DESIGN AND KINEMATICS ANALYSIS OF MECHANICAL ARM OF TRIMMER

/

枣树修剪机机械臂的设计与运动学分析

Qiang Liang[1)]*, Hao Wang[1)]
[1)] Xinxiang Vocational and Technical College, Xinxiang, Henan, 453006, China
E-mail: gipws4349@163.com
DOI: https://doi.org/10.35633/inmateh-64-40

Keywords: *trimmer, mechanical arm, kinematics analysis*

ABSTRACT

The development of mechanization has greatly liberated the labour force, promoted socialized mass production, and created infinite social wealth. Its influence is significant and far-reaching, and agricultural production has undergone revolutionary changes. Aiming at the problems of poor working environment, high labour intensity and low working efficiency of manual pruning, a mechanical arm of branch pruning machine was designed, which realized the three-dimensional layered cylindrical pruning of individual tree. In this paper, a five-degree-of-freedom trimmer manipulator is designed, which is mainly composed of base, big arm, small arm, wrist and finger blade. The motion equation of the mechanism is established by using the Denavit–Hartenberg parameter (D-H parameter) method, and the corresponding motion curve is fitted by using MATLAB software. The components of the trimmer arm are designed virtually by using 3D modeling software, and assembled into a complete trimmer arm. The assembly drawing is imported into the simulation analysis software ADAMS for kinematics simulation. The results show that the speed-time pattern has obvious positive and negative changes at 3s, which proves that this stage is the hand cutting stage of jujube pruning; The acceleration time graph is gentle in the whole movement, and the curve approaches to a straight line, which proves that the movement of the mechanical arm of the jujube pruning machine is stable in the pruning process. Through the analysis of the simulation curve, it provides a theoretical basis for the research of the mechanical arm of the trimmer.

摘要

机械化的发展极大地解放了劳动力， 促进了社会化大生产， 创造了无限的社会财富。其影响重大而深远， 农业生产发生了革命性的变化。针对人工修剪存在的工作环境差、劳动强度大、工作效率低等问题， 设计了一种树枝修剪机机械臂， 实现了单株树木的三维分层圆柱形修剪。本文设计了一种五自由度切边机械手， 主要由底座、大臂、小臂、手腕和指叶组成。采用 D-H 参数法建立了机构的运动方程， 并用 MATLAB 软件拟合了相应的运动曲线。利用三维建模软件对切刀臂的各部件进行虚拟设计， 组装成一个完整的切刀臂。将装配图导入仿真分析软件 ADAMS 进行运动学仿真。结果显示速度时间图形在 3s 处有较为明显的正负值变化，证明了该阶段为枣树修剪手切割阶段；加速度时间图形在全程运动中较为平缓，并且曲线基本趋近于一条直线，证明了在修剪过程中枣树修剪机机械臂的运动较为稳定。通过对仿真曲线的分析， 为切边机机械臂的研究提供了理论依据。

INTRODUCTION

There are many kinds of unmanned mechanical systems in the field of agricultural production, such as unmanned tractors, combine harvesters, transplanters and automatic thrusters, etc. They walk in the field by themselves through the combined sensing system *(Chaitanya D.N.V. et al., 2018)*. These different mechanical systems, with or without operators, can sense the environment through sensing systems and realize autonomous operation through algorithms, which is a control mode with functions similar to human perception and intelligence. These robots refer to robots in a broad sense, including most intelligent mechanical systems *(Zhang J. et al., 2020)*

There are two main types of existing branch pruning equipment, one is short twig pruning, the handle is short and unsuitable for pruning*,* and second, pruning of tall branches: aiming at pruning of tall and thick branches, the handle is long, the weight is heavy, the alignment is low during pruning, and it is not easy to operate *(He W. et al., 2018)*. Manual pruning tools, i.e. electric, pneumatic and hydraulic scissors, are commonly used for manual pruning of single branches. Among them, manual pruning tools are used for large-scale pruning operations, which have high labour intensity, low work efficiency and are easy to cause occupational diseases. Electric, pneumatic and hydraulic scissors need to be equipped with power sources, and the scissors are heavy, so manpower is not suitable for long-term operation *(Tian H. et al., 2020)*. The experiment shows that the above two new pruning pieces of equipment are not suitable for pruning operation of low and dense planting. Therefore, the mechanical arm of trimmer with simple and practical design mechanism will have a good market prospect in the field of agricultural equipment with its lower manufacturing cost and higher economic benefit *(Li X. et al., 2020).*

This paper has studied the mechanical arm of branch trimmer, which is an agricultural mechanical arm. The performance of the mechanical arm is directly related to the overall performance of the mechanical arm control system. In this paper, based on the motion space analysis of the selected manipulator configuration, a 5-DOF manipulator is designed by using 3D software, and the hardware platform of the manipulator motion control system is realized. Finally, kinematics simulation and verification are carried out.

