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Unmanned Self-propelled Vegetable Seedling Planting Vehicle Based on Embedded System

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Agriculture is a labor-intensive traditional industry. As times change, more and more people are unwilling to engage in agriculture, resulting in a large shortage of agricultural manpower. Therefore, all parts of the world have begun to promote agricultural automation to solve the problem of serious shortage of manpower. In traditional agriculture, when transplanting vegetable seedlings, farmers need to bend down to dig holes for each vegetable seedling to be planted. This method is not only laborious but also extremely inefficient. In this study, we use a self-developed robotic arm combined with a traditional planter and motor to make an automatic planting machine to the achieve automatic planting of vegetable seedlings by the machine to reduce labor costs. This will further help agricultural automation.

1. Introduction

In recent years, owing to the negative growth of Taiwan's population, human resources have begun to diminish. Traditional industries are the first to bear the brunt. Many traditional industries are faced with a situation where no manpower is available, and they can only rely on hiring migrant workers to solve the problem of human resources. Southeast Asian countries are currently the main source of migrant workers in Taiwan. Because the wages of migrant workers have gradually increased in recent years, some countries have even established relevant laws to prevent labor outflow.(1) The above problems mean that Taiwan cannot rely solely on migrant workers to solve the problem of insufficient human resources in traditional industries.

In traditional agriculture, manpower is an indispensable and important resource. In recent years, the reduction of human resources and the poor working environment in traditional agriculture have caused many people to be unwilling to invest in traditional agriculture, and a large number of rural populations have moved out, leaving only the elderly in rural areas. To solve the above problems, the Taiwan government has vigorously promoted agricultural automation in recent years, hoping to improve the agricultural working environment. Taiwan's terrain is mostly mountainous, arable land is scarce, part of the farmland is deformed, and industrial roads are narrow. Therefore, Taiwan is not suitable for the use of large foreign

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agricultural machinery, and the arable land of many farmers is rented agricultural land, which cannot afford large and expensive agricultural machinery.

2. Motivation

Because traditional agriculture requires much human resources and the agricultural labor environment is harsh, many people are unwilling to engage in traditional agriculture. Therefore, Taiwan's agriculture can only rely on foreign labor to help with farming. There are many restrictions on foreign labor. For example, the Council of Agriculture restricts the number of foreign laborers to be hired (up to 35%) based on the total employee ratio. If necessary, additional mechanisms can be used, and the maximum ratio must not exceed 40%. Foreign laborers are also affected by the coronavirus disease (COVID-19). They need to be quarantined for 14 days, and the screening test result should be negative before they can start working. This prevents foreign laborers from entering agricultural work quickly, and the cost of pandemic prevention during the isolation period also increases the personnel cost considerably.

3. Robotic Arm System Design

The main focus of this study is the robotic arm. It is judged whether the robotic arm is correctly gripping the vegetable seedlings in the planter. During this period, other systems wait for the robotic arm to complete the action. The next step is to start sensing the distance between the car body and the mound. Figure 1 is a structural diagram of the system. It can be seen that in this research, we use robotic arms to replace manpower, saving manpower costs.

3.1 Embedded system—myRIO

myRIO is the latest embedded system development platform from National Instruments (NI) for teaching and student innovation applications. NI myRIO has Xilinx Zynq chips with dual-core ARM Cortex-A9 performance and Xilinx FPGA programmable I/O. Figure 2 shows an embedded entity diagram myRIO 1900.

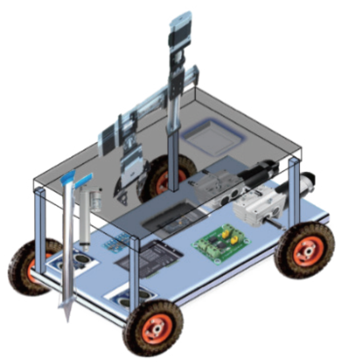


Fig. 1. (Color online) System structure diagram.

Fig. 2. (Color online) Entity diagram of NI myRIO1900.

3.2 Ball screw motor

Figure 3 shows the vegetable seedling planting tray. The main purpose of the self-developed robotic arm is to take the vegetable seedlings out of the plastic tray and put them into the planter, and the planter can then plant seedlings into the soil. Because the seedlings in the plastic tray have fixed intervals, and the seedlings themselves are relatively fragile, one must be very careful when picking up the seedlings. In this study, to achieve a certain accuracy when picking up the seedlings, the gripper jaw force must be controlled to a certain extent; a ball screw stepper motor and a servo motor gripper jaw are used to achieve this goal.(1)

The ball screw stepping motor combines a stepping motor with a platform and a screw. The stepping motor uses the step-by-step rotation characteristic to calculate a fairly accurate moving distance through the pitch between the screws, so that the platform can run accurately on the track. Therefore, the guide rail stepper motor is often used on high-precision instruments such as CNC machining tools and 3D printers. Figure 4 shows the entity diagram of the guide rail stepper motor.(2)

3.3 Robotic-arm-customized seedling gripper jaw

The type of machine gripping jaw used in this study is the parallel gripping jaw shown in Fig. 5. The angle of the parallel gripping jaw is convenient for gripping the seedlings, and the servo

Fig. 3. (Color online) Vegetable seedling tray.

