UNIVERSITI PUTRA MALAYSIA

DEVELOPMENT OF WIRELESS LINEAR MOTION CONTROLLER FOR A TWO-AXES GANTRY IN A PADDY TRANSPLANTER BASED ON THE SYSTEM OF RICE INTENSIFICATION (SRI)

SYED MOHD ASH-SYADIQ SYID PUTRA

DEVELOPMENT OF WIRELESS LINEAR MOTION CONTROLLER FOR A TWO-AXES GANTRY IN A PADDY TRANSPLANTER BASED ON THE SYSTEM OF RICE INTENSIFICATION (SRI)

SYED MOHD ASH-SYADIQ SYID PUTRA

189988

BACHELOR OF AGRICULTURAL AND BIOSYSTEMS ENGINEERING WITH HONOURS

FACULTY OF ENGINEERING

UNIVERSITI PUTRA MALAYSIA

2020

APPROVAL SHEET

This project report here, entitled '**Development of Wireless Linear Motion Controller for a Two-Axes Gantry in a Paddy Transplanter Based on the System of Rice Intensification (SRI)**' is prepared by and submitted by Syed Mohd Ash-Syadiq bin Syid Putra with the Matric Number, 189988, in partial fulfilment of the requirements for the Bachelor of Engineering with Honours (Agricultural and Biosystems) is hereby accepted.

Approved by,

______________________________ Date:

(Dr Muhammad Razif bin Mahadi)

Project Supervisor

______________________________ Date:

(Dr Muhamad Saufi bin Mohd Kassim)

Project Examiner

______________________________ Date:

(Dr Sharence Nai Sowat)

Project Examiner

COPYRIGHT

ACKNOWLEDGEMENT

In the name of Allah, the Most Gracious, the Most Merciful. All praises are for Allah, for His guidance and blessings, I am able to expand my horizon and gain a new invaluable experience during the process of planning and executing this project. This project consumed huge amount of work, research, and dedication. Still, implementation would not have been possible if I do not have support of many individuals. Therefore, I would like to express my sincere gratitude to all of them.

I am highly indebted to my research supervisor, Dr. Muhammad Razif bin Mahadi for his guidance and constant supervision as well as for providing necessary information regarding the project and also for his support in completing this project. Besides, I would like to express my appreciation towards my panel examiner Dr. Muhamad Saufi bin Mohd Kassim and Dr. Sharence Nai Sowat for their kind cooperation and encouragement which help me in the completion of this project.

I am using this opportunity to express my deepest gratitude and special thanks to all academic staffs and support staffs of the department who in spite of being extraordinary busy with their duties, took time out to hear, guide and keep me on the correct path throughout my studies in this university. I hope that all the knowledge gained will help me to strive further and higher.

It is my radiant sentiment to place on record my best regards of gratitude to all my beloved course mates especially Muhammad Khairulanam and Wan Muhammad Amir for their precious supports and suggestions which were valuable for my project both theoretically and practically. Last but not least, I would like to thank my mother, Mrs. Junaina Salleh and my sister, Miss Sh Syaza Fatimah for always believing in me. Any omission in this brief acknowledgement does not mean lack of gratitude.

ABSTRACT

System of Rice Intensification (SRI) practices have been developed in order to increase the production and quality of rice. However, the operation of SRI planting method required massive amount of manpower. Therefore, there is a need to develop the new design of transplanting machine in order to reduce labour intensity. In this study, 3D conceptual design was produced and the prototype of the automated SRI transplanting machine together with its wireless controller was built and tested. The general objective is to design and develop a pushing rod in the two-axes gantry which will act as the mechanism for a sub-component to a paddy transplanting system based on the SRI-Tray and the wireless linear motion controller to move the pushing rod in the gantry to desired positions. This automated paddy transplanting machine was developed by the combination of mechanical and electronic system. Modifications of an old and unused printer to form a two-axes gantry system that holds a pushing rod enable it to perform the transplanting task completely. The pushing rod in the gantry system that powered by two 12V DC motors and connected to the controller through a wireless communication are able to dispense a single pre-germinated paddy seedling at a time precisely according to the desirable spacing followed in SRI method.

ABSTRAK

Amalan *System of Rice Intensification* (SRI) telah dibangunkan untuk meningkatkan pengeluaran dan kualiti padi. Walaubagaimanapun, operasi kaedah penanaman SRI memerlukan sejumlah besar tenaga buruh. Oleh itu, terdapat keperluan untuk mereka bentuk mesin penanaman automatik SRI yang untuk mengurangkan penggunaan tenaga manusia. Dalam kajian ini, reka bentuk konsep 3D telah dihasilkan dan prototaip mesin penanaman automatik SRI serta pengawal tanpa wayarnya telah dibangunkan dan diuji. Objektif umum kajian ini adalah untuk mereka bentuk dan membangunkan mekanisma penolakkan dalam gantri dua paksi yang akan bertindak sebagai sub-komponen dalam sistem pemindahan padi yang berdasarkan SRI-Tray dan mengawal pergerakan mekanisma tersebut ke posisi yang diinginkan dengan menggunakan alat kawalan jauh. Mesin pemindahan padi automatik ini dibangunkan dengan gabungan sistem mekanikal dan elektronik. Pengubahsuaian yang dilakukan kepada pencetak lama dan tidak terpakai untuk membentuk sistem gantri dua paksi yang memegang batang penolak membolehkannya melakukan tugas pemindahan sepenuhnya. Batang penolak dalam sistem gantri yang digerakkan oleh dua motor DC 12V ini disambungkan ke alat kawalan jauh melalui komunikasi tanpa wayar mampu mengeluarkan satu bibit padi yang telah dicambah pada masa yang tepat mengikut jarak yang diinginkan yang berdasarkan kepada kaedah penanaman SRI.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1 Background

Paddy is one of the most significant crops in Malaysia and it is important for the food security of the nation. Statistic has also shown that paddy industry in Malaysia has generated stable income for the country (Fahmi, Abu Samah, & Abdullah, 2013). Malaysian government pays massive attention and emphasize on paddy and rice industry due to its strategic significance as the country's staple food.

Rice is a highly protected crop in a strategically important industry in Malaysia and always gets special treatment from the government. The industry is heavily regulated because of its social, political, and economic importance. Rice production have rose from 2,044,604 tons in 1980 to 2,126,000 tons in 1995. In 1997 however, production slipped to 1,970,00 tons but bounced back to 2,235,000 tons in the year 2000 and increased again to 2,813,000 tons in 2005. Apart of being the main sources of food, rice industry also provides the livelihood to 172,000 paddy farmers in the country in 2009. Land utilization for paddy production is currently at 674,928 hectares which consists of 76% in Peninsular Malaysia (515,657 ha) while Sabah and Sarawak accounted for 6% (40352 ha) and 18% (118,919 ha) of the total hectare respectively (Nurul Nadia Ramli, et al, 2015).

Basically, there are two methods of planting rice which are transplanting and direct seedling. Transplanting rice mechanically requires considerably less time and labour than manual transplanting. It increases the area a person can plant from 700m^2 to 10000m^2a day. However, rice transplanter is considerably expensive for almost all Asian small-scale farmers and are only popular among industrialized countries such as South Korea and Japan where labour cost is high. Mechanical transplanting of rice is the process of transplanting specifically raised seedling of rice as a mat nursery using a self-propelled machine at pre-determined and desired spacing.

The System of Rice Intensification (SRI) is a rice cultivation practices that is based on the cultivation from a single seedling. Based on the SRI practices, the rice seedlings are transplanted at a young age of 8 to 12 days old with only 2 leaves and carefully planting of just one seedling per hill and space the hills optimally wide in a square pattern of 25x25cm for better usage of water, sunlight, minerals, nutrients, space, weeding and pest management within shallow depth (1-2cm) in the moist soil condition. The conventional method of SRI transplanting used significant manual labours. Therefore, using mechanization for SRI practice would be more effective for the future of rice production.

1.2 Problems Statement

Based on the System of Rice Intensification (SRI), a seedling tray that consists of small rectangular cavities was developed at the Department of Biological and Agricultural Engineering UPM. However, there are several problems that need to be solved in order to increase the yield and quality of rice. The tray is used for germination of paddy seeds, whereas each cavity will germinate single seedling. The germinated seedling at the age of 8-12 days will be transplanted on the field. In order to transplant, the seedling together with the medium will be pushed down from the SRI-Tray which required a pushing mechanism to accomplish the mission.

A pushing rod in the two-axes gantry is proposed to overcome the issue and will acts as the pushing mechanism. The system will be based on two axes-gantry that utilized two cabling-systems, horizontal and vertical, which are interconnected to each other and will be actuated by two DC motors. A control algorithm will be embedded in microcontroller with a wireless module and used to control the DC motors, and thus determining the position where the pushing rod will be placed.

1.3 Objectives

The main objective of this study is to design and develop a fully automated paddy transplanting machine based on the System of Rice Intensification. The specific objectives of this study are:

1. To design and develop a pushing rod in the two-axes gantry which will act as the mechanism for a sub-component to a paddy transplanting system based on the SRI-Tray.
2. To develop a wireless linear motion controller to move the pushing rod in the two-axes gantry to desired positions.

1.4 Scope and Limitation

This study is based on application of precision agriculture practice for the development of a paddy transplanter for SRI in Malaysia. The design requirement of the proposed gantry was identified, the 3D conceptual design of the two-axes gantry was produced, and the prototype was fabricated. The test for the prototype was carried out in the laboratory, hence there are limitations in this study. First, the gantry system was built from salvage components which is taken from old and unused printer. Metal hollow rod was used as the pushing rod and was attached on the gantry. Besides, the test on the applicability of the system is carried out with an empty SRI-Tray. So, the rod was pushing the empty cavities of the tray without any single germinated seedling.

CHAPTER 2

LITERATURE REVIEW

2.1 System of Rice Intensification (SRI)

The system of Rice Intensification (SRI) is described as a farming system that overturns the conventional norms of rice cultivation. This system is said to have been synthesized initially in Madagascar by a French Jesuit priest, Father Henri de Laulanie in the early 1980s to increase the yield of rice produced in irrigated farming comprehensively. It comprises several particular agronomic management practices concerning the land preparation, transplanting of seedlings, water management, weed control and soil aeration as well as the use of organic nutrients. The SRI that have been developed has proven that, by modifying crop, soil, water, and nutrient management, it can under most of the circumstances evaluated thus far rise of the productivity of land, water, seeds capital and labour used for irrigated rice production (Stoop, Uphoff, & Kassam, 2002).

This new system of rice intensification is an improvement over conventional growing techniques by allowing maximum productivity. The components of the SRI are young seedling, single seedling, square planting, weeding, organic fertilizer, and alternate wetting and drying. This system plant single paddy seedling at the age of 8 to 12 days after the seeds has been germinate. Based on the SRI system, each single paddy seedling will be able to be planted in each respective space with a consistent space between each row depending on the paddy field fertility. The main purpose of this system is to double the yields of paddy production. This can be achieved by using less seeds per hectare and wider spacing pattern when applying the SRI system (Bashar, Wayayok, Amin, & Mahadi, 2015). SRI concepts and practices have continued to evolve as they are being adapted to rain-fed conditions and with transplanting being superseded sometimes by direct seedling. Regarding the management of rice plants, the basic practices of SRI according to SRI-Rice at Cornell University are:

- Rice plant seedlings should be transplanted very young (usually just 8-12 days old) with just two small leaves
- Seedlings should be transplanted carefully and quickly to inflict minimum trauma on the roots
- Seedlings should be transplanted singly, with only one per hill instead of 3-4 together to minimize root competition
- Seedlings should be widely spaced to encouraged greater root and canopy growth
- Seedlings should be transplanted in a square grid pattern (25x25cm, or wider in good quality soil)

2.2 SRI-Tray

The SRI-Tray that was developed at the Department of Biological and Agricultural Engineering, UPM (Figure 1) invented a new technique of nursing individual, young, delicate but healthier and root separated rice seedling with a sliding base to accurately transfer the seedlings to the transplanter for planting single seedling per hill in the paddy field. In rice production industry, seedling quality and transplanting skills play a significant role in promoting optimum yield. Therefore, this invention is intended to create modern techniques for increasing the production by mechanizing SRI nursery and transplanting standards. It involves fabricating a single seedling nursery rectangular tray of width, length and height of 33.5 cm, 63.5 cm, and 4 cm, respectively in order to allow resistance to the total load applied. The tray consists of 924 square growing cavities of 1.5×1.5 cm separated by a plate thickness of 0.1 cm with 0.3 cm height with an open top. A sliding base plate serves as support in holding and releasing the seedling for dropping or planting into the field (Bashar et al., 2015). The variant of SRI-Tray (Figure 2) that will be used in this proposed design has width, length and height of 40 cm, 40 cm, and 3.5 cm respectively to achieve compatibility with the design of the gantry. It consists of 400 space square growing cavities of 2x2 cm area with an open top. This tray can produce 400 vigorous and viable independently separated seedlings for transplanting singly upon SRI spacing standard through a suitably modified SRI transplanter.

