555. Wearable agrirobot

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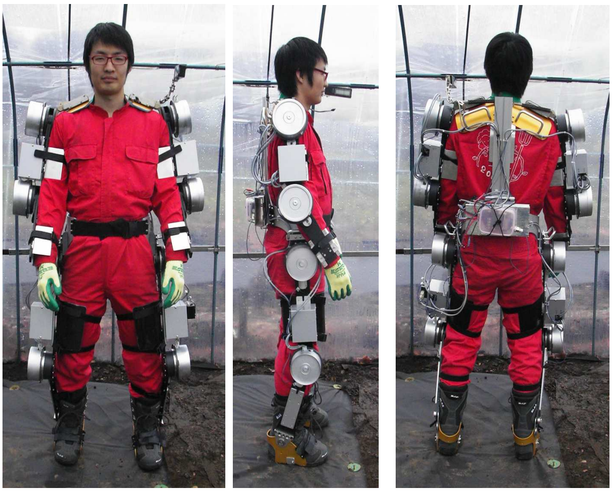
Abstract. We have developed an exoskeleton robot for agriculture. It assists farmers in harvesting vegetables and fruits, and carrying the heavy load such as potato bags and cabbage boxes. We have made the robots for some types of farming and discussed the sensors and control of it. We have also performed experiments in order to demonstrate how the robot operates for agricultural purposes thereby showing the potential of the robot.

Keywords: robot, wearable robot, agriculture

Introduction

We have serious problems facing an aging society with falling birthrate. It has been estimated that thirty percent people in our society is sixty five years old or older. Although the present population of the agricultural work force is 3.12 million people, it decreases every year. In addition, about fifty nine percent of it is sixty five years old or older. Moreover, the food self-sufficiency rate for the major advanced countries is 130% for France, 119% for the United States, 91% for Germany, 74% for Britain, and only 40% for Japan. This data indicates the importance of improving agricultural efficiency in Japan.



(a) front view (b) side view (c) back view

Fig. 1. Wearable agrirobot

Numerous devices for farming equipment have been introduced to achieve efficiency of farming works. Combines and tractors are useful to cultivate and harvest rice fields. However, such large-scale machines are limited to large-scale farms. Small robots are desired for small-scale farm such as slope arable land, and the bottleneck in the house. Besides that, dexterous robots are also desired for harvesting fruits and vegetables. In order to solve these problems, we have developed an exoskeleton robot as shown in Fig. 1.

Structure of a wearable agrirobot

The robot has ten joints (two shoulders, two elbows, two hip joints, two knees, and two ankles). DC motors and drivers are installed to each joint without ankle joints [4-9]. The operation interface is also attached to the exoskeleton. The input operations are performed by voice recognition device. The status of the operational mode can be confirmed on a monitor in front of eyes. The controllers and the battery for the motors are installed in the exoskeleton.

The frame of the robot is constructed of aluminum and acrylonitrile-butadiene-styrene resin, which is lightweight and excellent in rigidity in bending. The gross weight is 30 kg. However, the user wearing it does not feel its weight because the robot stands by itself. It requires about five minutes to wear it.

Control system

Rotary encoders and gyro-sensors are used for joint angle and posture detection. Pressure sensors and hall sensors are used to follow the movement of a user. A pressure sensor detects the force when a user pushes the robot arm or foot from inside of it. Robot is controlled to keep the force within allowance level by driving motors. Hall sensors are used for a more precise control of the robot. A user has some magnets on the surface of arms and feet. Hall sensors attached on the surface of the robot, detect the fields of the magnets to measure the distance between hall sensors and magnets. The robot is controlled to keep the distance within the predetermined allowance.

Besides that, the robot has some special movement pattern of sequence control for some typical agricultural work such as harvesting grapes and carrots. The robot moves automatically to proceed the movement for harvesting. A user can confirm the movement mode (following control or special works) on the monitor display.

