A Robot System for Paddy Field Planting in the Philippines

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

In Partial Fulfillment of the
Requirements for the Degree of
Bachelor of Science in Electronics and Communications Engineering

by

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June, 2016

De La Salle University

ORAL DEFENSE RECOMMENDATION SHEET

This thesis, entitled **A Robot System for Paddy Field Planting in the Philippines**, prepared and submitted by thesis group, ESG-04, composed of:

ABE, Paul Vince A.
AMADO, Dan Paulo E.
MIRIDA, Joanna Katherine U.

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

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THESIS APPROVAL SHEET

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ACKNOWLEDGMENT

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ABSTRACT

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

Index Terms—PIC16F877A, soil moisture, greenhouse, automation.

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ABBREVIATIONS

NOTATION

$\mathcal{S}$	a collection of distinct objects	41
$\mathcal{U}$	the set containing everything	41
$\emptyset$	the set with no elements	41
$\lvert\mathcal{S}\rvert$	the number of elements in the set $\mathcal{S}$	41
$h\left(t\right)$	impulse response	31
$x\left(t\right)$	input signal represented in the time domain	31
$y\left(t\right)$	output signal represented in the time domain	31

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

169 # GLOSSARY

170 matrix — a concise and useful way of uniquely representing and working with linear transformations; a rectangular table of elements 41

LISTINGS

Chapter 1

INTRODUCTION

Contents

1.1 Background of the Study

The Philippines is the worlds eighth-largest rice producer. Its arable land totals 5.4 million hectares. Rice area harvested has expanded from nearly 3.8 million hectares in 1995 to about 4.4 million hectares in 2010. However, the countrys rice area harvested is still very small compared with that of the other major rice-producing countries in Asia. Climate change, growing population, declining land area, high cost of inputs, and poor drainage and inadequate irrigation facilities are the major constraints to rice production in the Philippines. Some of these constraints are interrelated. Unabated conversion of some agricultural land to residential, commercial, and industrial land reduces the area devoted to rice production, which leads to a shortage in domestic supply (ricepedia.org). The Philippines is one of the largest producers of rice in the world, despite of having an inadequate rice area caused by several factors which led to inadequacy of domestic supply. Meanwhile, in Japan, the rapid aging of farm workers and depopulation of farming communities are currently becoming a major concern. The number of farmers was 4.82 million in 1990 and is decreasing to 2.60 million in 2010. This decrease has been continuing for over 50 years. The farmer's average age is over 65 years old (MAFF 2012). This results into the decrease in production of rice in Japan, which then led to the development of fully robot-operated farming from tillage to harvest in large-scale agriculture (Tamaki, et al.).

The development or agricultural robot, led some researchers to utilize image processing for navigation. Digital image processing allows a much wider range of algorithms to be applied to the input data and can avoid problems such as the build-up of noise and signal distortion during processing. Today machine visions are applied in two dimensions (2-D) or three dimensions (3-D). The 2-D vision systems use area scan or line scan cameras as well as appropriate lighting to measure the visible characteristics of an object such as, quality of surface appearance, edge based measurements and presence and location of features. In agriculture, 2-D has applications in sorting based on color, shape and size. In 3-D analysis basically there are two techniques applied: stereo vision and LED/laser triangulation. Machine vision-based guidance showed acceptable performance at all speeds and different paths by average errors below 3 cm. It was proposed that using both machine vision and laser radar may provide a more robust guidance as well as obstacle detection capability (Mousazadech, 2013).

For the Philippines to become self-sufficient in rice, it has to adopt existing technologies such as improved varieties and know-how to have yield increase by 13 t/ha. Better quality seed combined with good management, including new postharvest technologies, is the best way to improve rice yields and the quality of production (ricepedia.org). The utilization of new technology could help increase the production of rice in the country, increase our domestic supply, decrease the need to import rice, reduce the consumer cost, and increase the profit gain of farmers. In this study, we focus on the development and research of a rice planting robot that could be implemented in the Philippines. This study specifically focuses on the use of image processing as the robots main navigation system, the development of a rice planting mechanism, and the possible effect of rice planting robot in Philippine agriculture.

1.2 Prior Studies

Pertinent to the needs of the country, the Philippines is centered and concentrated in conducting researches on agricultural technology. As a country highly capable of producing its own sources of food, there is no doubt that there is priority in funding these researches. These, in turn, allow its agriculture to be as advanced as it requires for its growing population. Following the groups interest in integrating its recent forms of technology in indigenous sectors of the society, the members conducted brief, prior studies about the current advancements in agricultural technology of different origins. They purposed to find foreign researches in order to extend the capabilities of local technology to be as equally competent.

- A resource entitled "A Robot System for Paddy Field Farming in Japan" is set to utilize a robot-operated farming technology guided from tillage to harvest in large-scale agriculture. In such application, it is seen that in the cultivation of rice, wheat and soybean (in Japan, as per the researchers' host country), there has been three types of robot in development. First, a robot tractor, followed by a rice transplanter, finally, combines harvester robots. Real-time Kinematic Global Positioning System (RTK-GPS) and Inertia Measurement Unit (IMU), or Global Positioning System (GPS) compass are utilized for navigation system. These robots have a Controller Area Network (CAN) bus that all sensors and computers can be connected and interfaced in common among other robots such as tractors, rice transplanters and combine harvesters. Hence, these could be officiated in autonomous operation in paddy fields as well as discussing in this paper the ability of moving across fields for effective operations and safe guidelines for robot systems.

- Another is a resource entitled A Global Positioning System guided automated rice transplanter" that speaks about a new Global Positioning System (GPS) guided rice transplanter. This study is very coherent to the aforementioned research as this resource speaks more about the utilization of the GPS technology they used in implementing the three robots as tractor, rice transplanter and combine harvester. With these, such robot systems were GPS-guided with their respective position data and inertia measurement unit direction data. This new one (inherent to this resource) is guided with GPS position data with tilt correction during straight driving and guided with the data gathered from the IMU during each robot's turning at the head land. An antenna prescribed to the GPS is set to 1.5 meters (as height) and 0.4 meters as its offset at the vehicle's front axle. The actuator control command and data communication protocols adhere through the controller area network (CAN) bus. Hence, steering and transmission systems are controlled through electrical actuators with respect to the location in a given field.

