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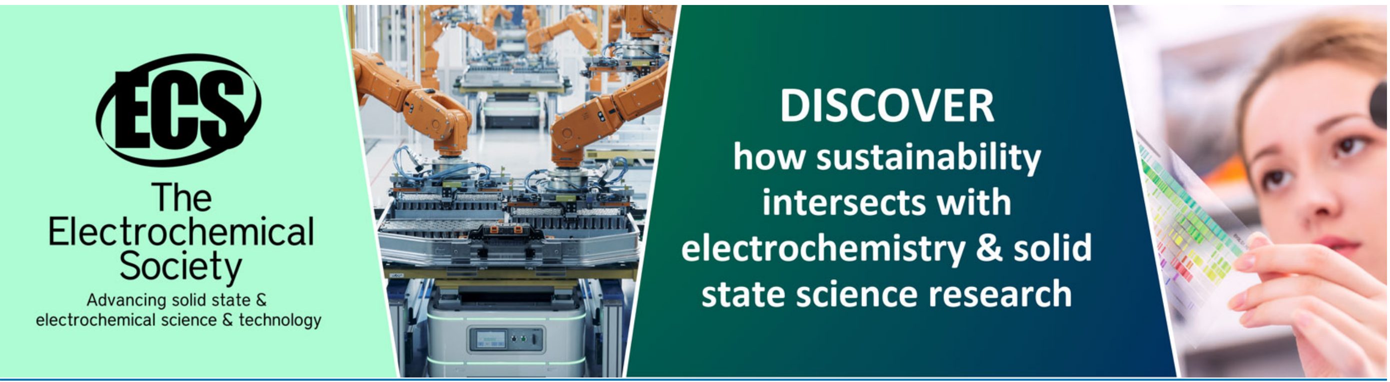

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Design and Analysis of Vegetable Transplanter Based on Five-bar Mechanism

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Abstract. As one of the important components of automatic transplanter, duckbilled planting device, is a significant factor affecting the efficiency of the transplanter. Aiming at the problems of low transplanting rate, poor upright angle and poor stability of the transplanter, a five-pole transplanting mechanism is designed. Firstly, the parameters of the five-pole transplanting mechanism are analyzed and confirmed by MATLAB software. After virtual prototype model is established by SolidWorks software, simplified model is imported into ADAMS software for kinematics simulation, and then the trajectory, velocity and acceleration curve of the duckbilled tip are obtained. The simulation results verify the rationality of the structure and parameters and show that the trajectory of duckbilled planter meets the agronomic requirements of vegetable cultivation.

1. Introduction

Planting industry accounts for more than half of the total agricultural production value in China [1]. Transplanting is an extremely important production link in planting industry. At present, most of the transplanting operations of dryland crops in China adopt manual transplanting. Because of the increase in the proportion of rural employees going out to work and the adjustment of the overall industrial structure, the actual labor cost has been significantly higher than that of mechanized operations. Therefore, it is necessary to develop the automation and machinery and imperative to mechanize transplanting and improve its efficiency. Dryland transplanter is an agricultural equipment mainly for maize, cotton, cabbage and other dryland crops transplantation. It can replace manual operation to achieve automatic and semi-automatic transplanting work, and has been more and more widely used in different regions of China [2].

Since planting mechanism is an important component of dryland transplanter, a five-bar planting mechanism is designed to improve the overall stability of the planting mechanism and ensure the accuracy of the overall movement through the transmission of the five-bar mechanism. In order to overcome the difficulty of designing five-bar mechanism, the parameters are designed by MATLAB software, 3D (three-dimensional) model is built by SolidWorks software, and the planting mechanism is simulated and analyzed by ADAMS software. Finally, all the structural parameters of the five-bar planting mechanism can be obtained.

