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Comparison of Gripper Designs for Robotic Kiwi Fruit Harvesting

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Abstract: ***N****One of the most important pieces of robotic fruit harvest is Gripper, which made the last cutting action.Other parts are robotic arm, image processing and image processing software. In this study, image processing was carried out for fruit harvesting with the robotic system.The position of the fruit on the branch was determined and the cutting operation was performed. Two-dimensional and real-time images were transferred to digital media with a 2D camera. The images of the fruit transferred to the digital medium were processed in real-time image based on shape feature with the help of camera program. The movement of the robotic system is provided by finding the coordinates of the X and Y coordinates on the branches of the fruits according to the received and processed data. The designed Pneumatic shear system and step motorized shear cutter were individually mounted on the end of the robotic arm. 100 pieces of kiwifruit were placed differently on the branch and designs were tried separately. As a result of the experiments, It has been observed that the stem diameter of the fruit and the stem breaking resistor are effective in breaking the fruit over the branch. As a result of experiments on different designs, The cutting success was statistically analyzed.It has been seen that the cutting system working with the pneumatic system can cut through the fruiting branch with %72 success rate.The success rate in the shears system working with the stepper motor is determined as 0% (no cutting).The failure rate of %28 in the shears system working with the pneumatic system and the failure rate in the stepper motor shears system were investigated. In the research results; The reasons for failure in the system of pneumatic system shears are that the fruit stem is at the tip of the shears, It has been shown that shears does not come off the stem of the fruit, but comes to the fruit burl or with the sharp knife, causing an error in the breakout process. It is understood that the cause of the high failure rate in the step motor shears system is due to the engine can not move cutting action with a strong shutdown. According to the results obtained, it is seen that the pneumatic shears system is the most suitable system that can be used for fruits.*

Keywords: *Robotics Harvest, Cutting, Gripper, kiwi*

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I. Introduction

Nowadays, the robot technology is in significant advancement process. The objective of robot technology, which is widely used in many fields from medical practice to agricultural implementations, is to ease the lives of human, to accelerate the processes, and to perform a uniform production. Considering the tasks, which the humans do not want to fulfil, or the tasks, which might result in life-threatening circumstances, it can be seen that the robot technology is used in all of these domains. In this approach, the robotic systems eases the lives of human and eliminates the risks, as well as the most important benefit of robotic systems is to protect the humans from potential damages. For these reasons, the robotic systems are the most popular technology of today. The advancements in robotic systems gained speed with the development of integrated circuits in 1980s, and the costs started to decline during this process. Due to these advancements and decrease in costs, this technology penetrated into all of the industries.

The development of robotic systems continues in parallel with the development of microchip technology. As the technology advances, the configurations required for these systems get smaller. Thus, the robotic structures transformed into more light-weight and more functional structures.

The term “robot” refers to the machines thinking like human, making decisions, and mimicking the human behaviors and motions. The development and design of robots is executed by inspiring from the characteristics the creatures have adopted in order to attune to the life. The best example that can be given about this subject is the similarity between the activity zones of robotic arm and human arm.

The common property of all the robotic systems is that they all work on a platform and the end-effectors at the end are designed in accordance with the tasks. In robotic technology, the gripper units, which are specially designed for fulfilling the defined functions, are needed. The systems that are capable of mimicking the motions, which the human hand can perform, are of significant importance. In design and working principles of these units, the human hand, which is the most functional hand, is taken as base.

The fundamental properties that a robot should have are as follows;

1. Capability of performing a task: The unit should physically or virtually fulfill the task that is expected from it.
2. Capability of determining the consequences of operation: It should be capable of determining the consequences of task expected from the unit.
3. Capability of decision-making: The unit should make decision based on the consequences of task, which it is expected to fulfil, or the external factors.

Any system that is capable of fulfilling a task, determining the consequences, and making decisions can be called robot. But, even though the robots are capable of fulfilling any task that human can do, they actually mimicking the capabilities of human. The robots are capable of performing task, which are assigned by human, in the way programmed by human.

The most important part of the design of a robot is the part that fulfills the final motion of gripper system attached to the tip of end-effector. The most important point to be paid attention in gripper design of robotic system is that the hand should be functional and ready-to-operate in accordance with desired function. In robotic systems used in agricultural operations, the design of gripper used in harvesting plays important role in efficiency of harvest. In order to cut the fruit on the branch, the gripper should perform the cutting operation at highest level. Another factor that should be considered in gripper design is that it should be suitable for the physico-mechanical properties of fruit to be harvested. While being cut from the branch, the fruit should completely fit into the gripper and the stem's breaking resistance should be eliminated.