Fig. 4. (Color online) Entity diagram of guide rail stepper motor.

Fig. 5. (Color online) Entity diagram of parallel gripper jaw.

motor can control the force when gripping the seedlings so that the seedlings will not be damaged. The seedlings should not be damaged so that they can grow as smoothly as the ordinary artificially planted seedlings. In this study, a pressure sensor module is added to the front of the customized mechanical gripper jaw, and the pressure of the gripper jaw can be sensed through the pressure sensor to determine whether the gripper jaw has caught the seedlings.

3.4 Automatic planter

Figure 6 shows the entity diagram of various vegetable seedling planters, which are quite long and heavy. Although these planters are already more labor-saving than traditional human planting, one can simply insert the planter into the soil and throw the vegetable seedlings into the planter and then lift the planter to transplant the vegetable seedlings into the soil.

A planter weighs about 5 kg, so it needs to use a motor that can go straight up and down and has enough torque. Therefore, an electric cylinder is combined with the planter. The use of an electric cylinder can ensure that the planter can be inserted into the soil completely. The entity diagram of the electric cylinder is shown in Fig. 7.

In this study, an infrared sensor is added to the top of the planter, and the infrared sensor signal is used to determine whether a vegetable seedling has fallen into the planter correctly. If it is not detected that the vegetable seedling has fallen into the planter, the robotic arm will be activated to clamp the vegetable seedling until the sensor detects that the vegetable seedling has fallen into the planter.

3.5 Drip irrigation system

Under the conditions of extreme global climate, Taiwan's weather has been quite unstable during the rainy season, and the country has experienced severe drought in recent years. Therefore, in this study, water will be sprayed on the vegetable seedlings immediately after

Fig. 6. (Color online) Entity diagram of various vegetable seedling planters.

Fig. 7. (Color online) Entity diagram of electric cylinder.

planting, and the Israeli drip irrigation method will be adopted. After planting a vegetable seedling, it is watered on the top, which can save a lot of water resources. Figure 8 shows a schematic diagram of drip irrigation.(3)

3.6 Robotic arm system process

Figure 9 shows the flow chart of the robotic arm. After the start, the *Z*-axis of the robotic arm moves down first and the *Y*-axis starts to move forward to the position of the vegetable seedling. The mechanical gripper is activated to determine whether the vegetable seedling is clamped through the pressure sensor. If the vegetable seedling is not clamped, the mechanical gripper will be restarted until it is determined that the vegetable seedling is clamped. After clamping the

Fig. 8. Schematic diagram of drip irrigation.