Figure 1: SRI-Tray

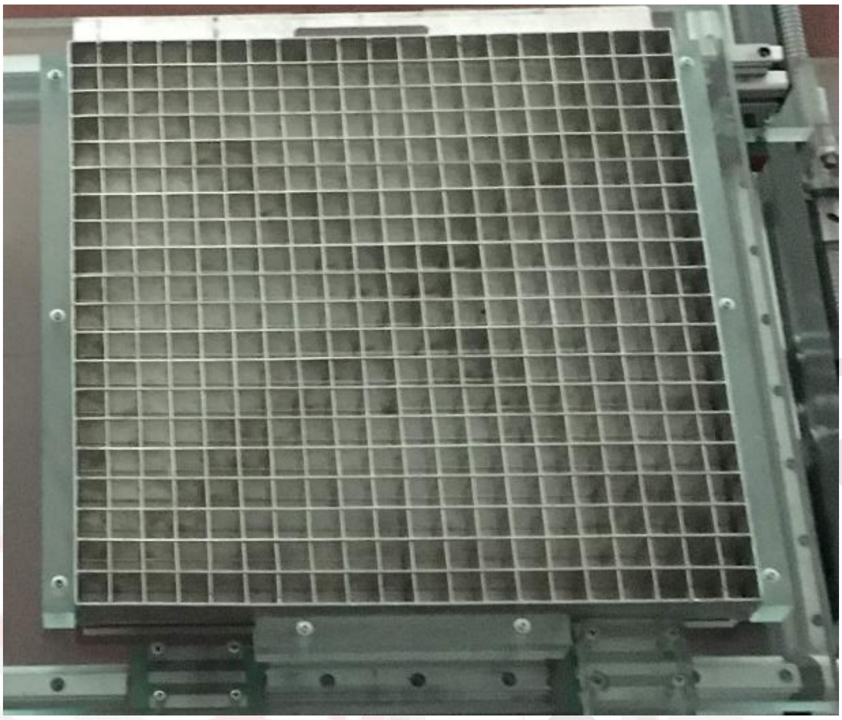

Figure 2:Variant SRI-Tray

2.3 Transplanting

There are several method of rice cultivations in the world. Most of small-scale farmers choose to plant paddy using broadcasting system where no transplanter are required. They only need to spread all the seeds into the soil. This method is the easiest but inefficient in terms of productivity since it requires more seed. Transplanting is one of the most popular technique of rice cultivation across Asia. Transplanting can be defined as the process of transferring pre-germinated seedlings from a seedbed to the wet field. This method requires less seed but is very efficient in terms of productivity and weed control. The disadvantage of this method is it requires more labour. Prior to transplanting, seedlings are germinated in a separate nursery area for a certain period of time before they are transplanted into the field. Transplanting can be implemented by either manually or mechanically.

Study from International Rice Research Institute (IRRI) shows that transplanting technique will ensures a uniform plant stand and gives the rice crop a head start over emerging weeds. Furthermore, the seedlings are already germinated although the field is not levelled adequately has various water levels. Transplanting may also allow crop intensification as the crop is grown in the main field for a lesser time.

Transplanting manually does not require costly machines and is most suited for labour-surplus areas and for small rice fields. (Bell et al, 2003). Manual transplanting can be done in the fields with less than optimal levelling and with various water levels. Seedlings are raised in a wet, dry, or modified at the nursery. With a proper nursery management, healthy, vigorous, and high-quality seedlings will be produced. One of the limitations of this manual transplanting method is tedious and time-consuming where it usually took up 30 person a day per hectare. Besides, farmers also face low plant density issue with contact transplanting on area basis lower yields, risk in rainfed areas, that seedlings (especially of modern varieties) may get too old before the rainfalls season and when the field is ready to be planted.

The usual practice of manual transplanting is by holding a bunch of seedlings on one hand and fixing 1 to 2 seedlings separated by the other hand in the puddle field in bending posture, which gives impact to the spinal cord of the farmers. The scarcity of labour during peak season of transplanting also delays the operation which cause progressive in the yields.

Direct sowing or mechanical transplanting is the answer to overcome the above problems. Despite of having less time consumption, which is very high in manual transplanting. It also reduces human drudgery and provides uniform and desired crop density. Besides, farmers can plant the crops in line without any extra cost and make weeding and integrated farming easier. Although many attempts have been made in different countries to develop a mechanical paddy transplanter, only a few countries such as Japan, Korea and China managed to successfully introduce and manufactured their machines. With the introduction of paddy transplanter in Japan, the labour requirement for transplanting has been reduced from 30 men a day per hectare to 15 men a day per hectare (Anoop Dixit et. al., 2007).

Manual paddy transplanting technique has been changed moderately into the new and more efficient way of mechanically transplanting method by using engine. This technique might be more expensive than the conventional technique, however, the benefits from high productivity due to higher population stand makes it profitable to be adapted. IRRI also stated that transplanting machine requires considerably less time and labour than manual transplanting.

2.4 Automated Seedling Transplanting Method

Automatic seedling transplanters for paddy have been under development for more than 20 years by several researchers. But there is no specific and special automated transplanter was developed based on the System of Rice Intensification. A water-wheel transplanting machine was designed and builds in Punjab, Pakistan (Asif Sharif et. al., 2009). However, this machine is not fully automated, it is semi-automatic machine which must be handle manually human in order to transplant the seedlings. The approaches to automated transplanting should follow all the guidelines and basic principles practices in SRI.

There are several mechanisms that need to be considered in order to build an automated transplanting machine, which are:

1 Planting the seeds in a seedbed or greenhouse tray.

2 Removing the seedlings from the seedbed with or without retaining soil on the roots.

3 Storing of single seedlings in a carrier on the transplanter.

4 Feeding the seedlings to the planting mechanism one at a time.

5 Opening a furrow or hole for insertion of the single seedlings.

6 Reaffirming the soil around the roots of the seedlings.

The transplanter that have been developed earlier only mechanized items number 5 and 6 while there are more seats provided on the transplanter for farmers to accomplish item number 4. Automated transplanting machine refers to as system that can accomplish item number 4 mechanically. (Brewer, 1988).

One promising method is to grow the seedlings in paper pockets attached to Z-folded strands which when the seedlings are ready, are loaded into a carrier on the transplanter. A Ferris wheel transplanter in which wheel-mounted grippers grasp each cell (segment of the strands containing one seedling), tear it from the strand, and carry it to the release point in the furrow. A strand restraint holds the strand to that only one cell is torn away by each set of grippers (Suggs et, al., 1987).

The dibble transplanter is similar to the spade planter, but it does not require a furrow. Rather a seedling bucket dibbles holes in the soil and places a seedling in each hole. Each bucket is pivotally connected to a pair of arms such that the top of each bucket must remain horizontal. The arms are pivotally connected to rotating disks at the midpoints so that the mid-points of the arms will travel on circular paths. The remaining end of each arm follows a cam which is specially shaped to control the movement of the buckets. The rotating disks should be ground driven so that the movement of the buckets is automatically coordinated to the forward motion of the transplanter. Seedlings released from a carrier fall vertically into the descending buckets. As the dibbles enter the soil, the cams cause the dibbles to move horizontal to the ground. Just before a dibble is raised from the soil, the bucket opens at the bottom to release the seedling into the hole. The bucket will then close as it rises to accept the next seedling, thus completing the cycle.

2.5 Gantry

Biaxial gantry systems are widely used for the automation of certain industrial tasks such as handling of deformable materials or for heavy loads transportation (Flixeder, Glück, Böck, & Kugi, 2017). The gantry system is required to move the payload from one point to a new desired point. The issues with the gantry system are the inadequate control input and interference resulting in the payload being held in swing motion from the trolley by the cable (Solihin, Chuan, & Astuti, 2020). A proper and precise controller are required to ensure the gantry system work in orderly manner so that the load reach the desired destination. Two motors which are mounted on two parallel slides drive a gantry simultaneously in tandem in the H-type configuration of cartesian robotic systems are commonly known as the moving gantry stage. When used with permanent magnet linear motors, the moving gantry stage can provide a high-speed, high-precision X, Y and Z axis motion required to facilitate accurate and automated processes. Due to its excellent performance opposed to the conventional linear positioning devices such as ball-screw devices, linear motors have been proclaimed as the motion tool for these purposes. The linear motor's most significant features for precision motion control are the lack of backlash and compliance which inhibit good control performances factors (Giam, Tan, & Huang, 2007).

2.6 Microcontroller

Microcontrollers is widely used as a term for a small computer on a single chip that includes a microprocessor, memory and other accessories. (Kelemen, Kelemenová, Virgala, Miková, & Lipták, 2014). Microcontrollers include not only a CPU, but also memory and peripherals such as flash memory, RAM or serial communication ports. Microcontrollers can be used for the development of embedded system applications. In comparison with other devices used to control embedded systems, microcontrollers have reduced size and price. Although some built-in systems are very advanced, many of them have limited memory and program size, no operating system, and low code complexity requirements. Microcontrollers often have several accessories such as analog to digital converters, digital to analog converters, programmable timer and tracker, pulse width modulation generators PWM, universal asynchronous receiver and transmitter (UART).

There are several types of microcontroller the 8051 is just a single microcontroller that belongs to the 8-bit family of microcontrollers. The prime use of a microcontroller is to control the operation of a machine using a fixed program that is stored in ROM and that does not change over the lifetime of the system. Arduino, on the other hand, is a microcontroller board that comes with pre-tested software and hardware libraries and has its own integrated development environment (IDE). Arduino is like a single component of a computer programmed to accomplish repetitive tasks and is used to develop electronics projects.

An embedded system is a combination of computer hardware and software, either fixed in capability or programmable, designed for a specific function or functions within a larger system. Embedded systems are becoming an increasingly important technical part of all sorts of complex technology systems, including cars, telephones, audio-video equipment, airplanes, toys, security systems, medical diagnostics, weapons, pacemakers, climate control systems, systems for production and intelligent power systems.

2.7 Internet of Things (IoT)

The network infrastructure evolves with the advancement of digital technologies and Internet technology, from the initial communication with humans to the direction of things and machines, objects, and devices. This is called the technology of Internet of Things (IoT). IoT technology takes sensible things into network communication. IoT can be used to connect sensors and devices in the field that analyse, visualize, and automate data to inform quick action.

There are four common factors that makes IoT as one of the reliable system technologies in the world which are the hardware, networks, cloud, and platform. The hardware for IoT such as low power yet high-performance sensors, actuator and microcontroller are becoming less expensive nowadays as it is easily available in the market. Besides, specialized networking protocols such as LPWAN have emerged for low-coverage areas like farms, forest, and rural areas. The power of cloud computing has enabled people to obtain big data and transform it into meaningful insight that help users to make educated decisions to improve efficiency. The last factor is the powerful software platforms that have come onto the market as the foundation for full connected solutions from devices to analytics to applications that makes IoT technology reliable. Node-RED is one of the IoT platform that been used in this study.

Although making information sharing more accessible, there are some defects on the IoT technology as it is restricted by its own volume and communication mode, resulting in its limited contact distance. Hence, IoT technology integrates with wireless communication technology represented by satellite communications to solve the issue of limited contact reach (Li, 2020).

2.8 Wireless Communication

Data communications protocol interacts with the rules for the data transmission between two or more points or nodes. The concept of layers is the centrals to these rules. Protocol layers were devised to divide a protocol's duties into manageable pieces. Each of the layers is independent and interacts with each other through well-defined interfaces. A layer does not know what happens within any of the other layers, only its interfaces (Insam, 2003). Communications protocol are systematic definitions of the formats and rules of the multimedia communication. They are used to exchange messages in or between computer systems and are necessary for telecommunications. Communication protocols include authentication, error detection, correction and transferring and receiving signal. They can also define the grammar, semantics, and synchronization of analog and digital communications. Communication protocols have been implemented in both hardware and software applications and there are several protocols that are used in analog and wireless communications. Computer network would not be existing without them.

Wireless communication is the fastest growing and most lively field of communication technologies. Wireless communication is a way of transferring information from one point to another without the use of any links such as wires, cables, or other physical medium. In general, information is transmitted from transmitter to receiver in a transmission network which is positioned over a short distance. The transmitter and receiver can be mounted somewhere from a few meters like a television remote control up to a few thousand kilometres such as the satellite communication with the assistance of wireless communication.

Communication devices can be wired or wireless and can be guided or unguided by the device used for communication. In a wired communication, the medium is a physical path such as Co-axial Cables, Twisted Pair Cables and Optical Fibre Links which guides the signal from one point to another to propagate. This medium form is called Medium Driven. While wireless connectivity needs no physical medium but propagates the signal across space. Since space only allows for signal propagation without any direction, Unguided Medium is the medium used in the wireless communication. Since there are no wires used in wireless networking, Antennas accomplishes the transmitting and receiving of the signals. Antennas are electrical instruments in the form of electromagnetic (EM) waves that converts the electrical signals into radio signals and vice versa. Such electromagnetic waves propagate across space. Therefore, both the transmitter and the receiver does contain antennas.

In addition to mobility, wireless communication also provides simplicity and user-friendliness, making it ever more popular. Wireless networking like mobile telephone can be obtained with relatively high throughput efficiency anywhere at every time. Infrastructure setup and installation for wired communication systems is a costly and time-consuming job. The infrastructure of the wireless communication system can be built conveniently and cost-effectively. Wireless connectivity is a feasible alternative in emergency circumstances and remote areas where wired contact is difficult to set up (Anusha, 2017).

CHAPTER 3

METHODOLOGY

3.1 General Overview

The aim of this project is to develop a wireless controller for transplanting paddy using the SRI method. This paddy transplanter for SRI method is designed to transplant only a single pre-germinated seedling at a widely space per hill without damaging, covering and suppression soil moisture precisely and accurately according to the desirable spacing followed in SRI method. This transplanter quantitatively will achieve accurate placing to dispense the seedling and a pushing rod is required to act as the pushing mechanism to ensure the paddy seeds will be placed in the best position of soil where it is optimum for seedling growth.

