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Tomato Harvesting Robot Based on Solid Work

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Abstract

Designing and development of agricultural robot is always a challenging issue, because of robot intends to work an unstructured environment and at the same time, it should be safe for the surrounded plants. Therefore, traditional robots cannot meet the high demands of modern challenges, such as working in confined and unstructured work spaces. Based on current issues, we developed a new tomato harvesting robot arm with a flexible backbone structure for working in confined and extremely constrained spaces. Moreover, we optimized a tomato detaching process by using newly designed gripper with passive stem cutting function. Moreover, by designing the robot we also developed ripe tomato recognition by using machine learning. This paper explains the proposed continuum robot structure, gripper design, and development of tomato recognition system.

Keywords: Tomato harvesting, gripper, tomato detection, design, agricultural robot.

1 Introduction

The harvest of fruits and vegetables is an activity of human existence. Fresh tomato is a good product, and it is widely used in China and the world every year. Tomato is one of the most popular and widely cultivated vegetables in the world, with an annual output of about 60 million tons. Fresh fruits and vegetables are very important sources of vitamins and minerals, which are very important to human health. Due to the rapid growth of population, the domestic consumption and demand of tomato are increasing, so it is necessary to harvest properly to ensure the quality of consumption. In many parts of the world, it is considered to be a major cash and industrial crop[1]. Due to the continuous rebound of labor costs, the cost of harvest has increased significantly in recent years, or the price of harvest has reached 1 / 4 of the total cost. With the decrease of agricultural population and the increase of labor cost, automatic harvesting technology has attracted people's attention and may be applied in the future. It's a fact that every year in China there is plenty of land for farming, and then good crops. The country is one of the leading producers of tomatoes and other vegetables. Tomato is one of the most common vegetables, because of its delicious taste, rich nutrition, easy to eat, and its yield accounts for 15% of the total yield of vegetables. Tomatoes are grown as fresh market and processed tomatoes. They are essential to the food industry because they are raw materials for the production of value-added products. Harvesting robots are designed to use a variety of sensors to sense the complex agricultural environment and use this information together. Harvesting robot is designed to use various sensors to sense the complex agricultural environment, and use this information with the target to perform certain operations. The main components of harvesting robot are a mobile platform, an arrival manipulator, a grasping tool and a tomato recognition algorithm. In this study, we propose a robot arm manipulation, grasping tool and tomato recognition system. In this study, we propose a new tomato harvesting robot system with arm and tomato detection system[5]. This paper is organized in the following order: design concept, motion / kinematics formula, development of recognition system and experimental results.

1.1 Project Background

This current project aims to design a robot that can recognize and harvest mature tomatoes without human help or guidance. If successful, the pilot project will be further developed in agriculture and greenhouse industry. The idea of self harvesting fruit is not new because it has been used in different countries. However, the implementation of these technologies is not very common in the region.

Today, depending on the type of crop that produces fruit, it can be harvested manually or by machine. Most commercial robots are used in industry, while robots for agriculture, forestry and fishery are being developed, but not yet commercialized. The reasons for the delay are the cost of robots, the safety of using robots, the difficulty of outdoor operation and the knowledge transfer from farmers to computers. If we can overcome these difficulties and apply robots to agriculture, robots can contribute to saving labor, improving production and automation of production lines. Moreover, it is possible to manage the quality, quantity and environmental conditions of agricultural products, and intelligent agriculture will be realized. Although harvesting robot has a broad prospect for the future, the overall performance of harvesting robot can not be compared with manual operation[2]. The bottleneck of commercialization of harvesting robot is low efficiency and high cost. The combination of human and robot is a feasible way to improve the success rate of robot harvesting line method. If we can promote agricultural robots, we can predict labor saving, automation, production growth and so on. In addition, it is possible to transform facts such as management of crops, environment, cultivation, state and quality. From the perspective of safety, appropriate guidance can be provided to consumers. There are many serious challenges to overcome, but it is possible to establish a new robot market in agriculture. Among all kinds of fruits and vegetables, tomato is one of the main fruits that consume a lot of fruits and vegetables. Many tomatoes are planted in houses and other facilities, but due to the high temperature and humid working environment and long harvest period, labor is large and labor needs to be saved.

