A Fast and Stable Motor Angle Based on PD Controller with Its Improvements

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Abstract. With the rapid development of IT technology, the field of industrial control is constantly innovating and developing, and PD control algorithm, as a classic and effective control method, will continue to play an important role in this field. By applying the PD control algorithm to the motor control, the angle of the DC motor can be controlled, and the time for the DC motor to stabilize can be shortened. PD control is proportional plus differential control, which can quickly predict future changes and respond when the system is stable. It is characterized by speed and stability. However, in some high-precision fields, if the PD controller used cannot be controlled in a specified short time and achieve the established stable voltage, then the role of PD control is very small. A proportional-derivative (PD) control with fast and stable motor angle output is displayed. The methods of design will be demonstrated. It can make the output steady at 227.3 milliseconds, which actually met the expectation of 300 milliseconds. However, there're still some things to improve. This kind of fast-response PD controller is to be used in some high-precision areas to assure the digits or other things conveyed promptly. While PD controllers have developed since long time ago, they remain to have a promising future to be applied to many others emerging domains.

Keywords: PD Control; DC Motor; Fast Response

1 Introduction

Today, with the rapid development of IT technology, the field of industrial control is also constantly innovating and developing, and PD control algorithm, as a classic and effective control method, will continue to play an important role in this field. By applying the PD control algorithm to the motor control, the angle of the DC motor can be controlled, and the time for the DC motor to stabilize can be shortened, thereby improving the applicability and efficiency. PD control is proportional plus differential control, which can quickly predict future changes and respond when the system is stable. It is characterized by speed and stability. The differential is a drag force that effectively dampens the oscillations generated by the system itself. The disadvantage is that there is electrostatic difference and amplified noise, and when the deviation is very small, P and D basically do not work, so there will be electrostatic difference. In

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order for the PD controller to be better used in the industrial field, especially for the high time delay requirements, the short stability time of the PD controller has become an important factor. However, in some high-precision fields, if the PD controller used cannot be controlled in a specified short time and achieve the established stable voltage, then the role of PD control is very small.

Therefore, in this paper, we will reduce the stability time to 0.2273 seconds based on the design of the Falstad circuit and the simulation of the Tinkercad model of the motor angle of the PD control motor circuit to achieve a faster stabilization time. Compared with the original 0.57 seconds, the final simulation result is also in line with the expected stability time of 0.3 seconds.

2 Methods and Material

In the process of this exploration, firstly, the Octave software was to help calculate the parameters and analyze the feasibility of the whole system. Secondly, the Falstad software was used to build the simulation circuit, the circuit was divided into three modules, built and integrated, and the parameters were analyzed, and after the analysis was roughly in line with the expectations, the simulation circuit was built by Tinkercad software, and whether the output of the oscilloscope and the results were roughly in line with the output of Falstad, and finally the conclusions were summarized by combining the two.

In the process of exploration, the main circuits used are as follows (see Fig. 1):

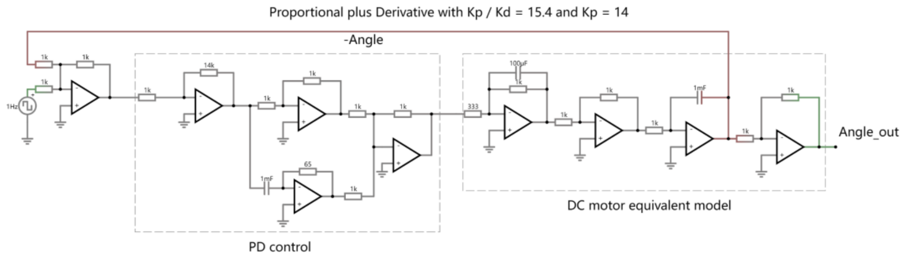

Fig. 1. The whole circuit system(Photo credited: Original)

The whole circuit system is shown in the Fig. 1, which is mainly divided into three modules: adder module, PD control module and DC motor equivalent analog module.

