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Design and Implementation of Bio-inspired Snake Bone-armed Robot for Agricultural Irrigation Application

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Abstract: This paper proposes a bionic electric spraying rod to perform the crop watering and spraying in the farm. The design concept of multiple vertebrae structures of snake is used to realize a reproducible snake bone arm and muscles of snake, which can be regarded as multiple sets of thin wires and be pulled and released through driver module. It results in different attitudes of the snake bone arm. A water pipe is installed in the snake arm connected to the spray nozzle for spraying. The mobile application interface (APP) is designed to provide the user to control the arm remotely. The maximum bending angle of the arm, which can reach to 115.7 degrees, and the jetting distance is up to 60 cm. Some spraying tests were performed to evaluate and verify the effectiveness of proposed bionic arm. The proposed snake bone-armed robot has high degree of freedom and low cost, which is more feasible than the rigid robotic arm. The robotic arm can be installed in the unmanned field mobile robot to perform spraying operation, reducing the burden of labor and the damage of on-site pesticide spraying to farmers.

Keywords: Robot arm, bionic snake robot, remote control, agricultural irrigation.

1. INTRODUCTION

In the 20th century, people deeply realize the importance of nature in developing various new materials and new engineering techniques, propose a concept of bionics and establish a discipline called bionics. With the development of research technology, bionics has become a major focus of natural Sciences. With the rapid material development of material in machinery manufacturing and control technology and the deep discussion of bionics, software robots have received more and more attention. Traditional rigid robots are composed of rigid moving parts based on hard materials (metal, plastic, etc.), which can achieve tasks that are fast, precise, and repetitive. However, this type of robot has limited freedom of motion and is only suitable for operation in a structured environment. The bionic arm can be seen as having unlimited degrees of freedom, so its various configurations allow the end effector to reach any point in the workspace. It can perform bending or swing behavior in a small space and conduct operations such as grabbing (Calisti et al., 2011; Chang et al., 2011; Chang and Shie, 2013; Khan et al., 2017). Compared with rigid robots, software robots have the ability to interact through different forms of motion in a non-structural complex environment with complex and variable objects that are difficult to describe with accurate mathematical models (Tolley et al., 2014). Despite the advantages of light weight, high degree of freedom, high material strain, high safety, high flexibility, and low maintenance costs, simple soft systems, rigid systems that can be fast, precise, and repeatable cannot be replaced. It is a challenging work for us to inspire creativity and thinking in combining with soft and rigid materials.

In recent years, environmental concerns justify development of bio-robots. The remote monitoring system in agriculture can save labor costs and mitigate environmental degradation (Cho et al., 2009). The use of robots in the application of pesticides can eliminate or reduce the exposure of people to chemical, which possibly results in decreased occurrence of poisoning incidents.

However, the use of desktop computer in the remote systems for image surveillance system is prominent which limits the use of mobile gadgets in the monitoring. The purpose of this research is to combine remote monitoring with mobile phones. The design of the mobile device application interface (APP) connected to the remote monitoring system has opened up a new field for industrial agriculture (Mosadegh et al., 2014). The advancement of smart phones has made the mobile phone important in daily life. Integrated image transmission monitors the remote environment via video mobile app and remote control technology.

2. DESIGN AND METHODOLOGY

2.1 Institutional Design

The idea of the arm results from the bones of the snake (see Fig. 1). The freedom of bending of the snake is very high. It simulates the connection of the bones of the snake to increase the degree of freedom of the arm shown in Fig. 2. Figure 3 represents the 3 dimension (3D) printed materials of an arm joint.

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Fig. 1. Appearance of snake bones.

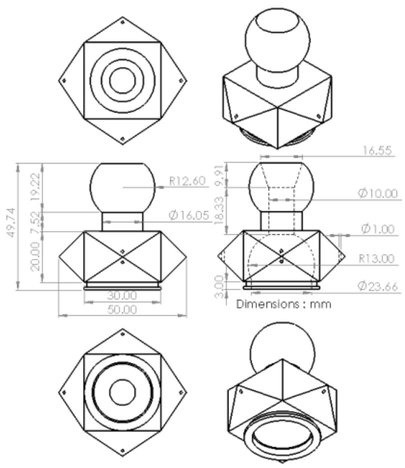
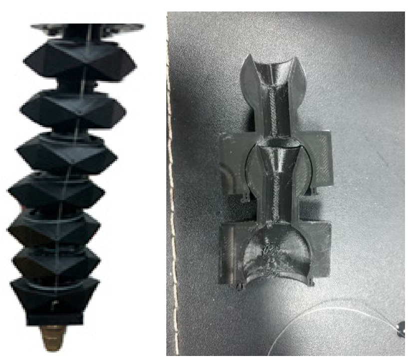


Fig. 2. 3D view and dimension of an arm joint.