Nowadays, robots are not only limited to factories, but also special robots have appeared in many specific occasions, such as: explosive robots, surgical robots, service robots, line patrol robots, forestry robots, picking robots, etc. The best development of robots used in pruning is automatic lawn mowers, which have the ability of path planning and have been applied to lawns in family communities. There are no robots with automation ability in trimmers. Although there are trimmers imitating robots, there are still many problems to be solved in performance *(Chatterjee N. and Gupta S., 2019)*.

At present, trimmers can be divided into three categories:

- Manual trimming equipment, namely hedge shears and hand saws;
- Backpack small portable trimmer;
- Large-scale airborne trimmers, namely, vehicle-mounted, vehicle-mounted suspension and boom suspension.

Different types of trimmers have been continuously upgraded and have gradually worked in corresponding workplaces.

It has been more than 40 years since the development of trimmer equipment in foreign countries, from the most primitive manual scissors to mobile equipment. The United States and Japan take the lead in promoting the use of vehicle-mounted hanging trimmer, which combines the cutting and conveying device of reciprocating trimmer, and adopts hydraulic drive to adjust the position and posture of cutting device to trim hedges with different heights and different inclination angles. It is suitable for trimming the central isolation belt and green belts on both sides of expressways, and can meet the requirements in similar places with heavy workload and height according to the growth characteristics of branches of grape, apple, pear and other fruit trees, curtain trimmer is introduced to trim upright branches, which improves the pruning efficiency *(Gonzalez D.J. and Asada H.H., 2017; Hong J. et al., 2020)*. Some researchers designed and developed a double reciprocating grape trimmer, which can trim by adjusting the angle of trimming cutter *(Kang J.L. et al, 2019).* Literature developed a front hanging red jujube trimmer. The trimmer is composed of top and side parts. The disc cutters are alternately arranged on the tool holder, driven by hydraulic system, and the "door" copying trimming operation is realized. The cutting missing rate is less than 10%, but the three-dimensional layered copying cylindrical trimming cannot be realized *(Bamdad M. and Bahri M.M., 2019)*.

The development of domestic pruning machinery started late. In the late 1970s, landscaping maintenance machinery began to appear. Domestic enterprises mainly relied on the introduction of foreign mature technologies or products in the early stage in combination with China's national conditions. In order to adapt to domestic characteristics, imitation or improved equipment began to appear. In order to solve the problems of narrow domestic roads and small scale of road greening, hanD-Held semi-automatic agricultural and forestry machinery was designed. The development of intelligent trimmer in China is still in its initial stage, without perfect technical system, unified standard, various control methods, and it often fails to achieve the desired results when working. The flexibility and reliability of trimming equipment are far behind those of foreign countries, so it is urgent to develop a small vehicle-mounted trimmer equipment.

The researcher studied and designed the double-sided high-efficiency trimming machine. The key technologies of loquat pruning robot are studied, the application of image recognition technology in loquat pruning robot is studied, and the loquat pruning end effector is designed *(Minakov I.A. and Nikitin A.V., 2019)*. Although these prototypes can realize automatic pruning to a certain extent, they are far from being fully automatic or even intelligent *(Roshanianfard A.R. and Noguchi N., 2018)*.

To sum up, domestic agricultural and forestry machinery and equipment are still in the primary stage, and there is a big gap with developed countries in terms of performance, quality and automation level. In the next stage, we should proceed from reality develop various types of equipment that can adapt to the planting characteristics of domestic green belts, develop stable and reliable operation platforms, gradually master core technologies, and produce key core components, so as to build intelligent modern trimmers *(Sharkawy A.N. et al., 2020; Freire-Tellado M.J. et al., 2020).*

MATERIALS AND METHODS

Mechanical arm design of trimmer

Its design idea is the working principle of linkage mechanism in mechanical principle (see Figure 1). The mechanical arm of trimmer is mainly composed of hydraulic motor, coupling, cutter shaft, cutter head, cutter head fixing sleeve, supporting device, copying wheel, bearing seat and frame. The cutter shaft is vertically installed on the frame through a bearing seat, and a plurality of groups of cutter heads are horizontally fixed on the cutter shaft to realize the three-dimensional layered sawing function; The cutter group assembly moves from side to side with the random frame, and moves back and forth with the whole machine at the same time, thus realizing the cylindrical trimming function.

