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A Robot System for Paddy Field Planting in the Philippines

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A Thesis

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Presented to the Faculty of the

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Department of Electronics and Communications Engineering

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Gokongwei College of Engineering

8

De La Salle University

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10

In Partial Fulfillment of the

11

Requirements for the Degree of

12

Bachelor of Science in Electronics and Communications Engineering

13

14

by

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July, 2016



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ORAL DEFENSE RECOMMENDATION SHEET

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

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in partial fulfillment of the requirements for the degree of **Bachelor of Science in 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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This thesis entitled **A Robot System for Paddy Field Planting in the Philippines**, prepared and submitted by:

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

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PANEL OF EXAMINERS

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ACKNOWLEDGMENT

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



61

ABSTRACT

62

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

63

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



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ABBREVIATIONS

164	AC	Alternating Current.....	44
165	HTML	Hyper-text Markup Language	44
166	CSS	Cascading Style Sheet.....	44
167	XML	eXtensible Markup Language	44



NOTATION

169	\mathcal{S}	a collection of distinct objects	46
170	\mathcal{U}	the set containing everything	46
171	\emptyset	the set with no elements	46
172	$ \mathcal{S} $	the number of elements in the set \mathcal{S}	46
173	$h(t)$	impulse response	36
174	$x(t)$	input signal represented in the time domain	36
175	$y(t)$	output signal represented in the time domain	36

176 Throughout this thesis, mathematical notations conform to ISO 80000-2 standard, e.g.
177 variable names are printed in italics, the only exception being acronyms like e.g. SNR,
178 which are printed in regular font. Constants are also set in regular font like j . Functions are
179 also set in regular font, e.g. in $\sin(\cdot)$. Commonly used notations are t , f , $j = \sqrt{-1}$, n and
180 $\exp(\cdot)$, which refer to the time variable, frequency variable, imaginary unit, n th variable,
181 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



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Chapter 1

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INTRODUCTION

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217 **1.1 Background of the Study**

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

235 The development or agricultural robot, led some researchers to utilize image processing
236 for navigation. Digital image processing allows a much wider range of algorithms to be
237 applied to the input data and can avoid problems such as the build-up of noise and signal
238 distortion during processing. Today machine visions are applied in two dimensions (2-D)
239 or three dimensions (3-D). The 2-D vision systems use area scan or line scan cameras



240 as well as appropriate lighting to measure the visible characteristics of an object such as,
241 quality of surface appearance, edge based measurements and presence and location of
242 features. In agriculture, 2-D has applications in sorting based on color, shape and size.
243 In 3-D analysis basically there are two techniques applied: stereo vision and LED/laser
244 triangulation. Machine vision-based guidance showed acceptable performance at all speeds
245 and different paths by average errors below 3 cm. It was proposed that using both machine
246 vision and laser radar may provide a more robust guidance as well as obstacle detection
247 capability (Mousazadech, 2013).

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

259 **1.2 Prior Studies**

260 Pertinent to the needs of the country, the Philippines is centered and concentrated in con-
261 ducting researches on agricultural technology. As a country highly capable of producing



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262 its own sources of food, there is no doubt that there is priority in funding these researches.
263 These, in turn, allow its agriculture to be as advanced as it requires for its growing pop-
264 ulation. Following the groups interest in integrating its recent forms of technology in
265 indigenous sectors of the society, the members conducted brief, prior studies about the
266 current advancements in agricultural technology of different origins. They purposed to find
267 foreign researches in order to extend the capabilities of local technology to be as equally
268 competent.