- Lastly, a resource entitled Robot Farming System Using Multiple Tractors in Japan with the objective to develop a robot farming system using multiple robots. It discusses the application of multiple robots in Japan agriculture for rice, wheat, and soybean. The system that is discussed in this paper includes a rice planting robot, a seeding robot, a robot tractor, a combine robot harvester, and several tools attached on the robot tractor. The main objective of this paper is to help the farmers gain more profit thru farming. The paper focused on robot management system, low-cost system, robot farming safety, and real-time monitoring/documentation.

1.3 Problem Statement

The Philippines is rich in fertile lands suitable for agricultural development. However, due to the absence of advanced tools for farming, rice shortage is becoming a problem.

Filipinos are importing rice from other countries such as Thailand and Vietnam in spite of the capability of the Philippine land to cultivate rice.

Philippine farmers are not equipped with tools that could compete with the advanced instruments used by foreign farmers. Most of the Philippine farmers rely on manual labor. Difficult tasks such as sowing the field are done by the farmers yet their salary is still below the minimum wage. The land may be rich and fertile for agriculture but the agricultural sector, specifically the local farmers, are considered one of the poorest sector in the country. In turn, the rice fields are neglected. According to National Geographic, Some 25 to 30 percent of the terraces are abandoned and beginning to deteriorate, along with irrigation systems. Investors and laborers are avoiding the agricultural industry due to the absence of advanced systems used in planting rice.

1.4 Objectives

1.4.1 General Objective(s)

To design and develop a system that would automate plantation of rice in paddy fields in the Philippines;

1.4.2 Specific Objectives

1. To implement computer vision, specifically edge detection, in tracing the path sections of the paddy field;

2. To utilize the flood fill algorithm in designing the optimal route for the mobile robot as it plant the rice;

3. To design an Arduino system in implementing computer vision as interface in robotic application;

4. To design and develop a mobile robot designed to withstand paddy field environmental factors (e.g. soil, mud, etc.);

1.5 Significance of the Study

Computer Engineering is the marriage of electronics and programming. Implementing a programming-based instruction on an electronic hardware is a fundamental action in the progression of this course. With the use of programming, hardware systems are automated with a more defined set of instructions. With this, the study of a Robot System for the Paddy Field in the Philippines would be an unwavering focus related to the field. The implementation of this robot system would reinforce automation with the aid of computer vision. Moreover, the electronic and programming skills of the students would be strengthened with this research. External elements such as the edge of the paddy field increase the complexity of this longstanding research. Robot systems are no longer fairly new. However, introducing computer vision that would direct a robot system that could withstand environmental factors, specifically in paddy fields, would establish an innovation for the field of Computer Engineering and for the country Philippines as well.

In social context, the employment of this robot system for paddy field planting would allow a decrease in production time of rice as it automates the planting of the crop. Additionally, it would lessen the manual labor provided by the local farmers. Instead of manually planting rice, local farmers would save time and effort as the robot system for paddy field planting would be utilized. The workload for the farmers would be decreased as the production is increased. It is anticipated that the use of this system would increase the productivity of agricultural sector in the country. It would aide local farmers in ensuring an increase in rice yield as plantation is automated. It will not only benefit the agricultural area but also the economic status of the Philippines.

By engaging software-heavy technique such as computer vision into an electronic device, this research would be principal in establishing further the discipline of Computer Engineering. Considering programming as the automation mechanism of systems would yield a better and more accurate result as the set of instructions is broadened. This research is also essential in developing the programming and hardware skills of the students. Simultaneously, this research is significant due to the demand of increasing the competency of the agricultural sector of the Philippines.

1.6 Assumptions, Scope and Delimitations

Across the whole duration of the study, the group concentrated on the following:

- Focused on guiding a robot system thru computer vision across a small-area of a rural paddy field
- With added mechanism of planting seedlings to tilled, muddy lands
- Utilization of the edge-detection algorithm to navigate a robot system
- Interfacing OpenCV to operate an Arduino-based Robot System

With this, there were limitations set to the following extents:

- Localization of field study with the environmental factors seen at Jaybanga, Lobo, Batangas
- Robot functionalities set to plant seedlings by picking holes of one-inch diameter per half-square meter of muddy land
- Robot vision from a 240P-resolution camera under live feed
- Tested twenty iterations of planting seedlings in one pass
- Ran two daytime field tests on two Saturdays of the month of July

1.7 Description and Methodology

The core of the mobile robot is the GizDuino X Version 2.0. It handles the operations of the robot by processing input data from the camera and commanding the motors of the wheels to mobilize the robot. Using edge detection software, in this case OpenCV, the robot calculates for the distance, speed, and direction it has to go. The edge of the paddy works as the limit where the robot needs to go, and with the use of a rice planting mechanism the robot fills the whole segment of the paddy area with rice seedlings placed on a specialized container. Light emitting diodes are utilized by the robot for night operations. Weatherproofing or waterproofing the robot should also be considered taking to account that the paddy area is damp or wet during the plantation process and puts the robot at risks of water damage. Unexpected rain and flood are also few of the risks that should be considered for waterproofing the robot. It is expected that once the robot is set, it will do its work with 0 to minimum human interaction or intervention, except during the refilling of the seedlings in the container.

The process of the study was to suggest an automated system that would plant rice seedlings on a rural paddy field. Apart from the projected upkeep from a commercial paddy field, it was manageable for the group to train the proposed system at a relatively lower upkeep; that is on a rural paddy field. The key method of testing was to implement a navigation system for the robot. Achieved through edge detection, the group mounted a camera that served as the robots guidance sensor for navigation. The algorithm was implemented thru OpenCV and was translated into machine-level instruction using Arduino to mandate basic directional movements of a robot: forwarding, backwarding and turning.

With a known, existing system that still utilized human interaction, (i.e. a Japanese farmer pulling a planting machine that picked holes and chuted seedlings), this was the framework of the study; but to not include human interaction in machine operation. Hence, with this framework, the group aimed to compare if removing human interaction would act as equally useful in full-automation. The variables at test were the accuracy and speed of the automated plantation. These variables were in applied in the performance of the farmer and the robot. The rice farmer played a vital role in this study, because the studys standards were based fully in his performance. Hence, the factors to be measured in the two performances were

- Time taken to plant twenty seedlings on a single crop row (Farmer and Robot)
- Proper picking depth, measured in millimeters (Farmer and Robot)

The group designated their independent study as the farmers performance; leaving out the robots performance as the dependent study. Therefore, to confirm gathered results about the robot, the group calculated the dispersion and central tendencies of the data taken from the dependent study to the independent study: from the time and depth variables. The group decided this validation method as such due to the ideal purpose of the proposed system: it should be able to replace farmers in field planting.

