Research Article

Optimization of Sorting Robot Control System Based on Deep Learning and Machine Vision

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To enhance the control technology of coal gangue dry separation method which is replaced by the machine in coal washing plant and to explore the control effects of traditional PID and dynamic domain fuzzy self-tuning PID, which will aid in determining the ideal position and orientation for grasping an object as well as understanding physical and logistic data patterns, an optimal design of PID controller for sorting robot based on deep learning is initiated. The mathematical model of ball screw system driven by a single joint motor of the robot is introduced, the control effects of classical PID and variable domain fuzzy self-tuning PID are studied and imitated, respectively. The simulation outcome appears that the selection time is 0.001 s and simulation time is 8 s. The tracking error of variable domain fuzzy PID is minor than that of PID tracking at the starting point, and the convergence rate of error is quick than that of PID manage, the steady-state error is minor than PID, the control accuracy is higher, and the tracking performance is better. The advantages of variable domain fuzzy PID control method in position tracking control are verified, the variable domain fuzzy PID can modify the control framework online as per the different position mistake and mistake change rate, the design of the variable domain of input and output makes the fuzzy inference rules locally finer, the speed of adjustment is faster and the tracking accuracy is further improved, so it has finer tracking presentation than the traditional PID tracking management.

1. Introduction

With explosive growth of the social economy and the widespread adoption of automated technology, human demands for small-scale production and quality of products have increased dramatically in recent years. To keep up with the trends, several companies have integrated robots into a variety of automated production lines [1, 2]. With China as the world’s major industrial products producer, industrial robots have been broadly used in various fields of factories production. In the national environment of “industry 4.0,” the research of industrial robot intelligence has great practical significance. As one of the representatives of industrial robots, the sorting robot can replace the human to complete some heavy workload and repetitive production activities [3]. Goods and production procedures are networked and can “speak” in this manner, allowing novel production methods, value development, and real-time optimization. Cyber-physical systems are used to generate the abilities necessary in smart manufacturing [4, 5]. Therefore, sorting robots are widely used in logistics, warehouses, workshops, and supermarkets; in addition, in some special environments, such as the disaster site and other harsh environment, industrial robots can replace
humans in the sorting work. How to make the sorting robot highly intelligent has high research value [6]. Inside the logistics industry, conventional manual sorting techniques include disadvantages such as low productivity, high cost, and high cost. At the same time, the use of machine vision for intelligent sorting activities is becoming more prevalent in smart logistics [7, 8]. The intelligence of the intelligent sorting robot is reflected in the hope that the robot can sense the target around like the human, and realize the discrimination and positioning of the target. Humans can use their eyes and brains to make sense of their surroundings. Uniformly, the intelligent resolving robot can sense the surrounding working environment through the machine vision system and can quickly detect targets [9]. The sort method was created with the goal of shallow learning in mind. Item identification and posture estimation are implemented using border detection methods, fundamental characteristics of complex objects, colour attributes, and structural light principles [10, 11]. In view of this research problem, Jiong Yan et al. believed that the motors used for robot joint drive usually include stepper motor, DC servo motor, and AC servo motor. Relatively speaking, the AC servo motor has fine velocity manage functions and great accuracy position managing performance [12]. Deng et al. believed that the upper computer, as the main part of human-computer interaction, could realize the monitoring of the system state, the planning of the manipulator’s motion trajectory and the delivery of motion control instructions [13]. Mahmoodabadi and Baghini believed that the communication layer connected the upper computer with the motion control system to complete data transmission and receiving, thus realizing the control of the robot [14]. Many earlier systems depend on target recognition or template matching to identify and locate things in a scene, but stacking provides a more consistent sorting result in the face of a variety of unknown object sorting criteria. Because of a lack of awareness of the spatial connections of items in the scene, the target item gets injured during the grasping process. As a result, it is vital to investigate how to use robots to sort complex multiobject scenarios in a safe, stable, and accurate manner. In the future, the identification of the grab point or extraction of the object’s general geometric features may be researched to establish the object’s attitude [15]. The underlying software is used to realize the real-time control of the robot, including the robot trajectory tracking control, target gangue capture and system feedback and other functions. This paper aims to study the control system of coal gangue classifying robot and improve the control mechanism of coal gangue dry separation method in coal washing plant. Based on the experimental ranking at home and abroad, the trussed robot is taken as the control object to study the control mechanism of coal and gangue classifying, the hardware and software subsystems of the managed process were optimized, and the managed process of the coal and gangue sorting robot was optimized.