When evaluating the closed-loop step response diagram, those parameters should be included, such as rise time, peak time, overshoot, steady-state error, number of oscillations, stability and so on.

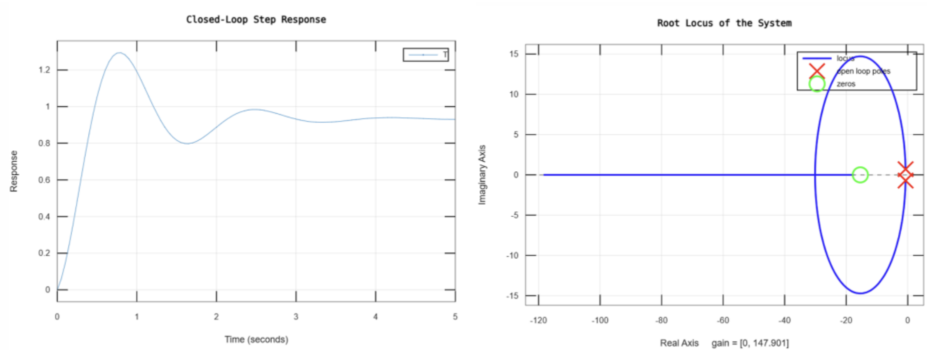

Fig. 2. The closed-loop step response and root locus of the system(Photo credited: Original)

The result of the closed-loop step response and root locus of the system is shown in Fig. 2. Firstly, the body plot just shows the response characteristic of the system. And in the frequency domain, that's the frequency here. The gain magnitude that is gain phase. So in the magnitude plot here, initially the gain is high, which is thirty. It means that the low frequency signal can be just greatly amplified. The gain of the system decreased as the frequency increase. And for the phase diagram here, it can be seen that the phase diagram just shows the system. Starting with the negative value next, ninety five here, it decrease as the frequency increase and then increase.

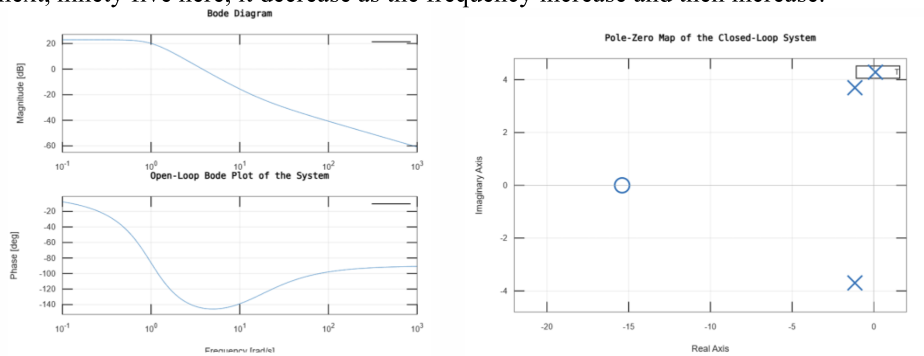

Fig. 3. The other parameters and results of the system(Photo credited: Original)

In the Fig. 3, the piece map here shows the distribution of dots and zeroes of the system in the that's a complex thing, so that is related to the time response character, so the dots here are all located in the left half. Complex plane indicates that code loop system is stable. So in this particular case, we can see two poles light on here on the real axis. Therefore, it can it normally just result in an over damp system response with our oscillation. The false can be done then by that simulation.

Given that the value of Kp is 1 and the value of Kd is 0.9, we can specifically correlate the simulation results of Octave to the circuit parameters based on these specific values. Here is a detailed explanation of how to do it: amplifier of an Op-Amp Gain = 1 + Rf/Rin To achieve Gain = 1, Rf needs to be 0Ω or negligible, making it similar to a buffer without gain. Derivative Controller (Kd = 0.9) Derivative controller design is complex, with Rf and Cf selected based on differentiator principles. Kd effect depends on input signal frequency. No direct formula exists to convert Kd to Rf and Cf, but circuit principles can guide selection. Gain = -RfCfω, where ω is signal angular frequency. Selection of Rf and Cf is based on desired Kd value at a specific operating frequency. For Kd = 0.9, adjustment of Rf and Cf is needed. Signal frequency range should be considered during design. A simplified approach is to assume an operating frequency and select Rf and Cf based on that frequency to achieve an approximate Kd effect. For example, at 1kHz, suitable Rf and Cf values can be found through experimentation and adjustment to achieve a differential gain of 0.9 at that frequency.