1.8 Estimated Work Schedule and Budget

TABLE 1.1 BILL OF COMPONENTS

UNIT	COMPONENT	PRICE/UNIT
1	GizDuino X	1090.00
1	Motor Driver (L293D)	80.00
2	Wheel	30.00
4	Universal Printed Circuit Board (Small)	10.00
5	DC Motor	70.00
1	Chassis (Material Enclosure)	100.00
1	Set of Nuts and Bolts	30.00
20	Jumper Wire	7.00
1	Serial Camera	1480.00
1	Rice Planting Mechansim	1000.00
1	Battery (9 Volts)	75.00
1	Voltage Regulator (LM7805)	20.00
10	Resistor (Ranging Values)	0.25
2	Ceramic Capacitor (Ranging Values)	2.00
2	Light-emitting Diode Lamp	40.00
TOTAL		**4551.50**

1.9 Overview

Provide here a brief summary and what the reader should expect from each succeeding chapter. Show how each chapter are connected with each other.

Chapter 2

LITERATURE REVIEW

Contents

2.1 Summary

A paper entitled Vision Based Guidance for Robot Navigation in Agriculture was based on a study conducted on Australia. Here, they had an implementation of a vision-based texture tracking method to guide autonomous vehicles in agricultural fields. While it imposed a challenging task to detect crop rows, existing methods require visual difference between what crop is against what soil is for visual segmentation. Their proposed method involves extracting and tracking the direction and offset that existed among parallel textures in a simulated overhead view of the scene. Also, they allowed neglecting of crop-specific details such as color, spacing and periodicity. The results explained the demonstration of the method in both day and night times to autonomously guide a robot across crop rows.

An abridged, proposed algorithm design was as follows

- Pre-processing the image to correct lens distortion and to downsample the image for better processing speed
- Using an Inertia Management Unit to detect the horizon
- Warping the stabilized image into an overhead view
- Estimating the vehicles heading with respect to the crop rows thru estimation of a dominant parallel texture in the overhead image
- Correcting heading in the overhead view via image-skewing from the estimated heading
- Generating a frame template thru the summation of the columns found on the skewed images

- Assuming a lateral motion that was relative to the crop by comparing such template to an initial crop template

Notably citing the Horizon Detection, the researchers began to track the horizon via selecting an image region (free of obstruction from a clear horizon view) within three standard deviations of estimated horizon position. In turn, the pixels were classified into as sky or ground. Further, they also had the estimation of the row direction. Their method was to sum skewed images from varying angles along the columns then calculating the variance of the resulting vector. The skew angle with the greatest variance was the best estimate to qualify as the heading angle. Finally mentioning the detection of rows, their study contained the instance on which the field did not have any crop rows to track (e.g. the ends of the field were bare patches). In these situations, they examined the output of the summation of skewed images aforementioned. They set a standard of frame templates that vary from +/- 30 degrees.

Another paper entitled Video Streaming In Autonomous Mobile Robot Using Wi-Fi was used to consider the relevance of a capable telemetry system. Having an autonomous mobile robot required to cover a distance from one point to another with two or more wheels. To reach a destination, it was not always possible that a person could not reach. Through an Autonomous Arduino Yun for four-wheeled mobile robots, it gave capabilities to robots to actually move from one point to another by finding paths and avoiding obstacles thru Video Streaming. Achieved thru Wi-Fi Technology (as avoidance to using Bluetooth technology due to its lesser security and shortness of range), the best path was identified thru Aggrandized Genetic Algorithm (AGA) which was comparatively greater than other algorithms. Wi-Fi (IEEE 802.11 b/g/n) was used to achieve secure communications at long distances.

Upon mentioning Arduino Yun, it was one of the many boards and kits that Arduino sell to their users. Weighing 32 grams with lateral dimensions of 73 millimeters by 53 millimeters, Arduino Yun was usually used for Wi-Fi technology; due to its in-built Wi-Fi (IEEE 802.11 b/g/n). Along with this, this board supported USB port, MicroSD card Slot, three reset buttons, In-circuit Serial Programming header, 16MHz Crystal Oscillator, 20 Digital Input and Output Pins and 12 Analog Channels. Concentrating more on the aspect of video streaming, the Arduino Yun was capable of capturing video data to an SD card. Hence, in order to facilitate teleportation that indicated two types of operation where a machine was set to a distance: automatic mode and manual mode. The former allowed the Arduino board to send Wi-Fi standard control signals in high data rate and good quality, uninterrupted video transmission. The latter allowed recorded data to be extracted from the SD card.

The study entitled Camera-Based Clear Path Detection used to detect clarity of paths as driver assistance towards obstacle avoidance on roads. With the assumptions made of video camera calibration and vehicle information (vehicle speed and yaw angle) were known, the researchers generated perspective patches for feature extraction in the image. Then, an initial estimate of the probability of a clear path is determined thru a support vector machine (SVM). With this, they performed probabilistic patch smoothing based on spatial and temporal constraints to improve estimates.

What was notable to this study was the perspective patch generation. Of which, the traditional way of determining objects without considering perspective information are fixed-grid patch and dynamic-size patch. Since objects were found to be perpendicular to the cameras optical axis, the clear path lied on the ground and was parallel to the cameras optical axis. Instead of defining patches in image coordinates, they referenced the patches according to world coordinates that were lying on the ground.

A paper entitled An Efficient Crop Row Detection Method for Agriculture Robots was used to develop an efficient crop row detection method on a vision-based navigation for agriculture robots. The researchers proposed no low-level features (such as edges and middle lines found on images) were needed. Therefore, complex algorithms for edging and matching (especially the Hough transform) were avoided. This enabled conservation of computation loads. Further, a flexible quadrangle was defined to detect crop rows, where it extended or shrank this quadrangle to localize the crop rows from captured frames. The study demonstrated that this method was proven effective with high time efficiency and detection accuracy.

