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

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

July, 2016

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**.

____
Engr. Donabel D. Abuan
Adviser

July 25, 2016

De La Salle University

THESIS APPROVAL SHEET

This thesis entitled **A Robot System for Paddy Field Planting in the Philippines**, prepared and submitted by:

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

with group number ESG-04 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.

PANEL OF EXAMINERS

Dr. Amado Z. Hernandez
Chair

Dr. Aaron F. Africa
Member

Engr. Argel A. Bandala
Member

Engr. Donabel D. Abuan
Adviser

Date: July 25, 2016

De La Salle University

2016

ACKNOWLEDGMENT

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

ABSTRACT

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

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

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS

NOTATION

$\mathcal{S}$	a collection of distinct objects	46
$\mathcal{U}$	the set containing everything	46
$\emptyset$	the set with no elements	46
$\lvert\mathcal{S}\rvert$	the number of elements in the set $\mathcal{S}$	46
$h(t)$	impulse response	36
$x(t)$	input signal represented in the time domain	36
$y(t)$	output signal represented in the time domain	36

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

182 # GLOSSARY

183 matrix a concise and useful way of uniquely representing and working with linear transformations; a rectangular table of elements 46

LISTINGS

Chapter 1

INTRODUCTION

Contents

De La Salle University

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.

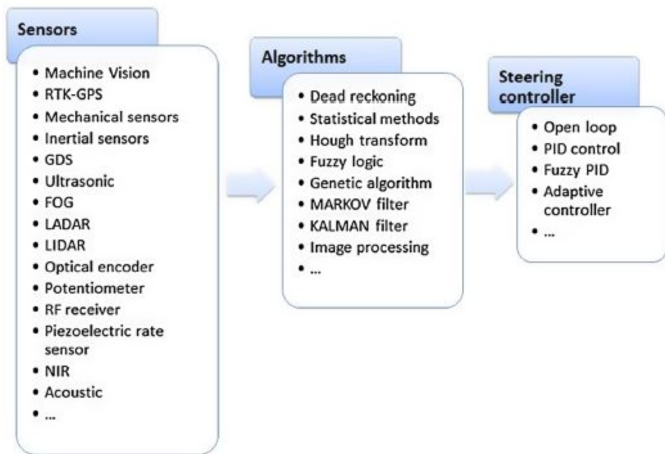

Fig. 2.1 Basic control diagram of autonomous vehicles.

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

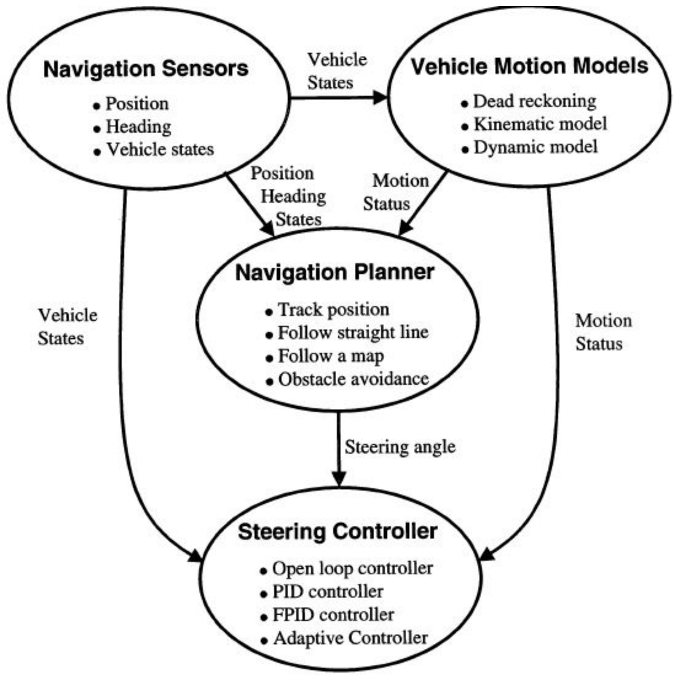

Fig. 2.2 Basic elements of agricultural vehicle automation systems

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.

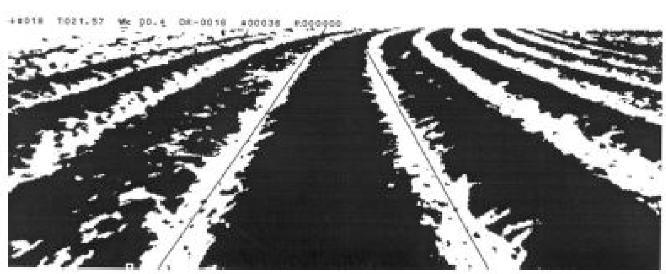

Fig. 2.3 Digitised image with guidelines.

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.

Chapter 3

THEORETICAL CONSIDERATIONS

Contents

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.

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.

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.

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.

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.

