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Research Article

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Robotic Impact of the Physicomechanical Properties of Kiwi Fruit

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Abstract This study aims to determine the physiomechanical properties of kiwi fruit that affect robotic harvesting. Coordinate axis values obtained by a camera is the most important input in a robotic harvesting system. Surface area of the fruit was used in determining the coordinates. As a result of the analysis, a correlation was found between measured values and robotic harvest. Measurements and calculations suggest that surface area and height, width, thickness and sphericity values are significantly correlated. It is understood that these factors have a direct effect on the surface area of the fruit. It was determined that the surface area is the value to be used for robotic harvesting. Since the coordinates are determined according to the midpoint of the surface area of the fruit, x and y coordinates vary for each fruit.

Keywords Kiwi, Physicomechanical, robotics harvesting, image processing

1. Introduction

Today's agriculture has adopted agricultural mechanization practices and abandoned the traditional production techniques. Therefore, mechanization practices have become widespread in various stages of production, such as planting, spraying, and harvesting. With the advances in technology and the introduction of computer technology, such computer-aided systems have begun to be used in the agricultural sector as well. Especially in harvester systems, all processes are performed automatically. Such systems enable the transition to robotic agriculture. Robotic agriculture is a form of agricultural application involving hydraulic and pneumatic systems, computer control systems and image processing technologies.

Although the systems are intelligent systems, all coding must be done by people. According to the operation to be performed, the system must be coded with the help of control parameters. It is expected that the machine should behave in accordance with its code entered by humans, who understand the one-way complexity of work. This type of behavior is called robotic system behavior.

The robotic system behavior depends entirely on the human factor. Sensitivity in defining the parameters of the work to be done affects robotic system behavior. If the parameter to be given is not suitable for the work to be performed, the expected result of the operational system will not be correct. Environmental effects, product characteristics, field structure, weather conditions are the factors that determine robotic system behavior.

2. Backgrounds

Numerous studies are being conducted worldwide in parallel with the decreasing prices and increasing use of robotic systems. Robotic harvesters have begun to be developed for many products such as apples and cucumbers. These studies, however, are not limited to harvesting. Robotic irrigation systems, robotic mapping systems are an example for other applications.

It is very important to protect the quality of the kiwi fruit, which is produced in Turkey increasingly in recent years and has an important export potential, both in the production stage and in the harvesting stage. In order to maintain these properties of the fruit, sensitive farming practices should be implemented. The quality of the fruit is significantly affected by the processes applied during the harvest.

In a study conducted by Celik et al. [1], the physical characteristics for the Hayward genus kiwi harvest have been determined as follows (Table 1)

Table 1: Some physical properties of kiwifruit cv. Hayward [1]

Property	Minimum	Maximum	Mean	Standard deviation
Porosity (%)	35.52	57.62	47.13	5.95
Sphericity index (%)	0.76	0.90	0.83	0.03
Aspect ratio	0.65	0.86	0.78	0.05
Geometric mean diameter (mm)	43.38	54.53	49.03	2.41
Surface area (mm^2)	5,912	9,340	7,552	741
Fruit length (mm)	49.79	68.39	59.41	3.88
Fruit width (mm)	40.24	53.68	46.28	2.93
Fruit thickness (mm)	38.87	47.17	42.87	1.96
Skin thickness (mm)	0.37	0.49	0.44	0.04
Fruit mass (g)	51.01	96.94	72.28	10.63
Hectoliter weight (kg)	483	664	572	54
Fruit density (kg/m^3)	982	1,355	1,093	86
Bulk density (kg/m^3)	492	677	575	56
Fruit volume (cm^3)	40.00	90.00	66.52	12.01
Spread area (m^2/kg^1)	0.040	0.046	0.042	0.002
Skin color				
L*	40.53	48.43	43.94	1.961
a*	2.44	7.85	5.51	1.135
b*	19.30	27.89	24.04	2.191
Flesh color				
L*	53.48	60.95	57.18	2.522
a*	-18.9	-16.24	-17.25	0.802
b*	35.79	39.72	37.46	1.144
Skin firmness (kg)	9.080	10.310	9.690	0.610
Flesh firmness (kg)	7.575	8.385	7.980	0.401
Coefficient of static friction on:				
Galvanized steel sheet	0.102	0.216	0.158	0.032
Rubber	0.108	0.233	0.163	0.037
Plywood	0.131	0.256	0.190	0.038
Polyethylene	0.108	0.250	0.173	0.040
Projected area (mm^2)				
x axis	4,112	7,088	5,595	743
y axis	3,235	6,559	4,829	805
z axis	3,934	6,957	5,334	720