Scarfe et al. (2009) designed a remote-controlled kiwi-harvesting robot. In this design, it is possible to harvest 14,000 kiwis per hour. Using the infra-rouge camera system attached on the harvesting arms, and they defined the fruit diagnostically. Under favor of arms capable of moving 360˚, the fruits are harvested by rotating them around their own axes depending on the penetrometric measurement results.

Zhi-Guo et al. (2009) carried out a study on impact-mechanical properties of robotic fingers used in tomato harvesting. In their study, the effects of input current, and engine speed and position were examined, as well as the control tests of fingers used in tomato harvest grippers. The current values of engine were set between 1200 and 2100 mA, while the engine speed varied between 25 and 3000 RPM. The optimum force for tomato harvesting was sought between these values.

Henten et al. (2010) designed an optimal manipulator for robotic cucumber harvesting. The algorithm used for optimization was the direct algorithm in the Tomlab package. The authors have used 4-connection PPRR type manipulator. They used the values of degree of freedom in cucumber harvesting in the tricyclic system rotating around the vertical axis for the robot. In Figure 1.1, the product selection and motion simulation of harvesting robot is presented.

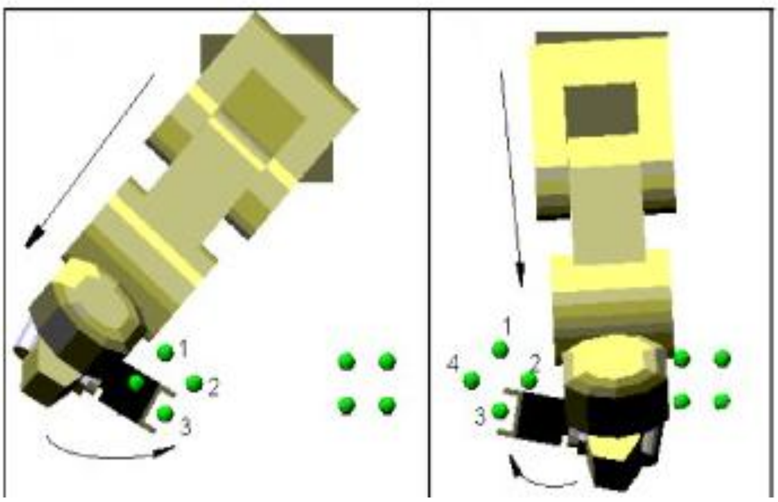

Figure1.1. The product selection and motion simulation of harvesting robot

The common point of all of these studies is that a different gripper was designed especially for harvesting different fruits. Even though the robotic system structures show certain similarities, they grippers were designed in accordance with physico-mechanical properties of fruits.

II. Material and Methods

2.1. MATERIAL

System design has been done for the creation of the system. The following elements are used for this system. These;

1. 2D camera
2. Robotic arm
3. Gripper
4. Ultrasonic sensor.
5. Robotic Control Card
6. Pneumatic System Control

2.1.1. 2D Camera

The 2D camera has a capture ratio of 30 FPS with a 640x380 pixel black and white sensor. Image processing is done with extended SDRAM memory running on a 1 GHz processor. The camera flash memory and images are stored in memory. In addition, the FPGA optimizes pixel processing. It uses TCP / IP and UDP / IP protocols with 10/100 Mb Fast Ethernet to communicate with the computer. Apart from these connections, the camera has the ability to communicate with the RS-485 serial port. Triggering feature is made by standard photoelectric switching. It is controlled by its own software.

2.1.2. Robotic Arm

A robot with 4 degrees of freedom (DOF) moving towards the fruit is used according to the coordinates of the image processing method. 4 Springr SM-8166B and 2 Savox SV-0236 MG model servo motors are used to move the 4 axis robot. Arm lengths L1 = 20 cm, L2 = 17 cm, L3 = 15 cm. The parts of the robot arm are shown in Figure.2.1.

