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Research Article

Fruit Sorting Automation; Cartesian Robot and Conveyor Design

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ABSTRACT

The quality control process, the process of sorting the products in the conveyor belt into intact, bruised, rotten, and raw types, is carried out by people. However, due to the human factor in the sorting process, achieving a certain standard and working consistently at the same efficiency is difficult. Therefore, performing this process autonomously using image processing, cartesian robots, and conveyor belt technologies is essential in terms of both accelerating the process and reducing its cost.

In this study, pick and place cartesian robot and conveyor belt are designed to be integrated for fruit sorting automation. The fruits whose image processing is completed are positioned in the conveyor belt. By adding partitions in the conveyor belt, the fruits falling from the image processing mechanism are ensured to reach the cartesian robot without changing their position. The cartesian robot starts moving according to the position of the fruit on the conveyor. When it reaches the location of the fruit, it holds it with the help of a vacuum generator and leaves it in the storage areas separated according to the condition of the fruit (color, damaged, undamaged). Thanks to the designed cartesian robot, it aims to minimize the error rate by sorting faster, less costly, and more reliable way. The study aims to provide physical separation. Using the prepared system in the industry aims to minimize labor costs and errors that may occur in the human factor.

Keywords: Cartesian robot, Conveyor Belt, Automation.

Meyve Ayırıştırma Otomasyonu; Kartezyen Robot ve Konveyör Tasarımı

ÖZET

Kalite kontrol işlemi, konveyör banttaki ürünleri sağlam, ezik, çürük ve ham şeklinde ayıklama prosesi insanlar tarafından yapılmaktadır. Fakat ayıklama işleminde insan faktöründen dolayı belli bir standart yakalayabilmek ve istikrarlı şekilde aynı verimde çalışmak zordur. Bu nedenle bu işlemin görüntü işleme, kartezyen robot ve konveyör bant teknolojileri kullanılarak otonom şekilde yapılması hem işlemin hızlanması hem de maliyetinin azalması açısından önemlidir.

Bu çalışmada, meyve ayırıştırma otomasyonu için al ve yerleştir kartezyen robot ve konveyör bant sistemi birbirine entegre olacak şekilde tasarlanmıştır. Görüntü işleme tamamlandıktan sonra meyveler konveyör bantın üzerine konumlandırılmaktadır. Konveyör bant üzerine bölmeler ekleyip görüntü işleme mekanizmasından düşen meyvelerin konumunu değiştirmeden kartezyen robota ulaşması sağlanmaktadır. Kartezyen robot, konveyörün üzerinde bulunan meyvenin konumuna göre harekete

başlamaktadır. Meyvenin konumuna ulaştığında bir vakum jeneratörü yardımıyla tutma işlemi yaparak, meyvenin durumuna göre (renk, hasarlı, hasarsız) ayrılan depolama alanlarına bırakma işlemini yapmaktadır. Tasarlanan kartezyen robot sayesinde daha hızlı, daha az maliyetli ve güvenilir bir şekilde ayırıştırma yaparak hata oranı minimuma indirilmesi amaçlanmaktadır. Çalışmada hedeflenen fiziki olarak ayırıştırma sağlamaktır. Hazırlanan sistemin endüstride kullanılacak olması ile işçilik maliyetini en aza indirmesi ve insan faktöründe oluşabilecek hataları minimize etmek hedeflenmektedir.

Anahtar Kelimeler: Kartezyen robot, Konveyör Bant, Otomasyon.

I. INTRODUCTION

According to the research titled "Global Food Losses and Food Waste" prepared by the UN Food and Agriculture Organization, 95% of food losses in developing countries occur "unintentionally" in the early stages of the supply chain (until it reaches the facility to be processed). These losses are caused by financial, administrative, and technical disruptions or inadequacies in production and harvesting techniques, transportation, storage and cooling, public infrastructure, transportation vehicles, packaging, and distribution systems. Loss rates can be up to 15% of the total production in grains and legumes and 35% in fruits and vegetables [1]. This situation reduces the consumer's trust in the manufacturer and causes the brand value to decrease.

