Development of Multifunctional Greenhouse Agricultural Robot

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Abstract. This paper developed a multifunctional greenhouse agriculture robot. Firstly, combining the advantages of wheel-tracked type and gantry frame type structure, the robot mechanical structure is designed, which includes three-axis motion mechanism, robot mobile platform and end-effectors. Secondly, the electrical design is completed. Raspberry Pi is selected as the main control due to powerful function, low cost and rich information and circuit design software Fritzing is used for robot hardware modeling. Multi-axis control algorithm for stepping motor is proposed. Finally, the robot prototype system is developed and each function is verified by experiments. The results show that the designed robot can not only be applied to many stages of greenhouse planting growth, complete data collection and perform farming tasks, but also has the advantages of high efficiency and low cost. It is easy to be popularized and applied in Greenhouse.

Introduction

The latest results of technology and research are increasingly used in agriculture, especially in intensive cultures that ensure remunerative returns. Most cultures in greenhouses are in this category where, despite the large use of technology, human operators still manually perform most operations on the crop although they are often highly repetitive and sometime even dangerous [1]. Because agricultural robots can improve production patterns, increase production efficiency, it has attracted scholars to research in recent years [2]. A strawberry harvesting robot consisting of a four DOF manipulator, an end-effector with suction pad, a three-camera vision system and a rail type traveling device is developed as a trial to conduct experiments in a tabletop culture greenhouse [3]. An autonomous picking robot system is developed for greenhouse-grown tomatoes, which consists of four major components: the end-effector, machine vision, robot carrier, and control system [4]. A hardware-software architecture for control engineering education is proposed and a developed example is applied to the greenhouse fertirrigation control. The control strategy is implemented on the PLC which interacts with the virtual process by carrying out the necessary actions in order to control the appropriate variables of the process [5]. In order to improve the efficiency of robotic harvesting in unstructured environment, a dual-arm frame equipped with two 3 DOF manipulators and two different type end-effectors used to pick tomatoes is designed [6]. For preserving the strawberry sites in Europe, a picking robot is developed that harvests strawberries on tabletop cultivation systems [7]. In order to overcome labor shortage in the agricultural industry, robots are considered as alternatives that can undertake manual and tedious tasks. A dual-arm cooperative approach is developed for a tomato harvesting robot using a binocular vision sensor [8]. A multi-objective algorithm to solve the path planning problem for pesticide spraying operation inside a greenhouse is presented [9].

Summarizing the existing research results, it can be seen that most agricultural robots are designed to perform certain function, such as picking, irrigation or sowing seeds. In this paper, a multifunctional greenhouse agricultural robot is developed for using in many stages of greenhouse planting growth, which can not only collect crop information and complete multiple farming operations by replacing the end-effector, but also can complete data supervision and remote control of agricultural equipment.
Robot Machinery Body

Wheel-tracked and gantry structures are usually used in greenhouse agricultural robots. Although wheel-tracked robots can carry out large-area operations by chassis moving, only remote spraying can be used. Gantry robots can deliver pesticides at fixed points for a single crop, but tracks need to be built in advance in order to reduce moving range [10]. Therefore, the agricultural robot body is designed by combining the two advantages shown in Fig.1, which is composed of XYZ three-axis motion mechanism, mobile platform and end-effector.

![Robot Machinery Body](image1.png)

Figure 1. Robot Machinery Body.

Figure 2. Drip irrigation end.

Mobile Platform

The mobile platform is consisted of a robot platform, a lifting mechanism and a motion mechanism, in which the robot platform is the main body. The upper part of the robot platform provides support for the XYZ three-axis motion mechanism, its lower part is connected with the lifting mechanism, and the side surface is used for installing hardware such as a controller, a sensor and so on. The lifting mechanism controls the robot height by using four linear motors to complete crop farming at different stages. The motion mechanism is driven by the motor with Hall encoder feedback.

Three-axis Motion Mechanism

As shown in Fig. 1, the two horizontal motion axes are denoted as X axis and Y axis, respectively, and the vertical motion axis is denoted as Z axis. The X axis is supported by two polished rods and driven by a ball screw. Y axis and Z axis are both driven by screw sliding table structure, and the two sliding blocks are installed face-to-face. The end-effector moves along with the movement of XYZ axis. It has the advantages of high positioning accuracy and simple control algorithm, and it is easy to complete quantitative irrigation of fixed-point.

End-effector

Different farming tasks, such as irrigation, weeding, soil moisture measurement can be completed by changing the end-effectors

![Modeling diagram](image2.png)

(a) Modeling diagram

![Seeding end](image3.png)

(b) Seeding end

![Soil moisture measuring end](image4.png)

(c) Soil moisture measuring end

Figure 3. Multifunctional end-effectors.

The drip irrigation end installed at the bottom of Z axis is designed shown in Fig 2. Under the influence of gravity, the water extracted by the pump flows into the hole at the top and out of the round hole at the bottom along the internal path. Drip irrigation is used to multiple plants. The built-in
metal steering gear completes the steering of different end-effectors. The multifunctional end-effectors are shown in Fig. 3, which includes seeding end and soil moisture measuring end.