(a) (b)

Fig. 3. Appearance of bionic robot arm (a) finished product, (b) entity of internal arm joint.

The wireless controller is used as the control terminal, and the drive signal is sent to the microcontroller board (Arduino UNO, Arduino.cc) to control the two direct current (DC) motors to connect two three-threaded screws shown in Fig. 4. The nylon rope fixed on the arm is wound around the screw, and the nylon thread is fixed by the groove of the thread. The length of the rope is shortened by the motor rotation to make the arm bend (Fig. 5). A battery is used as a source of power for the hardware module.

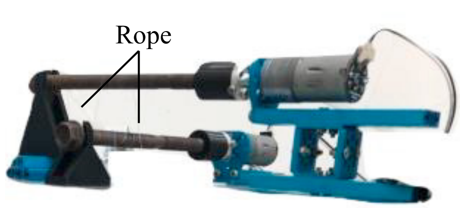


Fig. 4. Motor module.

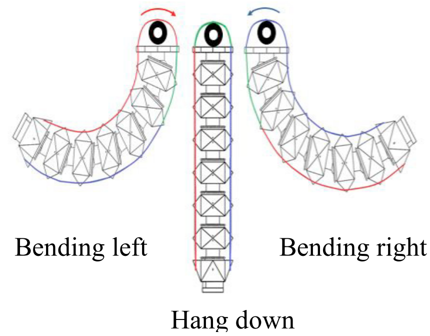


Fig. 5. The design concept of bionic arm movement.

2.2 Image module and APP

The APP is designed by android studio software development kit (SDK) tool. When the user clicks the APP icons, it automatically streams the uniform resource locator (URL) of the embedded module (Raspberry Pi 3 B+, Raspberry Pi Foundation) and uses the remote connection to transmit images. Remote controller and APP interface is shown in Fig. 6. The lens is installed in the arm head (see Fig. 7) and used to capture live image connected to the Raspberry Pi by a flexible ribbon cable. The arm end is also equipped with spray head.

Fig. 6. Remote controller and APP interface.

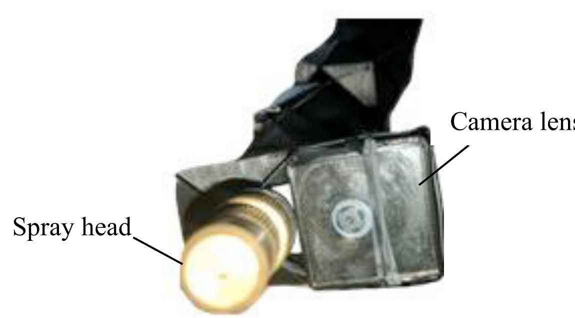


Fig. 7. Pi camera at the top of the arm.

2.3 System integration

This section focuses on institutional design, software and hardware integration, and wiring. Meanwhile, the relationship of hardware and software connection in the whole system is also illustrated. Figure 8 demonstrates the structure of control system, including control module, power module, image module, and rocker module. The solid line depicts the signal flow and presents the starting and end point of signal between different modules in the control system; the dotted line shows the power flow, indicating the corresponding voltage of each part of the driving. The power module provides the power source of Arduino UNO board and the wireless rocker receiver. The bionic arm is operated by the user through wireless rocker and control module. When the motor is rotated, the boom system can be bent. The pi camera is utilized to capture the image in real-time so that the target plant can be sprayed accurately. The pump is used to spray the plant while the spraying operation is performed, and the pump motor is started. The appearance of hardware is demonstrated in Fig. 9. All modules are placed in a control box.

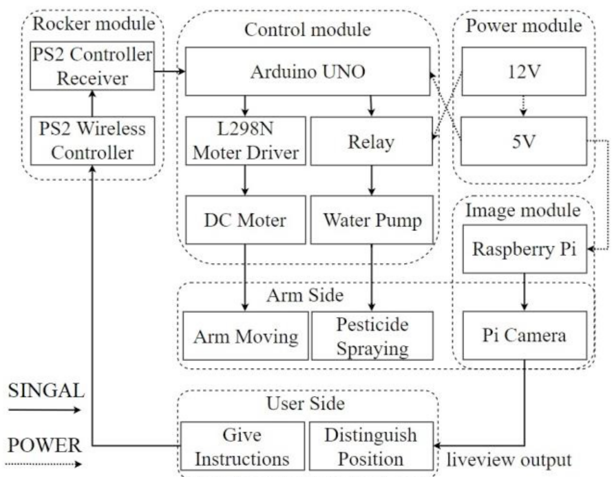


Fig. 8. Block diagram of control system structure.

