

Development of watermelon picking robot based on AioT

Chenshuo Yang, *Pingchuan* Zhang*, *Hao* Yu, *Yang* Xue, *Wenjie* Wang and *Shuquan* Xiao

School of Computer Science and Technology, Henan Institute of Science and Technology, Xinxiang, Henan, China

Keywords: 5G, Internet of Things, Beidou positioning, Hexapod robot, Machine learning, A* algorithm.

Abstract. This project integrates 5G, IoT, and AI technologies to develop a watermelon picking robot, aiming to solve the issue of watermelon harvesting in agricultural fields. The robot features a hexapod walking mechanism. By combining machine vision with a fan, it can avoid crushing melon vines. It uses a watermelon maturity - processing algorithm to identify, pick, weigh, and code ripe watermelons. With 5G communication, the robot uploads field operation data to the cloud platform. The Beidou navigation system and A* algorithm enable its autonomous movement in the melon field. This innovation offers an advanced solution for China's watermelon - planting industry and actively contributes to rural revitalization.

1 Introduction

According to relevant statistics, China is the world's largest producer and consumer of watermelon, ranking first in the world in terms of watermelon planting area and output. However, in the picking process of field watermelon, there are many industrial pain points that need to be solved for a long time. First of all, manual picking is expensive. With the development of social economy, labor costs continue to rise, and manual picking of watermelons is not only inefficient, but also requires a lot of manpower and material resources. Secondly, in the process of manual harvesting, due to improper operation, the crushing of melon vines often occurs, which not only affects the normal growth of melon vines, but also may lead to the reduction of subsequent watermelon yield^[1]. In addition, for the judgment of watermelon ripeness, there is a large error in manual identification, and it is easy to misjudge the maturity. In order to effectively solve the above problems in field watermelon picking, this study aims to propose a hexapod robot system solution integrating AioT (Artificial Intelligence Internet of Things) technology. Through the comprehensive use of advanced technologies such as 5G, artificial intelligence, Internet of Things, cloud technology, and Beidou navigation, we will create an intelligent robot suitable for watermelon picking in the field.

* Corresponding author: zhangpingc@hist.edu.cn

2 Technical principles and innovative design

2.1 AIoT technology convergence architecture

The AIoT-based watermelon picking robot designed in this study integrates various advanced technologies such as 5G, artificial intelligence, Internet of Things, cloud technology, and Beidou navigation to build a highly intelligent and collaborative system architecture. Based on the Internet of Things, the architecture collects real-time information about the watermelon planting environment and the status of the robot itself through various sensors^[2]. 5G communication technology is used to achieve high-speed and low-latency data transmission; With the help of artificial intelligence technology, the collected data is analyzed and processed to realize the identification and maturity judgment of watermelons and the autonomous decision-making of robots. Cloud technology provides support for data storage, management, and remote monitoring. The Beidou navigation system provides precise location information for the positioning and navigation of robots in the melon field.

2.2 Design of hexapod robot walking load mechanism

In order to meet the needs of the soft soil environment of the field watermelon field and avoid crushing the melon vines, a special hexapod robot structure was designed in this study^[3]. Its six-legged insect-like leg layout is evenly distributed around the chassis, and each leg is composed of multiple joints, with multiple degrees of freedom, which can achieve complex movement trajectories. The leg joints are specially flexible to provide sufficient torque and range of motion, as well as cushioning when walking, reducing the risk of soil impact and vine damage. A schematic diagram of the robot crank-slider drive structure is shown in Figure 1^[4].

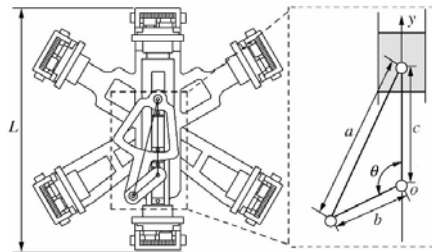


Fig. 1. Schematic diagram of the robot crank-slider drive structure.

$$c = b \cos \theta + \sqrt{a^2 - (b \sin \theta)^2} \quad (1)$$

$$\dot{c} = -b \sin \theta - \frac{b^2 \sin 2\theta}{2\sqrt{a^2 - (b \sin \theta)^2}} \quad (2)$$

$$s = \begin{cases} \frac{a + b - c}{2} & \dot{\theta} > 0 \\ \frac{3b - a + c}{2} & \dot{\theta} \leq 0 \end{cases} \quad (3)$$

$$v = \begin{cases} -\frac{\dot{c}}{2} & \dot{\theta} > 0 \\ \frac{\dot{c}}{2} & \dot{\theta} \leq 0 \end{cases} \quad (4)$$

In Figure 1, a represents the connecting rod length, b represents the crank length, c represents the slider displacement, and θ represents the angle between the crank and the slider. The robot parameters are as follows: $a=62\text{mm}$, $b=20\text{mm}$, $L=150\sim 185\text{mm}$, $\theta=0\sim 130^\circ$. θ is positive counterclockwise. The robot center of mass (COM) moves with displacement and velocity.

