Design and Development of Autonomous Pesticide Sprayer Robot for Fertigation Farm

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***Abstract*—The management of pest insects is the critical component of agricultural production especially in the fertigation based farm. Although the fertigation farm in Malaysia has advantages in the fertilization and irrigation management system, it still lacking with the pest management system. Since almost the insect and pests are living under the crop's leaves, it is difficult and hard labor work to spray under the leaves of the crop. Almost agricultural plants are damaged, weakened, or killed by insect pests especially. These results in reduced yields, lowered quality, and damaged plants or plant products that cannot be sold. Even after harvest, insects continue their damage in stored or processed products. Therefore, the aim of this study is to design and develop an autonomous pesticide sprayer for the chili fertigation system. Then, this study intends to implement a flexible sprayer arm to spray the pesticide under the crop's leaves, respectively. This study involves the development of unmanned pesticide sprayer that can be mobilized autonomously. It is because the pesticide is a hazardous component that can be affected human health in the future if it exposed during manual spraying method especially in a closed area such as in the greenhouse. The flexible sprayer boom also can be flexibly controlled in the greenhouse and outdoor environment such as open space farms. It is expected to have a successful pesticide management system in the fertigation based farm by using the autonomous pesticide sprayer robot. Besides, the proposed autonomous pesticide sprayer also can be used for various types of crops such as rockmelon, tomato, papaya. pineapples, vegetables and etc.**

Keywords*—Pesticide spryer; autonomous robot; fertigation; farm; under crop leaves

I. Introduction

The agriculture industry is growing from time to time as the demand on its yield abruptly rising in conjunction by the end of 2050, the agriculture yields are expected to be able to support the rapid population growth. From this forecast, the dependency on the agriculture yields to meet the population growth is a concern because the world population is expected to grow by over a third, or 2.5 billion people, between 2009 and 2050 [1]. For the countries that in the phase of developing, the population grew significantly faster compared to the countries that already developed hence result in the requirement on the feedstock that came from the agriculture yields. Agriculture industry become vastly practice all around the globe by make use of the prosperous motherland with the diversity natural resource and geographical advantages, the agriculture become applicable and acceptable to the certain countries because of its promising a good returns but there is a resemblance of the problem faced by all these countries which are in term of pest control.

In chili fertigation farms, pests such as mites, snails, and maggots are a common type of pest that can be found in this farm by making the plants as their source of food and breeding ground. In this case, pest invasion is an unavoidable circumstance but can be controlled by having pesticide spraying periodically. Normally, the worker needs to manually spray the pesticide while wearing protective gear and walking from crop to crop. This method indeed inefficient practice and hazardous chemicals used in spraying can be fatal to the worker even wearing protective gear because research conducted found that the protective gears do not stop the chemical but only reduce the amount of exposure [2]. Based on the studies conducted also, The World Health Organization (WHO) estimates approximately about 3 million cases regarding pesticide poisoning which happened every year, thus causing the death of 220,000 people who especially live in developing countries [3].

II. Related Works

With flourishing technology that is introduced in this 21st century, there is numerous types of robots been used in agricultural activity starting from the cultivation process to the production process. The autonomous robot had been introduced in various application such is in underwater [4], rescue[5], line following robot based on metal detection[6]. In agriculture field, the usage of robotics in agriculture operation able to help to increase the production process and improve efficiency[7]. One of the types of the robot used in agriculture is for the purpose of pesticide spraying with the ability to navigate in the farm, recognize the target and regulate the spraying mechanism[8]. The use of autonomous robot pesticide sprayer as the substitution of the worker who used conventional pesticide sprayer can be applicable.

Besides, the demand for the agriculture robot also stimulates the consciousness of how important its role in the current and future generations. The survey conducted shows that the demand for robots and drones in agriculture will be expected to be rose from 2018 to 2038. Hence, the usage of the autonomous robot is assumed to rise thus replacing the current labor worker. This granular 20 years market forecast covers all the aspect of the agricultural robots and drones for 16 market categories with the expectation by the end of 2038 [7], the market of the robots and drones in these categories is predicted will close to 35 billion with the viable technology and ongoing market demand by considering its technology and application .