The above mentioned properties indicate harvest criteria for kiwi fruit. In the light of these values, investigating the characteristics of fruit are important for robotic harvesting forms the basis of present study.

Kiwi fruit harvesting is mostly a manual task, and mechanization practices have not been applied to kiwi harvesting processes yet. For this reason, significant quality losses occur during harvest and require an important workforce.

Although there are studies in this area, the majority is prototype robotic harvest studies in the reviewed literature. Among the prototype works, few systems have been put into practice.

This research was planned to develop a robotic arm for reducing the harvest damage on kiwi fruits, and shortening the harvest time. The study aims to determine the location of the fruit by using image processing technique and to perform harvesting via robot arm. In this way, the harvest will be carried out quickly, independent from labor force.

Tanigaki et al [2] have conducted a study on robotics harvesting for cherry. They have used a fourth grade manipulator for the robot. They have used 3D image processing sensor equipment in order to measure the redness and have used infrared laser to measure the distance. They have recognized the fruit with 3D sensor. They have carried out to recognize the fruit with filtration to the red color.

Scarfe et al. [3], have conducted a study the design of remote-controlled robots that harvest kiwi.. It is the design of remote-controlled robots that harvest kiwi. Kiwi is 14,000 h with the design “pick you”. Harvest in the arms installed infrared camera system received and processed the image after that the fruit was defined as a diagnostic. Means capable of moving arms 360°, penetrometric measurement results determined by the hardness of the fruit were harvested the crop by rotating on its axis.

Hayashi et al. [4] conducted a research on field test evaluation for robot strawberry harvest.They used a robot consisting of a cylindrical manipulator, end-effector, artificial vision unit, carrier system and storage unit. They have developed a lighting unit to do the harvest night to overcome problems such as low work efficiency, low success rate, undecided lighting that they had in previous studies. The definition of the fruit maturity level is defined for the identification of the fruit.They found a success rate of 60% in detection of fruit stem with artificial vision unit. The success rate of the system is 34.9%.

Determination of the physicomechanical properties of fruits and carrying out the robotic harvest according to the determined characteristics are the common goals of the studies. The purpose of our research is to improve the harvesting technique with less damage and in a shorter time. It was aimed to determine the problems that may arise in the robotic harvest of kiwi fruit, to determine the solutions in this regard as well as determining the physicomechanical properties of kiwi fruit affecting the robotic harvesting.

The study focuses on image processing technique and robotic system in harvesting of kiwi fruit. The problems that may be encountered by the robotic system during harvesting were identified. Importance of calibrating the image processing and robotic system pair was emphasized. Physicomechanical properties affecting the robotic harvesting were shown by measurements.