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



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

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

304 1.3 Problem Statement

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



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

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

318 **1.4 Objectives**

319 **1.4.1 General Objective(s)**

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

322 **1.4.2 Specific Objectives**

- 323 1. To implement computer vision, specifically edge detection, in tracing the path sec-
324 tions of the paddy field;
- 325 2. To utilize the flood fill algorithm in designing the optimal route for the mobile robot
326 as it plant the rice;



- 327 3. To design an Arduino system in implementing computer vision as interface in robotic
328 application;
- 329 4. To design and develop a mobile robot designed to withstand paddy field environmen-
330 tal factors (e.g. soil, mud, etc.);

331 **1.5 Significance of the Study**

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

344 In social context, the employment of this robot system for paddy field planting would
345 allow a decrease in production time of rice as it automates the planting of the crop. Ad-
346 ditionally, it would lessen the manual labor provided by the local farmers. Instead of
347 manually planting rice, local farmers would save time and effort as the robot system for
348 paddy field planting would be utilized. The workload for the farmers would be decreased



349 as the production is increased. It is anticipated that the use of this system would increase
350 the productivity of agricultural sector in the country. It would aide local farmers in ensuring
351 an increase in rice yield as plantation is automated. It will not only benefit the agricultural
352 area but also the economic status of the Philippines.

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

360 **1.6 Assumptions, Scope and Delimitations**

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

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

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



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

375 **1.7 Description and Methodology**

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



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

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

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

408 The group designated their independent study as the farmers performance; leaving out
409 the robots performance as the dependent study. Therefore, to confirm gathered results about
410 the robot, the group calculated the dispersion and central tendencies of the data taken from
411 the dependent study to the independent study: from the time and depth variables. The group



412 decided this validation method as such due to the ideal purpose of the proposed system: it
 413 should be able to replace farmers in field planting.

414 **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 Mechanism	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

415 **1.9 Overview**

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



418

Chapter 2

419

LITERATURE REVIEW

420

Contents

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424 **2.1 Summary**

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

434 An abridged, proposed algorithm design was as follows

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



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

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

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



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

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

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



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493 according to world coordinates that were lying on the ground.

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

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



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

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

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



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

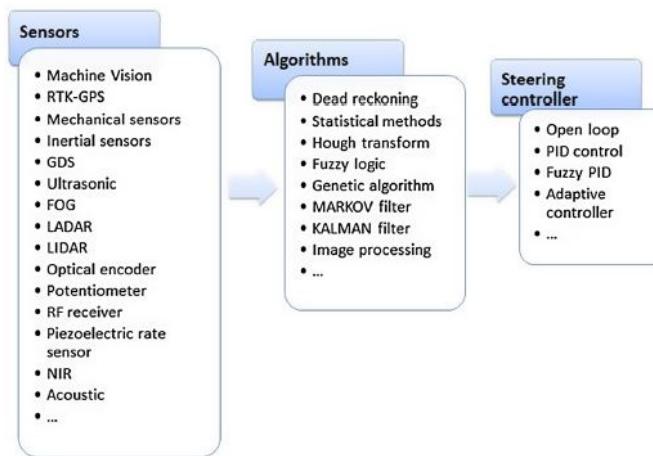


Fig. 2.1 Basic control diagram of autonomous vehicles.

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

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

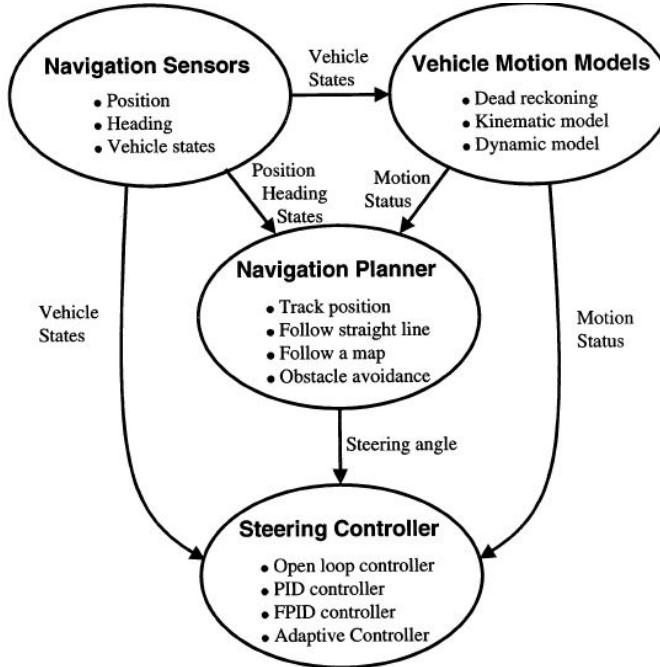


Fig. 2.2 Basic elements of agricultural vehicle automation systems

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



Fig. 2.3 Digitised image with guidelines.