The position and the motion of the pushing rod for the SRI-tray in the transplanter can be determined and controlled by user in the application in the phone wirelessly. The easy access and friendly user application of the wireless controller will ease direct seeding in rice cultivation field where the paddy transplanter will dispense a single pre-germinated paddy seedling automatically according to the desirable spacing to accomplish the SRI transplanting task. Figure 3 shows the flow chart of the proposed project concept.

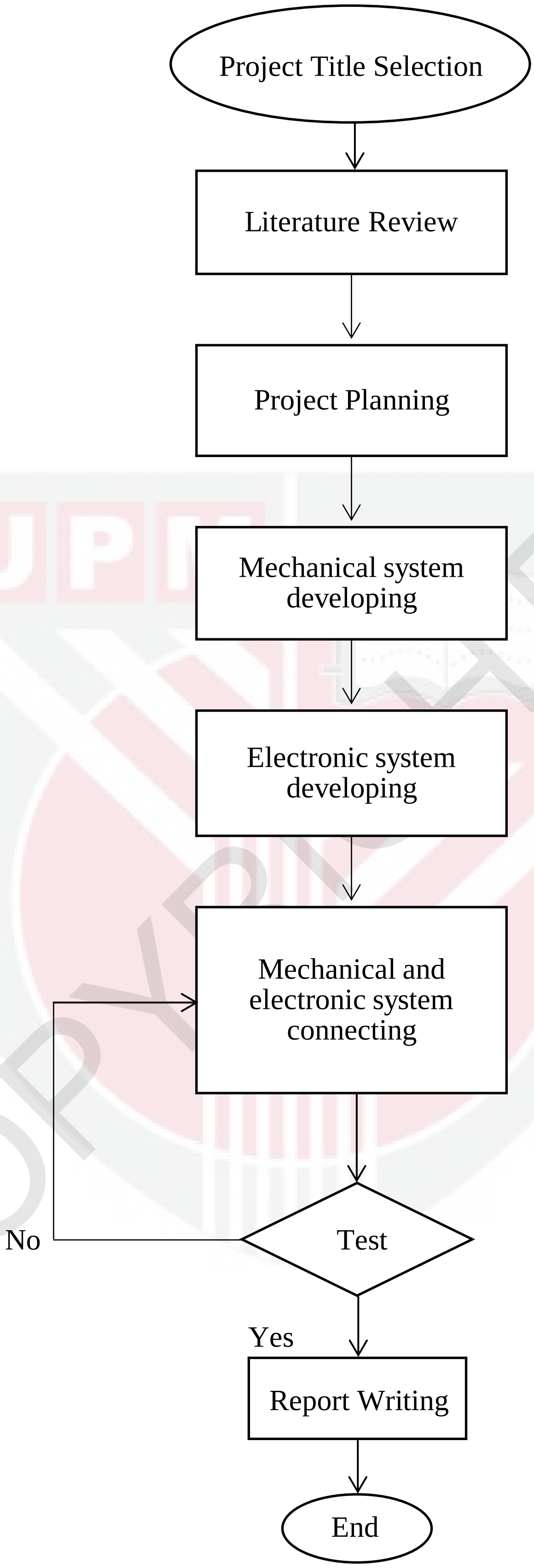

Figure 3:Flow Chart of the Proposed Project

3.2 General Connections

The SRI-Tray (Figure 2) that was developed in the Department of Biological and Agricultural Engineering will be place in the plate of the XY table on the tray platform. In a conventional gantry, one stepper motor responsible for the motion of each one axis while Core XY mechanism requires both stepper motors contribution for the motion of each axis. As a proof of concept in this project, a conventional gantry with two DC motors will be used so each motor will responsible for the movement of each axis. The vertical belting system is attached on the horizontal belting system which both of them are attached on the wooden planks. This whole mechanical system will be installed with Arduino Mega 2560 and powered by a 12V battery. The rotation of the DC motors will then be initiated by the L293D Motor Driver Shield which is also attached to the Arduino Mega 2560.

This microcontroller which is also called as The Slave is integrated with a nRF24L01 Transceiver Module that will receive data from another Arduino Mega board called The Master that is also integrated with a nRF24L01 that will act as the transmitter. The Arduino Mega Master is connected to an IoT platform which is Node-RED and will transmit data to the Arduino Mega Slave so both the Arduino boards will be able to communicate to each other through the internet. A website link will be provided from the Node-RED in a form of User Interface and can be access from any browser as long as the user is connected to the same network as the server. This link will eventually be used by user as the wireless linear motion controller for the paddy transplanter to move the pushing rod of the SRI-Tray and dispense the germinated paddy seedling in a desired position. Figure 4 shows how both the Arduino boards is connected with the whole system.

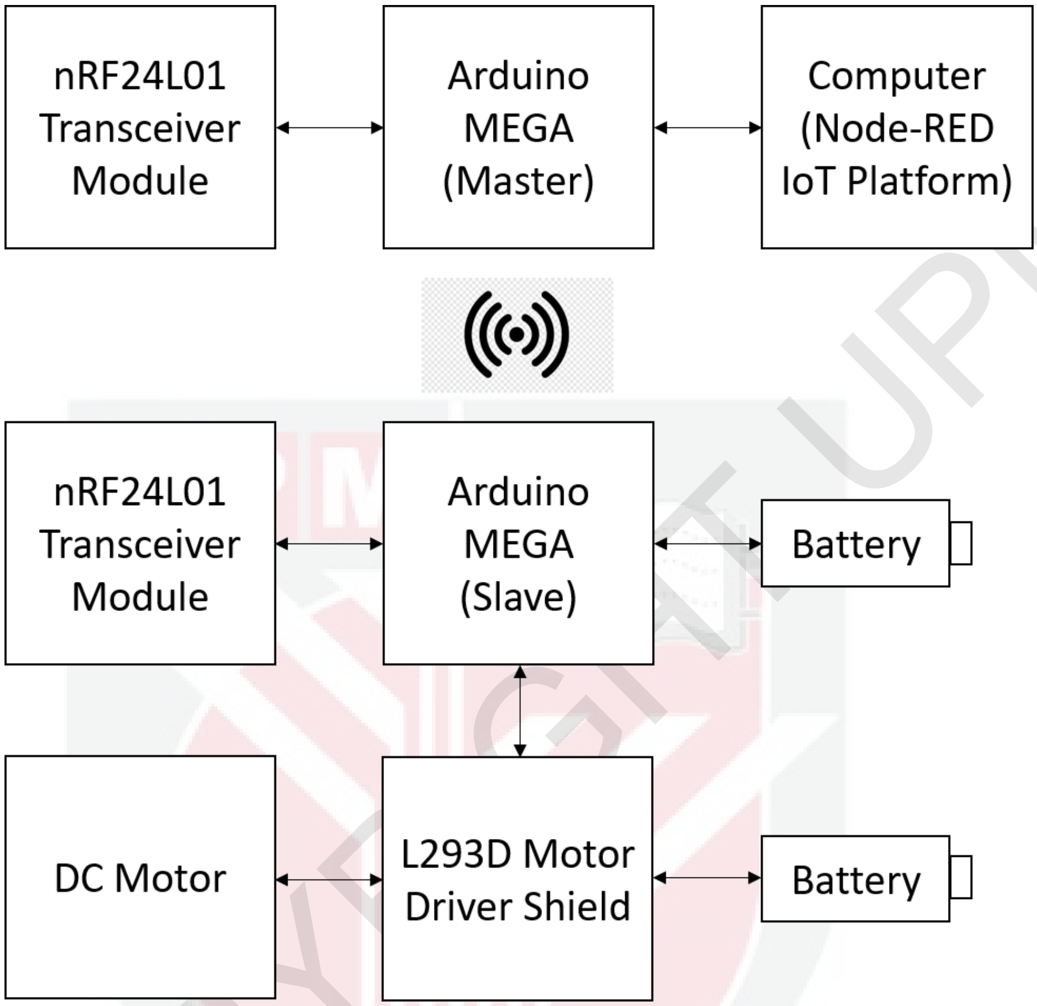

Figure 4:General Connection of the System

3.3 The Mechanical System

The design requirement of the proposed gantry was identified. Then, the 3D conceptual design of the two-axes gantry with the belting system was successfully produced. Most of the mechanical part of the gantry system was taken from salvage component of old and unused printers that is available in the laboratory from the Department of Biological and Agricultural Engineering, UPM. These two printers were dismantled in the lab and the gantry system that carries the ink was taken. Disassembling process was taken cautiously to ensure that no damage happened to the DC motor that readily attached in the gantry. The 12V DC motor was used to power up the cabling system that attached in the gantry through the power shaft. The rotation of the shaft will cause the movement of the ink carrier to move from one side to the other through the cabling system as it was attached to it.

Once both gantry systems of the unused printers have been obtained, a metal hollow rod was attached on the former ink carrier in one of them through the hole as it will be used as the vertical gantry. The metal rod will be the pushing rod of the system that moves upward and downward as its size is small enough to fit in the empty cavities in the SRI-Tray. The whole vertical gantry on the other hand will be attached on the ink carrier of the horizontal gantry where it will carry the gantry from left to right and vice versa.

The t-shaped two-axes gantry system will then be attached on wooden planks to make it stand on the edge of the SRI-Tray. The electronic component will be mounted at the back of the woods once it has completely connected. Nails and screws will be used as the fastener to ensure that the systems can stand for itself and withstand the motion impact as the pushing rod moves to its desired position. This is one of the reasons why a proper and precises linear motion controller is required to be established to ensure that the gantry system work in orderly manner. Figure 5-8 shows the front, right, back, and top view of the 3D conceptual design of the mechanical part of the gantry system.