The main function of the adder module is to accept the feedback signal from the DC module for the adaptive adjustment of the circuit. The main principles are as follows (see Fig. 4):

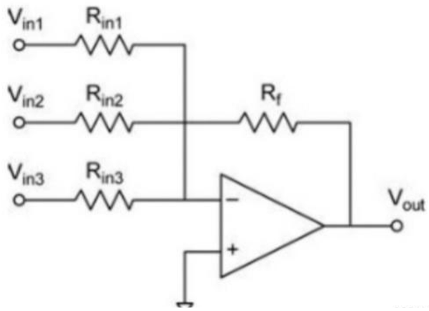

Fig. 4. An example of summer(Photo credited: Original)

For the reverse adder circuit above, the resulting output voltage Vout should be:

$$Vout = -\left(\frac{Rf}{Rin1}Vin1 + \frac{Rf}{Rin2}Vin2 + \frac{\mathrm{R}f}{Rin3}Vin3\right) \quad (1)$$

For the adder circuit used in the inquiry, the result is:

$$\mathrm{Vout1}=-(\mathrm{Vin1}+\mathrm{Vin2}) \quad (2)$$

An inverting adder is a basic circuit element widely used in analog and digital circuit design. It sums up different input signals by inverting and adding them. Specifically, when the input is positive, the output will be negative, and vice versa. Therefore, the word "invert" in its name indicates the negation of the input signal. In this circuit, it is used as a receiver for feedback and is adaptively stabilized.

The PD controller module is the most important part of the circuit system. It is mainly used to measure the error of the system and the rate of change of the error to calculate the control output so as to realize the stable control of the system. The algorithm works as follows:

$$\mathrm{u(t)} = Kp * e(t) + Kd * \frac{de(t)}{dt} \quad (3)$$

u(t) is the output signal of the controller, Kp is the proportional gain coefficient, Kd is the derivative gain coefficient, e(t) is the error of the system, and $\frac{de(t)}{dt}$ is the rate of change of the error.

The proportional term Kp of the PD controller is used to regulate the control output based on the current error, while the derivative term Kd is used to regulate the control output based on the rate of change of the error. The proportional term helps the system to respond faster to the error, while the derivative term provides better stability and suppresses oscillations.

In this study circuit, the PD control circuit is as follows (see Fig. 5):

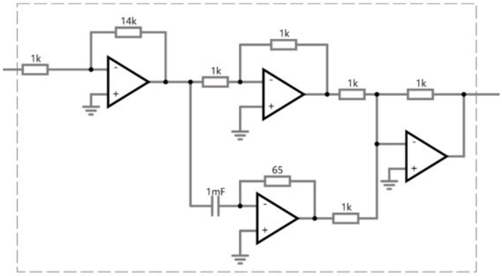

Fig. 5. The PD control circuit of the system(Photo credited: Original)

In the Figure 5, Proportional operation amplification circuit part is shown:

The circuit first consists of an inverting operational amplifier and a PD controller that can be controlled separately from Kp and Kd.

