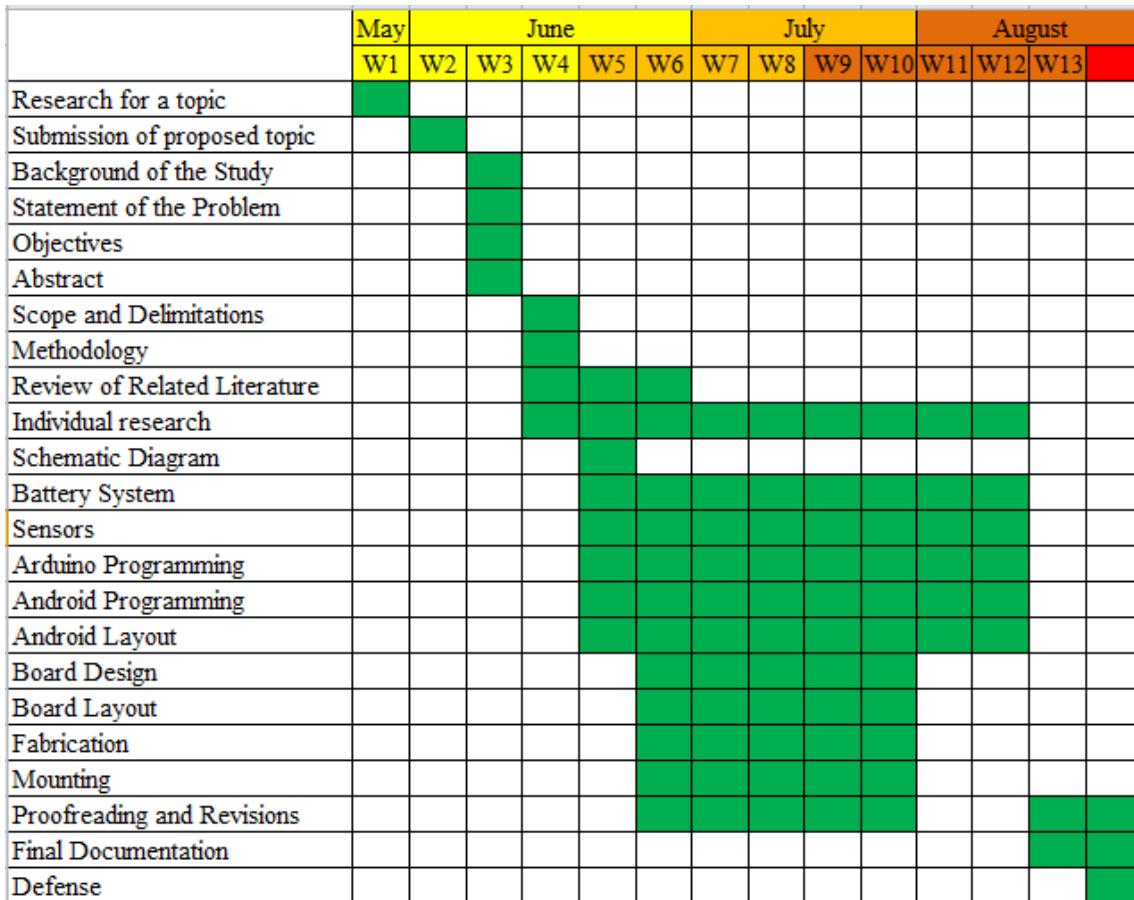
Item	Quantity	Price (PHP)
Arduino UNO (GizDuino Board)	1	400
Bluetooth Camera	1	430
Flame Sensor	3	135
Ultrasonic Sensor	3	750
Smoke Sensor	1	500
Used Exhaust Fan	2	400
Battery	2	300
Buzzer	1	15
Used RC Car	1	500
Fire Extinguisher	1	195
DC to DC Booster	1	140
Battery Management System Board	1	500
Total		4265

374

Figure 1. Estimated Budget



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375

376

377

Figure 2. Gantt Chart

MORFCPE : MICROCONTROLLER BASED FIRE SENSING AND EXTINGUISHING MOBILE ROBOT				Prepared by:	S.H. CHUA	J.S. LIMQUECO	E.L. LU	S.W. QUE	Approved by:
PLAN OF ACTIVITIES	P.I.C.	Wk-1 (May23-May29)	Wk-2 (May30-Jun05)	Wk-3 (Jun06-Jun12)	Wk-4 (Jun13-Jun19)	Wk-5 (Jun20-Jun26)	Wk-6 (Jun27-Jul03)	Wk-7 (Jul04-Jul10)	Engr. MELVIN CABATUAN
1.) Documentation	Herbie, Jerald, Ervin, Wyndell	plan actual							REMARKS
2.) BMS	Ervin, Jerald, Wyndell	plan							
3.) Mobile Robot	Ervin, Jerald, Herbie	plan actual							
4.) Sensors Testing	Herbie, Wyndell actual	plan							
5.) Face Detection	Herbie, Jerald, Ervin, Wyndell	plan actual							
6.) Debugging of Program	Herbie, Jerald, Ervin, Wyndell	plan actual							
7.) System Integration	Herbie, Jerald, Ervin, Wyndell	plan actual							
8.) Weekly Progress Report	Herbie, Jerald, Ervin, Wyndell	Generated topic idea actual	Completed Chapter 1 actual	Completed Chapter 1 and 2 actual					
9.) Final Report Preparation	Herbie, Jerald, Ervin, Wyndell	plan actual							
10.) Defense	Herbie, Jerald, Ervin, Wyndell	plan actual							

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379

380

Figure 3. Workplan



381

1.9 Overview

382

This paper shows how the researchers designed a firefighting mobile robot. It contains all the necessary informations needed to build the robot. The first chapter includes a description of the specifications and functions of the mobile robot. It also has prior studies about the topic that the researchers used to design the robot. The following chapters will cover the research undergone by the researchers to explore the possibilities attainable by the robot through academic articles.

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Chapter 2

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LITERATURE REVIEW

390

Contents

391

392	2.1	Mobile Robots	13
393	2.1.1	Operation of Mobile Robot	13
394	2.1.2	Mobile Robot Controlled with Android Device	13
395	2.1.3	Mobile Robot Navigation	13
396	2.2	Battery Management System	14
397	2.3	Sensor	15
398	2.3.1	Ultrasonic Sensor	15
399	2.3.2	Flame Sensor	16
400	2.3.3	Smoke Sensor	16

401



402 **2.1 Mobile Robots**

403 **2.1.1 Operation of Mobile Robot**

404 According to Pandey, Kumar, Pandey, and Parhi (2016), navigation and obstacle avoidance
405 are the most important task for any mobile robot. Using the Adaptive Neuro-Fuzzy
406 Interference System (ANFIS) controller, it uses several transducers to detects obstacles in
407 an unknown environment. The ANFIS is product of by Takagi-Sugeno fuzzy interference
408 system and Artificial Neural Networks (ANN). Similarly, the objective of this thesis is
409 to create a firefighting wheeled mobile robot that will be able to navigate through foggy
410 places.