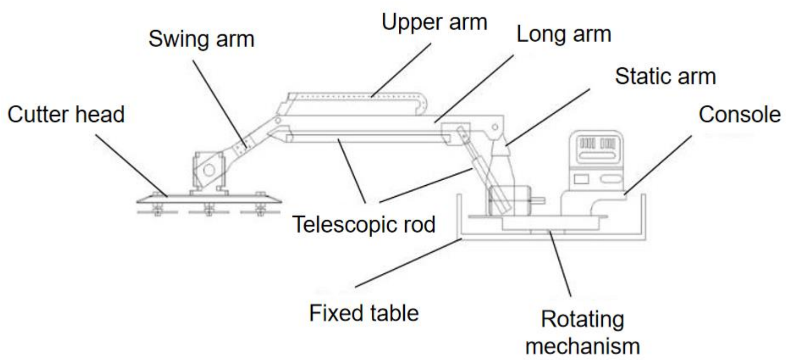

Fig. 1 - Overall plan view of mechanical arm of jujube trimmer

When working, the hydraulic system of the whole machine provides driving force for the trimming device. The hydraulic motor generates torque through the hydraulic system, drives the cutter shaft to rotate at high speed, and drives a plurality of groups of cutter heads horizontally fixed on the cutter shaft to rotate. The high-speed rotation of the cutter head produces inertial force, and the cutting edge of the cutter head performs sawing and trimming operation under the action of inertial force. The trimming device moves along with the whole machine, and two groups of cutter head assemblies of the trimming device are driven to move left and right respectively through the interaction between the follow-up copying wheel and the trunk. Three-dimensional layered trimming can be realized when multiple sets of horizontally installed and vertically spaced cutterheads are sawed and trimmed. During the advancing process of the trimming device, the two groups of cutter head assemblies fit the circular arc movement by moving left and right, which can realize the individual tree-like cylindrical trimming function.

The folding mechanism is the main component of this design. In order to meet the requirements of different shapes at present, the design goal is to realize the change from three-side trimming posture to one-side trimming on the premise of first meeting the simultaneous trimming on three sides. Moreover, because the industrial platform of this design selects the front tractor, which is equipped with hydraulic device and does not need to set up another power source (as the vertical and horizontal position control of trimming machinery operation), we choose the hydraulic cylinder as the expansion control component of the folding mechanism here. When the trimming mechanism is required to trim three sides, the hydraulic cylinder contracts, so that the cutters on both sides are folded to the vertical position, and the side of the green belt can be trimmed. When the trimming mechanism needs to complete the single-side trimming task, the hydraulic cylinder extends again, so that the three-side cutters are in a horizontal plane, which can complete the trimming work of a large area on one side. Not only the horizontal trimming task can be realized, but also the large-area trimming can be realized.

By using the hydraulic system, the control of each hydraulic cylinder can be realized through the joystick in the cab, and the semi-intelligent design is realized. Selecting hydraulic cylinder as the component for adjusting and controlling the working mode of the trimmer can meet the design requirements with only a small size, which is beneficial to the light weight of the whole tool holder and is more economical and practical.

Compared with other control devices, the hydraulic cylinder works more stably and the technology is more mature *(Redström J., 2020).*

The structure of the folding mechanism is shown in Figure 2.

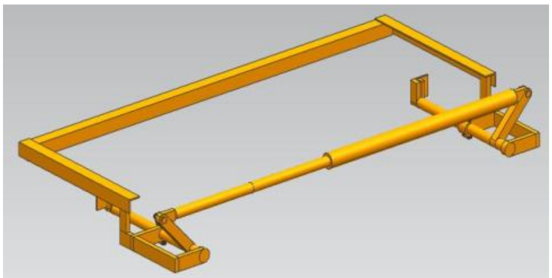

Fig. 2 - Basic mechanism diagram of folding mechanism

Fig.2 includes hydraulic cylinder, fixing bracket and cutter link plate. The cutters on both sides are linked with cutter link plates to form a rigid integrated structure, and the other side of the link plates is a transverse rotating shaft. The end points and middle points on the upper side of the rotating shaft are respectively in contact with the outer bracket, and under the constraint of the bracket, the shaft cannot move but can only rotate along the axis. The support bears the load of other components in the whole structure, and plays a certain role in restraining the rotating shaft. The hydraulic cylinder drives the rotation of the rotating shaft through its own expansion and contraction, thus realizing the vertical and horizontal transformation of the cutters on both sides.

The transmission system design of the mechanical arm of jujube trimmer adopts high-speed gear hydraulic motor to drive the triangle belt wheel. Among the classic chain drive and belt drive modes of long-distance transmission, belt drive is simple and safe, so belt drive mode is chosen. The high-speed hydraulic motor is used as the driving element, and the high-speed rotation operation of the auxiliary tip trimming scissors is realized by means of V-belt transmission.

Choose high-speed gear motor, in order to save space and reduce mass, choose O-shaped V-belt. Tractors with 50 HP (36.8 kW) are commonly used, and their hydraulic output is generally 40 L/min. The trimmer needs three hydraulic motors to drive. Considering the efficiency, the actual supply flow of each motor should be 10 L/min, and the motor speed should be 2 000 r/min. The transmission ratio should be i=1.4 if the speed of the auxiliary tip trimming scissors is n=3 000 r/min, and it is calculated that the minimum pulley diameter of the triangular pulley is d_1=100 mm when the quasi-0 = 38, so the pulley assembled by the motor is: $d_2 = d_1 \times i$ = 100×1.4=140 mm.