2. 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;

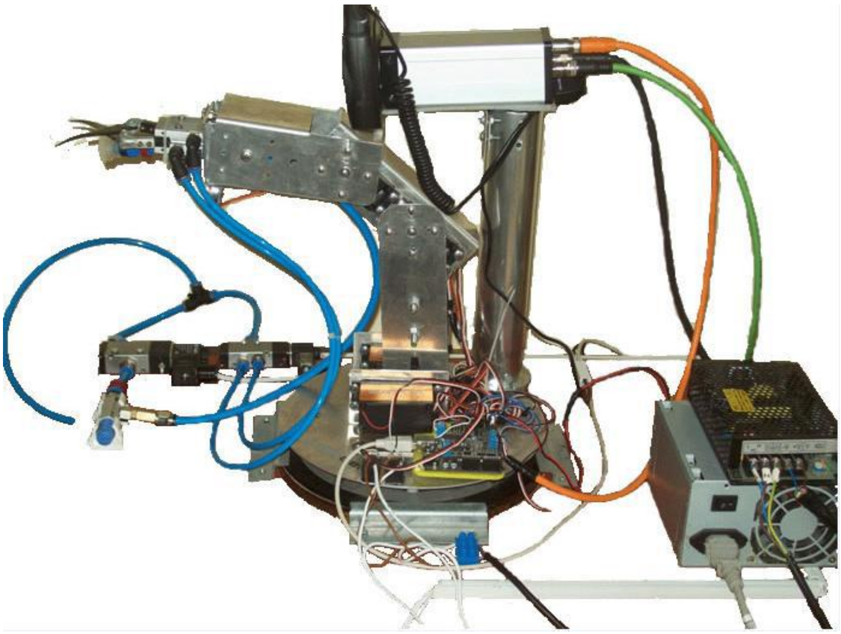

Figure 1: Robot arm design (original)

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 1.

2.1.3. Gripper

Scissor design which operates with pneumatic system has been made in order to pull the fruit from the branch. The picture of the design is shown in Figure 2.

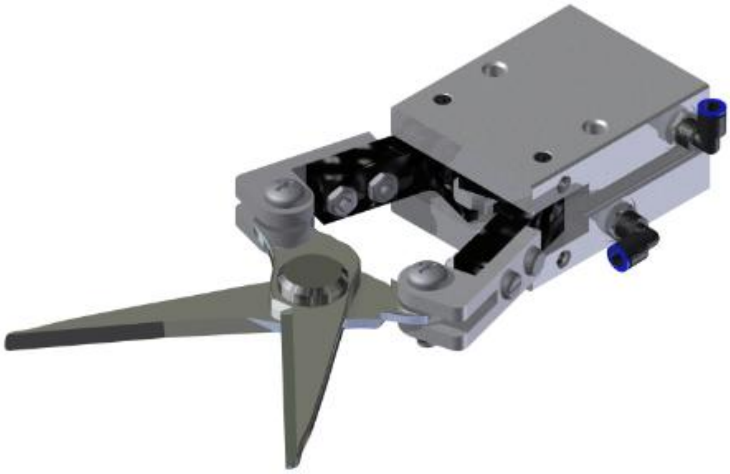

Figure 2: Control system with pneumatic system

Pneumatic scissors system was established 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.

2.1.7. Kivi

Experiments Kiwi fruit for October, fruit average height 62.17 mm. , width 45.97 mm., the thickness is 42.14 mm. and weight of 70.19 gr.

The experiments were made with 100 Hayward varieties kiwi fruit juice.

2.2. Methods

2.2.1. Determination of Physicomechanical Properties of Fruit

The kiwi fruit was chosen by chance (100 pieces) over the branch and measurements were made using a digital caliper capable of measuring 0-150 mm of 0.01 mm precision fruits.

The following equations were used to determine the geometric mean diameter and sphericity of the kiwi fruit. [5]

$$Dg = (LD^2)^{1/3} \quad (1)$$

Equality; Dg = geometric mean diameter (mm), L: length (mm) ve D: product diameter (mm)
The spherical value is calculated based on the geometric mean diameter value [5].

$$\Phi = \frac{Dg}{L} \quad (2)$$

Equality; Φ: sphericity coefficient (--), Dg: geometric mean diameter (mm) ve L: length (mm)
The surface area of the kivin is calculated by the following equation [5].

$$S = \pi D_g^2 \quad (3)$$

Equality; S: surface area (mm^2), Dg: geometric mean diameter (mm)
The volume of the samples was determined on the basis of changing the volume on a scale cap.
Fruit breaking force is determined by the dynamometer at the time of dangling break.

