Application of the PID Algorithm in Robot

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Abstract. Under the background of rapid development of science and technology and much attention in the field of robotics, the Vex robot is of great significance in the field of education, but there are difficulties in control. Given that the Proportional-Integral-Derivative (PID) algorithm is widely used in the control field and there are achievements and shortcomings in related research, this paper discusses in depth its application in the control of VEX robots, including the analysis of the mathematical principles of the PID algorithm, the specific operation steps in the practice of programming VEX robots, as well as the parameter optimization method through regression analysis. The results of the study show that this paper successfully analyzes the mathematical principles of the PID algorithm, has specific and effective steps in practice, and improves the machine rotational control performance through regression analysis. This research provides an important theoretical and practical basis for optimizing the application of the PID algorithm in VEX robots, which plays an important role in robot control, and the algorithm also has the potential to be applied and expanded in other operating robots.

1 Introduction

In today's era of rapid technological advancement, advances in the field of robotics have received a lot of attention. Some researchers expect robots to replace humans in performing various tasks, while others expect robots to be able to perform high-precision and complex tasks. While Vex robots are of limited value on a practical level, they have demonstrated significant importance in the field of education, where they teach students how to design and build robots, covering a wide range of aspects such as structural design, programming and algorithmic implementation. Additionally, during the competition, participants must strive to ensure accuracy and dexterity in the operation of the robot, a process that helps to effectively develop students' science, technology, engineering, and math [1] skills.

In recent Proportional-Integral-Derivative (PID) research, many scholars have explored the improvement and application of PID control methods in different fields. For example, Borase et al. [2] provided a review of PID control, tuning methods, and applications, which provided a reference basis for widely used PID algorithms. Meanwhile, some innovative methods have been proposed, such as Wang Zhu et al. [3] who developed an intelligent PID tuning method based on reliable identification in a long-period process, and the in-depth study of intelligent and fuzzy PID tuning methods. Some scholars study the neuron PID controller for membrane structure inflatable systems, which can automatically adjust the

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parameters, adapt to changes, and have high control accuracy [4]. There are also scholars through the underwater vehicle dynamics model to get the depth control transfer functio and introduce the fuzzy PID control algorithm steps, simulation shows that its control effect is good, but there are shortcomings such as difficulty in adjusting the parameters [5].

The purpose of this paper is to discuss in depth the application of the PID algorithm in VEX robot control, covering the analysis of the mathematical principles of the algorithm, the practical steps, and the method of parameter optimization through regression analysis. The paper begins with an overview of the wide application of PID algorithm in control systems and the current situation in the field of VEX robot control. Subsequently, the mathematical principle of the PID algorithm is analyzed in detail, and the roles of proportional, integral, and differential parts and the corresponding formulas are explained respectively. Then, an empirical analysis is carried out to introduce the specific steps in the programming practice of VEX robots, including the calculation of proportional, integral, and differential terms, the synthesis of control output, and the judgment of system stability. Finally, the PID parameters are adjusted in machine rotation control through regression analysis to enhance the control performance and ensure the stability of large-angle control and the accuracy of small-angle control under the control requirements of different angles.

2 Application of PID algorithm in VEX robot control

2.1 Overview of the PID Algorithm

The Proportional-Integral-Derivative algorithm is a classical feedback control mechanism used in control systems [6]. It is widely used in industrial control, robotics, automated driving, etc. to adjust variables to stabilize the system to a target value.Visioli and Zhong [7] discussed the application of PID in detail in the control of an integral process with time delays. Although many literatures mention the successful application of PID algorithms in complex systems, there is an urgent need for more specific application guidance in unique scenarios such as VEX robots.

In the application area of the PID algorithm, much literature and information has elaborated on the principles of the algorithm, and some studies have pointed out its superiority in multi-wheel control. However, there is a relative lack of guidance on how to effectively implement PID algorithms in practical applications. Globally, many VEX robotics teams have some understanding of the concepts and principles of PID algorithms, but the ability to apply them in real-world programming is still lacking, especially with respect to PID algorithms for turn control.

Turning control is regarded as a key difficulty in robot control, which usually needs to be solved by using complex algorithms. In contrast, PID algorithms are able to achieve more precise control results in a relatively simple and concise manner. Although there are many examples of PID algorithms being used in several industries and industrial robots, due to the unique VEX C++ library used in VEX robots, there are relatively few discussions in the literature for this specific environment.

