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Overview and development of PID control

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Abstract. Proportional integral differential control, referred to as PID control, is one of the earliest developed control methods, which is widely used in industrial process control because of its simple control algorithm, high reliability and good robustness. The classic PID controller is the simplest control system, but the actual control object usually has the characteristics of strong interference, transient uncertainty, nonlinearity, etc, so it is difficult to achieve the ideal control effect with the classic PID controller. In addition, with complex parameter tuning methods, it is often difficult to find an optimal result for the parameters of the classical PID controller. These factors lead to the fact that classical PID control cannot be applied to complex systems and high-performance systems, so people continue to develop PID control methods, introduce new models, and develop fuzzy PID controllers, expert PID controllers, neural network PID controllers, and PID controllers based on genetic algorithms. This paper will review the development history of PID controllers, and introduce fuzzy PID controllers, expert PID controllers, neural network PID controllers, and PID controllers based on genetic algorithms. The research status and future development prospects of these controllers are also prospected.

Keywords: Classic PID controller, Fuzzy PID controller, Expert PID Controller, Neural network PID controller

1. Introduction

Proportional integral differential control (PID control) is a control method widely used in industrial process control, which can adjust the output of the control system, control the controlled object through the output of the control system, and reduce the deviation between the controlled object and the set value. The PID controller is composed of a proportional unit, an integral unit and a derivative unit, and the control effect is adjusted through three parameters: Kp, Ki and Kd. The function of the proportional unit is to adjust the proportion of the control signal according to the magnitude of the deviation, and quickly reduce the deviation. The function of the integration unit is to gradually reduce the output value until the set value is reached by controlling the integration effect of the signal according to the accumulation of deviations. The role of the differential cell is to predict deviation trends and adjust control signals to correct deviations, thus achieving effective control in systems where accurate mathematical models are difficult to build. In practice, the parameters of the PID controller can be adjusted online or according to actual work experience to achieve the desired control requirements. This paper mainly studies the literature of other scholars and summarizes the classification and characteristics of classical PID controller and intelligent PID controller, as well as the problems and challenges faced by PID controller, and the development prospects of PID controller. Through this paper, readers can quickly have a basic understanding of PID controller, and clarify the research direction for readers according to the challenges and problems given later.

2. Development of PID control

PID controller has a history of nearly 70 years [1]. The development of PID control technology can be divided into two stages [2]. The addition of differential control in the late 30s of the 20th century marked the emergence of PID control as a standard structure and a watershed in the two stages of development of PID control [3]. The first stage was the invention stage (1900~1940) [3]. The idea of using PID control is gradually accepted by the public, and the focus is on the structural design of PID controller. After 1940, the second stage, the PID controller had developed into a robust, reliable, and easy-to-apply controller. The focus of research on PID control is also changing. From pneumatic control to electrical control to electronic control to digital control, the volume of PID controllers is gradually shrinking, and the performance is constantly improving [4]. Because of the development of industry and technology, the objects that need to be controlled have become more complex, especially for time-varying, large lag, nonlinear complex systems, some are the parameters of the system are unknown or slow change, some have delay or random interference, and some cannot get a more precise mathematical model. The effect of classical PID controller applications for these systems is not so ideal. The quality of control is increasing, and the defects of classical PID controller are gradually exposed. Therefore, various improvements have been made to the PID controller when applying it. It is mainly reflected in two aspects: one is the improvement of the structure of the traditional PID controller. On the other hand, expert control, fuzzy control, neural network control and based on genetic algorithm control are currently the most important fields in intelligent control, and they are combined with the classical PID controller to form the so-called intelligent PID controller.

3. Classic PID control

The classic PID controller is a linear controller, and its control principle is to generate system deviation from the expected value and the actual value, and then adjust the actual output value of the system through the proportional link, integration link and differential link, so that the actual value gradually reaches the expected value [4]. Therefore, the quality of the control effect of a classic PID controller depends to a large extent on the setting of the parameters of these three links. This article will introduce these three links in detail.

The proportional link is to input the difference between the actual value and the expected value into the system proportionally, and once a deviation occurs, the proportional link will scale up or down the output value to reduce the deviation. The output is proportional to the input deviation, so the deviation between the actual value and the expected value can be quickly reflected, and then the deviation can be adjusted to reduce the deviation. However, the proportional link cannot completely eliminate the static difference, because when the control process tends to be stable, only the difference between the expected value and the actual value can make the controller maintain a certain control output. So only if the deviation exists, the proportional link can be useful. Therefore, the proportional controller must have a static difference. The smaller the scale coefficient, the smaller the control effect and the slower the system response. The larger the scale coefficient, the stronger the control, and the faster the system response. However, the scale factor is too large, which leads to the deterioration of the stability and performance of the system, resulting in a large overshoot and oscillation of the system.

The main function of the integration link is to correct the static error and optimize the integration characteristics of the system. The intensity of the action is inversely proportional to the time constant, and the integration effect is significant when the time constant is low, and the integration effect is weakened when the time constant is low. The duration of the deviation of the system directly affects the activity of the integration link, and as long as the deviation of the system is not corrected, the integration link will continue to intervene. The deviation is integrated so that the continuous output of the controller

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is constantly changing, and the control effect is generated. But too strong integration will increase the system overshoot, and even make the system oscillate [5].

