The Research on Control System of Pipeline Dredging Robot based on Simulink

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Abstract: In order to control the new pipe dredging robot more accurately and ensure the stable operation of the robot in the harsh environment, the motion control system of the robot is designed and the PI algorithm based on double closed-loop speed control system for walking unit of wheeled mechanism is studied. According to the Simulations by Simulink and experimentations of the above control methods, it was indicated that the motor speed can be stabilized at the set speed value under the disturbance of load change, and the dynamic performance is also stable. Finally, a double closed-loop speed control system with strong anti-load fluctuation capability is adopted. The control method satisfied the requirements of the working condition of the robot in a complex environment and realized that the precise control of the motion state of the robot.

1. INTRODUCTION

At present, many universities and companies are working on the study of pipeline robots and have made considerable achievements. However, there are still few robots that can dredge automatically, and the control system of dredging robots is still not perfect. A dredging robot that its core controller is 51 MCU was developed in Changzhou University. The pressure value is automatically adjusted to its own size to adapt to different diameter pipes, which improves the adaptability of dredging robots. A detailed study on the pipeline inspection robot control and navigation system is studied in Shanghai Jiao tong university. The intelligent control of pipeline robot autonomous path planning, navigation and action is realized. Those dredging robots only have the function of checking the internal damage of the pipeline and replacing the staff to complete the cable-carrying operation (Chen Li Gang, 2016), the self-cleaning ability is poor. Therefore, the research of the dredging robot control system still needs to be further to improve the automation level of the dredging robot.

According to the mechanical structure and working requirements of the robot, the design of the whole control system is carried out to enhance the controllability of the robot and achieve independent dredging. In order to ensure the smooth and reliable movement of the robot, it is necessary to research on the motor control algorithm and the speed control system deeply.

2. THE ROBOT STRUCTURE AND CONTROL SYSTEM

2.1 The Mechanical System Structure of Pipeline Dredging Robot

The structure of the dredging robot is shown in Figure 1. Considering drainage pipe is mostly circular, the shape of the robot is designed with a cylindrical structure. The mechanical body is mainly composed of three parts, which are a wheeled walking mechanism, a step-push mechanism and dredging mechanism. The step pushing mechanism is an auxiliary mechanism for the pipeline robot. When the three walking units are all in a slipping state, the step pushing mechanism starts to assist robot to advance. The dredging mechanism is the core component of the pipeline dredging robot to remove the sludge from the pipeline.

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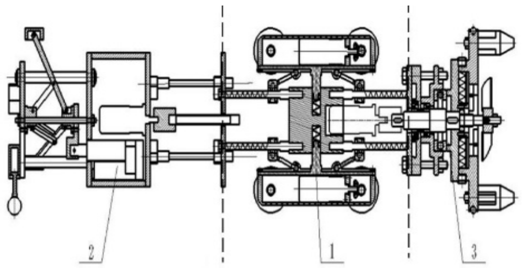


1. Wheeled walking mechanism 2. step-push mechanism
3. Dredging mechanism

Figure 1. The picture of robot structure.

It can be seen from Fig.1 that the wheeled traveling mechanism is in the middle position of the whole machine, and is the main driving mechanism for the robot. The structure of the wheeled walking mechanism is shown in Figure 2. It is mainly composed of three groups of walking units, and the three walking units are evenly distributed on the circumference, each walking unit is controlled by a motor. In an ideal state, the speed of the three independent drive motors should be same, so the control system needs to have better speed regulation capability, so that the robot can move smoothly and reliably.

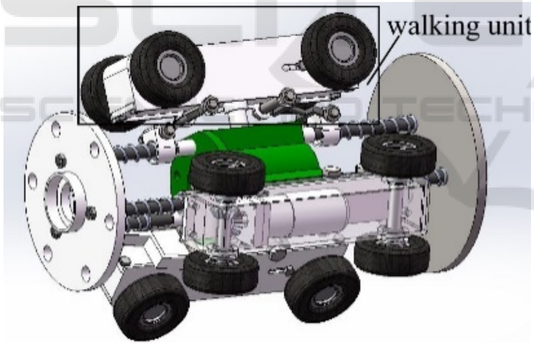


Figure 2. Wheeled walking mechanism.

2.2 The Hardware Configuration of Control System

According to the purpose and requirements of the design, a system diagram as shown in Figure 3. The robot control system is divided into the following parts according to functions, including control module, input module, output module and communication module. STM32 microcontroller is control module; the input module is composed of a detecting module, a speed measuring module and a photoelectric module; the output module is composed of a motor drive module, a drive motor and an electric push rod; the communication module is the blue-tooth module (Qian Xiao Long, 2017). As the core control device of the system, STM32 MCU is responsible for the precise control of each motor, the identification of the host computer commands and the transmission of data (Xie Shao Chun, 2018). The motor drive module amplifies the small signal generated by the controller to a high power voltage level and current level sufficient to drive the motor. The host computer sends commands to the lower computer through the blue-tooth module. At the same time, the information collected by various sensors and video modules is also fed back to the host computer.

