The optimization design and test of camfull-row-pick-up seeding mechanism

Li Liangliang¹,a, Niu Wenjing¹,a, Qi Zhengdong¹,*, Chen Jie¹,a, Lian Guodang²,a, Tang Haiyang³,b

¹Department of Mechanical and Electrical Engineering, Xinjiang Institute of Technology, Aksu, Xinjiang China
²Xinjiang Production and Construction Corps Key Laboratory of Modern Agricultural Machinery, Shihezi, 832003, China
³School of Mechanical Engineering, Chongqing University, Chongqing, China

aemail: 2019035@xjit.edu.cn, lll0721vip@163.com; bemail: lgd929@126.com

Abstract. The mechanism components and working principle were analysed, and then cam mechanism was simplified into slider-crank mechanism to facilitate the establishment of kinematic model. The target optimization function for structural parameters was solved out via mathematical model combined with the transplanting requirements, then a computer-aided analysis program based on Visual Basic 6.0 was developed for optimizing structural parameters of the mechanism. According to the optimized structural parameters, the three-dimensional model of mechanism was established and the automatic seedling pick-up test-bed was carried out. The analysis of kinematic simulation and the test of prototype test were carried out. The success rate of picking up seedlings reaches 95% and efficiency of taking seedling is 3600 strains per hour. The cam full-row-pick-up seeding mechanism is feasible and effective to achieve the operation requirements of whole-row-pick-up seedling.

1. Introduction
The specific aim of this article is to present a cam full-row-pick-up mechanism. The seedling tray is placed in horizontal orientation and multiple pick-up claws were controlled by cam rotating to finish taking full-row seedling and planting multi-line with auxiliary mechanism of separating and planting seedling. The theory analysis and mathematical model were put forward, and optimum parameter combination were derived through computer aided analysis program based on Visual Basic 6.0 which takes into account the requirement of agronomic. In addition, the simulation study and bench test were carried out. The final section summarizes the most important findings of the study.

2. Materials and methods
2.1. The composition and working principle of pick-up seedling mechanism
The working process of pick-up mechanism is as follows: The initial position is that seedling tray is placed in horizontal direction, the longer axis of drive cam of spring clip is in horizontal direction and has θ angles with the longer axis of the drive cam of seedling needle, the line got by the center point of
big disc and small disc is in horizontal direction, and the pick-up claws are at working position at the top of tray. When seedlings transmitted to working position by supplying stock seedling device, IImotor starts to work, the drive cam of spring clip rotates $\alpha$ angles driven by the upper screw, and wedge sideway spring clip and bilateral wedge sideway close certain angle to clamping seedling angle; the drive cam of seedling needle rotate $\alpha$ angles and pushes ejector pins overcome the ejector pins reset spring force, then seedling needles are inserted into substrate pushed by ejector pins; IImotor stops working and I motor rotates 180°, pick-up claws are raised to a certain height away from seedling tray and then arrive at dropping seedling position; IImotor reverses $\alpha$ degrees and I motor stops working, the drive cam of spring clip reverses $\alpha$ degrees driven by upper screw and drives wedge sideway spring clip and bilateral wedge sideway to open certain angle to dropping seedling angle; The drive cam of seedling needle also reverses $\alpha$ degrees and ejector pins rebound under the force of ejector pins reset spring, realizing dropping seedling; I motor reverses 180° and returns to the initial position.

2.2. Model building of seedling pick-up mechanism

In practice, the drive cam of spring clip and the drive cam of seedling needle is so difficult to express intuitively. So the corresponding mechanism was simplified to slider-crank mechanism[1-2]. The coordinate system was established that horizontal direction is X axis, vertical direction is Y axis, and the center of drive cam of spring clip is coordinate origin O. The schematic diagram of pick-up claw simplified is given in Figure 3. At the assumption of each part is rigid structure without elastic deformation, the kinematics model of pick-up claw was analyzed without considering the kinematic pair error.
Figure 3 Schematic diagram of pick-up claw simplified

B point is as follows:

\[
\begin{align*}
    x_B &= x_A + L_{AB} \cos \alpha_2 \\
    y_B &= y_A + L_{AB} \sin \alpha_2
\end{align*}
\] (1)

B point pushes C point moving along Y axis and rotating around D point with semidiameter R, so the displacement of C point is equal to B point in Y axis. Displacement equation for C point:

\[
\begin{align*}
    (x_C - x_D)^2 + (y_C - y_D)^2 &= R^2 \\
    x_C &= \sqrt{R^2 - (y_C - y_D)^2} + x_D \\
    y_C &= y_B \\
    \alpha_3 &= \theta + \beta \\
    \tan \theta &= (y_C - y_D)/(x_C - x_D)
\end{align*}
\] (2)

