

Design of Automatic Generation Platform for Agricultural Robot [†]

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Abstract

The design of robots is highly dependent on their applications. For agricultural robots, terrain, weather, and crop diversity need to be considered, and work efficiency, cost, and reliability must be evaluated. These factors are important to determine the design of agricultural robots. In this study, we identified the constraint factors of agricultural robots from the perspectives of navigation, movement, control, cost, and reliability. The orthogonal defect classification (ODC) method was used to classify and grade these factors and explore the relationships among these factors. Based on the results, the design rules of agricultural robots were created, and an automatic production knowledge base of agricultural robot design was constructed. The results contribute to the automatic generation of the design framework of agricultural robots under specific environments to effectively improve the design level and quality of agricultural robots and popularize agricultural robots.

Keywords: agricultural robot; scenario; ODC method; automatic design

1. Introduction

Compared with the regular factory environment, agricultural robots operate in an irregular, natural environment. They need to consider various complex conditions such as weather, temperature and humidity, terrain, and the diversity of crops. Moreover, agricultural robots must meet stringent requirements for cost-effectiveness and reliability. This leads to scenario dependence and complexity in the mechanical structure, electrical system design, selection of perception systems, and core algorithms of agricultural robots [1,2]. Based on previous design ideas and algorithms, the design cycle and error probability of agricultural robots need to be reduced to improve the success rate of design. Therefore, we introduced the orthogonal defect classification (ODC) method to standardize and organize the design of agricultural robots. Additionally, we constructed a design knowledge base for agricultural robots. To design a new agricultural robot, relevant design information can be retrieved from the knowledge base according to the design requirements and constraints, and a prototype design can be quickly created. The base improves the design efficiency and quality of agricultural robots.

2. Design Rules

ODC is a defect analysis method that lies between qualitative and quantitative approaches [3]. The ODC defect classification criteria follow the principles of orthogonality and completeness. Orthogonality refers to there being no overlap between categories while completeness refers to the union of all categories in the entire defect space. In other words, each defect can be uniquely classified into a category in every dimension. Here, the ODC



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concept is introduced to grade and classify the factors affecting the design of agricultural robots, thus providing a basis for constructing the design knowledge base of agricultural robots.

To adapt to the organization of agricultural robot design knowledge, the ODC is revised [4]. The design knowledge of agricultural robots is divided into four dimensions: the mechanical structure design knowledge of agricultural robots, the electrical system design knowledge of agricultural robots, the core control algorithms of agricultural robots, and the perception systems of agricultural robots. These four dimensions include all the contents of agricultural robot design being independent of each other [5].

In addition, each dimension can be further refined. For example, the mechanical structure design of agricultural robots is refined into moving chassis design, body design, and working structure design. Therefore, the agricultural research for the development of the (ARD)-ODC model for agricultural robot design knowledge is obtained. This ensures the collection of agricultural robot elements without duplication or omission and the provision of design solutions.

Therefore,

$$ARD = f(ARMS, ARES, ARCA, ARPS) \quad (1)$$

As mentioned previously, the design of agricultural robots is largely dependent on the environment. The design of each module needs to be tailored to task requirements. To reuse agricultural robot design knowledge, the scenario and task information must be integrated into these modules. Thus, Equation (1) is expressed as

$$ARD = f\{(ARMS, ARMS - ST), (ARES, ARES - ST), (ARCA, ARCA - ST), (ARPS, ARPS - ST)\} \quad (2)$$

where ST represents the working scenario and task characteristic information, which serves as the index information for the reuse of agricultural robot knowledge.

3. Refinement of ARD-ODC Model

Equation (2) is used for a preliminary classification of the information, but the content of each classification needs to be further refined to be operational.

3.1. Refinement of Mechanical Structure of Robot (ARMS)

The mechanical structure of an agricultural robot is composed of the chassis structure, the body structure, and the working component structure. The chassis structure affects the robot's passability on different terrains and the stability of its movement. It mainly includes two parts: the mobile mechanical structure and the suspension structure. The body structure is responsible for bearing the weight of the robot, installing various accessories, and providing support for the working components. It consists of the weight-bearing structure, the accessory-installing structure, and the actuator-supporting structure. The working components perform tasks as modules for realizing the functions of the robot. They include the end-effector module, the actuator power transmission module, and the actuator motion control module. Therefore, the mechanical structure part of the robot is expressed as

$$ARMS = f \left\{ \begin{array}{l} (Mobile\ mechanical\ structure,\ suspension\ structure) \\ (Load - bearing\ structure,\ accessory\ installation\ structure, \\ \quad \quad \quad actuator\ support\ structure) \\ (End\ effector,\ actuator\ power\ transmission,\ actuator\ motion\ control) \end{array} \right\}$$

3.2. Refinement of Electrical System of an Agricultural Robot (ARES)

The electrical system of an agricultural robot provides power for the robot, consisting of the power supply system, the drive system, and the communication system. The power supply system comprises the power source, the charging device, the power management module, and the power conversion and distribution module. The drive system contains the motor module, the transmission module, the drive control module, and the braking module. The communication system includes the internal communication module, the external communication module, the communication protocol conversion module, and the data processing and security module.