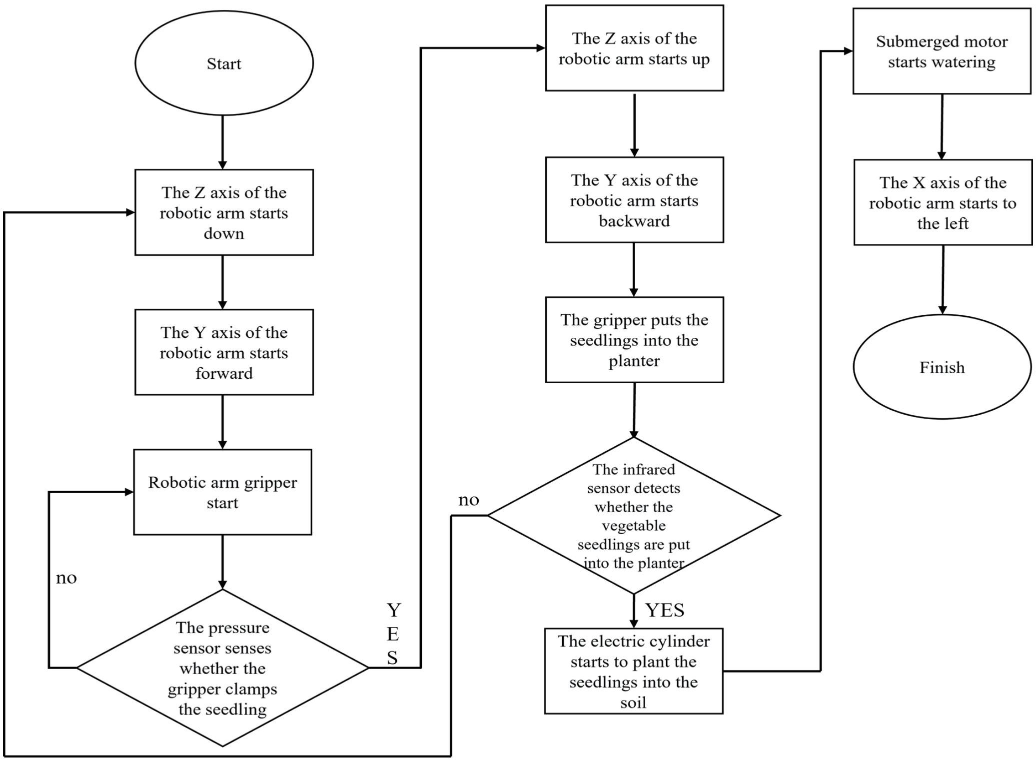


Fig. 9. Flow chart of robotic arm.

vegetable seedlings, the Z-axis of the robotic arm moves upward and pulls the vegetable seedlings out of the vegetable seedling plastic tray. After the vegetable seedlings are pulled out from the plastic plate, the Y-axis of the robotic arm moves back to the origin, and the mechanical gripper throws the vegetable seedlings into the planter. When the mechanical gripper drops the vegetable seedlings, the infrared sensor will sense whether the vegetable seedlings have entered the planter. If the infrared sensor senses that the vegetable seedlings have been dropped into the planter, the electric cylinder starts to plant the vegetable seedlings into the infrared sensor that detects whether the vegetable seedlings have entered the planter. When the vegetable seedlings are sensed, the robotic arm will move from the beginning until the vegetable seedlings are correctly dropped into the planter. If the infrared sensor senses that the vegetable seedlings have been dropped into the planter, the electric cylinder starts to plant the vegetable seedlings into the soil, the submersible motor starts to water the vegetable seedlings, and the X-axis of the robotic arm moves to the left. After the X-axis moves to the fixed point, the Z-axis of the robotic arm moves down again and repeats the above actions.

4. Motor Control System

4.1 Brushed DC electric motor

In this study, we consider the cost relationship and the difficulty of control, so a brushed DC electric motor is used as the power system of the self-propelled unmanned vehicle, and the power required for the robotic arm system and the planting system developed in this study is 24 V. It can be powered by a single power supply, minus the complexity of the power supply and wiring. Figure 10 is the physical diagram of the motor.

4.2 Ultrasonic ranging sensor

The ultrasonic sensor is composed of an ultrasonic transmitter (T), a receiver (R), and a control circuit. The distance to the obstacle is determined by calculating the time difference between launching and receiving. Figure 11 shows the entity diagram of the ultrasonic sensor.

Fig. 10. (Color online) Entity diagram of brushed DC electric motor.

Fig. 11. (Color online) Entity diagram of ultrasonic sensor.

Therefore, the ultrasonic sensor is also a very easy and convenient distance sensor to use, which can achieve obstacle avoidance function by detecting the distance by ultrasonic waves.[4]

In this study, we use two ultrasonic sensors as an obstacle avoidance system. Two ultrasonic sensors are added to the chassis in the two front wheels. The front ultrasonic sensor detects the difference between the wheel and the ridge when moving forward and backward. If the distance between the right front wheel and the ridge is less than 5 cm, one can reduce the motor speed of the right rear wheel so that the front of the car can be slightly corrected to the right. After correcting the distance between the two wheels and the ridge, one can continue straight ahead.

4.3 Gyroscope

A gyroscope is a device used to sense angles to maintain angle and direction. It is mostly used for balance, positioning, and so forth. The gyroscope architecture is shown in Fig. 12. It is often used in flight vehicles, ship navigation, mobile phone devices, and so forth.[5]

In this study, the angular velocity output by the gyroscope is converted into angular displacement after integral calculation. When the unmanned vehicle is moving forward steadily, the angular displacement waveform shows a smooth straight line, as shown in Fig. 13.[6]

Through the gyroscope waveform, it can be known that when the unmanned vehicle turns to the left, the waveform of the angular displacement waveform will rise to a positive value, and when the unmanned vehicle turns to the right, the waveform will fall to a negative value, as shown in Fig. 14.

The gyroscope can also be used to determine whether there is any abnormality in the current tilt angle of the car. For example, when the unmanned vehicle has been severely deviated, such as the wheel is already on the top of the soil ridge, it can be seen that the angular displacement waveform of the gyroscope has severe fluctuations, as shown in Fig. 15. At this time, the ultrasonic sensor can be used to correct the direction of the unmanned vehicle, so that the unmanned vehicle returns to the normal path.[7]

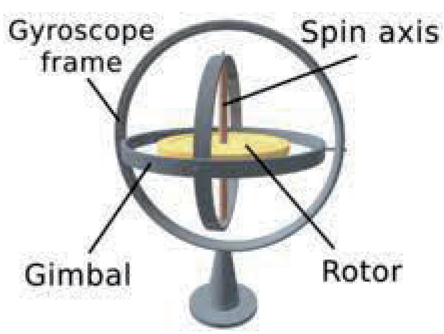


Fig. 12. (Color online) Internal structure of gyroscope.

