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Design and Development of an Agricultural Robot for Crop Seeding

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Abstract

Crop seeding is a time-consuming and tedious activity for farmers and is only exacerbated in large agriculture fields. Manually sowing seeds by hand is a highly inefficient process that requires a lot of human effort and can lead to health concerns for farmers, while spreading seedlings using tractors results in a high wastage of seedlings. This research paper describes the development of a low-cost agricultural robot for crop seeding. The prototype system consists of two parts, namely a mobile base for robot movement and a seeding mechanism attached to the mobile base for crop seeding application. The mobile base has a four-wheel design to ease movement on uneven terrains, while the seeding mechanism uses the concept of a crank-slider to continuously inject seedlings into the ground. Crop seeding tests show that the robot is able to sow 138 seedlings in 5 minutes, with an accuracy of 92%, compared to 102 seedlings by human workers. This demonstrates an increase in the crop seeding efficiency of over 35%. As for the battery life test, it was determined that the robot can function for up to 4 hours on a single charge. Thus, there will not be an increase in the operation time and reduction in the efficiency of the crop seeding process due to the recharging times when human workers are replaced with the prototype system. The recharging duration for the robot power supply is 1.5 hours. While the prototype system has successfully achieved its objective of reducing human interference, labour requirement, and the overall operating costs in the field of agriculture for crop seeding process, by making the robot fully autonomous, using either a rail- or line-following system, labour costs can be further reduced as an operator is not required to manually steer the robot to each seeding path.

Keywords: Precision agriculture; agricultural robot; seeding; sowing; crops

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1. Introduction

Agricultural robots are seen as one of the key trends that will deeply influence the agriculture industry in the near future. At the heart of this phenomenon is the need to significantly increase the crop production yields. With the global population projected to reach approximately 10 billion by 2050, agricultural consumption is expected to increase by a massive 70%, a figure further complicated by the dwindling agricultural workforce in developing countries [1-8].

Agricultural robots automate slow, repetitive, and dull tasks for farmers, allowing them to focus on improving the production yields, while increasing farm efficiency as well as reducing labour requirements and the 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 and contributing to a lower environmental impact [11].

In the field of agriculture, crop plantation begins with ploughing the land and sowing seeds. The traditional method of manually sowing seeds by hand is a highly inefficient and time-consuming process that requires a lot of human effort and can lead to health issues for the farmers due to excessive bending and ergonomic strain [12-15].

With the rise of large agriculture fields all over the world, traditional methods of sowing seeds have been unable to meet the increased crop seeding requirements. As such, agriculture machinery designed specifically for crop seeding were introduced. However, spreading seedlings using tractors results in a high wastage of seedlings and an irreversible damage to agriculture fields due to the compaction of soil from the weight of the heavy machinery [16-18].

Therefore, one area where robots are perfectly suited to be used in the agriculture operations is the crop seeding process [19-21]. Robot seeders 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 the robot seeders can improve the crop seeding efficiency by up to three times compared to the manual seeding by human workers [22-26]. Robot seeders also do not damage the soil structure in an agriculture field as opposed to heavy machinery [27-30].

This research work aims to develop a low-cost agricultural robot for crop seeding in agriculture fields. The driving force behind this work is to reduce human interference, labour requirements, and the overall operating costs in the field of agriculture. In order to keep the costs to a minimum, the robot seeder prototype was assembled using simple, cost-effective, and off-the-shelf components.

The agricultural robot developed in this research work consists of two parts, namely a mobile base for robot movement and a seeding mechanism attached to the mobile base for crop seeding application. The mobile base has a four-wheel design for ease of movement on uneven terrains, while the seeding mechanism uses the concept of a crank-slider to continuously inject seedlings into the ground. The agricultural robot operates in accordance to the commands of an operator.

2. Methodology

2.1. Description of the prototype system

The concept design of the agricultural robot for crop seeding consists of two parts, namely a mobile base for robot movement and a seeding mechanism attached to the mobile base for crop seeding application. The mobile base has a four-wheel design and 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.

For the seeding mechanism, the agricultural robot prototype utilises a crank-slider injection mechanism to perform the crop seeding. As shown in Figure 1, this mechanism uses the concept of a crank-slider to continuously inject seedlings into the ground. This is because every seedling has its own ideal seeding depth to ensure a successful germination.

