Kinematics Analysis and Trajectory Planning Computer Simulation of Smart Apple Bagging Robot by Hail Suppression

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Abstract. In view of the high labor intensity and low efficiency of artificial anti hail apple bagging work, it needs a lot of manpower and financial resources. Therefore, Gansu ZeDe Electronic Technology Co., Ltd. research and development suitable for the actual production of anti hail apple bagging robot has broad application prospects. In this paper, the kinematics model is established based on the standard matrix representation, and the forward kinematics and inverse kinematics of the anti hail apple bagging robot manipulator are solved and analyzed, and the robot toolbox based on MATLAB is used for simulation verification and joint space trajectory planning simulation.

Key words: Anti hail apple bagging robot, manipulator kinematics analysis, trajectory planning, simulation and analysis.

1. Introduction
Apple is an important fruit production variety in China. In recent ten years, the planting area and yield have been on the rise, and has occupied a place in the world apple industry[1]-[9]. However, at this stage, the apple production in China is still dominated by labor, and the artificial apple bagging work is labor-intensive and inefficient, which requires a lot of human and financial resources. Therefore, the research and development of anti hail apple bagging robot has broad application prospects. In particular, in 2016, the recent severe hailstorms have caused heavy losses to fruit farmers, who are in urgent need of an apple bag to prevent hail in order to reduce the losses caused by natural disasters, and our research and development of this plastic apple bagging just solve the problem of concern to fruit farmers, therefore, plastic apple bagging industry is a broad market prospects [10]-[19].

Autonomous Flight of four rotor vehicle has always been a research hotspot, and attitude control algorithm is one of its key technologies [20]-[26]. In reference [27]-[30], a sliding mode controller based on backstepping method is designed, which has strong anti-interference ability and better realization of fixed-point hovering and track tracking; in reference [31]-[33], a fuzzy PID controller of plant protection aircraft is designed, which has strong resistance to environmental disturbance and realizes on-line adjustment of PID parameters, which effectively solves the control stability problem of variable load condition of fuselage. It has a very
strong use value in monitoring and preventing hail of Apple Bagging, and has a good reference meaning and can achieve good results.

Kinematics is the research basis of manipulator control[35],[36]. The research methods mainly include graphic method. By using vector analysis, matrix and binary number and other mathematical tools, denavit and hartenberg proposed to use standard matrix representation to express the motion equation of any spatial mechanism. This method has been widely used in the kinematics problem of robot mechanism after appropriate modification by Paul. et al.

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2. Anti hail apple bagging robot
Due to Qingyang's lack of investment in apple bagging, apple bagging is in short supply, unable to meet demand, the majority of farmers to external purchase, the cost of larger, the entire Qingyang bagging industry industry appears industry hole. Apple Bagging Unmanned Quadrotor1 and Apple Bagging Unmanned Quadrotor 2, as shown in Figure 1.

![Fig. 1 Apple Bagging Unmanned Quadrotor1.](image)
3. Kinematic model of denavit hartenberg rule

3.1. Kinematic model
According to the denavit hartenberg rule (D-H rule for short), the coordinate system is established, and the D-H parameters of four joints are obtained, as shown in Table 1.

| Joint i | (0) | (mm) | (mm) | (0) |
|---------|-----|------|------|-----|
| 1       | 90  | 0    | 375  | (-90～90) |
| 2       | 0   | 650  | 0    | (-61～29) |
| 3       | 0   | 614  | 0    | (-153～0) |
| 4       | 90  | 300  | 0    | (0～153) |

3.2. Forward kinematics solution
Anti-hail apple quadcopter, as shown in Figure 3. The manipulator of apple bagging robot adopts 4 joint degrees of freedom, D-H coordinate system of bagging robot manipulator, as shown in Figure 4.
Fig. 3 Anti hail apple bagging robot.

Fig. 4 D-H coordinate system of bagging robot manipulator.

The end pose of the manipulator can be expressed as [3]:

\[
\text{end pose} = \begin{pmatrix}
    X_4 \\
    Y_4 \\
    Z_4 \\
\end{pmatrix}
\]
Where: \( \mathbf{n}_x, \mathbf{n}_y, \mathbf{n}_z \) is the normal vector; \( \mathbf{o}_x, \mathbf{o}_y, \mathbf{o}_z \) is the azimuth vector; \( \mathbf{a}_x, \mathbf{a}_y, \mathbf{a}_z \) is the approach vector; \( \mathbf{p}_x, \mathbf{p}_y, \mathbf{p}_z \) is the position of the end effector center in the base coordinate system.

\[
^0 A_4 = \begin{bmatrix} n_x & o_x & a_x & p_x \\ n_y & o_y & a_y & p_y \\ n_z & o_z & a_z & p_z \\ 0 & 0 & 0 & 1 \end{bmatrix}
\]  \tag{1}

\[
(\mathbf{A}^{-1})^{-1} = \begin{bmatrix} \cos \theta_i & \sin \theta_i & 0 & -a_i \\ -\sin \theta_i \cdot \cos \alpha_i & \cos \theta_i \cdot \cos \alpha_i & \sin \alpha_i & d_i \cdot \sin \alpha_i \\ \sin \theta_i \cdot \sin \alpha_i & \cos \theta_i \cdot \sin \alpha_i & \cos \alpha_i & d_i \cdot \cos \alpha_i \\ 0 & 0 & 0 & 1 \end{bmatrix}
\]  \tag{2}