Evaluation of maneuverability

The robot should be kinematically the same with the structure and functions of a human body joints. However, human body has multi-degree-of-freedom in one joint due to deformation and anatomical structure. The joints of the robot are rotational ones. An orientation vector of the rotational axis and the range of it characterize a rotational joint.

To evaluate maneuverability of the robot, we have proposed the following criteria.

$$n = \cos\psi \cdot g\left(\frac{\phi}{\theta}\right) \tag{1}$$

The range of motion of a joint of the human body is θ and the range of a joint of the robot is φ. The angle between rotation axis of the human body joint and the robot joint is ψ.

$$\begin{aligned} &if\left(\frac{\phi}{\theta}\right) < 1 \quad then \quad g\left(\frac{\phi}{\theta}\right) = \frac{\phi}{\theta} \\ &if\left(\frac{\phi}{\theta}\right) \geq 1 \quad then \quad g\left(\frac{\phi}{\theta}\right) = 1 \end{aligned} \tag{2}$$

For instance, the maneuverability of shoulder joint is expressed as follows.

$$n_S = r_1 \cos\psi_1 \cdot g\left(\frac{\phi_1}{\theta_1}\right) + r_2 \cos\psi_2 \cdot g\left(\frac{\phi_2}{\theta_2}\right) + r_3 \cos\psi_3 \cdot g\left(\frac{\phi_3}{\theta_3}\right) \tag{3}$$

where, r is a weight factor from total range of working area in a shoulder joint.

Since this criteria is easy to calculate, we can extend it to other joints and evaluate the whole body as follows.

$$N = R_s n_s + R_e n_e + R_b n_b + R_h n_h + R_k n_k + R_a n_a \tag{4}$$

where, R is also a weight factor from total range of working area in one joint. The affixing character is s: shoulder, e: elbow, b: dorsal, h: hip joint, k: knee and a: ankle, respectively. Fig. 2 shows the results of maneuverability of each joint. For a knee joint, the robot has good maneuverability due to a simple structure. However, it is poor in shoulder joint and back. This is because that the human back is combined with many small joints, but the robot has a just flexible one-rod. An actual shoulder joint is very complicated structure to make artificially.

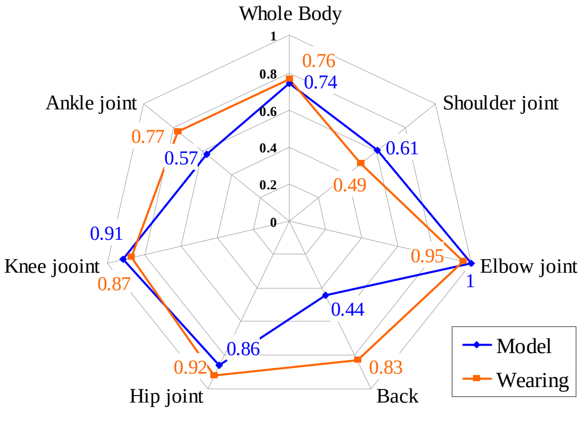


Fig. 2. Comparison of maneuverability

N_M and N_W for the whole body is 0.74 and 0.76, respectively. It shows the good maneuverability to move 74% freely without the robot even if a user wears it. If we add more degree of freedom to the robot, this criteria can be more improved, but it causes the increase of weight and cost. 74% is a good for practical use.

Analysis of farming operations

Farming operations consists of frequent movement of upper limb and lower limb. The robot has to store the movement data for agricultural works. We have measured the movement with special suits that has capability of measuring angles of each joint of the shoulder, elbow, hip and knee joints.

Radish Harvesting

Fig. 3(a) shows the angle of the lower limb joints when harvesting radishes. The movement of the joints of the lower extremities is a repetition of a certain movement pattern. It is the posture shown in Fig. 4(a). The arm also periodically repeats the same operation, along with the movement of the lower limbs.