2.2.2. Fruit Coordinates and Locations

The most important variable is to know the space coordinate axes of the fruits in order to harvest the fruit with robotics system. Image processing technique has been applied in order to find the coordinate axes. 2D camera model has been used for image processing. Both horizontal axis (x) and vertical axis (y) have been found in the space coordinate axis of the fruits with this camera. Ultrasonic sensor has been used for the distance (z) which is the third coordinate axis. The code has been written in C# for the use of this sensor and the robot has been prevented when it reaches a certain distance. Necessary smooth and kinematic calculations have been written in C# which is necessary for image processing. These calculations and the program have been installed to the processor in the robotics system control card with USB port. The communication between the writing of the program and 2D camera has been provided. Coordinate axes to be obtained as a result of image processing and 2D camera coding have been found. Obtained results have been identified by using 2D camera interface and it has been recorded. It has been provided that robotics arm stops and cut when it is 10cm in front of the fruit according to the value from the ultrasonic sensor via written program.

In the system installed for the experiments, the position of the camera is placed according to the maximum reach distance of the robot arm. The maximum reach distance and the location of the scissors on the stem of the fruit on the branch are provided. In the experiment period, 100 kiwi and apple juice were placed at random on the setup with random placement. Robot arm motion is provided according to the coordinates obtained in the image processing result. Coordinate values are read from the computer screen through the interface of the camera and the program written on the Robotic system control card.

3 Results and Discussion

3.1. Features of Physical Mechanics

The statistical values of the physicomechanical properties of the kiwifruit according to the calculated values are given in Table 2.

Table 2. Physicomechanical statistics

	Min.	Max.	Mean	Std. Deviation
Fruit detachment strength (kg)	2.08	4.70	2.712	0.668
Height (mm)	51.80	71.70	62.172	4.026
Width (mm)	37.80	52.70	45.977	2.821
Diameter(mm)	36.00	47.80	42.144	2.287
Weight (g)	42.23	98.47	70.166	11.079
Sphericity (%)	0.76	0.89	0.817	0. 0262
Surface area (cm^2)	55.78	103.32	81.400	9.355
Volume (cm^3)	40.00	180.00	70.600	16.006
Stem thickness(mm)	1.70	3.11	2.529	0.287

The results obtained from the research were evaluated statistically and correlation analysis was performed. Findings related to the correlation analysis are given in Table 3.

Table 3: Correlation values for kiwi

	Fruit detachment strength (kg)	**Height (mm)**	**Width (mm)**	**Diameter (mm)**	**Weight (g)**	**Sphericity (%)**	**Surface area (cm^2)**	**Volume (cm^3)**	**Stem thickness (mm)**
Fruit detachment strength		0.045	-0.076	-0.072	-0.101	-0.167	-0.030	-0.043	0.104
Height	0.045		0.708	0.548	0.860	-0.421	0.866	0.821	0.005
Width	-0.076	0.708		0.540	0.839	0.436	0.965	0.801	-0.038
Diameter	-0.072	0.548	0.540		0.742	-0.321	0.579	0.724	0.034
Weight	-0.101	0.860	0.839	0.742		-0.068	0.907	0.927	-0.010
Sphericity	-0.167	-0.421	0.436	-0.321	-0.068		0.082	-0.063	-0.064
Surface area	-0.030	0.866	0.965	0.579	0.907	0.082		0.864	-0.031
Volume	-0.043	0.821	0.801	0.724	0.927	-0.063	0.864		0.041
Stem thickness	0.104	0.005	-0.038	0.034	-0.010	-0.064	-0.031	0.041	

($P<0.05$; n=100)

According to the correlation analysis results carried out for kiwi fruit;

There was no relationship between fruit detachment strength and fruit weight.