Therefore, this section will not only explore the specific application of the PID algorithm in the program but also describe how to debug the appropriate PID parameters so that the algorithm can be utilized more effectively in the VEX robotics program.

In the C++ library for vex robots, there are no algorithms that can directly control and coordinate multiple motors. This makes it tough to accurately and completely execute a segment on a robot that is not controlled by a PID algorithm. And there are also problems such as front wheel buckling and slowing down too much. Pid will provide a lot of help to the players. Similar to balancing speed and accuracy, precise control of motor power, etc.

Most vex players do not understand how to use the pid algorithm on their robots. In this context, it becomes necessary to write a set of pid programs that can actually be used in the unique C++ library for Vex robots. In this, there are several difficulties to overcome: the fitting of the pid turning algorithm, the control of the different states of the pid turning algorithm, and how to keep the PID algorithm from overshooting and maintaining basic stability.

2.2 Analysis of mathematical principles of PID algorithm

In analyzing the mathematical principles of the PID algorithm, the approach of Wang et al. [8] in servomotor control and fuzzy PID applications can be used to provide a more specific description of the PID control strategy. These studies provide empirical support for PID algorithms to improve accuracy and control stability in physical systems.

PIDs are categorized as Proportional, Integral, and Derivative. In the practical application of p-algorithms, study usually creates an error that will give the robot a buffer of the distance it has already traveled before it reaches the target point. During research, a specific error is normally generated that allows for the difference between the distance the robot has covered before reaching the target point. The error is defined as the difference between the value of the sensor at the instant time and the value that the sensor value is expected to attain [9]. Based on this, it can already get the formula: error = set_angle - sensor value. For turning, the error in this pid becomes the encoder value of the gyroscope.

The closer they get to the target value, the slower the turn gets. It does not reach the desired value exactly and becomes infinitely slower in the last part of the turn.

At this point, a constant is needed: kp. This constant will manually adjust the error, and if it is accurate enough, the robot will be able to travel exactly to the specified target angle without performing any unnecessary movements.

The integral will eliminate these errors by slowly increasing the power. The integral is to recall all the errors that have been calculated by the system.

Moreover, the I-algorithm can control the power when the p-algorithm goes out of control, preventing uncontrollable behaviors such as overshooting.

At this point the I algorithm is formulated [10] :

$$\mathrm{I(t)} = \mathrm{K_i} \int_{\mathrm{e}}^{\mathrm{t}} \mathrm{e(t)d\tau} \tag{1}$$

Where, I is the output value of the integral term. K_i is the Integral Gain, i.e. the integration coefficient, which controls the strength of the integration term. The e is the error value of τ at each moment in the past, indicating the gap between the target value and the actual value. $\int_0^t e(\tau)d\tau$ represents the accumulation of error from time 0 to the current moment t. The integral term, by amplifying the sum of the error accumulation over time, allows the controller to generate larger and larger correction signals as the error persists. This effectively removes the steady state error from the system and brings the output value closer to the target value.

Suppose it wants to keep the angle at 25° in a turn. However, due to some disturbance, the actual angle is always 2° below the target. In this case, the proportional control may only be able to maintain the angle around 23°, but not 25°. The integral term accumulates this 2° error and gradually increases the control signal to maintain the angle at the target of 25°.

The D-algorithm stands for Differential. The differential term is used to calculate the rate of change of the error so that the future trend of the error can be predicted. Its main function is to suppress rapid changes in the error and reduce the oscillations of the system, thus improving the dynamic response of the system.

The main role of the D-algorithm is to suppress the error, and when there is a rapid change in the angular value, the D-algorithm intervenes and gives the reverse value

At this point the main formula of D algorithm

$$D(t) = K_d \frac{de(t)}{dt} \quad (2)$$

Where, $D(t)$ is the output value of the differential term.$\cdot K_d$ is the Derivative Gain, which controls the strength of the differential term.$\cdot e(t)$ is the error value at the current moment, indicating the difference between the target value and the actual value $\frac{de(t)}{dt}$ is the rate of change of the error over time.

3 Empirical analysis

3.1 Empirical Steps

In v5code practice, it is common to encapsulate the Proportional, Integral and Differential algorithms in three separate functions and call them uniformly when needed. However, in this instance, this study chose to create a total PID controller file in which all the PID control logic is integrated.

