ANALYSIS OF ELECTRIC CONTROL SYSTEM OF RICE TRANSPLANTER UNDER WSN (WIRELESS SENSOR NETWORK)

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WSN (WIRELESS SENSOR NETWORK)主导下的水稻插秧机电控系统分析

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ABSTRACT

In rice planting technology, the planting depth of seedlings has high requirements for transplanters, which directly determines the survival rate and tillering effect of seedlings. Aiming at the problems of low automation degree and low working efficiency of rice transplanter, the rice transplanter is designed under WSN (Wireless Sensor Network) technology, and its electric control system is optimized and analysed. In this paper, in order to optimize the overall working performance of the electronic control mechanism system of adjustable width and narrow row high-speed rice transplanter, the discipline analysis of the electronic control mechanism system is carried out based on WSN (Wireless Sensor Network) technology. Combined with the working characteristics of electronic control mechanism and the influence index of design parameters, the multidisciplinary design optimization framework of electronic control mechanism is established, and the optimization objectives, design variables and constraints at system level and discipline level are determined, and the multidisciplinary design optimization mathematical model of electronic control mechanism is constructed. Finally, the optimization results are analysed. The results show that the optimized design variable value can significantly improve the overall working performance of the adjusting mechanism of the electronic control system.

摘要

在水稻种植技术中，秧苗的栽插深度对插秧机有很高的要求，直接决定着秧苗的成活率及分蘖效果。 针对水稻插秧机自动化程度不高、工作效率较低的问题，在 WSN 技术下对水稻插秧机进行了设计，并对其电控系统进行优化并分析。本文以优化可调宽窄行高速水稻插秧机电控调节机构系统整体工作性能最优为目的。基于WSN(Wireless Sensor Network) 技术对电控调节机构系统进行了学科分析，结合电控调节机构的工作特性和设计参数的影响指数，建立电控调节机构的多学科设计优化框架，确定了系统级和学科级的优化目标、设计变量和约束条件，构建出电控调节机构多学科设计优化数学模型。 最后对优化结果进行了分析，结果表明，优化所得的设计变量值使得电控系统调节机构的整体工作性能显著提高。

INTRODUCTION

China has a vast territory and the largest rice planting area in the world, with an area of about 27 million hectares. The rice planting area in China has a very large span, and there are many types and varieties of rice. The development type of rice transplanting technology determines the development mode of rice transplanting mechanization *(Chaitanya D.N.V. et al., 2018; Feng X.T. et al., 2018)*. Wide-narrow row rice planting mode promoted in recent years is a direct embodiment of the idea of combining transplanting density. Wide-narrow row rice planting is a new planting mode put forward by agricultural researchers in China. Practical research shows that this planting mode can effectively improve the ventilation and light transmission characteristics and photosynthesis of rice, reduce the humidity between plants, effectively reduce the occurrence of rice diseases and insect pests, and is beneficial to the later field management, prevent lodging and increase the yield per unit area *(He J. et al., 2020).*

With the promotion and popularization of agricultural mechanization, the proportion of mechanized rice transplanting has been increasing, and the transplanter industry in China is also developing rapidly *(Jiangtao J. et al., 2020).* The front wheel positioning parameters of rice transplanter are important performance parameters of the steering system of rice transplanter.

Whether these parameters are designed reasonably or not is directly related to the steering performance of rice transplanter and the whole vehicle. For example, the reversibility of vehicles, the stability of straight running, the stability of braking and the portability of steering are mainly affected by the caster angle. However, there is still a big gap between China's agricultural mechanization level and Europe and America in rice planting, high efficiency work and intelligent control level *(Jin X. et al., 2018; Lee P.U. et al., 2018)*, so it is of great significance to develop intelligent rice transplanter for the development of China's agriculture. With the development of microelectronic system, system-on-chip and wireless communication technology, WSN (Wireless Sensor Network), which integrates sensing technology, microprocessor technology, embedded operating system, modern network, wireless communication technology and distributed information processing technology, has developed rapidly and significantly in recent years *(Li G. et al., 2018)*. Its development and application will bring far-reaching influence to all fields of human life and production. The research and application of WSN is an inevitable trend, and its appearance will bring great changes to human society, so it has been paid attention to by scientific research and commercial institutions in various countries. The electric control system is one of the key components to ensure the reliable and stable operation of rice transplanter. In order to make the rice transplanter work intelligently and efficiently, WSN technology was applied to the rice transplanter, and the electric control system was optimized and improved.