Involving this study was the image pre-processing. Two methods, as existent in the paper, pertained to this pre-processing: Full-color images to gray-level images and Binarization. The former was used to create convenience. But, the issue of preventing loss of information happened when colors were devoid. And, it was a very common practice to convert full-color images to grayscale ones. In agriculture applications, crops and/or weeds are taken into account. With the background soil as reference, plants that belong to the green chromatic coordinate, was referred to outline such component while depressing that of the soils. Therefore, it made it easier to isolate these from the background. Following, binarization was key to object-recognition and tracing applications. Under grayscale conditions, this method was highly used to isolate objects from the background. All the while, it was critical to consider thresholds. These might had lead to significant impact on the binary image quality and computation loads. A method was proposed to choose the threshold thru minimizing the intra-class variance of black and white pixels; which was widely used in image-processing called Otsus Threshold.

The highlight of the study was about the flexible quadrangle. The method implied the localization of crop rows without the need of edging or line fitting. The left and right boundarie of the quadrangle were split into four sections shown in the figure below. Each boundary box had a width of one pixel. These boxes were modified of their positions during the vehicles proceeding to assure that the quadrangle tightly locked the crop row through Hough Transforms. In essence, the whole gist of their proposed method were as follows:

- Initializing quadrangles. From the very first image, the quadrangle positions and dimensions were given by other methods or as manually indicated in the paper.
- Pre-processing of image. While the vehicle moved, it was obtained of the grey scaling image via 2G-R-B colour space and binarizing the grey scaling image using Otsus threshold at every image fed.
- Check the hitting and mishitting conditions of the boundary boxes.
- Modify the position of boundary boxes.
- For the following image, keep the boundary box positions and dimensions and repeat from second bullet.

A paper from Iran entitled A technical review on navigation systems of agricultural autonomous off-road vehicles was used to evaluate the navigation systems for autonomous vehicles used for agriculture. The predicament on the paper was that the man-power on agriculture were decreased as industries attracted these labor force away. As a solution, researchers on this paper were to design navigation systems for autonomous off-road vehicles. In order for the navigation system to work, multiple sensors were considered. Some of it were Machine Vision, Real Time Kinetic-Global Positioning, Mechanical

Sensors, Inertial Sensors Geomagnetic Direction Sensor (GDS), Ultrasonic, Fiber Optic Gyroscope (FOG), Laser Radar (LADAR), Light Detection And Ranging (LIDAR), Optical encoder, Potentiometer, Radio Frequency receiver (RF receiver), Piezoelectric yaw rate sensor, Near Infra-Red (NIR), and Acoustic sensor. These sensors are the initial element in controlling the autonomous vehicle. Fig. 2.1 shows the Block Control Diagram of autonomous vehicles.

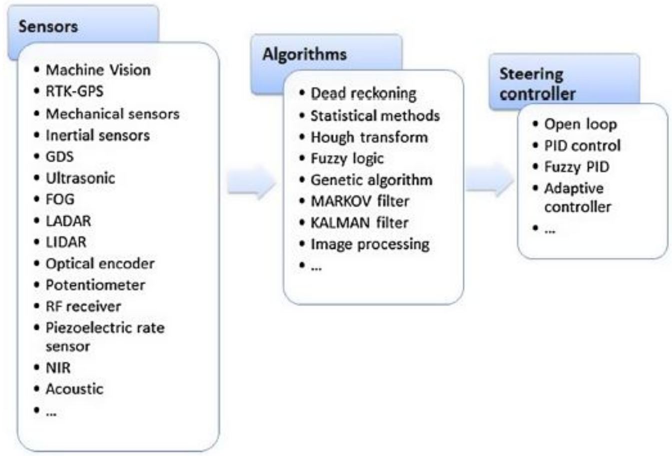

Fig. 2.1 Basic control diagram of autonomous vehicles.

In North America, the study Agricultural automatic guidance research in North America was published. It was established that Agricultural-related guidance research in North America has been review. Sensing Technologies were utilized and it was combined for automatic guidance. Automation depends on the ability of the researchers to maximize the performance of systems. Fig. 2.2 shows the basic elements of agricultural vehicle automation systems.

A similar study was implemented in Germany with the title Automatic guidance for agricultural vehicles in Europe was published. This paper focused on the automatic guidance of automatic agricultural vehicles. Different types of sensor and machine vision

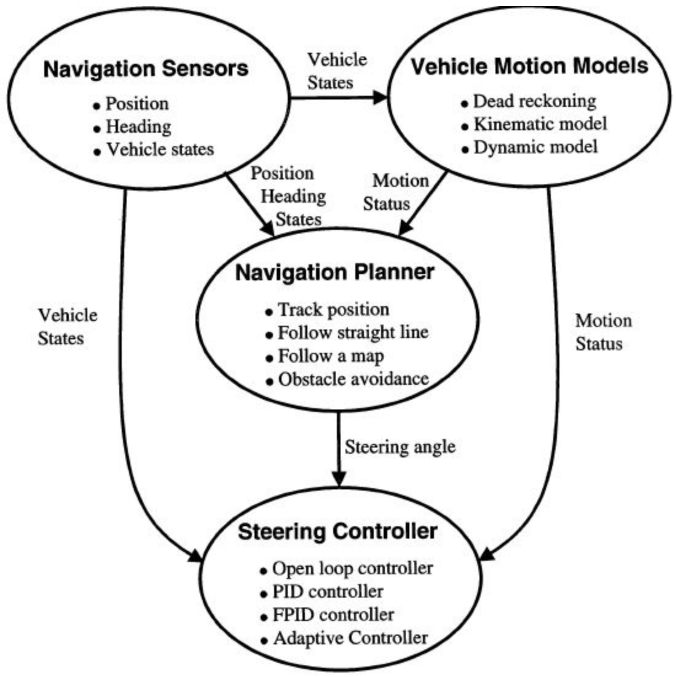

Fig. 2.2 Basic elements of agricultural vehicle automation systems

were used to implement the study. In line with the machine vision fragment, the row arrangement of crops were significantly considered in the development of the vehicle that utilizes machine vision. Fig. 2.3 shows the images related to the field tests performed. The image was digitized and guidelines were added.

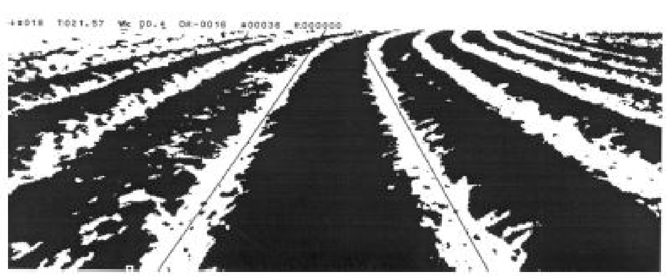

Fig. 2.3 Digitised image with guidelines.