411 **2.1.2 Mobile Robot Controlled with Android Device**

412 Basing from an article by Pahuja and Kumar (2014), controlling the mobile robot was
413 done using the HC serial bluetooth. In this article, the HC-06 bluetooth module was used
414 together with the 8051 microcontroller. The flow of the data is from the bluetooth module,
415 which will be sent to the decoder. Then, it goes straight to the microcontroller, which
416 dictates a different data depending on the buttons pressed by the master module. It will
417 dictate how the motors should operate based on the data received by the bluetooth module.

418 **2.1.3 Mobile Robot Navigation**

419 The mobile robot can be implemented using a microcontroller, the Programmable Interface
420 Controller (PIC). According to Kendre, Malmule, and Shinde (2010), the PIC is economical
421 and has a high computational performance. Based from the article, the mobile robot was



422 able to navigate through a simple lined map using a heuristic search algorithm. The mobile
423 robot is capable of mapping the layout of the area and can store the information. It also has
424 the capability of sharing the information with other mobile robots using an ASK transmitter
425 and ASK receiver. In its first run, it maps out the area and during its succeeding run,
426 the mobile robot knows the right path. This will be of significant help when creating a
427 robot that has the capability of traversing the room. According to Thrun (1997), there are
428 two types of indoor mapping: the grid-based and topological. The grid-based map is the
429 layout of the room. The topological map is the pathway map. The grid-based produces
430 more accurate metric maps but are complex and inefficient, especially in large rooms. The
431 topological is more efficient but is less accurate compared to the output of a grid-based
432 mapping.

433 **2.2 Battery Management System**

434 Modern battery operated robots performs very complicated tasks because more and more
435 applications are added unto its system which demands more power from its input. Some of
436 the new applications are cameras, navigation, bluetooth, mapping and etc. These robots
437 cannot tell if the battery used is enough or not when an additional component is added onto it
438 which may cause its operation to breakdown. Even worse, batteries may be used incorrectly
439 due to lack of knowledge which may reduce or damage its performance. According to Cai,
440 Du, and Liu, power supply is the basic problem when it comes to adding applications to a
441 robot. With these kind of problems, robots are being unacceptable to security or critical
442 applications. According to Lucas, Codrea, Hirth, Gutierrez, and Dressler, these problems
443 can be avoided with proper knowledge and proper battery management system. A robot



444 battery management and monitoring system is an improved interface between the battery
445 and the robot. It monitors the battery state and controls the charging process of the battery.
446 According to Lucas, Codrea, Hirth, Gutierrez, and Dressler, It is common for robots
447 to have lead-acid batteries as their supply. These batteries are accepted by the users even
448 though these cells have a low power-density because it is cheap and powerful. The RoBM2
449 board is an adaptable platform for implementing battery supervision policies, even without
450 the smart power supplies. Smart power system is a complete power system that has a
451 multiple specification for portable devices. Smart battery, smart battery charger and a
452 SMBus Host should always be present in a smart power system. The system management
453 bus or SMBus is a two-wire bus transporting data between devices.

454 **2.3 Sensor**

455 **2.3.1 Ultrasonic Sensor**

456 In order for the mobile robot to move autonomously, it needs distance measuring sensors
457 to determine the presence of an obstacle in front of it. Ultrasonic sensors are largely
458 used for this application due to its relatively high reliance and low cost. According to
459 Vaduva (2013), through the use of the triangulation method, the ability of the sensors to
460 detect an object would increase in efficiency. Using a single ultrasonic sensor would only
461 detect the presence of an object. However, using two ultrasonic sensors would allow a two
462 dimensional detection of an object. It will not only calculate the distance, but the angle at
463 which the obstacle is facing the sensor as well. There are some disadvantages in using the
464 ultrasonic sensor. Errors usually happen with transparent or shiny objects.



465 **2.3.2 Flame Sensor**

466 In a study made by Punuganti, Srinivas, Savanoor, and Shree (2014) in designing a fire-
467 fighting robot, they used a generic infrared fire sensor to detect flames. In the occurrence of
468 a fire, distinct changes in the IR region are exhibited by the flame. The fire sensor module
469 used weighs a total of five grams and has a maximum range of one meter. An LED is
470 attached to the module to indicate whether the sensor detected a fire or not. To cover a
471 wider field of view, the researchers used four IR fire sensors, one on each side of robot.

472 Another type of fire sensor is the ultraviolet fire sensor. According to Bharathi and
473 Prasad (2013), a flame from a tiny candle can be detected by the UV fire sensor five meters
474 away. The UV sensor in particular is called the Hamamatsu UV TRON Flame Detector. It
475 is more reliable and accurate than the IR sensor, but the price is much more expensive.

476 **2.3.3 Smoke Sensor**

477 According to Luis, Galan, and Espigado (2015), the use of smoke sensors is the most
478 popular method in detecting fires due to its quick response and low cost. However, they
479 stated that using only one sensor to detect fire can be unreliable. To improve the accuracy of
480 the smoke alarm, they added a few more relevant sensors. The smoke sensor triggers when
481 smoke particles enter into the chamber of the component and activates a photosensitive
482 device when light bounces off from the smoke particles. A carbon monoxide sensor is
483 added to the device to measure the level of carbon monoxide in the air. The main function
484 of this sensor is differentiating actual fire smoke from steam or dust. This added component
485 increased the reliability of the smoke detector significantly.

486 Another way to detect smoke is through image processing. According to Luo, Yan,



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487 Wu, and Zheng (2015), condensing a video can significantly increase the efficiency in
488 detecting the smoke through special characteristics exhibited by the smoke trajectories.
489 There are many advantages to using a video camera over a sensor. Not only is it cheaper,
490 it can be applied to a wider angle and longer range. This is especially effective for forest
491 fires. There are five unique smoke trajectory characteristics that can help in detecting the
492 smoke and these are the right-leaning line of the velocity-to-time trajectory, the smooth
493 streamline, the low frequency of the smoke clique, the fixed source of the smoke, and the
494 vertical-horizontal ratio. Since smoke always appear when there is fire, using this method
495 can make for an excellent early warning system.



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Chapter 3

497

THEORETICAL CONSIDERATIONS

498

Contents

499

500

501

3.1	Summary	20
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547 **3.1 Summary**



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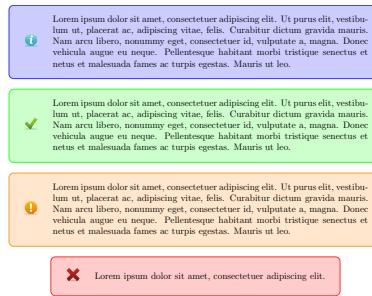


Fig. 3.1 A quadrilateral image example.