Nevertheless, the common problem with an autonomous robot use in agricultural activity is the navigation method used to able the robot fully-operated with decision making capability. In order to navigate through all the field, there are some research has been done [8-11]. It can be done through infrstructure ready or to be without infrastructure. Some research on RFID based navigation are conducted to be implemented as navigation tools [12-13]. As artificial intelligence (AI) starts to emerge, the current robot should be able to navigate the next movement by the adaptation of the surrounding environment and decide which path it will take. The typical method used in the detection is based on the targeted object orientation or repelled signal emits from the sensor itself then calculates the distance in between it [13-18]. Other than that, there is also the robot that uses the vision observation then accumulates all the acquired data to generate the data fusion that enables the robot to navigate itself through the farm [19].

The second problem with the agricultural robot is due to the dissemination of the pesticide to the crops. Unregulated spraying during the disposition of the pesticide to the crop can lead to the low rate of coverage on leaves, wastage of pesticide and hazardous exposure to workers due to disperse pesticide to the desired target [20]. With regulated spraying by the pump, the higher coverage of dissemination to the crops can be achieved whereby the positioning of each crop was varied from one another in the farm. Furthermore, instead of hiring the workers to do miscellaneous work on the farm which can affect themselves, it can be done by an autonomous agriculture robot thus save the expenses on the labor worker [21].

Lastly, the designed robot used in agriculture having the difference performance index depends on the variable they want to achieve. Certain researchers may focus on UAV based pesticide spraying, localization and motion control of agriculture mobile robot, pest image identification and else [22]. This also same goes to the type of the plant being used as the target which differs from one another in terms of size, leaves density and height. Hence, it would be difficult to decide which designed robot was most successful at the time being.

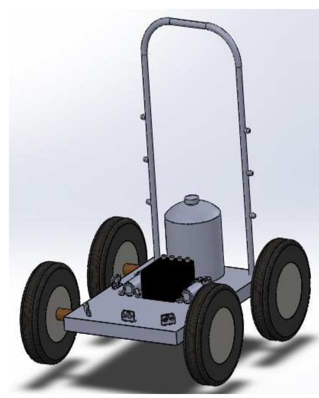
In this research, the aim of this study is to design and develop an autonomous pesticide sprayer for the chili fertigation system. Then, this study intends to implement a flexible sprayer arm to spray the pesticide under the crop's leaves, respectively. This study involves the development of unmanned pesticide sprayer that can be mobilized autonomously. It is because the pesticide is a hazardous component that can be affected human health in the future if it exposed during manual spraying method especially in a closed area such as in the greenhouse. The flexible sprayer boom also can be flexibly controlled in the greenhouse and outdoor environment such as open space farms. It is expected to have a successful pesticide management system in the fertigation based farm by using the autonomous pesticide sprayer robot. Besides, the proposed autonomous pesticide sprayer also can be used for various types of crops such as rockmelon, tomato, papaya. pineapples, vegetables and etc.

III. Hardware Configuration

A. System Construction

The overall design of the autonomous pesticide spraying robot is illustrated in Fig. 1. The design is done using Solidwork software and the development of the autonomous pesticide spraying system based on the design. The specification of the autonomous pesticide spraying robot is shown in Table I.

The dimension of autonomous pesticide spraying robot is determined to be 122 cm (2 feet) because the size of the row for fertigation farm is about 3 feet. In addition, the height autonomous pesticide spraying robot is determined to be 2 m because the normal height of the chili fertigation farm is below 2 m. The system overview for the autonomous pesticide spraying system is illustrated in Fig. 2 shows an overall connection between two different systems that will be combined inside of the autonomous pesticide spraying robot. The development of the autonomous pesticide sprayer prototype consists of two parts where the navigation system and the spraying system. The interconnection between the selected components in the designed robot is crucial and plays a major role to make sure the robot function as desired. Misconnection between the electronic components can lead to malfunction of the designed system thus deviated the operation from achieving the project objective.



(a) Designed Autonomous Pesticide Sprayer.

(b) Developed Autonomous Pesticide Sprayer.

Fig. 1. System Construction.

