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Design and development of a robot for spraying fertilizers and pesticides for agriculture

Afif Shazwan Abdul Ghafar [a], Sami Salama Hussen Hajjaj [a,b,c,*], Kisheen Rao Gsangaya [a], Mohamed Thariq Hameed Sultan [d,e,f,*], Mohd Fazly Mail [g], Lee Seng Hua [h]

[a] Department of Mechanical Engineering, Universiti Tenaga Nasional, Jalan IKRAM-UNITEN, 43000 Kajang, Selangor Darul Ehsan, Malaysia
[b] Centre for Advanced Mechatronics and Robotics (CaMaRo), Universiti Tenaga Nasional, Jalan IKRAM-UNITEN, 43000 Kajang, Selangor Darul Ehsan, Malaysia
[c] Institute of Informatics and Computing in Energy (IICE), Universiti Tenaga Nasional, Jalan IKRAM-UNITEN, 43000 Kajang, Selangor Darul Ehsan, Malaysia
[d] Laboratory of Biocomposite Technology, Institute of Tropical Forestry and Forest Products (INTROP), Universiti Putra Malaysia, 43400 UPM Serdang, Selangor Darul Ehsan, Malaysia
[e] Department of Aerospace Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor Darul Ehsan, Malaysia
[f] Aerospace Malaysia Innovation Centre (944741-A), Prime Minister's Department, MIGHT Partnership Hub, Jalan Impact, 63000 Cyberjaya, Selangor Darul Ehsan, Malaysia
[g] Farm Mechanization Program, Engineering Research Centre, Malaysian Agricultural Research and Development Institute (MARDI), 43400 Serdang, Selangor Darul Ehsan, Malaysia
[h] Laboratory of Biopolymer and Derivatives, Institute of Tropical Forestry and Forest Products (INTROP), Universiti Putra Malaysia, 43400 UPM Serdang, Selangor Darul Ehsan, Malaysia

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ABSTRACT

The agriculture industry is one that is highly resource- and labour-intensive. As such, farmers are increasingly turning to technology and automation to address this issue. However, agricultural robots are far too complicated, slow, and costly to be made publicly available. As a result, the agriculture sector still lags behind in integrating modern technologies. This research paper details the development of a low-cost agricultural robot for spraying fertilizers and pesticides in agriculture fields as well as for general crop monitoring. The prototype system is a two-wheeled robot that consists of a mobile base, a spraying mechanism, a wireless controller for controlling the robot movement, and a camera for crop health and growth monitoring as well as detecting the presence of pests in the agriculture field. Tests conducted on the prototype system show that while the productivity of the robot in terms of crop coverage is slightly lower than a human worker, the labour cost savings afforded by the agricultural robot prototype is much greater as it functions completely in an autonomous mode and only requires the operator to control the robot when placing it at the start of the crop path. Furthermore, the prototype system also provides greater resource savings and reduction in the contamination of underground water sources due to leeching process, thus achieving precision agriculture goals. Lastly, the excellent battery life of the prototype system ensures that there will be no increase in the operation times and reduction in the efficiency of the fertilizer and pesticide spraying process due to the recharging times when replacing human workers. Future recommendations include making the agricultural robot fully autonomous, using either a rail- or line-following system, to further reduce the labour requirements and costs.

1. Introduction

Farmers are increasingly turning to technology to address a number of pressing problems in the agriculture industry, such as the growing global shortage of food and dwindling agricultural workforce [1–8]. Agricultural robots automate slow, repetitive, and dull tasks for farmers, allowing them to focus on improving production yields, while increasing farm efficiency as well as reducing the labour requirements and overall operating costs [9,10].

Agricultural robots also enable precision agriculture, in which resources are distributed more efficiently, leading to significant savings in resource use [11]. Currently, advanced robotic systems are utilised in crop harvesting and picking process, weed control,

* Corresponding author.
E-mail addresses: ssalama@uniten.edu.my (S.S.H. Hajjaj), thariq@upm.edu.my (M.T.H. Sultan).