In the research of reference *(Li G. et al., 2020)*, the co-simulation optimization method is applied to the optimization design of the controlled rotating arm, and the mechanism system and the control system of the research object are simulated in parallel, and the design parameters of the two systems are optimized cooperatively. The parameter results obtained by the joint simulation optimization method can reduce the deformation energy of the rotating arm mechanism in the working process, and obviously improve the overall working stability of the system. Literature *(Peng H.H. and Shang Y.C., 2021)* puts forward a cooperative optimization method, which is different from the cooperative optimization algorithm in that there is no transmission of coupled design parameter data flow between each subsystem discipline, and it is a relatively completely independent space, and the constraints of subsystem discipline only assist the process of solving and optimizing this discipline. Literature *(Putri R.E. et al., 2020)* takes the manipulator as the research object, adds simulated stress and boundary conditions to its finite element model, and uses Shape Finder to optimize the structure of the research object. On the premise that the working strength of the manipulator system is taken as the constraint condition, the structural weight is reduced and the first-order natural frequency of the optimization target is effectively improved, and the working performance of the manipulator system is significantly improved. In the process of structural optimization design of the manipulator, this method is feasible and efficient.

Literature *(Samal P. et al., 2018)* studies the influence of front wheel alignment parameters on vehicle shimmy. The curves of camber angle and front wheel shimmy amplitude and the relationship between kingpin caster angle and front wheel shimmy amplitude are obtained through experiments. This experiment shows that kingpin caster angle and front wheel camber angle have great influence on front wheel shimmy. Literature *(Siddique A.A. et al., 2020)* designed the row spacing of wide row planting to be 297mm and that of narrow row planting to be 198 mm. Investigation after harvesting shows that: Compared with equal row spacing planting, the number of effective ears per hole increased by 0.96, the number of grains per ear increased by 10.7, the weight of 1000 grains increased by 0.5g, and the yield per mu increased by 50.06 kg and 9.1%. In reference *(Siddique M.A.A. et al., 2020),* planting with equal row spacing and planting with wide and narrow rows were carried out respectively (the width and narrow rows increased or decreased by 50mm respectively compared with the equal row mode). The results showed that the actual yield of wide and narrow row planting mode per hectare was 400 ~ 500 kg more than that of equal row spacing planting mode *(Sun X.Z., 2018)* Based on the riding type, the transplanting mechanism was improved, and the world's first wide and narrow row transplanter was born. The row spacing of the transplanter was 400mm and 200mm, and the field experiment was successful.

MATERIALS AND METHODS

WSN architecture

The system architecture of WSN is shown in Figure 1, which includes sensor nodes, coordinator nodes (also called aggregation nodes), monitoring stations and network protocols. The data monitored by sensor nodes are transmitted along other sensor nodes in multi-hops.

During the transmission, the monitoring data may be processed by multiple nodes, routed to the coordinator nodes in multi-hops, and finally sent to the monitoring station through the Internet or wireless network *(Ahn T.I. et al., 2020; Tong X.F., 2020).* Users configure and manage the sensor network, send monitoring tasks and receive monitoring data by giving operation instructions to nodes.

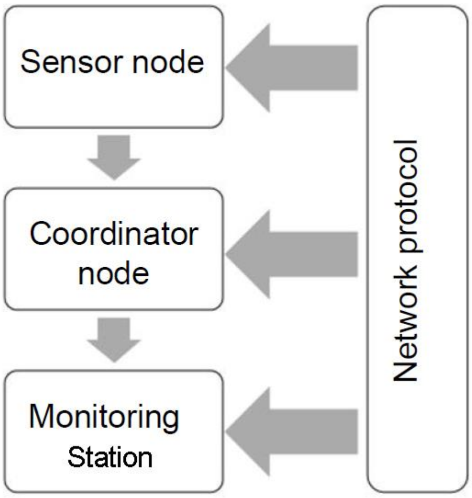

Fig. 1 - WSN system architecture diagram

Sensor network node is a miniaturized embedded system, which constitutes the basic support platform of WSN. The node part consists of four parts: sensor module, processor module, wireless communication module and power supply module *(Wang X.Z. and Li Y.D., 2018)*, as shown in Figure 2.