1.2 Research Status

In Japan, the Netherlands, Britain, France, Italy, the United States, Israel and other countries, various robots have been developed to harvest tomatoes, cucumbers, grapes and oranges. Kyoto University has developed a tomato harvesting robot manipulator with five degrees of freedom. Okayama University has developed a 7-DOF robot, which is composed of motion system, vision system, end effector, manipulator and control system. Later, a new tomato harvesting robot was developed, which was composed of vision system, manipulator, control system and rotating arm. It takes about 15 seconds for each tomato from recognition to input, and the success rate is 50% - 70%. In addition, the Korean Agricultural Mechanization Research Institute has also developed a series of tomato harvesting robots[3]. The vision system can accurately determine the surface color of tomatoes, so that the robot can selectively pick mature tomatoes. However, the potential disadvantages of these robots are slow response and clumsiness.

1.3 Domestic Research Status

In China, the research of tomato harvesting robot has made great progress, such as manipulator, image recognition and motion control. Panasonic demonstrated the initial version of the harvesting robot and exhibited it at the latest international robotics exhibition in December 2015. The robot can pick tomatoes and move around the place. The robot puts tomatoes in the basket and replaces them once they are full. The robot uses image sensing to detect the color and shape of tomatoes. It also uses sensors to identify the location of tomatoes. Usually, the current robot is not intelligent enough, and the success rate and pitching rate are far lower than expected. In addition, most tomato harvesting robots are designed to harvest tomatoes at a certain height along the guide rail. Two wheel drive control and differential steering control can not meet the demand of automatic harvesting of fruits and vegetables. Moreover, the picking arm is usually replaced by the industrial robot arm, which has the disadvantages of high cost and control complexity. The harvesting time of citrus is 3-7 s, melon is 15 s, cucumber is 10 s, eggplant is 1 min, and the harvest rate is less than 90%[4]. Fruits and vegetables are mainly identified by color features, gray threshold and geometric shape. These algorithms may be affected by illumination and environmental factors, and it is difficult to identify overlapping fruits.

1.4 Research Content

The task is to build a tomato harvesting robot, which can detect and harvest mature tomatoes, and learn the automatic system in the process to pick tomatoes from tomato plants safely and accurately. It is expected that modern farms will produce higher yield per unit area, provide high-quality products in a sustainable way at lower cost, and have less dependence on labor force. Implementing digital agriculture and the response of precision management in a specific location to this expectation, which not only depends on the sensor technology, but continuous collection of field data only through the proper use of agricultural robots is feasible.

Agricultural scientists, farmers and growers also face the challenge of sustainably producing more food on less land in a way that meets the projected needs of 9.8 billion people by 2050. This is equivalent to feeding a new city with 200000 people a day. Integrated digital tools, sensors, and control technology accelerates the design and development of agricultural robot technology, showing great potential and potential the benefits of modern agriculture. These developments start from the collection of accurate and detailed information to digitize the timely spatio-temporal information of plants and fields to complete the complex nonlinear control tasks of robots navigation. Robots and manipulators in the field of agriculture have become an important part of digital agriculture and precision agriculture[6].

2 Overall Design of Tomato Picking Robot

2.1 Gripper Design

We use solid works software to design the gripper of tomato harvesting robot. Solid works is a highly efficient 3D CAD software tool with integrated analysis tools and design automation functions, which can help stimulate various physical behaviors such as motion, dynamics, stress, deflection, vibration, temperature or fluid flow to adapt to all types of design. Designers and engineers from all over the world and industries are using solid works to create innovative products.