TABLE. I. AUTONOMOUS PESTICIDE SPRAYING ROBOT SPECIFICATION

Item	***Specification***
Robot dimension	122 cm x 122 cm x 200 cm (L x W x H)
Robot weight	12 kg without payload
Drive system	4-wheeled drive system
Power supply	24V DC lead-acid rechargeable battery
Ground clearance	12 cm from the ground
Payload	Max: 20 kg

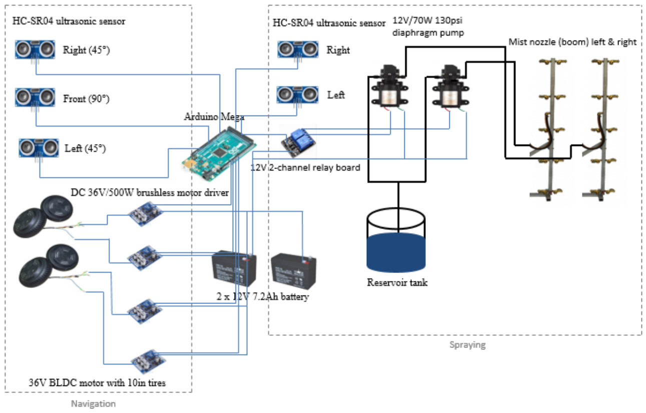


Fig. 2. System Overview of Acceleration-based Movement Detection.

B. Navigation System

The navigation system consists of some ultrasonic sensor, microcontroller, four units of brushless DC motor with a motor driver for each motor, and a 24 V DC rechargeable battery. The microcontroller is the heart of the system where the designer can write and load the program into it to control the sequence and operation of the peripheral that connected to its pin 12 in the microcontroller. Using the programming software which has been predetermined, the coding will be uploaded into the microcontroller which will determine how the designed robot will be operated. In this project, the Arduino Mega 2560 will be used as shown in Fig. 3 because has adequate I/O pins for input and output either analog and digital I/O.

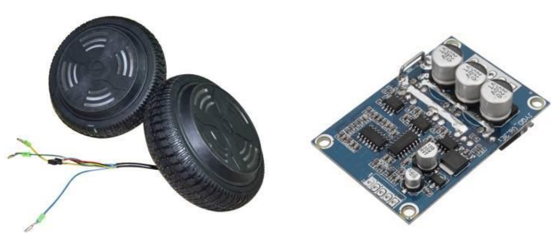
On the other hand, there are eight units of ultrasonic sensor which is mounted at the edge of the frame and the center of each frame. The sensor is an important component in designing and developing the robot with the necessity to move and navigate itself without human intervention. It acts as eyes and ears which will retrieve the data or information from surrounding before sending it to the brain, microcontroller to be processed. [12], where all data were accumulated altogether to generate more accurate and consistent data. The ultrasonic sensor operations are based on the distance calculated from the time interval taken by the emitted sound wave to repel back to the receiver. The ultrasonic sensor which mounted at the center of the frame is fixed perpendicularly 90° facing forward while the ultrasonic sensors mounted at the edge, right and left having 45° deflections each. This concept is referred from the previous design which has been implemented in the wearable device for the visually impaired person [13]. Other than navigation purposes, the ultrasonic sensors will be used to activate the spraying system when the plants were detected in range. Fig. 4 shows the type of ultrasonic used in this prototype.

Fig. 3. Arduino Mega 2560.

Fig. 4. HC-SR04 Ultrasonic Sensor.

Besides, the four units of brushless DC motor are used for the four-wheeled driving system. The brushless DC motor which is used is manufactured together with the tire that normally applied in a hoverboard. The diameter of the tire which is selected is 25.4 cm to have higher ground clearance about 12 cm. The higher ground clearance is important to pass the irregular surface such as stone or rock along the path. To facilitate the process of BLDC motor rotation and change its direction of rotation, the motor driver is used. With the method used for changing the direction of the motor wheels by the motor driver, it also can be implemented to change the heading and direction of the robot platform with the concept of the hoverboard drive. Hoverboard drive, in essence, use both tires left and right to change the heading and direction of the robot by manipulating the rotation of both tires.

For example, if the robot wants to turn to the right, the left tire is rotating forward while the right tire is rotating backward. This allowed the robot to have curve turning thus change its direction. The 3-phase supply and hall sensor of the BLDC motor will be connected to the out pin and hall pin on motor driver respectively. The 12V battery will provide the supply to BLDC motor by connecting it to the VCC pin of the motor driver. After that, the ZF and VR pin on the motor driver will be connected to the Arduino Mega digital input pins to control the rotation and Pulse Width Modulation (PWM) to the BLDC motor. Fig. 5 shows the hoverboard wheel with the brushless DC motor and the motor driver.



(a) 3-Phase Brushless DC Motor (b) Motor Driver.

Fig. 5. Three-Phase Brushless DC Motor with Motor Diver.