Humans carry out the quality control process on conveyor belts by sorting them into solid, crushed, rotten, and raw [2]. However, due to the human factor in the sorting process, achieving an exact standard and working consistently at the same efficiency is difficult. Therefore, performing this process autonomously using robots and image processing technology is vital in terms of both speeding up the process and reducing its cost. In the literature, Zhang et al. (2021) used image processing and parsing systems on the screw conveyor [3]. Erdoğan (2012) designed a system based on faulty product detection and classification in the processes that the product goes through in the conveyor belt until packaging [4]. Parlar et al. (2021) made a product placement system with robot guidance by performing image processing-based position analysis of the products coming in the conveyor belt [5]. Patil et al. (2016) conducted a study classifying fruit as defective, unripe, underripe, and overripe. They conducted the classification process using three paths and three separate pistons on the conveyor [6]. Kulaksız (2010) provided image processing support for parallel robot control. Thanks to the camera, the image is processed, and the position information is accurately transmitted to the parallel robot, which enables it to hold and stack the product, whose position is changing, from different positions with the vacuum gripper [7]. Dragusu et al. (2012) designed a 4-wheeled robotic arm for the pick-and-place robotic system. The process of picking up and placing objects was carried out with the gripper mechanism placed at the end of the robot arm [8]. Sarıyıldız and Demirhan (2021) detected red, blue, and green objects coming from the conveyor with a camera and sorted them according to the object's color with the help of a robotic arm. They managed to separate 150 objects, consisting of five blue, five red, and five green objects, with a success rate of 100% [9]. Arikapudi and Vougioukas (2023) aimed to guide the design of harvesting robots utilizing arrays of three degrees of freedom cartesian arms [10]. Altawil and Can (2023) provided a new methodology for multitasking in agricultural operations by designing a four-degrees-of-freedom robotic arm with different configurations and two grippers. They controlled the robotic arm with the Robot Operating System (ROS). [11]. Şenel and Çetişli (2015) identified the faulty products coming on the conveyor belt and sorted them with a robotic arm [12].

This study covers the design of the cartesian robot and the conveyor belt, which is the transport part of the fruit sorting automation. In automation, the products coming in the conveyor belt will be stored in the desired areas with the help of the cartesian robot. For the purpose of the conveyor belt, the fruit whose image processing is completed will be supported with a rubber sponge in the conveyor belt in case of damage when falling in the conveyor belt. This is to prevent the fruit from being damaged. The Raspberry Pi 4 control card provided control of the automation.

II. MATERIAL METHOD

A. CONVEYOR BELT

Conveyor belts are widely used in various industries, such as automotive, food, logistics, mining, packaging, and material handling. They are used in production lines to move materials from one workstation to another, carry out packaging, or organize materials in storage areas. Conveyor belts are faster and more efficient than manually moving materials. Thanks to the automatic working principle, manpower is saved, and production speed is increased. In this study, a special conveyor belt was designed and manufactured to regularly transport the fruits, whose image processing process was completed, to the area where the cartesian robot will carry out physical sorting without any damage. Figure 1 shows a model image of the conveyor belt system.

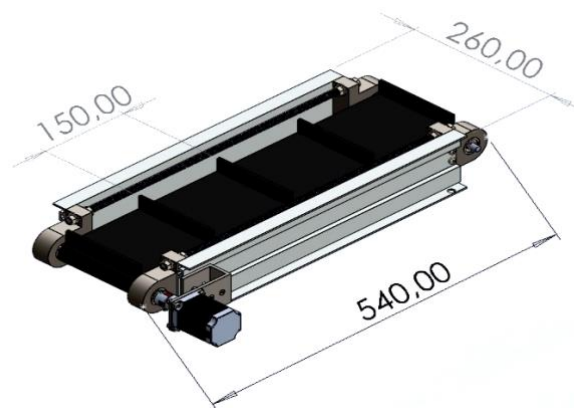


Figure 1. Model image of the conveyor belt system.

The side chassis of the conveyor belt system was selected from aluminum material and was determined to be a conveyor profile with dimensions of 25x105x530 mm. Tension and drive drums were made of aluminum material with a diameter of 30 mm and a length of 240 mm. The transmission band was made of blue tarpaulin, and its dimensions are 140x1320 mm. To prevent damage to the fruit, a flooring sponge measuring 5x140x1320 mm was fixed in the conveyor belt. In Figure 2, the conveyor belt system aims to ensure that the fruit (apple) falling from the image processing mechanism is transmitted to the cartesian robot without changing its position. To prevent the apple from changing its position, partitions measuring 70x140 mm were added to the conveyor belt. Nema 23, 2 Nm stepper motor was chosen for the movement of the conveyor belt. Python programming language was used with the Raspberry Pi 4 control card to control the Nema 23 stepper motor. With this programming language, parameters such as the number of steps, rotation speed and acceleration of the motor can be adjusted. TB6600 Motor driver was used to control the stepper motor and determine the desired speed.

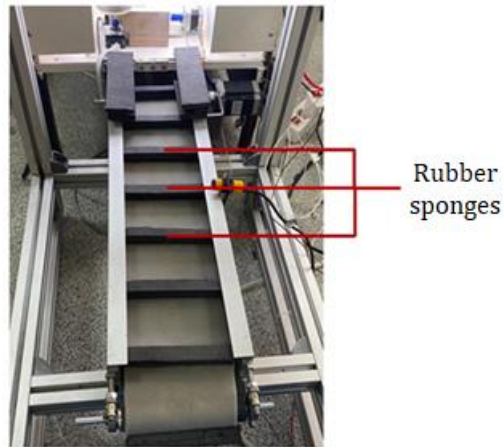


Figure 2. Conveyor belt application.