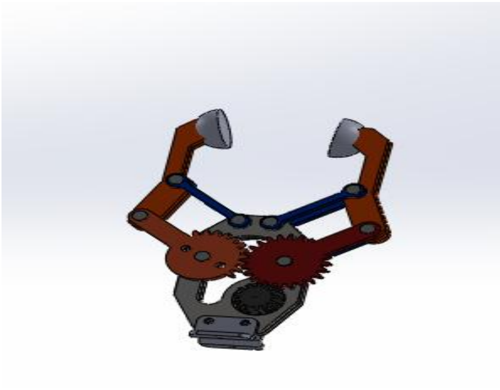


Fig 1: Solid grip design

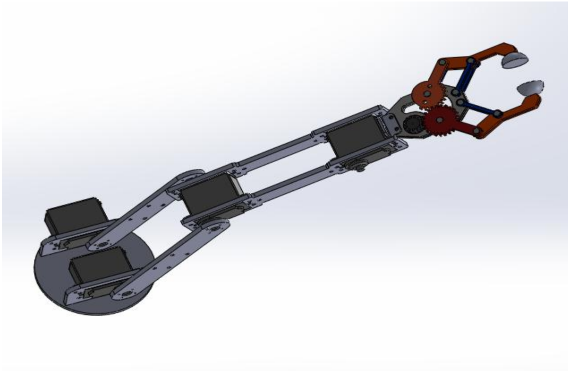


Fig2:Installation of gripper on Manipulator

2.1.1 Installation of Gripper on Manipulator

The manipulator has a system, which can quickly switch tools, supply power and exchange information between the manipulator and tools with the help of electronic connector. The gripper is instaled on the manipulator, which can pick up and pull out mature tomatoes without damaging them. To prevent tomatoes from falling, the gripper is equipped with a supporting spherical round clamp. The picture below is straight. The design of the gripper is based on the fixture of two fixtures. Two clamps enable the clamps to adapt to the shapes of tomatoes of different sizes. When the robot arm pulls the tomato out of the plant, both fingers hold the tomato in the fixture. However, instead of putting the tomatoes in the basket, place and hold the ball clip at the bottom so that the tomatoes do not fall. Once the tomato is firmly fixed, the robotic arm pulls and twists the tomato until it leaves the plant. The spherical clamp of the fixture shall be designed so that its surface is smooth and there is no edge that may damage the tomato or plant. The two s in the grippers are connected to each other at 120 degrees in opposite ways and are actuated by a single actuator using a gear train[7]. The servo motor is mounted on the base and drives the directly connected worm gear. The worm gear transmits rotational motion to the worm gear set, which is connected to each fixture. Clamping is of the highest importance because without this feature, the robot will not be able to collect tomatoes. Removing tomatoes from plants seems to be a cleaner way. The tomato will not be damaged by partial pressure, but the tensile force will lead to the peak pressure on the top of the tomato. But it's more important to hold on to the tomatoes because they slip during twisting. The main advantage of the robot arm fixture is flexibility.

2.2 Working Process of Gripper

Designing grippers for harvesting tomatoes is a challenging problem because tomatoes are a soft, juicy fruit. Grasp the tomato gently to prevent any malfunction such as over voltage. In addition, the separation of tomato and tomato stem should be considered in tool design. Therefore, we designed a hemispherical grab tool for grasping spherical objects such as tomatoes. To separate the tomatoes, we added a cutting blade to the edge of the cup. This design makes it possible to separate tomatoes in a passive way and shorten the harvest time

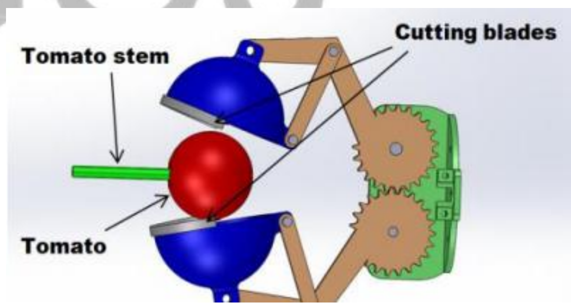


Fig 3: Working process of gripper

The average size of cherry tomato was calculated to define the size of grip cup. According to our calculation, the diameter of tomato is 48-54mm. Before designing the gripper, the requirements must be set. Since the grabber will be used to pick tomatoes, the earlier named features must be mentioned. The diameter of tomato can be classified as:
Extra small: 48-54mm
Small: 54-58
Middle: 58-64
Large: 64-73
Super large: 73-88
Up to 88 mm.
This means that the range of the gripper should be at

least 48mm to 88mm. A wider range is recommended, but not too large. The weight of a tomato depends on its diameter and type. Most tomatoes contain between 50 and 280 grams. Exceptions can be as high as 450 grams[8]. This means that the paper teeth should be able to carry at least 500 grams. Slightly recommended. The maximum weight of the fixture and tomato should not exceed 4.5 kg as it is within the range of the manipulator.