For instance, corn seedlings have an ideal seeding depth of approximately 1.5 to 2.5 inches. Planting corn seedlings too shallow can lead to an unsuccessful germination due to the lack of soil contact and moisture and can also end up being eaten by birds or rodents, while planting the seedlings too deep in the soil can cause issues with sprouting due to the compaction of soil. An ideal planting depth also ensures a strong nodal root system which is vital for the uptake of water, nutrients, and minerals needed for the optimal plant development.

The crank-slider mechanism is also attached to a seedling dispensing mechanism consisting of a circular plate with a scoop inside a seedling storage container attached to the robot. The purpose of this circular plate is to utilise the motion of the crank-slider mechanism to dispense the seedlings out of the storage container and into a hose attached under the storage container to be spread out onto the seeding path.

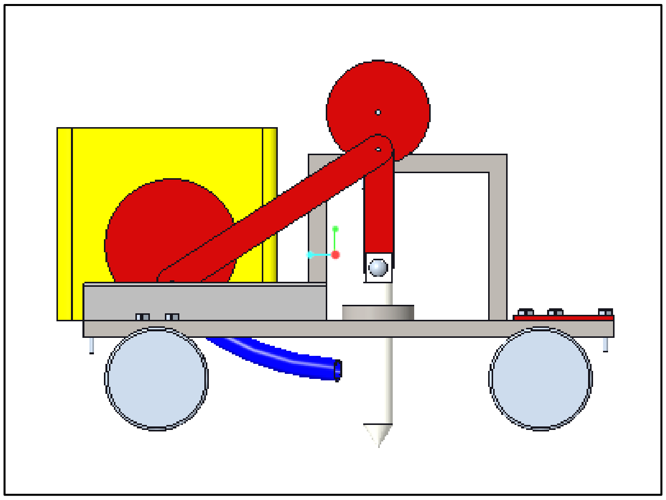


Fig. 1. Crank-slider based seeding mechanism.

The seeding mechanism was designed to accurately sow the plant seedlings one at a time, as opposed to the conventional seed spreaders attached to the back of tractors, thus improving the seedling germination success rate, reducing the wastage of seedlings, and achieving precision agriculture goals.

The agricultural robot prototype uses four outdoor rubber wheels to ensure ease of movement on loose, uneven soil and rough surfaces in an agriculture field. The agricultural robot can be easily steered using the wheels by braking one set of the wheels and moving the opposite set forward. For example, if the robot is to be steered towards the left direction, the front and rear left wheels are braked while the front and rear right wheels are 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 front and rear left wheels are moved forward while the front and rear right wheels are moved in reverse. Utilising this design for the prototype system is mechanically simpler than adding a differential gear and a rack and pinion steering, which 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 seeding path, the autonomous mode is launched, in which the robot travels in a straight line while operating the seeding mechanism, before coming to a stop at the end of the path based on the predetermined travel distance. The operator then moves the robot manually to the next path before repeating the process.

2.2. Components of the prototype system

The agricultural robot prototype consists of four 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 offered 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 two low-cost L298N motor drivers. The motor drivers act as a current amplifier by receiving a low-current control signal from a microcontroller and converting it into 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 the prototype system. The L298N motor driver allows speed and direction control of 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 Mega. The Arduino Mega 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, a fifth DC motor, with a voltage and current rating of 5 V and 0.1 A respectively, along with a third L298N motor driver was utilised to operate the crank-slider injection mechanism for crop seeding. When activated, the DC motor rotates the crank which drives the slider mechanism downwards into the ground to insert the seedlings into the soil. The rotation of the crank-slider mechanism, in turn, rotates the seedling dispensing mechanism for spreading the seeds.

2.3. Assembly of the prototype system

Firstly, the agricultural robot prototype was designed using a computer-aided design (CAD) software, namely SolidWorks, as shown in Figure 2. Next, the frame of the robot was fabricated using hollow square aluminium tubes, bolted at each corner using angle brackets, forming a rectangular base. Two aluminium tubes were bolted across the centre of the base which act as support beams in order to minimise wobble of the frame when in motion and ensure structural rigidity of the agricultural robot.