The movement of the conveyor belt was stopped using an infrared sensor. The infrared sensor was positioned in the conveyor belt, parallel to the belt. The conveyor belt is programmed to stop when the infrared sensor detects fruits moving on the belt. In this way, the position of the fruit was determined so that the cartesian robot could perform holding and placing operations. Figure 3 shows the installation of the infrared sensor in the conveyor belt.

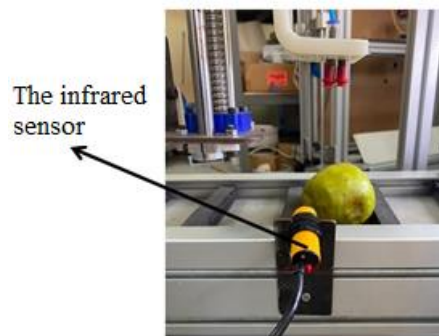


Figure 3. The infrared sensor installation in the conveyor belt.

B. CARTESIAN ROBOT

A cartesian robot was designed and integrated into the system to ensure the physical separation of fruits, which is the last step of fruit sorting automation. The cartesian robot was preferred in the physical sorting part of fruit sorting automation, minimizing the margin of error by eliminating human hand touch, thanks to its fast and efficient transportation processes and safe and controlled release processes. A 40x40 mm aluminum profile was used to create the skeleton of the cartesian robot system. Figure 4 shows the model image of the cartesian robot and the coordinates of the joints.

The Denavit-Hartenberg (DH) method is mostly used to create the kinematic model of robots in space. In this study, robot kinematics were derived using four main variables, as in the DH method. These variables are the bond length a_{i-1} between the two axes, α_{i-1} , the bond angle between (i-1) and i, the joint misalignment d_i between the overlapping bonds, and the joint angle θ_i between the two bonds. These four variables are referred to as the DH variable [13]. In the figure 4, d_1 , d_2 and d_3 are joint variables, respectively. DH variables were obtained as in Table 1 using the cartesian robot coordinate system.

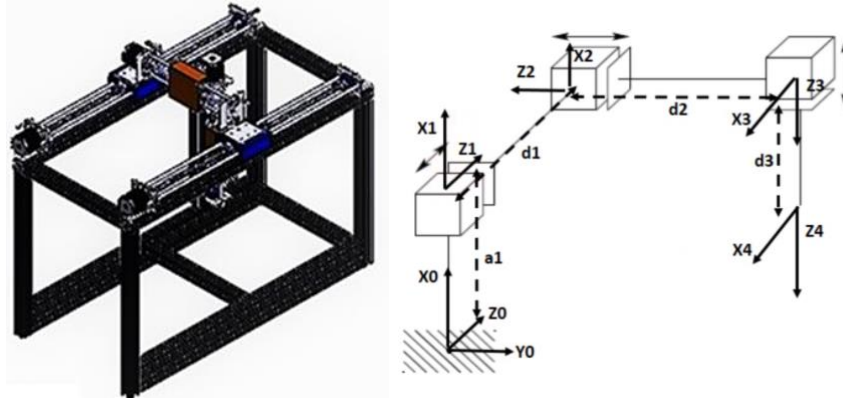


Figure 4. Model view and coordinates of the cartesian robot.

Table 1. DH variables.

DH variables				
i	a_{i-1}	a_i	d_i	θ_i
1	0	a1	0	0
2	90	0	d1	0
3	90	0	-d2	-90
4	0	0	d3	0

Table 1, i shows the joint row; the lengths are given in mm, and the angles are given in radians. The general transformation matrix given below can be used to obtain the forward kinematic equations of the robot mechanism using DH variables [13].

$$T_{i-1}^i = \begin{bmatrix} C\theta_i & -S\theta_i & 0 & a_i \\ S\theta_i C\alpha_i & C\alpha_i C\theta_i & -S\alpha_i & -d_i S\alpha_i \\ S\theta_i S\alpha_i & S\theta_i S\alpha_i & C\alpha_i & d_i C\alpha_i \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (1)$$

Equation 1, C denotes cosine, and S denotes sine. If the DH parameters are respectively replaced in the transformation matrix given in Equation 1, the forward direction transformation matrices required for each joint of the mechanism are obtained as follows [14].

$$T_0^4 = \begin{bmatrix} 0 & 0 & -1 & a_1 - d_3 \\ 0 & -1 & 0 & d_2 \\ -1 & 0 & 0 & d_1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (2)$$

While Equation 2 gives the orientation matrix of the 3x3 matrix in the first three rows and columns of the T_0^5 matrix, the first three elements of the last column give the position of the end function in 3-dimensional space. The position of the end functionalist was expressed in Equation 3.

