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A Robot System for Corn 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

9

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



De La Salle University

19

ORAL DEFENSE RECOMMENDATION SHEET

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This thesis, entitled **A Robot System for Corn 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

35

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

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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.



64 **Chapter 1**

65 **INTRODUCTION**

66 **Contents**

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80 **1.1 Background of the Study**

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

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



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

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

122 1.2 Prior Studies

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



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

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



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

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

167 1.3 Problem Statement

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



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

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

181 **1.4 Objectives**

182 **1.4.1 General Objective(s)**

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

185 **1.4.2 Specific Objectives**

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



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

194 **1.5 Significance of the Study**

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

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



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

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

223 **1.6 Assumptions, Scope and Delimitations**

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

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

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



- Localization of field study with the environmental factors seen at Jaybunga, 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.



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

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

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

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



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

277 **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

278 **1.9 Overview**

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



281

Chapter 2

282

LITERATURE REVIEW

283

Contents

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2.1	Summary	10
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287 **2.1 Summary**

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

297 An abridged, proposed algorithm design was as follows

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



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

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

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



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

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

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



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

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

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



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

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

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



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

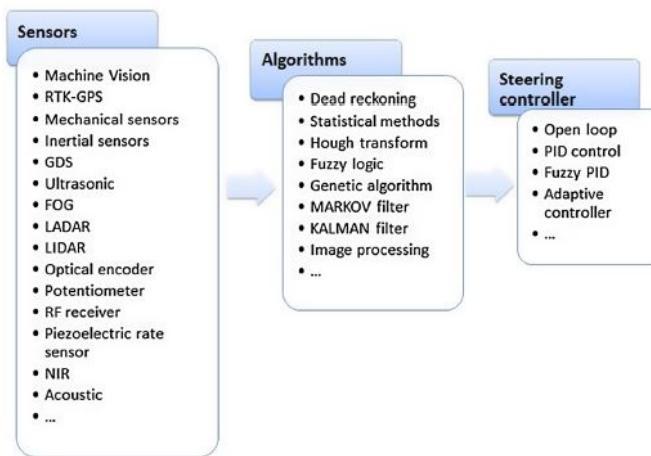


Fig. 2.1 Basic control diagram of autonomous vehicles.

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

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

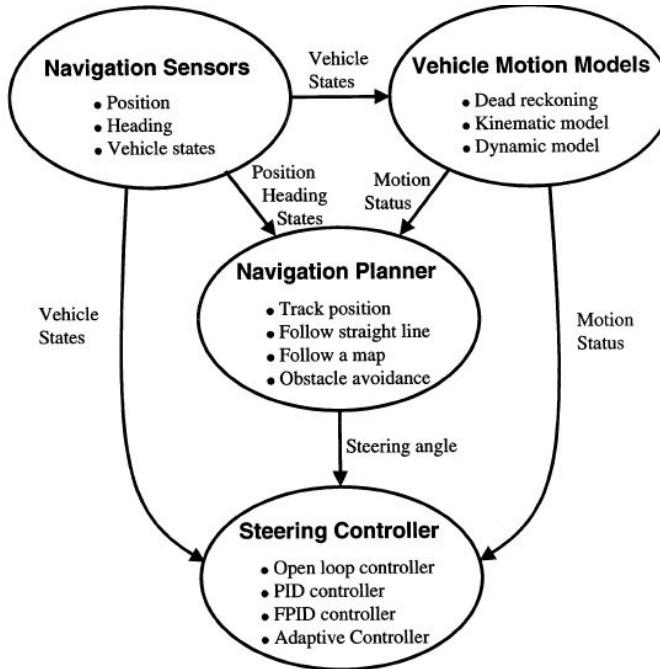


Fig. 2.2 Basic elements of agricultural vehicle automation systems

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



Fig. 2.3 Digitised image with guidelines.