In order for the robot to be able to stabilize the load of watermelons of about 100kg. The combination of high-strength and low-density materials such as aluminum alloy and carbon fiber to build the chassis and legs of the robot greatly reduces the weight of the robot itself, while ensuring the stability of the structure and providing a solid foundation for carrying heavy loads. The leg design has also been deeply improved, increasing the thickness and width of the legs, and optimizing the cross-sectional shape, effectively improving the bending and torsion resistance of the legs^[5].

In the field of control algorithms, adaptive control algorithms are introduced, which can collect key information such as robot attitude, load distribution, and ground conditions in real time. In addition, in order to further improve the robot's balance ability when walking with weight, an inertial measurement unit (IMU) and a pressure sensor are integrated. The IMU monitors the robot's attitude changes in real time, and a pressure sensor is mounted on the sole of the robot's foot to accurately measure the pressure between each leg and the ground. Through the data fed back by these sensors, the control algorithm can respond quickly and adjust the movement state of the robot in time, so that the robot can quickly restore its balance and move forward stably when it encounters uneven ground or external interference.

2.3 Watermelon recognition technology based on machine vision

In the field watermelon picking, the melon leaves block the watermelon and affect the image acquisition. In this study, a small fan was installed at the front end of the robotic vision system, which was activated when it was close to the watermelon plant, and the wind speed and angle were adjusted to blow the melon leaves apart in order to obtain clear images^[6]. Industrial cameras with high resolution, low illumination, high frame rate, and large dynamic range are selected for multi-angle shooting at the front of the robotic arm. After the image is obtained, the Gaussian filtering algorithm is used to reduce the noise, and the neighborhood pixel weighted average is denoised based on the Gaussian function and the edge details are preserved. Then, the histogram equalization algorithm is used to enhance the grayscale histogram to make the grayscale distribution uniform, highlight the details, and provide high-quality images for subsequent recognition.

In this study, a deep learning-based object detection algorithm was used for watermelon recognition and localization, and the YOLO algorithm was selected. In view of the characteristics of field watermelon, this study optimized its network structure, increased the convolutional layer to capture the overall features, and introduced the attention mechanism module to focus on the watermelon region to improve the detection accuracy. In the field watermelon planting test, the recognition accuracy of the algorithm reached more than 97%, and the average detection speed was 90 frames per second, which can cope with complex situations and provide a reliable basis for picking.

2.4 Ultrasonic-based watermelon ripeness detection

Ultrasonic waves are mechanical waves with a frequency higher than 20kHz, and have the characteristics of good directionality. Its characteristics are affected by the internal structure and composition of watermelon, which are closely related to the ripeness of watermelon. When the watermelon is ripe, the content and distribution of internal moisture, sugar, cellulose and other substances change, resulting in changes in physical parameters such as

density and elastic modulus, which in turn affect the ultrasonic propagation speed and attenuation coefficient. The propagation velocity v is related to the density ρ and the elastic modulus E , and the formula is

$$v = \sqrt{\frac{E}{\rho}} \tag{5}$$

The more ripe the watermelon, the softer the texture, so the acoustic vibration frequency of the watermelon can be used to calculate the elastic modulus of the melon, which has a good correlation with the ripeness of the watermelon. At the same time, from the peak value of the acoustic spectrum, it can be determined that the density and elastic modulus of watermelons with high maturity decrease, and the ultrasonic propagation speed slows down. Xiao Ke et al.^[7] (2009) judged the ripeness of watermelon based on the frequency range of the peak in the spectrogram: the frequency range greater than 189 Hz was the unripe melon; Between 160 and 189 Hz are ripe melons; At 133 - 160 Hz, it is overripe. Then, the convolutional neural network (CNN) was used to construct the judgment model, and the features were automatically extracted through convolutional layers and other components, with an accuracy of more than 97% on the test set, providing reliable technical support for the intelligent picking of watermelon picking robots.

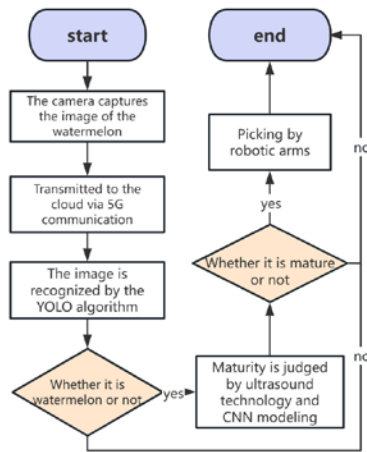


Fig. 2. Watermelon picking flow chart.