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} a_1 - d_3 \\ d_2 \\ d_1 \end{bmatrix} \quad (3)$$

To drive the cartesian robot, Nema 23 stepper motors with a power of 2.2 Nm were used, 2 in the X axis, 1 in the Y axis, and 1 in the Z axis, a total of 4 in total. The control of Nema 23 stepper motors used to drive the cartesian robot is provided by the TB6600 driver card. Python software language and GPIO library, and Raspberry Pi 4 as the controller card, were used to integrate the necessary processes,

such as the axial movements of the cartesian robot, the starting and stopping of the drive of the stepper motors, and the movement of the cartesian robot to the reference point at the end of the process. Figure 5 shows the driver and Raspberry Pi 4 connection of the stepper motor. Continuity of movement in the axes was ensured by 12 mm diameter linear shafts and 16 mm diameter ball screws. Parts measuring 50x100x100 mm were used to connect ball screws and linear shafts, and other stepper motors. Its parts measuring 50x100x100 mm were manufactured using 3D printers (Figure 6).

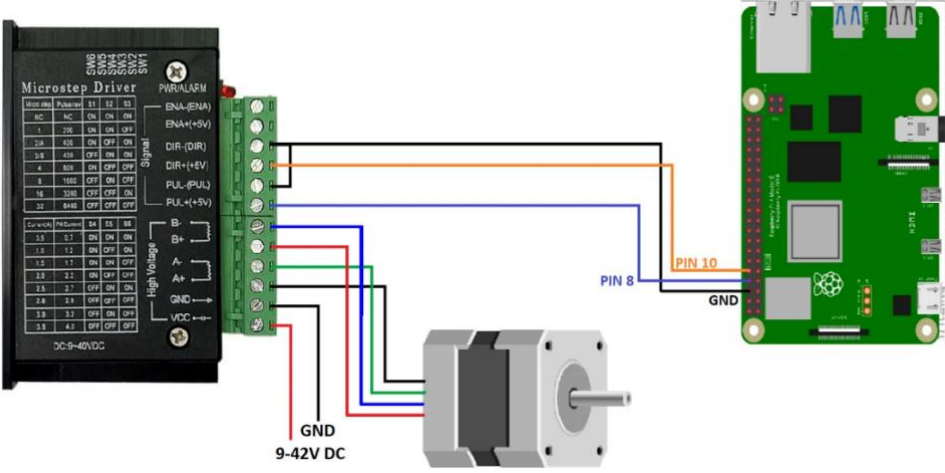


Figure 5. Stepper motor driver and Raspberry Pi 4 connection.

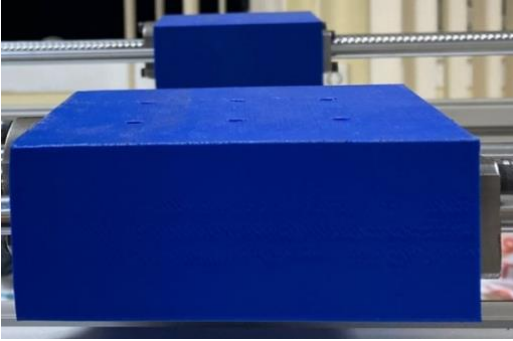


Figure 6. Assembly of parts used for axial movement on the cartesian robot.

The Z axis of the cartesian robot was used to take the fruits from the conveyor belt (Figure 7). A pneumatic vacuum holder was added to a specially manufactured L plate on the Z axis of the robot. Since the part on which the pneumatic vacuum gripper is assembled has a modular structure, it has been possible to carry out holding, carrying, and releasing operations by using different parts depending on the areas where the cartesian robot will be used. The pneumatic vacuum gripper carried out the transportation and placement of the fruits without mechanical damage with the air taken from the vacuum generator (Figure 8).

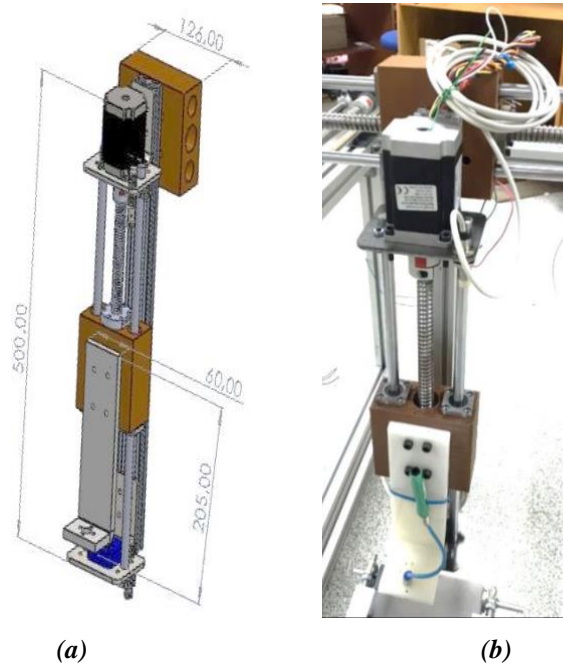


Figure 7. Z axis of the Cartesian robot (a) Modeling of the Z axis, (b) Assembly of the Z axis.