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mowing, seeding, as well as sorting and packing agriculture produce [12–18]. One area where robots are perfectly suited to be used in agriculture operations is the spraying of fertilizer and pesticides [19,20].

To maintain yields, crops require regular fertilizer and pesticide application. Manual fertilizer and pesticide application by workers with knapsack sprayers are methods of the past which are not only highly inefficient and time-consuming, but also result in high labour requirements and costs to cover large agriculture fields [21,22].

Fertilizer and pesticide spraying robots can carry large storage reservoirs, be operated safely and even autonomously, and be deployed at a fraction of the cost compared to the traditional methods. In fact, it is estimated that fertilizer and pesticide spraying by agricultural robots can reduce labour requirements by up to five times compared to human workers with knapsack sprayers [23,24].

Several agricultural robots that can carry out some of these operations are already available, while many others will hit the market soon. Today, however, agricultural robots are far too complicated, slow, and costly to be made publicly available to everyone. As a result, although the agriculture sector in Malaysia contributes massively to the economy of the country, it is still carried out in the conventional ways and lags behind in integrating modern technologies such as agricultural robots due to the high costs of these systems [25–30].

This research work aims to develop a low-cost agricultural robot for spraying fertilizers and pesticides in the agriculture fields. In order to keep the costs to a minimum, the fertilizer and pesticide spraying robot prototype was assembled using simple, cost-effective, and off-the-shelf components.

The agricultural robot developed for this research work focuses on two applications, namely fertilizer and pesticide spraying as well as general crop monitoring. The prototype system is a two-wheeled robot that consists of a mobile base, a wireless controller for controlling the movement of the robot, and a camera providing a live-video feed for general crop health and growth monitoring as well as detecting the presence of pests in the agriculture field. The agricultural robot operates in accordance to the commands of an operator.

2. Materials and methods

2.1. Description of the prototype system

The concept design of the agricultural robot for fertilizer and pesticide spraying is a two-wheeled robot, consisting of a mobile base that is controlled by an operator. The agricultural robot prototype was designed to be small and lightweight to ease manoeuvrability around crops in an agriculture field and to prevent damage to the crops and soil structure.

The agricultural robot can spray fertilizers and pesticides onto each individual plant in the crop. The prototype design, as shown in Fig. 1, includes a liquid sprayer to operate the spraying process. The spray system was designed to provide only the optimal required quantity of fertilizers and pesticides to individual plants, thus reducing wastage and achieving precision agriculture goals.

The spraying mechanism utilises liquid fertilizers and pesticides instead of the granule or pallet types. This is because liquid fertilizers can be absorbed by plants through their leaves as opposed to being absorbed by their roots, which ensures that these nutrients are available to the plants almost immediately, compared to dry fertilizers which are slow-release and can take up to a month to be absorbed by the plants. Liquid pesticides, meanwhile, are far more efficient at targeting and destroying pests in a short amount of time.

The agricultural robot prototype uses two outdoor wheels and a caster for ease of movement on soil and rough surfaces in an agriculture field. The agricultural robot can be easily steered using the wheels by braking one wheel and moving the other wheel forward. For example, if the robot is to be steered towards the left direction, the left wheel is braked while the right wheel is moved forward.

In order to make even tighter turns, the wheels can be moved in opposite directions. For example, in order to make a sharp right turn, the left wheel is moved forward while the right wheel is moved in reverse. Utilising this design with two wheels and a caster for the prototype system is mechanically simpler than adding a differential gear and a rack and pinion steering, which in turn reduces the overall cost of the agricultural robot, ensuring a low-cost system.

The agricultural robot prototype is comprised of an autonomous mode and a manual mode. The robot is first moved manually by the operator using the controller from one path to the next. Once optimally placed in the crop path, the autonomous mode can be launched in which the robot travels in a straight line while operating the spraying mechanism at set intervals before coming to a stop at the end of the crop path based on the predetermined travel distance. The operator can then move the robot manually on to the next path before repeating the process.