3.1 Summary

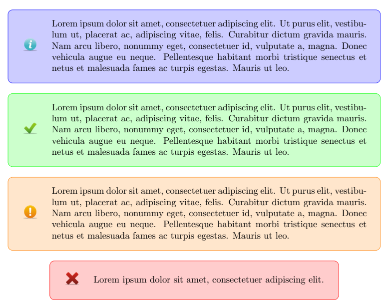

Fig. 3.1 A quadrilateral image example.

Chapter 4

DESIGN CONSIDERATIONS

Contents

4.1 Design Reference

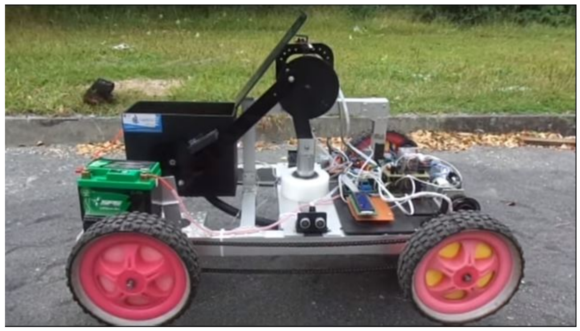

Fig. 4.1 Design Reference for The Corn Planting Robot

Figure 4.1 shows the researchers design reference for the corn planting robot. The design was found online (youtu.be/QooHpnYLj1w) which is uploaded by user named Luthfi Hasni. The design uses a PIC or a Programmable Integrated Circuit to control the robot. It uses several sensors as its navigation system. Besides from the 2 motors that controls the wheels of the robot, it has a third motor that controls the boring of the soil and the sowing of the cord seeds at the same time.

4.2 Design and Dimensions

Portability is one of the main considerations of the robots design. Figures 4.2 - 4.4 shows the design and dimensions of the corn planting robot. The figures show that the researchers robot is much smaller compared to the design reference. The robot has a length of 262 mm, a width of 215 mm, and a height of 180 mm.