First, this paper calculates the proportional term [10]. The formula for the proportional term is to multiply the proportional gain coefficient with the current error , and the resulting result is called P_put. the main function of this proportional term is to provide an immediate corrective force based on the magnitude of the current error, and the larger the value of the proportional term, the faster the control system will respond.

Next, this paper calculates the integral term. During the calculation process, if the absolute value of the current error is greater than a specified threshold, the integral amount will be reset to zero, indicating that no integral adjustment is performed when the error is too large. Otherwise, the integral quantity continues to accumulate the current error until its absolute value exceeds the maximum limit. Eventually, the output of the integral term is derived by multiplying it by the integral gain coefficient, which also limits its maximum output value to no more than max_I_put.

This is followed by the calculation of the differential term. The calculation of the differential term is accomplished by the difference between the current error and the previous error, which represents the rate of change of the error. This rate of change is amplified by the differential gain coefficient to obtain the differential term output.

Subsequently, the outputs of the three terms P, I and D are synthesized into the final control outputs. This output is the sum of the three and is limited when its absolute value exceeds the maximum power.

Finally, the stability of the system is determined. When the current error is within a set blind zone and the rate of change of the error is below a tolerance value, the system can be considered to have reached a stable state if this state lasts for more than a set period of time. For this reason, this study uses a timer to determine how long the system lasts in the steady state.

3.2 Regression analysis

In machine rotation control, the PID parameters will be adjusted accordingly with the change of target angle, so regression analysis can be used to quickly estimate the suitable parameters. The specific steps are as follows:

1) Set the sampling points in SPSS software, for example, select 10, 20, 30, 60, 90, 120,

150 and 180 degrees as the test angle.

2) Set the integral gain and differential gain to 0, and test the appropriate proportional gain value for each sampling point in order to realize the fast approach to the target and avoid overshoot and instability.

3) Plot a scatter plot to observe the distribution of data points and their approximate curve model. Many points can be seen in Fig. 1, which represent at each angle corresponding to the k_p value.

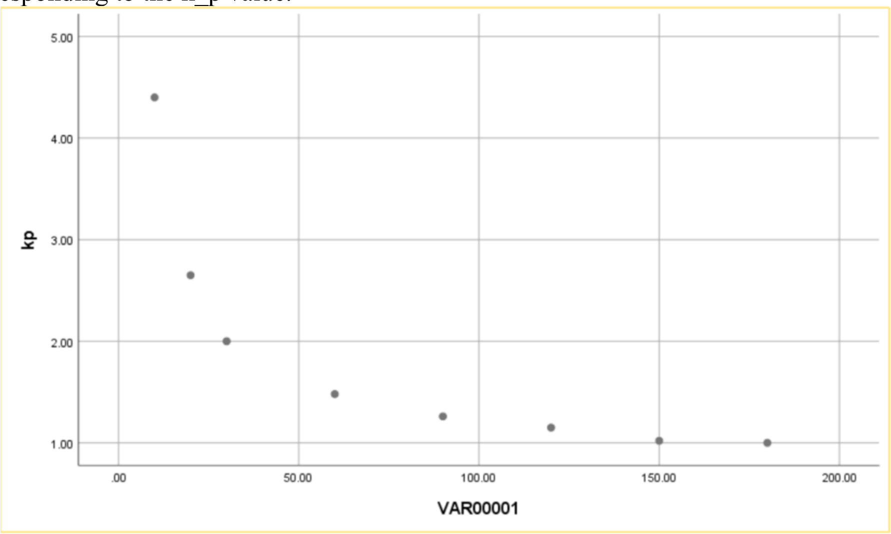

Fig. 1 Distribution of kp at different angles (Photo/Picture credit: Original)

In Fig. 2, this paper creates a fitted curve, as these points get closer to the fitted curve, this represents that the k_p data is healthy.