One research is about the autonomous agriculture vehicles in Japan. This research has been developed in universities and government institutes, and by agricultural machinery manufacturers. The research wasnt able to push through the whole research in the universities due to funding limitations, because of this research in universities has concentrated on methodologies, such as navigation, sensing, and application of control theory. Development of a one dimensional image sensor, and application of neural networks and genetic algorithms, has taken place at Hokkaido University; vision guidance and fuzzy logic application at the University of Tokyo; an automatic follow-up vehicle has been developed at Kyoto University; and an automatic transport vehicle at Ehime University. At research institutes and manufacturers, with their greater financial freedom, more practical systems have been developed. A tilling robot and a driver-less air blast sprayer is being developed in the Bio-oriented Technology Research Advancement Institute (BRAIN); and an autonomous rice planter, a tillage robot and autonomous forage tractor in the research institute of the Ministry of Agriculture, Forestry, and Fishery (MAFF). Kubota Co. Ltd has developed autonomous rice planting and husbandry vehicles.

Another research is about the variable field-of-view machine vision based row guidance of agricultural robot. A new variable field-of-view machine vision method was developed allowing an agricultural robot to navigate between rows in cornfields. The machine vision hardware consisted of a camera with pitch and yaw motion control. Guidance lines were detected using an image-processing algorithm, employing morphological features in a far, near and lateral field of view, and the robot was guided along these lines using fuzzy logic control. The vehicle that they tested successfully traveled through a distance of 30 m towards the end of a crop row in three replications.

Another article discusses the navigation system for agricultural machines. This article presents a new kind of navigation system for agricultural machines. The focus is on trajectory control where a Nonlinear Model Predictive path tracking for tractor and trailer system is presented. The experiments of the proposed method are carried out by using real agricultural machines in real environments. The goal of the research was to build a system, which is able to have at least the same accuracy as a human driver. The sufficient accuracy requirement was at most 10 cm lateral error at a speed of 12 km/h. The results presented in the article show that the goal was met and NMPC is a feasible method for accurate path tracking.

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Appendix A
ANSWERS TO QUESTIONS TO THIS THESIS

Contents

A1 How important is the problem to practice?

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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A7.1 Can you come up with illustrating examples, or even better, 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

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

B1 Equations

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

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

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

Other example equations are as follows.

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

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

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

De La Salle University

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

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

```
The following examples show how to typeset equations in \LaTeX.

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}.

\begin{eqnarray}
     y\left( t \right) = h\left( t \right) * x\left( t \right)=\int_{-\infty}^{+\infty}h\left( t-\tau \right)x\left( \tau \right) \mathrm{d}\tau
   \label{eq:conv}
\end{eqnarray}

Other example equations are as follows.

\begin{eqnarray}
   \left[ \dfrac{ V_{1} }{ I_{1} } \right] =
   \begin{bmatrix}
      A & B \\
      C & D
   \end{bmatrix}
   \left[ \dfrac{ V_{2} }{ I_{2} } \right]
   \label{eq:ABCD}
\end{eqnarray}

\begin{eqnarray}
{1\over 2} < \left\lfloor \mathrm{mod}\left(\left\lfloor {y \over 17} \right\rfloor 2^{-17 \lfloor x \rfloor - \mathrm{mod}(\lfloor y\rfloor, 17)},2\right)\right\rfloor,
\end{eqnarray}

\begin{eqnarray}
| \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}}\ge 1
\end{eqnarray}
```

B2 Notations

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

Math alphabets

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

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

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

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

Do the math alphabets match?
$x\alpha\omega$ $\boldsymbol{ax\alpha\omega}$ $\mathsfbfit{ax\alpha\omega}$ $\mathsfbfit{TC\Theta\Gamma}$ $\boldsymbol{TC\Theta\Gamma}$ $TC\Theta\Gamma$

Vector symbols

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

Matrix symbols

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

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

Tensor symbols

Symbols for tensors are sans-serif bold italic,

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

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

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

Bold math version

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

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

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

Do the math alphabets match?

$\boldsymbol{ax\alpha\omega ax\alpha\omega} ax\alpha\omega \quad TC\Theta\Gamma TC\Theta\Gamma TC\Theta\Gamma$

Vector symbols

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

Matrix symbols

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

Tensor symbols

Symbols for tensors are sans-serif bold italic,

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

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

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

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

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

Listing B.2: Sample LaTeX code for notations usage

```
% A teststring with Latin and Greek letters::
\newcommand{\teststring}{%
% capital Latin letters
% A,B,C,
A,B,
% capital Greek letters
%\Gamma,\Delta,\Theta,\Lambda,\Xi,\Pi,\Sigma,\Upsilon,\Phi,\Psi,
\Gamma,\Delta,\Theta,\Lambda,\Xi,\Pi,\Sigma,\Phi,\Psi,\Omega,
% small Greek letters
\alpha,\beta,\pi,\nu,\omega,
% small Latin letters:
% compare \nu, \omega, v, and w
v,w,
% digits
0,1,9
}


\subsection*{Math alphabets}

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

\begin{eqnarray*}
\mbox{mathnormal} &  & \teststring \\
\mbox{mathit} &  & \mathit{\teststring}\\
\mbox{mathrm} &  & \mathrm{\teststring}\\
\mbox{mathbf} &  & \mathbf{\teststring}\\
\mbox{mathsf} &  & \mathsf{\teststring}\\
\mbox{mathtt} &  & \mathtt{\teststring}
\end{eqnarray*}
 New alphabets bold-italic, sans-serif-italic, and sans-serif-bold-italic.
\begin{eqnarray*}
\mbox{mathbfit}     &  & \mathbfit{\teststring}\\
\mbox{mathsfit}     &  & \mathsfit{\teststring}\\
\mbox{mathsfbfit} &  & \mathsfbfit{\teststring}
\end{eqnarray*}
%
Do the math alphabets match?

$
\mathnormal  {a x \alpha \omega}
\mathbfit    {a x \alpha \omega}
\mathsfbfit{a x \alpha \omega}
\quad
\mathsfbfit{T C \Theta \Gamma}
\mathbfit    {T C \Theta \Gamma}
\mathnormal  {T C \Theta \Gamma}
$

\subsection*{Vector symbols}

```

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```
Alphabetic symbols for vectors are boldface italic,
$\vec{\lambda}=\vec{e}_{1}\cdot\vec{a}$,
while numeric ones (e.g. the zero vector) are bold upright,
$\vec{a} + \vec{0} = \vec{a}$.