According to the hydraulic flow and v, the linear speed of V-belt, should be less than 25 m/s. Considering the interference problem, set the pulley size d_2=140mm between trimming knives, and according to formula (1),

$$v = \pi d_2 n \tag{1}$$

Available:

$$n = \frac{v}{\pi d_2} = \frac{25}{3.14 \times 140} \times 1000 \times 60 = 3412\ r/min \tag{2}$$

Too high speed of trimmer can easily cause vibration, noise and resonance, etc. Finally, the pulley diameter d_2=140mm between trimmers is selected, and the moving speed range of trimmer is 3 000 ~ 4 000 r/min.

The wrist of the mechanical arm determines the attitude of the end effector. According to the characteristics of pruning operation, in order to ensure the closed inverse kinematics solution, the three-degree-of-freedom common intersection RBR wrist structure is selected, which has the advantages of compact and flexible structure. Wrist can be divided into single degree of freedom, two degrees of freedom and three degrees of freedom, among which wrist with three degrees of freedom is called "universal" wrist because of its high flexibility. In this paper, the orthogonal spherical wrist structure of the mechanical arm RBR of jujube trimmer is designed, that is, the wrist can realize two coaxial rotary motions (R) and one pin rotary motion (B). RBR orthogonal spherical wrist structure, with wrist rotation, wrist swing and hand rotation.

The transmission chain is divided into two parts: one part is at the rear end of the forearm, which is transmitted from the distal end of the forearm to the proximal end of the forearm in the way of parallel shaft output, and finally transmitted to the coaxial transmission mandrel and sleeve. The other part of the transmission chain is wrist, which realizes wrist rotation, wrist swing and hand rotation.

X-axis, *Y*-axis and *Z*-axis of wrist mechanism meet at one point. When the rotation angle is not limited, it can theoretically achieve any posture, and the position and posture can solve the problem, which is beneficial to inverse kinematics analysis. In the specific pruning process, the control strategy can be simplified by controlling the position and posture in sequence, that is, the wrist is delivered to the vicinity of the fruit through the base, arm and forearm, and then trimmed by adjusting the wrist posture.

Kinematics parameters between joints are determined by the connecting rod between them, and the connecting rod module is another important module to determine the configuration. The connecting rod modules with vertical axis and parallel axis are designed for the connection between joint modules. In addition, for the convenience of configuration, the threaded quick connection structure is adopted between the modules.

Each joint module and connecting rod module have the same mechanical interface and electrical interface, which can be quickly assembled into mechanical arms with different configurations to meet the needs of users, and the ends can be connected with different clamping or operating mechanisms.

Kinematics analysis

Manipulator dynamics studies the relationship between the motion of manipulator and the force and moment that makes it move. The dynamics of manipulator belongs to the category of mechanism dynamics, and the dynamics of manipulator involves two problems. One is the inverse dynamics problem, which is known as the trajectory point of manipulator and the velocity and acceleration at the end to solve the joint force, and the inverse dynamics problem is used to solve the control and structural design problems. The other is the forward dynamics problem, in which the position, velocity, acceleration and other parameters of the operating arm are solved by knowing the shutdown force, which is mainly used for the simulation of the operating arm.

Up to now, this method has become the basic method to study the establishment of robot kinematic coordinate system. By using this method, the mathematical modeling of robot motion analysis can be carried out, and the homogeneous transformation matrix of the whole mechanism can be established by the homogeneous matrix of each mechanism obtained after modeling. The three-dimensional coordinate system of trimmer manipulator established by Cartesian coordinate system is an orthogonal coordinate system, and its three coordinate axes *X, Y, Z* are established perpendicular to each other. Because the mechanical arm of the trimmer is composed of five joints, it is very important to set the motion parameters if we want to calculate the motion equation of the end position of the trimmer hand which changes with the size and length of each joint and the joint angle. Setting motion parameters in Cartesian coordinate system not only makes the set parameters clear, but also improves the accuracy of data.

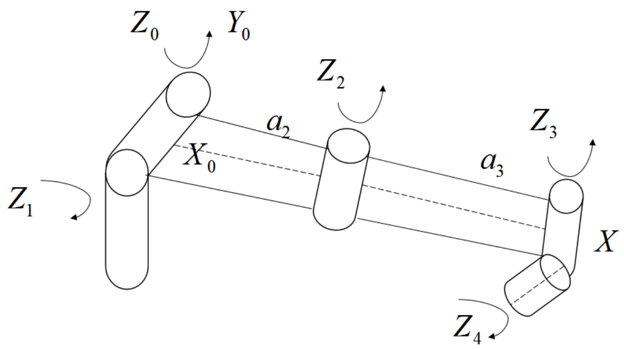

Fig. 3 - Mechanism coordinate system

According to the D-H parameter representation, a coordinate system is established for each mechanism of the trimmer manipulator, and then the transformation process from the current joint to the next joint is determined. As shown in Figure 3, the Z -axis direction is expressed as the joint axis direction of each rotating joint, so the Z -axis set from the base, the joint between base and big arm, the joint between big arm and small arm, the joint between wrist and small arm, and the joint between hand and wrist are Z_0-Z_4 respectively. The direction of X axis is expressed as the extension line direction of the current joint axis along the next joint axis. Y-axis direction can be determined by right-hand rule.

