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ACCURATE SYNTHESIS OF SEEDLING SEPARATING-PLANTING MECHANISM OF RICE TRANSPLANTER

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ABSTRACT

In order to improve the adaptability of rice transplanter to seedlings with different length when transplanting multicropping rice in south China, the seedling separating planting mechanism is resynthesized in the paper. According to the agronomy requirements of seedlings' transplanting, the optimum motional path of the tip point of planting needle is obtained. By applying the established kinematic model of the separating planting mechanism, the relevant software is compiled. On the basis of the features of the problem, the constrained optimization method is utilized to solve the problem with 24 restrictions. Thus, the optimum structure parameters are obtained to satisfy the path points accurately.

Key words: rice transplanter, separating planting mechanism,accurate point synthesis, restrained optimization

INTRODUCTION

Domestic product 2ZT-7358 type rice transplanter (i.e. 7358 Type) has been used universally in China. It performs high planting quality when seedling height is within 10 to 20 cm. In the southern China, however, the hybrid rice of double cropping has been widely accepted. But as the seedling of late rice may be 30cm high, the 7358 Type cannot operate properly. Hence, to enlarge the adaptation range of the seedling's height is the crux of multicropping rice transplanter's design. Based on the 7358 Type, the multicropping rice transplanter enlarges motion path range of the planting finger and optimizes the oscilating crank linkage design to satisfy the operation requirements of double-cropping rice planting with the seedling height 10 to 30 cm. The accurate synthesis of separating-planting mechanism is the key technique to the design of multicropping rice transplanter.[1]

SYNTHESIS APPROACH OF SEEDLING SEPARATING-PLANTING MECHANISM

The separating-planting mechanism should generate the assigned paths. Hence, the relative motion paths of planting finger, which is applied to plant the seedlings of 10 to 30 cm high, should be determined first.

Method of Solution

This is a mechanism synthesis problem of path generation. Being a real mechanism, there are some structural parameter constraints. Optimization techniques are adopted to seek for the optimal solution inside its feasible region. Because no special demand is presented for the objective function's characteristics of the problem, and the optimization method, the Constrained Random Ray Approach (CRR), possesses the traits of structure distinctness and convenience, the CRR method is employed. Provided the appropriate initial design is determined, the iterative frequency can be reduced evidently. It has been an effective approach for the small-sized problem of mechanical design although the optimal solution obtained is merely a partial optimal solution. The present mechanism has been analysed and a satisfied initial design is recommended.

The CRR method is a direct solution method. It belongs to the constraint random approach as Random Gradient method and Gauss-Seidel method, etc..[2] Such a method includes the steps of initial design selection, random iteration direction search and random step selection.

Model Building

The objective function of the model is devised to minimize the locus error. As shown in Fig. 1, the trajectory $y=f(x)$ generated by the mechanism should approach optimally along the given path $Y=F(X)$.

The desired path has been expressed by the point array $M(i)(x_M(i), y_M(i))$, $i=1,2,\ldots k$. The calculation equations are given by:

$$x_M(i) = x_A + a\cos(\varphi_1 + \beta) + e\cos(\theta + \delta_i) \quad (1)$$

$$y_M(i) = y_A + a\sin(\varphi_1 + \beta) + e\sin(\theta + \delta_i) \quad (2)$$

where:

$$\delta_i = \lambda_i - (\beta_i - \beta) = \beta + \lambda_i - \beta_i \quad (3)$$

$$\lambda_i = \arccos\frac{a^2 + b^2 - c^2 + d^2 - 2ad\cos\varphi_i}{2b\sqrt{a^2 + d^2 - 2ad\cos\varphi_i}} \quad (4)$$

$$\beta_i = \arctan\frac{a\sin\varphi_i}{d - a\cos\varphi_i} \quad (5)$$

The quantities appearing in the above equations are defined in Fig. 1.

The locus errors are expressed by the coordinate errors of the connecting rod point $M^{(i)}$ and the desired path $M_0^{(i)}$, i.e.,

$$\triangle x(i) = x_M(i) - x_{Mo}(i) \quad (6)$$

$$\triangle y(i) = y_M(i) - y_{Mo}(i) \quad (7)$$

To merely minimize the locus error, the following form of the objective function is devised:

$$f(X) = \sum_{i=1}^{k} W_i\{[x_M(i) - x_{Mo}(i)]^2 + [y_M(i) - y_{Mo}(i)]^2\} \quad (8)$$

where W_i is the weight factor.

