Research on Automatic Control of Agricultural Robot Trajectory Optimization Based on Mathematical Model

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Abstract. In order to improve the work efficiency of agricultural robots and reduce the errors in the operation process, the trajectory optimization control of agricultural robots is taken as the research object, and the mathematical model is introduced into the automatic controller to analyze the basic principles of kinematics and dynamics of agricultural robots. Design the motion control system of agricultural robot, conduct in-depth analysis of uncertain dynamic factors, and propose an adaptive learning method. Finally, computer simulation software was used for verification, and the results showed that the introduction of mathematical models into the design of automatic control of agricultural robots can optimize its motion trajectory, significantly improve the efficiency of agricultural robots, and reduce external interference factors.

Keywords: Agricultural Robot, Precise Trajectory Optimization, Mathematical Model, Calculation Torque Method

1. Introduction

In recent years, with the development of new agricultural planting models and computer technology, the research of intelligent robots has made great breakthroughs, and the application of robots in agricultural production has become more and more popular. Agricultural robots need to work while moving [1, 2]. The walking path is not only the minimum distance between the start and end points, but often needs to walk across the entire work area, and the environment is generally complex and changeable, so it often needs to implement new optimizations on the original plan [3, 4]. Path optimization is the core part of the agricultural robot operation process, and its intelligence is mainly reflected in the planning of the range of motion and the work space [5, 6]. In this paper, the mathematical model and the calculation torque method are combined with the control system to calculate and optimize the motion trajectory of the agricultural robot, and MatLab is used to simulate and predict certain collisions and successful avoidance of obstacles that may occur during the operation of the agricultural robot, while providing path optimization and Strategies to avoid obstacles.

2. Neural network algorithm

Neural network is a central processor composed of simple processing units that is magnificent and can
perform distributed processing at the same time. It can save past experience data and proven characteristics. The neural network mainly simulates the brain from two parts: acquiring knowledge and preserving knowledge. Neural networks acquire knowledge mainly through practice and continuous learning from the outside, while the mutual synaptic connections of internal neurons are mainly used to store information.

The information received by the cell body is generally transmitted through the dendrites first, and then forms an electrical impulse that is transmitted from the axon to the synapse of another neuron, and the information is continuously transmitted in this way.

The mathematical model is a multi-layer feedforward network trained according to the error back propagation algorithm, which can learn and store a large number of mapping relationships between input and output modes, and the specific mathematical equations of the algorithm are not required before calculation. The basic principle is: by comparing the output value, find the error value, and estimate the error of the leading layer; then, use the error to derive the error of the previous layer, and finally, reverse the transmission in turn to find the error estimate of the other layers.

The mathematical model is mainly composed of input layer, hidden layer and output layer. The neurons of every two adjacent layers are all related, but there is no relationship between the same layer.

Assuming that the input layer is not included, it has N0 elements. Suppose a network has an L layer and the output is the Lth layer, and the Lth layer has NK elements. Let $u_k(i)$ denote the information received by the i-th neuron in the k-th layer, $w_k(i,j)$ is the weight from the j-th element in the k-1 layer to the i-th element in the k-th layer, $a_k(i)$ is the output of the i-th element of the k-th layer, and the neurons in each layer have information exchange, then the input-output relationship can be expressed as

$$w_l^{(p)}(i,j) = w_l^{(p-1)}(i,j) + \eta \delta_l^{(p)} a_{l+1}^{(p)}(j) \quad (l = 1, \ldots, L) \tag{1}$$

The steps of the mathematical model algorithm are: ① Select the learning data, $p=1,...,p$, and randomly determine the initial weight matrix $W(0)$; ② Use the learning data to calculate the network output; ③ Use the formula (2) to reverse the correction, Until all learning data is used up.

3. Establish a mathematical model of agricultural robots

Establishing the mathematical model of agricultural robot is an important prerequisite for tracking and optimizing its trajectory. It is mainly based on the change relationship between various forward parameters and control variables of the robot to realize the control of the robot and achieve the purpose of optimizing the trajectory.