In the process of setting parameters, the variable θ_1-θ_5 is used to express the angle between the common vertical lines of the two connecting rods. d_1-d_5 is used to represent the common vertical distance of two connecting rods.

a_1-a_5 is respectively expressed as the distance of the common perpendicular of the two shafts of the two connecting rods. Because the trimming hand and the upper part of the base are on the same horizontal line in the initial position of the mechanism, the distance a_1 between the base and the axis of the big arm is 0.

Because the axis perpendicular direction of wrist and the axis perpendicular direction of forearm are also on the same line, the distance a_4 between wrist and forearm is 0.

Since the direction of the axis perpendicular of the hand and the direction of the axis perpendicular of the wrist are also on the same line, the distance a_5 between the axis perpendicular of the hand and the wrist is 0.

The known motion parameters include the distance a_2 between the axis of the big arm and the base and the distance a_3 between the small arm and the axis of the big arm. The axial included angle of the two connected rotating joints is expressed by a_1-a_5, and the degrees expressed by a_1-a_5 of the mechanical arm of the trimmer are 90°, -90°, 0°, 90°, 0° respectively according to the initial position.

According to the motion parameters analysed above, the D-H parameters of the mechanical arm of the trimmer are shown in the following Table 1.

Table 1

Parameter table of D-H of trimmer mechanical arm

Variable/joint	1	2	3	4	5
θ_i	θ_1	θ_2	θ_3	θ_4	θ_5
d_i	0	0	0	0	0
a_i	0	a_2	a_3	0	0
a_i	90°	-90°	0°	90°	0°

By setting the D-H parameter table accurately, it can provide a data source for the position kinematics of the mechanical arm of the trimmer, and provide a powerful basis for the establishment of the homogeneous coordinate matrix of each rotating mechanism.

Static analysis and kinematics equation theory analysis

Static equation

On the basis of the previous analysis, in the following analysis, it is necessary to assign the velocity and acceleration to 0, and then get the following formula (1) (called statics equation) after finishing.

$$\begin{bmatrix} \frac{\partial F}{\partial q}\left(\frac{\partial \Phi}{\partial q}\right)^T \\ \frac{\partial \Phi}{\partial q} \end{bmatrix}_j \begin{Bmatrix} \Delta q \\ \mathrm{H}\lambda \end{Bmatrix}_j = \begin{Bmatrix} -F \\ -\Phi \end{Bmatrix}_j \tag{3}$$

where: $\frac{\partial F}{\partial q}$ is the stiffness matrix of the system; $\frac{\partial \Phi}{\partial q}$ - Damping matrix of the system; Δq -Stiffness;

$\mathrm{H}\lambda$ - speed; F - acceleration; Φ - resistance.

Kinematics equation is mainly obtained after simplifying the analysis process. After processing, the main content is to theoretically analyse the displacement, velocity, acceleration and resistance of the constrained parts in the whole system, so solving the constraint equation of the system becomes formula (2).

$$\Phi(q,t_n)=0 \tag{4}$$

where: q - constrained parts; t_n - displacement.

Newton-Raphson iterative method in the equation can be used to solve the change of the specific position of the main components, such as formula (3).

$$\frac{\partial \Phi}{\partial q}\Big|_j \Delta q_j = -\Phi(q_n,t_n) \tag{5}$$

in which:

$$\Delta q_j = q_{j+1} - q_j \tag{6}$$

where: q_{j+1} is the part of the $j+1$-th constraint; j-the j th iteration.

The calculation of speed and acceleration at t_n time can be realized by first-order or second-order derivation of formula (3), such as formulas (5) and (6).

$$\left(\frac{\partial\Phi}{\partial q}\right)\dot{q}=-\frac{\partial\Phi}{\partial t} \tag{7}$$

$$\left(\frac{\partial\Phi}{\partial q}\right)\ddot{q}=\left\{\frac{\partial^2\Phi}{\partial t^2}+\sum_{k=1}^{n}\sum_{l=1}^{n}\frac{\partial^{2\Phi}}{\partial q_k\partial q_t}\dot{q}_k q_l+\frac{\partial}{\partial t}\left(\frac{\partial\Phi}{\partial q}\right)\dot{q}+\frac{\partial}{\partial q}\left(\frac{\partial\Phi}{\partial t}\right)\dot{q}\right\} \tag{8}$$

where: $\frac{\partial\Phi}{\partial q}$ - damping matrix of the system; $\frac{\partial\Phi}{\partial t}$ - speed.