CAD SYNTHESIS OF SEPARATING–PLANTING MECHANISM

Accurate Synthesis of Medium Path

Establishment of Synthesis Model When the finished cost, fully utilization of the existing moulds and fittings, and the decrease of the re–process amount are taken into account, the original 7358 Type planting arm's structure and dimensions are remained unchanged. In order to make the structure compact and meet the manufacture demands, the length of the crank is limited to be in the range of 40 to 42 mm.

a. Design variable values:

Known: $x_A=0$, $y_A=0$, $b=90$ mm, $\theta=161.5°$, $e=200$ mm;

Unknown: a, c, d, β, φ_1, ⋯, φ_6, i.e., the design variable vector

$X=[x_1, x_2, \cdots, x_{10}]^T=[a, c, d, \beta, \varphi_1, \varphi_1, \varphi_2, \cdots, \varphi_6]^T$.

b. Objective function ($W_i=1$):

$$f(X)=\sum_{i=1}^{6}\{[x_M(1)\cos x_{4+i}+x_3\cos(\theta+\delta_i)-x_{Mo}(i)]^2+[x_M(1)\sin x_{4+i}+x_3\sin(\theta+\delta_i)-y_{Mo}(i)]^2\} \quad (9)$$

where:

$$\delta_i=x_4+\arccos\frac{x_1^2+b^2-x_2^2+x_3^2-2x_1x_3\cos x_{4+i}}{2b\sqrt{x_1^2+x_3^2-2x_1x_3\cos x_{4+i}}}-\arctan\frac{x_1\sin x_{4+i}}{x_3-x_1\cos x_{4+i}},$$

$$i=1,2,\cdots,6 \quad (9)$$

c. Constraints:[3]

existance of crank:

$$g_1(X)=x_2+x_3-x_1-b\geqslant 0 \quad (11)$$

$$g_2(X)=x_3+b-x_2-x_1\geqslant 0 \quad (12)$$

$$g_1(X)=b+x_2-x_3-x_1\geqslant 0 \quad (13)$$

continuous rotation:

$$g_{3+i}(X)=x_{5+i}-x_{4+i}\geqslant 0 \quad (i=1,2,\cdots,5) \quad (14)$$

length range of crank:

$$g_9(X)=42-x_1\geqslant 0 \quad (15)$$

$$g_{10}(X)=x_1-40\geqslant 0 \quad (16)$$

rotation angle range:

$$g_{7+i}(X)=360-x_i\geqslant 0 \quad (i=4,5,\cdots,10) \quad (17)$$

$$g_{14+i}(X)=x_i\geqslant 0 \quad (i=4,5,\cdots,10) \quad (18)$$

d. Optimization approach:

Because totally 24 constraints are imposed by the required conditions of linkage closure and mobility or dictated by constructive feasibility, the Constrained Random Ray method is adopted.

Realization of Software Values of initial step h_0 of 0.5, convergence criterium ε of 0.005 and maximum number M of permissible random search directions of each iterative point of 80, are assumed in the calculations.

According to the initial analysis of the mechanism,[1] the variable design values for the initial design are:

$$X^{(0)} = [42,\ 90,\ 115.8,\ 317.5,\ 87.8,\ 132.9,\ 154.9,\ 173.6,\ 283,\ 330]^T \tag{19}$$

Two flow charts of the programs are given in Fig. 2 and Fig. 3.

Synthesis Solution The program "CRR" is written in FORTRAN language. The relevant execute file is produced through debugging, linking and compiling. From the initial design to the final optimum, the total number of iteration N is 2364. The desired path has been generated by a mechanism with the following set of variable design values:

$AB = a = 41.998$ mm, $CD = c = 89.507$ mm, $AD = d = 115.543$ mm,

$$\varphi_1 \sim \varphi_6 = 87.392°, 132.481°, 153.784°, 175.282°, 282.034°, 330.090°. \tag{20}$$

The square sum F of errors between the synthesis trajectory and the desired path is 3.02×10^{-3} mm^2 which meets the accurate synthesis requirements.