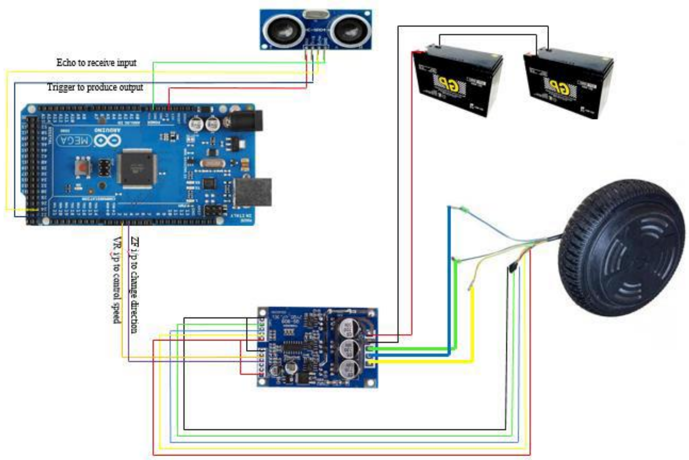


Fig. 6. Connection for Controlling Motor after Ultrasonic Sensor Detection.

The connection of the microcontroller, Arduino Mega 2560, brushless DC motor through 36V/500W brushless motor driver and received the power supply from 24V batteries (2x12V battery in series) as shown in Fig. 6. The motor drivers are able to manipulate the rotation of the motor using its phase connected to the gate driver MOSFET on its circuit.

C. Spraying System

While the microcontroller executing the condition in the navigation part, the condition for the spraying system also will be considered. As the autonomous pesticide spraying robot needs to be able to execute both of the operations simultaneously, the sequence inside of the programming code plays a critical role in the designed project. The main components consist of the spraying system are reservoir tank, pesticide pump, 2-channel relay circuit, tube and some mist nozzles for spraying under the crop leaves. The reservoir tank which is used in the autonomous pesticide spraying robot will be filled with pesticide incapacity of 10L although the maximum of 20 kg of the payload can be carried out.

In order to supply the pesticide from the reservoir tank to the end of the spraying nozzle, the use of the 12V/ 70W 130 psi diaphragm pesticide pump is selected is shown in Fig. 7. The selection of a pesticide pump is crucial because the pump needs to be eligible to push the pesticide out with desired pressure. With the help of the pump, spraying can be directly allocated to the desired targeted plants especially under the crop leaves, by only giving electrical input to the pump which procured by sensor upon detection of the plants.

In term of connection, the microcontroller and the 12V/ 70W 130 psi pump was interconnected through 12V 2-channel relay board where the relay will receive the input signal from the microcontroller to change its contact thus closed the circuit connection from battery to pump hence activating pump. Fig. 8 shows a connection between microcontroller to pump.

Fig. 7. 12V/70W 130psi Diaphragm Pesticide Pump.

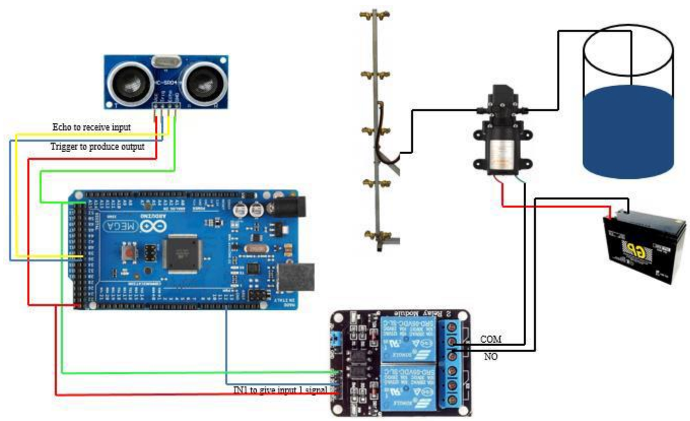


Fig. 8. Connection for Activating after Ultrasonic Sensor Detection.

IV. Autonomous Pesticide Sprayer Operation Flowchart

A. Navigation System Flowchart

Based on the autonomous pesticide sprayer operation, the designed project is divided into two sub-disciplinary part which is the navigation and spraying system. Once the autonomous pesticide sprayer robot activated, it will mobilize through the farm while considering all the operation which is executed simultaneously. The designed project will be regarded to be close to the success after all the execution of the operation undergoes seamlessly and then the robot will be evaluated based on its performance in measurable engineering variables. In order to allow the robot to follow the instruction in the programming code, it is important to identify each step that wants to be executed by the autonomous pesticide sprayer robot step by step as the robot will consider the condition in the top step before moving to the bottom step. Fig. 9 shows the process flowchart inside of the navigation system to make the robot move autonomously throughout the field.