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Chapter 4

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DESIGN CONSIDERATIONS

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Contents

551

552

553

4.1	Summary	24
-----	---------	----



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599 **4.1 Summary**



Chapter 5

METHODOLOGY

Contents

5.1	Implementation	26
5.2	Evaluation	27
5.3	Summary	27

The proposed study work is mainly focused to find out whether the proposed mobile robot can detect and locate a fire, suck smoke away from the human face, and detect a human face in a smokey room effectively and efficiently. The main hypothesis of the proposed system is the effective and efficient fire detection, smoke redirection, and human face detection. The proposed mobile robot will be using two Arduino UNO boards that will serve as the main controllers, three HC-SR04 ultrasonic sensors that will aid the robot to navigate through a room, two infrared flame sensors that will detect and guide the robot to the flame source, one L298N dual bridge motor controller module that will drive the main motors of the mobile robot, one toy tank chassis, which includes the rubber tracks and the motors, that will serve as the mobile robot itself, one MQ2 smoke sensor that will detect the presence of smoke, one exhaust fan, which is composed of four 12V computer fans, that will suck the air away, one buzzer that will serve as an alarm when fire and smoke are detected, rechargeable batteries that will serve as the main power supply for the robot, one fire extinguisher that will be used to extinguish the fire, and a laptop that will be our workstation in implementing, coding, and interfacing everything all together.



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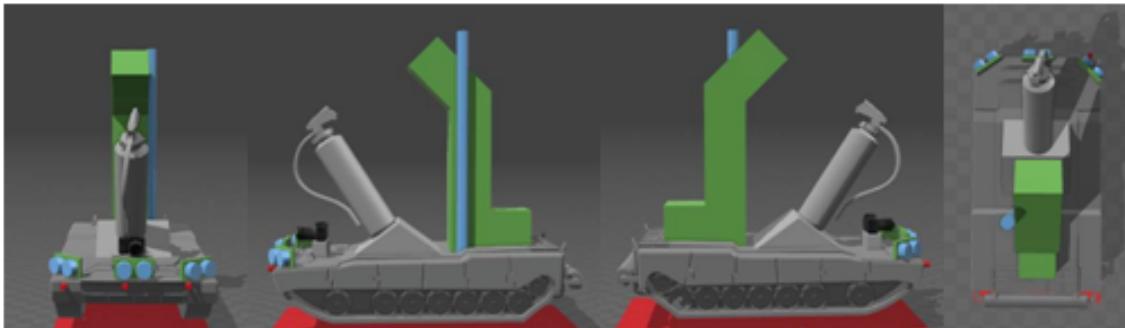


Fig. 5.1 Target Mobile Robot Design



Fig. 5.2 Current Mobile Robot Design

623

5.1 Implementation

624

The proposed mobile robot will be connected as shown in Figure 5.1 with the actual set up
625 (as of the moment) and the exhaust fan shown in Figure 5.2.



626 The implementation phase of the proposed system was broken into two sub phases, the
627 individual tests where each component of the proposed mobile robot are put into rigorous
628 testing to their maximum capacity without breaking down, and the actual testing where
629 everything is assembled together and the actual performance of the system can be tested.
630 The researchers are currently in the individual tests interfacing the two Arduino UNO
631 boards. The proposed algorithm for the system will be composed of two parts, the Room
632 Handling Algorithm, and the Navigation Algorithm. The flowchart on the program flow is
633 shown in Figures 5.3 and 5.4 respectively.