Robot Hardware

The robot hardware mainly includes data input, processing and execution units shown in Fig. 4(a). Raspberry Pi is mainly responsible for human-computer interaction and control decision-making. External data collected by camera, laser ranging, obstacle avoidance and other modules are sent to Mega 2560. Mega 2560 completes collecting sensor data and control the executive mechanism. After data are interacted and processed between Raspberry Pi and Mega 2560, the end-effector, mobile platform, XYZ three-axis motion mechanism and other execution mechanisms are controlled to run shown in Fig. 4(b).

Robot Software

Multi-axis Control Algorithm for Stepping Motor

The motion speed of the stepping motor is determined by the frequency of PWM pulse signal. In order to control the three-axis motion mechanism, an algorithm which use system time to control stepping motor is proposed. Mega 2560 receives the number of steps $P$, the maximum speed $V_{\text{max}}$ and the acceleration $a$ required by the motor. The entire rotation process is divided into three stages of S1, S2 and S3, wherein S1, S2 and S3 are acceleration, uniform speed and deceleration stages, respectively. And the step numbers $P_1$, $P_2$ and $P_3$ in S1, S2 and S3 stages are expressed as:

$$P_1 = P / 4, P_2 = P / 2, P_3 = P - P_1 - P_2.$$  \hspace{1cm} (1)

According to the maximum speed of the motor, the time interval $T_2$ between every two rising edges in S2 and the initial pulse interval $T_0$ in phase $P_1$ are calculated as:

$$T_2 = 1000 * 1000 / V_{\text{max}}, \quad T_0 = T_2 * (a + 1).$$ \hspace{1cm} (2)

The time decreasing steps $N_1$ and $N_3$ in $P_1$ and $P_3$ are calculated as:

$$N_1 = a * T_2 / S_1, \quad N_3 = a * T_2 / S_3.$$ \hspace{1cm} (3)

The next execution time $t_{1\text{next}}$, $t_{2\text{next}}$ and $t_{3\text{next}}$ of S1, S2 and S3 stages are expressed as:
\[ t_{\text{next}} = T_0 - N_1 \cdot P_{\text{GO}}, \quad t_{2\text{next}} = T_2, \quad t_{3\text{next}} = T_2 + N_3 (P_{\text{GO}} - P_1 - P_2 + 1) \]

where \( P_{\text{GO}} \) is the finished step numbers of the motor.

Since there is no long delay, Mega 2560 is always in the calculation and judgment state during operation, it can control multi-motor at the same time. The simulation results of three-axis motion are shown in Fig. 5. It can be seen that multi-motor can be effectively controlled from rising speed to uniform speed.

![Graph showing simulation of three-axis motion.](image)

**End-effector Control**

Steering gear, water pump and air pump need to be programmed and controlled. LDX-218 digital steering gear is selected. Compared with analog steering gear, it only needs to send one signal to maintain the angle unchanged and has the advantages of high control precision and fast response. The end to be used is judged by self-defined function \( \text{sizeof}() \) and is controlled to move to the working position by the steering gear. After debugging, the position of the steering gear is determined and recorded when each end-effector is in the working state. If the sowing end rotates to the working position, the air pump switch is controlled by On and Off commands. Weeding is completed by controlling Z axis to move up and down if the weeding end rotates to the working position. If the drip irrigation end rotates to the working position, the water pump switch is controlled by On and Off commands. The sensor data are read and uploaded when the soil humidity measuring end rotates to commands. The control flow of the end-effector is shown in Fig. 6.

![Control flow of the end-effector.](image)

**PID Control Algorithm of Mobile Platform**

The distance between the robot and the fence is measured by the laser ranging module and PWM is used to control the robot to move. Because X axis length is long and it may result in a large swing when walking, PID controller is adopted. GP2Y0A02YK0F laser ranging module produced by Sharp company is selected, which can complete ranging from 10cm to 150cm. The output signal from laser ranging module is taken as PID feedback. Laser rangefinder readings without PID and with PID are shown in Fig.7 (a) and (b), respectively. It can be seen that the robot has less shake when adding PID controller.
Design of Robot Prototype System

The robot prototype system is shown in Fig.8. The robot frame is made of European standard aluminum profiles, with low price and stable structure. X axis selects a ball screw with a length of 1000mm, a diameter of 16mm and a lead of 5mm, and two optical axis guide rails for bearing. 57 two-phase stepping motor with torque of 3.1n.m is selected. Y axis and Z axis select the screw slide table with a stroke of 400mm and 500mm, a diameter of 8mm and a lead of 2mm, respectively. 57 two-phase stepping motor with torque of 1.2N.m is selected. Dc motor of 37GB550 with 6V130RPM, rated torque 5kg.cm, maximum torque 9kg.cm and reduction ratio of 65 is adopted to realize transmission by connecting 95mm aluminum alloy wheels with 6mm coupling.

UI is developed in Python3 and Tkinter shown in Fig.9. It is not only convenient for users to conduct watering, ventilation, sowing, weeding and other operations, but also can remotely recall the camera or read sensor data to learn real-time situation of crops.
Conclusion

In this paper, a kind of multifunctional greenhouse agricultural robot based on the three-axis motion mechanism is designed. Firstly, the overall design of the robot is determined. Then, the mechanical structure, hardware structure and control algorithm of the robot are analyzed. Finally, an agricultural robot system is manufactured and validated by experiments. The results show that the developed agricultural robot can not only be used in many stages of greenhouse planting, but also it can complete data collection and remotely recall the camera or read sensor data to learn real-time situation of crops. And its cost is low and easy to be popularized.

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