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



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

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

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



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



453

Chapter 3

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THEORETICAL CONSIDERATIONS

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463 3.1 Agricultural Robots

464 Agricultural robots are designed to be implemented on an unstructured environment. Hence,
 465 these robots are expected to be dynamic, uncertain, complex, highly variable, and hostile. In
 466 order to build an agricultural robot, multiple design principles are taken into consideration.
 467 This includes product specification such as speed, system analysis such as the function, con-
 468 cept development such as alternative methods, feasibility, and what not. Figure 3.1 shows
 469 the flowchart of the implementation of concepts on an agricultural robot. [Edan et al.,]

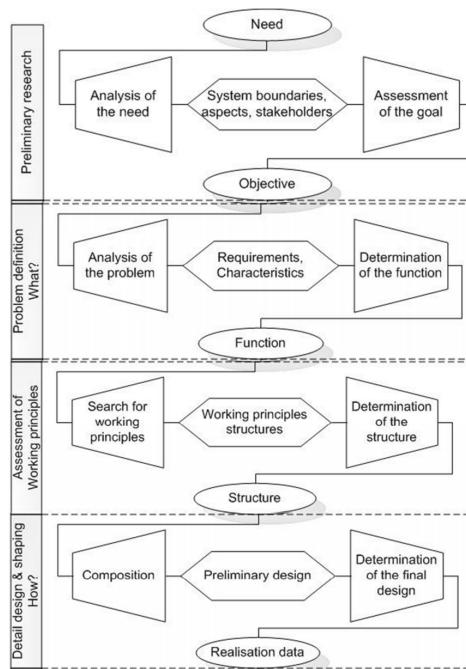


Fig. 3.1 Flowchart of Agricultural Robot Design



3.2 Raspberry Pi 3 Model B

Raspberry Pi is a low-cost microcomputer originally designed to aide young people in programming. It is advantageous in terms of size, portability, cost, programmability, and connectivity. [RaspberryPiFoundation, c] Raspberry Pi is mounted on a credit card-sized board and has multiple feature ports such as USB 2.0, HDMI, Power, SD Card, and many more depending on the model.

On this research, Raspberry Pi 3 model B is used. Its features include:

- A 1.2GHz 64-bit quad-core ARMv8 CPU

- 802.11n Wireless LAN

- Bluetooth 4.1

- Bluetooth Low Energy (BLE)]

- 1GB RAM

- 4 USB ports

- 40 GPIO pins

- Full HDMI port

- Ethernet port

- Combined 3.5mm audio jack and composite video

- Camera interface (CSI)

- Display interface (DSI)



- 489 • Micro SD card slot (now push-pull rather than push-push)
 490 • VideoCore IV 3D graphics core

491 Figures 3.2, 3.3, 3.4, 3.5 and 3.6 show the schematic diagrams essential to this research.

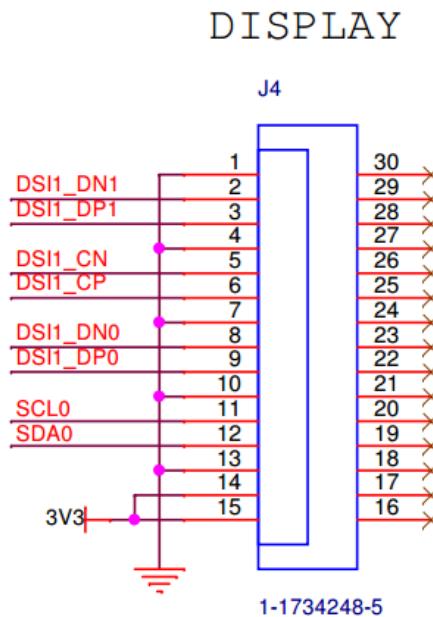


Fig. 3.2 Schematic of Display

3.3 Raspberry Pi Camera Module

492
 493 The PiCamera is a camera module for Raspberry Pi that allows the users to capture still
 494 photos and record videos in high definition. A camera port on the microcomputer is
 495 available for this device. In this port, the camera is connected while Pi is still switched off
 496 and once it is connected to the board, the devices are switched on. The camera software is
 497 available on the Raspberry Pi Configuration Tool. Python3 is utilized in order to preview

