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Research State and Trend of Fruit Picking Robot Manipulator Structure

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Abstract: Starting from the characteristics of fruit picking, the characteristics of fruit picking robot manipulators and the research state at home and abroad are reviewed. The analysis summarizes the difficulties in fruit picking robotic arm research. Aiming at the configuration of the manipulator, the structure and characteristics of the manipulator with redundant degrees of freedom are introduced, and the feasibility of the redundant mechanism is demonstrated through the current research state of the manipulator.

Keywords: fruit picking robot; research state; redundant degrees of freedom

1 Introduction

In life, fruits are essential foods, and the area and output of fruit in the world are increasing year by year. In 2016, world fruit production (excluding melons) was 71.678 million tons with an increase of 23.831 million tons comparing with that in 2000[1].

In the fruit planting and production process, the picking process is mainly characterized by strong seasonality and requiring a large amount of labor for high-intensity work[2], and in the fruit

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picking process, the task of fruit picking accounts for 50%–70%[3], whether the fruit collection can be completed on time determines the subsequent processing quality and sales, which affects the price and economic benefits of the fruit market. However, the needs of domestic industrial production and the construction of urbanization have caused a large number of labor to flood into the cities, and there are also reasons for an aging population, which has led to a reduction in labor engaged in agricultural production and an increase in agricultural production costs. With the improvement of the mechanical manufacturing technology, electronic technology, image processing technology and control technology, many countries have also begun to design fruit picking robots to replace manual picking operations. Fruit picking robots are a type of automated mechanical harvesting system that can programmatically sense and pick fruits[4-5]. They involve the mechanical structure, vision and image processing, sensors, and dynamics[6]. Research of fruit picking robots is important in replacing manual labor to reduce labor intensity, solving labor shortages and harvesting fruits on time.

For a component system of a fruit picking robot, it usually includes motion subsystem, identification subsystem, and control subsystem. The motion subsystem consists of a robotic arm, an end effector, a drive, and a transmission component[7]. Among the mechanical components of the fruit picking robot, the structure and accuracy of the mechanical arm mainly determine the movement trajectory and reachable position of the whole machine picking, which is an important component of the picking robot. The appearance of most fruits is relatively fragile. Therefore, when the end effector touches and picks the fruit, there is an error in the movement track of the robot arm, which causes the end effector to scratch the outer skin of the fruit and the end effector places the picked fruit with the picked fruit. Fruits collide and squeeze, resulting in fruit damage, and the flexibility and operability of the robotic arm is also one of the factors that determine the efficiency of the entire picking process. From this point of view, the research on the fruit picking robot manipulator has great significance.

2 Research state and existing problems at home and abroad

The basic research of fruit harvesting with robots started in orchard fruit, and was first proposed by American scholars Schertz and Brown in 1968[8], because the technology was limited at that time, the harvester they developed was semi-automated requiring human-machine collaboration mechanical. With the maturity of various technologies, developed countries such as Japan and the United States have done a lot of research on various structures of fruit picking robots, and designed different picking robot arms for different picking objects, such as apple picking robotic machinery, strawberry harvesting robot mechanical arm, and so on, and carried out picking tests.

In China, research of picking robots started relatively late, beginning in the middle 1990 s[9]. The current research is mainly concentrated in universities and institutes. After years of research, progress has also been made.

2.1 Research state

2.1.1 Apple picking robot

Davidson et al. from the School of Mechanical and Materials Engineering, University of Washington designed an apple picking robot with 6 degrees of freedom for unstructured apple tree and orchard automation applications, focusing on improving obstacle avoidance during harvesting[10-11]. The structure of the picking robot arm and end effector is shown in Figure 1.