2.2.1 Fixture Specifications

The fixture we designed will meet the following specifications:
Grasp tomatoes with a diameter of 60mm to 80mm.
Load bearing 500g
It will be waterproof.
The tomato will not be damaged in any way.
It should be durable
It can remove tomatoes from plants,
Flexible movement
Measure when picking tomatoes. The pressure sensor and servo system are managed by the robot or the external electronic board which only manages the motion and sensors of the servo system.

3 Mechanical Design of Tomato Harvesting Robot

3.1 System Overview

To create an overview, the robot is divided into different subsystems. In any production sector, there is a growing need to increase production and revenue while reducing time and costs. One of the solutions to this challenge is to develop an automatic system, which can replace manual tasks when human precision and work cycle are worse than automatic equipment. Harvesting beautiful tomatoes takes a lot of time and manpower, so the cost is very high. Therefore, it will be a great leap for the agricultural industry to develop an automated system that can perform personalized collection, harvest only tomatoes with the required conditions by using the selective strategy, and provide a system that can work 24 hours a day[9]. The vision system used in the automatic harvester is designed to detect tomatoes and provide information, tomato fruit size and other parameters (such as ripening stage) to the robot controller. The main purpose of this paper is to introduce the research carried out in order to evaluate the latest technology level of automatic system development, which aims to detect, identify and locate mature tomato fruits without manual help or guidance.

3.2 Three Degree of Freedom Design Mechanism and calculation

The conceptual design process consists of several stages that lead to the final design, as shown in

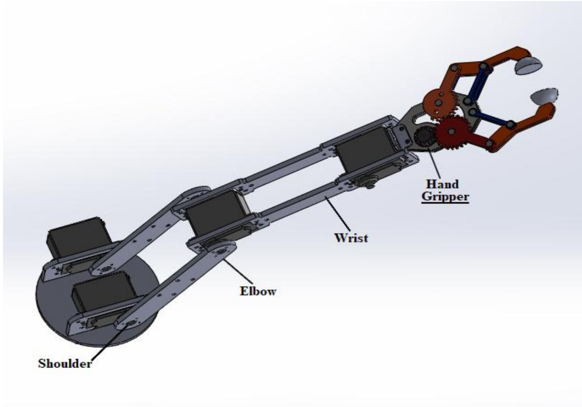


Figure 1. The design of the manipulator consists of three links, three joints, a parallel plate fixture, a rotary table, an acrylic disc and a rectangular platform[10]. The chain link is a pair of two rectangular beam structures connected by supports. There are two brackets for the U-shape. The rectangular platform is used to stabilize the turntable and support the whole structure. The acrylic disc is used to mount the turntable to the platform.

The joints in the chain of motion between the manipulator and the hand or tool are called mechanical wrists. Depending on the application, the wrist may have one or more degrees of freedom. The arm and wrist components of the robot are used to position the end effector. In the end, it's the effector that really does the job. It must grasp, lift and manipulate the workpiece without damaging it or loosening it.