Therefore, the electrical system of an agricultural robot is expressed as

$$ARES = f \left\{ \begin{array}{l} \text{Power supply, charging, power management, power conversion and distribution} \\ \text{Motor module, transmission module, drive module, braking module} \\ \text{Internal communication, external communication, communication} \\ \text{protocol conversion, data processing and analysis security} \end{array} \right\}$$

3.3. Refinement of Control Algorithms of Agricultural Robot (ARCA)

The core control algorithms of agricultural robots consist of robot path planning and scheduling algorithms. Path planning algorithms include environmental modeling, search strategies, performance evaluation, and multi-robot path planning. The scheduling algorithm includes task allocation, path planning coordination, resource allocation and management, and performance evaluation and optimization.

Therefore, the core control algorithms of agricultural robots are expressed as:

$$ARCA = f \left\{ \begin{array}{l} \left(\begin{array}{l} \text{Environmental modeling, search strategy, performance} \\ \text{evaluation, multi – robot path planning} \end{array} \right) \\ \left(\begin{array}{l} \text{Task allocation, path planning coordination, resource allocation,} \\ \text{management and performance optimization} \end{array} \right) \end{array} \right\}$$

3.4. Refinement of Perception System of Agricultural Robots (ARRS)

The perception system of agricultural robots includes perception system hardware, sensor data processing algorithms, target recognition and classification algorithms, and environmental perception and modeling algorithms.

$$APRS = f \left\{ \begin{array}{l} \left(\begin{array}{l} \text{Perception system hardware} \\ \text{Sensor data processing, target recognition and classification algorithms, environmental} \\ \text{perception and modeling algorithms} \end{array} \right) \end{array} \right\}$$

Through the above process, the design process of agricultural robots is reasonably classified and formally described. By inputting this information into the database, the design knowledge base of agricultural robots is obtained. When designing a new agricultural robot, it is necessary to collect the working scenario information and task requirement information of the agricultural robot. After standardizing the information, the similarity between each piece of ST information and the internal ST information of the knowledge base is obtained. This similarity is used as the weight value for information retrieval and recommendation. The term frequency-inverse document frequency (TF-IDF) weighted sorting algorithm is used to search for relevant previous agricultural robot design cases in the knowledge base and provide a reference for the design of the new robot and improve the efficiency and quality of robot design. The first step is to search for relevant information in the database based on each piece of information in ST. The second step is to assign weights to the retrieved information according to the matching degree between the information in

ST and the retrieved information. The third step is to calculate all the information according to the weights to recommend the obtained information.

4. Application

Taking the wheat field pesticide spraying robot as an example, the obtained ST information is as follows.

$$\begin{aligned} \text{ST} = \{ & \text{Navigation accuracy} \leq \pm 20 \text{ cm}; \text{ No RTK equipment}; \text{ Turning radius} \leq 1.5 \text{ m}; \\ & \text{Turning radius} \leq 1.5 \text{ m}; \text{ Load capacity} \geq 50 \text{ kg}; \text{ Robot width} \leq 50 \text{ cm}; \text{ Wheat height } 65\text{--}80 \text{ cm}; \\ & \text{Loose soil}; \text{ Trees within } 100 \text{ m, swaying with the wind}; \\ & \text{Pesticide spraying requirements: no repetition and no omission} \} \end{aligned} \quad (3)$$

Based on the above information, after retrieval, the recommended information is obtained as follows.

- Robot chassis: The soil is soft, and the turning radius is less than 1.5 m. The reference solution is a differential wheel chassis. The width of the robot body is not more than 50 cm, and the wheel radius is 25–35 cm. The wheel radius can be appropriately widened to enhance the passability on soft soil.
- Navigation method: The navigation accuracy is $\leq \pm 20$ cm. There are big trees around. The reference solution is a 3D radar with a navigation accuracy of ± 10 cm.
- Radar installation: The height of the wheat is 65–80 cm. The reference solution is the column installation method, and the radar installation height is higher than that of the wheat.
- Electrical system: According to the field operation in the wheat field, the reference solution is that the protection level is IP65, and the electrical system adopts the lithium battery and 48 V electrical system solution.
- Path planning: Single-machine operation and the spraying method are applied without repetition or omission. The reference solution is that the multi-machine scheduling system is not considered, and the A* algorithm is recommended for the path planning algorithm.

Based on the above information, a robot system design for spraying operations in the wheat field is created using simple software and hardware selection.

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