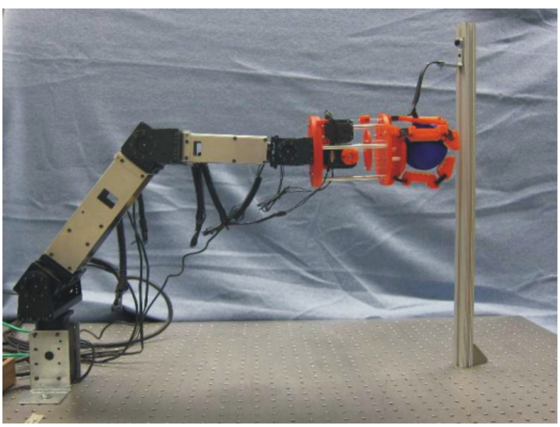


Figure 1 Structure diagram of apple picking manipulator

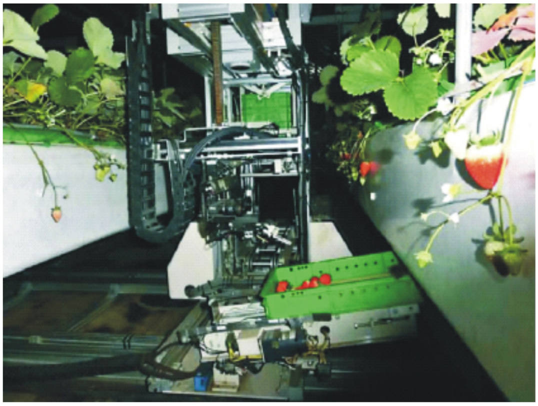
This robotic arm is an open-chain tandem manipulator with a rotary joint, with a maximum stroke of approximately 0. 6 m. The robotic arm contains a modular dynamic actuator and a custom frame made of aluminum plate. An inverse kinematics algorithm has been developed in MATLAB, compiled into a C++ shared library, and the robotic arm control in Microsoft Visual Studio development environment Device integration. The picking robot identified 95 of the 100 test results, with an average positioning time of 1. 2 s and a picking time of 6. 8 s. The main reason which affects the success rate is due to the presence of blind spots in leaf occlusion.

Li Wei of China Agricultural University and others applied a parametric analysis method and optimized simulation to design an articulated apple picking robot arm with three degrees of freedom[12]. The results show that the reachable picking area of the robotic arm is of 90. 2% in the total area.

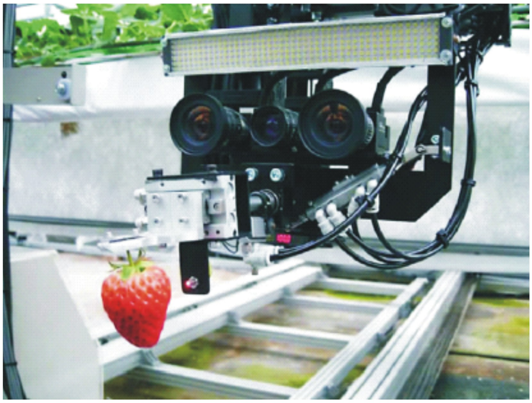
Zhao De′an and Lu Jidong of Jiangsu University designed an apple picking robot with a five-degree-of-freedom multi-joint picking robot arm[13]. The lifting of the robot arm uses a pump-driven lifting platform, which can adapt to the special situation of high fruit crops. The rotary joint and flexible joint are driven by servo motors. And through laboratory tests and field tests, the effectiveness of the picking robot prototype was verified. The success rate of apple harvest was of 77%, and the average harvest time was about 15 s. And the end effector is unstable to grab.

2.1.2 Strawberry picking robot

The Japanese Agricultural Machinery Institute and the Ehime Agricultural Institute jointly developed a strawberry harvesting robot based on the principle of night work and human-machine cooperation. It consists of a polar coordinate arm, a sensor, a machine vision unit, a storage unit, and a mobile unit. Culture of the culture[14-15], as shown in Figure 2. The robotic arm is a three-degree-of-freedom arm, which rotates at a speed of 360 °/s through a rotary brake, and uses a linear actuator to move 400 mm vertically and 300 mm horizontally at a speed of 500 mm/s. The execution time for testing the robot to harvest fruit is 11. 5 s, which is 2. 5–3 times longer than the time required for human harvesting. The average harvest success rate is 54. 9%. The main reason which affects the harvest is that the shielding of the harvested strawberries by other strawberries makes it difficult to pick a single strawberry.