3.2.1 Master the Process

It can be divided into the following steps:

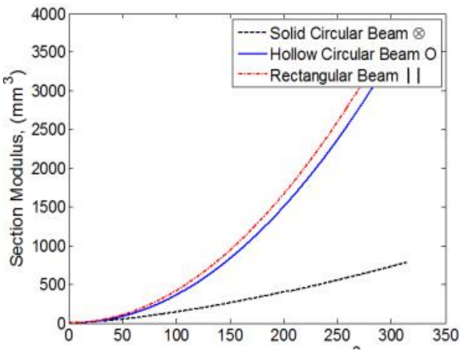
I. Approach the object: this step is to place the gripper near the object.
II. Contact: at this time, the clamping claw contacts with the workpiece. In the case of non-contact processing, the workpiece is within the force field of the gripper.
III. Increasing force: the force increment should be within a certain range, so that the pre installed parts will neither be damaged nor slide out of the claw.
IV. Fixed object: when enough force is applied, the total degree of freedom of the object is removed, and the object is fixed stop moving independently of the gripper.
V. Move object: this step involves moving the object to the desired location. vi。 Release objects: at the macro level, objects are usually released by gravity.

3.2.2 Section Modulus

The manipulator consists of three joints. The lumbar joint is represented by the rotation of the turntable, the shoulder joint is represented by the rotation of the connecting rod (1), and the elbow joint is represented by the rotation of the connecting rod (2). Each joint uses a specific servo motor to provide the torque required for movement. Each motor receives shaft position control signal from matlab code through Arduino microcontroller. The Cartesian position of the object to be picked is detected by using the camera and the available matlab plug-in, which is identified by its color.

$$s = \frac{1}{c} \quad (1)$$

I am the second moment in the region, and C is the maximum distance from the neutral axis (mm).
As can be seen from the generated graph, for any value of cross-sectional area, two
The s value of the parallel rectangular beam is the highest, followed by the hollow cylindrical beam. This means that two parallel assembled rectangular beams have the highest structural strength, considering that they are all made of the same material with the weight ratio of the three links[11]. Therefore, the rectangular beam is used for the link of the manipulator

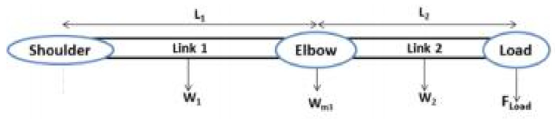


The relationship between cross-sectional area and cross-sectional area for three beams considered

In order to determine the most appropriate cross-sectional shape of the link, three possible geometric shapes are considered. Solid cylindrical beam, hollow cylindrical beam and a group of two rectangular beams. The section modulus s is a geometric property that represents the strength based on the shape or area of the cross section of the beam.

3.2.3 Static Torque

In order to ensure that the torque of the elbow and shoulder motors is sufficient to rotate the joint, the maximum payload is 200g, the following calculation is carried out. The figure shows the number of maximum required torque corresponding to the worst case of full arm extension. From the moment of equilibrium equation, equation. The results show that the elbow needs at least 0.351n. M and the shoulder needs at least 1.259n. M. Therefore, according to the servo motors available in the market, the servo motors selected for elbow joint and shoulder joint provide maximum torque of 0.941n. M and 2.422n. M respectively.



Configuration of free body figure fully extended in robot arm

Where W_1 and W_2 represent the weights of links (1) and (2), respectively W_{m3} . It's the weight of the elbow muscle. Represents the total weight of the payload and gripper.

3.3 Recognition of Mature Tomato

The goal of the recognition system is to find all the tomatoes in the plant and know which are ripe and which are not. Therefore, it is very important to understand the characteristics such as the color, shape, type, weight and water ratio of tomatoes. The color of the tomato is a good way to know if the tomato is harvested. However, when tomatoes are fully ripe, they must be eaten within a few days. As a result, tomatoes are collected when they continue to ripen during transportation, and the flavor of tomatoes is less than that of tomatoes that have been preserved for a longer time. One of the main difficulties in using color as a visual discrimination parameter is that it may suffer from uncontrolled or changing lighting and shadows. There are many different varieties of tomatoes and many different shapes[12]. So let's focus on the round tomatoes. Weight is another factor in determining whether a tomato is ripe. As tomatoes grow, their size increases with their weight. If the volume and density of a tomato are known, its weight can be easily determined.