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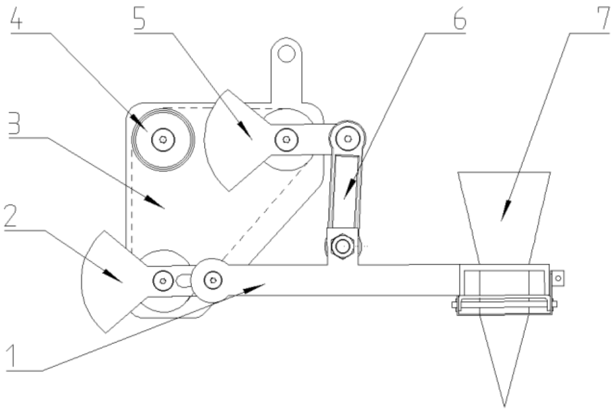
2. Structure and working principle of the planter

Five-bar mechanism is a multi-degree-of-freedom mechanism with the least number of links and rings. It is relatively stable and has more dimension and angle parameters. It can realize abundant curve trajectories. Therefore, five-bar mechanism is used as the executing mechanism of duckbilled tip trajectory [3].

The planting structure of transplanter is mainly composed of five parts: fixing plate, driving sprocket, upper cranks, lower cranks and duckbill, as shown in figure 1.



1-guide rod 2-lower crank 3-fixed plate 4-driving sprocket
5-upper crank 6-connecting rod 7-duckbill

Figure 1. Structural diagram of planting mechanism

In figure 1, one end of the upper and lower cranks are connected with the bearing seat, the other end of the upper crank is hinged with the guide rod and the other end of the lower crank is hinged with the slider embedded in the guide rod, which form a double crank guide rod mechanism. During operation, the upper and lower cranks of the planter rotate at equal speed under the action of driving sprockets. At the same time, the planting mechanism moves in a uniform straight line in the horizontal direction.

Under the compound movement, the duckbill can be planted vertically by adjusting the structural parameters of the mechanism, so as to ensure that the pot seedlings have a good upright angle after planting. The lower crank has a sliding groove, and the planting depth can be adjusted by changing the length, which can meet the requirements of different crops for planting depth and ensure the planting quality of seedlings.

3. Establishment of mathematical model

In order to study the motion law of the five-bar mechanism, the motion of the planter mechanism is analyzed by analytic method, and the closed vector position equation of the mechanism is established. The law of speed and acceleration could be obtained by further derivation. The schematic diagram of the transplanting device with five-bar mechanism is shown in figure 2.

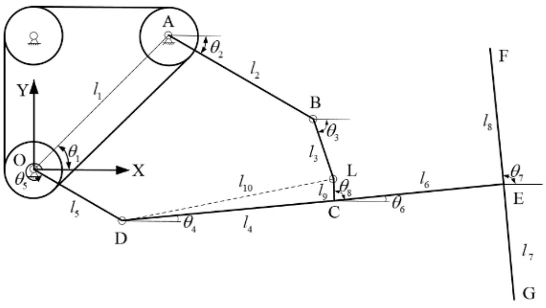


Figure 2. Mathematical model of planter mechanism

Cartesian coordinate system is established with O point as origin, horizontal direction as X axis and vertical direction as Y axis. The displacement equation of point D can be listed by analytic method as

$$\begin{cases} X_D = X_O + l_5 \cos\theta_5 \\ Y_D = Y_O + l_5 \sin\theta_5 \end{cases} \tag{1}$$

Similarly, the displacement equation of point B is defined as

$$\begin{cases} X_B = X_A + l_2 \cos\theta_2 \\ Y_B = Y_A + l_2 \sin\theta_2 \end{cases} \tag{2}$$