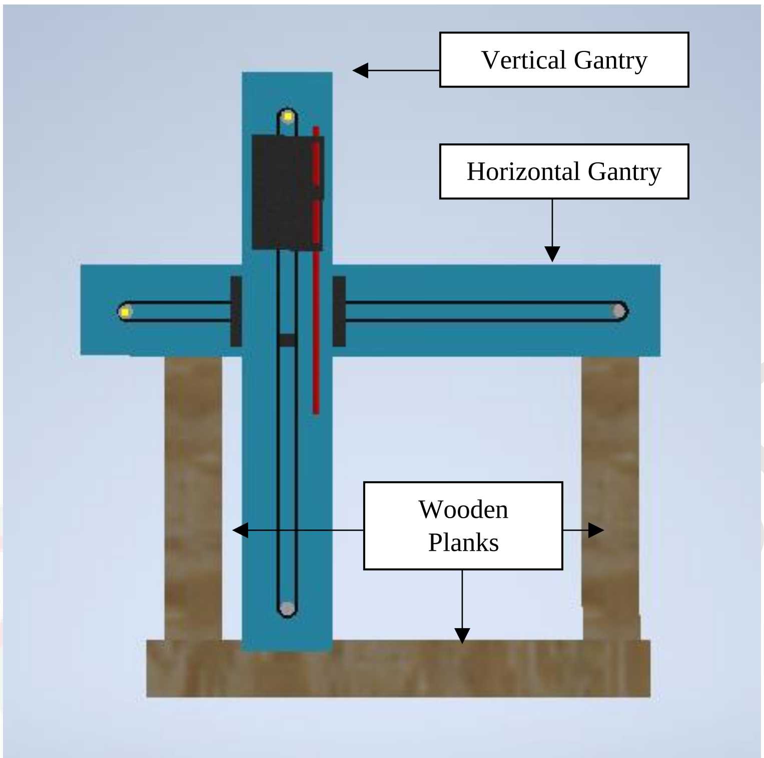

Figure 5: Front View of the 3D Conceptual Design

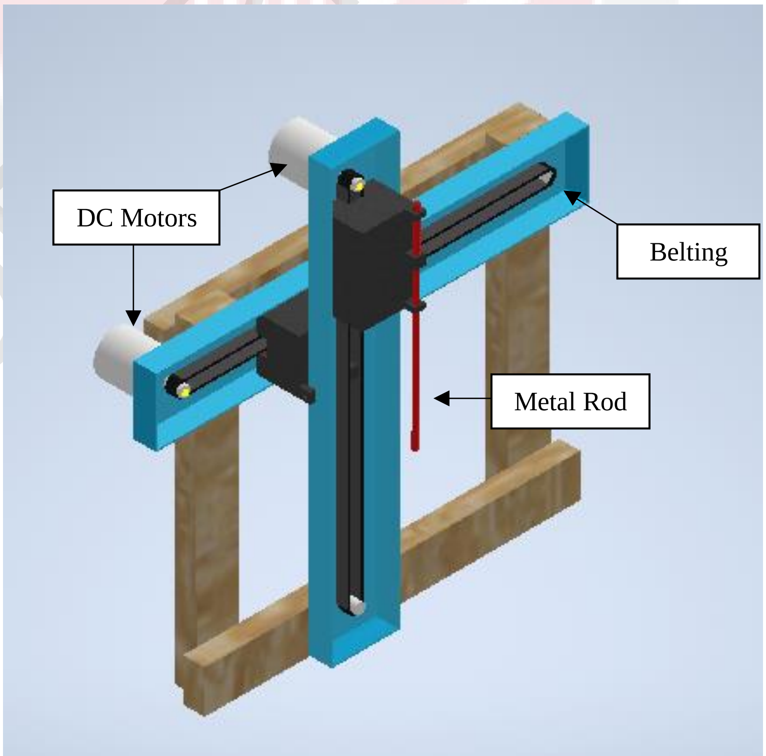

Figure 6: Right View of the 3D Conceptual Design

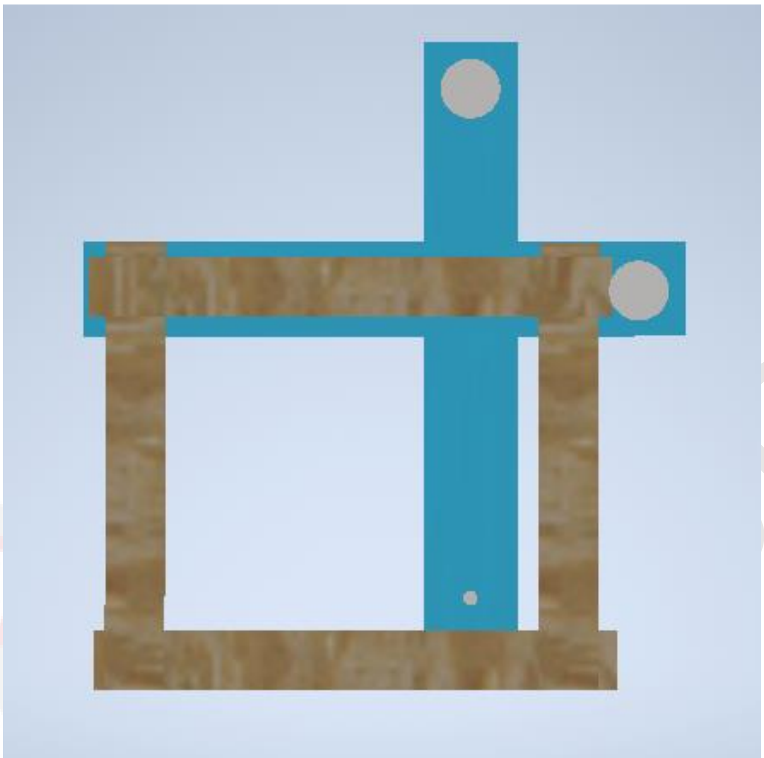

Figure 7: Back View of the 3D Conceptual Design

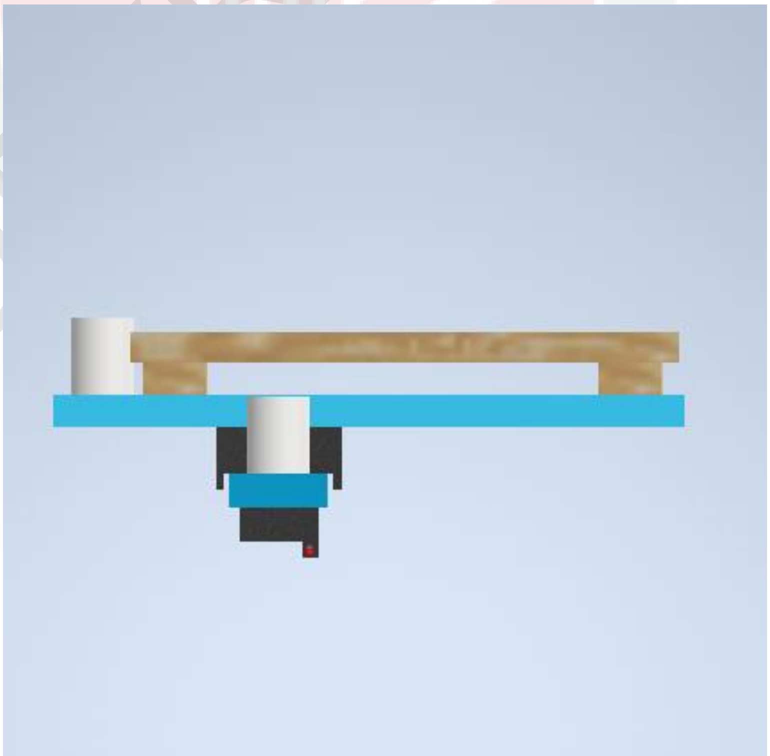

Figure 8: Top View of the 3D Conceptual Design

3.4 The Electrical and Electronic System

The electrical and electronic system for the paddy transplanter was designed to enable the fully automated pushing rod of the SRI-Tray to be control wirelessly. The electronic system includes two Arduino Mega 2560 boards (Master and Slave), two nRF24L01 Wireless Modules, L293D Motor Driver Shield, two DC motors, and several connection wires. The Arduino Mega Master board is required to be connected to Node-RED IoT platform in the computer that will act as the server so the pushing rod could be controlled through the Internet.

3.4.1 Arduino Mega 2560

Arduino is an open-source electronics platform based on easy-to-use hardware and software where it combines microcontroller with standard hardware in a board and its software with an integrated development environment (IDE) that helps writing, debugging, and burning program into Arduino (Grasshopper.iics, 2014). A developed programming code written in the Arduino Sketch can easily be upload to the board by user through USB cable so that the desired operation can be executed.

The Arduino Mega 2560 (Figure 9) is a board based on the ATmega2560 microcontroller. It has 54 digital input or output pins where 15 of it can be used as Pulse Width Modulation (PWM) outputs, 16 analog inputs, four UARTs, a USB jack, a power connection, a 16 MHz crystal oscillator, a ICSP header and a reset button. A simple connection to a computer through a USB cable, or power it with AC-to-DC adapter or battery are enough to start the microcontroller. Since it has the same width as the Arduino Uno board with a longer length, this Arduino Mega board are also compatible with most shield designed for Arduino Uno. The main information of the specification of the Arduino Mega 2560 is described in the Table 1.

Microcontroller	ATmega2560
Operating Voltage	5V
Input Voltage	7-12V
DC Current per I/O pin	40mA
DC Current for 3.3V pin	50mA
Flash Memory	256KB

Table 1: Main Specification of the Arduino Mega 2560

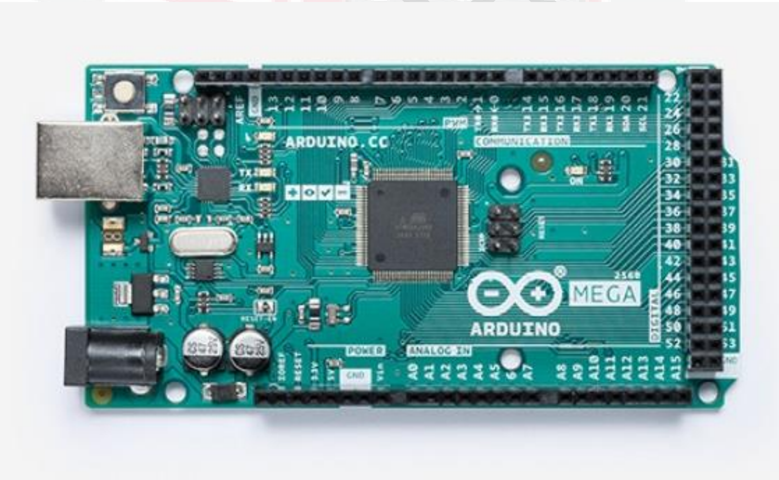

Figure 9: Arduino Mega 2560 Board

The microcontroller board used in this study were the Arduino Mega 2560. Two Arduino Mega Boards are required in this system and both are connected through nRF24L01 Wireless Module and communicate with each other through the internet. The first board is known as the Master will transmit signal to the other board known as the Slave.

3.4.2 L293D Motor Driver Shield

The L293D (Figure 10) is a H-bridge motor driver with two channel that can control a pair of DC or one stepper motor. Considering that the shield has two L293D motor driver chipsets, this means that it can drive four DC motors independently, making it suitable for constructing toy vehicles with four wheels. The shield provides 4 H-bridges in total, and each bridge can deliver 0.6A to the motor. The shield also comes with a 74HC595 switch register, expanding Arduino's 4 digital pins to the two L293D chips' 8 direction control pin.

The output channels of both the L293D chips with two 5-pin screw terminals namely M1, M2, M3 & M4 are split out to the edge of the shield. Such terminals can be attached to four DC motors with voltages in the range of 4.5 to 25V. The DC motor can be supplied up to 600mA by every channel on the board. The amount of current supplied to the motor however depends on the power supply of the system. Two stepper motor can also be attached to the output terminals. One stepper motor to M1-M2 motor port and another to M3-M4 motor port. In case of having a unipolar stepper motor, the GND terminal are also provided. This terminal can be attached by the centre taps of both stepper motor. The shield brings out the 16bit PWM output lines to Two 3-pin headers where two servo motors can be connected.

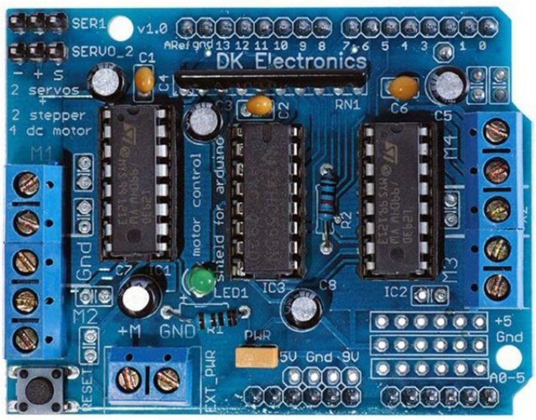

Figure 10: L293D Motor Driver Shield

3.4.2.1 Driving DC Motors

The first step to drive the DC motors with the motor driver is to plug the shield on top of the Arduino Mega Slave. It is ensured that all the pin of the shield is connected to the same pin of the Arduino Mega board since it has a difference in size. Next, power supply is connected to the motors. In this case, 12V Lithium-Poly battery is connected to the EXT_PWR Terminal since the DC motors that are attached on the gantry are rated for 12V. Then, DC motor for the vertical gantry is connected to the M4 motor terminal while the DC motor for the horizontal gantry is connected to M3 motor terminal.

Some individual shields and building blocks need respective libraries to provide access to the required programming interfaces. In this case, AFMotor.h library is required to be install first in order to communicate with the motor driver shield. Once the library has been downloaded from the internet and installed, user will be able to issue simple commands from the Arduino IDE to control any motor that are connected to the L293D Motor Driver Shield

The next step is to write the sketch to program the Arduino Mega board and drive the DC motors. The sketch or the code written for the Arduino Mega board needs to consider the points of linkage between the input or output of the microcontroller and the input or output of the hardware to run. In the sketch, the AFMotor.h library is included by inserting '#include'. Then, objects of the library are created by inserting 'AF_DCMotor motor(motorport)' and declaring the motor port number to which motor is connected. Since there are two motors that connected to the shield, two separated objects are created for each motor. For instance, 'AF_DCMotor

motor1(4)' for the DC motor of vertical gantry and 'AF_DCMotor motor2(3)' for the DC motor of horizontal gantry.

Every sketch requires two types of void functions to declare the functions inside the sketch. Void setup () is a void function that run once while void loop () is a void function that run continuously after the void setup (). In setup and loop section of the sketch, two functions are simply called to control the speed and spinning direction of a motor. The 'setSpeed(speed)' function sets the speed of the motor that ranges from 0 to 255 with 0 being off and 255 as full throttle while the 'run(command)' functions sets the rotation direction of the motor.

There are three valid values for the command namely FORWARD, BACKWARD and RELEASE. The FORWARD command will make the motor to run forward depending on the motor wiring while the BACKWARD command will be the rotation of the opposite direction of the FORWARD command. The RELEASE command is to stop the motor from running that cause the removal of power from the motor and is similar to setSpeed(0). Noted that the motor shield does not implement dynamic breaking, so the motor might take some time to spin down. The 'delay(time)' function is to pauses the program for the amount of time in milliseconds. So, the amount of time of the DC motor to keep on running can be determine from this function.

3.4.3 nRF24L01 Transceiver Module

Having two or more Arduino boards to be able to communicate wirelessly with each other over a certain distance opens up several possibilities such as remote sensor data monitoring, home automation, robots' control as well as smart farming. Not only because of its tiny size, nRF24L01 Transceiver Module are one of the most affordable yet reliable two-way RF solutions that are capable to operate data communications that can be obtained in the market. This module is designed to operate in an ISM frequency band worldwide at 2.4 GHz and uses GFSK modulation for data transmission. The data transmission rate can be 250Kbps, 1Mbps, and 2Mbps. The nRF24L01 Transceiver module can be operated with voltages range from 1.9 to 3.6V but the logic pins are 5-volt tolerant which is compatible to an Arduino or any 5V logic microcontroller without using any logic converter. The main information of the specification of this module is described in the Table 2.

Frequency Range	2.4 GHz ISM Band
Maximum Air Data Rate	2 Mbps
Modulation Format	GFSK
Maximum Output Power	0 dBm
Operating Supply Voltage	1.9V to 3.6V
Maximum Operating Current	13.5 mA
Minimum Current (Standby Mode)	26 µA
Logic Inputs	5V Tolerant
Communication Range	800+ m (line of sight)

Table 2: Main Specifications of L293D Motor Driver Shield

The nRF24L01 Transceiver Module transmit and receives data on a certain frequency called Channel. Two or more transceiver modules need to be on the same channel in order for them to be able to communicate with each other. This channel could be in any frequency in the ISM band of 2.4 GHz or to be more accurate, between 2.4 to 2.525 GHz. Each channel occupies a bandwidth of less than 1MHz that gives 125 possible channels with 1MHz spacing. That means that the module can therefore use 125 different channels and provides a possibility to have a network of 125 modems working independently in one location.

The nRF24L01 Wireless Transceiver Module (Figure 11) provides a feature called Multiceiver which means Multiple Transmitter Single Receiver. This feature means that each RF channel is logically split into 6 parallel channels of data called Data Pipes. Each data pipe can be configured and has its own physical address (Data Pipe Address). The primary receiver will act as a hub receiver which will collect information from 6 different transmitter nodes simultaneously. The hub receiver can stop listening, and act as a transmitter at any time. But just one pipe or node at a time can do this.