The displacement of E point must be obtained before solving the displacement of F point. Displacement equation for E point:

\[
\begin{align*}
    x_E &= x_D + L_{DE} \cos(\alpha_3) \\
    y_E &= y_D + L_{DE} \sin(\alpha_3)
\end{align*}
\] (3)

The equation (6) is solved based on the geometric relationships. And displacement equation for F point:

\[
\begin{align*}
    \alpha_4 &= \pi - (2\pi - \alpha_3) + \gamma = \gamma + \alpha_3 - \pi \\
    x_F &= x_E + L_{EF} \cos(\alpha_4) \\
    y_F &= y_E + L_{EF} \sin(\alpha_4)
\end{align*}
\] (4)

Displacement equation for H point, I point, J point can be solved similarly:

\[
\begin{align*}
    x_H &= x_G + L_{GH} \cos \varphi_1 \\
    y_H &= y_G + L_{GH} \sin \varphi_1 \\
    x_I &= x_H + L_{HI} \cos \varphi_2 \\
    y_I &= y_H + L_{HI} \sin \varphi_2 \\
    x_J &= x_I + L_{IJ} \\
    y_J &= y_I
\end{align*}
\] (5)

When pick-up claw works, \( L_{FE} \) and \( L_{XJ} \) is always keep parallel, \( \varphi_3 = \alpha_4 \), so placement equation for K point:
Where, OA represents long radius of cam that drives seedling needle, α2 represents the angle of drive cam rotating, L_{OA}, L_{AB}, L_{DE}, L_{EF}, L_{GH}, L_{JI}, L_{JK} represents bar length respectively, mm; α1, α2, α3 represents the angle between crank OA, CD, EF and X axis.

2.3. The development of optimization software and the optimization of structural parameters based on the VB 6.0

2.3.1. Establishment of the optimization objective

The angle of clamping seedling: The angle of clamping seedling is the angle between seedling needle and Y axis when picking up seedling. It can be modified by α2 that the drive cam of spring clip rotating, as shown in Figure 4. When α2=90°, the angle of clamping seedling gets the maximum value. Considering the force analysis of seedling needle contacting with substrate, the larger the clamping force and the higher the success rate with the decrease of clamping seedling angle[3-4]. When taking seedlings, setting the angle Y1<15°, α2=90°and two point (x_J, min y_J), (x_K, min y_J), can be founded based on the displacement equation of J point and F point.

The objective function:

\[ Y_1 = 90 - \arctan \left( \frac{\min y_J - \min y_K}{x_J - x_K} \right) \]  (13)

Depth of clamping seedling: The depth of clamping seedling is the depth seedling needle inserted into substrate. Set the depth of clamping seeding Y_2>15 mm (Seedling tray depth: 40 mm). When the crank rotates once, loop operations and judges \( y_k \) using the software. The objective function:

\[ Y_2 = \min y_k - L_H \]  (14)

Where, L_H is he distance between the top of substrate and O point.

Spacing of seedling needles inserted into the substrate:Seedling root fibril is concentrated in the center of the substrate, so the integral substrate should be took out as soon as possible that better growth environment for seedling can be gained. Set the ideal interval of space 25>Y_3>15 mm(Tray size: 28 mm×28 mm). (x_K, min y_J) was found and calculated using Equation (11). The objective function was determined according to Equation (13):

\[ Y_3 = (\min y_K - L_H) \arctan \left( \frac{\min y_K - \min y_J}{x_K - x_J} + x_K \right) \]  (15)

Spacing of wedge sideway spring clip and seedling crown: The spacing of wedge sideway spring clip and seedling crown Y_4 decides the situation of dropping seedling. If the space is too small, leafs will be locked by wedge sideway spring clip, affecting dropping posture and planting upright degree. According to Equation (1) and Equation (7), parameters were adjusted to change y_B and then find F (max x_F, max y_F) in one motion cycle. The open distance of spring clip is twice as max x_F because of the spring clip is symmetric structure. Set 10>Y_5>0 mm, Y_4 was determined according to Equation(16):

\[ Y_4 = 2 \max x_F - D_{miao} \]  (16)

Where, D_{miao} is diameter of seedling crown.

Interference problem between seedling needle and wedge sideway spring clip: In the process of picking up seedlings and dropping seedlings, the long radius of drive cam of seedling needle must have no interference with wedge sideway spring clip. Set Y_5>0. The linear equation about D、E point can be conducted by Equation (5) :
Regard the distance equation between J point and liner equation as Y5:

\[
\frac{y_E - y_D}{x_E - x_D} x - y + \frac{y_E - y_D}{x_E - x_D} x_E - x_D = 0
\]  

(17)

2.3.2. Computer aided analysis and optimization

2.3.2.1 The compilation of optimization software

Physical parameters of seedling and substrate, the length of \( L_{OA}, L_{AB}, L_{CD}, L_{DE}, L_{EF}, L_{GH}, L_{HI}, L_{IJ}, L_{JK} \); coordinates of R, D, G; the distance between F and O in Y axis; \( \beta, \alpha \). The output parameters are as follows: the crank angle of spring clip, the crank angle of drive cam of seedling needle, the distance between spring clip and seedling needle in X axis, the angle and depth of clamping seedling, and space of seedling needle inserted into the substrate, dynamic coordinates of contact point of seedling needle and wedge sideways spring clip. The software interface of picking up and dropping seedling are shown in figure 4.