Since the displacement vector **OL** can be represented as

$$\boldsymbol{l}_{OA} + \boldsymbol{l}_{AB} + \boldsymbol{l}_{BL} = \boldsymbol{l}_{OD} + \boldsymbol{l}_{DL} \tag{3}$$

the coordinate of point L can be calculate by

$$\begin{cases} X_L = l_1 \cos\theta_1 + l_2 \cos\theta_2 + l_3 \cos\theta_3 = l_5 \cos\theta_5 + \cos\left(\theta_4 + \arctan\dfrac{l_9}{l_4}\right)\sqrt{l_4^2 + l_9^2 - 2 l_4 l_9 \cos\theta_8} \\ Y_L = l_1 \sin\theta_1 + l_2 \sin\theta_2 + l_3 \sin\theta_3 = l_5 \sin\theta_5 + \sin\left(\theta_4 + \arctan\dfrac{l_9}{l_4}\right)\sqrt{l_4^2 + l_9^2 - 2 l_4 l_9 \cos\theta_8} \end{cases} \tag{4}$$

To simplify the operation, a definition is written as

$$\begin{cases} a = l_1 \cos\theta_1 + l_2 \cos\theta_2 - l_5 \cos\theta_5 \\ b = l_1 \sin\theta_1 + l_2 \sin\theta_2 - l_5 \sin\theta_5 \\ c = \dfrac{l_4^2 + l_9^2 - 2 l_4 l_9 \cos\theta_8 - a_2 - b_2 - l_3^2}{2 l_3} \end{cases} \tag{5}$$

The parameter θ_3 can be given as

$$\theta_3 = 2\arctan\frac{b \pm \sqrt{a^2 + b^2 - c^2}}{a - c} \tag{6}$$

Referring equation (4) and equation (6), parameter θ_4 can be obtained. So the displacement equation of point C is defined as

$$\begin{cases} X_C = X_L + l_9 \cos(\pi - \theta_8 + \theta_4) \\ Y_C = Y_L + l_9 \sin(\pi - \theta_8 + \theta_4) \end{cases} \tag{7}$$

The displacement equation of point E is expressed as

$$\begin{cases} X_E = X_D + (l_4 + l_6)\cos\theta_4 \\ Y_E = Y_D + (l_4 + l_6)\sin\theta_4 \end{cases} \tag{8}$$

The displacement equation of point F is described as

$$\begin{cases} X_F = X_E + l_8 \cos(\theta_7 - \theta_4) \\ Y_F = Y_E + l_8 \sin(\theta_7 - \theta_4) \end{cases} \tag{9}$$

The displacement equation of point G is defined as

$$\begin{cases} X_G = X_E + l_7 \cos(\theta_7 - \theta_4) \\ Y_G = Y_E - l_7 \sin(\theta_7 - \theta_4) \end{cases} \tag{10}$$

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The displacement equation of the five-bar mechanism is solved. If the first derivative and the second derivative of the corresponding displacement equation is accomplished, the velocity and acceleration equations of the five-bar mechanism can be obtained respectively.

4. Parameter design of five-bar mechanism

According to the above formulas and the existing parameters, combined with the agronomic conditions of vegetable planting, the design objectives of the planting mechanism are set as follows:

(1) the efficiency of duckbill planting mechanism is 60-80 plants per minute.
(2) pot seedling spacing requirements is 200-350 mm;
(3) bowl seedling planting depth is 130-150 mm;
(4) the angle between bowl seedling and ridge is more than 80 degree.

Because it is difficult to complete the design of five-bar mechanism by traditional calculation method, the amount of calculation is too large and the efficiency is low[4]. If the parametric design of five-bar mechanism is completed by computer-aided method. Therefore, according to the established kinematics model, the parametric model of the five-bar planting mechanism is established using MATLAB software, so that the relevant parameters can be adjusted at any time to observe the movement law of the planting mechanism. Figures 3 and 4 show the relationship between the length of L2 and L5 and the end trajectory, respectively. Repeat this process to obtain a set of better parameters: l_1=300mm, l_2=100mm, l_3=175mm, l_4=215mm, l_5=50mm, l_6=265mm, l_7=280mm, l_8=170mm, l_9=45mm, θ_1=45°, θ_2=90°, θ_5=45°, θ_7=45°, θ_8=90°.

