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Development of Thermal Cutting System for Sweet Pepper Harvesting Robot in Greenhouse Horticulture

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This paper proposes the new design of thermal cutting system for 5 degree of freedom robotic arm, designed to harvest sweet peppers in horticultural green house. The design consists of two parallel gripper bars mounted on a frame connected by specially designed notch plate and operated by servo motor. The special electric device was developed to obtain the high frequencies with high voltage to perform the cutting operation. The output from the device was connected to the electric rods mounted at the front of the specially designed notch plate. At higher frequencies, the rods generate thermal arc which helps to cut the stem of the sweet pepper. The recognition system assists to locate the fruit.

Key Words: Robot, thermal cutting, gripper

1. Introduction

The development in technology leads to wide applications of industrial robots in a large number of areas such as assembly, material handling and machine tending, packing, picking, palletizing, gluing and sealing, arc welding, spot welding, painting and coating, foundry applications and water jet cutting. Fruit harvesting is one of the important application in green house horticulture that helps to save the labor cost and input harvesting energy consumption. Robot gripper is the main functional part of robot arm that helps to grasp the fruit and then cut accordingly. It can also be used for pick and place, packing or welding operations. In agricultural harvesting many researchers are engaged to design robotic devices for efficient and delicate agricultural product picking and handling. The agricultural production rates are significantly influenced by utilization of robots and tools and techniques developed for decision support system [1]. The brief review of different types of the fruit harvesting robots and grippers is given by *Y. Sarig* [2] and *A. K. El-Kalay and et al.* [3].

To avoid the physical damage to fruits, manual harvesting is preferred which significantly increases the total cost of fruit production. For the efficient mechanical harvesting, the most important part is to design the proper gripper that can handle soft, delicate objects like fruits, with respect to their various shapes and sizes. The mechanism based on cutting device attached to a tubular arm for picking soft fruits were designed by *Harrell and et al.* [4] which consists of a rotating lip that detaches the fruit already enclosed in the tube; the fruit then rolls down the tube to a container. The use of vacuum grippers in delicate fruit harvesting that avoids high air pressure and physical damage to fruit was tested by *Sarig and et al.* [5], *Hayashi and et al.* [6] and *Monta and et al.* [7] with the help of vacuum technology. This type of grippers shows good results for picking tightly clustered fruits. At the same time, for vacuum grippers, small leakage in the system leads to failure of operation and higher construction and operating cost results in expensive system.

Thus, by considering the need of simple and economical gripper, this research was carried out. Sweet pepper is the 4th most important fruit vegetable in Japan grown on approximately 357 hector area of land which needs not only high man power but also high input energy consumption during harvesting operation leading to increase in labor cost and production cost [8]. This issue also relates with the decreasing population of Japan in recent decades [9]. On the other hand, as both, sweet pepper and leaves has almost same color and due to that it is very difficult to recognize them separately during automatic harvesting. Hence, by considering these issues, a sweet pepper was selected for the study. *Kitamura and Oka* [10] developed sweet pepper picking robot in greenhouse to resolve these issues. This paper proposes the further development in sweet pepper gripping and cutting system of old robotic arm. The old model was able to pick and cut sweet peppers by using two different servo motors for gripping and cutting but in proposed design, both operations intended to perform by using only single servo motor. This paper also focuses on the new cutting device based on thermal cutting technique which uses high frequencies and high voltage for cutting operation.

2. Concept of Harvesting Robot

Fig. 1 shows the overview of the concept of sweet pepper harvesting robot. The harvesting robot is composed of three main units; first unit refers to recognition system in which identification and location of the fruit confirmed, second unit refers to picking system in which grasping of fruit and then cutting operation performed; and third unit refers to moving system in which the programmed base sub-unit of the robot moves in the furrows during harvesting operation in greenhouse.

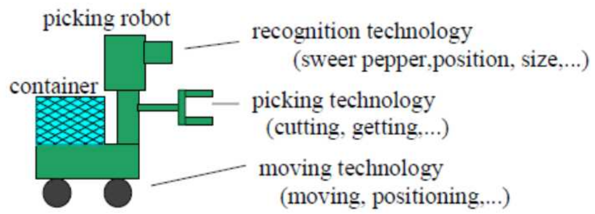

Fig. 1 Concept of sweet pepper harvesting robot

3. Design of New Gripping and Cutting Tool

3.1 System Design

The mechanical system to which this paper represents is a picking system which composed of two parts; the first part is aimed at grasping the sweet pepper and the second part is aimed at cutting the stem of sweet pepper from plant. These both parts have been specifically designed with the purpose of imitating the manual operations by labors.

Fig. 2 shows the concept of the new gripping and cutting tool designed to harvest the sweet peppers. In this system, the servo motor was installed on the supporting frame and the rotary motion was converted into linear motion which helps to drive the notch plate. The gripping bars also attached to the same frame and two vertical poles were installed on the inner side of bars which connects the notch plate and gripping bars. 1 cm internal layer of thermo-col was applied to the end of grasping bars which helps to avoid any physical damage to the fruits. The notch plate (100 mm X 80 mm) was specially designed to move the gripper bars by making two internal curvatures of same size of diameter of the poles. This notch plate was driven by the linear motion converted from the rotary motion of servo motor.