The relationship between fruit height, fruit detachment strength and stem thickness was not statistically significant, but the relationship between width, thickness, weight, surface area and volume was found to be significant ($P<0.05$).

The relationship between fruit width, fruit detachment strength and stem thickness was not significant, but the relationship between height, weight, sphericity, thickness, surface area and volume was found to be statistically significant ($P<0.05$).

The relationship between fruit thickness and fruit detachment strength, sphericity, surface area and stem thickness was not significant, but the relationship between height, width, weight and volume was found to be statistically significant ($P<0.05$).

The relationship between fruit weight and fruit detachment strength, sphericity and stem thickness was not statistically significant, but the relationship between height, width, thickness, surface area and volume was found to be statistically significant ($P<0.05$).

The relationship between fruit sphericity and height and width was statistically significant ($P<0.05$). The relationship between fruit sphericity and fruit detachment strength, thickness, weight, surface area, volume and stem thickness was not significant.

The relationship between fruit surface area and fruit detachment strength, thickness, sphericity and stem thickness was not statistically significant, but the relationship between height, width, weight and volume was found to be statistically significant ($P<0.05$).

The relationship between fruit volume and fruit detachment strength, sphericity and stem thickness was not statistically significant, but the relationship between height, width, thickness, weight and surface area was found to be statistically significant ($P<0.05$).

There was no relation between the stem thickness and fruit detachment strength and other characteristics.

3.2. Fruit Locating Features

The rate of finding fruit juice for kiwi was 83%, which was determined at the end of the analysis.

The statistical values of these are given in Table 4 and in Table 5 success rates are given according to x and y coordinates.

Table 4: Mean and standard deviation values for find

Find Yes		**N**	**Mean**	**Std. Deviation**	**Std. Error Mean**
CamCoordx**	1,00*	83	344,792	118,615	13,019
	,00*	17	544,936	29,949	7,268
CamCoordy**	1,00*	83	313,589	13,512	1,483
	,00*	17	312,038	13,217	3,205

*0=No, 1=Yes

**CamCoordx=x camera coordinate, Camcoordy=y camera coordinate

Table 5: Finding percentages by x and y coordinates of the camera (t-test)

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Camcoordx*	Equal variances assumed	19,988	,000	-6,886	98	,000	-200,143	29,064	-257,820	-142,467
	Equal variances not assumed			-13,424	94,212	,000	-200,143	14,908	-229,744	-170,542
Camcoordy*	Equal variances assumed	4,073	,051	1,520	98	,132	6,656	4,380	-2,036	15,3495
	Equal variances not assumed			1,034	17,957	,315	6,656	6,436	-6,869	20,181

*CamCoordx=x camera coordinate , Camcoordy=y camera coordinate

According to the T-test on the find values, it is seen that the value of x coordinate is important for locating the robot arm's fruit.

After the position of the robotic arm, the information about the status values for fruit cutting values were statistically analyzed and the results are summarized in Table 6 for kiwi.

Table 6: Cutting condition for kiwi

Cut Yes		**N**	**Mean**	**Std. Deviation**	**Std. Error Mean**
Camcoordx**	1,00*	72	337,162	123,140	14,512
	,00*	28	485,929	88,294	16,686
Camcoordy**	1,00*	72	314,281	9,506	1,120
	,00*	28	306,421	26,872	5,078

*0=No, 1=Yes

**CamCoordx=x camera coordinate , Camcoordy=y camera coordinate

For the kiwi, the cutting rate of the robot fruit was determined as 72% at the end of the analysis.

For the independent T-test, the effects of the coordinates on the cut were analyzed. Table 7 summarizes the analysis values for kiwi.