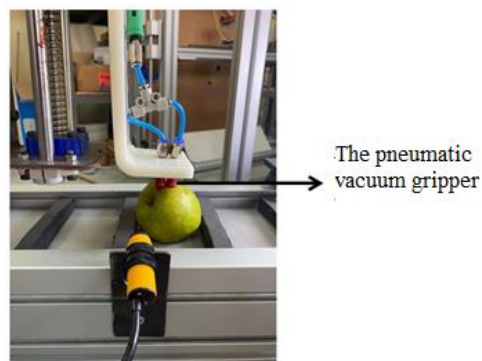


Figure 8. The pneumatic vacuum gripper assembly of the cartesian robot.

PNP inductive proximity sensors, which enable essential tasks such as material detection and position detection, were used to prevent the moving system from hitting the walls. The PNP proximity sensor used was mounted on the sheet metals where the stepper motors used to start the drive were located (Figure 9). Python software language and GPIO library were used to control the PNP proximity sensor, and Raspberry Pi 4 was used as the controller card. Figure 10 shows the final assembled version of the cartesian robot.

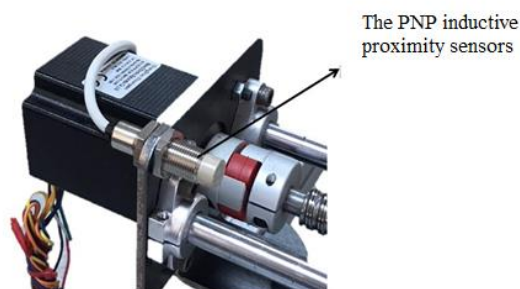


Figure 9. Installation of inductive sensors used in the cartesian robot.

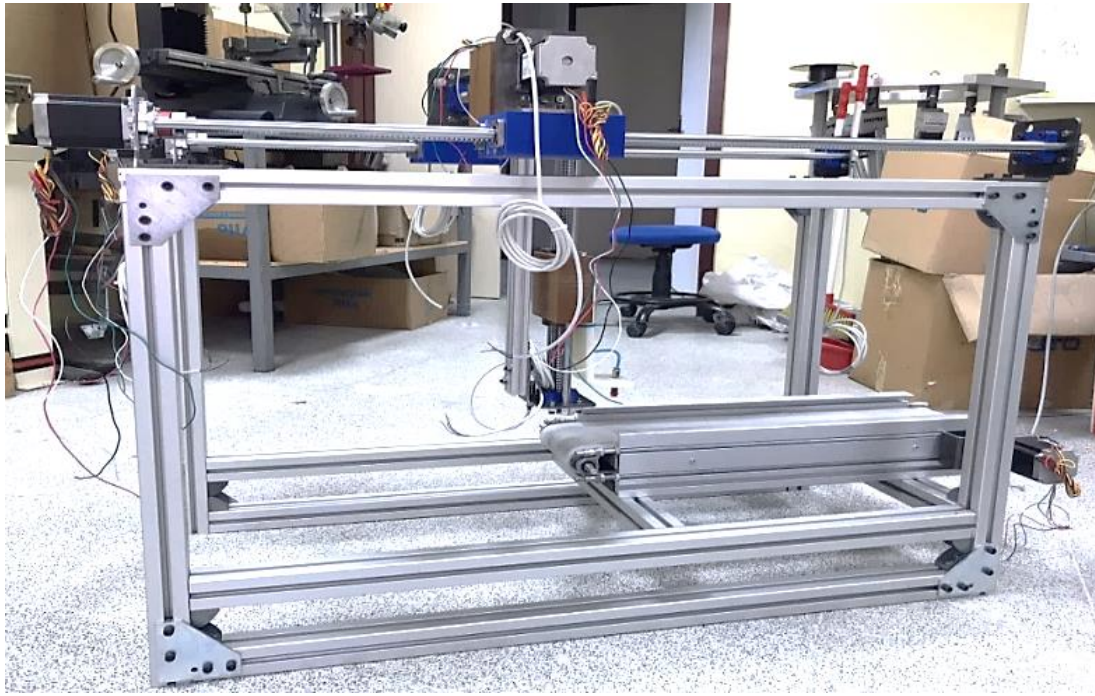


Figure 10. Completed assembly view of the cartesian robot.

After the manufacturing and installation of the fruit sorting automation was completed, the sorting of rotten and healthy apples in red and green colors was carried out. The process is shown in the flow diagram in Figure 11. After the infrared sensor detected the apples, the conveyor belt movement ended. Simultaneously with the end of the conveyor belt movement, the cartesian robot Z axis movement was enabled, and the operation of the pneumatic vacuum gripper on the Z axis to hold the fruits in the conveyor belt was carried out autonomously (Figure 12). After the apple was held with the pneumatic vacuum gripper, the Z axis completed its movement to the determined safe distance. After completing the movement in the Z axis, the cartesian robot autonomously completed the separation and release processes of the apple, according to the output results of a healthy apple or rotten apple during the image processing process (Figure 13). Figure 14 and Figure 15 shows the entire model of fruit sorting automation.