An action camera mounted onto the agricultural robot prototype, as shown in Fig. 2, provides a live-video feed to monitor the movement of the robot in the agriculture field during the fertilizer and pesticide spraying process. This will ease the manual control and placement of the robot by the operator. Besides that, the camera will also assist farmers in monitoring the general crop health and growth as well as detecting the presence of pests in the agriculture field.

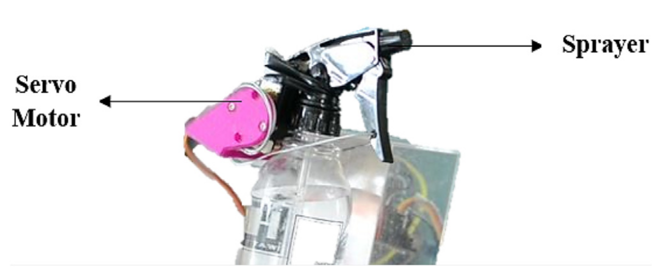

Fig. 1. Prototype of the agricultural robot spraying mechanism.

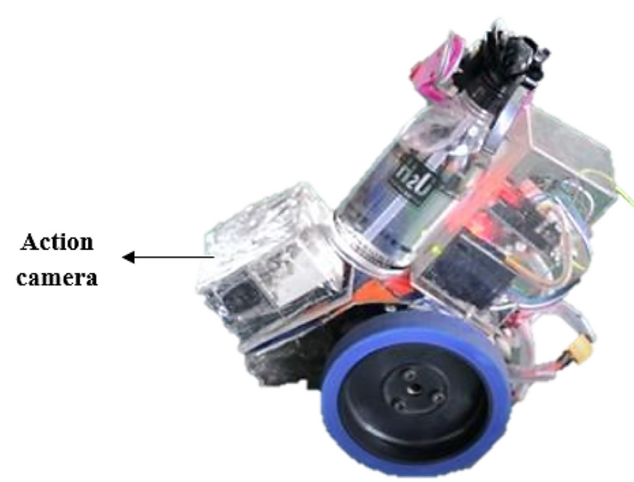

Fig. 2. Action camera attachment on the agricultural robot prototype.

2.2. Components of the prototype system

The agricultural robot prototype consists of two geared DC motors–each with a voltage and current rating of 5 V and 0.2 A respectively–driving each wheel to enable movement of the robot base. For this application, DC motors were selected due to their high torque characteristics, good reliability, and low maintenance requirements. The high torque and precise speed regulation afforded by the DC motors ensure that the robot can overcome loose soil or muddy surfaces as well as rough terrains in the agriculture fields without issue.

The DC motors are driven by a low-cost L298N motor driver. The motor driver acts as a current amplifier by receiving a low-current control signal from a microcontroller and converting it to a higher-current signal which can drive a motor. The L298N motor driver is powerful enough to drive motors of up to 2 A per channel with a voltage rating of 5–35 V, which is adequate for the DC motors used in this prototype system. The L298N motor driver allows speed and direction control of the two DC motors at the same time.

The microcontroller transmits linear speed and steering instructions using digital signals to the motor driver which, in turn, controls the speed and direction of rotation of the DC motors. The microcontroller used for the prototype system is an Arduino Uno. The Arduino Uno is a low-cost and widely available microcontroller with an adequate processing power for this application and can be programmed easily via the Arduino Integrated Development Environment (IDE).

Next, a controller is required to govern the movement of the agricultural robot prototype. For this application, a remote-control system was utilised. Remote control is meant to control one or more machines from a distance. In particular, a remote-controlled robot is defined as a robot that is controlled by means that do not limit its movement to external media, such as wiring between the controller and the robot. A wireless PlayStation 2 controller was used to control the agricultural robot prototype as the existing library in the Arduino IDE makes it quick and simple to program compared to other wireless systems such as Bluetooth controllers.

Additionally, an MG995 metal gear servo motor was utilised to operate the fertilizer and pesticide spraying mechanism on the agricultural robot prototype. When activated, the servo motor triggers the spraying mechanism which sprays the liquid fertilizer and pesticide onto the leaves of the crop in the agriculture field.