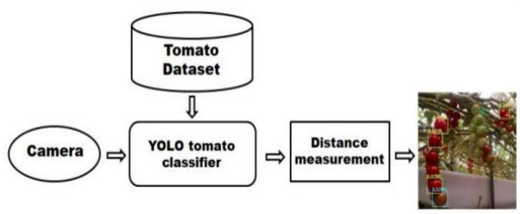


Fig 4: tomato detection

3.3.1 YOLO Tomato Classifier

Mature tomato recognition is also a key part of the robot. In this study, we used machine learning to train neural networks to distinguish mature tomatoes from immature tomatoes and other similar fruits. As a tomato classifier, we use YOLO We developed three main filters to distinguish tomatoes. The first filter detects the shape of the object, the second filter detects the color or (RGB) filter, and the third filter is machine learning. This is necessary because there are many fruits or objects that may be very similar to tomatoes, such as apples or oranges. In addition, it should be possible to calculate the distance between the camera and the tomato using the classification camera. For this technique, we use a measurement method for a single camera by using the focal length of the camera.

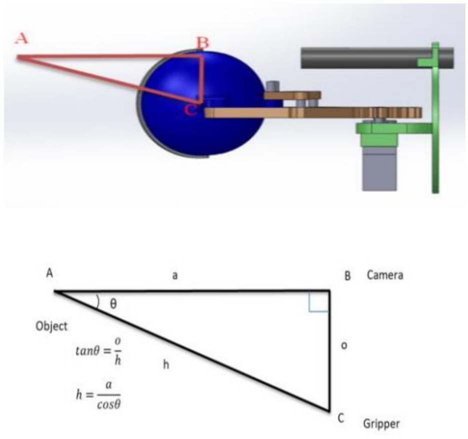


Fig 5: fixture calibration (a) geometric formula (b)

Here are (o) opposite, (H) hypotenuse and (a) adjacent. The relative distance is fixed, and the adjacent distance is provided with the camera. Based on this formula, we can calibrate the position of the gripper to grasp accurately.

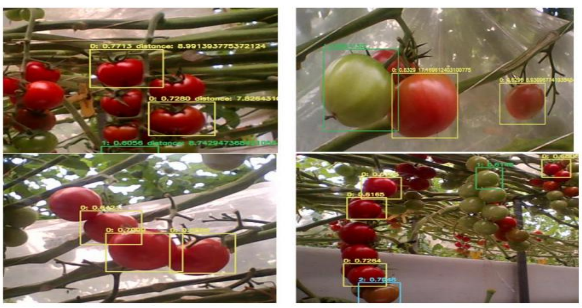


Fig 6: tomato test in real environment

The camera measures the distance and detects the ripe tomatoes[13]. The experiment has been carried out in a tomato greenhouse in Kawasaki, Japan. In this study, we used a 2 megapixel resolution duct mirror camera.

3.4 End Effector

The end effector is mainly composed of frttom of the sleeve to detect whether the fruit is in the sleeve. When the fruit enters the sleeve, the infrared sensor will detect the fruit and control the air compressor to inflate the air bag, while the DC motor drives the clamp to clamp the stem properly.

The pressure sensor can detect the pressure between the fruit and the air bag under the premise of reliably clamping the fruit, so as to ensure that there is no damage on the fruit. Until it is stable, then drive the double acting cylinder to shrink the sleeve to cut and pick the tomato. Our harvesting tools are able to grab tomatoes with suction cups and then use swinging blades. Natural changes in crop size, shape and direction make it challenging and reliable to select a single end effector pose to grab and cut each tomato at the same time. In order to overcome this difficulty, a key feature of our harvesting tool design is the passive decoupling mechanism, which allows sequential grasping and cutting operations. The decoupling mechanism is a kind of flexible strip, which is fixed on the main body of the end effector together with the suction cup. The suction cup is also magnetically connected to the lower side of the cutting blade, allowing the manipulator to guide the suction cup during the installation phase. After fixing, lift the cutting blade to separate the suction cup from the cutting blade. The suction cup is then attached to the end effector only by a flexible piece, allowing the cutting blade to move independently of the suction cup during the cutting operation.