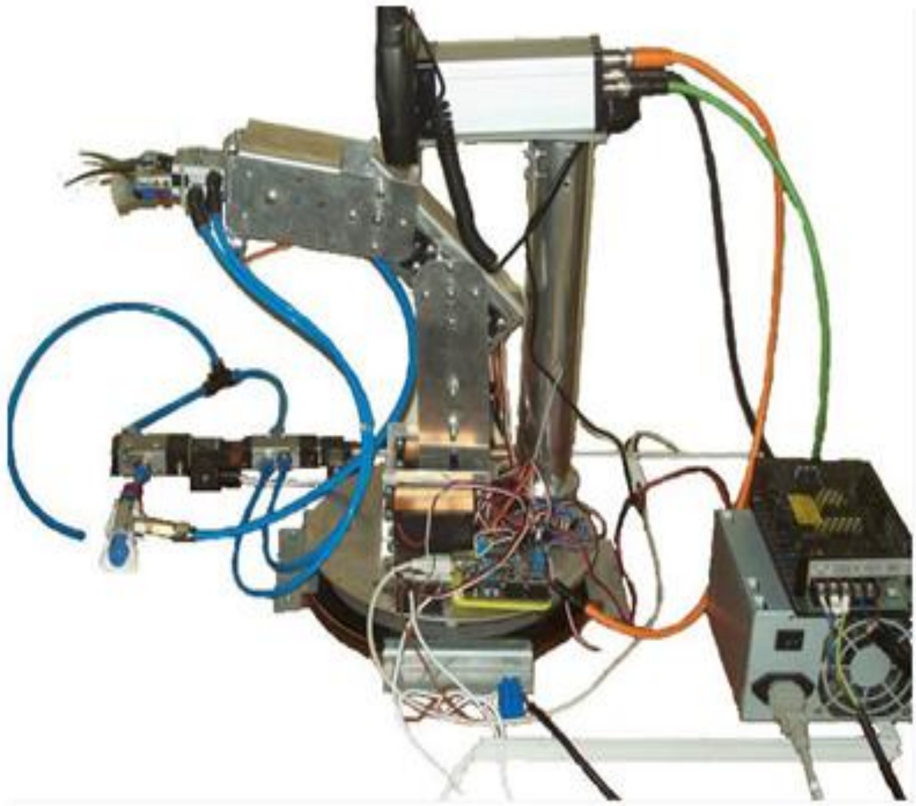

Figure2.1. Robot arm design (original)

2.1.3. Gripper

Two different gripper designs were used in the study. The first method is the servo motor controlled system shown in Figure 2.2. The second method is the system controlled by the pneumatic system shown in Figure 2.3.