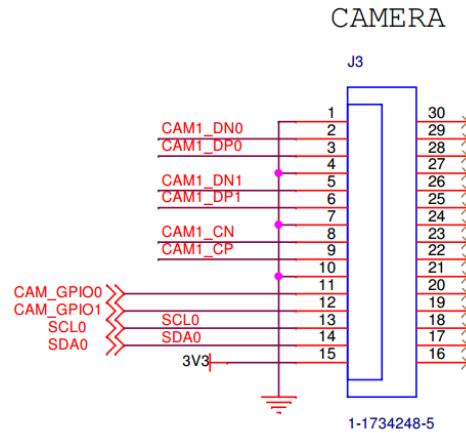


Fig. 3.3 Schematic of Camera Port

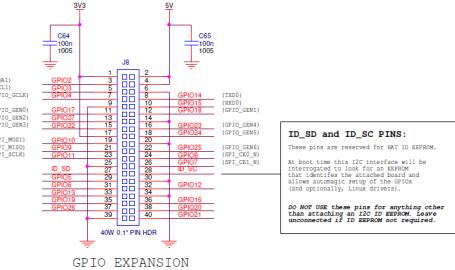


Fig. 3.4 Schematic of GPIO Expansion

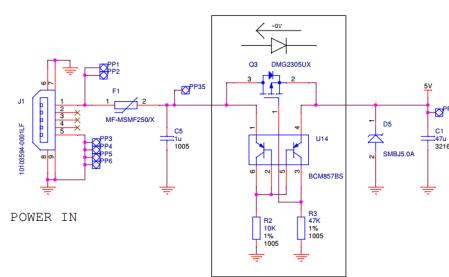


Fig. 3.5 Schematic of Power Input



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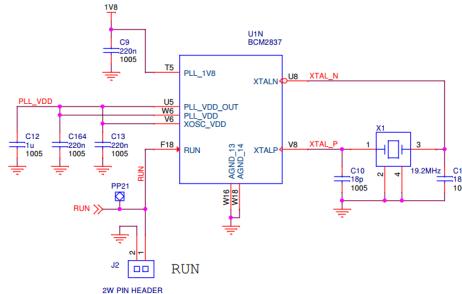


Fig. 3.6 Schematic of RUN

498 the camera. Figure 3.7 shows the code to be executed in order to allow the preview of the
499 camera. [RaspberryPiFoundation, a]

```
from picamera import PiCamera  
from time import sleep  
  
camera = PiCamera()  
  
camera.start_preview()  
sleep(10)  
camera.stop_preview()
```

Fig. 3.7 Code for Camera Preview

3.4 Virtual Network Computing

Virtual Network Computing (VNC) is a graphical sharing system on a desktop that allows remote access and control of a desktop interface of on device from another. The events from the controller such as keyboard and mouse are transmitted to the screen over the network from the remote host. On the Raspberry Pi, it is necessary to install the TightVNC package in order to utilize this system. To install this package, the code `sudo apt-get install`



506 *tightvncserver* is used. Running the TightVNC Server would prompt the user to input the
507 password *tightvncserver*. From the terminal, VNC is started. A session on VNC display
508 one with full HD resolution is written as *vncserver :1 -geometry 1920x1080 -depth 24*.
509 In order to run the VNC server on the Pi, a command on a file is necessary. The shell
510 script *!/bin/sh (next line) vncserver :1 -geometry 1920x1080 -depth 24 -dpi 96* is to be
511 created. By inputting the code *chmod +x vnc.sh*, the shell script with filename *vnc.sh* is
512 made executable. In order to run the file at any time, the code *./vnc.sh* is executed. The
513 procedure mentioned above is the initialization of VNC on the Pi module. With this, a
514 VNC client on the personal computer is needed in order to connect the computer to the
515 VNC server and have control of it. [RaspberryPiFoundation, b]

516

3.5 IP Address

517 Internet Protocol (IP) Address is an address that is used to identify a unique device over
518 an IP network. It is a core in network design as it is a Network Foundation service. It
519 provides the foundation of other network and user services and it allows the interaction of
520 devices within the network. [Cisco,] Raspberry Pi 3 model B is connected to a Local Area
521 Network. Hence, as any device connected to a LAN, Pi is assigned a unique IP address. IP
522 address is vital information in connecting the Pi to another machine using VNC. The code
523 *hostname I* reveals the IP Address of the Pi using the terminal.



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Chapter 4

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DESIGN CONSIDERATIONS

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532

4.1 Design Reference



Fig. 4.1 Design Reference for The Corn Planting Robot

533

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.

539

4.2 Design and Dimensions

540

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.