4 Motion Analysis

For kinematic analysis, the coordinate frame 23 has been rigidly attached to each link.
As shown in the figure, the initial frame is connected to the base of the manipulator,
According to the D-H coordinate system

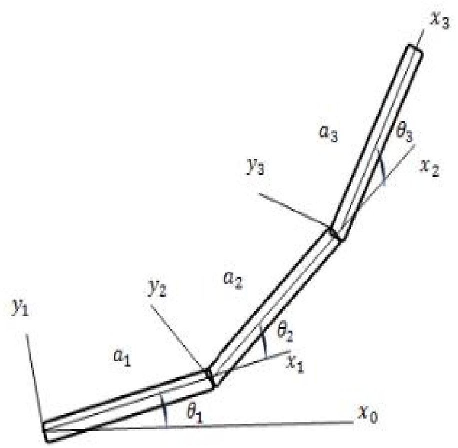


Table 1 DH parameters of various links

link	d_i	θ_i	a_i	α_i
L1	0	θ_i	a_1	0
L2	0	θ_2	a_2	0
L3	0	θ_3	a_3	0

Here a_i is the length of the ith connection and is constant, while θ_i is the angle of the (i)th connection, which is variable.
Is the homogeneous transformation moment that represents the position and direction of $o_i x_i y_i z_i$ relative to $o_{i-1} x_{i-1} y_{i-1} z_{i-1}$

$$A_i = \begin{bmatrix} c\theta_i & -s\theta_i c\alpha_i & s\theta_i s\alpha_i & a_i c\theta_i \\ s\theta_i & c\theta_i c\alpha_i & -c\theta_i s\theta_i & a_i s\theta_i \\ 0 & s\alpha_i & c\alpha_i & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

(1)

$c\theta_i = \cos\theta_i$ and $ca_i = \cos a_i$

$$A_I = \begin{bmatrix} c\theta_1 & -s\theta_1 & 0 & a_1 c\theta_1 \\ s\theta_1 & c\theta_1 & 0 & a_1 s\theta_1 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$A_2 = \begin{bmatrix} c\theta_2 & -s\theta_2 & 0 & a_2 c\theta_2 \\ s\theta_2 & c\theta_2 & 0 & a_2 s\theta_2 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

From $T_J^I = A_{I+1} A_{I+2} \ldots\ldots A_J$ I<j

Give help to $o_j x_j y_j z_j$ The position and direction of is converted to $o_i x_i y_i z_i$ Transformation matrix T_J^I

$T_1^0 = A_1$

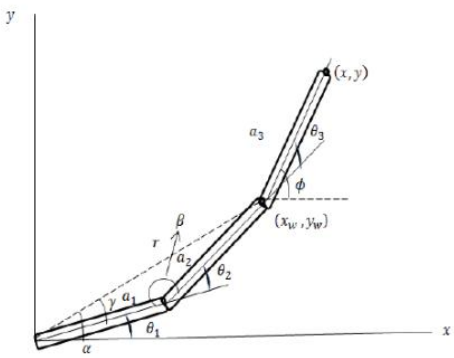
$T_2^0 = A_1 A_2$

$T_3^0 = A_1 A_2 A_3$

T_3^0 is a transformation matrix representing the visibility of the end effector relative to the basic framework

A. Inverse kinematics of manipulator

The figure above shows the method that can be used for inverse kinematics analysis



In order to determine the required joint angle of the end effector and the desired position (x, y) of the manipulator in the work area[15], it is necessary to know the coordinates of the wrist and the direction of the end effector