\subsection*{Matrix symbols}

Symbols for matrices are boldface italic, too:%
\footnote{However, matrix symbols are usually capital letters whereas vectors
are small ones. Exceptions are physical quantities like the force
vector $\vec{F}$ or the electrical field $\vec{E}$.%
}
$\matrixsym{\Lambda}=\matrixsym{E}\cdot\matrixsym{A}.$


\subsection*{Tensor symbols}

Symbols for tensors are sans-serif bold italic,

\[
   \tensorsym{\alpha}  =  \tensorsym{e}\cdot\tensorsym{a}
   \quad \Longleftrightarrow \quad
   \alpha_{ijl}  =  e_{ijk}\cdot a_{kl}.
\]


The permittivity tensor describes the coupling of electric field and
displacement: \[
\vec{D}=\epsilon_{0}\tensorsym{\epsilon}_{\mathrm{r}}\vec{E}\]



\newpage
\subsection*{Bold math version}

The ``bold'' math version is selected with the commands
\verb+\boldmath+ or \verb+\mathversion{bold}+

{\boldmath
   \begin{eqnarray*}
   \mbox{mathnormal} &  & \teststring \\
   \mbox{mathit} &  & \mathit{\teststring}\\
   \mbox{mathrm} &  & \mathrm{\teststring}\\
   \mbox{mathbf} &  & \mathbf{\teststring}\\
   \mbox{mathsf} &  & \mathsf{\teststring}\\
   \mbox{mathtt} &  & \mathtt{\teststring}
   \end{eqnarray*}
    New alphabets bold-italic, sans-serif-italic, and sans-serif-bold-italic.
   \begin{eqnarray*}
   \mbox{mathbfit}     &  & \mathbfit{\teststring}\\
   \mbox{mathsfit}     &  & \mathsfit{\teststring}\\
   \mbox{mathsfbfit} &  & \mathsfbfit{\teststring}
   \end{eqnarray*}
   %
   Do the math alphabets match?
```

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```
$
\mathnormal  {a x \alpha \omega}
\mathbfit    {a x \alpha \omega}
\mathsfbfit{a x \alpha \omega}
\quad
\mathsfbfit{T C \Theta \Gamma}
\mathbfit    {T C \Theta \Gamma}
\mathnormal  {T C \Theta \Gamma}
$

\subsection*{Vector symbols}

Alphabetic symbols for vectors are boldface italic,
$\vec{\lambda}=\vec{e}_{1}\cdot\vec{a}$,
while numeric ones (e.g. the zero vector) are bold upright,
$\vec{a} + \vec{0} = \vec{a}$.



\subsection*{Matrix symbols}

Symbols for matrices are boldface italic, too:%
\footnote{However, matrix symbols are usually capital letters whereas
     vectors
are small ones. Exceptions are physical quantities like the force
vector $\vec{F}$ or the electrical field $\vec{E}$.%
}
$\matrixsym{\Lambda}=\matrixsym{E}\cdot\matrixsym{A}.$


\subsection*{Tensor symbols}

Symbols for tensors are sans-serif bold italic,

\[
    \tensorsym{\alpha}  =  \tensorsym{e}\cdot\tensorsym{a}
    \quad \Longleftrightarrow \quad
    \alpha_{ijl}  =  e_{ijk}\cdot a_{kl}.
\]

The permittivity tensor describes the coupling of electric field and
displacement: \[
\vec{D}=\epsilon_{0}\tensorsym{\epsilon}_{\mathrm{r}}\vec{E}\]
}
```

B3 Abbreviation

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

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

- extensible markup language (xml) and cascading style sheet (css).
- Next use: xml and css.
- Full form: extensible markup language (xml) and cascading style sheet (css).
- Reset again.
- Start with a capital. Hyper-text markup language (html).
- Next: Html. Full: Hyper-text markup language (html).
- Prefer capitals? Extensible markup language (XML). Next: XML. Full: extensible markup language (XML).
- Prefer small-caps? Cascading style sheet (CSS). Next: CSS. Full: cascading style sheet (CSS).
- Resetting all acronyms.
- Here are the acronyms again:
- Hyper-text markup language (HTML), extensible markup language (XML) and cascading style sheet (CSS).
- Next use: HTML, XML and CSS.
- Full form: Hyper-text markup language (HTML), extensible markup language (XML) and cascading style sheet (CSS).

- Provide your own link text: style sheet.

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

Listing B.3: Sample LaTeX code for abbreviations usage

```
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:

\begin{itemize}

   \item \acr{xml} and \acr{css}.

   \item Next use: \acr{xml} and \acr{css}.

   \item Full form: \gls{xml} and \gls{css}.

   \item Reset again. \glsresetall{abbreviation}

   \item Start with a capital. \Acr{html}.

   \item Next: \Acr{html}. Full: \Gls{html}.

   \item Prefer capitals? \renewcommand{\acronymfont}[1]{\MakeTextUppercase{#1}} \Acr{xml}. Next: \acr{xml}. Full: \gls{xml}.

   \item Prefer small-caps? \renewcommand{\acronymfont}[1]{\textsc{#1}} \Acr{css}. Next: \acr{css}. Full: \gls{css}.

   \item Resetting all acronyms.\glsresetall{abbreviation}

   \item Here are the acronyms again:

   \item \Acr{html}, \acr{xml} and \acr{css}.

   \item Next use: \Acr{html}, \acr{xml} and \acr{css}.

   \item Full form: \Gls{html}, \gls{xml} and \gls{css}.

   \item Provide your own link text: \glslink{[textbf]css}{style}

\end{itemize}
```

B4 Glossary

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

Please make sure that the entries in `notation.tex` are those that are referenced in the LaTeX document files used by this Thesis. Please comment out unused notations and be careful with the commas and brackets in `notation.tex`.

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

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

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

```
\begin{itemize}

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

   \item A set, denoted as \gls{not:set}, is a collection of objects.

   \item The universal set,  denoted as \gls{not:universalSet}, is the
       set of everything.

   \item The empty set, denoted as \gls{not:emptySet}, contains no
       elements.

   \item The cardinality of a set, denoted as \gls{not:cardinality}, is
       the number of elements in the set.

\end{enumerate}
```

B5 Figure

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

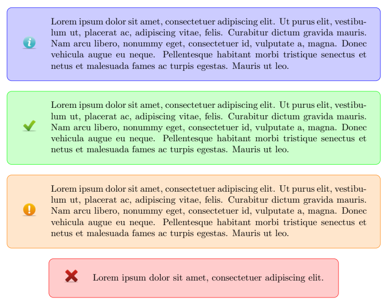
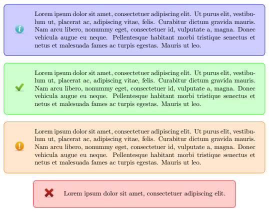


Fig. B.1 A quadrilateral image example.