Table 7: Cutting T-test for kiwi

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Camcoordx*	Equal variances assumed	5,448	,022	-5,829	98	,000	-148,767	25,523	-199,418	-98,115
	Equal variances not assumed			-6,727	68,409	,000	-148,767	22,114	-192,890	-104,644
Camcoordy*	Equal variances assumed	10,795	,001	2,170	98	,032	7,860	3,621	,67314	15,047
	Equal variances not assumed			1,511	29,665	,141	7,860	5,200	-2,765	18,486

*CamCoordx=x camera coordinate , Camcoordy=y camera coordinate

Table 8 gives the maximum and minimum values of the coordinates according to the presence or absence of the fruit.

Table 8: Maximum and minimum statistical values of coordinates

Find yes				**Statistic**	**Std. Error**
camcoordx	0.00	Mean		206.5723	12.56385
		95% Confidence Interval for	Lower Bound	180.8764	
			Upper Bound	232.2683	
		5% Trimmed Mean		207.7619	
		Median		210.0350	
		Variance		4735.507	
		Std. Deviation		68.81502	
		Minimum		63.36	
		Maximum		331.44	
		Range		268.08	
	1.00	Mean		436.4137	9.46923
				Statistic	**Std. Error**
		95% Confidence Interval for	Lower Bound	417.5619	
			Upper Bound	455.2655	
		findyes		**Statistic**	**Std. Error**
		5% Trimmed Mean		437.6592	
		Median		431.0400	
		Variance		7083.636	
		Std. Deviation		84.16434	
		Minimum		246.90	
		Maximum		590.20	
		Range		343.30	

findyes					**Statistic**	**Std. Error**
camcoordy	0.00	Mean			317.3390	3.98424
		95% Confidence Interval for		Lower Bound	309.1903	
				Upper Bound	325.4877	
		5% Trimmed Mean			319.9052	
		Median			320.3350	
		Variance			476.226	
		Std. Deviation			21.82259	
		Minimum			220.86	
		Maximum			346.73	
		Range			125.87	
	1.00	Mean			312.9794	1.48006
		95% Confidence Interval for		Lower Bound	310.0328	
				Upper Bound	315.9259	
		5% Trimmed Mean			312.4809	
		Median			311.7000	
		Variance			173.055	
		Std. Deviation			13.15505	
		Minimum			275.29	
		Maximum			392.37	
		Range			117.08	

Statistically, maximum and minimum values of x coordinate was between 590.20 and 246.50 for the 'yes, found' output. The maximum value for the y coordinate was 392.37 and the minimum value was 275.29.

Statistically, maximum and minimum values of x coordinate was between 331.44 and 63.36 for the 'no, not found' output. The maximum value for y coordinate was 346.73 and the minimum value was 220.86 in this case.

Finding and cutting values of fruits have been analyzed as 1 (yes) and 0 (no). The success rate is 83% for kiwi as a result of experiments. Horizontal axis (x) was significant for kiwi and apple according to the T-test which provides both horizontal (x) and vertical (y) axes values help to the robot arm. It has been found that horizontal axis (x) has been the necessary axis in order to move the robot arm along with image processing.

At the end of the experiments, the wrong value of the robot arm has been determined as 17% for kiwi. The reason for this is that the camera chooses the fruit randomly during finding the coordinate in the fruits that stand side by side or back to back in the experiments. It has been determined that the most suitable fruit coordinates have been given.

4. Conclusions

As a result of the study, robotic fruit harvesting was found to be affected by the physicomechanical properties of the fruit. Weight, height, width, thickness values and surface area were observed to be the most important input values in robotic fruit harvesting. It was observed that image processing techniques are effective in robotic system operation in robotic fruit harvest. In experiments using image processing techniques, it was understood that the results of image processing affect the robotic harvesting directly. It was concluded that image processing techniques must be selected properly for a correct and quick robotic harvesting. It was also understood that the software used in the robotic fruit harvest has to operate in parallel with the system and image processing. It was seen that the design of the gripper, which will perform the fruit detachment, should be designed in accordance with the physicomechanical properties of the fruit. It was also concluded that the operational motors of the system should be powerful, and the cutter system should be appropriate for the specific detachment operation.

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