634 **5.2 Evaluation**

635 **5.3 Summary**



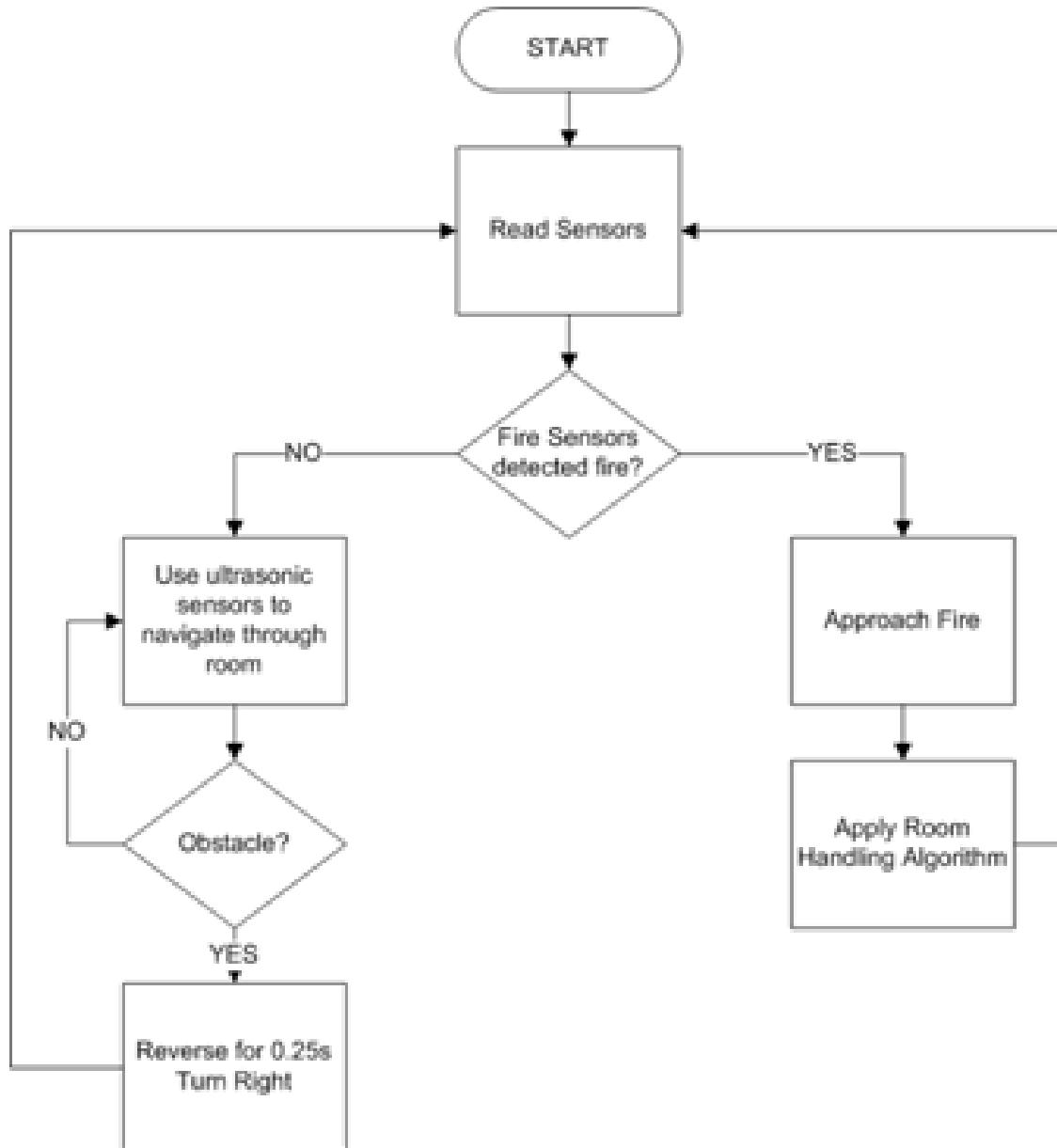


Fig. 5.4 Navigation Algorithm



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Chapter 6

637

RESULTS AND DISCUSSION

638

Contents

639

640

641

6.1	Summary	32
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687 **6.1 Summary**



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Chapter 7

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CONCLUSIONS, RECOMMENDATIONS, AND FUTURE DIRECTIVES

690

691

Contents

692

693

7.1	Concluding Remarks	34
7.2	Contributions	34
7.3	Recommendations	34
7.4	Future Prospects	36

694

695

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698 7.1 Concluding Remarks

699 In this Thesis, ...

700 7.2 Contributions

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

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706 7.3 Recommendations

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752 7.4 Future Prospects

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

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Appendix A ANSWERS TO QUESTIONS TO THIS THESIS

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Contents

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A1	How important is the problem to practice?	39
A2	How will you know if the solution/s that you will achieve would be better than existing ones?	39
A2.1	How will you measure the improvement/s?	39
A2.1.1	What is/are your basis/bases for the improvement/s?	40
A2.1.2	Why did you choose that/those basis/bases?	40
A2.1.3	How significant are your measure/s of the improvement/s?	40
A3	What is the difference of the solution/s from existing ones?	41
A3.1	How is it different from previous and existing ones?	41
A4	What are the assumptions made (that are behind for your proposed solution to work)?	41
A4.1	Will your proposed solution/s be sensitive to these assumptions?	42
A4.2	Can your proposed solution/s be applied to more general cases when some of the assumptions are eliminated? If so, how?	42
A5	What is the necessity of your approach / proposed solution/s?	42
A5.1	What will be the limits of applicability of your proposed solution/s?	43
A5.2	What will be the message of the proposed solution to technical people? How about to non-technical managers and business men?	43
A6	How will you know if your proposed solution/s is/are correct?	43
A6.1	Will your results warrant the level of mathematics used (i.e., will the end justify the means)?	44
A7	Is/are there an/_ alternative way/s to get to the same solution/s?	44
A7.1	Can you come up with illustrating examples, or even better, counter examples to your proposed solution/s?	44
A7.2	Is there an approximation that can arrive at the essentially the same proposed solution/s more easily?	45
A8	If you were the examiner of your proposal, how would you present the proposal in another way?	45
A8.1	What are the weaknesses of your proposal?	45



799 A1 How important is the problem to practice?

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809 A2 How will you know if the solution/s that you will 810 achieve would be better than existing ones?

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

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

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

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

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860 **A3 What is the difference of the solution/s from ex-**
 861 **existing ones?**

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

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881 **A4 What are the assumptions made (that are be-**
 882 **hind for your proposed solution to work)?**

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892 **A4.1 Will your proposed solution/s be sensitive to these as-**
 893 **sумptions?**

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

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

906 Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Etiam lobortis facilisis sem.
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 914 amet ipsum. Nunc quis urna dictum turpis accumsan semper.

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

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

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 929 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec
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937 **A5.2 What will be the message of the proposed solution to**
 938 **technical people? How about to non-technical managers**
 939 **and business men?**

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

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

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

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

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

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

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

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A8.1 What are the weaknesses of your proposal?

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Appendix B USAGE EXAMPLES



1027 The user is expected to have a working knowledge of L^AT_EX. A good introduction
 1028 is in [Oetiker et al., 2014]. Its latest version can be accessed at <http://www.ctan.org/tex-archive/info/lshort>.
 1029

1030

B1 Equations

1031 The following examples show how to typeset equations in L^AT_EX. This section also shows
 1032 examples of the use of `\gls{ }` commands in conjunction with the items that are in
 1033 the `notation.tex` file. **Please make sure that the entries in `notation.tex` are**
 1034 **those that are referenced in the L^AT_EX document files used by this Thesis. Please**
 1035 **comment out unused notations and be careful with the commas and brackets in**
 1036 **`notation.tex` .**

1037 In (B.1), the output signal $y(t)$ is the result of the convolution of the input signal $x(t)$
 1038 and the impulse response $h(t)$.

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

1039 Other example equations are as follows.

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

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

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



1040

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

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

```

1 The following examples show how to typeset equations in \LaTeX.
2
3 In ^\eqref{eq:conv}, the output signal \gls{not:output_sigt} is the
   result of the convolution of the input signal \gls{not:input_sigt}
   and the impulse response \gls{not:ir}.
4
5 \begin{eqnarray}
6     y\left( t \right) = h\left( t \right) * x\left( t \right)=\int_{-\infty }^{+\infty }h\left( t-\tau \right)x\left( \tau \right) \
7         \mathrm{d}\tau
8 \label{eq:conv}
9 \end{eqnarray}
10 Other example equations are as follows.
11
12 \begin{eqnarray}
13     \left[ \frac{V_1}{I_1} \right] = \begin{bmatrix} A & B \\ C & D \end{bmatrix}
14     \left[ \frac{V_2}{I_2} \right]
15 \label{eq:ABCD}
16 \end{eqnarray}
17
18 \begin{eqnarray}
19 \left\{ \frac{1}{2} < \left\lfloor \mathrm{mod}\left(\left\lfloor \frac{y}{17} \right\rfloor - \left\lfloor \frac{x}{17} \right\rfloor, 2 \right) \right\rfloor \right\} \right\} \geq 1
20 \end{eqnarray}
21
22 \begin{eqnarray}
23 \left| \zeta(x)^3 \zeta(x+iy)^4 \zeta(x+2iy) \right| = \exp \sum_{n,p} \frac{3+4 \cos(ny \log p) + \cos(2ny \log p)}{np^{nx}} \geq 1
24 \end{eqnarray}
25
26 \begin{eqnarray}
27 \left| \zeta(x)^3 \zeta(x+iy)^4 \zeta(x+2iy) \right| = \exp \sum_{n,p} \frac{3+4 \cos(ny \log p) + \cos(2ny \log p)}{np^{nx}} \geq 1
28 \end{eqnarray}
29

```



1041 B2 Notations

1042 In order to use the standardized notation, the user is highly suggested to see the ISO 80000-2
 1043 standard [ISO, 2009]. The following were taken from `isomath-test.tex`.