Lastly, a GoPro Hero 5 action camera was utilised to monitor the movement of the robot in the agriculture field during the fertilizer and pesticide spraying process, as well as to assist the farmers in monitoring the general crop health and detecting the presence of pests. The GoPro Hero 5 was selected, thanks to its small, lightweight, rugged, water-resistant, and easy-to-install characteristics.

2.3. Components of the prototype system

The frame of the agricultural robot prototype was first fabricated using Perspex sheets in order to keep fabrication costs at a minimum. Perspex also has high strength, lightweight, durable, and corrosion resistant properties which makes it perfect for this application. The frame of the robot provides structural rigidity for the attachment of hardware components to perform the fertilizer and pesticide spraying tasks, while providing protection against accidental splashes from the spray for the sensitive electronic components.

Next, the spraying mechanism, along with a storage reservoir for the liquid fertilizer and pesticide, in this case a 400 ml plastic bottle, was attached to the robot base. The spraying mechanism trigger was attached to the shaft of the servo motor using a fishing line. The servo motor was then connected to the microcontroller. The servo motor was programmed to pull the trigger of the spraying mechanism based on the timing intervals set in the programming of the Arduino Uno microcontroller. The servo motor can be powered directly via the digital pins on the Arduino Uno without the need of an additional motor driver.

The two outdoor wheels and caster were attached to the robot frame to enable motion of the agricultural robot. The wheels were connected to the DC motors which were connected to the L298N motor driver, which was then connected to the Arduino Uno microcontroller. The speed of the DC motors was governed by controlling the input voltage to the motors using a method known as Pulse Width Modulation (PWM). PWM is a technique which adjusts the average value of the voltage that is received by the motors by turning on and off the power at a fast rate. The average voltage depends on the duty cycle, or the amount of time the signal is on versus the amount of time the signal is off in a single period of time, as shown in Fig. 3.

The functions to control the movement of the robot were programmed into the Arduino Uno microcontroller using the Arduino IDE, as shown in Fig. 4. The agricultural robot prototype is able to move in four directions, namely forward, backward, left, and right. An additional stop function ensures that the robot remains stationary pending further commands. An autonomous mode function was also programmed into the microcontroller which moves the agricultural robot in a straight line while operating the servo motor and the spraying mechanism at set intervals before coming to a stop at the end of the crop path based on the travel distance set.

The PS2 controller functions were similarly programmed into the microcontroller to allow operators to control the movement of the robot via remote-control. The movement of the robot is controlled using the arrow buttons on the PS2 controller, as opposed to toggling the joystick, to ensure ease of control. The movement functions were mapped to the respective buttons on the PS2 controller. For example, the left arrow button on the controller was mapped to the left movement function. Thus, if the operator presses the left arrow button on the controller, the robot turns left. The autonomous mode function was programmed to launch at the press of the red circular button on the controller.

The GoPro Hero 5 action camera was mounted at the front of the robot in a clear Perspex casing to assist the operators during the fertilizer and pesticide spraying process and in crop monitoring. Using the camera, the operators can accurately manoeuvre the robot around crops and in tight spaces before placing the robot in the optimum position for the spraying process. The camera broadcasts a live-video feed over a Wi-Fi network which can be viewed by users on smart devices via the accompanying GoPro mobile application.

A rechargeable 12 V lithium polymer (LiPo) battery with a 3000 mAh capacity was used to power the agricultural robot prototype. A lithium polymer battery is a rechargeable battery of lithium-ion technology using a polymer electrolyte instead of a liquid electrolyte. The battery was connected to the Arduino Uno microcontroller and motor driver to power all the electronic com-

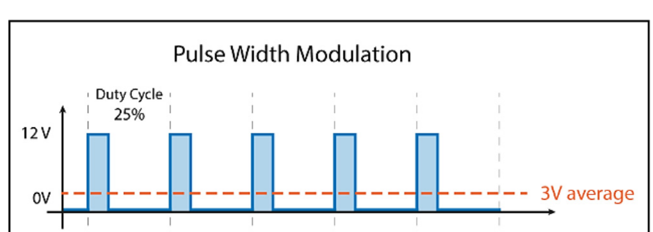

Fig. 3. Pulse width modulation technique.

```
void forward(int SForward)
{
  analogWrite(PWM1,SForward);
  analogWrite(PWM2,SForward);

  digitalWrite(DIR1,HIGH);
  digitalWrite(DIR2,HIGH);          //motor movement functions
}
```