Another two aluminium tubes were welded to the base to support the DC motor utilised for the seeding mechanism. An inverted U-shaped bracket, fabricated out of the same hollow square aluminium tubes, was welded to these two beams to hold the DC motor and crank-slider components for the seeding mechanism in place.

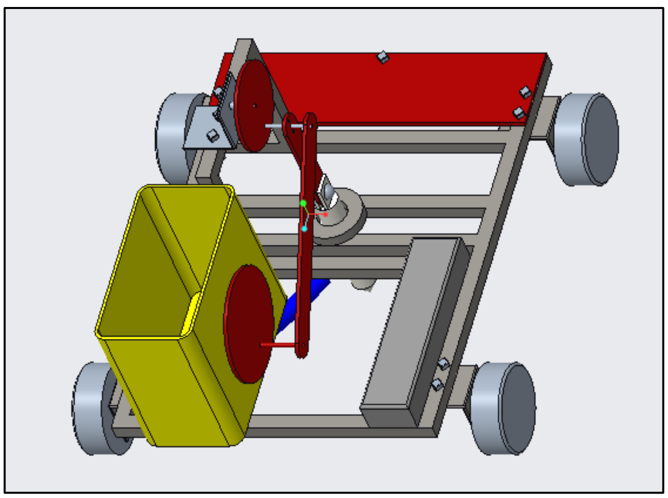
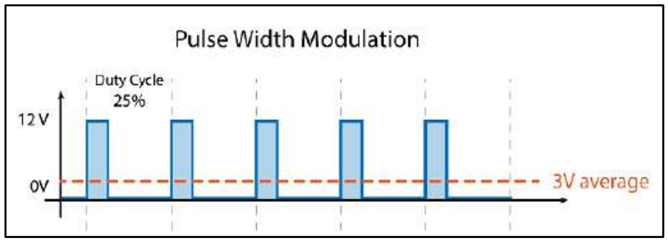


Fig. 2. CAD model of the agricultural robot prototype.

Next, four metal brackets designed to hold the four outdoor rubber wheels in place, along with the corresponding DC motors, were bolted to all the four corners of the robot base. Double bolts were utilised to ensure a rigid support for the motors and wheels. The wheels were then attached to the brackets to enable motion of the agricultural robot. The wheels were connected to the DC motors which were connected to the L298N motor drivers, which were then connected to the Arduino Mega 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 Figure 3.

The functions to control the movement of the robot were programmed into the Arduino Mega microcontroller using the Arduino IDE, as shown in Figure 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 to move the



agricultural robot in a straight line while operating the seeding mechanism, before coming to a stop at the end of the path based on the travel distance set. The microcontroller and motor drivers were screwed onto an acrylic sheet panel at the front of the robot.

Fig. 3. Pulse width modulation technique.

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

```
void forward()
{
  digitalWrite(IN1,LOW);
  digitalWrite(IN2,HIGH);
  digitalWrite(IN3,LOW);
  digitalWrite(IN4,HIGH);          //motor movement functions
}

void backward()
{
  digitalWrite(IN1,HIGH);
  digitalWrite(IN2,LOW);
  digitalWrite(IN3,HIGH);
  digitalWrite(IN4,LOW);
}

void Stop()
{
  digitalWrite(IN1,LOW);
  digitalWrite(IN2,LOW);
  digitalWrite(IN3,LOW);
  digitalWrite(IN4,LOW);
}

void Right()
{
  digitalWrite(IN1,HIGH);
  digitalWrite(IN2,LOW);
  digitalWrite(IN3,LOW);
  digitalWrite(IN4,HIGH);
}

void Left()
{
  digitalWrite(IN1,LOW);
  digitalWrite(IN2,HIGH);
  digitalWrite(IN3,HIGH);
  digitalWrite(IN4,LOW);
}
```

The PS2 controller functions were similarly programmed into the microcontroller to allow the 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.

Next, the seedling storage container was fabricated using Perspex sheets. Perspex has high strength, lightweight, durable, and corrosion resistant properties which makes it perfect for this application. A hole was cut into the bottom of the container through which a rubber hose was fitted to dispense the seedlings onto the seeding path. The container was then attached to the back of the robot. A circular hole was cut into the right side of the container for the fitment of the circular plate and scoop which make up the seedling dispensing mechanism.