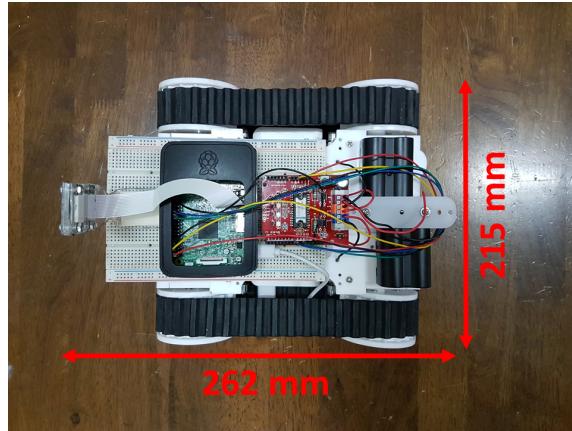


Fig. 4.2 Top View of the Corn Planting Robot and its Dimensions

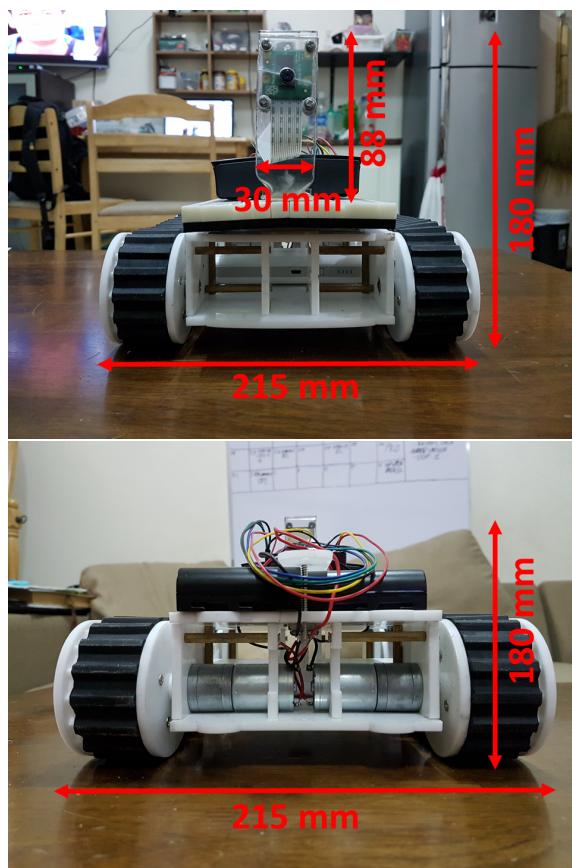


Fig. 4.3 Front and Back View of the Corn Planting Robot and its Dimensions



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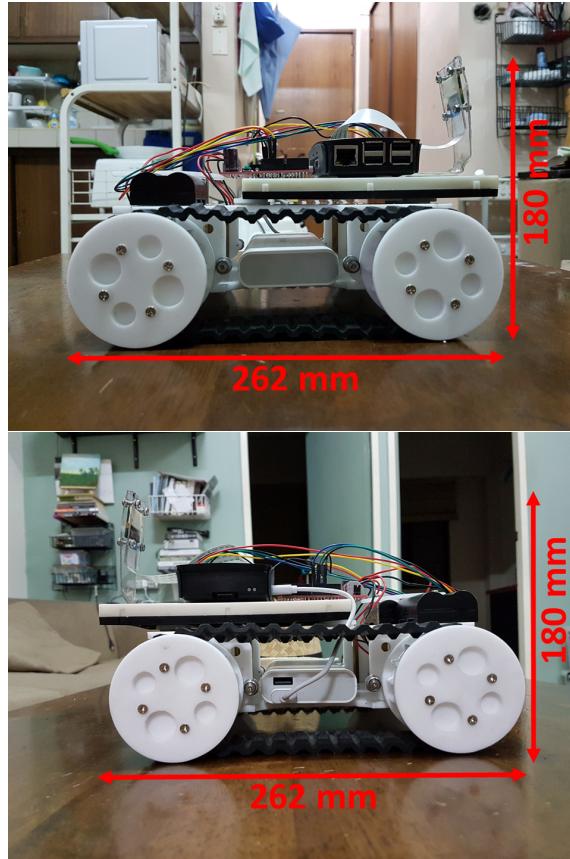