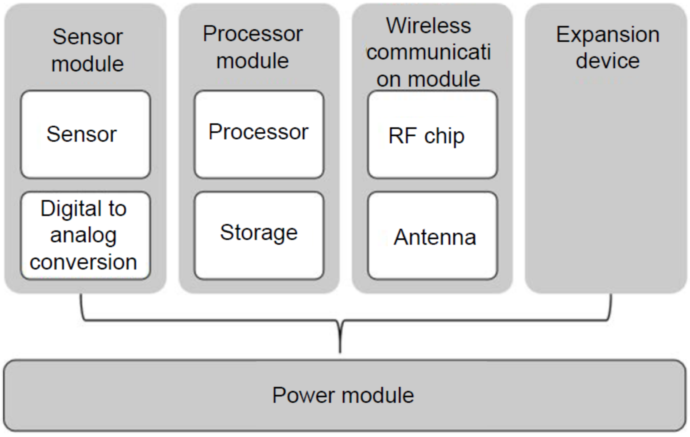

Fig. 2 - Composition of WSN nodes

They are responsible for their own work:

(1) The data acquisition module of sensor module is composed of sensor and A/D converter, which is responsible for collecting information in the monitoring area, converting data format, converting original analog signals into digital signals, and converting AC signals into DC signals for subsequent modules to use *(Wen C.J. et al., 2018; Wen F. and Fu K., 2019);*

(2) The processor module is divided into two parts, processor and memory, which are responsible for the control of processing nodes and data storage. The data processing and control module includes memory and microprocessor, which controls the operation of the whole sensor node, processes and stores the data collected by itself and the data sent by other nodes.

(3) The wireless communication module is composed of radio transceiver devices such as radio frequency chips and antennas, and is specially responsible for the mutual communication between nodes *(Xinchun Y. and Meihua, 2018).*

(4) The power supply module is used to provide energy for the sensor nodes, which is generally powered by miniature batteries.

Establishment of mathematical model for design optimization of electric control adjusting mechanism

The structure of mechatronics system is complex, especially that the mechanical subsystem has many design variables, complex constraints, complex mathematical models, and it is difficult to get effective and comprehensive objective functions.

The optimization analysis process is slow, the efficiency is low, and the decoupling effect is not necessarily ideal, which cannot meet the requirements of optimal design.

In the process of designing and optimizing the electric control mechanism of the adjustable wide and narrow row high-speed rice transplanter, the discipline analysis of the structure is needed first. According to the different characteristics of the research object, the system is decomposed into several independent sub-discipline systems, and all the subsystems obtained by decomposition can be analysed and optimized based on the existing mature basic theory of disciplines. Combined with the working characteristics of the electronic control mechanism and the corresponding design theory knowledge, the decomposed subsystems are divided into four relatively independent subsystems for discipline analysis: structural mechanics system, dynamics system, kinematics system and control system.

Therefore, considering the stability of components and the overall energy consumption, the smaller the weight of the adjusting mechanism, the smaller the inertia and energy consumption of the structure.

Therefore, it is necessary to analyse the static strength of the structure, and the structure should be as light as possible while satisfying the deformation and strength.

The installation position of the electric control adjusting mechanism is the middle and upper part of the seedling box. The seedling box moves back and forth at high speed in the process of transplanting rice, and at the same time, the transplanting arm is in a working state of rotating at high speed, so the whole unit of the seedling box in operation is always in a vibrating state. In the process of rotation adjustment, the unbalanced balance of inertia force will lead to the vibration of the mechanism itself. In order to avoid the resonance between the adjusting mechanism and the seedling box unit, it is necessary to analyse the structural vibration of the mechanism to minimize the vibration influence of the adjusting mechanism in operation. Reasonable structural design and optimal optimization scheme are to ensure that the high-speed rice transplanter can stably, effectively and accurately adjust the row spacing of rice transplanter under the action of the electronic control mechanism. The transmission efficiency of the mechanism system can be maximized under different working environments and working conditions.

Multidisciplinary design optimization method is derived from the theoretical basis of traditional optimization design method. Compared with traditional optimization design method, multidisciplinary design optimization method has more optimization strategies, and there will be a most suitable optimization scheme for different optimization objectives. The serial optimization method of traditional optimization design method will be developed into a parallel method for simultaneous optimization of multiple subsystems, which will more effectively decompose complex large modules into special small modules, and solve the highly coupled system-level optimization problem with effective subsystems and optimization strategies.