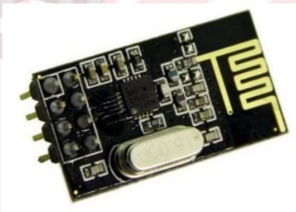

Figure 11: The nRF24L01 Wireless Transceiver Module

3.4.3.1 Connecting nRF24L01 Transceiver Module to Arduino Mega

There are eight pins in the nRF24L01 Transceiver Module. The first step to connect the module to Arduino Mega is to identify all the pins and learn the function of each pins. Figure 12 below shows the pinout of the nRF24L01 Transceiver Module and the following Table 3 described the function of each pin.

Figure 12: The Pinout of the nRF24L01 Wireless Transceiver Module

No.	Symbol	Name	Description
1	GND	Ground Pin	The pin usually marked by encasing it in a square as a reference to identify the other pins
2	VCC	Power Supply Pin	Supplies power for the module from 1.9-3.9V so it can be connected to the 3.3V output from the Arduino.
3	CE	Chip Enable	It is an active-HIGH pin and will either transmit or receive depending on the mode its currently in.
4	CSN	Chip Select Not	It is an active-LOW pin and is normally kept HIGH. This pin will begin to listen on its SPI port for data and processes it accordingly when it goes LOW.
5	SCK	Serial Clock	This pin accepts clock pulses provided by the SPI bus Master.
6	MOSI	Master Out Slave In	This is SPI input to the nRF24L01.
7	MISO	Master In Slave Out	This is SPI output from the nRF24L01.
8	IRQ	Interrupt pin	It can alert the master when new data is available to process.

Table 3: The Function of the Pinout of the nRF24L01 Wireless Transceiver Module

Once all the pins have been identified, it is easier to connect the module with the Arduino Mega boards. First of all, the VCC pin on the module are required to be connected with the 3.3V on the Arduino Mega board and the GND pin to the ground. Any digital pin on the Arduino can be connected to the CSN and CE pins which in this case, it is connected to digital pin 7 and 8, respectively. The remaining pins that need to be connected are used for the SPI communication. Since the wireless transceiver module needs a lot of data transmission, they can provide the best output when connected up to the hardware SPI pins on microcontroller. Hardware SPI pins are much faster than using another set of pins to 'bit-bang up' the interface code. Each Arduino Board has different SPI pins which should be connected accordingly. Since Arduino Mega board is use in this system, the pins are digital pin 52 for SCK pin, digital pin 51 for MOSI pin and digital pin 50 for MISO pin. The same connections are made for the Arduino Mega Slave that has a L293D Motor Driver Shield plugged on top of it.

Just like developing the sketch for the L293D Motor Driver Shield, the sketch for the nRF24OL01 module also requires library to provide access to the required programming interfaces. There are a number of libraries available for this module, but RF24 is the most popular one. This library can be downloaded from the internet and installed easily. Developing the sketch for the Master and Slave are similar but slightly different in terms of functions. To start developing the code for the Master or Transmitter in the Arduino IDE, the SPI.h library, nRF24L01.h library and RF24.h library are included by inserting #include in the sketch. The SPI.h library handles the SPI communication while nRF24L01.h library and RF24.h library controls the module. Then, an RF24 object need to be created by inserting 'RF24 radio(CE, CSN)'. The object takes two pin numbers as parameters where CE and CSN signals are connected. Next, a byte array which will represents the pipe address that the two nRF24L01 modules use to communicate are created by inserting ‘const byte address [6] = 00001’. This address is necessary if there are a few modules in a network. Since there are only two modules that been used in this system, the same address will be used for both the Master and Slave.

In the void setup function, the radio object needs to be initialized by inserting ‘radio.begin()’ and set the address of the transmitter by inserting ‘radio.openWritingPipe()’. Then, to set the module as the transmitter or Master, function ‘radio.stopListening()’ need to be inserted. In the void loop section, an array of characters is created to which the message was assigned. The message will be sent to the receiver by using the ‘radio.write(&val, sizeof(val))’ function. The first argument is the message that wanted to be sent while the second argument is the number of bytes present in that message.

To start developing the code for the Slave or Receiver in the Arduino IDE, there are some changes need to be done from the sketch of the Master. Including libraries, creating radio object, and creating byte array for the pipe address are the same step that need to be repeated in the sketch of the Slave. A serial communication is started at the beginning of the setup function by inserting ‘Serial.begin(9600)’. Next, the same address as transmitter is set by inserting the ‘radio.openReadingPipe(0,address)’ function to enable the communication between the Master and the Slave where the first argument is the number of stream that have been created which is stream number 0. There are up to 6 streams that can be created that will responds to different address. The address to which the stream will collect the data is the second argument. In order to make the module to start receiving data, ‘radio.startListening()’ function is used to set the module as the receiver. From that moment, the modem waits for data to be sent to the specified address.

In the void loop function, the sketch will check if there are any data that has arrived at the address by using the ‘radio.available()’ method. This method will then return TRUE value if there are any data that is available in buffer. Once the data is received, then it will create an array of 32 characters filled with zeros. The ‘radio.read(&val, sizeof(val))’ method is used in order to read the data. This method will store the received data in the character array that have been created earlier. Figure 13 shows the connection of the Arduino Mega Master to the nRF24L01 Wireless Transceiver Module by using Fritzing software while Figure 14 shows the connection between Arduino Mega Slave, DC motors, L293D Motor Driver Shield, and the nRF24L01 Wireless Transceiver Module by using Fritzing software.

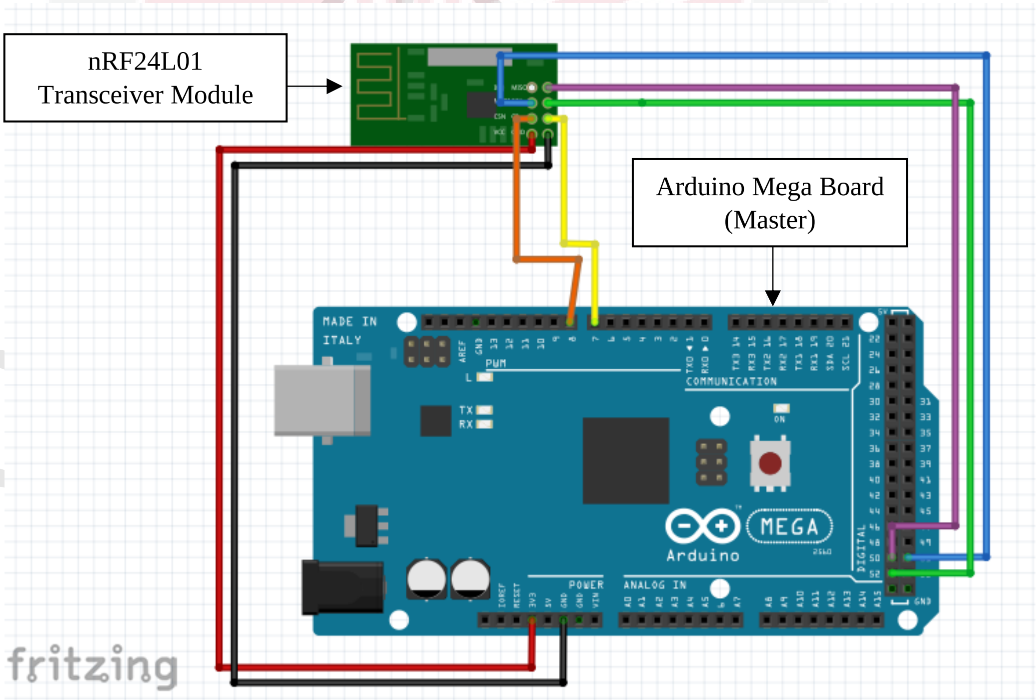

Figure 13: : The Drawing of the Connections of the Arduino Mega Master to the nRF24L01 Wireless Transceiver Module using Fritzing Software

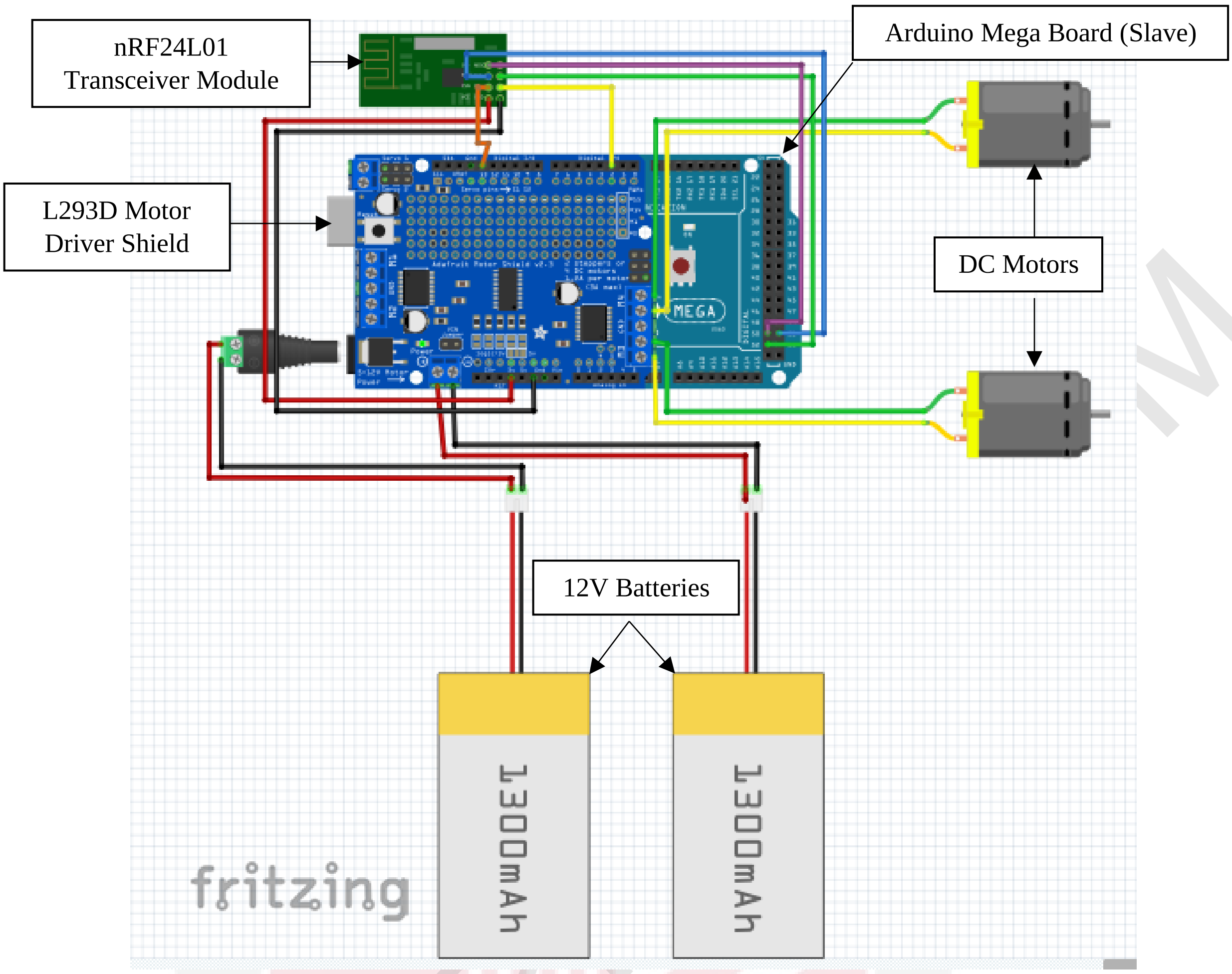

Figure 14: The Drawing of the Connections between the DC Motors, the L293D Motor Driver Shield, the Arduino Mega Slave and the nRF24L01 Wireless Transceiver Module using Fritzing Software

3.4.4 Node-RED

Node-RED is an open-source visual editor that allows programmers of any level to rapidly interconnect physical I/O, cloud-based systems, databases, and most APIs in any combination. It offers a browser-based editor that can connect flows together using the large variety of nodes in the palette easily and can be deployed in a single click to its runtime. Node-RED can be run on most modern computer systems including Windows, Mac and Linux PCs or even lightweight computers such as Raspberry Pi or industrially hardened appliances such as groov AR1. The website of Node-RED that can be accessed from https://nodered.org/ has instructions on how to get the application running on the system that been used. In this case, Node-RED is installed from the Internet and used on Windows 10. Once the installation successfully finished, Node-RED can be access from the Command Prompt and can be run by typing 'node-red'. To run the software from browser, an IP address that have been shown on the command prompt or the 'localhost:1880' are required to be copied and browsed.

There are three main section on the main landing page for Node-RED namely, the node palette on the left, the main workspace on the centre, and the output pane that located on the right. The nodes on the left are organized into collapsible categories to sort that available nodes. Most of the nodes are included in the software by default called 'core nodes'. Any external nodes can be installed from the internet to get more functionality. Each node performs a specific function and that the modular nodes are self-contained and reusable with most of the JavaScript program logic and API overhead hidden in the coloured rounded boxes. The nodes can be inserted into the program by simply clicking and grabbing them from the node palette and dragging them into the workspace. Node-RED uses flow-based programming and message need to be injected into the flow to make it start where the inject node pushes a timestamp in by default. The node can be edited by double clicking it and an editor pane will pop out.