For proportional amplifiers such as (see Fig. 6):

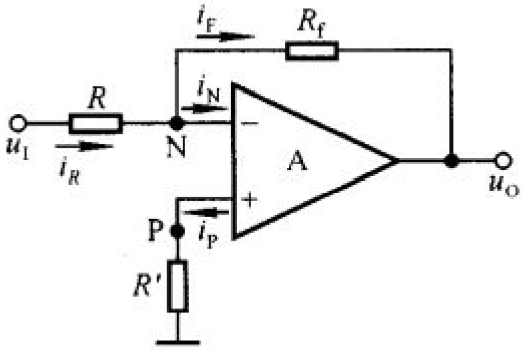

Fig 6. An example of the invert operational amplifier [1]

This is a typical parallel feedback negative feedback circuit, the input voltage U1 acts on the reverse input terminal through the resistance R, so the output voltage is reversed with the input voltage, and the inverting input terminal is grounded by the compensation resistance R', and its value is the equivalent resistance of the inverting input terminal when U1=0, that is, the parallel connection of the resistance of each branch, so R'=R//Rf. Negative feedback is introduced by Rf, so Un=Up=0, i.e. "virtual ground", which means it's not attached to ground, Ip=In.

For the output voltage uo there are:

$$\mathrm{u}o = -\frac{Rf}{R}ui \tag{4}$$

According to the proportional amplifier circuit applied to this study, it can be inferred that the bond between the output uo and the input is as follows:

$$\mathrm{u}o = -\ 14\ ui \tag{5}$$

The main body of the PD controller:

PD control is essentially a kind of advance manipulation. The controller can predict the direction of the error and thus improve the control of the system. Generally, in a linear system, if the slope of the input signal or the output obtained by the step response is above the expectation, a large overshoot will be generated correspondingly, and the instantaneous slope of the input signal is measured by differential control, and the large overshoot is predicted in advance, and the appropriate correction is made before the large overshoot occurs.

By and large, differential control only works when the stable-state error of the system changes over time. If the stable-state error stays constant over time, the time differential of the error is zero, and the differential portion of the controller cannot provide input to the system. When the error of stable-state increases with time, the torque changes proportionally to (de(t))/dt, which decreases the error amplitude. More importantly, the PD control does not change the type of system due to errors in the feedback control system.

The control signal output by the controller is only proportional to the coefficient of the controller, and this kind of control is called proportional control. In general, in addition to proportional operations, differential or integral operations of input signals can also be used. Therefore, a more general continuous controller should include elements such as addition (subtraction), amplifiers, attenuators, differentiators, and integrators. Therefore, it is important to have a clear understanding of the functions of the individual components and to put them together in a reasonable way. For example, the most commonly used type of controller in practical applications is the PID controller, and the three letters represent proportional, integral, and derivative, and the differential and integral parts of the PID controller have their own performance meanings. For the PD control circuit of the exploration circuit, you can refer to the following example circuit to design:

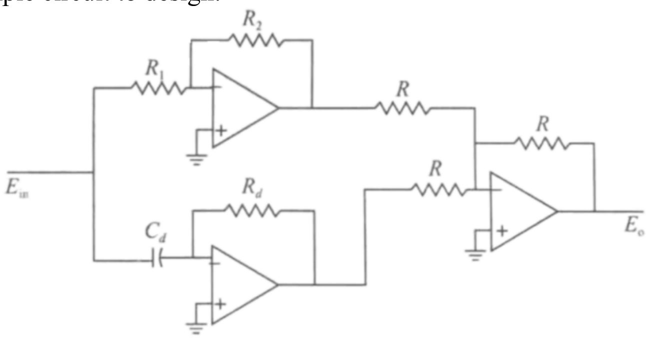

Fig 7. An example of the PD control circuit [2]

In the Fig. 7, the proportional gain coefficient Kp is:

$$\mathrm{Kp} = \frac{R2}{R1} \tag{6}$$

The derivative gain coefficient Kd is

$$\mathrm{Kd} = \mathrm{RdCd} \tag{7}$$

This circuit allows independent control of Kp and Kd values. You can choose a larger Rd value to compensate for the larger Kd, so that the Cd value is more reasonable.