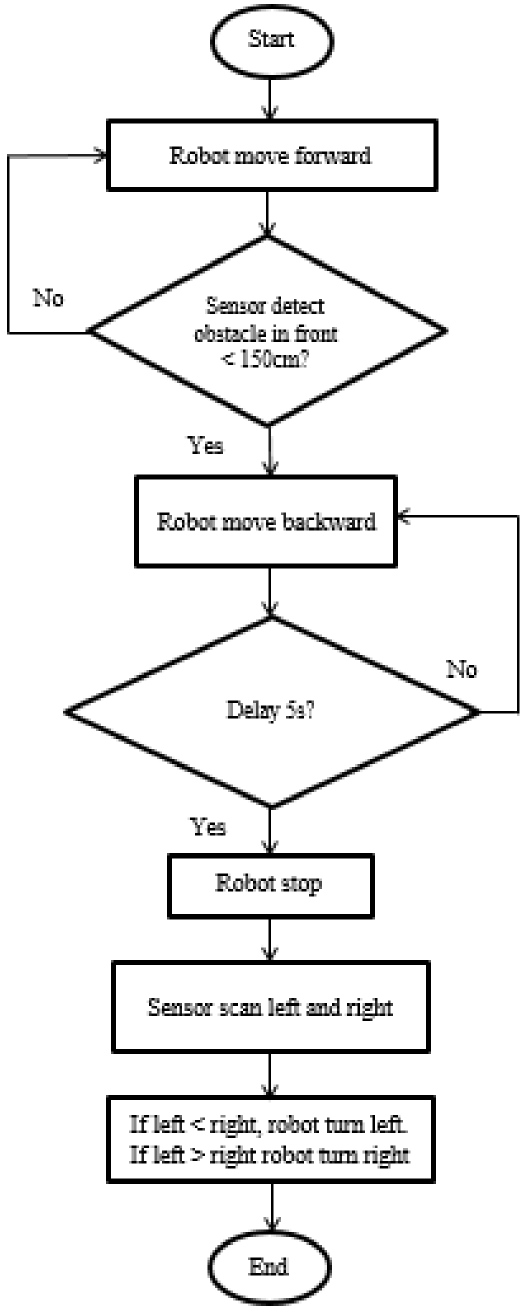


Fig. 9. Navigation System Flowchart.

B. Spraying System Flowchart

On the other hand, while the microcontroller executing the condition in the navigation system, the condition for the spraying system also will be considered. As the autonomous pesticide sprayer robot needs to be able to execute both of the operations simultaneously, so the sequence inside of the programming code plays a critical role in the designed project. Fig. 10 shows the process flowchart inside of the spraying system including the.

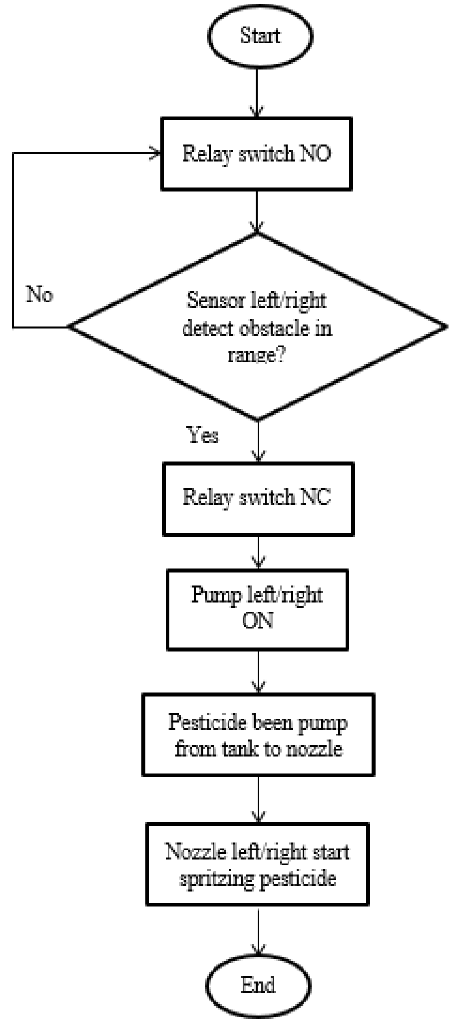


Fig. 10. Spraying System Flowchart.