The optimization model of traditional optimization design method is as follows *(Yang X.D. and Zhang S.X., 2019)*:

$$Min: f(x) \tag{1}$$

$$s.t.:$$

$$\begin{cases} g_i(x) \geq 0 & (i = 1,2,\cdots,m_1) \\ h_i(x) = 0 & (j = 1,2,\cdots,m_2) \\ x_{\min} \leq x \leq x_{\max} \end{cases} \tag{2}$$

In formulas (1) and (2), f is an objective function, x is a design variable, $g_i(x)$ is an inequality constraint, and $h_i(x)$ is an equality constraint.

It is necessary to separate the traditional optimization model from multiple subsystems when the traditional optimization design method is derived and developed into multidisciplinary optimization design.

The multidisciplinary design optimization model after separating the optimization model in the above formula from subsystems is as follows:

$$Min: f(x) = f\left(f_1(x, x_1, y_1), f_2(x, x_2, y_2), \cdots, f_n(x, x_n, y_n)\right) \tag{3}$$

$$s.t.:$$

$$\begin{cases} g_i(x, x_i, y_i) \geq 0 \\ h_i(x, x_i, y_i) = 0 \\ E_i\left(x, x_i, y_i, y_{i1}(x, x_1, y_1), \cdots, y_{ij}(x, x_i, y_i), \cdots, y_{in}(x, x_n, y_n)\right) = 0 \end{cases} \tag{4}$$

In formulas (3) and (4), $i,j=1,2,...,n,i\neq j$; $f_1,...,f_n$ is the objective function of each subsystem level, x is the system level design variable, x_i is the subsystem level design variable, y_i is the subsystem level state variable, and y_{ij} is the coupling state variable between each subsystem level. $g_i(x,x_i,y_i)$ is an inequality constraint; $h_i(x,x_i,y_i)$ is the equality constraint and the system state equation. E_i the basic flow of multidisciplinary design optimization system is shown in Figure 3.

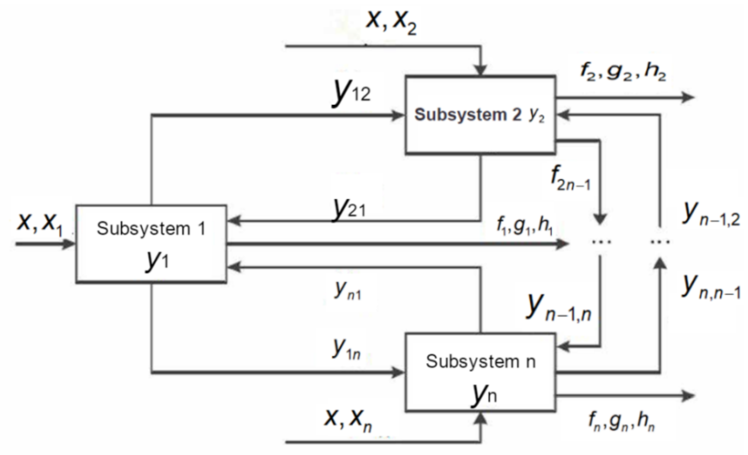

Fig. 3 - Typical multidisciplinary design optimization system

In the multidisciplinary design optimization system shown in fig. 3, the system-level design variable x is in n subsystems at the same time, and the state variables of each subsystem will become the input variables of other subsystems at the same time, thus forming a complete system-level framework by data transmission of coupling parameters among subsystems. The input variables of subsystem 1 include not only system-level design variables x and discipline design variables x_1, but also state variables $y_{21}, y_{31}, ..., y_{n1}$ from subsystem 2 to subsystem n. It reflects the modular analysis of multidisciplinary design optimization, and there are certain coupling variables among subsystems, so parallel optimization can get more effective optimization results.

Optimal design of steering trapezium

After the overall basic parameters of rice transplanter are determined, such as kingpin inclination angle α, kingpin inclination angle β, wheelbase L, kingpin centre distance B and steering gear forward extension distance, trapezoidal bottom angle φ_0, φ_1, steering tie rod l_1 and trapezoidal arm length m can be determined. In this paper, m and l_1 are taken as optimization variables.

In view of the steering trapezoidal structure itself, it is impossible to absolutely guarantee that the steering trapezoidal structure can meet the requirements of theoretical turning characteristics at any turning angle. Therefore, the objective function takes the minimum difference between the actual trapezoidal characteristics and the theoretical trapezoidal characteristics. It is hoped that the deviation will be as small as possible in the small angle range near the middle position which is often used, so as to reduce the wear of tires at high speed.