The PD controller parameter initially used for this investigation was Rd=90.9Ω, but the stabilization time was too long, about 0.5s; the Kd parameter was adjusted to shrink Kd so that Rd=65Ω, and the final stabilization time was shortened to 0.273s. It can be obtained:

Proportional gain factor Kp=1, derivative gain factor Kd=0.065 (see Fig. 8):

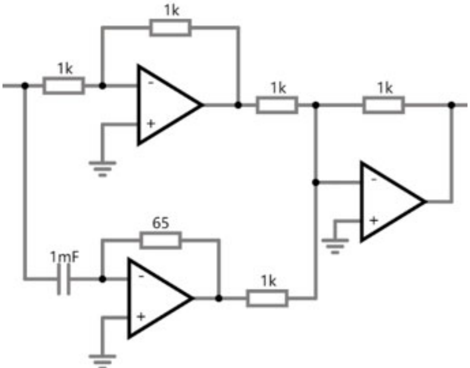

Fig 8. The PD control circuit of the system (Kd=0.065) (Photo credited: Original)

In the Figure 9, the DC motor equivalent model is shown:

This part is to simulate the DC motor to output the result of angle-out to observe.

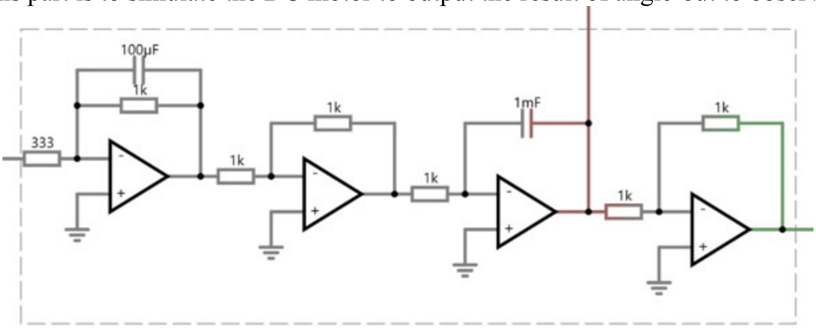

Fig 9. The DC motor equivalent model circuit of the system(Photo credited: Original)

After the parameters of each part are calculated, the three modules are integrated. The simulation circuit is first built using Falstad software and the total circuit diagram is shown in Fig. 1. the simulation results are as follows (see Fig. 10):

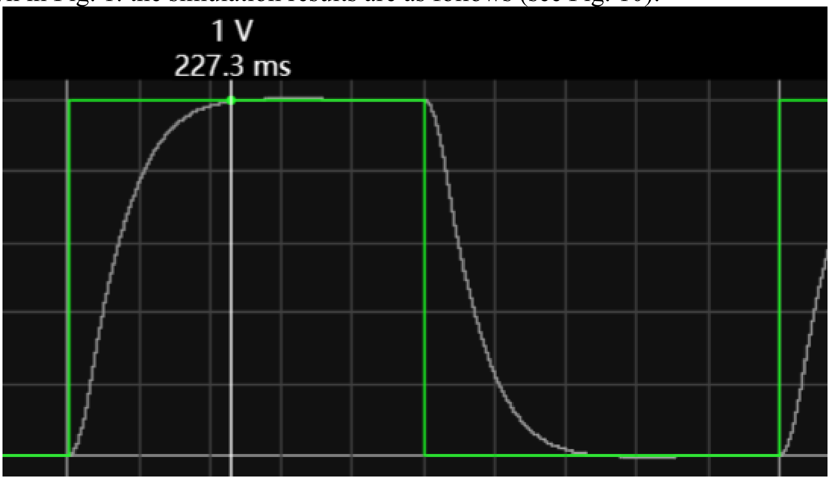

Fig 10. The response time result of Falstad(Photo credited: Original)

In the Fig. 10, it can be seen from the simulation result plots: the maximum value of the output voltage of the circuit system is 1V and the voltage stabilization time is 227.3 milliseconds. The latter meets the expectation and is much less than 300 ms.