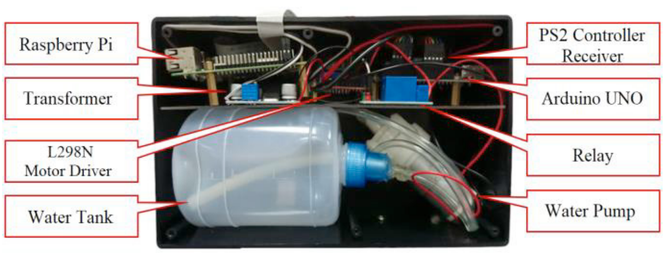


Fig. 9. Configuration of bionic arm control platform.

3. EXPERIMENTS AND RESULTS

3.1 Experimental planning

In terms of experimental planning, the software tool is used to simulate the relationship between the total bending angle of the spraying arm and the bending angle of each joint. Then, the bionic arms are respectively moved in different directions. The large bending angle in different direction is measured and an effective bending covered range is also obtained. Finally, the accuracy of the spraying of the bionic arm is tested and evaluated.

3.2 Experimental result

Figure 10 shows the simulation results of bending angle for bionic arm. It can be observed that the maximum angle of bending angle is 133.88 degree. The range of arm coverage is shown in Fig. 11. It can be seen from the figure that the bending angle at which the arm bended can be directed toward the side object. Figure 12 illustrates the experiment platform used in spraying test for bionic arm. The apple hanging from the side can be used to test whether the apple can be sprayed accurately by bionic arm. The experiment results show that the arm has the highest accuracy at the centre point and the lowest accuracy at the angle (see Fig. 13). It is not recommended to place the target crop on the corner, and the risk of the drug not being accurately injected is high.

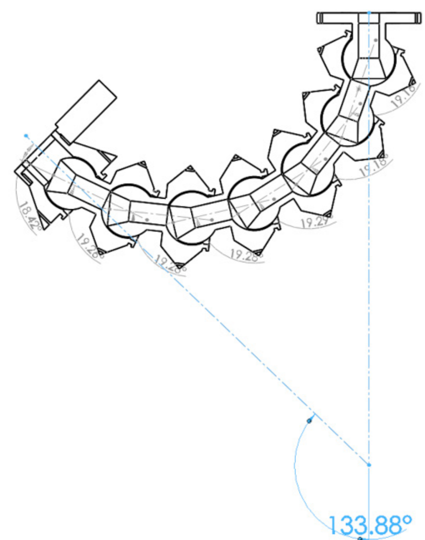


Fig. 10. The bending angle of bionic arm.

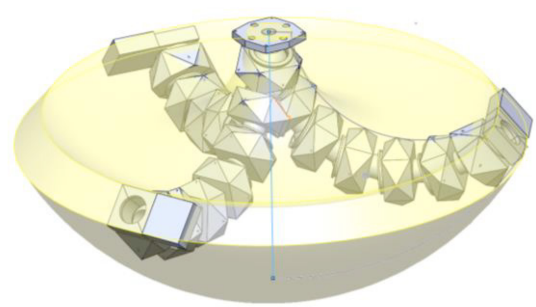


Fig. 11. Bionic arm coverage.

Fig. 12. Pesticide spraying test in the tray.

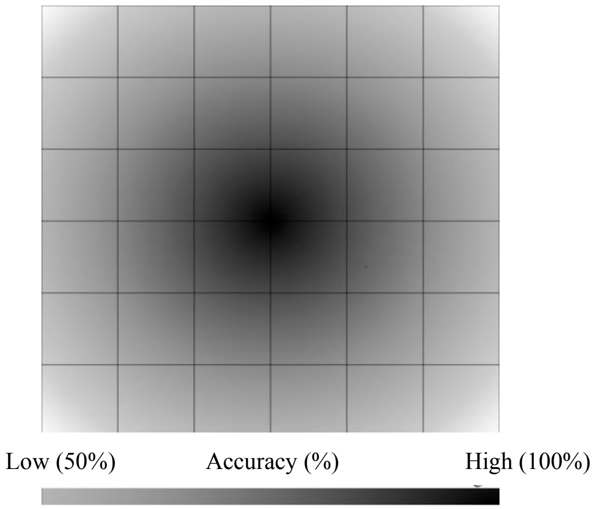


Fig. 13. Accuracy test of snake bone-armed robot for spraying.

4. CONCLUSION.

The maximum bending angle of the snake bone-armed robot in this experiment is 133.88° and there is no problem of insufficient power. The more the centre deviation distance of the spray bar is, the lower the accuracy is. The accuracy of the corner will be lower than the edge, within 10 cm. The accuracy is 100%, and the accuracy will begin to decrease after 10 cm, especially in the corner. In the future, the following points can be improved: 1. Accuracy of centre deviation distance; 2. Add multi-directionality to make the machine flexible; 3. Combine with mobile APP so that one can directly use mobile phone monitoring and control.

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