The main research contents are as follows: set up the mathematical pattern of the ball screw system driven by the robot, single joint motor, site on this pattern as the managed object, on the basis of studying the classical PID manager, the model process of variable domain fuzzy PID manager is studied, and the control effect is simulated and verified by comparing with traditional PID on MATLAB [16]. Function verification was carried out on the optimized control system, test platform of the coal and gangue sorting robot, the managed effect of the modeled manager, and the reliability and feasibility of the developed control system were verified, which laid a foundation for the subsequent research on the coal and gangue sorting robot based on multimanipulator cooperative sorting. The variable domain fuzzy PID can accommodate the control framework online as stated in the different position mistake and mistake change rate, the design of the variable domain of input and output makes the fuzzy inference rules more fine locally, the adjustment speed is faster, and the tracking accuracy is further improved; therefore, it has finer tracking presentation than the traditional PID tracking management. The proposed strategy will assist robots in comprehending physical and logistical data patterns so that they may be proactive and behave appropriately. It will also help robots retain productivity by assisting them with dynamic engagement and obstacle avoidance. AI is assisting robots in detecting previously unseen things and recognizing objects in considerably higher detail. The novelty of the work lays in the fact that variable domain fuzzy PID can adjust the control parameters online in accordance with the different mistake and mistake change rate. Conclusively, the future replacement of manual labor by robots is a key trend. The usage of robots contributes to higher levels of societal output, which is critical for traditional manufacturing processes [17, 18].

2. Methods

A mathematical model for a single joint robot has been proposed and the rotation of the motor shaft of the robot has been recorded. Through the fuzzy algorithm and reasoning, the output of the fuzzy controller has been diffused by weighted average method, that itself completes the self correction of PID base parameters. The appropriate trajectory tracking control algorithm is studied to improve the motion characteristics of the manipulator as much as possible, so that it can progress in accordance with the craved path. Aiming at the problem that the parameters of traditional PID algorithm cannot be adjusted, the fuzzy self-tuning PID managed algorithm combined with fuzzy algorithm and PID is studied, to further improve the control accuracy, a variable domain adjustment part is added on the basis of fuzzy PID, the fuzzy domain can be changed according to the change of the input to improve the tracking accuracy of the trajectory.

2.1. Establishment of Mathematical Model of a Single Joint of Robot. For the truss sorting robot body used in this system, its drive system can be regarded as three orthogonal servo feed systems, in essence, taking one of the servo feed systems as an example, its mathematical model is established [19].

The circuit part establishes the differential equation as
Here, $e_d = k_d \omega$, is substituted as

$$L \frac{di}{dt} + R_i + e_d = e_1. \quad (1)$$

Here, $k_d$ is the back electromotive force constant. The Laplace transform is given by

$$LsI(s) + R(s) + k_d \theta(s) = E(s). \quad (3)$$

In addition, $M_1 = bs \theta/dt$ and $k_m$ are electromagnetic torque constants of the motor, which are substituted into

$$K_m I(s) = f \frac{d\omega}{dt} + b \frac{d\theta}{dt}. \quad (6)$$

In the formula, $b$ is the damping, and the Laplace transform is

$$K_m I(s) = f s^2 \theta(s) + bs \theta(s). \quad (7)$$

The transfer function relationship between the system input $E(s)$ and output $\theta(s)$ is obtained by combining the two equations, as

$$E(s) = \left[ \frac{R(Fs^2 + bs)}{K_m} + L_0(2s + bs) + K_m \right] \theta(s). \quad (8)$$

As the inductance $L$ is much minor than the inaction of the motor rudder and burden, it is ignored. The convey purpose is simplified as

$$G(s) = \frac{E(s)}{\theta(s)} \approx \frac{k_m}{R(Fs^2 + bs)K_m K_d s} \quad (9)$$