In the differential control link, with the sensitive capture of the deviation change trend, the system is intervened in advance and the correction signal is added, which significantly improves the response speed of the system and effectively compresses the adjustment process. On the other hand, the integration link has the advantage of eliminating static errors, although it comes at the expense of dynamic reaction speed, especially for those objects with high inertia. The power of the differential link is that it not only reacts to the measurement of deviations, but also predicts subtle trends in deviation changes, so that control measures can be implemented in advance, effectively curbing the first signs of deviations, and greatly reducing the time required for the accumulation and adjustment of deviations in the dynamic process of the system. Therefore, the purpose of differential links is to reduce system overshoot, overcome oscillations, speed up the response speed of the system, and reduce the role of adjustment time. However, if the differential time constant is too large, the system becomes unstable.

4. Smart PID control

In recent years, intelligent control has been combined with conventional PID control to form the so-called intelligent PID control [6]. Intelligent PID control combines the essence of traditional PID with the innovation of intelligent control, and its self-learning, self-adaptation and self-organization characteristics give it the ability to actively adjust parameters in the ever-changing control environment. At the same time, it inherits the characteristics of simple structure, superior robustness and high reliability of traditional PID controllers, showing excellent application potential. Because of these two advantages, intelligent PID controller has become an ideal control device for many process controls. Therefore, people have begun to pay more attention to several popular intelligent PID controllers, and examine their composition, their respective characteristics and future development trends.

4.1. Expert PID control

Expert system is a new field of artificial intelligence research pioneered by E.A. Feigenbanm of Stanford University in 1965, and the concept and method of the expert system were introduced into the field of control in the 80s [7]. The expert system consists of two parts: a knowledge base and an inference mechanism, it has domain expert-level expertise, can perform symbolic processing and heuristic reasoning, has the ability to acquire knowledge, and has a certain degree of flexibility, transparency and interactivity [8-9]. In the design of expert PID controller, according to the experience of the control experts, starting from the state characteristics and performance characteristics of the system obtained by feature identification, the control law of PID parameters should be summarized by the expert system, and the law should be stored in the knowledge base to improve the knowledge base. When the system is working, the state of the plant object is input into the expert controller, and the inference machine conducts heuristic inference according to the knowledge base to determine the control parameters of the PID controller required by the system at this time.

4.2. Fuzzy PID control

L.A. Zadeh, an expert in automatic control theory at the University of California, first proposed the concept of "fuzzy sets" in 1965 [10]. Fuzzy control is a new type of computer control algorithm based on fuzzy language variables, fuzzy set theory and fuzzy logical reasoning, which does not rely on the mathematical model of the control object and has the advantages of intelligence and learning [7]. In the design of a fuzzy PID controller, it is necessary to formulate a fuzzy rule table based on the experience and knowledge of the practical operation, and then it is necessary to determine the domain and membership function of the input and output quantities of the fuzzy controller, and the parameters can be obtained by fuzzy reasoning. Therefore, the characteristic of fuzzy PID control is that it does not require an accurate mathematical model of the system, and can also use prior knowledge and expert experience to fuzzy the complex, nonlinear, and time-varying system to quickly obtain the control structure. Therefore, fuzzy PID controller has the characteristics of flexible and adaptable fuzzy control, and has the characteristics of high PID controller accuracy.

4.3. Neural network PID control

Neural network control is an intelligent control and identification method based on structural simulation of the physiological structure of the human brain [7]. With the deepening of the application research of artificial neural network, new neural network models continue to appear, and in the field of intelligent control, the most widely used is BP neural network. Compared with traditional control, neural network control can model complex nonlinear systems that are difficult to describe accurately and do not have accurate mathematical models, which means that neural network control can fully describe a nonlinear system. Since it simulates the structure of the human brain, it will have strong parallel distribution processing capabilities; excellent learning and adaptability; it also has multivariate problem handling capabilities, which can handle multi-input and multi-output problems. The control methods combining neural network and PID control can be divided into three categories, adaptive PID control based on single neuron, PID control based on multi-layer forward network, and PID control based on multi-layer network [11].

4.4. PID control based on genetic algorithm

A genetic algorithm is an iterative adaptive probabilistic search algorithm based on the principles of natural selection and genetic inheritance [8]. The basic idea is to transform the problem to be solved into an evolutionary population composed of individuals and a set of genetic operators that operate on the group, including three basic operations: replication, crossover, and mutation [8]. In the PID controller design of the genetic algorithm, it is necessary to form a gene code of the parameters in the controller, and then transform the code through the three basic operations of the genetic algorithm to obtain a plurality of gene codes, screen the gene codes, and leave the codes with high adaptability to form a new population, and the new groups inherit the information of the previous generation and are better than the previous generation, and the optimal parameters of the problem are obtained over and over again.

5. Conclusion

With the continuous development of science and technology, technological progress has led to the increasing complexity of the control system, and the traditional PID control is unable to cope with the performance of more complex systems. Intelligent PID control has been applied and recognized in many fields due to its adaptability to imprecise knowledge of the model and excellent robustness. All of the PID controllers mentioned in this paper have proportional, integral, and differential links, but this article does not explore how to quickly and accurately determine the parameters of these three links. Since the 20th century, PID has undergone nearly a hundred years of development. However, in terms of theory, such as parameter tuning, a large number of industrial needs still require more in-depth research in this field. The ultimate goal is to find a simpler and more practical method of parameter tuning with as little prior knowledge as possible. Intelligent PID control technology needs to be deeply explored, and the automatic diagnosis mechanism of self-adaptation, adjustment and gain planning should be integrated to improve its precise control ability. Combined with expert experience, knowledge, intuitive logic and other expert system thinking methods, the original PID controller design idea and tuning method are improved. Starting from the reality of the production process, the design of a control scheme that meets the requirements of the actual process, and the combination of expert control, fuzzy control, neural network control, genetic algorithm control and PID control is a very promising direction for the development of intelligent control.

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