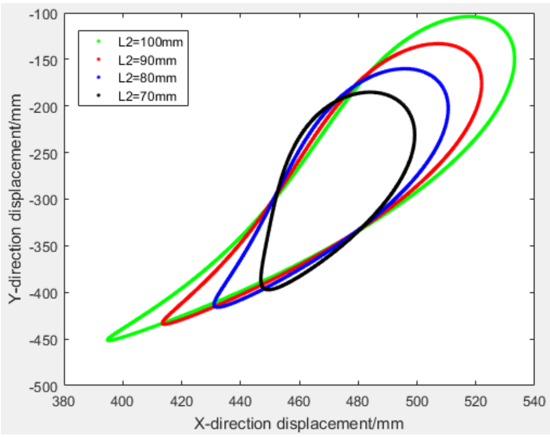

Figure 3. The relationship between L2 length and endpoint trajectory

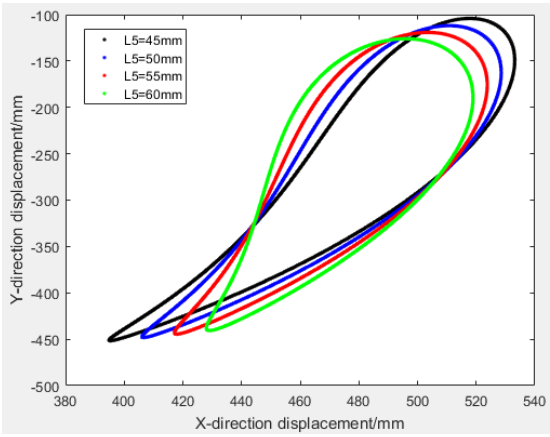

Figure 4. The relationship between L5 length and endpoint trajectory

5. Construction and simulation of virtual prototype for the transplanting mechanism

5.1 3D modeling

The parameters obtained by MATLAB software are modeled by SolidWorks software to form an assembly and check the interference, as shown in figure 5.

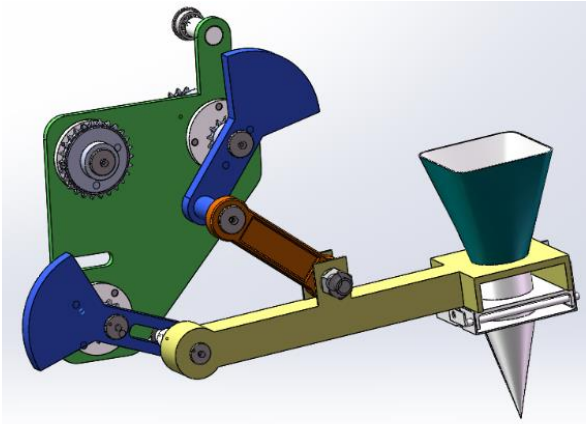

Figure 5 3D model of planter

5.2 Modeling of virtual prototype

ADAMS has powerful dynamic simulation function and can simulate the virtual mechanical system in real time [5], but its 3D modeling ability is relatively poor. With parameters designed using MATLAB Software, the virtual prototype model of planting mechanism is established by SolidWorks software, and the model is assembled and checked for interference. At the same time, simplification of components with less influence on mechanism motion is made and then it is imported into ADAMS software. Attention should be paid to the coordinate system of SolidWorks and ADAMS software when importing, so that the coordinate system is consistent and the trajectory coordinates of duckbill can be accurately collected.