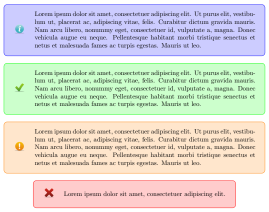
Fig. B.1 is a gray box enclosed by a dark border. List. B.5 shows the corresponding LaTeX code.

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

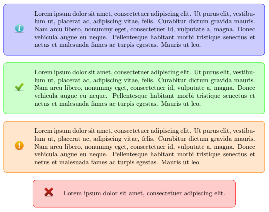
```
\begin{figure}[!htbp]
   \centering
      \includegraphics[width=0.5\textwidth]{example}
   \caption{A quadrilateral image example.}
   \label{fig:example}
\end{figure}
\cleardoublepage

Fig.~\ref{fig:example} is a gray box enclosed by a dark border. List.~\ref{lst:onefig} shows the corresponding \LaTeX \ code.
\end{figure}
```



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



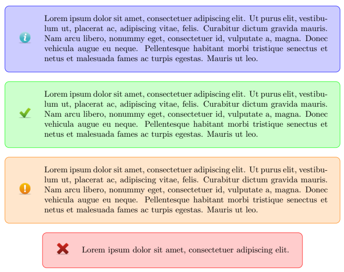
(b) A sub-figure in the middle row.



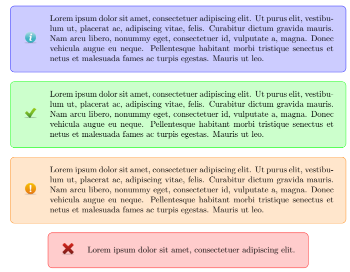
(c) A sub-figure in the bottom row.

Listing B.6: Sample LaTeX code for three figures on top of each other

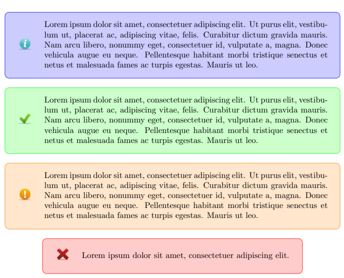
```
\begin{figure}[!htbp]
\centering
\subbottom[A sub-figure in the top row.]{
\includegraphics[width=0.35\textwidth]{example}
\label{fig:top}
}
\vfill
\subbottom[A sub-figure in the middle row.]{
\includegraphics[width=0.35\textwidth]{example}
\label{fig:mid}
}
\vfill
\subbottom[A sub-figure in the bottom row.]{
\includegraphics[width=0.35\textwidth]{example}
\label{fig:botm}
}
\caption{Figures on top of each other}
\label{fig:tmb}
\end{figure}
```



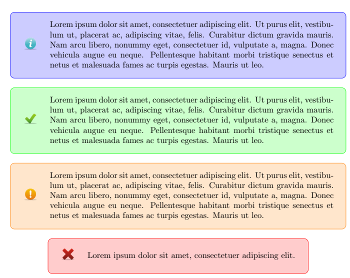
(a) A sub-figure in the upper-left corner.



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



(c) A sub-figure in the lower-left corner.



(d) A sub-figure in the lower-right corner

Fig. B.3 Four figures in each corner. See List. B.7 for the corresponding LaTeX code.

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

```
\begin{figure}[!htbp]
\centering
\subbottom[A sub-figure in the upper-left corner.]{
\includegraphics[width=0.45\textwidth]{example}
\label{fig:upprleft}
}
\hfill
\subbottom[A sub-figure in the upper-right corner.]{
\includegraphics[width=0.45\textwidth]{example}
\label{fig:uppright}
}
\vfill
\subbottom[A sub-figure in the lower-left corner.]{
\includegraphics[width=0.45\textwidth]{example}
\label{fig:lowerleft}
}
\hfill
\subbottom[A sub-figure in the lower-right corner]{
\includegraphics[width=0.45\textwidth]{example}
\label{fig:lowright}
}
\caption{Four figures in each corner. See List.~\ref{lst:fourfigs} for the corresponding \LaTeX \ code.}
\label{fig:fourfig}
\end{figure}
```

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B6 Table

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

TABLE B.1 FEASIBLE TRIPLES FOR HIGHLY VARIABLE GRID

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

Continued on next page

Continued from previous page

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

List. B.8 shows the corresponding LaTeX code.

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

```
\begin{center}
{\scriptsize
\begin{tabularx}{\textwidth}{p{0.1\textwidth}|p{0.2\textwidth}|p{0.5\textwidth}}
\caption{Feasible triples for highly variable grid} \label{tab:triple_grid} \\
\hline
\hline
\textbf{Time (s)} &
\textbf{Triple chosen} &
\textbf{Other feasible triples} \\
\hline
\endfirsthead
\multicolumn{3}{c}%
{\textit{Continued from previous page}} \\
\hline
\hline
\textbf{Time (s)} &
\textbf{Triple chosen} &
\textbf{Other feasible triples} \\
\hline
\endhead
\hline
\multicolumn{3}{r}{\textit{Continued on next page}} \\
\endfoot
\hline
\endlastfoot
\hline

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) \\
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) \\
\end{tabularx}
}
\end{center}
```

B7 Algorithm or Pseudocode Listing

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

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

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

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

$y \Leftarrow 1$
if $n < 0$ **then**
  $X \Leftarrow 1/x$
  $N \Leftarrow -n$
else
  $X \Leftarrow x$
  $N \Leftarrow n$
end if
while $N \neq 0$ **do**
  if N is even **then**
    $X \Leftarrow X \times X$
    $N \Leftarrow N/2$
  else $\{N$ is odd$\}$
    $y \Leftarrow y \times X$
    $N \Leftarrow N - 1$
  end if
end while