4. Forward kinematics and inverse kinematics are analyzed

We can get the following results:

\[
^0 A_1 = \begin{bmatrix} c_1 & 0 & s_1 & 0 \\ s_1 & 0 & -c_1 & 0 \\ 0 & 1 & 0 & d_1 \\ 0 & 0 & 0 & 1 \end{bmatrix}, \quad ^1 A_2 = \begin{bmatrix} c_2 & s_1 & 0 & a_2 c_2 \\ s_2 & 0 & -c_2 & a_2 s_2 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}
\]  \tag{3}

\[
^2 A_3 = \begin{bmatrix} c_3 & s_3 & 0 & a_3 c_3 \\ s_3 & c_3 & 0 & a_3 s_3 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}, \quad ^3 A_4 = \begin{bmatrix} c_4 & 0 & s_1 & c_2 a_4 \\ s_4 & 0 & -c_1 & s_4 a_4 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}
\]  \tag{4}

\[
\begin{align*}
\mathbf{n}_x &= c_1 c_{234} \mathbf{n}_y = s_1 c_{234} \mathbf{n}_z = s_{234} \\
\mathbf{o}_x &= s_1 \mathbf{o}_y = -c_1 \mathbf{o}_z = 0 \\
\mathbf{a}_x &= c_1 c_{234} \mathbf{a}_y = s_1 c_{234} \mathbf{a}_z = -c_{234} \\
\mathbf{p}_x &= c_1 (a_2 c_2 + a_3 c_3 + a_4 c_{234}) \\
\mathbf{p}_y &= s_1 (a_2 c_2 + a_3 c_3 + a_4 c_{234}) \\
\mathbf{p}_z &= d_1 + a_2 s_2 + a_3 s_3 + a_4 s_{234}
\end{align*}
\]  \tag{5}

Among them:

\[
c_1 = \cos \theta_1, s_1 = \sin \theta_1, c_{12} = \cos (\theta_1 + \theta_2), s_{12} = \sin (\theta_1 + \theta_2)\]

\[
c_{234} = \cos (\theta_2 + \theta_3 + \theta_4), s_{234} = \sin (\theta_2 + \theta_3 + \theta_4)
\]  \tag{6}

\[
c_1 = \cos \theta_1, s_1 = \sin \theta_1, c_{12} = \cos (\theta_1 + \theta_2), s_{12} = \sin (\theta_1 + \theta_2)
\]  \tag{7}

\[
c_{234} = \cos (\theta_2 + \theta_3 + \theta_4), s_{234} = \sin (\theta_2 + \theta_3 + \theta_4)
\]  \tag{8}
5. Experiment simulation and data analysis

The robot toolbox based on MATLAB platform, robotics toolbox, can realize the kinematics simulation of the manipulator. This simulation process can not only visually view the motion of the robot, but also display the required data in graphics [4].

5.1. Comparative analysis of theoretical contour and actual contour of bagging

The optimal control model of unmanned quadrotor aircraft is established. The results of Matlab simulation show that the optimal control system of quadrotor aircraft based on genetic algorithm is simulated by Matlab and Simulink, and compared with the linear quadratic control based on test method.

It can be seen from Figure 3 that in the plane trajectory, the bagging theoretical contour of the anti hail bagging robot is consistent with the actual bagging contour of the anti hail bagging robot, which meets the actual requirements of the bagging plane trajectory simulation of the anti hail bagging robot.

It can be seen from Figure 5~Figure 6 that: in the space trajectory, the bagging theoretical contour of the anti hail bagging robot is consistent with the actual bagging contour of the anti hail bagging robot, which meets the actual requirements of the bagging space trajectory simulation of the anti hail bagging robot.
Through the above analysis, whether in the plane trajectory or in the space trajectory, the bagging theoretical contour of anti hail bagging robot is consistent with the actual contour of anti hail bagging robot, which meets the actual requirements of bagging trajectory simulation of anti hail bagging robot.

5.2. Angular velocity of robot

![Fig. 7 Bagging distance of anti hail apple bagging robot 1.](image1)

![Fig. 8 Bagging distance of anti hail apple bagging robot2.](image2)

It can be seen that the angular velocity curves of the robot are very smooth without sudden change, which ensures the smooth operation.

In this paper, we use denavit hartenberg rule to establish the kinematics model, and solve the forward kinematics, and use matlab robotics toolbox to verify the results of forward kinematics. Secondly, according to the characteristics that the end effector keeps horizontal when the manipulator is bagged, the solution of inverse kinematics is simplified, and the results of inverse kinematics are verified by robotics toolbox. Finally, the trajectory planning of the manipulator is preliminarily explored, and the trajectory planning simulation of the manipulator in joint space is carried out by using robotics toolbox, which achieves good results.

6. Summary

In view of the high labor intensity and low efficiency of artificial anti hail apple bagging work, it needs a lot of manpower and financial resources. Therefore, Gansu Zede Electronic Technology Co.,
Ltd. research and development suitable for the actual production of anti hail apple bagging robot has broad application prospects. In this paper, the kinematics model is established based on the standard matrix representation, and the forward kinematics and inverse kinematics of the anti hail apple bagging robot manipulator are solved and analyzed, and the robot toolbox based on MATLAB is used for simulation verification and joint space trajectory planning simulation.

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