a)



b)

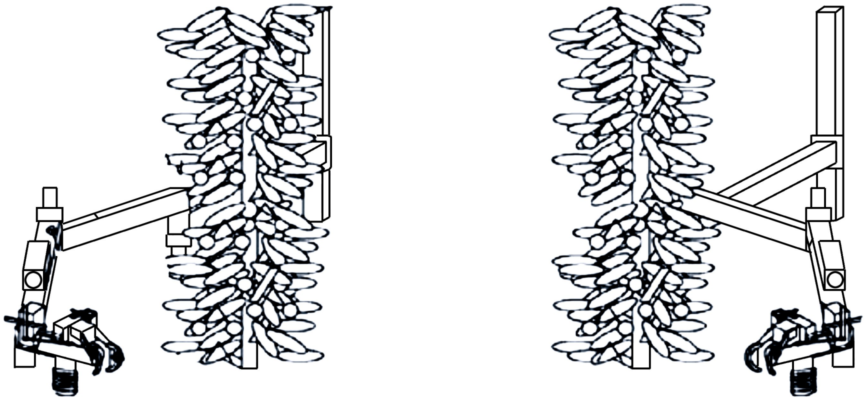
Figure 2 Strawberry picking robot

Zhang Kailiang of China Agricultural University designed a picking robot for high-growing strawberries[16], in which a robotic arm is used to precisely adjust the relative position between the end effector and the strawberry. And the robot has 4 degrees of freedom, including 3 translational degrees of freedom and 1 rotational degree of freedom. The picking success rate is 88%, and the picking time for a single strawberry is 18. 54 s.

2.1.3 Cherry picking robot

In Japan Osaka Prefectural University, Yamagata University, and the Nara Fruit Research

Center have jointly developed a cherry picking robot[17], which is mainly composed of a robotic arm, end effector, vision sensor, and computer control. Its mechanical arm has 4 degrees of freedom, one of which can move up and down, and the remaining three axes can move left and right. The structure is shown in Figure 3.



a) b)

Figure 3 Cherry picking robot manipulator

Because the fruit is located around the trunk, if the vision sensor scans from one angle, the fruits outside the trunk will be hidden. In order to scan from different angles, the 3D vision sensor is connected to the robot arm, and the movement of the robot arm changes. The position and orientation of the 3D vision sensor make the visual dead angle smaller. It takes about 14 s to harvest each fruit, and the success rate of picking is 83.3%.

2.2 Existing problems

2.2.1 Difficulties in picking in an unstructured environment

Fruits are grown in the natural environment, which will change with the change of climate, season and region[18], and different fruits also have different growth patterns. This requires that the picking robot has a flexible range of movement space and obstacle avoidance, and must be able to adapt to different environments.

2.2.2 Long time and less efficient fruit picking

The essence of the research design of the picking robot arm is to improve the movement efficiency of the picking robot, thereby improving the picking efficiency. However, the current kinematic efficiency of the picking robot arm is not high, which has led to an increase in picking time. For example, the picking time of the strawberry picking robot arm is 11.5 s, which is 2.5 – 3 times longer than the time required for humans to pick a single strawberry[14-15].

2.2.3 Insufficient automatic recognition

Because of the complexity of the picking environment, the automatic identification of fruits has the problem of difficult identification. Due to the uncertainty of lighting conditions and leaf occlusion, the system does not recognize the existence of fruits, which affects the planning of the movement track of the robotic arm[19-20].

2.2.4 High manufacturing cost

Comparing with industrial manipulators, picking manipulators have to face unstructured environments, so the structure and corresponding control systems are more complicated[21], which leads to higher manufacturing costs of picking manipulators. At the same time, the working time of picking the robotic arm is seasonal, which results in low equipment utilization, high equipment maintenance costs, and the use of equipment requires high technology, which has caused difficulties in promotion.