The circular plate and scoop, along with the crank-slider mechanism and its linkages, as well as the injection pole to place seedlings into the ground were 3D-printed using Polylactic Acid (PLA) filament, a plant-based plastic that is extremely durable and waterproof. This ensures that the seeding mechanism does not corrode under extended usage. The seeding mechanism was then attached to the robot base. The DC motor utilised for the seeding mechanism was bolted to the bracket, welded earlier to the robot frame, along with the other crank-slider components. The DC motor was connected to the crank mechanism and an L298N motor driver which was then connected to the microcontroller.

When activated, the DC motor rotates the crank which drives the injection pole attached to the slider downwards into the ground to insert the seedlings into the soil. As the crank-slider rotates, the circular plate rotates, and the scoop picks up the plant seedlings and funnels them into the rubber hose to be spread out onto the seeding path. The seeding mechanism was attached at the middle of the robot body to ensure robot stabilization. A hollow circular guide was fitted to the robot base to ensure the accuracy of the injection pole when the seedlings are placed into the soil.

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 Mega microcontroller and motor drivers to power all the electronic components. A switch was connected to the battery to enable users to switch the robot on or off in order to conserve energy. The fully assembled agricultural robot prototype is shown in Figure 5.

Fig. 5. Fully assembled agricultural robot prototype.

2.4. Testing procedures

The agricultural robot prototype was tested in an agricultural greenhouse provided by the Malaysian Agricultural Research and Development Institute (MARDI). As shown in Figure 6, the layout of the greenhouse consists of two seeding paths of 20 m in length each. The agricultural robot prototype was placed at the starting point, labelled as Point 1, and moved based on the direction of the red arrows.

As shown in Figure 7, the robot was set to the autonomous mode in which it was programmed to travel in a straight line for 20 m while operating the seeding mechanism at 30 rpm. This would result in a seeding rate of 1 seed every 2 seconds. As the robot has an average speed of 0.1 m/s, this results in a seeding interval of 0.2 m between consecutive plants. This gap between successive plants ensures an optimum plant growth.

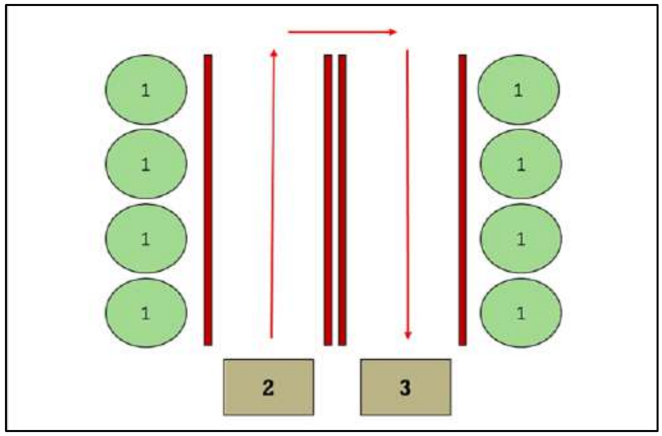


Fig. 6. Layout and path plan of the tested greenhouse.

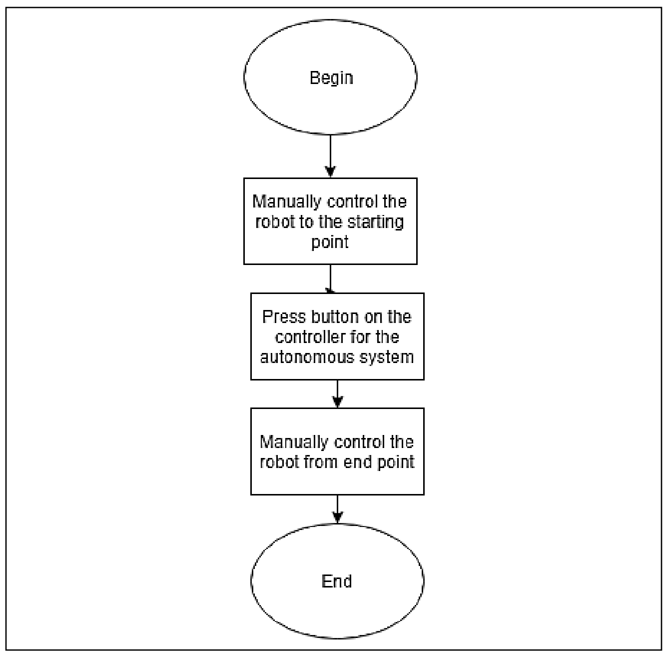


Fig. 7. Flowchart of the motion of the agricultural robot prototype.