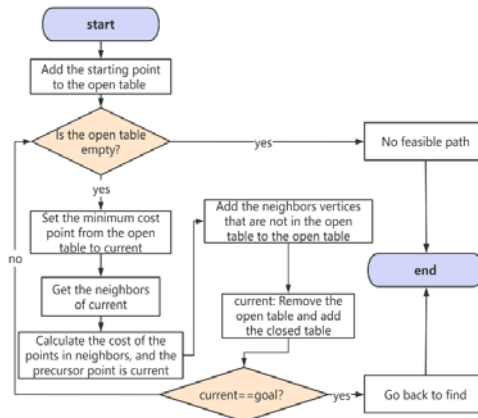


Fig. 3. Flow diagram of the A* algorithm.

2.5 Navigation and positioning and path planning based on Beidou system

In this study, the Beidou satellite navigation system was used as the positioning core of the watermelon picking robot, and the high-precision Beidou positioning module was integrated on the robot to achieve real-time positioning by means of multiple satellite signals and the principle of triangulation. In order to solve the problems of signal occlusion and multipath effect in melon fields, signal processing and error correction techniques were used to improve the accuracy^[8]. The signal processing uses an adaptive filtering algorithm to suppress the noise, and adjusts the parameters according to the real-time changes of the signal. Inertial navigation-aided positioning technology is introduced to measure acceleration and angular velocity by IMU, and the position attitude is calculated when the BeiDou signal is abnormal, which is complementary to BeiDou positioning. The watermelon picking flow chart is shown in Figure 2. In order to improve the efficiency of watermelon picking and avoid repeated picking, a path planning strategy based on A* algorithm was designed. The A* algorithm is a heuristic search algorithm that combines the actual cost from the current node to the starting point and the estimated cost to the target node, selects the node with the least cost to expand, and then finds the optimal path. The flow chart of the A* algorithm is shown in Figure 3.

A* The definitions of the relevant terms in the algorithm are as follows: **open table**: the priority queue of nodes to be evaluated, sorted by evaluation value. **current**: the node that is currently being processed or investigated. **neighbors**: A collection of nodes directly connected to the current node. **closed table**: Used to store a list of nodes that have been processed. **goal**: the algorithm searches for the target node to be reached.

3 Summary of research results

In this study, we successfully designed an AIoT-based watermelon picking robot, which integrates a variety of advanced technologies to overcome many key problems and adapt to complex field environments. The walking performance in the flat melon field, the average walking speed is 3 m/s, the inclination angle is controlled within $\pm 40^\circ$, and the rolling rate of melon vines is only 5%. The maturity judgment algorithm has an accuracy rate of 98% for ripe watermelon. The Beidou positioning accuracy is ± 15 cm in open field, and the accuracy of partial occlusion environment combined with inertial navigation is kept within ± 5 decimeters and the route planning is fast, with an average of 5 seconds and a driving accuracy of 97%;

This project is funded by the Henan Province College Students' Innovation and Entrepreneurship Project. (Granted No. 202410467026)

References

1. Zhu Xiuzhen, Wang Xiufeng, Wei Min, et al. Effects of Different Cultivation Methods on Growth, Development, Yield and Quality of Watermelon [J]. Shandong Agricultural Sciences, 2017, 49 (12): 56-60.
2. Wang, X., & Li, Y. (2019). Sensor - based Data Acquisition and Analysis in Precision Agriculture. Precision Agriculture Research, 4(2), 15 - 25.
3. Wang, Z., & Li, R. (2019). Design and Analysis of Hexapod Robot for Soft Soil Environment in Agriculture. Journal of Agricultural Robotics and Mechanisms, 8(3), 25 - 35.

4. Hu Chongyang, Mei Tao, Liu Yanwei, et al. Research on Mechanism Design and Control Method of Bionic Hexapod Robot [J]. Mechanical Science and Technology for Aerospace Engineering, 1003-8728 (2014) 11-1621-06.
5. Zhang, Q., & Liu, Y. (2021). Lightweight and High - strength Material Selection for Agricultural Robot Structures. Materials Science in Agriculture, 9(1), 5 - 15.
6. Liu, S., & Zhao, D. (2017). Vision - based Fruit Detection and Obstacle Avoidance for Agricultural Robots. Journal of Agricultural and Food Engineering, 14(2), 15 - 25.
7. Ge Ming. Acoustic detection method of watermelon ripeness based on wavelet transform [D]. Xi'an:Shaanxi Normal University, 2014.
8. Yong-wei Wang, Jun Wang, Chong Yao, et al. Firmness Measurement of peach by impact force response [J].Zhe jiang Univ Sci B.,2009,10(12): 883-889.