3 Structural features of a manipulator with redundant degrees of freedom

Among the structural characteristics of mechanical arm of the fruit picking robot, it should have the following characteristics:

1) Good generality. Because the need to design different robotic arms for different fruits will also cause difficulty in promotion, and for fruits with the same growth mode It should be possible to use the same robotic arm.

2) Strong flexibility. The robot should provide excellent obstacle avoidance performance and good trajectory movement in the face of unstructured environment, and has the ability to quickly

recover from singular points that can be avoided.

For the flexibility of a robotic arm, operability is one of the important indicators. Manipulability can comprehensively measure the movement ability of the robotic arm in various directions, and it is an index for judging the overall flexibility of the mechanism[22].

Usually the design freedom of the robotic arm is less than or equal to 6, which is the so-called non-redundant robotic arm, such as the common SCARA robotic arm. When the degree of freedom of the structure is greater than 6, it has redundant degrees of freedom. At this time, the mechanical arm is called a redundant mechanical arm. The excess degrees of freedom in the redundant mechanical arm can be used to more easily perform obstacle avoidance processing. And eliminate singularity without affecting the operation of the end effector[23-24]. In general, one end pose of a conventional robotic arm will correspond to several different sets of inverse solutions, but these sets of inverse solutions are discretely distributed in the configuration space. Generally, it cannot be changed from one to the other under the condition of ensuring the end pose.

The group of inverse solutions is transformed to another group of inverse solutions, but for a seven-axis robotic arm, it has one more redundant degree of freedom, and there are multiple groups of inverse solutions that are continuous in the configuration space. In other words, it may be at the end of the guarantee. The trajectory avoids singular points and obstacles at the same time.

Comparing with general non-redundant manipulators, redundant manipulators not only have advantages in handling obstacle avoidance problems and singularities, but redundant manipulators can also use their extra degrees of freedom to make up for The adverse effects of some joint motion failures enable the robotic arm to continue working tasks without stopping the work, that is, to achieve fault-tolerant operations.

Aiming at the above objectives, the research on the manipulator with redundant degrees of freedom has an effective role in achieving the structural flexibility requirements of the picking manipulator.

4 Development of redundant robotic arms

Okayama University in Japan has developed a tomato picking robot. The main mechanisms are a robotic arm, end effector, vision and control system[25-26]. Because tomatoes have many stems and leaves in their growing environment, fruit picking is prone to collisions. In order to improve the obstacle avoidance of stems and leaves, the robot arm adopts a redundant 7-degree-of-freedom design. It consists of 5 rotating joints, which improves the trajectory avoidance ability during the picking process. Figure 4 shows a 7-degree-of-freedom tomato picking robotic arm designed by Liang Xifeng of China University of Metrology[27]. This robotic arm is a redundant robotic arm with 5 rotating joints and 2 translational joints. The trajectory of the robotic arm is optimized by using the fifth-degree polynomial interpolation method, which reduces the joint speed change by an average of 6.26% and improves the robotic arm Safety performance.

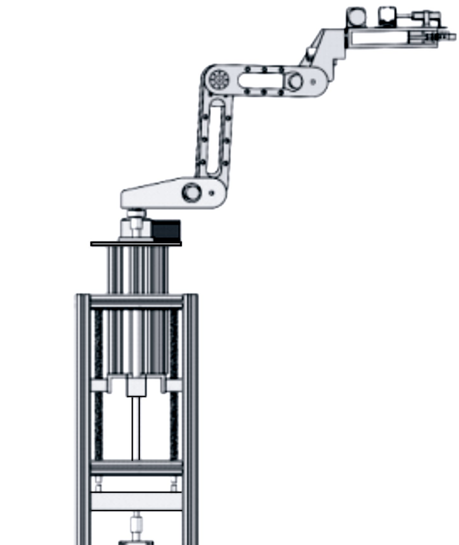
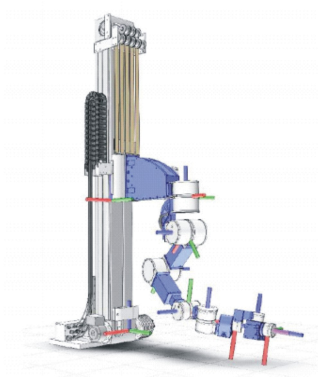