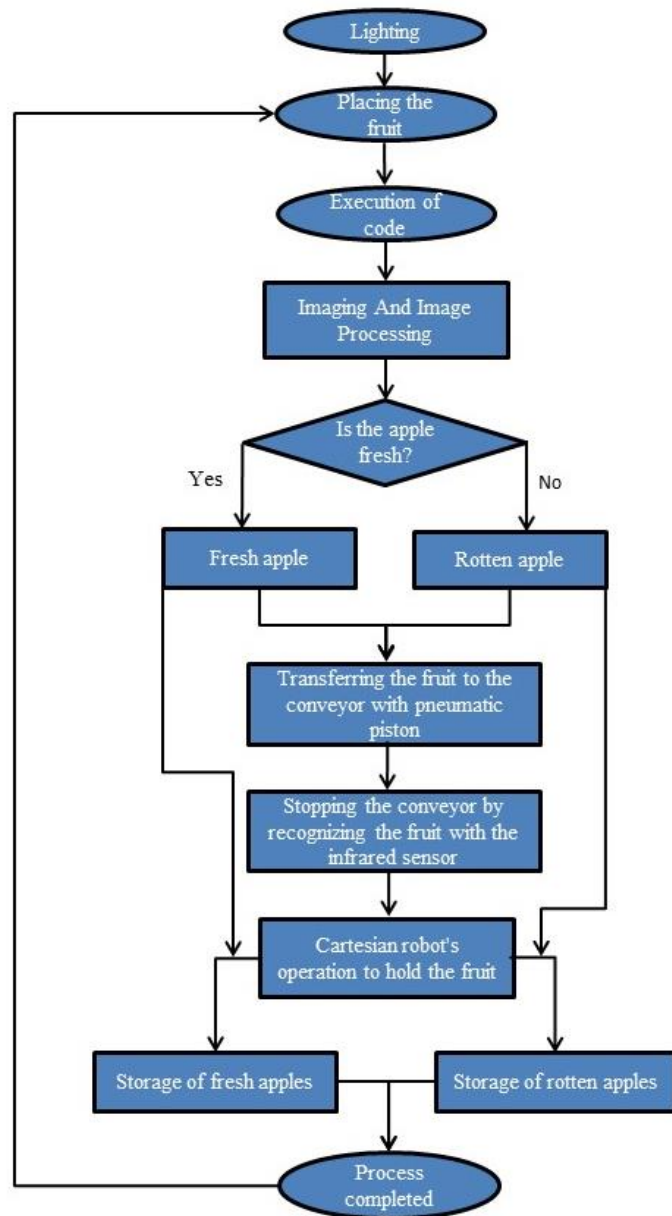


Figure 11. Fruit sorting automation flow diagram.

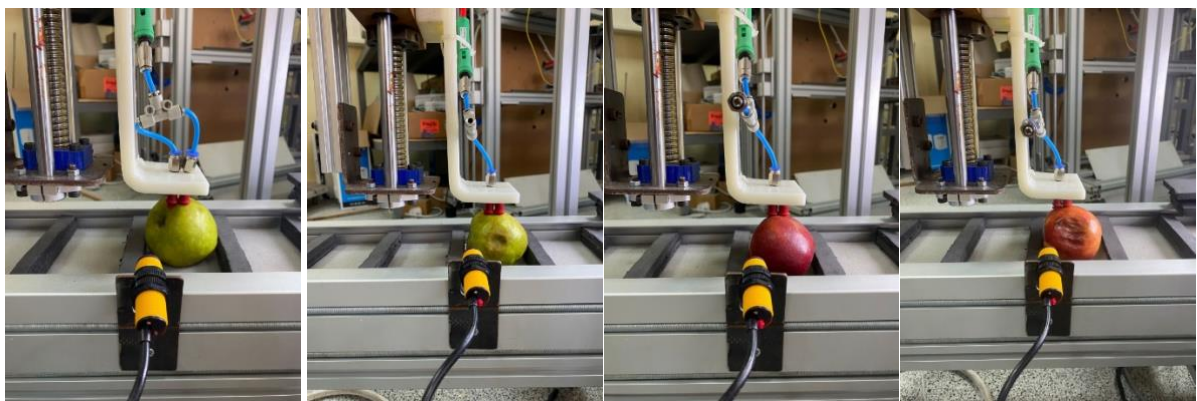
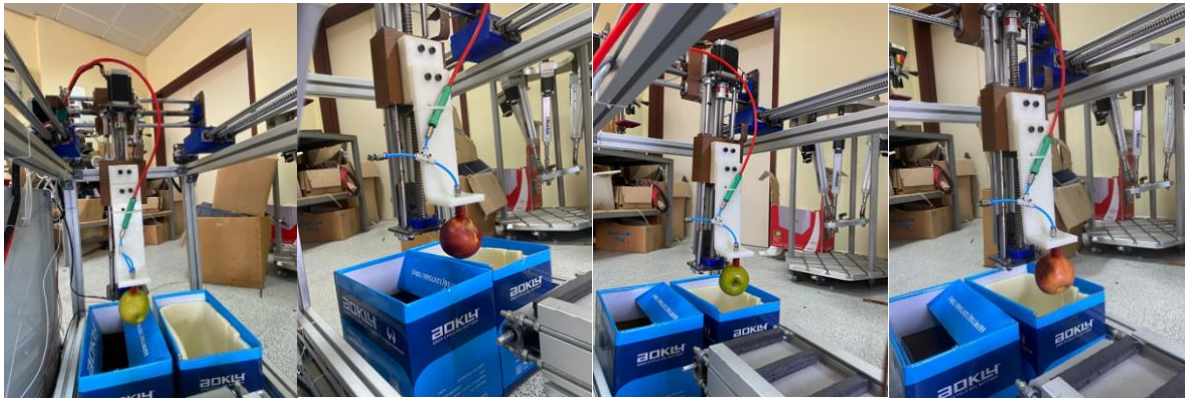