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. Once positioned optimally, the autonomous mode was launched once again and the robot repeated the crop seeding process until it reaches the end point, labelled as Point 2.

3. Results and Discussion

3.1. Crop-seeding test

In order to validate that the agricultural robot prototype can reduce labour requirements and the associated costs for the crop seeding process, the number of seedlings sowed by the robot in 5 minutes was compared to that done manually by a human worker. For this test, the type of the seedling selected was corn seeds as they are large in size to simplify the seeding process and are easy to observe on the ground.

As shown in Table 1, the agricultural robot prototype should be able to, theoretically, sow 30 seeds per minute based on the robot motion and seeding mechanism speed. This would result in a total of 150 seedlings planted in 5 minutes. However, the actual number of seeds successfully planted can vary slightly due to the inaccuracy and lack of precision of the robot. As such, for this test, the robot was able to successfully sow 138 seedlings into the ground, resulting in a success rate of 92%.

Table 1. Crop seeding by robot prototype vs human worker.

Minutes	Theoretical no. of seeds (robot)	Actual no. of seeds (robot)	No. of seeds (human worker)
1	30	27	18
2	30	28	21
3	30	26	21
4	30	28	22
5	30	29	20
Total	150	138	102

Compared to the crop seeding rate of the human worker with 102 seedlings, the agricultural robot prototype performed much better, demonstrating an increase in the crop seeding efficiency of over 35%.

Thus, not only is the productivity of the robot in terms of crop seeding significantly higher than the human worker, but the labour cost savings afforded by the agricultural robot prototype is also much greater as it functions completely in an autonomous mode, as shown in Figure 8, and only requires the operator to control the robot to place it at the start of the seeding path.

As such, the labour cost of an additional worker for the crop seeding process can be completely eliminated. This is especially true in large farms where multiple workers are required for sowing the seedlings. 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.

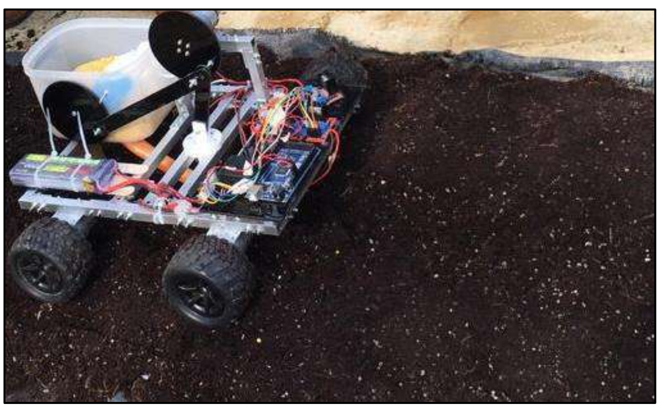


Fig. 8. Flowchart of the motion of the agricultural robot prototype.

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 for crop seeding process 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. The time taken for the robot's power supply to deplete from a full battery level was tested.

As shown in Figure 9, the battery life test for the robot base was conducted by running the agricultural robot prototype continuously over the length of the first seeding path in the autonomous mode. During this time, the seeding mechanism was activated intermittently to simulate a real-world usage. Once the robot reached the end point of the first path, the operator took over the control of the robot using the manual mode and placed it at the start point of the second seeding path. The autonomous mode is reactivated and the robot travels down the second seeding path towards the end point of the second path before the operator manoeuvred it back to the start point of the first path to repeat this process.

Fig. 9. Battery test of the agricultural robot prototype.