For the thermal cutting, the electric device was designed and fabricated which operates on 12 V DC supply of battery and generates 220 V AC output with 60 Hz frequency. Fig. 3 shows the fabricated electric device used to generate required specifications that help for thermal cutting. This device was mobile and could be installed at distance from whole system connecting electrodes and device output with wires. The output from this device was supplied to the electrodes mounted at the front side of the notch plate. The electrodes were placed at 2 mm to 5 mm distance from each other and the diameter was measured as 1 mm for each electrode.

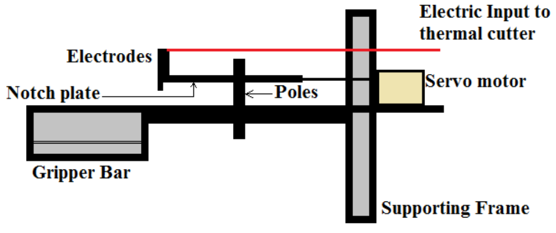

Fig. 2 Concept of picking and cutting tool

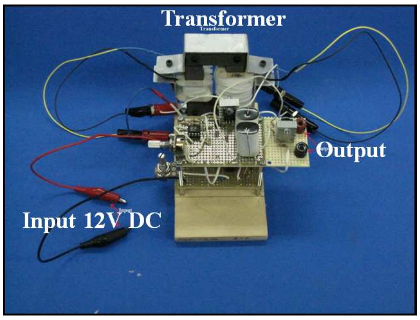

Fig. 3 Special Electric Device

This device also works with 12 V AC supply of electricity which can be used as alternative source for input.

3.2 System Operating Mechanism

The rotating motion from the servo motor was converted into the linear motion by means of rack and pinion mechanism. This linear motion was used to drive the notch plate. During back and forth movement of the notch plate, the poles inside the notches also follows the same motion within the curvature of notch. This curvature motion drives the gripper bars near and away from the center of the system which helps to grasp and leave the sweet pepper. At the end of gripping bars, a box structure was provided which make easy grasping action and also it helps to hold the small size sweet peppers.

The electric device was installed opposite side of the frame with input of 12 V DC supply from battery. This device generates the required output which needs for thermal cutting. The output from this device was used to cut the sweet peppers by means of thermal arc created in between two electrodes. The notch plate also helps to move the electrodes installed at front. When the gripper bars moves near to the center, the electrodes moves in forward direction which helps to cut the fruit and when gripper bars moves away from the center, the electrodes moves backward direction.

3.3 Speed control of the system

The gripping system and cutting system were controlled by using *Kondo KRS 6003 HV* servo motor through computer and whole system was programmed to operate accordingly.

Figure 4 represents the detailed block diagram of the control system used to operate and control the gripping and cutting system in which program was written in VB C++ to interface between servo motor and computer. The servo controlled *KCB-1* was used to control the Kondo servo motor. The motor rotates by 270^0 without restriction and the program was used to control the rotation of the motor by 160^0 at slower speed.

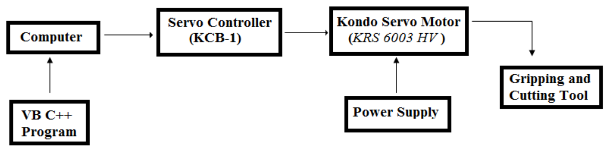

Fig. 4 Block diagram of speed control of the system

4. Gripping and Cutting System

Based on the concept, the prototype of the system was fabricated with the help of various materials available. In the prototype, aluminum was used to make the supporting frame, gripping bars while notch plate was designed by using plastic material. For some cases, wood was used as a replacement material for safer side. The servo motor was fixed on the back side of the supporting frame and rack and pinion technique was used to convert the rotary motion into linear motion. The developed electrical device was placed away from the system to avoid any physical damage to the device during the harvesting operation. The input to the electrodes was supplied through the wires connecting it to the electrical device. Fig. 5 represents the isometric view of the system model designed in the Solidworks while Fig. 6 shows the developed experimental prototype.