Figure 12. The process of the pneumatic vacuum gripper holding different apples, (a) Fresh green apple, (b) Rotten green apple, (c) Fresh red apple, (d) Rotten red apple.



(a) (b) (c) (d)

Figure 13. Decomposition process of apples, (a) Fresh green Apple, (b) Fresh red apple, (c) Rotten green Apple, (d) Rotten red apple.

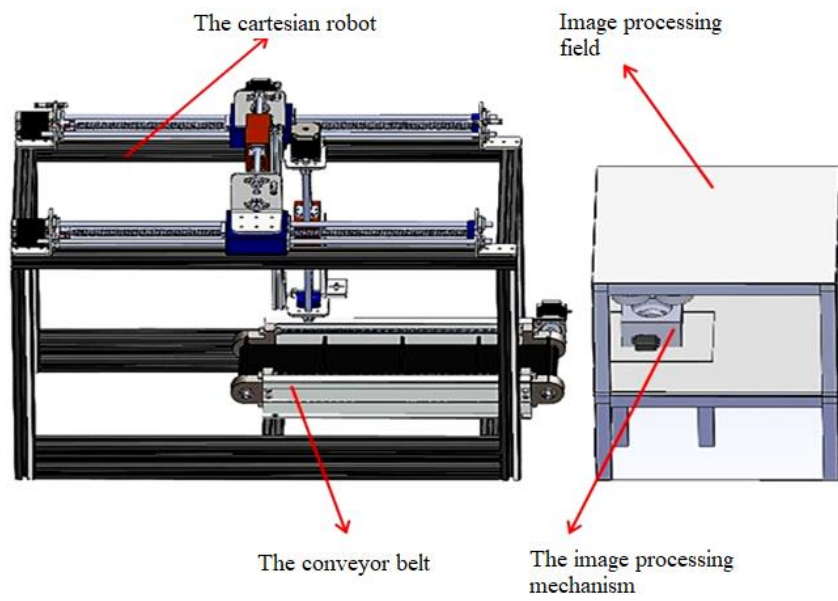
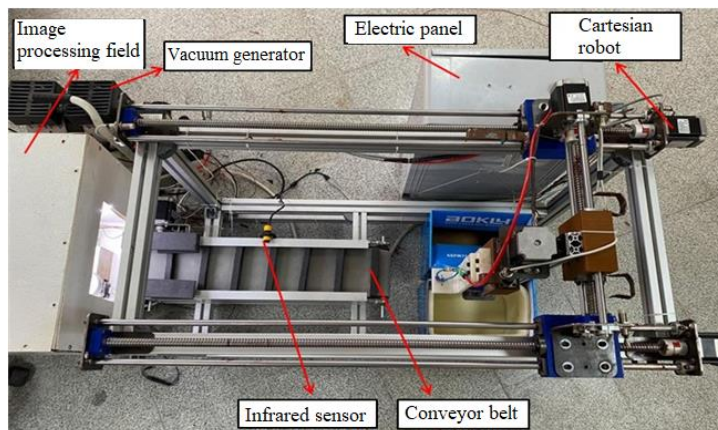


Figure 14. Model view of the entire system.