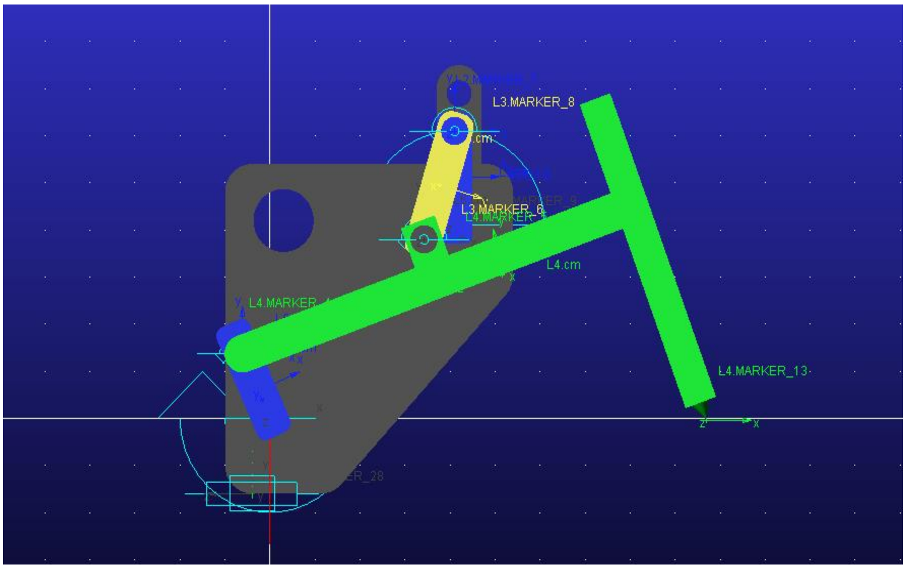

Figure 6 Planting mechanism model

A rotating pair is added to the hinge of the crank, a moving pair is added to the slider of the guide rod and a fixed pair is added to the fixed end of the connecting rod. As a result the whole virtual prototype model is completed as shown in figure 6.

5.3 ADAMS virtual simulation

According to the actual design requirements, adding driver to virtual prototype in ADAMS software, the end of the duckbill will be used as a measuring point for the trajectory of the duckbill planting mechanism. The simulation time is set to 10 seconds and the simulation steps are 500. As a result the trajectory curve of planting mechanism is shown in figure 7.

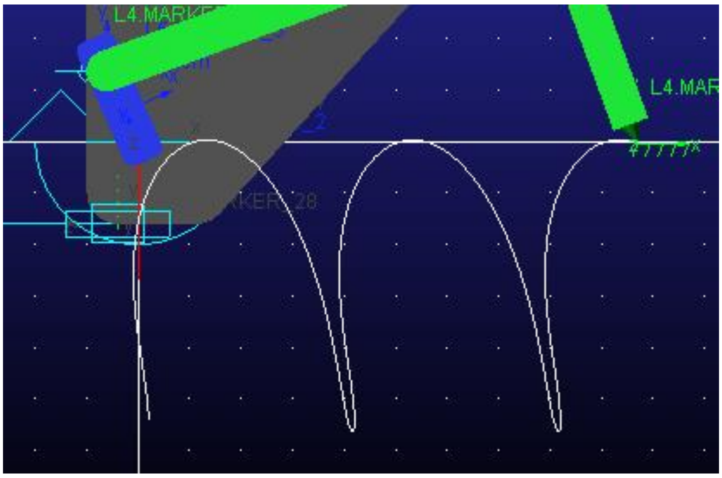

Figure 7 Trajectory of planting mechanism

Figure 7 shows the motion track of the duckbill tip. It can be seen from the graph that the trajectory of the tip of the duckbill is nearly perpendicular to the ground. The distance between the trajectory of entering soil and the trajectory of unearthing is small and the horizontal displacement is close to zero when planting, which improves the survival rate of potted seedlings and guarantees the quality of transplanting.

Based on the analysis of the simulation results above, the parameters can meet the requirements of the design objectives and the transplanting operation requirements.

6. Conclusion

A five-bar planting mechanism consisting of a fixed plate, a driving sprocket, a five-bar mechanism and a duckbill is described in this paper. The structure and working principle of the mechanism are introduced. The parameters of the mechanism are selected through mathematical modeling and MATLAB simulation. A virtual prototype of the five-bar planting mechanism is established by SolidWorks software. After simplification, the kinematics is simulated by ADAMS software. The results show that the parameters are reasonable.

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