However, when it is not used frequently and the vehicle speed is slow, the requirements can be relaxed appropriately *(Zha X., Zhang G. and Zhang S., 2020)*. Therefore, the weighting factor $\omega(\theta_1)$ is introduced, and this article $\omega(\theta_1)=-\theta/\theta_{1max}+1.5$ usually takes $\theta_{1max}=90°$.

For the overall structure layout, if the m value, that is, the size design of the steering knuckle arm is too large, the size of the whole trapezoid will also become larger, and it will be difficult to adjust the overall structure; If the value of m is designed too small, the axial force on the steering cross-pull will be increased, and the cross-pull may contact the front axle of the front axle during the movement of the whole steering system, thus causing motion interference. If the steering trapezoid is closer to the rectangle *(Zhang C.Z., 2021)*, the value of $F(X)$ will be larger. Because the optimization in this paper is to find the minimum value of $F(X)$, the upper limit can be ignored.

The two constraint values mentioned in the plane constraint, in the spatial model, in order to make the optimal solution within the constraint range, the range of statistical values is generally relaxed, and the relaxed expression is as follows:

$$g_1=\left(x_1=m\right)=m-0.10K=0 \tag{5}$$

$$g_2=\left(x_1=m\right)=m-0.16K=0 \tag{6}$$

In addition, according to the understanding of mechanical principle, the minimum transmission angle constraint condition of the four-bar mechanism can be obtained by cosine theorem when the vehicle turns left to the limit position *(Zhang X S. 2018)*; δ should not be too small, generally take $\delta \geq \delta_{min}=40°$. When δ reaches the minimum value. Combined with cosine theorem, the following constraint relation of minimum transmission angle can be obtained through a certain mathematical relationship:

$$\begin{gathered} g_3=\left(x_1=m, x_2=\phi\right) \\ \cos^{-1}\frac{2\left(B+2l_2\sin\alpha\right)\cos\phi-\left(B+2l_2\sin\alpha\right)\cos\left(\phi+\theta_2\max\right)-2m\cos^2\phi}{B+2l_2\sin\alpha-2m\cos\phi}+40=0 \end{gathered} \tag{7}$$

RESULTS

Automatic navigation test

A piece of cement pavement and farmland were selected as the test site, and the transplanter was driven by the driver, and the driving routes were straight and turning. The electric control system records the driving route as the preset route, so that the transplanter can automatically navigate and drive according to the preset route; The electronic control system automatically records the heading deviation and lateral deviation during driving. The test results are shown in Table 1.

Table 1

Automatic navigation test results

Situation	**Drive straight**		**Turn and drive**	
	Maximum deviation of course/ (°)	Maximum lateral deviation/ (°)	Maximum deviation of course/ (°)	Maximum lateral deviation/ (°)
Cement pavement	6.3	4.2	5.2	4.3
Farmland pavement	7.1	4.7	7.3	4.6

It can be seen from table 1 that the deviation results of rice transplanter running on farmland pavement and cement pavement are similar, and the straight running is less than the maximum deviation value of turning; However, the heading deviation and lateral deviation of straight driving and turning are small, which can meet the requirements of automatic navigation.

Analysis of multidisciplinary design optimization results of electronic control mechanism system

Sequential Quadratic Programming NLPQL, pp. This algorithm is mostly used in nonlinear optimization systems with constraints, and the objective function is assumed to be continuously differentiable. The basic step is to expand the objective function by the second-order Taylor series, and then linearize the constraint conditions, so that it can be transformed into a quadratic programming problem. The second-order equation is improved by quasi Newton formula, and straight line search is added as an aid to enhance the stability of the algorithm.

Multi-island Genetic Algorithm MIGA, pp. In multi-island genetic algorithm, like other genetic algorithms, each design point has a fitness value, which is based on the cardinality of objective function and constraint penalty function value. If an individual has a good objective function value, the penalty function will have a higher fitness value.

Combined with the analysis of optimization strategy selection, the combination optimization algorithm of MIGA and NLPQL is selected for multidisciplinary design optimization of electronic control adjusting mechanism. Based on the established collaborative optimization platform, the electronic control adjusting mechanism is optimized and analysed. The numerical changes of system-level design variables before and after optimization are shown in Table 2.