It is verified that the circuit system can achieve faster steady state response of the circuit. The next step is to perform the solid circuit simulation in Tinkercad software. The solid circuit is as follows:

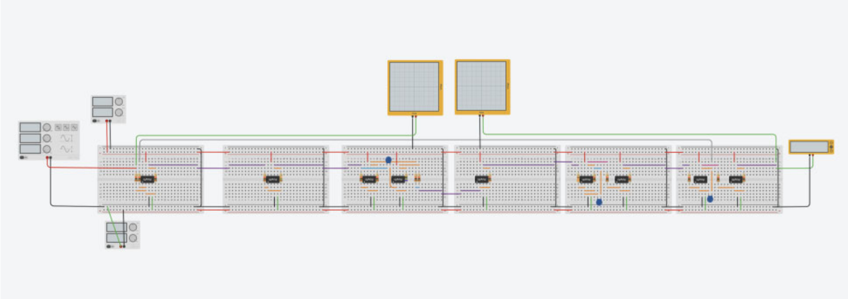

Fig 11. The Tinkercad model of the system (Photo credited: Original)

Turn on the power of the circuit in the Fig. 11 and wait for a few seconds to get the following result:

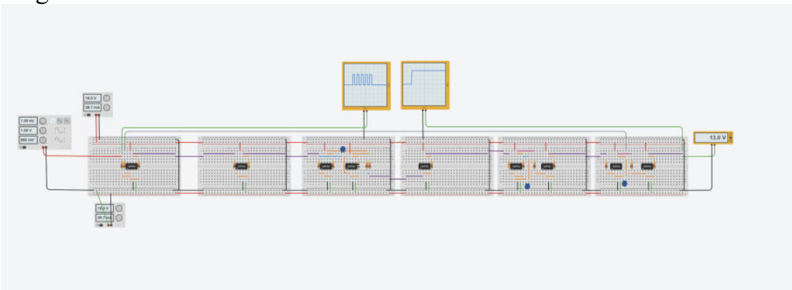

Fig 12. The Tinkercad model of the system with the result of oscilloscope (Photo credited: Original)

To enlarge the result of the oscilloscopes in the Fig. 12, the result are shown below:

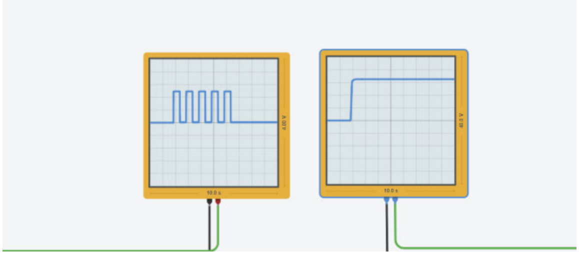

Fig 13. The result of oscilloscopes (Photo credited: Original)

In the Fig. 13, it can be seen: the oscilloscopes divide each time for 1s, so the circuit voltage stabilization time is less than 300ms established, which is roughly as expected.

3 Results and Discussion

After all these parameters calculated, models built as well as result analyzed, it can be concluded that the whole circuit have the capability to stabilize faster than the initial one, meeting the demands. In the Falstad simulation tool, the real-time response of the signal can be visually seen by building the circuit and running the simulation. Falstad's results should focus on: Output waveform as expected: Check that the shape, amplitude, and frequency response of the waveform are consistent with Octave's predictions. System stability and response time: Assess how quickly the circuit reaches steady state and whether there are overshoots or oscillations. Tinkercad provides an entity simulation environment closer to the actual hardware operation, where the general result analysis also includes: Check the output waveform: simulation with Falstad to verify the waveform characteristics. Problems that may be encountered in actual operation: such as wiring errors, improper component selection, etc. Results Comparison and analysis. Comparison standard: The simulation results of Falstad and Tinkercad are compared with the theoretical prediction of Octave, mainly to see whether the three agree with each other in terms of output waveform, stability and response time. Analyze the differences: If differences are found, analyze possible causes, such as the accuracy of simulation tools, non-ideal characteristics of circuit components, etc. Tuning and optimization: Depending on the results of the analysis, it may be necessary to adjust the circuit parameters or reconfigure the circuit layout to more closely match the performance predicted by theory.