3.4.4.1 Connecting Node-RED to Arduino Mega Master

The Node-RED IoT platform can be connected to the Arduino Mega Master through serial connections. To start the connections, the Arduino Mega Master needs to be ensured to be connected into the computer via a universal serial bus (USB) cable into the correct USB port. But before that, some program needs to be developed first in the workspace of the platform. In order to do that, Node-RED need to be access from the command prompt and run on the browser based on the IP address provided.

The most common node which is the inject node was dragged in the main workspace at the centre of the IoT platform to begin developing some programme. Strings which is arrays of characters are the message payload that been used in this communication. By double clicking the node, some changes such as the message payload can be made as the editor pane pop out. The directions of movement for the pushing rod such as ‘DOWN’ are used as the string value to send the message payload. The same step was repeated to insert string value for the other movements by dragging more inject nodes into the workspace

All the message payload in a form of string in the inject nodes for the movement of the pushing rod are sent to the serial out node since the connections of the Node-RED IoT platform are through serial communications. The deploy button on top of the workspace was clicked once everything was connected. The first flow of the program developed in the Node-RED is shown in the Figure 15 below.

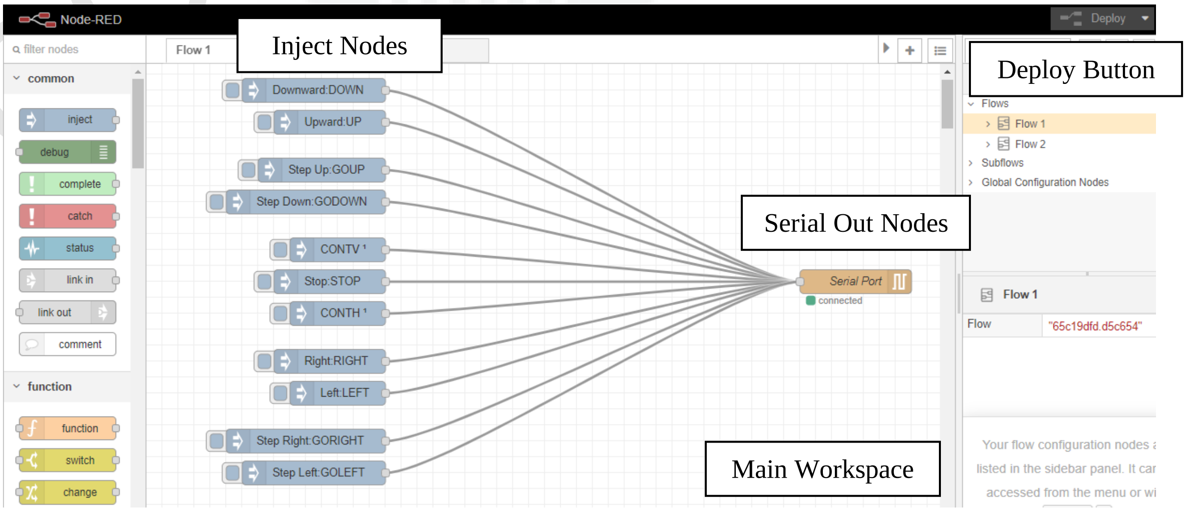

Figure 15: The First Flow of the Developed Program in the Main Workspace of the Node-RED Platform

Then, from the same sketch that has been written earlier, some changes need to be updated. After including all the libraries for the L293D Motor Shield Driver and nRF24L01 Wireless Transceiver Module, a string variable need to be declared globally. In this case, the string was declared as 'strVar'. In the void setup function, a serial communication was started by inserting 'Serial.begin(baud rates)'. The baud rates are the rate at which information is transferred in a communication channel where the serial port is capable of transferring 9600 bits per second at maximum in this case.

In the void loop function, the initial string value was declared locally as empty since there are no array of characters in the beginning. By using the if functions, the string that have been sent through the serial communications will call the 'Serial.readString()' function if it is available from the 'Serial.available()' functions. Arduino Mega Master will the send the same message through radio communication in a form of integer to the Arduino Mega Slave by 'radio.write(&val, sizeof(val))' function that have been written earlier.

Just like the Master, some changes need to be updated in the Arduino Mega Slave. Under the declaration of the string value, integer variable needed to be declared globally too. By using the if functions, the integer that have been sent through radio communications will call the 'run(command)' functions of the DC motor to execute the task commanded if it is available from the 'radio.available()' functions.

In simple words, the inject button from the Node-RED will send a message to the Arduino Mega Master through serial port in a form of string. If the message is available and once the Arduino Mega Master received the message, it will send the message to the Arduino Mega Slave in a form of integer through radio communications. Once Arduino Mega Slave receives the message, it will execute the task for the DC motor to move the pushing rod to a desired position based on the message send from the inject button of Node-RED.

For instance, if the ‘DOWN’ inject button is pressed on the Node-RED, it will send the message payload to Arduino Mega Master. By using if functions in the void loop, Arduino Mega Master would send integer value of 1 to the Arduino Mega Slave if it received a ‘DOWN’ string message. Then, by using if functions too, Arduino Mega Slave would call the motor1.run(FORWARD) function if it received a ‘1’ integer message as it would cause the vertical DC motor to run in a direction that makes the pushing rod going downward.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 General Overview

The wireless linear motion controller in the System of Rice Intensification has been successfully developed. With the fabrication of the two-axes gantry, the pushing mechanism, the development of the electric and electronic system, and the user interface, operation of transplanting germinated single-seedling paddy can be done fully automated.

4.2 The Mechanical System

Based on the conceptual 3D design that have been produced, the fabrication of the mechanical part of the pushing rod in the two-axes gantry system was made successfully in the Machine Design Laboratory in the Department of Biological and Agricultural Engineering, UPM. The two gantry systems from the old printers were successfully modifies and assembled. The position of the gantry system was modified to accommodate the pushing rod to ease the pushing mechanism into the empty cavities of the SRI-Tray.

In order to ensure the whole mechanical system to stand still on the edge of the tray, an aluminium plate was used on the bottom as the base and was sticked on the SRI platform. Aluminium was used as it is light and does not add much weight onto the glass platform. Two wooden planks were used on the left and right side that acts as the pillar that hold the horizontal gantry system. Connecting the two pillars and the aluminium base is a rectangular plywood that holds the electronic system especially the Arduino Mega Slave to makes it easy to connect with the DC motor of the gantry systems.

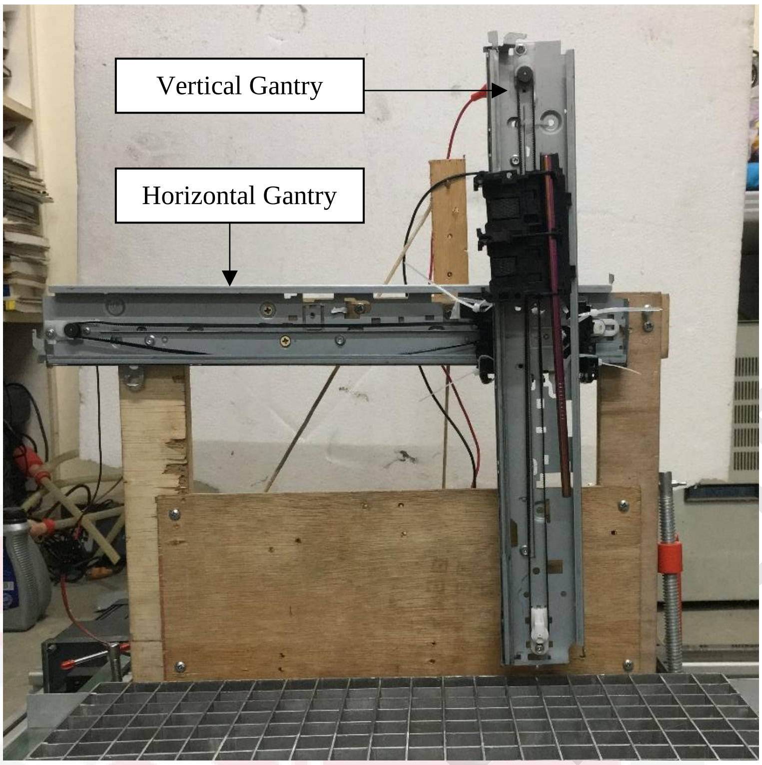

Figure 16: The Front View of the Mechanical Part of the Gantry System

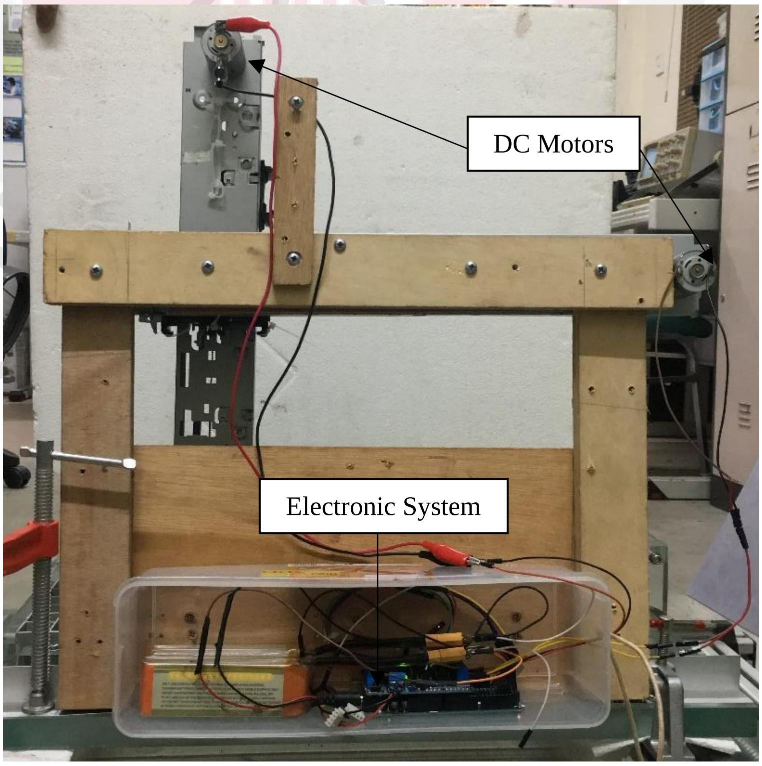

Figure 17: The Back View of the Mechanical Part of the Gantry System

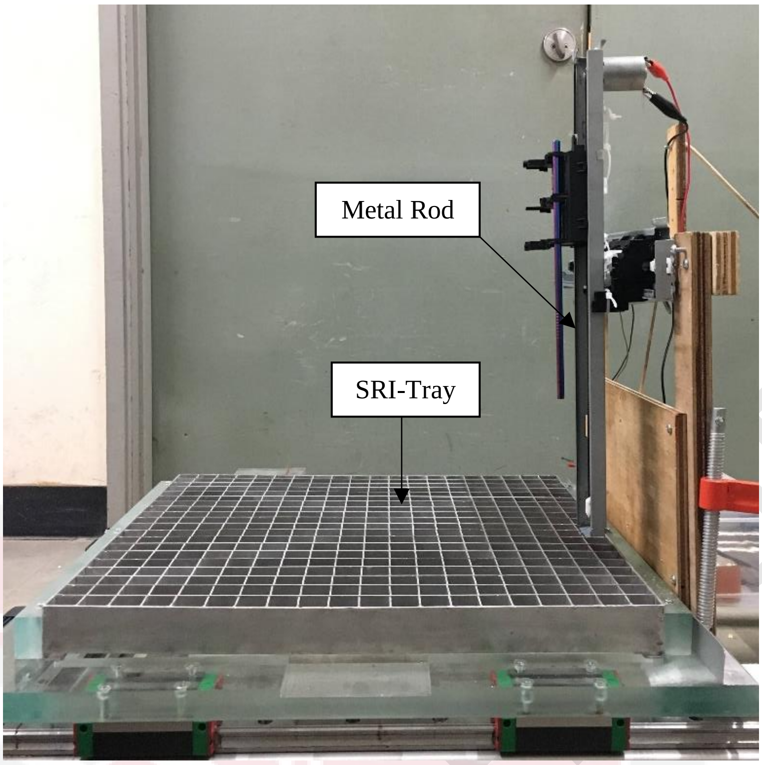

Figure 18: The Side View of the Mechanical Part of the Gantry System

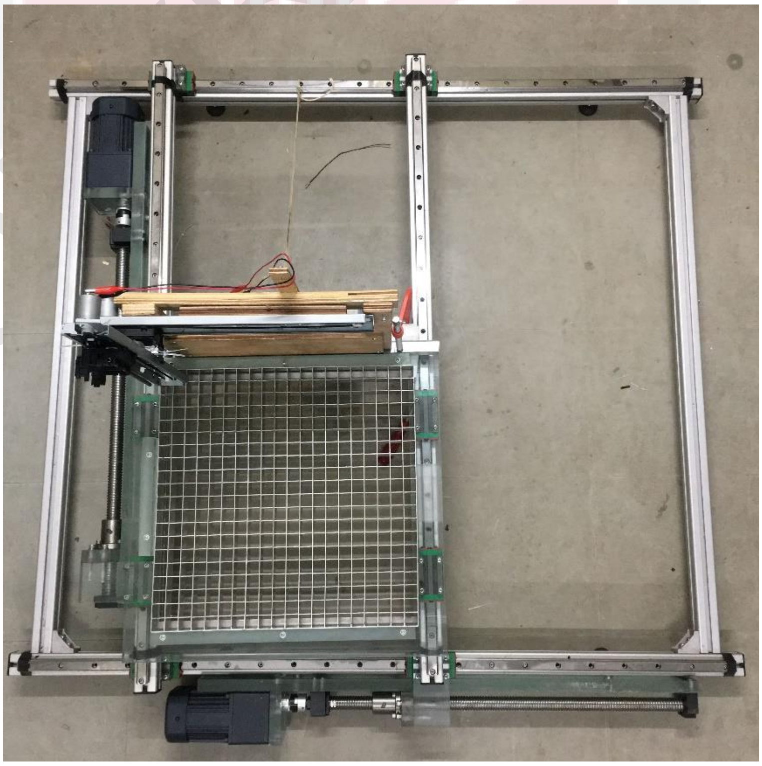

Figure 19: The Top View of the Mechanical Part of the Gantry System

4.3 The Electronic System

The designated electronic system for the paddy transplanter was successfully developed. The electronic system consists of two Arduino Mega 2560 boards connected wirelessly to each other through their own nRF24L01 Transceiver Module, and L293D Motor Driver Shield. Two 12V Lithium-Poly batteries were used to supply power to both the Arduino Mega Slave board and the Motor Driver Shield, respectively. The Arduino Mega Master on the other hand was powered by a computer through universal serial bus (USB) cable as it is required to access the Node-RED IoT platform.