The following formula (7) can be obtained by bringing the force at t_n time into Lagrange equation.

$$\left(\frac{\partial\Phi}{\partial q}\right)^T\lambda=\left\{-\frac{d}{dt}\left(\frac{\partial T}{\partial\dot{q}}\right)^T+\left(\frac{\partial T}{\partial q}\right)^T+Q\right\} \tag{9}$$

where: $\frac{\partial T}{\partial q}$ -the quality matrix of the system; λ-coefficient of friction; Q-mechanical arm length.

According to the Jacobian of the manipulator, the kinematic model of the manipulator can be established, and the linear velocity v and angular velocity w of the end-effector can be expressed as linear functions of the joint velocity.

RESULTS

Motion simulation and analysis

Kinematics simulation analysis is mainly to verify the correctness of the kinematics model of trimmer manipulator and the correctness of the algorithms of forward and inverse pose solutions. The results of kinematics analysis lay a foundation for dynamic modeling and analysis. Kinematics simulation, dynamics simulation and optimization simulation are all programmed by MATLAB software. The shape of the trimmer arm is shown in Figure 4, and its working process is shown in Figure 5.

Fig. 4 - Modeling of mechanical arm of trimmer

Fig. 5 - Working process of mechanical arm of trimmer

In order not to drive the big joints as much as possible, the waist joints of the mechanical arm can be locked when trimming a certain area, and the position and posture of the end effector can meet the trimming requirements by relying on other joints. After the operation in this area is completed, the waist joints and the mobile platform are adjusted again, so that the trimming operation can be regarded as plane motion locally, thus simplifying kinematic analysis. However, in order to check the performance of the designed mechanical arm, in the forward kinematics simulation, only the length of the arm is locked equal to that of the arm, so that the basic kinematics performance of the trimmer mechanical arm can be checked.

Establishment of physical model

The steps of modeling and simulation are shown in Figure 6.

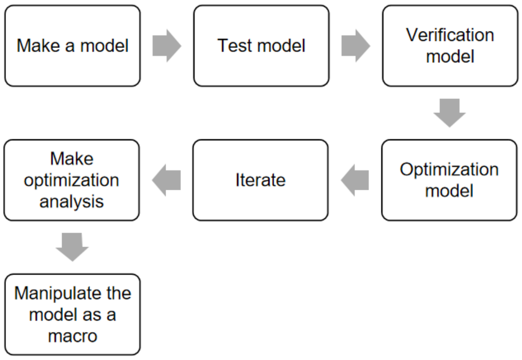

Fig. 6 - Flow chart of modeling and simulation steps

Main contents: (1) select the desired coordinate system; (2) Setting the material properties of parts; (3) Add corresponding constraints to each component. Analyse the constraints of each component in the working process of the designed trimming mechanism, and input and output various data on the pulley, and the cutting tool outputs corresponding data. The constraints of each component are shown in Table 1.

Table 1

Constraint summary table of each component of trimming mechanism

Constrained object	Types of constraints
Pulley-spindle	Fixed pair
Base-spindle	Rotating pair
Base-earth	Fixed pair
Pendulum ring-spindle	Rotating pair
Pendulum fork-pendulum ring	Rotating pair
Pendulum fork-base	Fixed pair
Swing fork-swing arm	Fixed pair
Swing arm-connecting rod	Rotating pair
Connecting rod-moving tool	Fixed pair

Motion simulation and measurement results

The motion simulation of the end position and posture of the trimmer manipulator is carried out by using the simulation in ADAMS to study the motion performance of the end position and posture of the trimmer manipulator. After the simulation is finished, save the simulation results, and enter the post-processing module in ADAMS to analyse the simulation results of the mechanism. The position, velocity and acceleration images of the end pose of the trimmer arm in X, Y, Z axis obtained by simulation are shown in Figure 7 and Figure 8.