![Software Interface of Optimization Software](image)

Figure 4 The software interface of optimization software

Specific results are as follows:

1. \( L_{OA}=8 \, \text{mm}, \, L_{AB}=23 \, \text{mm}, \, R=40 \, \text{mm} \), the coordinate of D is \((37, -15)\), \( L_{CD}=30 \, \text{mm}, \, \beta=280^\circ, \, L_{DE}=23.7 \, \text{mm}, \, L_{EF}=60 \, \text{mm}, \, \gamma=138^\circ, \) the coordinate of G is \((46, 0)\), \( L_{GH}=8 \, \text{mm}, \, L_{HI}=12 \, \text{mm}, \, L_{IJ}=20 \, \text{mm} \). The long radius of drive cam of spring clip is 31 mm, and the long radius of drive cam of pick-up claw is 20 mm calculated by the length of \( L_{GH} \) and \( L_{HI} \);

2. Angle of seedling needle inserted into the substrate \( Y_1 \) is 13.5\(^\circ\);

3. Depth of seedling needle inserted into the substrate \( Y_2 \) is 30 mm;

4. Spacing of seedling needle inserted into the substrate \( Y_3 \) is 20.57 mm;

5. Spacing of wedge sideways spring clip and seedling crown \( Y_4 \) is 18.06 mm (\( D_{miao} \) is 40 mm);

6. The distance between J point and liner equation about D, E point \( Y_5=5.92 \, \text{mm}>0 \), there is no interference between seedling needle and wedge sideways spring clip.

2.3.2.2 Simulation analysis and taking seedling test

Kinematics simulation analysis: According to mechanism parameters optimized, kinematics equations above mentioned were programmed and then numerical integration was carried out using Matlab[5-6]. The deformation trace of F in plane XOY is shown in Figure 6. When \( \alpha_1=\pi/2 \) and \( \alpha_2=3\pi/2 \), \( \tan \alpha_2=\infty \)
that mathematical model jumps. The spline curve was used to fit the trace, as shown the dotted line in Figure 5.

Three-dimensional model and assembly model for pick-up claw were built by NX. The assembly model was imported into computer simulation analysis software Adams, and then motion was simulated. The trajectory of endpoint F in XOX plane as shown in Figure 6.

Providing a contrast between three-dimensional model and the mathematical model, the trajectories of F in Y axis have same change trend that can verify the theoretical design reliability. Analysis on velocity and acceleration of endpoint F by motion simulation draws conclusion that pick-up claw moves smoothly with velocity and acceleration floating in a smaller range as shown in Figure 7.

2.4. Institutional test verification

Figure 8 Bench test
2.4.1. Bench test for picking up seedlings

The test object and index: The test object is plug seedling of chili, which of its physical characteristic are: the age 40 days, the average height 150 mm, and the maximum diameter of crown 40 mm. The seedlings were raised in plastic tray, which of its specification are: the distribution of sinus 8×16 and in inverted-rectangle-terrace-shaped, the upper size of sinus 28×28 mm while lower size 15×15 mm, the depth of sinus 40 mm. The substrate contains peat and vermiculite 1:1 in volume, the moisture content 60% approximately.

The test index is the success rate of picking up seedling. The number of seedlings that successful gripping and accurate dropping to the corresponding sinus is N, while the number of seedlings which are transported to the pick-up seedling position by feeding-seedling device is n. So the definition of success rate of picking up seedling is:

\[
rc = \frac{N}{n} \times 100\% 
\]  

Where, \( rc \) is the success rate of picking up seedling.

2.4.2. Test methods and factors

The speed for I motor is 30 r/min while II motor is 20 r/min, the center distance between big disc and small disc is 100 mm according to the height of seedlings, the displacement of horizontal feed mechanism is 28 mm and its speed is 30 mm/s. There are four pick-up claws on seedling pick-up mechanism so that full-row seedlings can be planted while horizontal feed mechanism moves once. Through adjusting the angle \( \alpha \) that the drive cam of spring clip and the initial installation angle \( \theta \) between the drive cam of seedling needle and drive cam of spring clip, the compatibility of seedling pick-up mechanism was tested and the rationality of the timing sequence distribution was verified.