Move Forward

```
void backward(int SBackward)
{
  analogWrite(PWM1,SBackward);
  analogWrite(PWM2,SBackward);

  digitalWrite(DIR1,LOW);
  digitalWrite(DIR2,LOW);
}
```

Move Backward

```
void Stop()
{
  analogWrite(PWM1,0);
  analogWrite(PWM2,0);
}
```

Stop

```
void Left(int SLeft)
{
  analogWrite(PWM1,SLeft);
  analogWrite(PWM2,SLeft);

  digitalWrite(DIR1,LOW);
  digitalWrite(DIR2,HIGH);
}
```

Move Left

```
void Right(int SRight)
{
  analogWrite(PWM1,SRight);
  analogWrite(PWM2,SRight);

  digitalWrite(DIR1,HIGH);
  digitalWrite(DIR2,LOW);
}
```

Move Right

Fig. 4. Code to control the movement of the agricultural robot prototype.

ponents including the DC motors and servo motor. A switch was connected to the battery to enable users to switch the robot on or off in order to conserve energy. The camera is powered by its own built-in rechargeable battery which further simplifies the wiring connections. The fully assembled agricultural robot prototype is shown in Fig. 5.

2.4. Testing procedures

The agricultural robot prototype was tested in a small greenhouse with Rosemary crops. Rosemary plants grow to about three feet tall which is suitable for the height of the robot prototype. As shown in Fig. 6, the layout of the greenhouse consists of two crop paths of 20 m length with the Rosemary plants on either side, labelled as Point 1.

The agricultural robot prototype was placed at the starting point, labelled as Point 2, and moved based on the direction of the red arrows. As shown in Fig. 7, the robot was set to the auton-

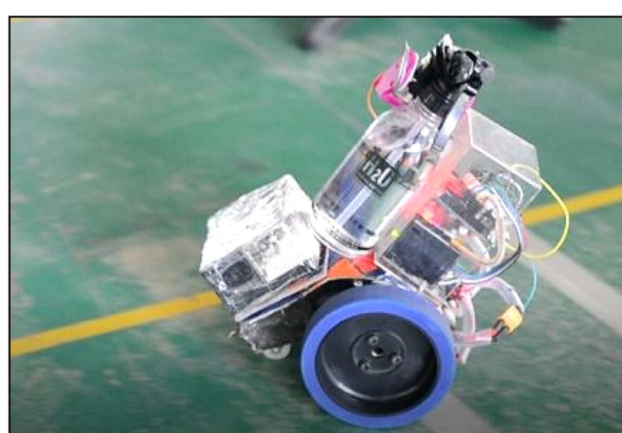

Fig. 5. Fully assembled agricultural robot prototype.

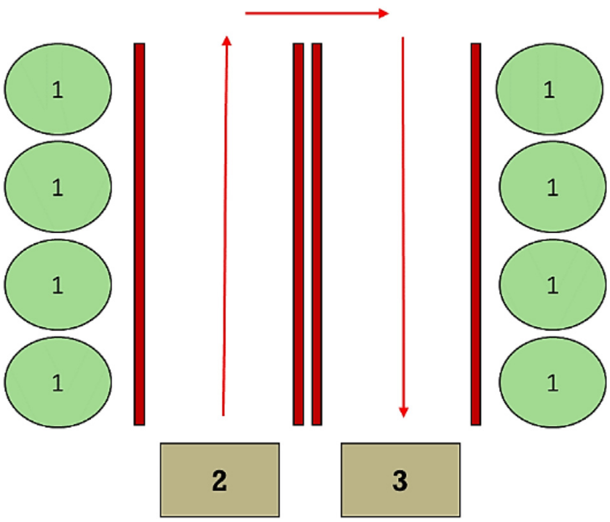

Fig. 6. Layout and path plan of the tested greenhouse.