1044 Math alphabets

1045 If there are other symbols in place of Greek letters in a math alphabet, it uses T1 or OT1
 1046 font encoding instead of OML.

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

1047 New alphabets bold-italic, sans-serif-italic, and sans-serif-bold-italic.

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

1048 Do the math alphabets match?

1049 $ax\alpha\omega ax\alpha\omega ax\alpha\omega \quad TC\Theta\Gamma TC\Theta\Gamma TC\Theta\Gamma$

1050 Vector symbols

1051 Alphabetic symbols for vectors are boldface italic, $\lambda = e_1 \cdot a$, while numeric ones (e.g.
 1052 the zero vector) are bold upright, $a + 0 = a$.

1053 Matrix symbols

1054 Symbols for matrices are boldface italic, too:¹ $\Lambda = E \cdot A$.

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



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1055 Tensor symbols

1056 Symbols for tensors are sans-serif bold italic,

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

1057 The permittivity tensor describes the coupling of electric field and displacement:

$$\mathbf{D} = \epsilon_0 \epsilon_r \mathbf{E}$$



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1058 Bold math version

1059 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	$A, B, \Gamma, \Delta, \Theta, \Lambda, \Xi, \Pi, \Sigma, \Phi, \Psi, \Omega, ff, fi, \beta, ^\circ, !, v, w, 0, 1, 9$
mathrm	$A, B, \Gamma, \Delta, \Theta, \Lambda, \Xi, \Pi, \Sigma, \Phi, \Psi, \Omega, ff, fi, \beta, ^\circ, !, v, w, 0, 1, 9$
mathbf	$A, B, \Gamma, \Delta, \Theta, \Lambda, \Xi, \Pi, \Sigma, \Phi, \Psi, \Omega, ff, fi, \beta, ^\circ, !, v, w, 0, 1, 9$
mathsf	$A, B, \Gamma, \Delta, \Theta, \Lambda, \Xi, \Pi, \Sigma, \Phi, \Psi, \Omega, ff, fi, \beta, ^\circ, !, v, w, 0, 1, 9$
mathtt	$A, B, \Gamma, \Delta, \Theta, \Lambda, \Xi, \Pi, \Sigma, \Phi, \Psi, \Omega, ff, fi, \beta, ^\circ, !, v, w, 0, 1, 9$

1060 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	$A, B, \Gamma, \Delta, \Theta, \Lambda, \Xi, \Pi, \Sigma, \Phi, \Psi, \Omega, \alpha, \beta, \pi, \nu, \omega, v, w, 0, 1, 9$
mathsfbit	$A, B, \Gamma, \Delta, \Theta, \Lambda, \Xi, \Pi, \Sigma, \Phi, \Psi, \Omega, \alpha, \beta, \pi, \nu, \omega, v, w, 0, 1, 9$

1061 Do the math alphabets match?

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

1063 Vector symbols

1064 Alphabetic symbols for vectors are boldface italic, $\lambda = e_1 \cdot a$, while numeric ones (e.g.
1065 the zero vector) are bold upright, $a + 0 = a$.

1066 Matrix symbols

1067 Symbols for matrices are boldface italic, too:² $\Lambda = E \cdot A$.

1068 Tensor symbols

1069 Symbols for tensors are sans-serif bold italic,

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

1070 The permittivity tensor describes the coupling of electric field and displacement:

$$D = \epsilon_0 \epsilon_r E$$

1071 ²However, matrix symbols are usually capital letters whereas vectors are small ones. Exceptions are physical quantities like the force vector F or the electrical field E .



1072 The verbatim L^AT_EX code of Sec. B2 is in List. B.2.

Listing B.2: Sample L^AT_EX code for notations usage

```

1073
1074 % A teststring with Latin and Greek letters::
1075 \newcommand{\teststring}{%
1076 % capital Latin letters
1077 % A,B,C,
1078 A,B,
1079 % capital Greek letters
1080 %\Gamma,\Delta,\Theta,\Lambda,\Xi,\Pi,\Sigma,\Upsilon,\Phi,\Psi,
1081 %\Gamma,\Delta,\Theta,\Lambda,\Xi,\Pi,\Sigma,\Phi,\Psi,\Omega,
1082 % small Greek letters
1083 \alpha,\beta,\pi,\nu,\omega,
1084 % small Latin letters:
1085 % compare \nu, \omega, v, and w
1086 v,w,
1087 % digits
1088 0,1,9
1089 }
1090
1091
1092 \subsection*{Math alphabets}
1093
1094 If there are other symbols in place of Greek letters in a math
1095 alphabet, it uses T1 or OT1 font encoding instead of OML.
1096
1097 \begin{eqnarray*}
1098 \mbox{\rmfamily} & & \teststring \\
1099 \mbox{\itshape} & & \mathit{\teststring}\\
1100 \mbox{\rmrm} & & \mathrm{\teststring}\\
1101 \mbox{\bfseries} & & \mathbf{\teststring}\\
1102 \mbox{\rmss} & & \mathsf{\teststring}\\
1103 \mbox{\rmtt} & & \mathtt{\teststring}\\
1104 \end{eqnarray*}
1105 New alphabets bold-italic, sans-serif-italic, and sans-serif-bold-
1106 italic.
1107 \begin{eqnarray*}
1108 \mathbf{\teststring} & & \mathbf{\teststring}\\
1109 \mathsf{\teststring} & & \mathsf{\teststring}\\
1110 \mathbf{\mathsf{\teststring}} & & \mathbf{\mathsf{\teststring}}\\
1111 \end{eqnarray*}
1112 %
1113 Do the math alphabets match?
1114
1115 $
1116 \mathnormal {a x \alpha \omega}
1117 \mathbf{a x \alpha \omega}
1118 \mathsf{a x \alpha \omega}
1119 \quad
1120 \mathbf{\mathsf{a x \alpha \omega}}
1121 \mathbf{a x \alpha \omega}
1122 \mathnormal {a x \alpha \omega}
1123 $
1124
1125 \subsection*{Vector symbols}
1126