Fig. 4.4 Left and Right Side View of the Corn Planting Robot and its Dimensions

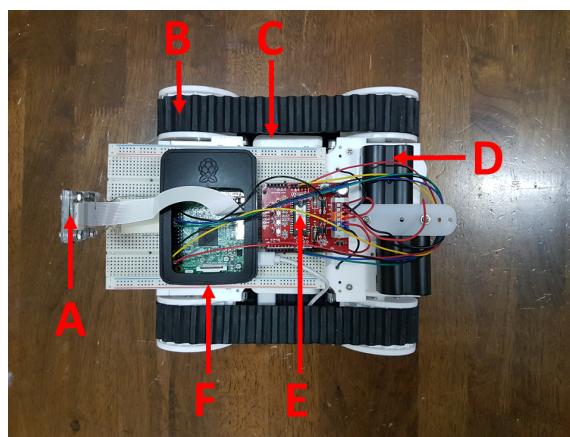


Fig. 4.5 Top View of the Corn Planting Robot with its Main Components Pointed Out



544 4.3 Components

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

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



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



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Chapter 5

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METHODOLOGY

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578 5.1 Implementation

579 The project governed the interfacing of computer vision for a robot systems navigation.
580 This proposed system was conditioned to navigate on dry land terrains at daytime. Further,
581 certain considerations were taken as per testing. The land area for corn plantation had been
582 downscaled to a 60-inches by 20-inches (by a factor of 1/65th length-wise and 1/197th
583 width-wise) plant box for conduciveness of the study. Such downscaling managed to model
584 two cornrows which was enough to attempt the turning control of the robot system. Made
585 out of cardboard boxes lined with garbage bags (for water-proofing), the box frame was
586 filled with loam soil: pre-plowed with two-inches deep as irrigation lines, and pre-holed,
587 five-inches apart. Proceeding, the mechanism produced for this study was a mechanically-
588 driven sower machine; independent of any device to operate. Its cost-effectiveness and
589 no electrical power usage made it easier to consider isolating the battery supply of the
590 system for the chassis itself. The proposed sower machine was made of a used compact
591 disc fitted inside an ordinary funnel. The disc was holed as exit points for the seeds that
592 were fed through the narrowed end of the funnel. Prior to the feeding of the corn seeds
593 into the funnel, the seeds were soaked overnight as preconditioning for the following days
594 planting. The feature of this model was that it all depended on the rolling motion it made
595 as the robot navigated. Hence, the robot system dragged the sower machine as it proceeded
596 forward. Finally, a paddle was added behind the seeding machine in order to refill the
597 hole with soil. Mentioning that the land was pre-holed, this was due to the algorithm
598 implemented with the system that required marking points as references for its calculation.
599 These holes were fitted with flags to indicate the needed references. The whole system
600 had been under the implementation of a Raspberry Pi 3 Model B SBC microprocessor unit



601 with Raspberry Pi Camera V2 Video Module as its vision peripheral. With these systems,
602 interfaced and connected to a tank chassis with two motors rated at 0.5A and 6V each; back
603 wheels connected directly to the motor, leaving the front wheels as free wheels. Supplied
604 by two batteries (one per motor) rated at 5.7V with 5780mA current delivery each.

605 **5.2 Evaluation**

606 The robot system was expected to plant 11 holes in 1.286 minutes per row. With these
607 benchmarks scaled from a 100-meter-by-100-meter land area with eight persons to labor
608 the whole field, the system relatively delivered to emulate the benchmarked performance.
609 With three seeds to be planted per hole set for twenty trials, the gathered data managed
610 to reach an observable consistency during the 11th trial onwards. With the amount of
611 seeds and time taken to finish the whole course taken as the observed variables, the factors
612 affecting the prior trials had been the following:

- 613 • Misaligned seeding machine
- 614 • Stillness or non-rotation of the seeding machine
- 615 • Wrong dispensing of seeds (with less than 3 seeds)
- 616 • Positioning of the chassis in-line with the irrigation line
- 617 • Unlevelled land area where the belt wheel got jammed



618 **5.3 Summary**

619 In a nutshell, the whole study was a downscale simulation of a corn field plantation seen in
620 the Philippines. With a system made out of Raspberry Pi system and a homemade seeding
621 mechanism, the system was set to plant three corn seeds in an 11-hole cornrows in under a
622 minute. Through the implementation of a computer vision algorithm to navigate the whole
623 system across the field, the study delivered pleasing results.



624

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