However, during the whole procedure, a series of problems were encountered. To start first, the tracking speed of the expected output signal might be restrained by peaking phenomenon while it have been already solved by utilizing the NLESO-based PD controller, which is declared in PD controller for linear motors via nonlinear extended state observer [3]. This type of PD controller via nonlinear extended state observer has the advantages of high tracking speed and precision, small peaking phenomenon and strong robustness. Another nonlinear PD controller is mentioned in A Nonlinear PD Controller and Its Control Surface Rotating [4], which can consider the stability margin and the stiffness of the system separately, which is a good compromise between the different performance indexes. The same theory comes up in The Development of a New Approach for Nonlinear PD Control [5]. Besides, in another reference, a differential gauge improved PD controller combining the advantages of linear PID and nonlinear PID can greatly improve the response speed of the system, optimizing the rapidity and stability, with the control performance of the system improved so as to expand its scope of application [6]. All improvements like the above are the needed in this period.

What's more, the models building can have diverse methods. For example, Matlab software provides the environment where parameters of the closed-loop transferer of the system would be defined, contributing to the foundation of system time-domain model, which is mentioned in Experimental modeling and simulation of linear motor drive system based on PD control [7].

Today's controller development direction tends to be digital, integrated, intelligent, networked, which means the same for PD controllers. In Research on Improved PD

Control of Flexible Manipulator [8], a PD controller based on NNs (neural networks) is proposed, with the optimization of PD parameters achieved by NNs as well as the performance of PD control improved. As for the aspect of intelligent control, a composite control of RBF and PD is proposed for the tracking control of nonlinear dynamic systems which is more generally appealing compared to polynomial NARMAX (Nonlinear Autoregressive Moving Average with Exogenous inputs) model and many others [9]. There's another example that is mentioned in Variable Parameters PD Control and Stability of a High Rate Rigid Rotor-Journal Active Magnetic Bearing System [10], where a lot of adjusting work of control was reduced providing great convenience. Also, in an article about reinforcement learning compensation which is set up on PD control [11], PD control is combined with Q-learning techniques based on reinforcement learning for an inverted pendulum. This can bring the pendulum to its inverted vertical position, regardless of the applied disturbance. As a trend of integration of multiple fields so as to apply to science,

PD control also needs to get attached to other advanced techniques to improve itself. As for digital improvements, in Stability Analysis for Digital PD Control of Flexible Systems Including Damping [12], digital PD control has been an essential tool in the high-precision domains. In the domain of artificial intelligence, traditional PD control algorithm can help extended the application of AI. It is mentioned in Finite-time PD control of robot manipulators with adaptive gravity compensation that this sort of control is an extension of the conventional linear PD control [13], which is adaptive gravity to compensate for robot manipulators.

With its wide versatility, PD controllers have become a vital as well as irreplaceable tool for the science field and definitely have a prosperous future. In Research on Robot Position Control Based on Improved PD algorithm [14], PD control is believed to motivate the intelligent robot area continuously. Beside, this perspective is also mentioned in PD control with on-line gravity compensation for robots with flexible links [15].

4 Conclusion

All in all, an fast-stabilized PD controller has been displayed. It can make the angle output steady at 227.3 milliseconds, which actually met the expectation of 300 milliseconds. It is hoped to be applied to some high accuracy areas to improve efficiency as well as precision. However, there're still some things to improve. For example, different models building methods can be applied to the parameter-design part, such as Matlab and stimulink. This kind of fast-response PD controller is to be used in some high-precision areas to assure the digits or other things conveyed promptly. But not meeting the expectations of its practicality, it remains to get advanced in its availability for wider domains. While PD controllers have developed since long time ago, they remain to have a promising future to be applied to many others emerging aspects. And in order to adapt to the modern science much easier, it needs to combine itself with advanced technique so that the PD controller can be vibrant for much longer time.

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