Figure 4 Tomato picking manipulator

Jochen Hemming and others in the Netherlands have developed a sweet pepper picking robot[28]. The picking robot arm part can be changed between 9 and 7 degrees of freedom in combination with the difference of the crop environment, and the drive module is sealed. The splash-proof and waterproof function. The structure of the mechanical arm is shown in Figure 5. When picking, the carrier platform moves to the designated position for work.



a) 9 degrees of freedom

b) 7 degrees of freedom

Figure 5 Sweet pepper picking manipulator in greenhouse

Mehta, Burks and others at the University of Florida developed a vision-based citrus picking robotic arm[29-31]. The picking robot has 7 degrees of freedom of rotation. In order to be able to receive feedback and respond in time, the system of the robot adopts closed-loop control and adopts a dual camera system. One of the cameras is installed at the end of the robot and can follow the robot. Information while moving. The robot arm has a 95% success rate in picking medium and large citrus, but has a low success rate in picking small citrus.

In addition, Charles and Bruce also studied the kinematics and control of redundant robotic arms[32]. Mayorga and colleagues studied singularity avoidance methods for redundant robotic arms[33].

5 Conclusions

In China, as labor enters the city and the aging population increases, the use of automated robots to harvest fruits is a development trend. From the current research progress at home and abroad, picking robots are in the stage of experimental promotion. Structural flexibility requirements, the use of picking robot arms with redundant degrees of freedom is a development direction. The redundant design of the fruit picking robot arm is a cross fusion of traditional agricultural equipment technology and robotics, which reflects the intelligent development of agricultural picking technology, and it has great application value to conduct in-depth research on it.

References

[1] National Bureau of Statistics. International statistical yearbook 2017[DB/OL]. http://data.stats.gov.cn/files/lastestpub/gjnj/2017/indexch.htm (in Chinese)

[2] Kataoka T, Murakami A, Bulanon D M, et al. Estimating apple fruit locations for

manipulation by apple harvesting robot[J]. Ifac Proceedings Volumes, 2000, 33(29): 67-72

[3] Xu L M, Zhang T Z. Research status and key problems and countermeasures of fruit and vegetable harvesting robots[J]. Journal of Agricultural Engineering, 2004, 20(5): 38-42 (in Chinese)

[4] Edan Y, Ganines E. Systems engineering of agricultural robot design[J]. IEEE Transactions on systems, Man, and Cybemetics, 1994, 24(8): 1259-1265

[5] Sario Y. Robotics of fruit harvesting: a state-of-the-art review[J]. Journal of Agricultural Engineering Research, 1993, 54(3): 265-280

[6] Tang X Y, Zhang T Z. Review of fruit harvesting robot research[J]. Robot, 2005, 27(1): 90-95 (in Chinese)

[7] Subir Kumar Saha. Introduction to robotics[M]. Fu Y L, Zhang S Y, trans. Harbin: Harbin Institute of Technology Press, 2017 (in Chinese)

[8] Schertz C, Brown G. Basic considerations in mechanizing citrus harvest[J]. Transactions of the ASAE, 1968, 11(2): 343-348

[9] Yang W L. Structural design and analysis of apple picking robot manipulators[D]. Jiangsu Zhenjiang: Jiangsu University, 2009(in Chinese)

[10] Davidson J R , Silwal A , Hohimer C J , et al. Proof-of-concept of a robotic apple harvester[C]// IEEE/RSJ International Conference on Intelligent Robots & Systems. IEEE, 2016

[11] Silwal A, Davidson J R, Karkee M, et al. Design, integration, and field evaluation of a robotic apple harvester[J]. Journal of Field Robotics, 2017, 34(6): 1140-1159

[12] Li W, Li J Z, Jun X, et al. Optimization design and simulation of apple picking robot

manipulator[J]. Journal of Beijing University of Technology, 2009, 35(6): 721-726. (in Chinese)