```



```

1127 53 Alphabetic symbols for vectors are boldface italic,
1128 54  $\vec{\lambda} = \vec{e}_1 \cdot \vec{a}$ ,
1129 55 while numeric ones (e.g. the zero vector) are bold upright,
1130 56  $\vec{a} + \vec{0} = \vec{a}$ .
1131 57
1132 58 \subsection*{Matrix symbols}
1133 59
1134 60 Symbols for matrices are boldface italic, too: %
1135 61 \footnote{However, matrix symbols are usually capital letters whereas
1136 62 vectors
1137 63 are small ones. Exceptions are physical quantities like the force
1138 64 vector  $\vec{F}$  or the electrical field  $\vec{E}$ .%}
1139 65  $\mathtt{\Lambda} = \text{matrixsym}{\Lambda}$ 
1140 66
1141 67
1142 68 \subsection*{Tensor symbols}
1143 69
1144 70 Symbols for tensors are sans-serif bold italic,
1145 71
1146 72 \[
1147 73   \text{tensorsym}{\alpha} = \text{tensorsym}{e} \cdot \text{tensorsym}{a}
1148 74   \quad \Longleftarrow \quad
1149 75   \alpha_{ijk} = e_{ijk} \cdot a_{kl}.
1150 76 \]
1151 77
1152 78
1153 79 The permittivity tensor describes the coupling of electric field and
1154 80 displacement: \[
1155 81 \vec{D} = \epsilon_0 \text{tensorsym}{\epsilon}_{\mathrm{r}} \vec{E} \]
1156 82
1157 83
1158 84
1159 85 \newpage
1160 86 \subsection*{Bold math version}
1161 87
1162 88 The ‘‘bold’’ math version is selected with the commands
1163 89 \verb+\boldmath+ or \verb+\mathversion{bold}+
1164 90
1165 91 {\boldmath
1166 92   \begin{eqnarray*}
1167 93     \mathnormal{} & & \text{teststring} \\
1168 94     \mathit{} & & \mathit{\text{teststring}} \\
1169 95     \mathrm{} & & \mathrm{\text{teststring}} \\
1170 96     \mathbf{} & & \mathbf{\text{teststring}} \\
1171 97     \mathsf{} & & \mathsf{\text{teststring}} \\
1172 98     \mathtt{} & & \mathtt{\text{teststring}}
1173 99   \end{eqnarray*}
1174 100   New alphabets bold-italic, sans-serif-italic, and sans-serif-bold-
1175 101   italic.
1176 102   \begin{eqnarray*}
1177 103     \mathbf{fit}{} & & \mathbf{fit}\{\text{teststring}\} \\
1178 104     \mathsf{fit}{} & & \mathsf{fit}\{\text{teststring}\} \\
1179 105     \mathtt{fit}{} & & \mathtt{fit}\{\text{teststring}\}
1180 106   \end{eqnarray*}
1181 107   %
1182 108   Do the math alphabets match?

```



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```

1184 108
1185 109 $ 
1186 110 \mathnormal {a x \alpha \omega}
1187 111 \mathbf{fit} {a x \alpha \omega}
1188 112 \mathsf{fbfit}{a x \alpha \omega}
1189 113 \quad
1190 114 \mathsf{fbfit}{T C \Theta \Gamma}
1191 115 \mathbf{fit} {T C \Theta \Gamma}
1192 116 \mathnormal {T C \Theta \Gamma}
1193 117 $
1194 118
1195 119 \subsection*{Vector symbols}
1196 120
1197 121 Alphabetic symbols for vectors are boldface italic,
1198 122 $ \vec{\lambda} = \vec{e}_1 \cdot \vec{a} $,
1199 123 while numeric ones (e.g. the zero vector) are bold upright,
1200 124 $ \vec{a} + \vec{0} = \vec{a} $.
1201 125
1202 126
1203 127
1204 128
1205 129 \subsection*{Matrix symbols}
1206 130
1207 131 Symbols for matrices are boldface italic, too:%
1208 132 \footnote{However, matrix symbols are usually capital letters whereas
1209 133 vectors
1210 134 are small ones. Exceptions are physical quantities like the force
1211 135 vector $ \vec{F} $ or the electrical field $ \vec{E} $.%}
1212 136 $ \mathbf{matrixsym}{\Lambda} = \mathbf{matrixsym}{E} \cdot \mathbf{matrixsym}{A} . $%
1213 137
1214 138
1215 139 \subsection*{Tensor symbols}
1216 140
1217 141 Symbols for tensors are sans-serif bold italic,
1218 142
1219 143 \[
1220 144 \mathbf{tensorsym}{\alpha} = \mathbf{tensorsym}{e} \cdot \mathbf{tensorsym}{a}
1221 145 \quad \Longleftarrow \quad
1222 146 \alpha_{ijl} = e_{ijk} \cdot a_{kl}.
1223 147 \]
1224 148
1225 149 The permittivity tensor describes the coupling of electric field and
1226 150 displacement: \[
1227 151 \vec{D} = \epsilon_0 \mathbf{tensorsym}{\epsilon}(\mathbf{r}) \vec{E} \]
1228 152 \}
1229 153

```



B3 Abbreviation

This section shows examples of the use of L^AT_EX commands in conjunction with the items that are in the `abbreviation.tex` and in the `glossary.tex` files. Please see List. B.3. **To lessen the L^AT_EX 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).



- 1260 • Provide your own link text: style sheet.

1261 The verbatim L^AT_EX code of Sec. B3 is in List. B.3.

Listing B.3: Sample L^AT_EX 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}
```



1262 B4 Glossary

1263 This section shows examples of the use of `\gls{ }` commands in conjunction with the
 1264 items that are in the `glossary.tex` and `notation.tex` files. Note that entries in
 1265 `notation.tex` are prefixed with “`not:`” label (see List. B.4).

1266 **Please make sure that the entries in `notation.tex` are those that are referenced
 1267 in the L^AT_EX document files used by this Thesis. Please comment out unused notations
 1268 and be careful with the commas and brackets in `notation.tex`.**

- 1269 • Matrices are usually denoted by a bold capital letter, such as \mathbf{A} . The matrix’s (i,j) th
 1270 element is usually denoted a_{ij} . Matrix \mathbf{I} is the identity matrix.
- 1271 • A set, denoted as \mathcal{S} , is a collection of objects.
- 1272 • The universal set, denoted as \mathcal{U} , is the set of everything.
- 1273 • The empty set, denoted as \emptyset , contains no elements.
- 1274 • The cardinality of a set, denoted as $|\mathcal{S}|$, is the number of elements in the set.

1275 The verbatim L^AT_EX code for the part of Sec. B4 is in List. B.4.

Listing B.4: Sample L^AT_EX code for glossary and notations usage

```

1 \begin{itemize}
2
3   \item \Glspl{matrix} are usually denoted by a bold capital letter,
4       such as $\mathbf{A}$. The \gls{matrix}'s $(i,j)$th element is
5       usually denoted $a_{ij}$. \Gls{matrix} $\mathbf{I}$ is the
6       identity \gls{matrix}.
7
8   \item A set, denoted as \gls{not:set}, is a collection of objects.
9
10  \item The universal set, denoted as \gls{not:universalSet}, is the
11      set of everything.
12
13  \item The empty set, denoted as \gls{not:emptySet}, contains no
14      elements.
15
16  \item The cardinality of a set, denoted as \gls{not:cardinality}, is
17      the number of elements in the set.
18
19 \end{itemize}

```



1276

B5 Figure

1277

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

1278

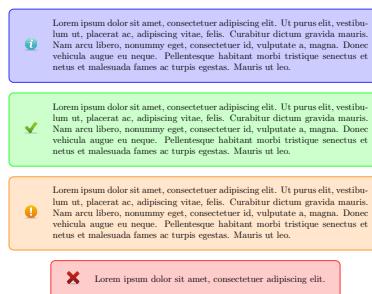


Fig. B.1 A quadrilateral image example.