Servo feed system includes servo motor, reducer, ball screw, working table, etc, set the instant of inertia of the motor rudder shaft as $J_1$, and the moment of inertia of the decreased resulting ray as $J_2$, the deceleration proportion of the reducer is $i$, the tone of the ball screw is $P$, the mass of the working table is $m$, considering the use of rolling bearings and ball screws, the viscous damping torque related to the relative velocity of each pair can be ignored, at the same time, because the elastic deformation of the moving parts is small, the elastic moment related to the elastic deformation of the moving parts is ignored. Considering that the displacement $x_0$ of the working table is proportional to the angle $\theta$ of the motor shaft, it is shown as follows.

$$x_0 = K_i \theta. \quad (10)$$

$J$ is the entire moment of inertia changed to the motor shaft. According to the preservation of energy law, the entire energy of the system leftover unchanged before and after conversion, as

$$\frac{1}{2} J_1 \omega_1^2 =\frac{1}{2} J_2 (\omega_1 / i)^2 + \frac{1}{2} m \left( \frac{P}{2\pi i} \right)^2, \quad (11)$$

$$J = J_1 + \frac{J_2}{i^2} + \left( \frac{P}{2\pi i} \right)^2. \quad (12)$$

2.2. Model of Fuzzy Self-Tuning PID Manager

2.2.1. Classical PID Management. PID control algorithm as a traditional classical algorithm, its technology has been very mature, broadly used in the factorial field. In robot management, most of the current is use of independent joint PID control. Generally, the controlled object is the dynamic model of the robot’s independent joint, or the solved transfer function [20]. According to the deviation signal $e(t)$, the system carries out the linear combination of proportion, integral and differential links according to the set coefficient, after the output of the control quantity is obtained, the system error is corrected and the system tends to be stable as far as possible. The PID control law can be expressed as

$$u(f) = K_p \left[ e(t) + \frac{1}{T} \int_0^t e(t) dt + \frac{1}{T_d} \frac{de(t)}{dt} \right]. \quad (13)$$

The transfer function form is

$$G(s) = \frac{U(s)}{E(s)} = \frac{K_p \left( 1 + \frac{1}{T_i s} + T_d s \right)}{T_s}. \quad (14)$$

Expanding the proportional coefficient can accelerate the adjustment speed of the arrangement, but too large will make the system response overshoot and produce oscillations. The integral time constant $T_i$ determines the steady-state performance of the process. Reducing $T_i$ can enhance the steady-state performance of the process, but it is prone to instability. The differential time constant $T_d$ term can predict the variation trend of the error, thus exerting appropriate control. In the verified computer management, the continuous PID management algorithm needs to be discretized to get the following positional and incremental formula. Position PID Set $T_s$ as the sampling period and $k$ as the sampling signal, as

$$\frac{de(t)}{dt} \approx \frac{e(kT_s) - e((k-1)T_s)}{T_s} = \frac{e(k) - e(k-1)}{T_s}. \quad (15)$$

The positional PID expression is
\[ u(k) = k_p e(k) + k_i \sum_{j=0}^{k-1} e(j) + k_d (e(k) - e(k-1)). \] (16)

In formula (16), \( e(k-1) \) and \( e(k) \) are the deviation signals obtained at the \( k-1 \)st and \( k \)th times of sampling, respectively, the control output of a position-type PID is related to the sum of the past deviations, this may lead to large changes in the output, which is unfavorable to the control of the robot, therefore, the incremental formula is used instead of the positional formula, and the principle of recursion is

\[ u(k-1) = k_p e(k-1) + k_i \sum_{j=0}^{k-2} e(j) + k_d (e(k-1) - e(k-2)). \] (17)

The change obtained by subtraction is

\[ \Delta u(k) = k_p (e(k) - e(k-1)) + k_i e(k) + k_d (e(k) - 2e(k-1) + e(k-2)). \] (18)

Incremental PID control incremental output is only related to the latest three deviation values of the sampling, to avoid the generation of excessive cumulative error. In principle, the traditional PID managed procedure is independent of the specific mathematical design of the managed object, but the control parameter setting is complicated. For the truss robots, it is difficult to obtain consistent PID parameters because of the errors caused by the machining accuracy and assembly of each joint. The traditional PID management procedure cannot connect the managed requirements of the robot, so the fuzzy algorithm is used for self-tuning PID control parameters.