558 One research is about the autonomous agriculture vehicles in Japan. This research has



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

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

581 Another article discusses the navigation system for agricultural machines. This article
582 presents a new kind of navigation system for agricultural machines. The focus is on



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



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Chapter 3

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THEORETICAL CONSIDERATIONS

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641 3.1 Summary



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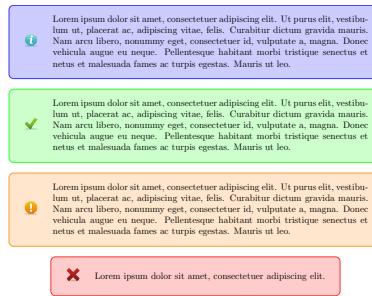


Fig. 3.1 A quadrilateral image example.



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Chapter 4

643

DESIGN CONSIDERATIONS

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4.1 Design Reference

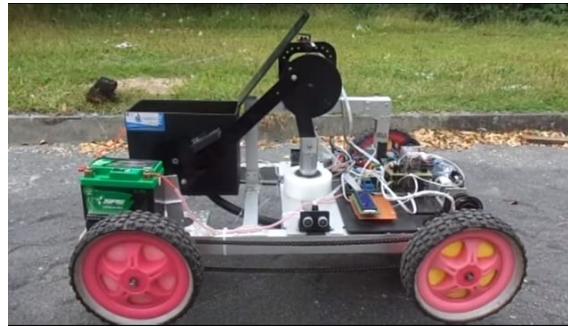


Fig. 4.1 Design Reference for The Corn Planting Robot

651

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 corn seeds at the same time.

657

4.2 Design and Dimensions

658

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.