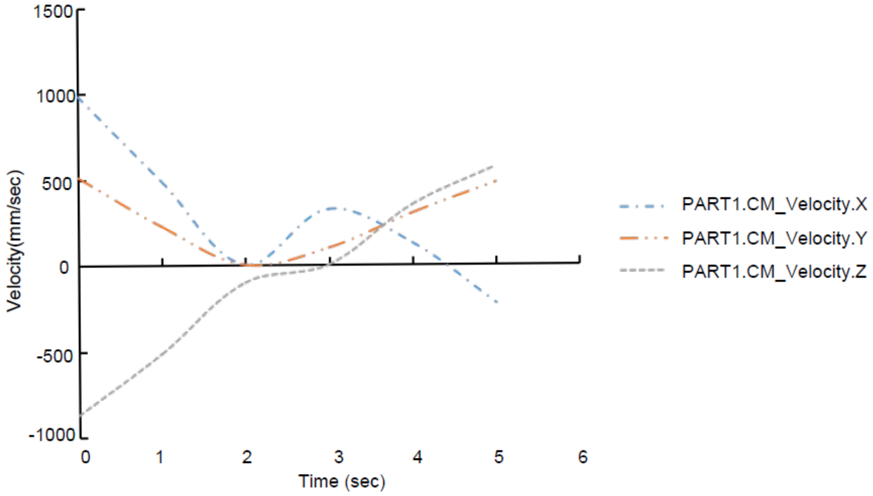

Fig. 7 - Velocity-time graph at the end

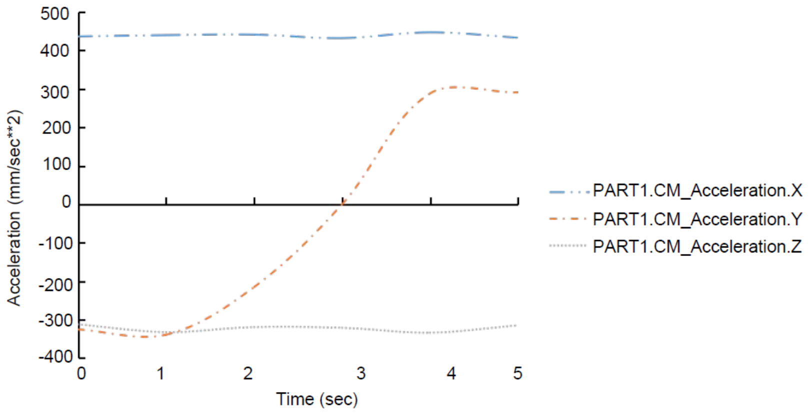

Fig. 8 - End pose acceleration-time graph

From the simulation characteristic curves in Figure 7 and Figure 8, it can be seen that the position and time graph of the end position of the trimmer manipulator is relatively flat in the whole movement process, and there is no drastic transformation stage, which verifies the rationality of the designed motion equation. The velocity-time pattern has obvious positive and negative changes at 3s, which proves that this stage is the cutting stage of pruning hand. The acceleration time graph is gentle in the whole movement, and the curve approaches to a straight line, which proves that the motion of the trimmer arm is stable in the trimming process, which is convenient for the trimmer arm to realize the trimming.

Introduction of the force changes of the cutter and swing arm under the condition that the input speed is 300r/min, the simulated resistance is 1000N, and the relative friction of each rotating pair is not considered (ideal condition). The tool force is shown in Figure 9. The force on the swing arm is shown in Figure 10.