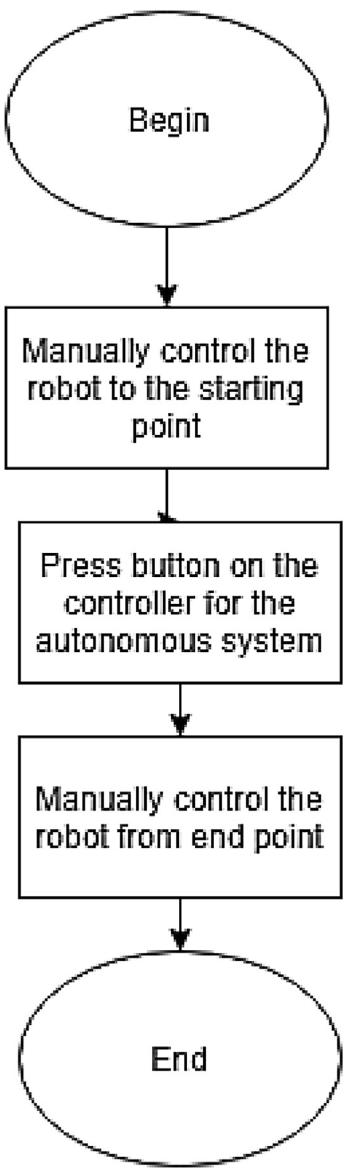

Fig. 7. Flowchart of the agricultural robot prototype's motion.

omous mode in which it was programmed to travel in a straight line for 20 m while operating the spraying mechanism for 1 s with an interval of 2 s between each spray. As such, the liquid fertilizer or pesticide was sprayed onto the leaves of the Rosemary plants on the left of the path.

At the end of the first path, the robot stopped, and the operator took over using the manual mode. The operator then steered the robot to the starting point of the second path with the help of the attached camera. Once positioned optimally at the starting point of the second path, the autonomous mode was launched once again and the robot repeated the spraying process until it reaches the end point, labelled as Point 3.

3. Results and discussion

3.1. Spray test

In order to validate that the agricultural robot prototype is capable of reducing labour requirements and the associated costs for the fertilizer and pesticide spraying process, the number of plants covered by the robot in 5 min was compared to a human worker using a knapsack sprayer. For this test, the liquid fertilizer and pesticide was replaced with water in order to reduce the overall testing costs.

As shown in Table 1, the agricultural robot prototype was able to spray liquid fertilizers and pesticides on 20 plants per minute using the autonomous mode as opposed to 30 plants per minute by the human worker with a knapsack sprayer. This led to a total of 100 plants covered by the robot in 5 min compared to 150 plants by the human worker.

While the productivity of the robot in terms of the crop coverage is slightly lower than that of the human worker, the labour cost savings afforded by the agricultural robot prototype is much greater as it functions completely autonomously and only requires the operator's control when it needs to be placed at the start of the crop path.

As such, the labour cost of an additional worker for the fertilizer and pesticide spraying process can be completely eliminated. This is especially true in large farms where multiple workers are required for the process. Using multiple agricultural robots for this process results in long-term cost savings as the robots need to be purchased only once and maintained intermittently, as opposed to paying workers by the hour.

Moreover, as shown in Fig. 8, the agricultural robot prototype targets and sprays the liquid fertilizer and pesticide only on the plants and not in the spaces between individual plants, thanks to the 2-s interval between consequent sprays, as opposed to human workers with knapsack sprayer that flood the entire crop path with liquid fertilizer and pesticide. In fact, it was determined that after the 5-min spray test, the robot had used only 200 ml of the liquid fertilizer compared to 1000 ml by the human worker. Thus, the prototype system is able to not only reduce the labour requirements and costs, but also result in greater resource savings and reduction in the contamination of underground water sources due to leeching.

Table 1
Plant coverage by robot prototype vs human worker.

Minutes	Number of plants sprayed by robot prototype	Number of plants sprayed by human worker
1	20	30
2	20	30
3	20	30
4	20	30
5	20	30
Total	100	150

Fig. 8. Liquid fertilizer and pesticide spraying process.