Give Way,

$x_w y_w$ Wrist coordinates

ϕ_z is the angle made by the end effector relative to the x-axis, and then

$x_w = x - a_3 \cos_\phi$

$y_w = y - a_3 \sin_\phi$

$a = \tan^{-1}\left(\frac{y_w}{x_w}\right)$

$$r^2 = a_1 + a_2 - 2a_1 a_2 \cos\beta \qquad (1)$$

$r^2 = x_w^2 + y_w^2$

β is obtained from equation 1

$\theta_2 = \pi - \beta$

since

$$r^2 + a_1^2 - 2ra_1 \cos\gamma = a_2^2 \qquad (2)$$

If we get γ from equation (2), we can find θ_1

$$\theta_1 = \alpha - \gamma$$

$$\theta_2 = \phi_3 - \theta_1 - \theta_2$$

4.2 manipulator Jacob

The upper joint angle is for the elbow down configuration

Jacobian matrix is one of the most important tools in robot motion control because it has been developed joint and end effector speed. Jacobi's law transforms the ratio of forces into joint coordinates. Given an N-linked manipulator

Jacobian

$$j = \left[j_1 j_2 \ldots j_n \right]$$

ith column in Jacobian of ith link j_i

$$j_i = \left(\frac{z_{i-1} \times (a_n - o_{i-1})}{z_{i-1}} \right) \tag{3}$$

From the forward kinematics analysis, we have

$$o_o = \begin{bmatrix} 0 \\ 0 \\ 1 \end{bmatrix} \qquad o_1 = \begin{bmatrix} a_1 c_1 \\ a_1 s_1 \\ 0 \end{bmatrix}$$

$$o_2 = \begin{bmatrix} a_1 c_1 + a_2 c_{12} + a_3 c_3 c_{12} - a_3 s_3 s_{12} \\ a_1 s_1 + a_2 s_{12} + a_3 c_3 s_{12} - a_3 s_3 s_{12} \\ 0 \end{bmatrix}$$

Now put the above vector into equation (3) above and evaluate the Jacobian matrix of different links as

$$j_1 = \begin{bmatrix} a_1 s_1 - a_2 s_{12} - a_3 c_3 s_{12} - a_3 s_3 c_{12} \\ a_1 c_1 + a_2 c_{12} + a_3 c_3 c_{12} - a_3 s_3 s_{12} \\ 0 \\ 0 \\ 0 \\ 1 \end{bmatrix}$$

$$j_2 = \begin{bmatrix} -a_1 s_1 - a_3 c_3 c_{12} - a_3 s_3 s_{12} \\ a_2 c_{12} + a_3 c_3 c_{12} - a_3 s_3 s_{12} \\ 0 \\ 0 \\ 0 \\ 1 \end{bmatrix}$$

$$j_3 = \begin{bmatrix} -a_3 c_3 s_{12} - a_3 s_3 c_{12} \\ a_3 c_3 c_{12} - a_3 s_3 s_{12} \\ 0 \\ 0 \\ 0 \\ 1 \end{bmatrix}$$

The whole matrix of the whole system is compiled by Jacobi

$$j = \left[j_1 j_2 j_3 \right].$$

5 Conclusion

This paper introduces a tomato harvesting manipulator for tomato harvesting. In addition, the robot design, motion / kinematics formula, tomato recognition system and robot control architecture are discussed. The proposed manipulator can control objects less than 200 grams, and the slender part of the robot achieves high rigidity in the harvesting process[16]. In terms of speed, the proposed manipulator is slower than the commercially available prototype, but the main advantages of the robot are accessibility and selectivity. Experiments have proved the ability of the manipulator to work in a very narrow environment. In addition, the proposed claw simplifies the harvesting process by passively cutting the stem.

As a plan, we plan to use machine learning for manipulator control. According to the data obtained, the manipulator spends more time to avoid obstacles and grasp tomatoes. Therefore, by using machine learning tools, we can shorten the harvesting time and achieve the best continuous robot shape, so as to achieve rapid harvesting. The robot is equipped with a gripper and measuring tools. The vision system can accurately determine the coordinates, but the tomato must be suspended at a fixed distance because a single camera cannot see the depth. Because of the low resolution of 3dcamera, the precision of reference point is low, but it can determine three coordinates. The gripper can grab tomatoes and transport them to the desired destination. The robot can prevent the tomato from being damaged when a pressure sensor is installed in the finger of the gripper. Though, tomatoes have to be regular in shape[17]. In the development process of harvesting robot, the knowledge of controlling robot arm has been greatly improved, and the processing technology has been developed.

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