(a)

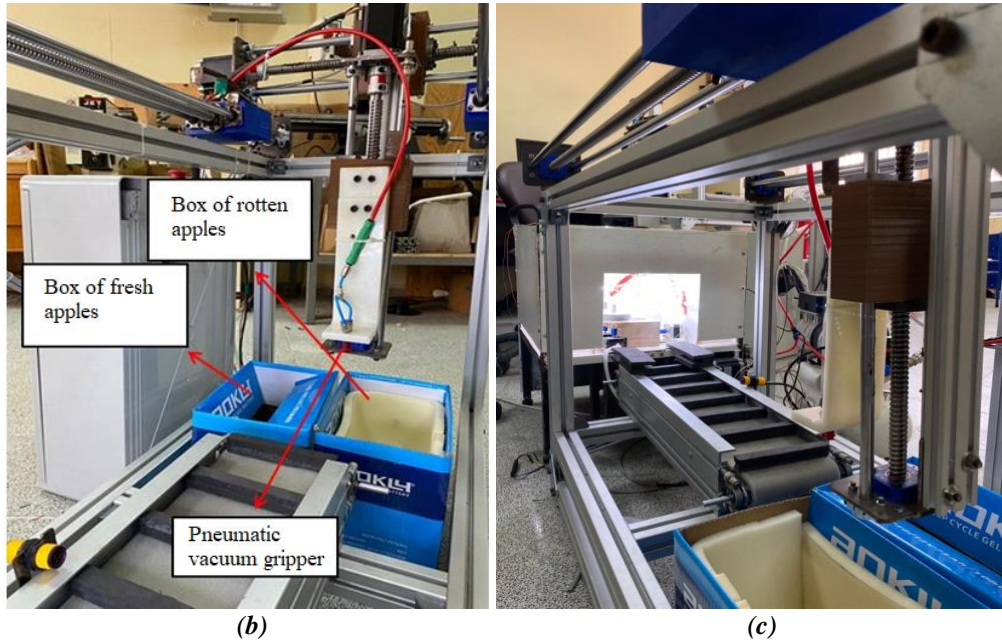


Figure 15. View of the entire system, (a) Top view, (b) The cartesian robot view, (c) The image processing mechanism view.

III. CONCLUSION

The top priority is to ensure that the apples are not damaged during the conveyor belt transportation. The sponge covered in the conveyor belt to prevent the apples from being damaged successfully ensured that the fruits were transmitted to the cartesian robot without being damaged. The conveyor belt system provided that the apple falling from the image processing mechanism was transmitted to the cartesian robot without changing its position. Partitions measuring 70x140 mm were added to the conveyor belt to prevent the apple from changing its position. Adhesive rubber to create the compartments enabled the apples to be transmitted to the cartesian robot without damaging or changing their position. Nema 23 stepper motors and TB660 motor drivers used in the cartesian robot and the conveyor belt system were successfully connected to the Raspberry Pi 4 control card, enabling movement. The use of inductive sensors increased the positioning accuracy of the robot. Sensors enabled the robot's axes to be accurately targeted and move precisely to the desired target points. Thus, the robot's working processes achieved greater precision and repeatability. Additionally, inductive sensors enabled the robot to accurately determine position information, prevent axes from colliding, and perform movements precisely. This way, the robot worked more safely, efficiently, and precisely.

Table 2. Performance of the developed system

	Positioning at the reference point	Apple detection from the conveyor belt	Placing apples in relevant boxes
The conveyor belt speed	126 mm/s	126 mm/s	-
The cartesian robot speed	19.4 mm/s	-	19.4 mm/s
Running time	33 s	2 s	72 s

The developed system sorted rotten and fresh apples at a conveyor speed of 126 mm/s, and the cartesian robot machine's speed was 19.4 mm/s (Table 2). Before starting the image processing process in fruit sorting automation, the cartesian robot was sent to the specified reference point from the coordinates X0, Y0, and Z0. The cartesian robot completed this first movement in 33 seconds at a speed of 19.4 mm/s. The apples were transferred onto the conveyor belt without any damage, and thanks to the partitions added to the conveyor belt, they were prevented from moving on the belt. In this way, the apple is recognized when it comes in front of the infrared sensor. After the infrared sensor recognized

the apple, it started to move for the holding operation on the Z axis of the cartesian robot. The process of detecting the apples transferred from the image processing mechanism by the conveyor belt by the infrared sensor after the conveyor started working took 2 seconds at a speed of 126 mm/s. The infrared sensor detected the fruit in the conveyor belt and stopped its movement.

As the cartesian robot started to move for the Z axis holding operation, the vacuum generator was activated for the holding operation by automatically opening the relay circuit of the solenoid valve to which the pneumatic vacuum gripper on the axis was connected. In this way, the pneumatic vacuum gripper was able to lift the apple from the conveyor belt. The process of the cartesian robot holding the apples in the conveyor belt and placing them in the relevant boxes was carried out in 72 seconds at a speed of 19.4 mm/s. The designed cartesian robot and conveyor belt successfully operated the fruit conveying and transportation process.

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