Table 2

Optimization result of electric control adjusting mechanism

Design variable	Initial value	Optimization result	Optimization increment (%)
Adjust the total length of the lead screw	1820	1802.32	-0.97
Adjust the length of screw thread section	140	133.63	-4.6
Adjust the lead screw diameter	17	16.20	-4.71
Height of screw thread	1.3	1.21	-6.92
Adjust the lead screw pitch	2.5	1.97	-2.12
Adjust the screw speed	0.6	0.57	-0.05
Proportional control coefficient	5.6	4.33	-22.68
Integral regulation coefficient	10.2	13.02	27.65
Differential regulation coefficient	5.9	0.77	-86.95

The optimization results in Table 2 show that the overall performance of the system-level optimization target mechanism system based on the collaborative optimization method is optimal when the design variables of the electronic control mechanism system are above the design values. The final solution of the optimization objectives of each subsystem discipline is not necessarily the optimal solution within the constraints of the current discipline, but under the influence of cross-coupling design variables among subsystem disciplines, different subsystem disciplines restrict and adjust each other in a balanced way, which makes the system-level optimization objectives achieve the best under the premise that the optimization objectives of this discipline are as close as possible to the optimal solution.

In this paper, the four subsystem-level optimization objectives of structural mechanics, dynamics, kinematics and control of the electronic control mechanism system are: minimum weight, minimum vibration, maximum transmission efficiency and minimum adjustment response error, and the optimization results are shown in the following figure 4:

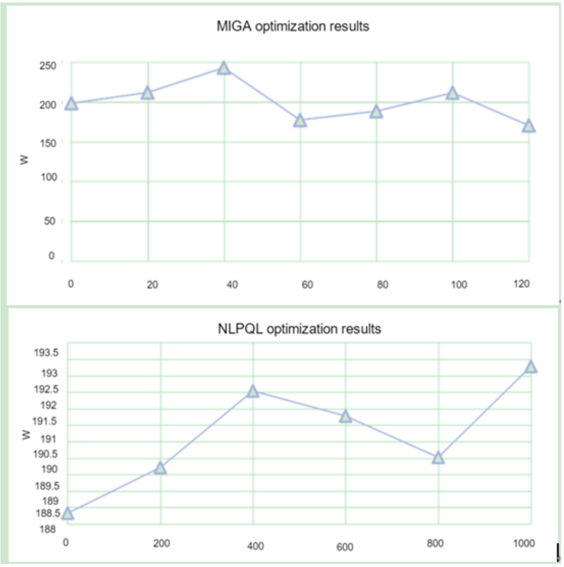

Fig. 4 - Optimization results of dynamic subsystem

It can be seen from fig. 4 that, in the structural mechanics subsystem, the weight of the optimization target electronic control adjustment mechanism is optimized from 2.617kg in the initial state to 2.453kg by MIGA algorithm, and then the final optimization solution is 2.214kg by NLPQL algorithm. On the premise of satisfying the working performance, the weight of the rod is reduced by 12.36% after optimization.

Significance analysis

In scientific experiments and production practice, things are affected by many factors, and if the factors change, they will have a certain impact on products, such as the quantity and quality of products. There will be many differences in the degree of influence, such as some factors causing great influence, some causing little influence or even ignoring it. In this paper, in order to ensure high quality and high output, and make the production process of enterprises stable, the factors affecting products are analysed with mathematical significance. The analysis uses mathematical variance analysis, which is mainly to further calculate and analyse the experimental results. This analysis can further compare the influence degree of each factor on the experiment, which is an effective method in a short time.

The primary and secondary relationship of the influence of factors on the experiment is judged by the magnitude of the extreme value, and the primary and secondary relationship is:

A→B→D→C, Corresponding relationships are kingpin inclination angle, steering knuckle arm and tie rod. Although the extreme value can reflect the primary and secondary relationship of the factors, it cannot reflect the influence of the factors on the experiment. Because there is no standard for the degree of influence on the experiment, it is impossible to scientifically judge whether all factors have significant influence.

Let F ratio F_j of factor j be:

When $F_j > F_{0.01}(2,2)$, it shows that the change of this factor level has a significant impact on the experimental results, which is denoted as $* *$.

When $F_j > F_{0.05}(2,2)$, it shows that the change of this factor level has a significant impact on the experimental results, which is denoted as $*$.

When $F_j > F_{0.1}(2,2)$, it shows that the change of this factor level has a certain influence on the experimental results, which is recorded as 0.