Based on the battery life test, it was determined that the agricultural robot prototype takes 4 hours to completely deplete from a full battery level. This result is rather respectable as a crop seeding shift with human workers lasts 3 hours with a break of 2 hours between consecutive shifts over an 8-hour workday. As such, the crop seeding robot can last for approximately one whole shift 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 crop seeding process due to the recharging times when human workers are replaced with the prototype system. The recharging duration for the robot's power supply is 1.5 hours.

4. Conclusion

The objective of this research work was to develop a low-cost agricultural robot for crop seeding in agriculture fields. The agricultural robot prototype developed for this research work consists of two parts, namely a mobile base for robot movement and a seeding mechanism attached to the mobile base for crop seeding application. The mobile base has a four-wheel design for ease of movement on uneven terrains, while the seeding mechanism uses the concept of a crank-slider to continuously inject seedlings into the ground. The agricultural robot operates in accordance to the commands of an operator.

Tests conducted on the agricultural robot prototype showed that it could perform as required under real-world usage scenarios. The crop seeding test shows that the robot is able to sow 138 seedlings in 5 minutes, with an accuracy of 92%, compared to 102 seedlings by human workers. This results in an increase in the crop seeding efficiency of over 35%. Besides, as the prototype robot functions completely in an autonomous mode and only requires the operator's control to place it at the start of the seeding path, greater the labour cost savings can be obtained. Lastly, with a respectable battery life of up to 4 hours on a single charge, the crop seeding robot can last for approximately one whole crop seeding shift, of 3 hours with human workers, and be recharged fully in 1.5 hours during the shift break, of 2 hours in between consecutive shifts, over an 8-hour workday. As a result, operation times and crop seeding efficiency will not be affected when replacing human workers with the prototype system.

While the prototype system has successfully achieved its objective of reducing human interference, labour requirement, and the overall operating costs in the field of agriculture for the crop seeding 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 seeding path.

Acknowledgements

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References

[1] United Nations, "World Population Projected to Reach 9.8 Billion in 2050," Department of Economic and Social Affairs, 2017.

[2] United Nations, "Global Agriculture Towards 2050," Food and Agriculture Organization of the United Nations, 2009.

[3] K. Thornton and S. Pradhan, "Is Agricultural Adaptation to Global Change on Track to Meet the Future Food Production Challenge?" Global Environmental Change, Vol. 52, pp. 37-48, 2018.

[4] R. Sonnino, C. Tegoni, and A. Cunto, "The Challenge of Systemic Food Change: Insights from Cities," Cities, Vol. 85, pp. 110-116, 2019.

[5] A. Dinar, A. Tieu, and H. Huynh, "Water Scarcity Impacts on Global Food Production," Global Food Security, Vol. 23, pp. 212-226, 2019.

[6] W. Silvade and N. Arun, "Urban Challenges and Opportunities to Promote Sustainable Food Security through Smart Cities and the 4th Industrial Revolution," Land Use Policy, Vol. 87, 2019.

[7] J. Erbaugh and B. Hansen, "Toward Sustainable Agriculture in the Tropics," World Development, Vol. 121, pp. 158-162, 2019.

[8] D. Blandford, J. B. Braden, and J. S. Shortle, "Economics of Natural Resources and Environment in Agriculture," Encyclopaedia of Agriculture and Food Systems, pp. 18-34, 2014.

[9] D. McGowan and C. Vasilakis, "Reap What You Sow: Agricultural Technology, Urbanization and Structural Change," Research Policy, Vol. 48, Issue 9, 2019.

[10] J. P. Vasconez and G. A. Kantor, "Human-Robot Interaction in Agriculture: A Survey and Current Challenges," Biosystems Engineering, Vol 179, pp. 35-48, 2019.

[11] A. Ullah, J. Ahmad, K. Muhammad, and M. Y. Lee, "A Survey on Precision Agriculture: Technologies and Challenges," International Conference on Next Generation Computing, 2017.

[12] V. Marinoudi, C. G. Sorenson, S. Pearson, and D. Bochtis, "Robotics and Labour in Agriculture. A Context Consideration," Biosystems Engineering, Vol. 184, pp. 111-121, 2019.