2.2.2. Design of Fuzzy Self-Tuning. PID controller during the operation of the motion managed system, the control object will be affected by interference factors, as the object characteristics or parameter structure changes, a single control parameter cannot cope with high-precision situations [21]. The fuzzy self-tuning PID parameters can be automatically adjusted in accordance with the actual response of the system. It is mainly composed of fuzzy manager and PID manager. The two-dimensional input is selected, and the error \( e \) and error change rate \( e_c \) between the theoretically calculated expected trajectory of the manipulator and the actually measured trajectory are taken as inputs, after fuzzy reasoning, the scaling coefficient variation \( \Delta k_p \), integral coefficient variation \( \Delta k_i \), and differential coefficient variation are calculated with the initial value of PID parameters, the final parameters are obtained to realize the control of the manipulator movement. Fuzzy reasoning is to determine the relationship between \( \Delta k_p \), \( \Delta k_i \), and \( \Delta k_d \) and \( e \) and \( e_c \), respectively. After finding \( \Delta k_p \), \( \Delta k_i \), and \( \Delta k_d \), add it to the initial parameters \( k_{p0} \), \( k_{i0} \) and \( k_{d0} \), \( k_p \), \( k_i \) and \( k_d \) as systems.

\[ k_p = k_{p0} + \Delta k_p, \]
\[ k_i = k_{i0} + \Delta k_i, \]
\[ k_d = k_{d0} + \Delta k_d. \] (19)

In this system, the object theory domain of the inputs \( e \), \( e_c \) and outputs \( \Delta k_p \), \( \Delta k_i \) and \( \Delta k_d \) is quantized as the theory domain \([-1, -2/3, -1/3, 0, 1/3, 2/3, 1]\) on the fuzzy set, the corresponding fuzzy subset is \{NB, NM, NS, ZO, PS, PM, PB\}. For the fuzzy subsets NB and PB on both sides, z-type and S-type enrollment functions with strong adaptability are adopted, respectively, the triangle membership function is used in the middle range. The actual domain scope needs to be transformed into the fuzzy domain scope by quantization factor, the quantization factors \( k_e \) and \( k_{ec} \) of the inputs \( e \) and \( e_c \) are

\[ k_e = \frac{1}{x_e}, \]
\[ k_{ec} = \frac{1}{x_{ec}}. \] (20)

3. Results and Analysis

According to the basic rules of PID controller parameter setting, an appropriate fuzzy control rule table is established. Table 1 is the \( \Delta k_p \) fuzzy managed rule table of the variation of the scaling coefficient, Table 2 is the \( \Delta k_i \) fuzzy managed rule table of integral coefficient variation, and Table 3 is the \( \Delta k_d \) fuzzy control rule table of differential coefficient variation.

After fuzzy method reasoning, the output of the fuzzy controller is defuzzy by weighted average method, which complete the online self-correction of PID parameters. Using the fuzzy PID controller, when the system enters the stable running state, the deviation gradually decreases, but the continued use of the previous membership function will reduce the trajectory tracking accuracy, based on this, to further improve the precision of fuzzy PID management, the variable domain fuzzy PID control method is adopted. The original fuzzy inference rule entries remain unchanged, and the scaling factor is introduced, the scope of input and output is adjusted by the change of the stretching factor, as the error and the change rate of error decrease gradually, the local part of the fuzzy rule becomes finer, the fuzzy subset interval becomes smaller, which improves the accuracy of trajectory tracking of the manipulator, this also increases the practicability of variable domain fuzzy PID control method in gangue picking by mechanical arm. The change of the domain mainly lies in the setting of the scaling factor [23]. In general, the mistake and the rate of change of the mistake are bounded by a rectangle or a square, as the system becomes increasing stable, the errors and the rate of change of error decrease gradually, and the input and output domains contract toward the center, and expand outward otherwise. This change process is described by the stretching factor, which can be constructed based on function and fuzzy reasoning.