Determination of Mechanism Parameters for Up and Down Path

By the accurate synthesis of the medium path, we obtain the planting mechanism's position and size. The other two desired paths will be generated through the position adjustment of point D on the rocker link CD.

In order to meet the demands to the full of seedlings with different heights by the generated trajectory, the accurate generation of the top and bottom points (M_1 and M_5 in Fig. 1) of the desired paths is identified as an synthesis principle.

The reverse ratiocination method is adopted as synthesis approach. Starting from points M_1 and M_5, we use a method of knowing two points and two opposite sides in a triangle to seek the third two points and two opposite sides in a triangle to seek the third one. Determining step by step, we have C_1 and C_5 corresponding to M_1 and M_5. From C_1 and C_5 and the length of two opposite sides $C = 89.50$ mm, point D is fixed. For this reason, the subprogram "SOLT", which seeks the third point C's coordinate (C_x, C_y) in a triangle ABC when the other two points $A(A_x, A_y)$, $B(B_x, B_y)$ and two opposite sides a and b are known, has been compiled.

The calculation formulae are given by:

$$C_y = \frac{2(A_y - E\ D) \pm \sqrt{4(E\ D - A_y)^2 - 4(E^2 + 1)(D^2 + A_y^2 - b^2)}}{2(E^2 + 1)} \tag{21}$$

$$C_x = \frac{b^2 - a^2 + B_x^2 + B_y^2 - (A_x^2 + A_y^2) + 2(A_y - B_y)C_y}{2(B_x - A_x)} \tag{22}$$

where:

$$E=\frac{A_y-B_y}{A_x-B_x} \tag{23}$$

$$D=\frac{b^2-a^2+B_x^2+B_y^2-2A_xB_x+A_x^2-A_y^2}{2(B_x-A_x)} \tag{24}$$

The "±" sign in the expression (21) indicates the different point order of triangle ABC.

The calculation process is shown in Fig. 4. The program is written in Turbo C 2.0 language. The results are:

D_1(70.791, 74.480) for up path and D_2(100.365, 80.235) for down path.

CONCLUSIONS

By applying numerical method and optimization theory, the accurate synthesis of separating–planting mechanism is conducted with the aid of computer. Thus, the design precision is greatly improved. The design period is also shortened.

The verification of the synthesis results indicates that the mechanism is compact and meets the demand of its transmission angle over 40°. The synthesis solution also establishes the foundation for further study of the project.

The developed software and its synthesis method given here by authors aremeaningful for similar mechanisms.

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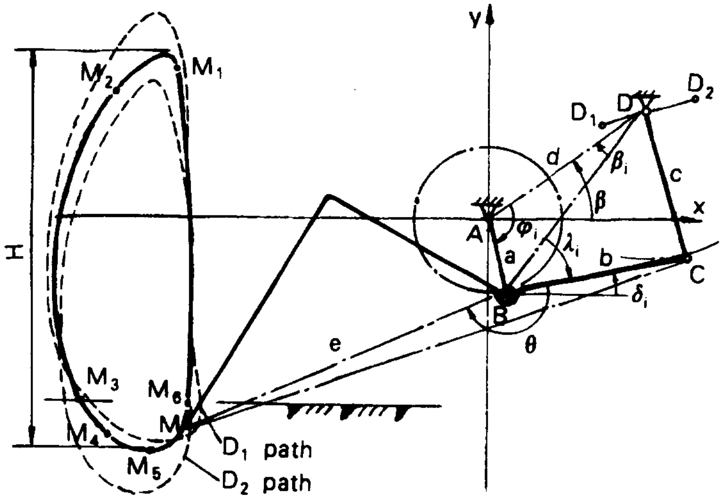