The Arduino Mega Slave that was plugged together with the L293D Motor Driver Shield were put into a transparent rectangular box that was mounted at the back of the plywood. A tiny hole was made at the right of the box to make a penetration of connecting wires from the motor driver shield to the DC motors. The 12V batteries and the transceiver module together with extra connecting wires were put in the box as well.

All the programs that have been written in the sketch was uploaded into the Arduino Mega boards. Trial and error method were implemented to identify the exact timing of the DC motors rotation that cause the movement of the pushing rod from one point to another. For instance, 1 seconds were taken for the ink carrier without any load to move from the left end to the right end when it was put horizontally. When it was put vertically, 1.5 seconds were required for it to moves from the bottom end to the top end due to the gravitational force. Same goes to the horizontal gantry system, it took 5 seconds for the ink carrier to move from the right end to the left end and vice versa when there is load attached on it which is the vertical gantry system.

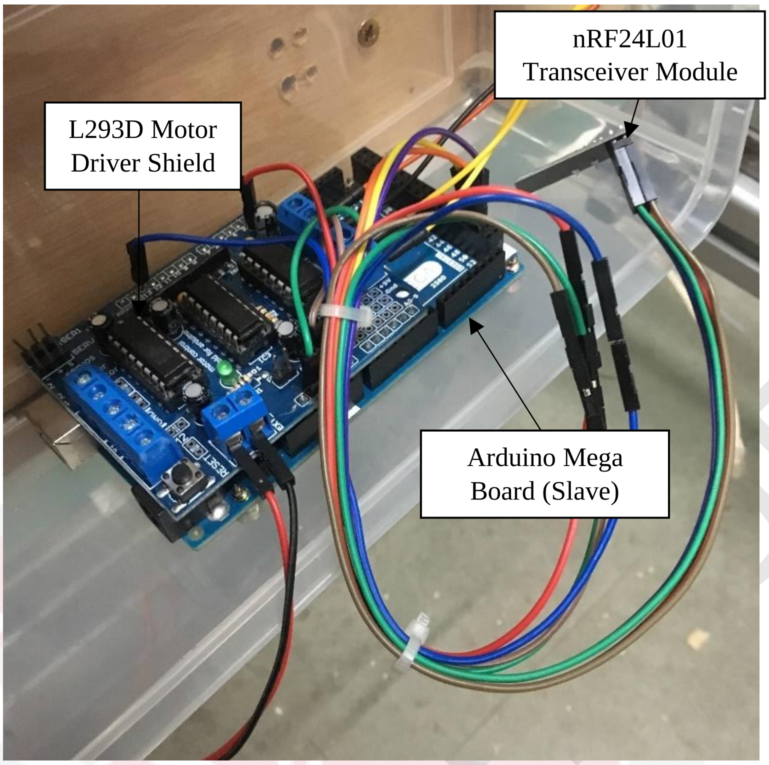

Figure 20: The Arduino Mega Slave Connections at the back of the Gantry System

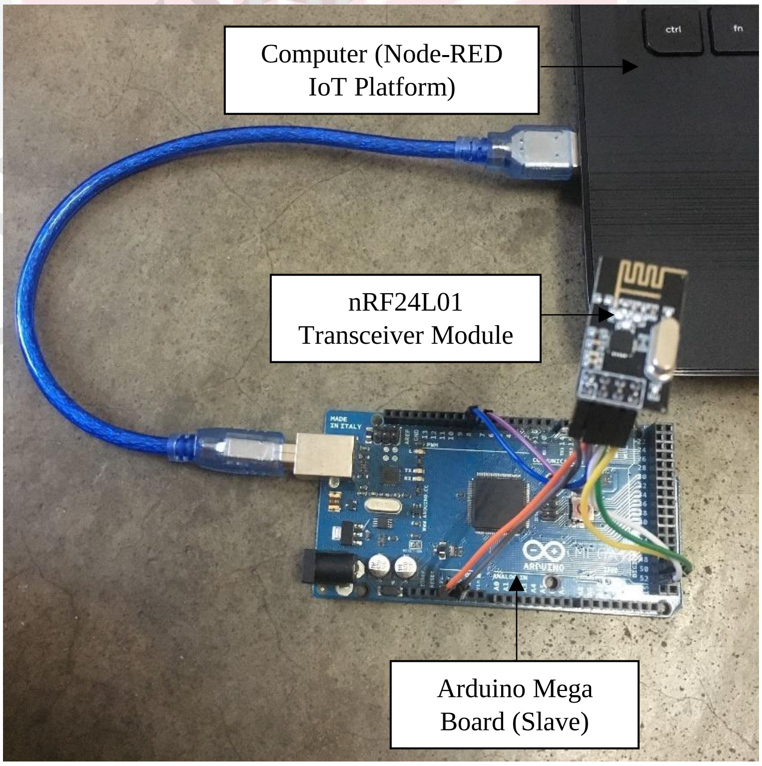

Figure 21: The Arduino Mega Master Connected to the Node-RED in the Computer through Serial Port

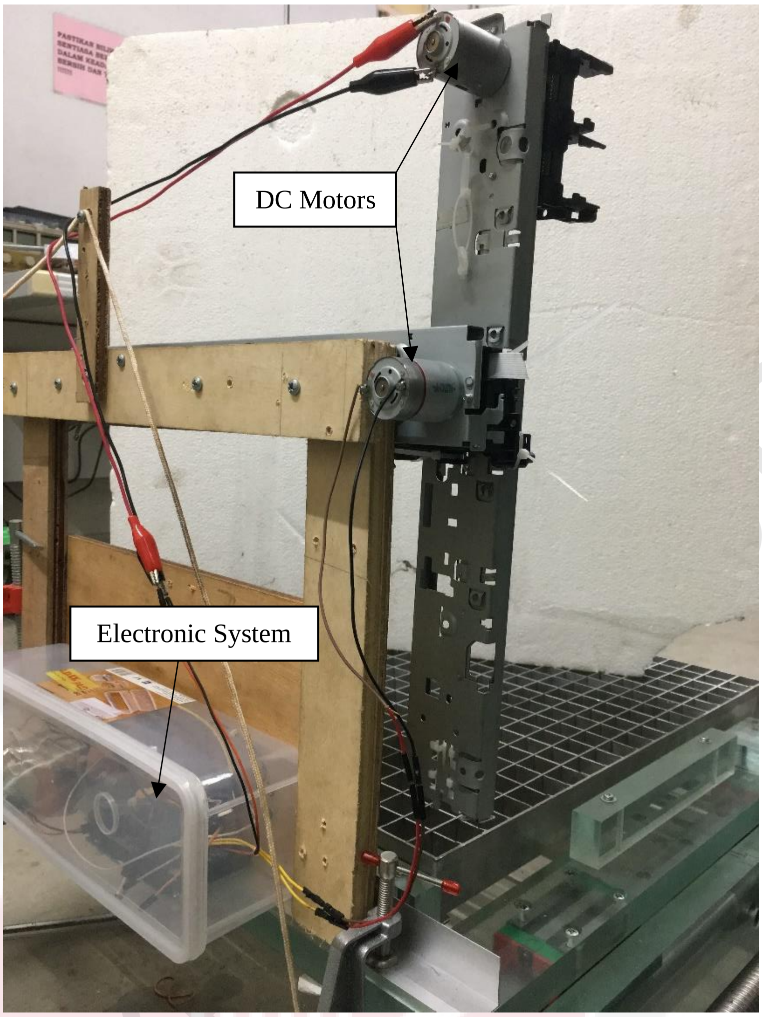

Figure 22: The Box that holds the Electronic System Mounted at the Back to be Connected with DC Motors

4.4 User Interface

In the second flow of the Node-RED IoT platform, a user interface program was developed to be accessed by users in order to control the pushing rod in the two-axes gantry system for the SRI-Tray wirelessly. The user interface can be accessed by connecting to the same network where the Arduino Mega Master and the Node-RED is connected. Users can access the interface by simply adding ':1880/ui' at the back of the IP address that have been obtained from the network in the browser from their phone.

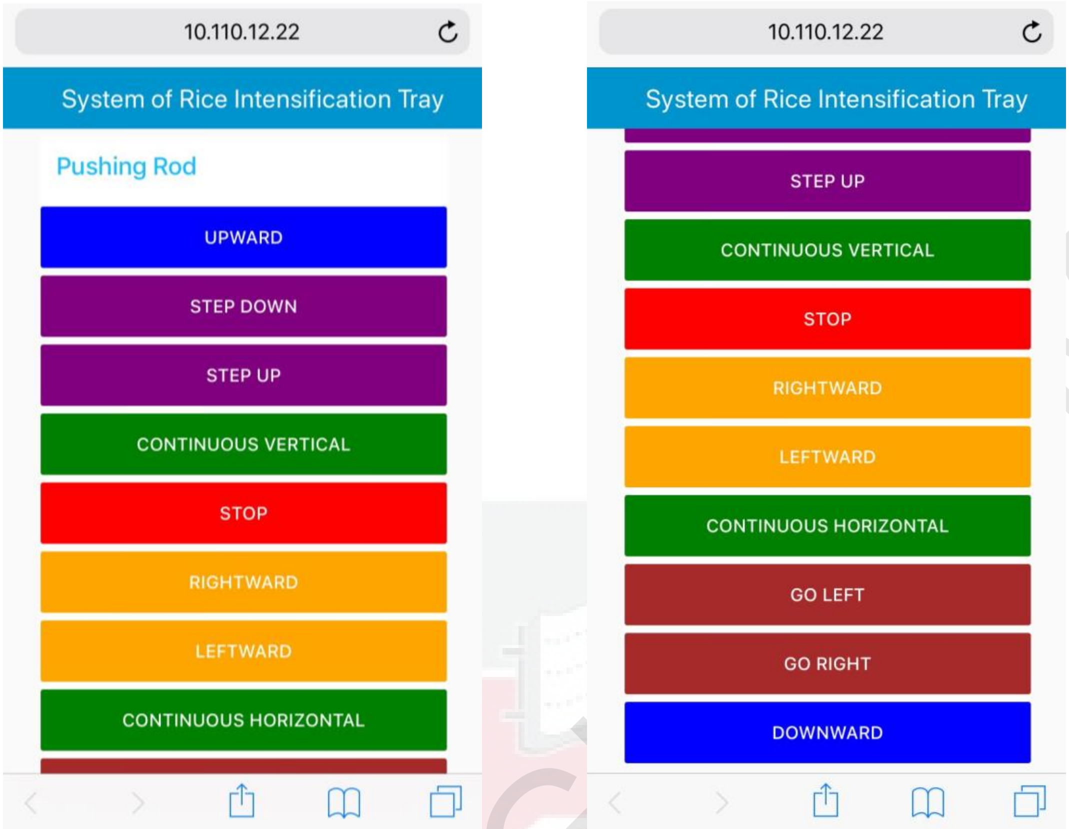

Figure 23: The User Interface Browsed from Safari in the iPhone

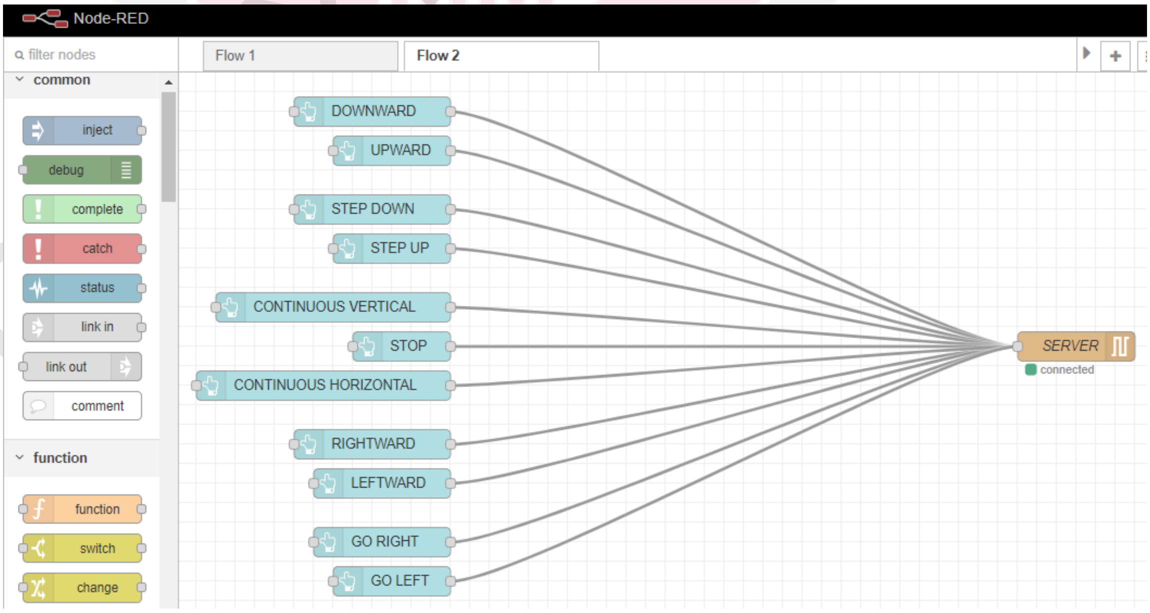

Figure 24: The Second Flow of the Developed Program in the Main Workspace of Node-RED Platform which is the User Interface

4.5 Testing the System

The operating system developed was to test all the available movement of the pushing rod in the two-axes gantry system. There are several movements available, namely up and down of the pushing rod on the vertical axis; UPWARD and DOWNWARD, left and right of the vertical gantry on the horizontal axis; LEFTWARD and RIGHTWARD, and a continuous movement of the pushing rod both vertically and horizontally; CONTINUOUS VERTICAL and CONTINUOUS HORIZONTAL. There are also stepping movements of the rod to all four directions where it only moves a small step in a range of 2-3 cm, namely STEP UP, STEP DOWN, GO LEFT, GO RIGHT in the user interface. The operating system can be stopped at any time by pressing the STOP button in the user interface. All the movement of the pushing rod in the two-axes gantry system can be control wirelessly through a user interface that can be access by searching the weblink in a browser as shown in Figure 23.