3.2. Battery life test

A battery life test was conducted on the agricultural robot prototype to ensure that it is able to perform all the required functions including liquid fertilizer and pesticide spraying as well as general crop monitoring over an extended period of time. As the prototype system was developed to replace human workers to reduce the labour requirements and costs, a good battery life is essential so that the robot needs not to be recharged often which increases the operation times and reduces efficiency. As the robot base and action camera are powered by separate battery packs, the time taken for both batteries to be depleted from a full battery level was tested.

As shown in Fig. 9, the battery life test for the robot base was conducted by running the agricultural robot prototype continuously over the length of the first crop path under the autonomous mode. During this time, the spraying mechanism was activated intermittently to simulate a real-world usage. Once the robot reached the end point of the first crop path, the operator took over control of the robot using the manual mode and placed it at the start point of the second crop path. The autonomous mode was reactivated and the robot travelled down the second crop path towards the end point before the operator manoeuvred the robot back to the start point of the first crop path to repeat this process. The action camera was switched on and the live-video feed, broadcasted over a local Wi-Fi network provided by a mobile hotspot router, was viewed on a smartphone.

Based on the battery life test, it was determined that the robot base takes 6.5 h to completely deplete from a full battery level. The action camera, meanwhile, was determined to have a battery-life rating of 8 h. These results are rather respectable as a regular fertilizer and pesticide spraying shift with human workers lasts 3 h with a break of 2 h between consecutive shifts over an 8-hour workday. As such, the agricultural robot prototype can last for up to two shifts and be recharged during the shift break. Thus, there will not be an increase in the operation times and reduction in the efficiency of the fertilizer and pesticide spraying process due to the recharging times when human workers are replaced with the prototype system. The recharging duration for the robot base and action camera are 1.5 h and 45 min, respectively.

Fig. 9. Agricultural robot prototype moving along the crop path.

4. Conclusion

The objective of this research work was to develop a low-cost agricultural robot to spray fertilizers and pesticides in agriculture fields as well as for general crop monitoring. The prototype system is a two-wheeled robot that consists of a mobile base, a spraying mechanism, a wireless controller to control the movement of the robot, and a camera for crop health and growth monitoring as well as detecting the presence of pests in the agriculture field.

Tests conducted on the agricultural robot prototype showed that it could perform as required under real-world usage scenarios. The spray test shows that the robot is able to spray liquid fertilizers and pesticides on 20 plants per minute using the autonomous mode as opposed to 30 plants per minute by the human worker with a knapsack sprayer.

While the productivity of the robot in terms of crop coverage is slightly lower than a human worker, the labour cost savings afforded by the agricultural robot prototype is much greater as it functions completely in an autonomous mode and only requires the operator's control to place the robot at the start of the crop path.

Furthermore, the agricultural robot prototype targets and sprays the liquid fertilizer and pesticide only on the plants and not in the spaces between individual plants, as opposed to the human workers with knapsack sprayer that flood the entire crop path with liquid fertilizer and pesticide. Thus, the prototype system is able to not only reduce the labour requirements and costs, but also result in greater resource savings and reduction of the contamination in underground water sources due to leeching process.

As for the battery life test, it was determined that the robot base takes 6.5 h to completely deplete from a full battery level. The action camera was determined to have a battery life rating of 8 h. These results are rather respectable as a regular fertilizer and pesticide spraying shift with human workers lasts 3 h with a break of 2 h in between consecutive shifts over an 8-hour workday. As such, the agricultural robot prototype can last for up to two shifts and be recharged during the shift break. Thus, there will not be an increase in the operation times and reduction in the efficiency of the fertilizer and pesticide spraying process due to the recharging times when human workers are replaced.

While the prototype system has successfully achieved its objective of reducing the labour requirements and costs for the fertilizer and pesticide spraying process, one recommendation has been identified for future work. By making the robot fully autonomous, by using either a rail- or line-following system, the labour costs can be further reduced as an operator is not required to manually steer the robot to each crop path.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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