Listing B.9: Sample LaTeX code for algorithm or pseudocode listing usage

```
\begin{table}[!htbp]
   \caption{Calculation of $y = x^n$}
   \label{tab:calcxn}
   {\footnotesize
   \begin{tabular}{lll}
   \hline
   \hline
   {\bfseries Input(s):} & & \\
   $n$ & : & $n$th power; $n \in \mathbb{Z}^{+}$ \\
   $x$ & : & base value; $x \in \mathbb{R}^{+}$ \\
   \hline
   {\bfseries Output(s):} & & \\
   $y$ & : & result; $y \in \mathbb{R}^{+}$  \\
   \hline
   \hline
   \\
   \end{tabular}
   }
   \begin{algorithmic}[1]
   {\footnotesize
      \REQUIRE $n \geq 0 \vee x \neq 0$
      \ENSURE $y = x^n$
      \STATE $y \Leftarrow 1$
      \IF{$n < 0$}
            \STATE $X \Leftarrow 1 / x$
            \STATE $N \Leftarrow -n$
      \ELSE
            \STATE $X \Leftarrow x$
            \STATE $N \Leftarrow n$
      \ENDIF
      \WHILE{$N \neq 0$}
            \IF{$N$ is even}
                  \STATE $X \Leftarrow X \times X$
                  \STATE $N \Leftarrow N / 2$
            \ELSE[$N$ is odd]
                  \STATE $y \Leftarrow y \times X$
                  \STATE $N \Leftarrow N - 1$
            \ENDIF
      \ENDWHILE
   }
   \end{algorithmic}
\end{table}
```

B8 Program/Code Listing

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

Listing B.10: Computing Fibonacci numbers in C (./code/fibo.c)

```
/* fibo.c -- It prints out the first N Fibonacci
 *             numbers.
 */

#include <stdio.h>

int main(void) {
    int n;          /* Number of fibonacci numbers we will print */
    int i;          /* Index of fibonacci number to be printed next */
    int current;    /* Value of the (i)th fibonacci number */
    int next;       /* Value of the (i+1)th fibonacci number */
    int twoaway;    /* Value of the (i+2)th fibonacci number */

    printf("How␣many␣Fibonacci␣numbers␣do␣you␣want␣to␣compute?␣");
    scanf("%d", &n);
    if (n<=0)
       printf("The␣number␣should␣be␣positive.\n");
    else {
      printf("\n\n\tI␣\t␣Fibonacci(I)␣\n\t=====================\n");
      next = current = 1;
      for (i=1; i<=n; i++) {
   printf("\t%d␣\t␣␣␣%d\n", i, current);
   twoaway = current+next;
   current = next;
   next     = twoaway;
      }
    }
}

/* The output from a run of this program was:

How many Fibonacci numbers do you want to compute? 9

   I   Fibonacci(I)
   =====================
   1      1
   2      1
   3      2
   4      3
   5      5
   6      8
   7      13
   8      21
   9      34

*/
```

List. B.11 shows the corresponding LaTeX code.

Listing B.11: Sample LaTeX code for program listing

```
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

```
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.

B9.1 A subsection

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

Listing B.13: Sample LaTeX code for referencing subsections

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

Lorem ipsum dolor sit amet, 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.

B9.1.1 A sub-subsection

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

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

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

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

B10 Index

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

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

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

Listing B.15: Sample LaTeX code for Index usage

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

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

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

Listing B.16: Sample LaTeX code for including PDF pages

```
\includepdf[pages={8-10},%
offset=3.5mm -10mm,%
scale=0.73,%
frame]
{./reference/Xilinx2015-UltraScaleArchitectureOverview.pdf}
```

1275

Virtex UltraScale FPGA Feature Summary

Table 6: **Virtex UltraScale FPGA Feature Summary**

	VU065	VU080	VU095	VU125	VU160	VU190	VU440
Logic Cells	626,640	780,000	940,800	1,253,280	1,621,200	1,879,920	4,432,680
CLB Flip-Flops	716,160	891,424	1,075,200	1,432,320	1,852,800	2,148,480	5,065,920
CLB LUTs	358,080	445,712	537,600	716,160	926,400	1,074,240	2,532,960
Maximum Distributed RAM (Mb)	4.8	3.9	4.8	9.7	12.7	14.5	28.7
Block RAM/FIFO w/ECC (36Kb each)	1,260	1,421	1,728	2,520	3,276	3,780	2,520
Total Block RAM (Mb)	44.3	50.0	60.8	88.6	115.2	132.9	88.6
CMT (1 MMCM, 2 PLLs)	10	16	16	20	30	30	30
I/O DLLs	40	64	64	80	120	120	120
Fractional PLLs	5	8	8	10	15	15	0
Maximum HP I/Os[(1)]	468	780	780	780	650	650	1,404
Maximum HR I/Os[(2)]	52	52	52	104	52	52	52
DSP Slices	600	672	768	1,200	1,560	1,800	2,880
System Monitor	1	1	1	2	3	3	3
PCIe Gen3 x8	2	4	4	4	5	6	6
150G Interlaken	3	6	6	6	8	9	0
100G Ethernet	3	4	4	6	9	9	3
GTH 16.3Gb/s Transceivers	20	32	32	40	52	60	48
GTY 30.5Gb/s Transceivers	20	32	32	40	52	60	0

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

Virtex UltraScale Device-Package Combinations and Maximum I/Os

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

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

Notes:

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

Virtex UltraScale+ FPGA Feature Summary

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

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

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

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

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

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

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

Appendix C
PUBLICATION LIST AND AWARD

Journal

1. ...
2. ...

Conference

1. ...
2. ...

Others

1. …
2. …

Award

1. …
2. …

Appendix D
VITA

Paul Vince A. Abe is currently pursuing Bachelor of Science Degree in Computer Engineering at De La Salle University-Manila. His role in the group is the Domain Expert. Along with his extensive ability in correlating needed topics in specifying both the strengths and projected weaknesses of the project, he contributes mainly in creating the knowledge pool of the group.

Dan Paulo E. Amado is currently pursuing Bachelor of Science Degree in Computer Engineering at De La Salle University-Manila. His role in the group is the Master Programmer. With his adept skills in computer programming, he functions as the brain of the project, as he provides the main idea along with its purpose it serves. His research interests include mountaineering, agriculture, and robotics.

Joanna Katherine U. Mirida is currently pursuing Bachelor of Science Degree in Computer Engineering at De La Salle University-Manila. With her keen sight for details, she provides constructive criticisms as to where the group will set rooms for further improvements and necessary corrections from established ideas. Her research interest include biomedical engineering, nanotechnology, and energy management systems.

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