Table 3

Significance analysis

Variance source	Sum of squares S	Freedom f	Mean square $\bar{S}$	F value	Significance
A	12.01	3	6.20	27.21	*
B	10.24	3	5.63	24.06	*
$\triangle C$	0.44	3	0.20	2	
D	5.36	3	2.71	12.50	0
e	0.41	3	0.22		

It can be seen from Table 3 above that factors A and B are significant, factor D has certain influence, and factor C is not significant and can be ignored. From this conclusion, we can see that among the four parameters of front wheel alignment and steering trapezoid, kingpin inclination and kingpin caster angle have great influence on the whole steering system.

However, the influence of tie rod and knuckle arm in trapezoidal structure on the whole system is not great, and the influence of tie rod on trapezoidal structure is greater than that of knuckle arm, which is also consistent with the production practice. The above conclusions provide a certain reference for the improvement of steering system structure.

In order to show the change results of the curves before and after optimization more clearly, we draw the curves of the actual rotation angle and the ideal rotation angle with the input angle before and after optimization, as shown in Figure 5 below.

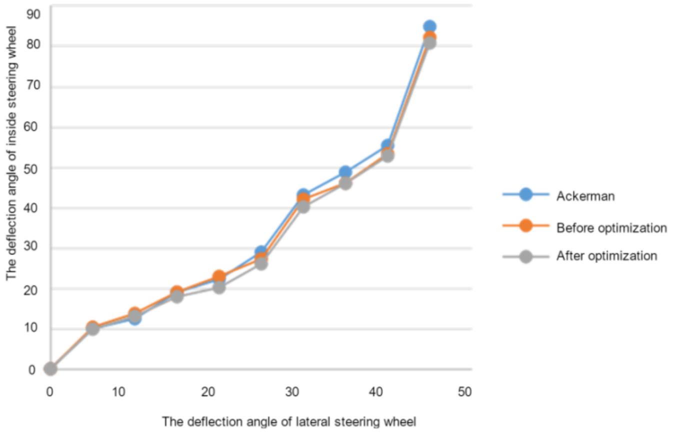

Fig. 5 - Theory and curve before and after optimization

As shown in Figure 5, the theoretical Ackermann curve is closer to the optimized curve when the outer wheel angle is in the range of 0° to 25°, but when the outer wheel angle is greater than 25°, the optimized curve is farther and farther away from the theoretical Ackermann curve, while the curve before optimization is closer to the Ackermann curve. Although this situation occurs, it does not affect the work of the transplanter in the field. Because the speed of the transplanter in the field is relatively small, the work site is limited, and the corner of the field work is mostly in a small angle range, it shows the scientificity of the optimization method to a certain extent.

CONCLUSIONS

Mechatronics system is a nonlinear complex system integrating mechanics and control, in which mechanical system includes many different disciplines such as statics, structural mechanics, dynamics and kinematics. In this paper, the multidisciplinary design optimization of adjustable wide and narrow row high-speed rice electric control mechanism is discussed and studied by analysing the research status of multidisciplinary design optimization of wide and narrow row rice transplanter and mechatronics system at home and abroad. The hybrid algorithm based on WSN technology, which uses MIGA algorithm to determine the optimal value range, and then uses NLPQL algorithm to find the optimal value within the range, shortens the calculation time and ensures the accuracy and global optimality of the final optimized value. The results show that the hybrid optimization algorithm has high computational efficiency and good optimization effect, and is suitable for multidisciplinary design optimization of mechatronics system.

REFERENCES

[1] Ahn T.I., Yang J.S., Park S.H., (2020), "Translation of Irrigation, Drainage, and Electrical Conductivity Data in a Soilless Culture System into Plant Growth Information for the Development of an Online Indicator Related to Plant Nutritional Aspects." *Agronomy,* Vol. 10, Issue 9, pp. 1306. USA;

[2] Chaitanya D.N.V., Arunkumar S., Akhilesh G.B., (2018), Design of Rice Transplanter. *Iop Conference,* p. 377. United Kingdom;

[3] Feng X.T., Hu H.H., Chen R., (2018), Electric Drive Automatic Control System "Engineering Quality Teaching Reform. *Journal of Electrical and Electronic Teaching*, Vol. 040, Issue 003, pp. 47-49, 114. China;

[4] He J., Luo X., Zhang Z., (2020), Positioning correction method for rice transplanters based on the attitude of the implement. *Computers and Electronics in Agriculture*, Issue 176, p. 105598. Netherlands;