First establish the XOY global coordinates; then establish the X1OY1 coordinate system on XOY with the center of mass of the chassis, the robot running direction is the X1 axis direction of X1OY1; finally, the robot is regarded as a point, and its position and running direction are analyzed. Among them, $\theta$ is the direction angle between the horizontal axis and the direction of motion; [v w]r is the control parameter of the robot.

3.1. Agricultural robot kinematics model

During the operation of agricultural robots, the wheels will roll and slide when they contact the farmland. In order to simplify the problem, according to the established mathematical model, this article only chooses normal rolling as the analysis object.

The kinematic model of the agricultural robot mainly describes the relationship between its forward direction and speed, and intuitively transforms the motion problem into a mathematical problem.

$$\dot{y} \cos \phi - \dot{x} \sin \theta = 0 \tag{2}$$
\[
\begin{bmatrix}
\dot{x} \\
\dot{y} \\
\dot{\theta}
\end{bmatrix} =
\begin{bmatrix}
\cos \theta & 0 & 0 \\
\sin \theta & 0 & 0 \\
0 & 0 & 1
\end{bmatrix}
\begin{bmatrix}
v \\
w
\end{bmatrix}
\] (3)

Among them, formula (5) is the constraint condition in robot motion; formula (6) is the kinematics model of robot.

During the movement of the agricultural robot, there is a certain relationship between the linear velocity \(v\) and the angular velocity \(\omega\), then

\[
\begin{bmatrix}
v_L \\
v_R
\end{bmatrix} =
\begin{bmatrix}
1/R & L/2R \\
1/R & -L/2R
\end{bmatrix}
\begin{bmatrix}
v \\
\omega
\end{bmatrix}
\] (4)

Based on the above formulas, the kinematics model of agricultural robot can be obtained as

\[
\begin{bmatrix}
\dot{x} \\
\dot{y} \\
\dot{\phi}
\end{bmatrix} =
\begin{bmatrix}
R/2 \cos \theta & R/2 \cos \theta \\
R/2 \sin \theta & R/2 \sin \theta \\
R/L & R/L
\end{bmatrix}
\begin{bmatrix}
v_L \\
v_R
\end{bmatrix}
\] (5)

3.2. Agricultural robot dynamic model

The dynamic model of agricultural robot mainly describes the relationship between its movement direction, acceleration and force. Applying Lagrangian equations, there are differential equations in agricultural robot mechanical systems, then

\[
\frac{d}{dt} \left( \frac{\partial L}{\partial \dot{q}} \right) - \frac{\partial L}{\partial q} = A(q) \lambda + B(q) u
\] (6)

Among them, \(L(q, \dot{q})\) is the kinetic energy during the robot movement; \(A(q)\) is the robot constraint matrix; \(B(q)\) is the robot movement matrix.

According to the above definition, formula (9) can be rewritten as follows, namely

\[
M(q) \ddot{q} + f(q, \dot{q}) = A(q) \lambda + B(q) u
\] (7)

The dynamic equation of the agricultural robot dynamic system is

\[
\ddot{q} = 0
\] (8)

Define the full rank matrix \(S(q)\) as

\[
S(q) = [S_1(q), S_2(q), \cdots, S_{n-u}(q)]
\] (9)

Then there is

\[
S^T(q)A(q) = 0
\] (10)

After combining formula (7) and formula (10), we get

\[
S^T(q)[M(q) \ddot{q} + f(q, \dot{q})] = S^T(q)B(q) \tau
\] (11)

It can be found that the static state feedback can be simplified to a simple form of non-holonomic constraints, and the position of the agricultural robot in the Cartesian coordinate system can be derived
from the vector. Among them, \((x, y)\) is the reference position of the robot; \(\theta\) is the coordinate angle. The constraints when the robot rolls in the agricultural area are

**4. Design of agricultural robot control system**

In general, because the dynamic parameters of the system are often uncertain, the accuracy of the robot model is difficult to know. In order to overcome the uncertain factors in the dynamics system, the control system specially adopts the calculation torque controller, and at the same time adds the auxiliary mathematical model fuzzy controller, through the two actions, the control system optimizes the path. The structure of the control system is shown in Figure 1.