1279 Fig. B.1 is a gray box enclosed by a dark border. List. B.5 shows the corresponding
1280 L^AT_EX code.

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

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



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(i) LOREM IPSUM DOLOR SIT AMET, CONSECTETUR ADIPISCING ELIT.

(ii) LOREM IPSUM DOLOR SIT AMET, CONSECTETUR ADIPISCING ELIT.

(iii) LOREM IPSUM DOLOR SIT AMET, CONSECTETUR ADIPISCING ELIT.

X LOREM IPSUM DOLOR SIT AMET, CONSECTETUR ADIPISCING ELIT.

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

(i) LOREM IPSUM DOLOR SIT AMET, CONSECTETUR ADIPISCING ELIT.

(ii) LOREM IPSUM DOLOR SIT AMET, CONSECTETUR ADIPISCING ELIT.

(iii) LOREM IPSUM DOLOR SIT AMET, CONSECTETUR ADIPISCING ELIT.

X LOREM IPSUM DOLOR SIT AMET, CONSECTETUR ADIPISCING ELIT.

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

(i) LOREM IPSUM DOLOR SIT AMET, CONSECTETUR ADIPISCING ELIT.

(ii) LOREM IPSUM DOLOR SIT AMET, CONSECTETUR ADIPISCING ELIT.

(iii) LOREM IPSUM DOLOR SIT AMET, CONSECTETUR ADIPISCING ELIT.

X LOREM IPSUM DOLOR SIT AMET, CONSECTETUR ADIPISCING ELIT.

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

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

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

B. Usage Examples



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

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

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

✗ Lorem ipsum dolor sit amet, consectetur adipiscing elit.

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

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

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✗ Lorem ipsum dolor sit amet, consectetur adipiscing elit.

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

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

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

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

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

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

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

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

✗ Lorem ipsum dolor sit amet, consectetur adipiscing elit.

(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 L^AT_EX code.

Listing B.7: Sample L^AT_EX 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}
```



1281

B6 Table

1282

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

TABLE B.1 FEASIBLE TRIPLES FOR HIGHLY VARIABLE GRID

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

Continued on next page



Continued from previous page

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



1284 List. B.8 shows the corresponding L^AT_EX code.

Listing B.8: Sample L^AT_EX code for making typical table environment

```

1285 1 \begin{center}
1286 2 {\scriptsize
1287 3 \begin{tabularx}{\textwidth}{p{0.1\textwidth}|p{0.2\textwidth}|p{0.5\textwidth}}
1288 4 \caption{Feasible triples for highly variable grid} \label{tab:triple_
1289 5 \grid} \\
1290 6 \hline
1291 7 \textbf{Time (s)} &
1292 8 \textbf{Triple chosen} &
1293 9 \textbf{Other feasible triples} \\
1294 10 \hline
1295 11 \endfirsthead
1296 12 \multicolumn{3}{c}{\textit{Continued from previous page}} \\
1297 13 \hline
1298 14 \hline
1299 15 \textbf{Time (s)} &
1300 16 \textbf{Triple chosen} &
1301 17 \textbf{Other feasible triples} \\
1302 18 \hline
1303 19 \endhead
1304 20 \hline
1305 21 \endlastfoot
1306 22 \multicolumn{3}{r}{\textit{Continued on next page}} \\
1307 23 \endfoot
1308 24 \hline
1309 25 \endlastfoot
1310 26 \hline
1311 27
1312 28 0 & (1, 11, 13725) & (1, 12, 10980), (1, 13, 8235), (2, 2, 0), (3, 1, 0)
1313 29 \\
1314 30 2745 & (1, 12, 10980) & (1, 13, 8235), (2, 2, 0), (2, 3, 0), (3, 1, 0)
1315 31 \\
1316 32 5490 & (1, 12, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1317 33 8235 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1,
1318 34 0) \\
1319 35 10980 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1,
1320 36 0) \\
1321 37 13725 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1,
1322 38 0) \\
1323 39 16470 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1324 40 19215 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1,
1325 41 0) \\
1326 42 21960 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1,
1327 43 0) \\
1328 44 24705 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1,
1329 45 0) \\
1330 46 27450 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1,
1331 47 0) \\
1332 48 30195 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
1333 49 32940 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1334 50 35685 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1335 51 38430 & (1, 13, 10980) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1336 52
1337 53
1338 54

```



De La Salle University

```

1339 43 | 41175 & (1, 12, 13725) & (1, 13, 10980), (2, 2, 2745), (2, 3, 0), (3, 1,
1340           0) \\
1341 44 | 43920 & (1, 13, 10980) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1342 45 | 46665 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
1343 46 | 49410 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
1344 47 | 52155 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3, 1,
1345           0) \\
1346 48 | 54900 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1347 49 | 57645 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1348 50 | 60390 & (1, 12, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1349 51 | 63135 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1350 52 | 65880 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1351 53 | 68625 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
1352 54 | 71370 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1353 55 | 74115 & (1, 12, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1354 56 | 76860 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1355 57 | 79605 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1356 58 | 82350 & (1, 12, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1357 59 | 85095 & (1, 12, 13725) & (1, 13, 10980), (2, 2, 2745), (2, 3, 0), (3, 1,
1358           0) \\
1359 60 | 87840 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1360 61 | 90585 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1361 62 | 93330 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1362 63 | 96075 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1363 64 | 98820 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1364 65 | 101565 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1365 66 | 104310 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1366 67 | 107055 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1367 68 | 109800 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1368 69 | 112545 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3,
1369           1, 0) \\
1370 70 | 115290 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1371 71 | 118035 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1372 72 | 120780 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1373 73 | 123525 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1374 74 | 126270 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3,
1375           1, 0) \\
1376 75 | 129015 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
1377 76 | 131760 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
1378 77 | 134505 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1379 78 | 137250 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1380 79 | 139995 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
1381 80 | 142740 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
1382 81 | 145485 & (1, 12, 16470) & (1, 13, 13725), (2, 2, 2745), (2, 3, 0), (3,
1383           1, 0) \\
1384 82 | 148230 & (2, 2, 2745) & (2, 3, 0), (3, 1, 0) \\
1385 83 | 150975 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1386 84 | 153720 & (1, 12, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1387 85 | 156465 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1388 86 | 159210 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1389 87 | 161955 & (1, 13, 16470) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1390 88 | 164700 & (1, 13, 13725) & (2, 2, 2745), (2, 3, 0), (3, 1, 0) \\
1391 89 | \end{tabularx} \\
1392 90 | } \\
1393 91 | \end{center}

```



1395

B7 Algorithm or Pseudocode Listing

1396

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

1397

1398

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

Input(s):

n	:	n th power; $n \in \mathbb{Z}^+$
x	:	base value; $x \in \mathbb{R}^+$

Output(s):

y	:	result; $y \in \mathbb{R}^+$
-----	---	------------------------------

Require: $n \geq 0 \vee x \neq 0$
Ensure: $y = x^n$