(a) radish harvesting (b) cucumber harvesting (c) fruit tree pruning
Fig. 3. Harvesting operations

Cucumber Harvesting

In general, cucumbers are grown on a trellis. Mature cucumbers are harvested from this trellis. Fig. 4(b) shows the angle of the lower limb joints when harvesting cucumbers. Unlike the radish harvesting operation, it does not involve a repetitive movement pattern. This is because the positions of the harvestable cucumbers are not constant like the radishes. It is difficult to find cucumbers among the leaves because they grow at various heights from the top to the bottom of the trellis. Therefore, numerous bending exercises are involved, like the posture of half-sitting, and these postures appear at random. The operation also involves moving leaves with one hand so that the other may discover them.

Fruit tree pruning

As for fruit trees, cultivation is done from the height a little in general with a high shelf. Therefore, the height of the branches and fruits is over the head. Both hands are raised, and the face assumes an upward posture. Fig.4(c) shows the angle of the arm joint when working on fruit tree pruning.

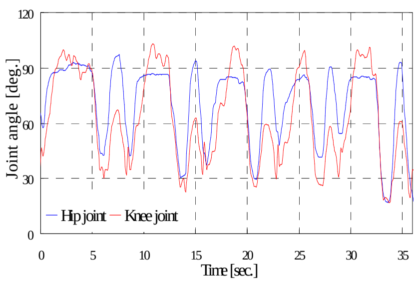
Evaluation of adaptability

The analysis above indicates that there are many movement patterns for each agricultural works. We suppose that the robot is suitable for some works and not for others. So, we have to introduce criteria of adaptability of the works.

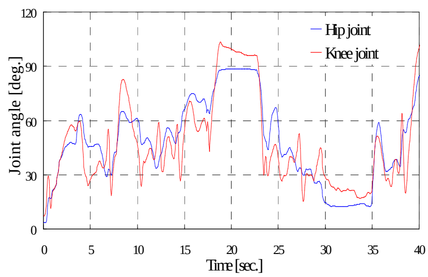
The adaptability is based on the definition of the degree of freedom achievement rate. The usual range of motion for a joint of worker body performing farm labor is assumed to be θ_{adp}, the range of motion for a joint when wearing the robot is assumed to be φ_{adp}. Adaptability is defined as follows.

$$n_{adp} = g\left(\frac{\phi_{adp}}{\theta_{adp}}\right) \quad (5)$$

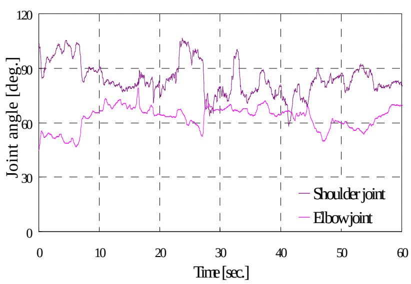
The n_{adp} of each joint and N_{adp} of the whole body are calculated as well as the maneuverability. **Fig. 5.** presents the adaptability and indicates that the robot works well with harvesting these agricultural products. However, the values of the shoulder joint and back are poor. Improvement of these joints may be necessary.



(a) harvesting operation of radish



(b) harvesting operation of cucumber



(c) pruning operation of fruit tree

Fig. 4. Joint angle

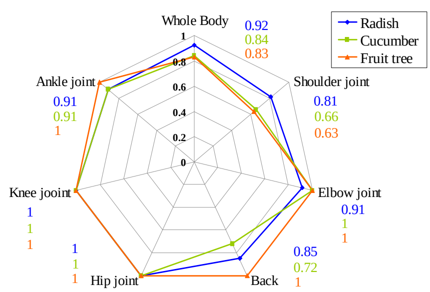


Fig. 5. Comparison of Adaptability

Conclusions

We have developed a wearable agrirobot. We have introduced the criteria for fitness and usefulness of the robot: maneuverability and adaptability. We have succeeded in demonstrating how well it functions in various agricultural operations.

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