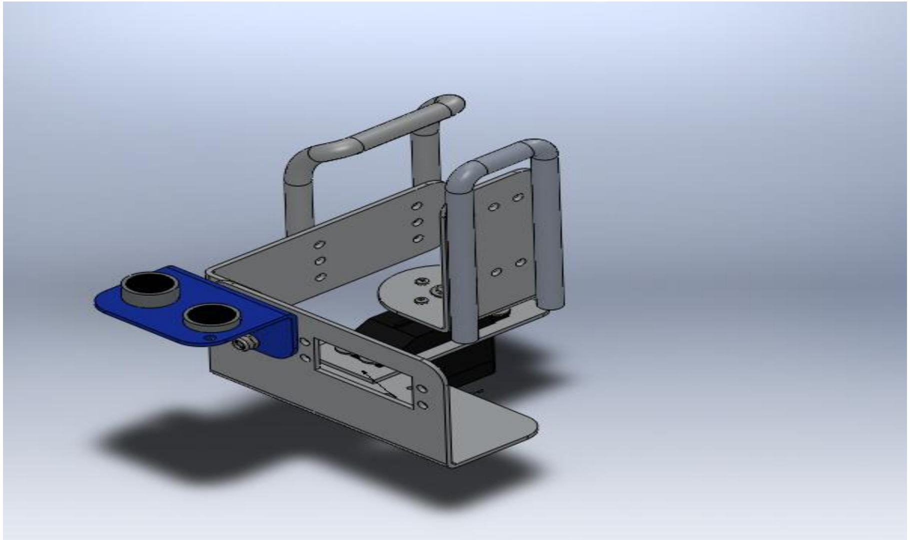

Figure2.2. System controlled by servo motor

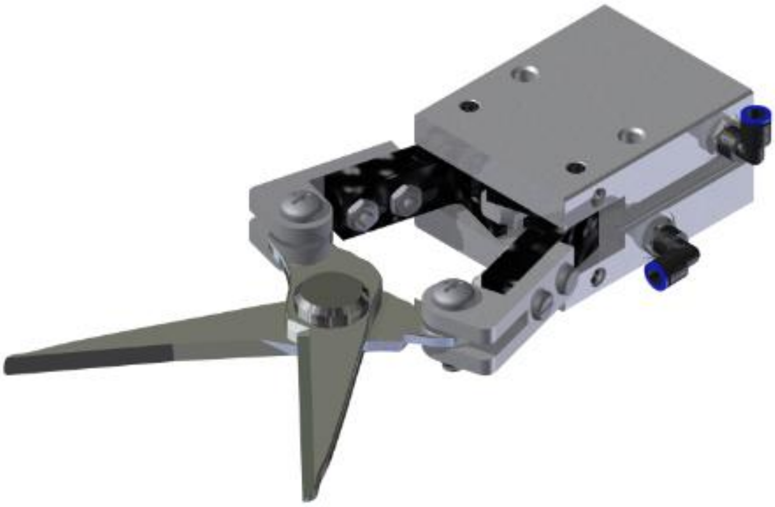

Figure2.3. Control system with pneumatic system

Cutting apparatus used in the system has a size of 17.5 cm lower jaw and 15 cm upper jaw. A blade of 3 cm length was placed on the ends of the jaws. In the second method, a pneumatic scissors system was installed by combining 1 parallel holder and 1 pruning shear.

2.1.4. Ultrasonic Sensor

Parallax Ping Ultrasonic sensor is used to stop the fruit located on the branch of the robot arm at a certain approach distance. The sensor used calculates the distance as the processing of the sound signals. The sensor is scanning the distance between 2 and 3 meters and detects the obstacles in the front. The ping sensor has an I / O pin and a status LED. There are two sensors on the card and 3 pins (5V, GND and signal).

2.1.5. Robotic Control Card

Arduino Uno has been used as a robotic control card. The ATmega 328 is a microprocessor development card and has 14 digital input / output connections, 6 analog inputs, 16 Mhz crystal oscillator, USB connection, power connection, ICSP connection and reset button.

2.1.6. Pneumatic System Control

Two solenoid valves MVSO-180-4E1 were used to control the pneumatic system in the system.

2.2. METHODS

The servo engine in first method and pneumatic pruner in second method were controlled via a robotic control card, and a program was coded for rotation of servo. The pneumatic system was connected to a

compressor, which provides 5-8 Bars of pressure, via 8mm-diameter hoses. The system was controlled by running the control valves via the coded program. The control valves were used for operating the pruner under 5-8 Bars of pressure.
The calculation of cutting pressure of pruner was calculated according to the formula below:
Cutting Stress (D. Dursun, 2001):

$$\tau = \frac{F}{A} \quad (1)$$

τ=Cutting stress (N/ mm^2)
A=Cross-section area (mm^2)

$$A = \frac{\pi * d^2}{4} \quad (2)$$

d=Stem diameter

Cutting Force (D. Dursun, 2001):

$$F_1 * L_1 = F_2 * L_2 \quad (3)$$

L_1 = Stem length
L_2 = Cutting length

Pneumatic pressure (D. Dursun, 2001):

$$P= F/A \quad (4)$$

P=Pressure (Pascal)
F=Force (N)
A=Cross-section area (mm^2)

In order to cut the fruits on the stem, the systems presented in Figures 2.2 and 2.3 were mounted on the robotic system. The cutting stress during cutting the fruits was calculated using Formulas 1, 2, 3, and 4. During the calculations, the stem diameters were measured using a caliper. L_1 and L_2 lengths and the inner diameter of pneumatic hose were measured using a caliper, and the results are presented below.
L_1=20 mm
L_2=25 mm

The inner diameter of hose was 4 mm. The area of hose (A) was calculated to be 12.56 mm^2.

The pressure values of compressor running the pneumatic system were set between 5 and 8 Bars. The force applied on the lever (F_1) was calculated using Formula 4, while the cutting force (F_2) was calculated by using Formula 3. By putting the values of force applied on lever (F_1) cutting force (F_2) in Formula 1, the stem cutting stress (τ) was calculated. The calculations repeated for 100 times for each fruit species were statistically analyzed.