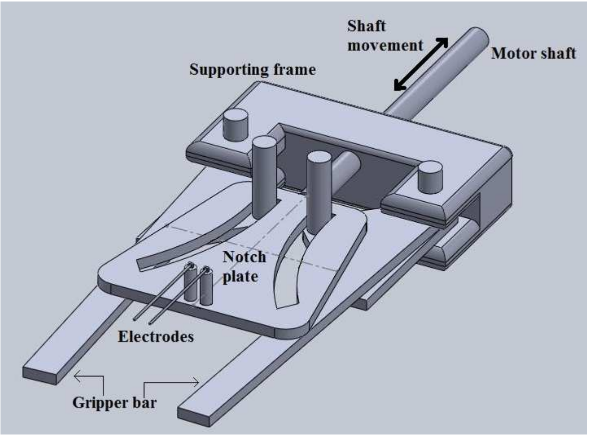

Fig. 5 Model of gripping and cutting system

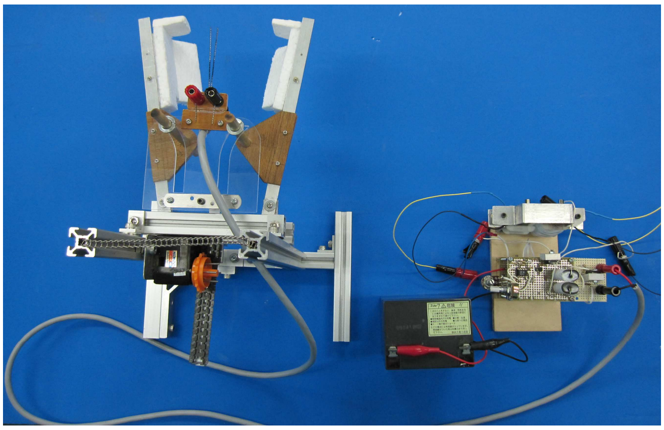

Fig. 6 Prototype with experimental set up

In the prototype, the distance between two electrodes were set such as; free ends measure 5 mm apart while connected ends measure 2 mm apart from each other.

In horticultural practice, the labor uses a knife to cut the stem of the fruit. By using the same knife over and over again, there is a risk of transportation of viruses from one plant to the other. In horticultural practice this is prevented by immersing the knife in skimmed milk before each plant contact. For a robotics application this approach was not considered to be practical. Thus, for automated cutting of the stems a thermal cutting technique from medicine was considered as better solution. Once a stem contacts the electrodes, due to high voltage, an electric arc is created which results in sudden temperature increase at that point and hence the cutting operation is carried out. Clearly, the high water content of the tissue material alleviates this process. This approach has two distinct advantages. First of all, during the cutting process viruses are killed due to the distinct temperature increase at the cutting surface. Secondly, the wounds of both the fruit and the plant are closed during the cutting process. This results in less water loss from the fruit and consequently a longer shelf life. Also, by closing the wounds, the plant is considered to become less vulnerable to fungal diseases.

To confirm these facts, the prototype was tested in the lab by adopting prototype for harvesting operation of sweet peppers. Fig. 7 shows the prototype adopted for the harvesting operation in the lab.

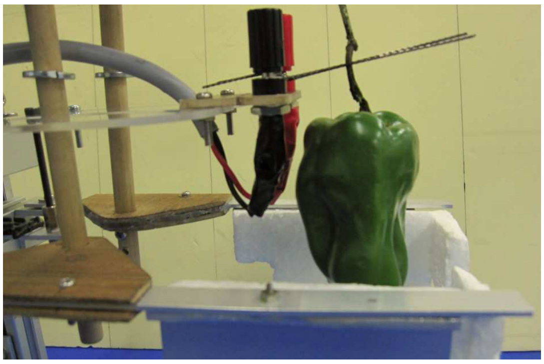

Fig. 7 Testing of prototype

During the testing, the sweet peppers were harvested successfully without any difficulty in the harvesting operation. Also, the testing was carried out with two types of electric rods; 1 mm and 2 mm diameter. Electrodes with 1 mm diameter were found more suitable for harvesting operation as they took less time to complete the task compared to 2 mm diameter electrodes. Fig. 8 represents completion of the task while inset shows the harvested sweet pepper (45 mm in diameter, 72 mm in height, 4 mm stem diameter and 5 mm height of cut).

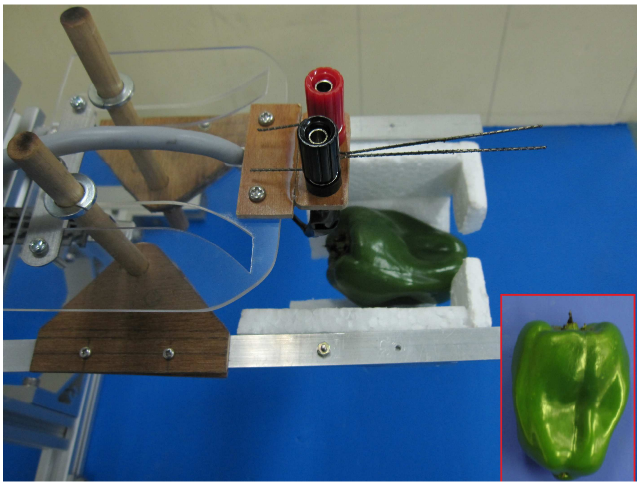

Fig. 8 Harvested sweet pepper

5. Conclusions

The thermal cutting and gripping system was designed developed successfully. The system was programmed to operate and control the harvesting operation. The successful lab testing of the prototype confirms significant performance of the system. 1 mm diameter electrodes were found more suitable for cutting operation compared to 2 mm diameter electrodes.

Moreover, confirming the horticultural advantages by testing the prototype in real greenhouse environment with different types of electrode material and diameter for virus transformation and shelf life of fruits can be considered as further research.

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