In order to ensure the pushing rod in the two-axes gantry system are able to execute all the designated task commanded by the controller, a simple testing was carried out. In this test, the pushing rod is required to move downward and push an empty cavity of the SRI-Tray, moves upward back to its initial position and moves to the adjacent cavity and repeat the same movement for ten empty cavities form left to right. The time taken for the pushing rod to complete the whole task which is pushing the first cavity to the tenth cavity was recorded as well as number of empty cavities that managed to be pushed by the Pushing Rod. The test was repeated for three times and the average time taken was recorded. The Table 4-5 below shows the data recorded.

	The time taken for the Pushing Rod to complete the whole task. (s)
First Attempt	20.34
Second Attempt	22.15
Third Attempt	20.29
Average Time Taken	20.93

Table 4: The Table of the Time Taken for the Pushing Rod to Complete the Whole Task.

	Number of empty cavities that managed to be pushed by the Pushing Rod
First Attempt	6/10
Second Attempt	8/10
Third Attempt	6/10
Average Number of Empty Cavities	2/3

Table 5: The Table of the Number of Empty Cavities that Managed to be Pushed by the Pushing Rod

There are some issues and limitations in constructing and controlling the pushing rod in the two-axes gantry system of the SRI-Tray. Since there are only two axes, the pushing rod are only capable to push the third row of the cavities of the tray. The length of the horizontal gantry system was also insufficient to carry the pushing rod along the third row, hence only 10 cavities are available to be pushed. The belting system of the horizontal gantry are a little bit loose that cause the veritical gantry to move slightly slower. This also cause the movement of the pushing rod from left to right and vice versa to be inconsistent although the same timer has been set. Thus, the pushing rod will be pushing the divider of the cavities or the same empty cavities twice. The cause of friction that reduce the speed of the vertical gantry system was also identified. Multipurpose lubricants, degreaser and rust inhibitors was sprayed along the gantry to overcome this issue.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

All objectives for this study had been achieved. A fully automated paddy transplanting machine based on the System of Rice Intensification was successfully developed. A pushing rod in the two-axes gantry had been fully developed as it will act as the pushing mechanism to the paddy transplanting system based on the SRI-Tray. In addition, the wireless linear motion controller for the movements of the pushing rod in the two-axes gantry was fully developed as well.

The mechanical system of the paddy transplanting machine was successfully designed, fabricated, and assembled with the existing SRI-Tray platform that have been developed in the Machine Design Laboratory at the Department of Biological and Agricultural Engineering, UPM. The movement of the downward, upward, leftward, and rightward of the pushing rod was feasible by using the 12V DC motor and can be control wirelessly. The convenient, easy access and user-friendly interface also helps in reducing labour workloads as well as improving the productivity.

Development of an automated paddy transplanter for System of Rice Intensification performed by using wireless controller can ease the operation of single seedling dispensing in the field. This operation is able to cut down paddy seedling input and reduces operation time per hectare with more yield produced compared to conventional method.

5.2 Recommendation

From the developed automated paddy transplanter based on the System of Rice Intensification, there are several recommendations that can be done to improve the performance, precision, and accuracy of the system. First recommendation is to use stepper motor instead of DC motor. A stepper motor differs from a normal DC motor in that the movements consist of individual steps rather than a continuous rotation. These individual steps allow for precise positioning that can be repeated with accuracy. By energizing each phase of rotation in sequence, the motor will rotate, one step at a time. With a computer control stepping motor, a very precise positioning and speed control can be achieved. For this reason, stepper motors are the kind of motors that recommended to be used in the future work for any precision motion control applications.

Second recommendation that can be done is to include encoder as the position sensor in the two-axes gantry system. A rotary encoder is an electro-mechanical device that are capable to converts the angular position or motion of a shaft to analog or digital output signal. These sensors are very significant in order to make a precise movement of the pushing rod along the axis in the gantry system. To produce a better performance of SRI transplanting machine, it is important to include encoder in the future work.

Lastly, it is suggested to develop three-axes gantry system in the future research. Two-axes gantry system of paddy transplanter based on the SRI is apparently insufficient to produce positive convincing results. Once the triaxial gantry system complete with the wireless controller has been developed, full performance analysis can be done thoroughly on the machine to evaluate its reliability.

REFERENCES

Bashar, Z. U., Wayayok, A., Amin, M. S. M., & Mahadi, M. R. (2015). Single seedling nursery tray: An innovative breakthrough to quality seedling raising technique for sri transplanting machine. *Research Journal of Applied Sciences, Engineering and Technology*, *10*(11), 1258–1265. https://doi.org/10.19026/rjaset.10.1820

Fahmi, Z., Abu Samah, B., & Abdullah, H. (2013). Paddy industry and paddy farmers well-being: A success recipe for agriculture industry in Malaysia. *Asian Social Science*, *9*(3), 177–181. https://doi.org/10.5539/ass.v9n3p177

Flixeder, S., Glück, T., Böck, M., & Kugi, A. (2017). Model-Based Signal Processing for the Force Control of Biaxial Gantry Robots. *IFAC-PapersOnLine*, *50*(1), 3208–3214. https://doi.org/10.1016/j.ifacol.2017.08.439

Giam, T. S., Tan, K. K., & Huang, S. (2007). Precision coordinated control of multi-axis gantry stages. *ISA Transactions*, *46*(3), 399–409. https://doi.org/10.1016/j.isatra.2007.02.002

Insam, E. (2003). Protocols and Communications Models. *TCP/IP Embedded Internet Applications*, 55–68. https://doi.org/10.1016/b978-075065735-8/50030-8

Kelemen, M., Kelemenová, T., Virgala, I., Miková, L., & Lipták, T. (2014). Rapid control prototyping of embedded systems based on microcontroller. *Procedia Engineering*, *96*, 215–220. https://doi.org/10.1016/j.proeng.2014.12.146

Li, L. (2020). Real time auxiliary data mining method for wireless communication mechanism optimization based on Internet of things system. *Computer Communications*, *160*(June), 333–341. https://doi.org/10.1016/j.comcom.2020.06.021

Solihin, M. I., Chuan, C. Y., & Astuti, W. (2020). Optimization of fuzzy logic controller parameters using modern meta-heuristic algorithm for gantry crane system (GCS). *Materials Today: Proceedings*, *29*(November 2018), 168–172. https://doi.org/10.1016/j.matpr.2020.05.641

Stoop, W. A., Uphoff, N., & Kassam, A. (2002). A review of agricultural research issues raised by the system of rice intensification (SRI) from Madagascar: Opportunities for improving farming systems for resource-poor farmers. *Agricultural Systems*, *71*(3), 249–274. https://doi.org/10.1016/S0308-521X(01)00070-1

APPENDICES

Programming Code in Arduino IDE for Arduino Mega Master

```
#include <AFMotor.h>
#include <SPI.h>
#include <nRF24L01.h>
#include <RF24.h>
String strVar; //declare string

//AF_DCMotor motor(4);
RF24 radio (7, 8); // CE, CSN
const byte address [6] = "000001";


void setup()
{
  //Set initial speed of the motor & stop
  // motor.setSpeed(200);
 Serial.begin(9600);
  // motor.setSpeed(255);
  // motor.run(RELEASE);
 radio.begin();
 radio.openWritingPipe(address);
 radio.setPALevel(RF24_PA_MIN);
 radio.stopListening();
}

void loop()
{
 strVar = "";
 Serial.print (strVar);
 if (Serial.available())
  {
  strVar += Serial.readString();
  }

    if (strVar == "DOWN") { //Sends val = 1 to to arduino slave
      const int val = 1;
      radio.write(&val, sizeof(val));
      delay (1000);
      /* motor.run(FORWARD);
      delay(2000);*/
      }
```

```
else if (strVar == "UP") {
  /* motor.run(BACKWARD);
  delay(2000);*/
  const int val = 2;
  radio.write(&val, sizeof(val));
  delay (1000);
  }

else if (strVar == "GODOWN") {
  const int val = 3;
  radio.write(&val, sizeof(val));
  delay (1000);
  }

else if (strVar == "GOUP") {
  /* motor.run(BACKWARD);
  delay(2000);*/
  const int val = 4;
  radio.write(&val, sizeof(val));
  delay (1000);
  }

else if (strVar == "CONTV") {
  const int val = 5;
  radio.write(&val, sizeof(val));
  delay (1000);
  }

else if (strVar == "STOP") {
  const int val = 6;
  radio.write(&val, sizeof(val));
  delay (1000);
  }

else if (strVar == "RIGHT") {
  const int val = 7;
  radio.write(&val, sizeof(val));
  delay (1000);
  }

else if (strVar == "LEFT") {
  const int val = 8;
  radio.write(&val, sizeof(val));
  delay (1000);
  }
```

```
    else if (strVar == "GORIGHT") {
     const int val = 9;
     radio.write(&val, sizeof(val));
     delay (1000);
     }

    else if (strVar == "GOLEFT") {
     const int val = 10;
     radio.write(&val, sizeof(val));
     delay (1000);
     }

    else if (strVar == "CONTH") {
     const int val = 11;
     radio.write(&val, sizeof(val));
     delay (1000);
     }
}
```

Programming Code in Arduino IDE for Arduino Mega Slave

```
#include <AFMotor.h>
#include <SPI.h>
#include <nRF24L01.h>
#include <RF24.h>
String strVar;
int val; //declare globally

AF_DCMotor motor1(4);
AF_DCMotor motor2(3);

RF24 radio (2, 13);
const byte address [6] = "000001";


void setup()
{
  //Set initial speed of the motor & stop
 // motor.setSpeed(200);
 Serial.begin(9600);
 motor1.setSpeed(255);
 motor1.run(RELEASE);
 motor2.setSpeed(255);
 motor2.run(RELEASE);
 radio.begin();
 radio.openReadingPipe(0,address);
 radio.setPALevel(RF24_PA_MIN);
 radio.startListening();
}

void loop()
{
  if (radio.available()) {
  int val = 0;
  radio.read(&val, sizeof(val));
  Serial.print (val);

   if (val == 1) {
     motor1.run(FORWARD);
     delay(500);
     motor1.run(RELEASE);
     delay(500);
     }

   else if (val == 2) {
     motor1.run(BACKWARD);
```

```
  delay(1500);
  motor1.run(RELEASE);
  delay(500);
  }

else if (val == 3) {
  motor1.run(FORWARD);
  delay(80);
  motor1.run(RELEASE);
  delay(100);
  }

else if (val == 4) {
  motor1.run(BACKWARD);
  delay(180);
  motor1.run(RELEASE);
  delay(100);
  }

else if (val == 5) {
  SRIV();
  }

else if (val == 7) {
  motor2.run(BACKWARD);
  delay(5000);
  motor2.run(RELEASE);
  delay(500);
  }

else if (val == 8) {
  motor2.run(FORWARD);
  delay(5000);
  motor2.run(RELEASE);
  delay(500);
  }

else if (val == 6) {
  rest();
  }

else if (val == 9) {
  motor2.run(BACKWARD);
  delay(250);
  motor2.run(RELEASE);
  delay(100);
```

```
    }

   else if (val == 10) {
     motor2.run(FORWARD);
     delay(250);
     motor2.run(RELEASE);
     delay(100);
     }

   else if (val == 11) {
     SRIH();
     }
  }
}

void SRIV() {
  while (5==5){
     motor1.run(FORWARD);
     delay(500);
     motor1.run(BACKWARD);
     delay(1500);

      if (radio.available()){
      int val = 0;
      radio.read(&val, sizeof(val));
      if (val == 6){
      rest();
      break;
      }
    }
  }
}

void SRIH() {
  while (0==0) {
     motor2.run(FORWARD);
     delay(5000);
     motor2.run(BACKWARD);
     delay(5000);

      if (radio.available()) {
      int val = 0;
      radio.read(&val, sizeof(val));
      if (val == 6) {
      rest();
      break;
```

```
      }
    }
  }
}

void rest() {
  motor1.run (RELEASE);
  motor2.run (RELEASE);
  }
```