V. EXPERIMENTAL SETUP

As the autonomous pesticide sprayer robot needs to be tested in the real working environment, the fertigation farm by planting the chili using as the experimental setup environment. The experiment setup in the fertigation farm with approximately 100 chili plants is set. Fig. 11 shows the experimental setup in the chili fertigation farm.

This experiment is performed to know the capability of the sensor to detect the presence of the obstacles in front of it then decide which way it will turn as its next route. The ultrasonic sensor basically emits the soundwave thus received the repelled soundwave as the signal. In this experiment, the sensor distance will be recorded when the autonomous pesticide sprayer robot is moving. The value for front, right and left sensor when there is an obstacle versus the distance took by the robot along the path. The conceptual function for obstacle detection to turn the navigation platform into left direction with ultrasonic affixed 90°, 45° and 135° respectively is shown in Fig. 12.

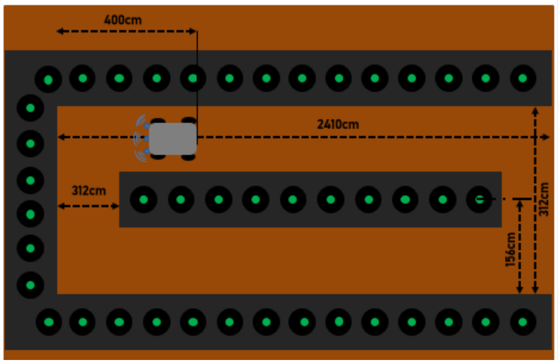


Fig. 11. Experimental Floor Layout in Chili Fertigation Farm.

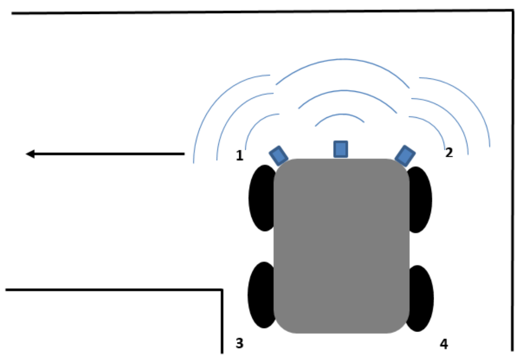


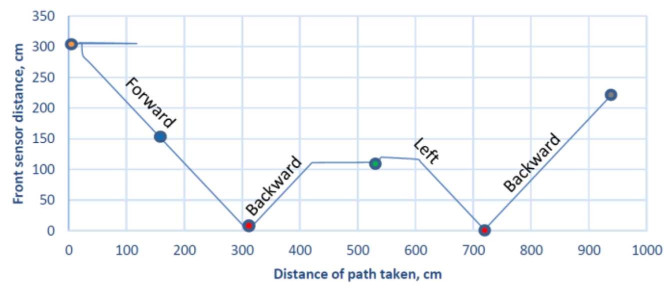
Fig. 12. The Conceptual Function of Sensor Detection in Turning.

VI. Experimental Results

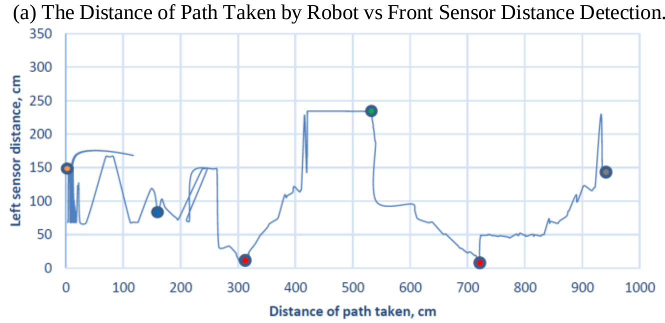
All the measurement data obtained from the ultrasonic sensor on the autonomous pesticide sprayer robot in this experiment are recorded and the moving path of the autonomous pesticide sprayer robot is plotted into the graph as shown in Fig. 13. The graph will be divided into three graphs where represent the front, right and left sensor distance versus the distance of path taken mutually. The experimental method which is applied has been referred from previous works conducted [14]. As shown in Fig. 13. the starting point for the autonomous pesticide sprayer robot started at 3000 cm from the end of the junction. So, the max detection from the front sensor should be below the 300 cm which will become closer as the robot moving forward and farther as the robot moving backward. In Fig. 13, only at point of condition's occurred will be shown as the data was too many to display such as in here it got starting, detection, stopping, turning and ending point in highlighted color which is orange for starting point of the detection, blue for stop detection point, red for actual stopping point, green for start left-turning point and grey for ending point of the detection.