![Figure 1. The structure of the agricultural robot control system.](image)

It can be seen from Figure 1 that the system is closed-loop, and the overall control of the system is controlled by the fuzzy mathematical model control and the parameter adaptive calculation torque controller. Maintain the minimum error value convergence accuracy.

**5. Path optimization modeling and simulation verification**

**5.1. Path optimization modeling for agricultural robots**

When the agricultural robot seeks path and avoids obstacles for path planning, it needs to use the maximum linear speed to select the optimal motion trajectory among all paths, and calculate the motion time of the optimal path according to the characteristics of the mathematical model and the calculated torque method compound control system. And the linear speed of the robot wheel, and then adjust the motion state, get the optimal path result. Fig. 2 The state diagram of agricultural robot motion constraint.

![Figure 2. The motion constraint state diagram of agricultural robot.](image)

In Figure 2, A1, A2, and A3 are the distances between obstacles; Cp is the center of mass of the robot. The time required to run the optimal path is
\[ T_G = T_T + T_R \] (12)

Among them, \( T_T \) is the time required for movement; \( T_R \) is the time required for rotation. Both meet

\[ \begin{align*}
T_T &= \sum_i \frac{D(A_{i-1}, A_i)}{V} \\
T_R &= \sum_i \frac{A(A_{i-1}, A_i)}{\omega}
\end{align*} \] (13)

Among them, \( D \) is the distance; \( A \) is the angle.

According to the characteristics and control status of the agricultural robot, and then consider the time of other feasible paths, use the control cycle and linear speed to solve the movement distance and rotation angle in each operation cycle, then

\[ \begin{align*}
L &= V \times T \\
\theta &= \omega \times T
\end{align*} \] (14)

Among them, \( T \) is the movement period.

According to the movement distance and rotation angle between the mass points, the movement distance and rotation angle of each path of the agricultural robot are obtained; then, according to the fitness function optimized for the new path, the optimal solution can be obtained.

5.2. Simulation verification

In order to verify the reliability of the system, this paper conducts MatLab verification on the designed control system. Among them, the operating environment of the agricultural robot is in an area of 3m \( \times \) 3m, the starting point and ending point are (0,0), (0,0), the control parameter is 0.01, and the initial moving direction error is (0,0.45)T. Each time the simulation is performed, the calculation is repeated 100 times. The simulation result is shown in Figure 3, and the specific data is shown in Table 1.

![Simulation result](image)

**Figure 3.** Simulation results of agricultural robot path optimization.

**Table 1.** Specific data of simulation results.

| Trajectory optimization | Walking distance/m | Walking time/s | Translation time/s | Rotation time/s |
|-------------------------|--------------------|---------------|-------------------|----------------|
|                         | 4.62               | 34.5          | 19.2              | 15.3           |

It can be seen from Figure 6 and Table 1: that the movement distance and time of the agricultural robot path optimization are relatively small, the average position error is only 0.085m, and the rotation space of the robot is increased, making the movement trajectory relatively smooth and the operation.
efficiency is obvious improve.

6. Conclusion
Aiming at the problems of excessively long moving routes of agricultural robots in the field, high travel costs and low path planning efficiency, a research method based on mathematical models and calculation torque methods to control the trajectory of agricultural robots is proposed, and the system is optimized by MatLab. Simulation. The results show that the compound control algorithm can effectively optimize the movement trajectory of the agricultural robot, improve its movement efficiency, smooth the movement trajectory of the agricultural robot in the process of avoiding obstacles, and greatly improve the operation efficiency of the robot; at the same time, it strengthens the operation process. The stability of the fruit grower saves a lot of time and economic costs, and the system has a strong learning ability to the uncertain factors of the external environment.

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