Three trays plug seedlings were taken randomly as test set to evaluate the effect of cam full-row-pick-up seedling mechanism. The angle \( \alpha \) that the drive cam of spring clip rotates determines the angle of clamping seedling, and the initial installation angle \( \theta \) between the drive cam of seedling needle and drive cam of spring clip determines the depth of clamping seedling. The effect of different structural parameters for taking seedling was studied by two factors and three levels of orthorhombic method[7].

The bench test is shown in figure 8. Analyzing and discussing the test target, the optimum mechanism parameters were determined. The factors and levels are shown in Table 1.

| Level | Experiment factor |
|-------|-------------------|
| 1     | 7° 20 mm          |
| 2     | 10° 25 mm         |
| 3     | 13° 30 mm         |

2.4.3. The results of test

The results are as follows: when \( \alpha=80^\circ \) and \( \theta=85^\circ \), the angle of clamping seedling is 10° and the depth of clamping seedling is 25 mm, the effect of taking seedling is best. The seedling pick-up mechanism meets the transplanting requirements and the success rate of picking up seedling reaches 95%. The transplanting mechanism is compatible and the timing sequence distribution is rational. Efficiency of taking seedling is 3600 strains per hour and can achieve the operation requirements of whole-row-pick-up seedling.

3. Conclusions

Cam full-row-pick-up seedling mechanism was proposed, and its working principle and characteristics were analyzed, then the mechanism kinematics model was established. The characteristics and formation principle of picking up seedling trajectory were analyzed. A computer-aided analysis program based on Visual Basic 6.0 was developed for optimizing structural parameters of the pick-up claw. By means of human-computer interaction analysis method, the structural parameters were
analyzed and then optimized to satisfy the requirements of picking up seedling. According to the
optimized structural parameters, the three-dimensional model of mechanism was established and the
automatic seedling pick-up test-bed was developed. Based on Matlab and Adams, the comparison
study of numerical trajectory and simulation trajectory was made to verify the reliability of theoretical
design. Taking the chili seedlings as object, the bench test was carried out to determine the optimum
structural parameters and evaluate the effect of cam full-row-pick-up seedling mechanism. when α=80°
and θ=85°, the angle of clamping seedling is 10° and the depth of clamping seedling is 25 mm, the
effect of taking seedling is best. Efficiency of taking seedling is 3600 strains per hour and can achieve
the operation requirements of whole-row-pick-up seedling.

Acknowledgments
This article is one of the phased achievements of the Xinjiang Institute of Technology project
(XLY1910) and the Xinjiang Uygur Autonomous Region University Scientific Research Project
(XJEDU2020Y048), And this article is funded by the Open Project of the Key Laboratory of the
Modern Agricultural Machinery Corps(BTNJ2019002)

References
[1] Han,C.Y., W. zhang., and X.J.Zhang. Design and test of automatic feed system for tray seedlings
transplanter[J].Transactions of the Chinese Society of Agricultural Engineering
(Transactions of the CSAE),2013,29(8):51-61.(in Chinese with English abstract)
[2] Konosuke,T. Development of fully automatic vegetable transplate[J].Japan Agricultural Research
Quarterly,2000,34(1):More references
[3] Xiao,M.T.,S.L. Sun.,H.F. Luo. Kinematic analysis and experiment of dual parallelogram multi-
pole planting mechanism[J].Transactions of the Chinese Society of Agricultural
Engineering(Transactions of the CSAE),2014,30(17):25-33.(in Chinese with English abstract)
[4] Zuo,Y.J.,P.Cao.,Y.Zhao. Design and optimization of transplanting mechanism with B-spline non-
circular planet gear train for rice pot seedling[J]Transactions of the Chinese Society of
Agricultural Engineering(Transactions of the CSAE),2014,30(15):10-17.(in Chinese with
English abstract)
[5] Wu,C.Y.,Y.Zhao., J.N.Chen. Optimization design of transplanting mechanism of rice transplanter
based on visualization human-computer interaction[J].Transactions of the Chinese Society of
Agricultural Engineering(Transactions of the CSAE),2008,39(1):46-49.(in Chinese with
English abstract)
[6] Tong,J.H.,H.Y.Jiang,. Z.H. Jiang. Experiment on parameter optimization of gripper needles
clamping seedling plug for automatic transplanter[J]Transactions of the Chinese Society of
Agricultural Engineering(Transactions of the CSAE),2014,30(16):8-16.(in Chinese with
English abstract)
[7] Han,L.H., H.P. Mao.,J.P. Hu. Experiment on mechanical property of seedling pot for automatic
transplanter[J].Transactions of the Chinese Society of Agricultural Engineering
(Transactions of the CSAE),2013,29(2):20-29.(in Chinese with English abstract)