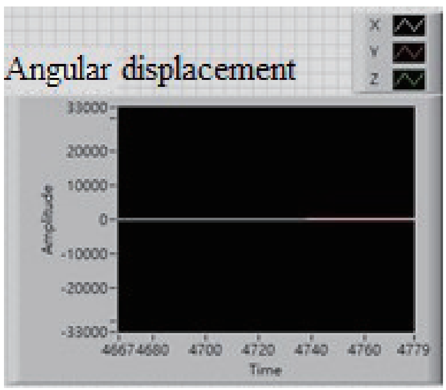
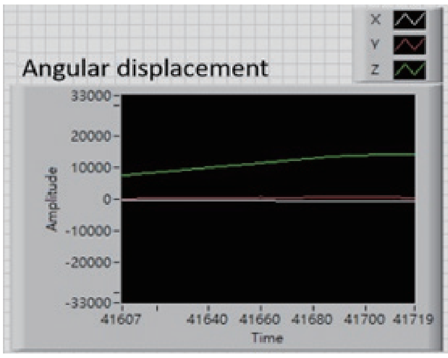
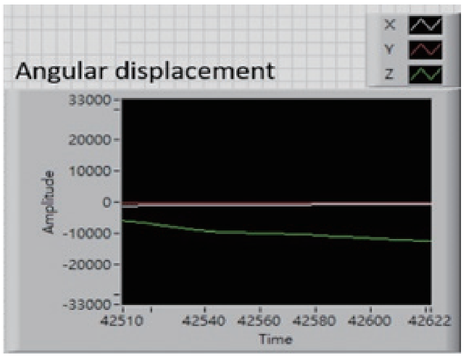


Fig. 13. Angular displacement waveform.



(a)



(b)

Fig. 14. (Color online) Waveform of unmanned vehicle when turning. (a) Turn left. (b) Turn right.

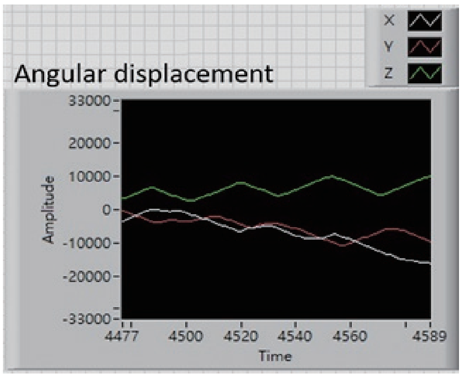


Fig. 15. (Color online) Angular displacement waveform

4.4 Practical testing

To verify the feasibility of unmanned vehicles, we will move unmanned vehicles to the field for practical testing. Figure 16 shows the practical testing of the robotic arm. It can be seen from the figure that the robotic arm accurately takes out the seedlings. After accurately removing the vegetable seedlings, the robotic arm moves to the top of the planter and throws the vegetable seedlings into the planter.

Figure 17 shows the practical testing diagram of the planter (inserted into the soil). It can be seen from the figure that the tip of the planter is inserted into the soil by the electric cylinder. Figure 18 shows that the planter opens the tip to make the vegetable seedling fall into the soil. Figure 19 is a picture of the actual conditions of vegetable seedlings after planting and watering. It can be seen from the figure that the mechanical planting method can make the vegetable seedlings stably planted into the soil, and the soil around is moist due to the drip irrigation system. Compared with manual operations, the robotic arm automated planting technology developed in this study can maintain stable planting and complete operations more efficiently.

Fig. 16. (Color online) Practical testing diagram of robotic arm.

Fig. 17. (Color online) Practical testing diagram of planter (inserted into soil).

Fig. 18. (Color online) Practical testing diagram of planter (planting seedlings in soil).

Fig. 19. (Color online) Completion of vegetable seedling planting.

5. Conclusion

Compared with the planting vehicles on the market, the unmanned self-propelled vegetable seedling planting vehicle developed in this study has a lower planting speed but is automatic. When planting, only the vehicle needs to be placed and positioned, and no extra equipment is required. The manpower sits on the car to control, and this improves farmers' watering habits, which can save labor costs and water resources.

On the whole, the unmanned self-propelled vegetable seedling planting vehicle based on the embedded system developed in this study can meet the requirements of automatic agricultural planting and can operate continuously, but there is still room for improvement in this research. It is currently a development template and commercialization cannot be achieved yet. At the stage of real commercialization, there is room for improvement in overall precision, production process, stability, and operating speed. After the above improvements, the requirements for commercialization can be met.

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