To verify the good control effect of variable domain fuzzy PID, the transfer function of the second-order motor drive system deduced in the above section is the control object, simulation and verification of unit step signal and sinusoidal curve control are carried out based on MATLAB. Figure 1
show the output curve of step response at a given position of 1 mm when PID and variable domain fuzzy PID control are adopted, respectively. By comparison with Figure 1, it can be seen that both PID and variable domain fuzzy PID have good tracking effect on position step, but by contrast, since the variable domain fuzzy PID controls the PID parameters in accordance with the mistake and mistake change rate online self-tuning, the managed effect of the system is finer than PID, with quicker reply speed and lesser overshoot.

In Figure 1, for the 1 mm position, the proposed Fuzzy PID control has shown the speed of adjustment is faster and the tracking accuracy is further improved, so to compare the control effect of the two controllers, given the displacement output curve of the sinusoidal signal, the two control methods are applied to the same given signal, and the sinusoidal displacement curve is set as: \( y = 5 \sin(2t) \), the sampling time is 0.001 s, and the simulation time is 8 s. Figure 2 shows the tracking curve of the two control methods, and Figure 3 shows the output error curve of the two control methods, according to the analysis of Figures 2 and 3, the tracking error of fuzzy PID in variable domain is smaller than that of PID tracking at the starting point, in addition, the convergence rate of error is faster than that of PID control, and the steady-state mistake is lesser than PID control, the control accuracy is higher, and the tracking performance is better [24]. In Figure 2, The sinusoidal displacement curve has shown for fuzzy PID in variable domain. For Figure 3, for PID and variable the error curves has been illustrated and position tracking control are verified. Hence, through the presented algorithm, we can build a robot sorting system based on machine vision, which is a speedy hand eye calibration approach. Deep learning...
algorithms have a high calculation speed as one of its characteristics. The system as a whole is capable of sorting any work piece placed in any location.

4. Discussion

The target object is harmed during the grasping process because to a lack of awareness of the spatial linkages of items in the scene. It is critical to figure out how to employ robots to sort complicated multiobject scenarios in a safe, reliable, and precise way. The findings revealed traits that would aid robots in interpreting physical and logistical data patterns, allowing them to be proactive and respond accordingly. This will help them to keep Productive capacity by supporting them with Active Involvement and Blockage. Because of the changeable domain of input and output design, the fuzzy inference rules are locally finer, the adjustment speed is faster, and the tracking accuracy is increased even more, resulting in finer tracking presentation than classic PID tracking management.

5. Conclusions

The optimal design of PID controller for sorting robot based on deep learning is proposed. The control effects of classical PID and variable domain fuzzy self-tuning PID are studied and simulated, respectively. Based on the detailed introduction of the fuzzy management principle, the fuzzy management is applied to the PID parameter tuning, and the fuzzy self-tuning PID manager is designed, and the variable field adjustment scheme in accordance with the input and output of the function is designed, finally, the derived model of the motor screw drive system is taken as the control object, step signal and sinusoidal signal tracking simulation is carried out based on MATLAB, the tracking error of variable domain fuzzy PID is smaller than that of PID tracking at the starting point, and the convergence rate of error is faster than that of PID control, the steady-state error is smaller than PID, the control accuracy is higher, and the tracking performance is better. Because the classical PID control cannot adjust the control parameters online, while the variable domain fuzzy PID can adjust the control parameters online in accordance with the different mistake and mistake change rate, the adjusting speed is faster and the managed effect is improving than PID control. It is clear that by merging machine vision technology with robotics, we can build a robot sorting system based on machine vision, which is a speedy hand eye calibration approach. The deep learning algorithm has a fast computing speed. In addition, the coal gangue sorting robot method is a typical nonlinear and strongly coupled method, and when the robot is sorting gangue, there are a lot of uncertain disturbances that are hard to describe mathematically, therefore, the variable domain fuzzy PID control robot has great advantages, it can modify the managed parameters online according to the
replacement of the robot system, this will result in better control performance. In the future, the identification of the grab point or extraction of the object’s general geometric features may be researched to establish the object’s attitude.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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