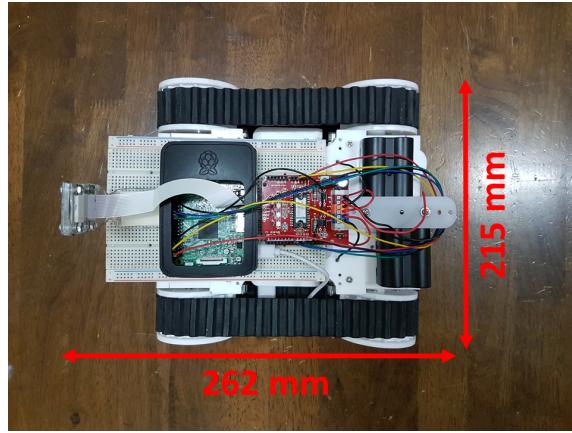


Fig. 4.2 Top View of the Corn Planting Robot and its Dimensions

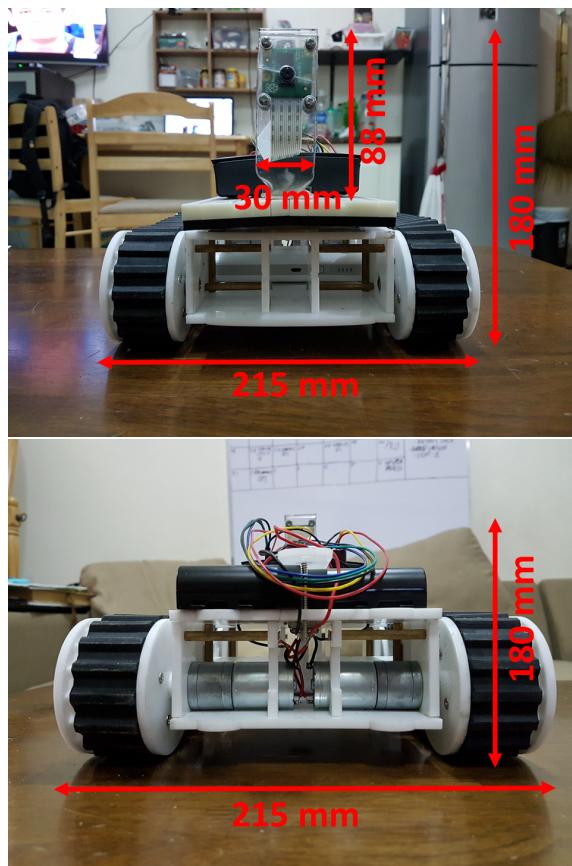


Fig. 4.3 Front and Back View of the Corn Planting Robot and its Dimensions



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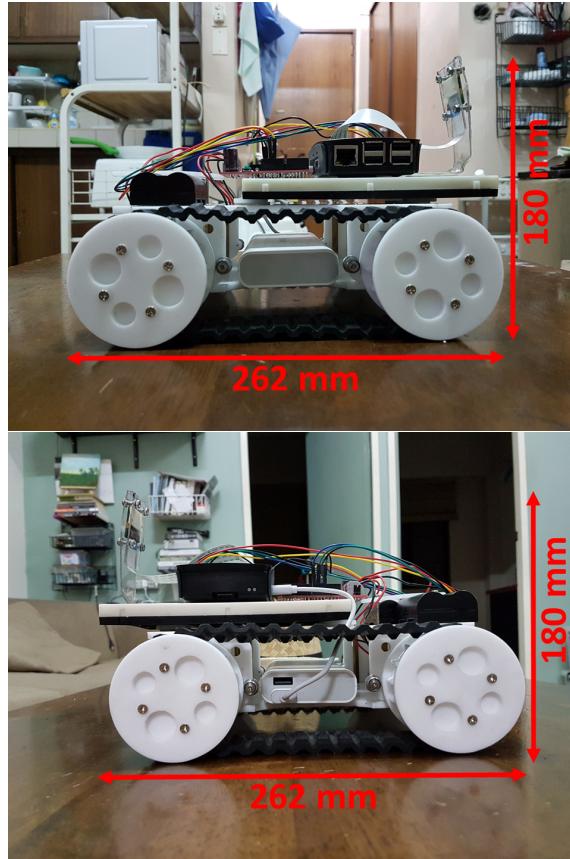


Fig. 4.4 Left and Right Side View of the Corn Planting Robot and its Dimensions

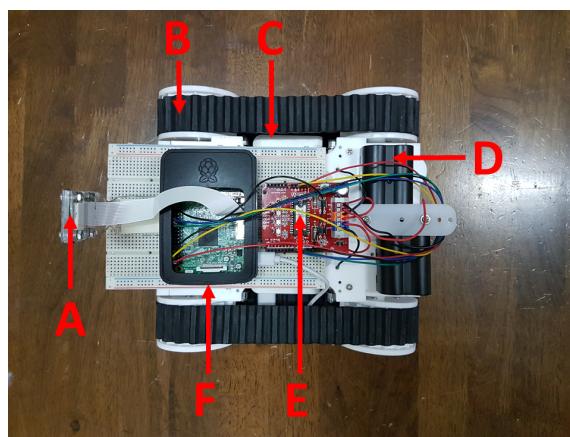


Fig. 4.5 Top View of the Corn Planting Robot with its Main Components Pointed Out



662 **4.3 Components**

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

679 The researchers decided to use the Raspberry Pi instead of PIC or Arduino and other
680 development boards due to its high processing ability, especially on image processing. PIC
681 and Arduino are more suitable for applications that uses analog sensors or is more focused
682 on hardware projects while the Raspberry Pi is more suitable for software processing. Since
683 the corn planting robot would use computer vision to navigate across the corn field, the
684 Raspberry Pi is more suitable for this kind of application. With a dedicated camera module



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685 that is directly compatible and can be easily set up, and a GPU or a Graphical Processing
686 Unit, the Raspberry Pi can do image processing a lot faster which would allow the robot to
687 do real time image processing and navigate across the field at the same time.



688

Chapter 5

689

METHODOLOGY

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5.1 Implementation

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5.2 Evaluation

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5.3 Summary



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Appendix A ANSWERS TO QUESTIONS TO THIS THESIS

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