[13] De-An Z, Jidong L, Wei J, et al. Design and control of an apple harvesting robot[J]. Biosystems Engineering. 2011, 110(2): 112-122

[14] Hayashi S, Shigematsu K, Yamamoto S, et al. Evaluation of a strawberry-harvesting robot in a field test[J]. Biosystems Engineering, 2010, 105(2): 160-171

[15] Hayashi S, Yamamoto S, Tsubota S, et al. Automation technologies for strawberry harvesting and packing operations in Japan[J]. Journal of Berry Research, 2014(4): 19-27

[16] Zhang K L, Yang L, Wang L G, et al. Design and experiment of an elevated strawberry picking robot[J]. Journal of the Chinese Society of Agricultural Machinery, 2012, 43(9): 165-171 (in Chinese)

[17] Tanignkia K, Fujiuraa T, Akaseb A, et al. Cherry-harvesting robot[J]. Computers and Electronics in Agriculture, 2008, 63: 65-72

[18] Song J, Sun X Y, Zhang T Z, et al. Design and experiment of an open eggplant picking robot[J]. Journal of the Chinese Society of Agricultural Machinery, 2009, 40(1): 143-147 (in Chinese)

[19] Foglia M M, Reina G. Agricultural robot for radicchio harvesting[J]. Journal of Field Robotics, 2006, 23(6-7):363-377

[20] Liu X K, Li B, Chang J, et al. Design and analysis of the structure of a double manipulator of a wolfberry picking robot[J]. High Technology Letters, 2019, 29(2): 175-182(in Chinese)

[21] Fang J J. Design of open control system for picking robot[J]. Journal of the Chinese

Society of Agricultural Machinery, 2005, 36(5): 83-86 (in Chinese)

[22] Yoshikawa T. Manipulability of robotic mechanisms [J]. The International Journal of Robotics Research, 1985, 4(2): 3-9

[23] Gao H, Zhang M L, Zhang X J. Overview of spatial trajectory planning for redundant manipulators[J]. Mechanical Transmission, 2016, 40(10): 176-180 (in Chinese)

[24] Yahya S, Moghavvemi M, Mohamed H A F. Singularity avoidance of a six degree of freedom three dimensional redundant planar manipulator[J]. Computers and Mathematics with Applications, 2012,64(5): 856-868

[25] Kondo N, Monta M, Fujiura T. Fruit harvesting robot in Japan[J]. Advanced Space Research, 1996, 18(1-2):181-184

[26] Hayashi S, Ota T, Kubota K, et al. Robotic harvesting technology for fruit vegetables in protected horticultural production[C]// Information and Technology for Sustainable Fruit and Vegetable Production, 2005: 227-236

[27] Qin C, Liang X F, Lu J, et al. Trajectory planning and simulation of a seven-degree-of-freedom tomato harvesting robot[J]. Journal of Zhejiang University, 2018, 52(7): 1260-1265 (in Chinese)

[28] Hemming J, Bac C W, Tuijl B A J V. A robot for harvesting sweet-pepper in greenhouses[C]// International Conference of Agricultural Engineering, Zurich switzeriand, July, 2014

[29] Mehta S S, Burks T F. Vision-based control of robotic manipulator for citrus harvesting[J]. Computers and Electronics in Agriculture, 2014, 102: 146-158

[30] Mehta S S, MacKunis W, Burks T F. Nonlinear robust visual servo control for robotic citrus harvesting[J]. FAC Proceedings Volumes, 2014, 47(3): 8110-8115

[31] Mehta S S, MacKunis W, Burks T F. Robust visual servo control in the presence of fruit motion for robotic citrus harvesting[J]. Computers and Electronics in Agriculture, 2016, 123: 362-375

[32] Charles A K, Bruce E B. Dexterity measures for the design and control of kinematically redundant manipulators[J]. The International Journal of Robotics Research, 1987, 6(2): 72-83

[33] Mayorga R , Wong A . A singularities avoidance method for the trajectory planning of redundant and nonredundant robot manipulators[C]// IEEE International Conference on Robotics and Automation, 1987:1707-1712

Brief Biographies

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