The developed autonomous pesticide sprayer robot was tested to stop at the point of detection by front sensor which is below 150 cm but due to BLDC motor can not instantaneously stop its rotation due to its characteristic of brushless that do not have braking system and also cause by inertia acts upon it, there will be overshoot of autonomous pesticide sprayer robot movement before it was fully stopped at distance 305.03 cm. After fully stop, the robot will take a backward step with delay 5 s until it reaches 227.28 cm from the stopping point. Then, at this point, the value of distance for the left and the right sensor was compared by the given condition in programming code whereas based on which distance was the most farthest detect an obstacle whether left or right sensor. If the left sensor distance was highest means farther from obstacle compared to the right one, the function for turning left will be called out in the programs looping then executed or otherwise.

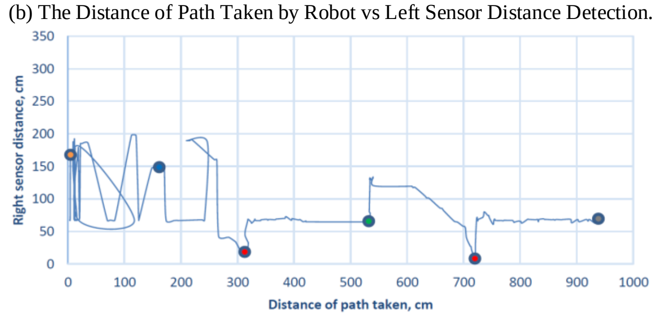
However, since the autonomous pesticide sprayer robot was tested out to take a left turn in this experiment, the measurement data between left sensor distance is 233.9 cm and right sensor distance, 64.44 cm at this point. Later, the motor will manipulate its direction through gate driver in motor driver to take left turn and basically, the method used to change the heading direction of the autonomous pesticide sprayer robot was based on the combination of motor drive with differential drive when to take left direction, the motor 1 and 3 will turn backward with PWM speed of 80, while motor 2 and 4 will turn forward with PWM speed of 200. Thus, this could allow the autonomous pesticide sprayer robot to have some sort of gliding effect during changing direction. The operation for right-turning can be vice versa to left turning in terms of motor direction turning and its speed. After the left turning with 90° curve, the robot will stop at distance 717.91 cm due to overshoot during turning and then take a backward step once again for 5 s.



(a) The Distance of Path Taken by Robot vs Front Sensor Distance Detection.



(b) The Distance of Path Taken by Robot vs Left Sensor Distance Detection.



(c) The Distance of Path Taken by Robot vs Left Sensor Distance Detection.

Fig. 13. Measurement Data from the Ultrasonic Sensor for Autonomous Pesticide Sprayer Robot.

Based on the experimental results shown, the navigation system for an autonomous pesticide sprayer robot is successfully conducted. The autonomous pesticide sprayer robot could navigate autonomously throughout the experimental field.

VII. Conclusions and Future Tasks

As a conclusion, in order to design and develop an autonomous pesticide spraying for a fertigation farm has successfully conducted. All the subsystem such as navigation systems and spraying systems are included. Although the navigation part has been tested, the autonomous pesticide sprayer robot can be self-navigate by turning at the junction by using the obstacles detection concept inside the fertigation farm. The ultrasonic sensors were used which for front sensor it was adjacently facing forward in 90° while the other two left and right both facing forward with deflection 45°. The ultrasonic sensor could detect the obstacles and stop without hitting the obstacles, respectively.

For future works, the spraying pressure of the autonomous pesticide sprayer robot will be tested and the electronic circuits need a waterproof structure since the autonomous pesticide sprayer robot deals with a pesticide which is fluid. Therefore, the isolation of the electronic component should be done well by separating each electronic component in the container box to prevent it from being damaged if the flooding or leakage happened inside the robot. On the other hand, the pest monitoring system should be developed to be an auto-monitoring device while spraying the pesticide.

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