The pressure of system run by servo engine was calculated to be 0.68 Bar. The force applied on lever (F_1) was calculated using Formula 4, whereas the cutting force (F_2) was calculated according to Formula 3. By putting the values of force applied on lever (F_1) cutting force (F_2) in Formula 1, the stem cutting stress (τ) was calculated. The calculations repeated for 100 times for each fruit species were statistically analyzed.

III. Results and Discussion

The pressure values of compressor running the pneumatic system varied between 5 and 8 Bars. The force applied on lever (F_1) was calculated using Formula 4, whereas the cutting force (F_2) was calculated according to Formula 3. F_1 and F_2 values are presented in Table 1.

Table 1. Pneumatic cutting system

	Pressure Values (Bar)			
	5	6	7	8
F_1(N)	6.28	7.53	8.79	10.04
F_2(N)	5.02	6.03	7.03	8.04

By putting the values of force applied on lever (F_1) cutting force (F_2) in Formula 1, the stem cutting stress (τ) was calculated. The calculations repeated for 100 times for kiwi fruit were statistically analyzed. The statistical analysis was performed according to the cutting status of fruits. The results are summarized in Table 2.

Table2. Exchanges cutting force for Kiwi

		Sum of Squares	df	Mean of Squares	F	Sig.
a*	Between Groups	6.698	62	.108	4.859E32	.000
	In-Group	.000	38	.000		
	Total	6.698	100			

b*	Between Groups	9.682	62	.156	2.916E33	,000
	In-Group	.000	38	.000		
	Total	9.682	100			
c*	Between Groups	13.132	62	.212	1.905E33	.000
	In-Group	.000	38	.000		
	Total	13.132	100			
d*	Between Groups	17,243	62	.278	2.502E33	.000
	In-Group	.000	38	.000		
	Total	17.243	100			

*a=5 bar, b=6 bar, c=7 bar, d=8 bar

The pressure of system run by servo engine was computed to be 0.68 Bar. The force applied on lever (F_1) was calculated using Formula 4, and the cutting force (F_2) was calculated by using Formula 3. By putting the values of force applied on lever (F_1) cutting force (F_2) in Formula 1, the stem cutting stress (τ) was calculated. No statistical analysis could be performed, since no cutting could be made in 100 attempts made for kiwi fruit.

During the experiments, the percentage of accurate positioning of robotic arm was found to be 83%. The reason for this is that the camera chose the fruit randomly during determining the coordinates when the fruits are collateral or consecutive. It was found that the coordinates of fruit that better fits to the defined shape was given, rather than the fruit with perfect shape.

The rate of cutting was 72%. The reason for difference between finding and cutting was found to be the position of fruit on the pruner. As a result of T-test performed, it was determined that not only x-axis but also y-axis is important for cutting the fruit from branch. During positioning the pruner, it was determined that axis ensured the positioning of pruner on the stem of fruit. The position of fruit stem on the tip of pruner, the position of pruner corresponding to the body of fruit, the fruit, or the beginning of stem rather than the stem, and the position of pruner on the shoot of stem were observed to cause failure during cutting.

According to the results of ANOVA test, the pressure values of pressure varying between 5 and 8 Bars were found to be significant for cutting force. It was determined that the compressor pressure running the pneumatic system provided enough pressure for cutting operation. The pressure values varying between 5 and 8 Bars were observed to be enough for cutting. It was determined that the change in pressure of compressor wouldn't affect the cutting force.

IV. Conclusion

In experiments carried out with servo engine, the cutting couldn't be accomplished. As servo engine, the servo engines running on AC power that has higher pressure values should be preferred. Since the stem diameters affect the stem's breaking resistance, the system failed. The pressure that was applied was observed to be unsuitable for cutting the fruit stem.

It was determined that the system to be used as gripper providing the final motion of robotic system was the pneumatic one. It was concluded that the success rate of cutting can be increased by pulling the fruit inwards from the tip of blade and keeping it stable in order to improve the plucking success. Specially designing the vacuum pad at the tip of vacuum generator used for pulling the fruit inside is believed to improve the success in keeping fruit stable. In the present study, it was concluded that the most important factor in robotic design is the gripper fulfilling the final motion. Although the determination of fruit's position, all of the parts moving the robotic arm, and all of the software were the same, the higher level of success of system driven by the pneumatic system also corroborates this.

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