Fig. 1 The motional path and parameters of planting mechanism

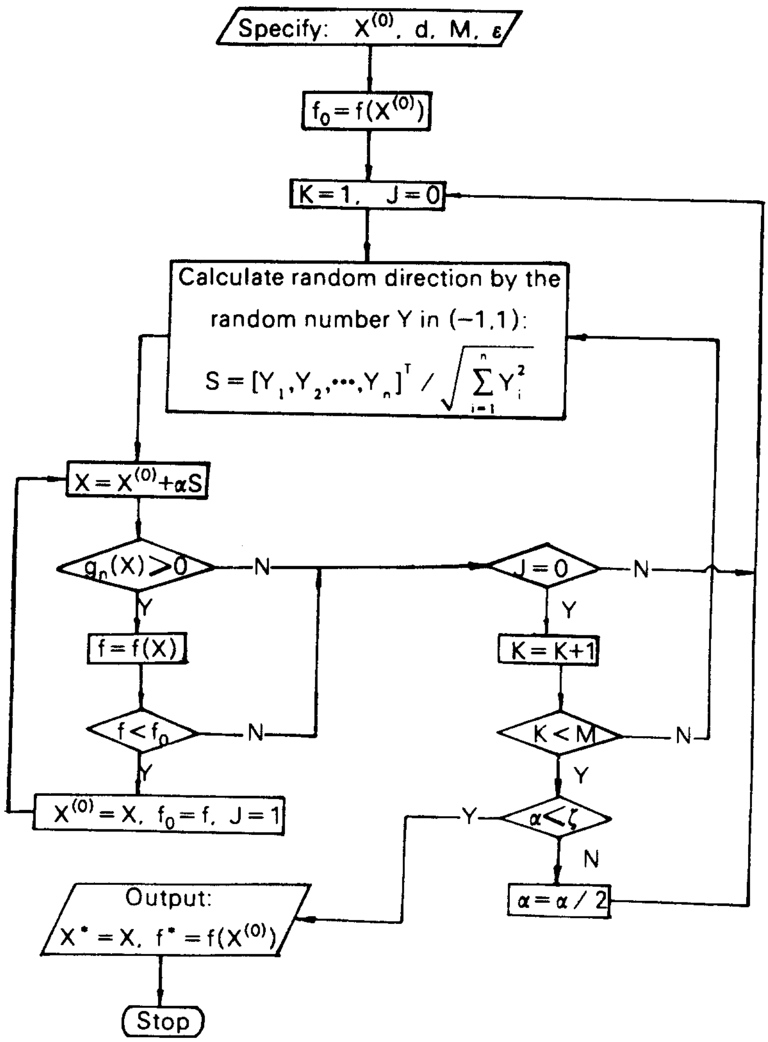

Fig. 3 Flowchart for program "CRR"

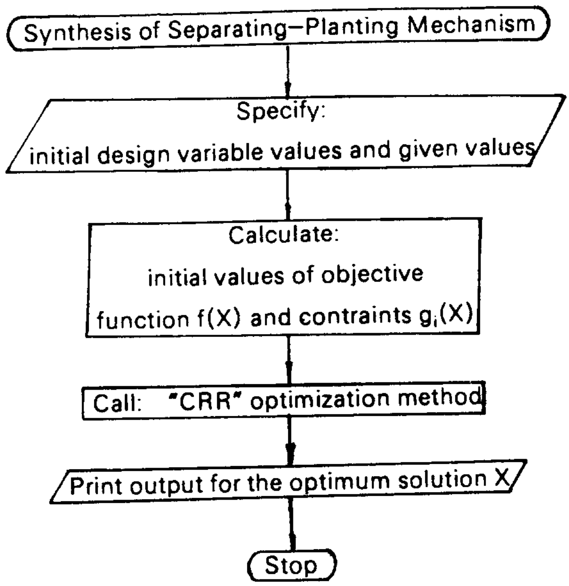

Fig. 2 Flowchart of main program

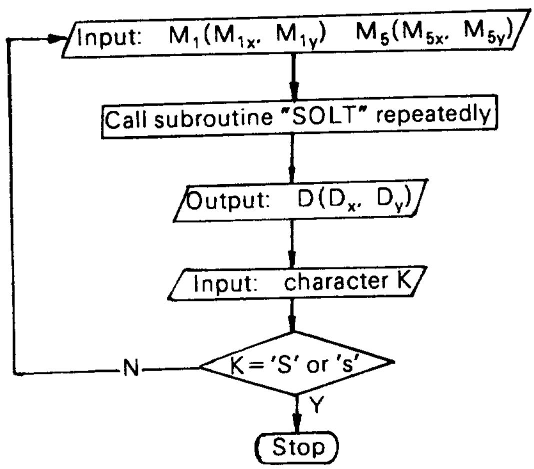

Fig. 4 Flowchart of synthesis program for up and down paths