[5] Jiangtao J., Kaikang C., Xin J., (2020), High-efficiency modal analysis and deformation prediction of rice transplanter based on effective independent method. *Computers and Electronics in Agriculture,* Issue 168:105126. Netherlands;

[6] Jin X., Chen K.K., Ji J.T., (2018), Modal analysis and structural optimization of support arm of rice transplanter based on modal confidence criterion. *Transactions of the Chinese Society of Agricultural Engineering (Transactions of the CSAE)*, Vol. 34, Issue 18, pp. 93-101. China;

[7] Lee P.U., So J.H., Nam Y.S., (2018), Power analysis of electric transplanter by planting distances. *Korean Journal of Agricultural Science,* p. 45. Korea;

[8] Li G., Wang Y., Guo L.F., (2018), Improved pure tracking algorithm for transplanter navigation path tracking. *Journal of Agricultural Machinery*, Vol. 049, Issue 005, pp. 21-26. China;

[9] Li G., Xia P.S., Yu C., Li X., (2020), Investigation and analysis on the quality of rice transplanters in Chongqing. *Agricultural Machinery Quality and Supervision*, Vol. 191, Issue 11, pp. 19-20. China

[10] Peng H.H., Shang Y.C., (2021), Fixed optimization analysis of a power steering pipeline system. *Power system and control,* Vol. 10, Issue 1, pp. 7. China;

[11] Putri R.E., Fadhilah R., Cherie D., (2020). Analysis of Energy Consumption and Performance Test on Rice Planting Using Rice Transplanter: A Case Study in West Sumatera Province, Indonesia. *Journal of Applied Agricultural Science and Technology*, Vol. 4, Issue 1, pp. 12-25. China;

[12] Samal P., Din M., Mondal B., (2018), Promotion of Self-propelled Rice Transplanters in Odisha state of India. *Agricultural mechanization in Asia, Africa and Latin America*, Vol. 49, Issue 1, pp. 28-35. Japan;

[13] Siddique A.A., Kim Y.J., Kim W.S., (2020), Analysis of the Axle Load of a Rice Transplanter According to Gear Selection. *Journal of Drive and Control,* Vol. 17, Issue 4, pp. 125-132. China;

[14] Siddique M.A.A., Kim W.S., Kim Y.S., (2020). Effects of Temperatures and Viscosity of the Hydraulic Oils on the Proportional Valve for a Rice Transplanter Based on PID Control Algorithm. *Agriculture*, pp. 10. Switzerland;

[15] Sun X.Z., (2018), Optimization design analysis of PLC automation control system. *Computer nerd,* Issue 02, p. 31. China;

[16] Tong X.F., (2020), Design Analysis of Optimizing PLC Automation Control System. *Information Recording Materials,* Vol. 21, Issue 11, pp. 128-129. China;

[17] Wang X.Z., Li Y.D., (2018), Optimization design analysis of electrical control system based on PLC technology. *Times Agricultural Machinery,* Vol. 45, Issue 10, pp. 242. China;

[18] Wen C.J., Wang H.L., Wang M., (2018), Transplanting mechanism for rice transplanter. *Journal of Physics Conference Series,* pp. 1087. United Kingdom;

[19] Wen F., Fu K., (2019), Simulation analysis and optimization design of transplanting mechanism of rice transplanter. *China plant engineering,* Vol. 000, Issue 007, pp. 167-168. China;

[20] Xinchun Y., Meihua, (2018), Development and Experiment of 2ZB-79 Shallow Rice Seedling Transplanter. *Asian Agricultural Research,* Vol. 10, Issue 06, pp. 90-92. China;

[21] Yang X.D., Zhang S.X., (2019), Analysis of technical status and existing problems of rice transplanter. *Agricultural machinery use and maintenance,* Vol. 279, Issue 11, pp. 114-114. China;

[22] Zha X., Zhang G., Zhang S., (2020). Design and experiment of centralized pneumatic deep precision fertilization device for rice transplanter. *International Journal of Agricultural and Biological Engineering,* Vol. 13, Issue 6, pp. 109-117. China;

[23] Zhang C.Z., (2021), Optimization analysis of electric control system of rice transplanter under WSN. *Research on agricultural mechanization*, Vol. 43, Issue 09, pp. 111-114+126. China;

[24] Zhang X.S., (2018), Analysis of factors affecting the operation effect of rice transplanter. *Agricultural Equipment Technology,* Vol. 044, Issue 006, pp. 32-33. China.