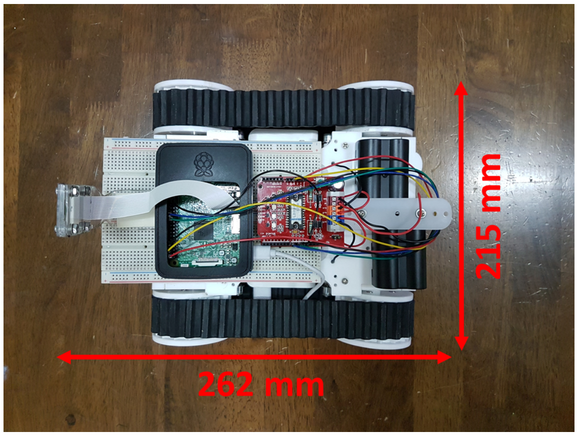

Fig. 4.2 Top View of the Corn Planting Robot and its Dimensions

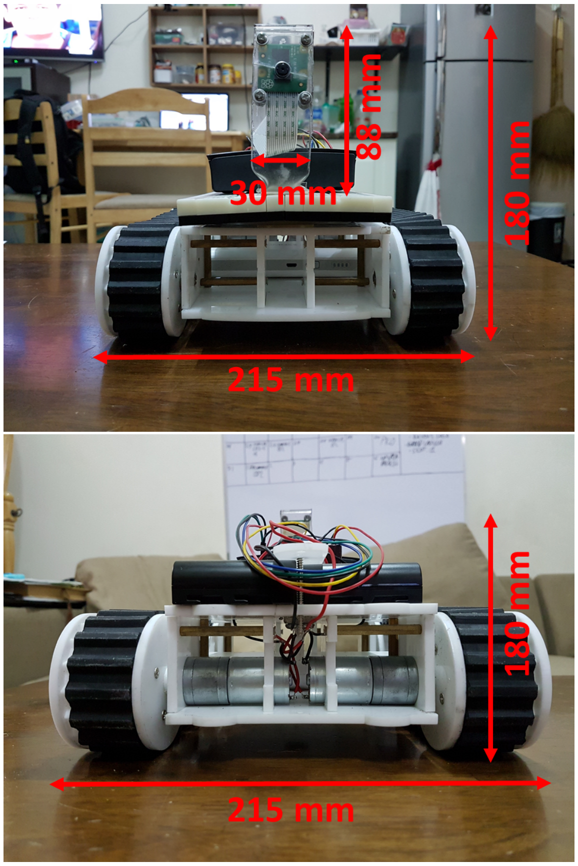

Fig. 4.3 Front and Back View of the Corn Planting Robot and its Dimensions

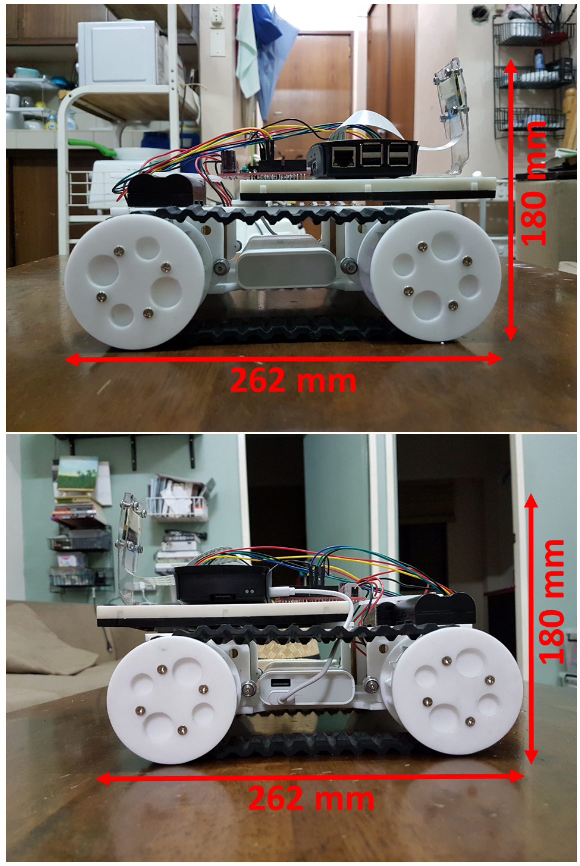

Fig. 4.4 Left and Right Side View of the Corn Planting Robot and its Dimensions

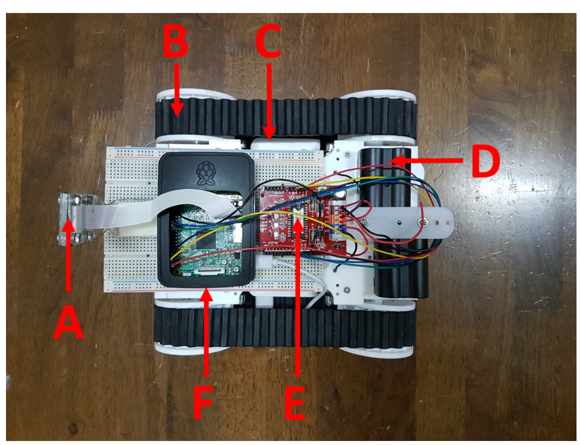

Fig. 4.5 Top View of the Corn Planting Robot with its Main Components Pointed Out

De La Salle University

4.3 Components

As seen on Figure 4.5, part B is the continuous track of the robot. The researchers chose to use a continuous track for the robot since it is more suitable to be used on off-road environments on which corn in planted. The continuous track will help on the slip of the robot on the soil and help with the mobility of the robot. The robot uses a 6V DC geared motor which controls the continuous track (B) which makes the robot move. Two 7.4 V battery packs (D) that is connected in parallel is used to supply voltage to the motors. The motors and the battery packs (D) are then connected to the motor driver shield (E) which controls the direction of the motors individually thereby controls the movement of the whole robot. The motor driver shield is connected to the Raspberry Pi 3 Model B (F). The Raspberry Pi is the main processing unit of the robot. It is responsible for the image processing, remote connection, and the control of the motor driver shield (E). For the image processing, the researchers used the Raspberry Pi Camera v2.1 (A). We used the Raspberry Pi Camera for it allows the robot to utilize the GPU (Graphical Processing Unit) of the Raspberry Pi, which makes the image processing faster and decrease the processing load on the main processing unit. Lastly, the Raspberry Pi is then powered separately by a power bank.

The researchers decided to use the Raspberry Pi instead of PIC or Arduino and other development boards due to its high processing ability, especially on image processing. PIC and Arduino are more suitable for applications that uses analog sensors or is more focused on hardware projects while the Raspberry Pi is more suitable for software processing. Since the corn planting robot would use computer vision to navigate across the corn field, the Raspberry Pi is more suitable for this kind of application. With a dedicated camera module that is directly compatible and can be easily set up, and a GPU or a Graphical Processing Unit, the Raspberry Pi can do image processing a lot faster which would allow the robot to do real time image processing and navigate across the field at the same time.

Chapter 5

METHODOLOGY

Contents

5.1 Implementation

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.

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.

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.

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.

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.

5.2 Evaluation

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.

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.

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.

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.

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.

5.3 Summary

REFERENCES

[ISO, 2009] ISO (2009). 80000-2. *Quantities and units–Part 2: Mathematical signs and symbols to be used in the natural sciences and technology*.

[Oetiker et al., 2014] Oetiker, T., Partl, H., Hyna, I., and Schlegl, E. (2014). *The Not So Short Introduction to $\LaTeX 2_\varepsilon$ Or $\LaTeX 2_\varepsilon$ in 157 minutes*. n.a.

Appendix A
ANSWERS TO QUESTIONS TO THIS THESIS

Appendix B
USAGE EXAMPLES

Contents