```

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

```

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

```

1 \begin{table} [!htbp]
2   \caption{Calculation of $y = x^n$}
3   \label{tab:calcxn}
4   \footnotesize
5   \begin{tabular}{lll}
6     \hline
7     \hline
8     {\bf Input(s):} & & \\
9     $n$ & : & $n$th power; $n \in \mathbb{Z}^{+}$ \\
10    $x$ & : & base value; $x \in \mathbb{R}^{+}$ \\
11    \hline
12    {\bf 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}

```



1399

B8 Program/Code Listing

1400

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

1401

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\tFibonacci(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

```



1402

List. B.11 shows the corresponding L^AT_EX code.

Listing B.11: Sample L^AT_EX code for program listing

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



B9 Referencing

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

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

Listing B.12: Sample \LaTeX code for referencing sections

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

Lorem ipsum dolor sit amet, 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.



1418 B9.1 A subsection

1419 Referencing subsections: This section is Sec. B9.1, which shows how to refer to a subsection.
 1420 List. B.13 shows the corresponding L^AT_EX code.

Listing B.13: Sample L^AT_EX 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.
```

1421 Lorem ipsum dolor sit amet, consectetur adipiscing elit. Etiam lobortis facilisis sem.
 1422 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec
 1423 ullamcorper, felis non sodales commodo, lectus velit ultrices augue, a dignissim nibh lectus
 1424 placerat pede. Vivamus nunc nunc, molestie ut, ultricies vel, semper in, velit. Ut porttitor.
 1425 Praesent in sapien. Lorem ipsum dolor sit amet, consectetur adipiscing elit. Duis fringilla
 1426 tristique neque. Sed interdum libero ut metus. Pellentesque placerat. Nam rutrum augue
 1427 a leo. Morbi sed elit sit amet ante lobortis sollicitudin. Praesent blandit blandit mauris.
 1428 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit
 1429 amet ipsum. Nunc quis urna dictum turpis accumsan semper.



1430 **B9.1.1 A sub-subsection**

1431 Referencing sub-subsections: This section is Sec. B9.1.1, which shows how to refer to a
 1432 sub-subsection. List. B.14 shows the corresponding L^AT_EX code.

Listing B.14: Sample L^AT_EX 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.

1433 Lorem ipsum dolor sit amet, consectetur adipiscing elit. Etiam lobortis facilisis sem.
 1434 Nullam nec mi et neque pharetra sollicitudin. Praesent imperdiet mi nec ante. Donec
 1435 ullamcorper, felis non sodales commodo, lectus velit ultrices augue, a dignissim nibh lectus
 1436 placerat pede. Vivamus nunc nunc, molestie ut, ultricies vel, semper in, velit. Ut porttitor.
 1437 Praesent in sapien. Lorem ipsum dolor sit amet, consectetur adipiscing elit. Duis fringilla
 1438 tristique neque. Sed interdum libero ut metus. Pellentesque placerat. Nam rutrum augue
 1439 a leo. Morbi sed elit sit amet ante lobortis sollicitudin. Praesent blandit blandit mauris.
 1440 Praesent lectus tellus, aliquet aliquam, luctus a, egestas a, turpis. Mauris lacinia lorem sit
 1441 amet ipsum. Nunc quis urna dictum turpis accumsan semper.



1442 B10 Index

1443 For key words or topics that are expected (or the user would like) to appear in the Index, use
 1444 `\index{key}`, where `key` is an example keyword to appear in the Index. For example,
 1445 Fredholm integral and Fourier operator of the following paragraph are in the Index.

1446 If we make a very large matrix with complex exponentials in the rows (i.e., cosine real
 1447 parts and sine imaginary parts), and increase the resolution without bound, we approach
 1448 the kernel of the Fredholm integral equation of the 2nd kind, namely the Fourier operator
 1449 that defines the continuous Fourier transform.

1450 List. B.15 is a program listing of the above-mentioned paragraph.

Listing B.15: Sample L^AT_EX 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.
```



1451 **B11 Adding Relevant PDF Pages (e.g. Standards,**
1452 **Datasheets, Specification Sheets, Application**
1453 **Notes, etc.)**

1454 Selected PDF pages can be added (see List. B.16), but note that the options must be tweaked.
1455 See the manual of `pdfpages` for other options.

Listing B.16: Sample L^AT_EX 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.



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

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

Notes:

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



Virtex UltraScale+ FPGA Feature Summary

Table 8: Virtex UltraScale+ FPGA Feature Summary

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

Notes:

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

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

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

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

Notes:

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



1459 **Appendix C**
1460 **PUBLICATION LIST AND AWARD**

1461 **Journal**

1462 1. ...

1463 2. ...

1464 **Conference**

1465 1. ...

1466 2. ...



De La Salle University

1467 **Others**

1468 1. ...

1469 2. ...

1470 **Award**

1471 1. ...

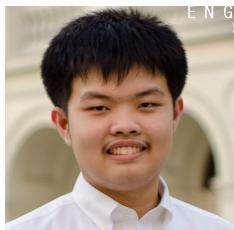
1472 2. ...



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Appendix D VITA

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1484 previous projects. He has also programmed several applications using java and C language.
1485 His research interests include environmental friendly gadgets, mobile robots that can help
1486 the society and agricultural technologies.

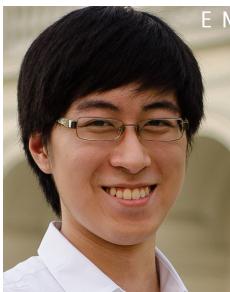


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Ervin Lester G. Lu is a third year engineering student taking up B.Sc. Computer Engineering at De La Salle University. He has designed and programmed several applications using C and Java languages, and electronic circuits using Arduino and PIC as microcontrollers in some of his previous projects. His research interests include educational mobile applications, environmental friendly innovations, and agriculture technologies.



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Sean Wyndell T. Que is a third year engineering student taking up B.Sc. Computer Engineering at De La Salle University. He has designed and programmed several electronic circuits using PIC microcontrollers and mobile applications using C and Java languages. His research interests include cool electronic gadgets and awesome mobile applications.



INDEX

- | | |
|------|-----------------------|
| 1498 | contributions, 34 |
| 1499 | Fourier operator, 76 |
| 1500 | Fredholm integral, 76 |