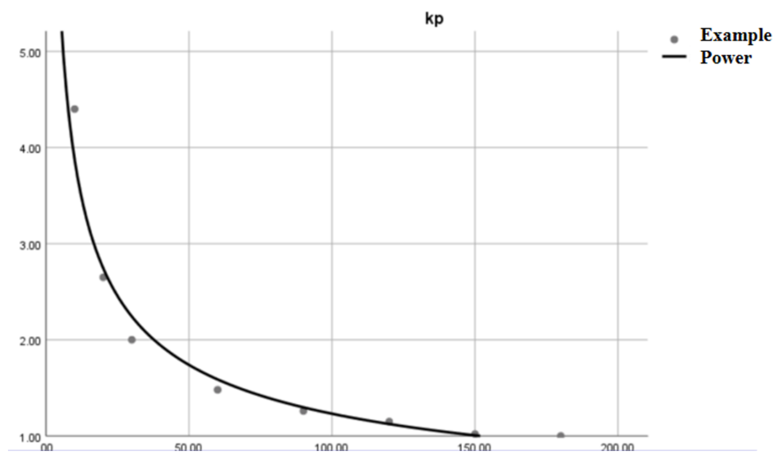

Fig. 2 Fitting curve (Photo/Picture credit: Original)

Selecting the appropriate model for data fitting in SPSS, Table 1 can be obtained.

Table 1. Fitting results

	square sum	degrees of freedom	equal square	F	significance
regression	1.876	1	1.876	255.148	.000
residual	0.44	6	007		

total	1.920	7			

The results of the fit are observed to ensure that the model fits the actual data better. In this example, the fitting relationship obtained is .

5)Apply the calculated value in the program and set to 0.05 as an empirical parameter.

6)For the actual points in the fitted image that are below the fitted curve are tested, noting possible overshoot . If overshoot occurs, the value of is gradually reduced until the overshoot is eliminated.

7) For the test of real points in the fitted image that are higher than the fitted curve, consider the lack of response due to the farther angle of the target. In this case, the value of can be increased moderately or the limit of can be decreased.

8) Repeat steps 7 and 8 until the control requirements for all angles are largely satisfied. When dealing with large angles, the focus is on the stability of the control, while in small angle control, accuracy needs to be ensured and overshooting avoided.

9) Through the above steps, the PID parameters can be systematically adjusted and optimized to improve the performance of machine rotation control.

In application practice, adjusting PID parameters through regression analysis provides an optimization path for actual control. This section discusses how to apply software tools for parameter tuning, in analogy with the control of electrohydraulic servo systems. The specific analysis steps described in the article can help us better understand and apply PID control.

4 Recommendations

This article provides the readers with the simplest PID turning algorithm, followed by some suggestions for some scholars who want to study PID in depth.

The optimization of PID algorithm involves two main aspects. First, researchers are committed to exploring more efficient algorithms and data structures to improve the accuracy and efficiency of PID control in the steering process. Second, the research of adaptive PID algorithm has also attracted wide attention, which requires more and more sophisticated sensors to monitor the system status in real-time, so as to realize the dynamic adjustment of control parameters to adapt to the changing environment and task requirements.

The application of PID algorithms is not only limited to Vex robots but also has significant potential for application in various types of operational robots. For example, PID algorithms can be used in diving robots and operational drones to achieve efficient and stable working conditions. Through the rational application of PID control strategies, these robots can maintain good control performance in complex operating environments, thus enhancing their operational efficiency and reliability.

5 Conclusion

This paper centers on the application of the PID algorithm in VEX robot control to carry out an in-depth study. Firstly, it describes the relative lack of guidance on the effective implementation of the PID algorithm in practical applications, especially in the unique C++ library environment of VEX robots, which is less discussed. Then, it is pointed out that turn control is a key difficulty in robot control, and the PID algorithm can realize precise control in a relatively simple way, but it is not enough to be applied in VEX robots.

In the paper, the mathematical principles of the PID algorithm are analyzed in detail, including the proportional term, which provides instant correction force by calculating the error and proportional gain coefficient; the integral term, which eliminates the steady state error by accumulating the error; and the differential term, which calculates the rate of change of the error to inhibit the rapid change of the error and reduce the oscillation of the system.

In the empirical analysis section, specific steps in VEX robot programming practice are presented, such as encapsulating the proportional, integral, and differential algorithms in a single file, calculating the outputs of each separately and synthesizing the final control outputs, and also judging the system stability based on the current error and the rate of change of the error. In addition, the PID parameters are also adjusted in the machine rotary control by regression analysis, including the steps of setting the sampling points to test the proportional gain value in SPSS software, plotting the scatter plot to observe the data distribution, and selecting the model for data fitting to improve the performance of the machine rotary control.

In summary, this paper provides a comprehensive and in-depth study of the application of the PID algorithm in VEX robot control, which provides an important theoretical and practical basis for further optimizing the application of this algorithm in VEX robots.

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