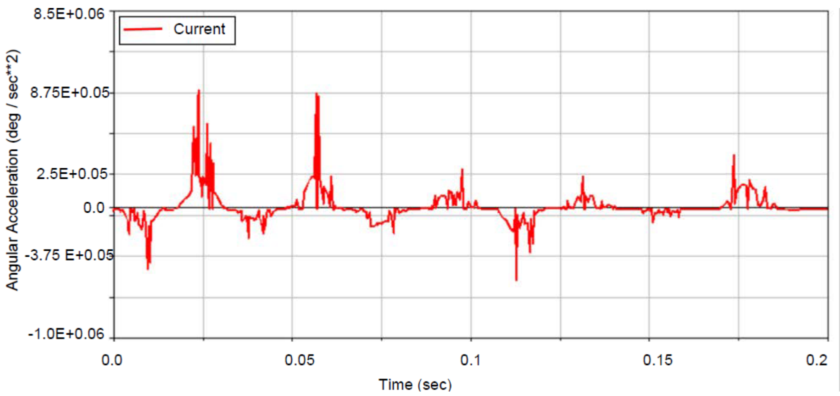

Fig. 9 - Force situation of cutting tools

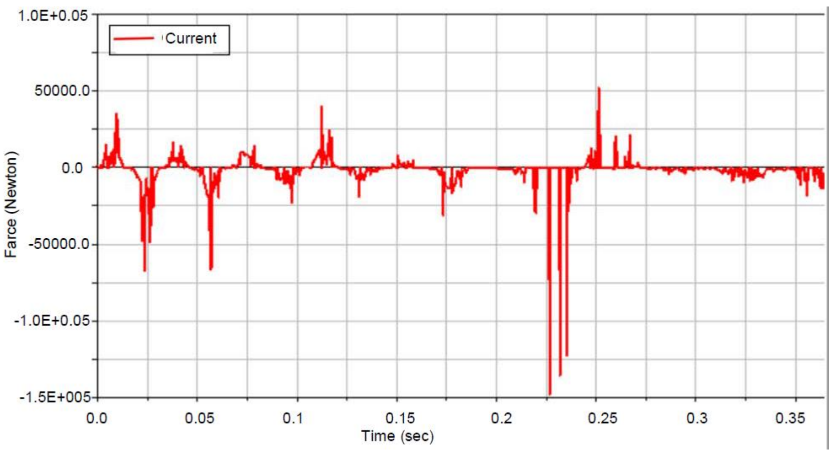

Fig. 10 - Force situation of swing arm

CONCLUSIONS

In this paper, a robot arm of jujube pruning machine is designed. According to the simplified model of the robot arm of jujube pruning machine, D-H parameters are listed, and the linkage coordinate system is established. Then the coordinate transformation matrix and Jacobian matrix of the robot arm are established by D-H method. On this basis, the kinematic model of the robot arm of jujube pruning machine is established. Finally, the ADAMS program is compiled to simulate the forward kinematics of the mechanical arm of jujube trimmer. Through ADAMS motion simulation, it is concluded that under the condition that the input speed is 300r/min, the simulated resistance is 1000N, and the relative friction of each rotating pair is not considered (ideal condition), the force changes of the cutter and swing arm, the movement speed and acceleration curve of the mechanism change smoothly, and the mechanism has good movement performance.

REFERENCES

[1] Bamdad M., Bahri M. M., (2019), Kinematics and manipulability analysis of a highly articulated soft robotic manipulator. *Robotica*, Vol. 37, Issue 5, pp. 868-882. United Kingdom;

[2] Chaitanya D. N. V., Arunkumar S., Akhilesh G. B., (2018), Design of Rice Transplanter. *IOP Conference Series: Materials Science and Engineering. IOP Publishing*, Vol. 377, Issue 1, pp. 012037. United Kingdom;

[3] Chatterjee N., Gupta S., (2019). Efficient Phrase Table pruning for Hindi to English machine translation through syntactic and marker-based filtering and hybrid similarity measurement. *Natural Language Engineering*, Vol. 25, Issue PT.1, pp. 171-210. England;

[4] Freire-Tellado M. J., Muñoz-Vidal M., Pérez-Valcárcel J., (2020), Scissor-Hinged Deployable Structures Supported Perimetrally on Rectangular Bases. *Journal of the International Association for Shell and Spatial Structures*, Vol. 61, Issue 2, pp. 158-172. Spain;

[5] Gonzalez D. J., Asada H. H., (2017), Design and analysis of 6-dof triple scissor extender robots with applications in aircraft assembly. *IEEE Robotics and Automation Letters*, Vol. 2, Issue 3, pp. 1420-1427. United States;

[6] He W., He X., Zou M., (2018), PDE model-based boundary control design for a flexible robotic manipulator with input backlash. *IEEE Transactions on Control Systems Technology*, Vol. 27, Issue 2, pp. 790-797. United States;

[7] Hong J., Kim T., Chae H., (2020), Design of window-cleaning robotic manipulator with compliant adaptation capability. *IEEE/ASME Transactions on Mechatronics*, Vol. 25, Issue 4, pp. 1878-1885. United States;

[8] Kang J. L., Hou W. P., Li C. Y., (2019), Design and characteristic analysis of multifunctional gardening pruning robot arm. *Forest Engineering,* Vol. 35, Issue 04, pp. 86-92. Croatia;

[9] Li X., Quan Z., Liu D., (2020), Design of Control System for 6-DOF Manipulator. *OP Conference Series: Materials Science and Engineering. IOP Publishing*, Vol. 772, Issue 1, pp. 012041. United Kingdom;

[10] Minakov I. A., Nikitin A. V., (2019), Agricultural market development: trends and prospects. *International journal of innovative technology and exploring engineering*, Vol. 9, Issue 1, pp. 3842-3847. India;

[11] Redström J., (2020), Certain uncertainties and the design of design education. *She Ji: The Journal of Design, Economics, and Innovation*, Vol. 6, Issue 1, pp. 83-100. Netherlands;

[12] Roshanianfard A. R., Noguchi N., (2018), Kinematics analysis and simulation of a 5DOF articulated robotic arm applied to heavy products harvesting. *Journal of Agricultural Sciences*, Vol. 24, Issue 1, pp. 90-104. Serbia;

[13] Sharkawy A. N., Koustoumpardis P N, Aspragathos N., (2020), Neural Network Design for Manipulator Collision Detection Based Only on the Joint Position Sensors. *Robotica*, Vol. 38, Issue 10, pp. 1737-1755. England;

[14] Tian H., Wang T., Liu Y., (2020), Computer vision technology in agricultural automation—A review. *Information Processing in Agriculture*, Vol. 7, Issue 1, pp. 1-19. China;

[15] Zhang J., Yang X., Li Y., (2020), Path Planning Simulation of 6-DOF Manipulator. *Journal of Physics: Conference Series*, Vol. 1574, Issue 1, pp. 012156. United Kingdom;