[13] S. Sakai, K. Osuka, and M. Umeda, "Global Performance of Agricultural Robots," International Conference on Intelligent Robots and Systems, Vol. 1, pp. 461-466, 2004.

[14] N. Ito, "Agricultural Robots in Japan," International Workshop on Intelligent Robots and Systems: Towards a New Frontier of Applications, Vol. 1, pp. 249-253, 1990.

[15] K. Shaik, E. Prajwal, S. B, M. Bonu, and V. R. Balapanuri, "GPS based Autonomous Agricultural Robot," International Conference on Design Innovations for 3C: Compute Communicate Control, pp. 100-105, 2018.

[16] X. Gao, "Review of Wheeled Mobile Robots' Navigation Problems and Application Prospects in Agriculture," IEEE Access, Vol. 6, pp. 49248-49268, 2018.

[17] M. H. Ko, B. Ryuh, K. C. Kim, A. Suprem, and N. P. Mahalik, "Autonomous Greenhouse Mobile Robot Driving Strategies from System Integration Perspective: Review and Application," Transactions on Mechatronics, Vol. 20, No. 4, pp. 1705-1716, 2015.

[18] S. Konam, R. N. Naga Srinivasa, and K. K. Mohan, "Design Encompassing Mechanical Aspects of ROTAAI: Robot to Aid Agricultural Industry," International Conference on Soft Computing and Machine Intelligence, pp. 15-19, 2014.

[19] M. Monta, N. Kondo, and Y. Shibano, "Agricultural Robot in Grape Production System," International Conference on Robotics and Automation, Vol. 3, pp. 2504-2509, 1995.

[20] P. V. S. Jayakrishna, M. S. Reddy, N. J. Sai, N. Susheel, and K. P. Peeyush, "Autonomous Seed Sowing Agricultural Robot," International Conference on Advances in Computing, Communications and Informatics, pp. 2332-2336, 2018.

[21] P. V. Santhi, N. Kapileswar, V. K. R. Chenchela, and C. H. V. S. Prasad, "Sensor and Vision based Autonomous AGRIBOT for Sowing Seeds," International Conference on Energy, Communication, Data Analytics and Soft Computing, pp. 242-245, 2017.

[22] B. S. Shivaprasad, M. N. Ravishankara, and B. N. Shoba, "Design and Implementation of Seeding and Fertilizing Agriculture Robot," International Journal of Application or Innovation in Engineering and Management, Vol. 3, Issue 6, 2014.

[23] T. Swapnil, M. L. Kasturi, P. Girish, and P. Rajkumar, "Design and Fabrication of Seed Sowing Machine," International Research Journal of Engineering and Technology, Vol. 4, Issue 9, 2017.

[24] A. Sneha, E. Abirami, A. Ankita, R. Praveena, and R. Srimeena, "Agricultural Robot for Automatic Ploughing and Seeding," Technological Innovation in ICT for Agriculture and Rural Development, pp. 17-23, 2015.

[25] H. Lin, S. Dong, Z. Liu, and C. Yi, "Study and Experiment on a Wheat Precision Seeding Robot," Journal of Robotics, 2015.

[26] N. S. Naik, V. V. Shete, and S. R. Danve, "Precision Agriculture Robot for Seeding Function," International Conference on Inventive Computation Technologies, pp. 1-3, 2016.

[27] K. Saravanan, S. P. Sundar, S. Rajendra, and K. Sathiya, "Design and Fabrication of Automatic Seed Sowing Robot for Agricultural Field," International Journal of Pure and Applied Mathematics, Vol. 120, No. 6, 2018.

[28] B. Deshmukh and D. Verma, "Fabrication and Implementation of Automatic Seed Sowing Machine," International Journal of Engineering Sciences and Research Technology, Vol. 7, No. 1, 2018.

[29] S. J. O. Corpe and L. Tang, "GPS-guided Modular Design Mobile Robot Platform for Agricultural Applications," International Conference on Sensing Technology, pp. 806-810, 2013.

[30] Z. Fan, Q. Qiu, and Z. Meng, "Implementation of a Four-Wheel Drive Agricultural Mobile Robot for Crop/Soil Information Collection on the Open Field," Youth Academic Annual Conference of Chinese Association of Automation, pp. 408-412, 2017.