3. RESEARCH AND SIMULATION OF SPEED CONTROL SYSTEM

The robot driving control system is the core of completing the operation successfully, and ensure that it has an excellent capability of passivity anti-overturning and obstacle resistance.

Now the motor control system mostly adopts the method of closed-loop feedback to improve the performance indexes. The single-closed loop control with negative speed feedback and double closed-loop control of current and speed are widely used. Both of these control methods can make the output speed follow-up and stable without static error. In this paper, the simulation of these two control systems are carried out by Simulink, and compared effects of the two control systems (Li Xian, 2015).

3.1 PID Control Algorithm

PID is a control method with stable effects and wide application (Hung Ping, 2017). It is widely used in control systems with clear mathematical models. The proportional link can play a role in speeding up the adjustment; the integral link can weaken the steady-state error; although the differential link helps to overcome the system oscillation and reduce the system overshoot, it is sensitive to the noise of the input signal, making the control system susceptible to the high frequency electromagnetic interference.

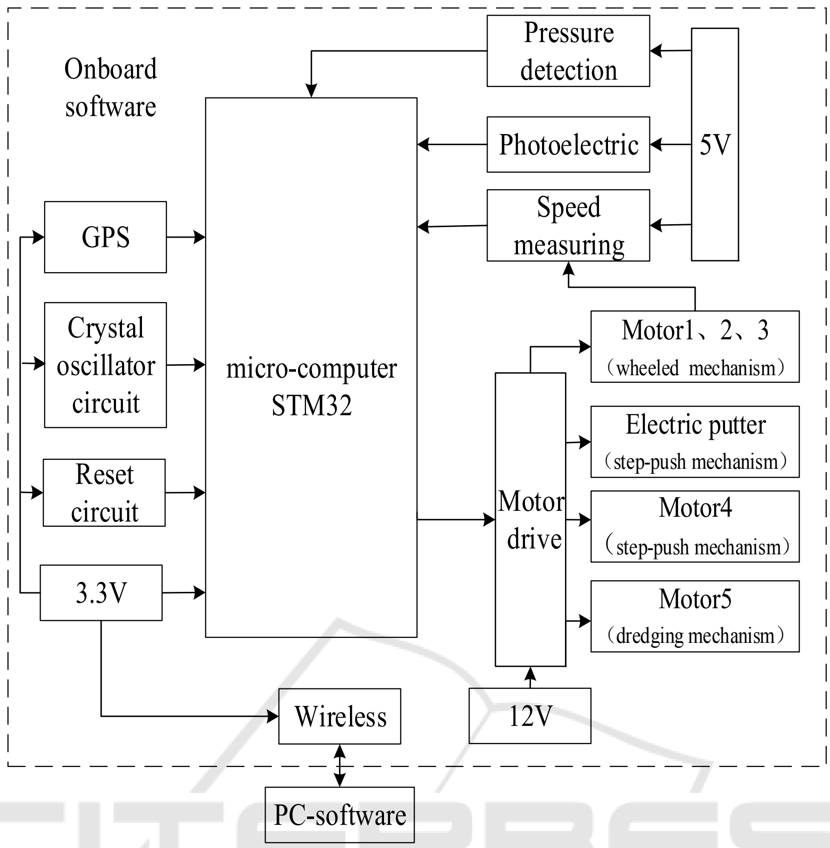


Figure 3. System block diagram.

In practical applications, the three links of proportional, integral and differential can be combined according to the needs. In order to achieve a fast and stable control effect, the proportional and integral links are finally selected for motor speed control. The PI controller is consisted of three parts: measurement, comparison and execution. As shown in Figure 4, firstly setting a command value, then it is compared with the feedback value to get the system deviation. After the PI operation, the control quantity is output.

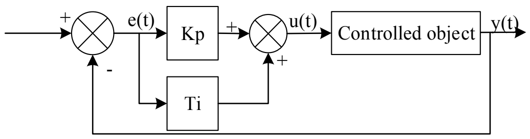


Figure 4. Schematic diagram of PI control.

3.2 The Control System Speed of Single Closed Loop

It can be seen from Figure 5 that the single closed-loop control system with the negative speed feedback can obtain the deviation speed (e) by comparing the commanded speed value (n*) with the feedback speed value (n). After the corresponding operation is performed by the PI controller, the output signal adjusts the PWM duty cycle to provide an appropriate driving voltage to the motor, and finally adjusts the motor speed (Wang Gui Yu, 2018) .The control system can quickly and smoothly make the motor reach the commanded speed value and maintain the ability of follow-up; and it will weaken the fluctuation caused by the load change.

According to Figure 5, established the simulation model as Figure 6. Setting the given speed is 200r/min, then compared it with the motor feedback speed, and obtain the deviation speed. After the PI regulator calculates, the PWM control signal is applied to the corresponding switch tube, and finally achieves the purpose of speed regulation (Wang Dian Jun, 2008).

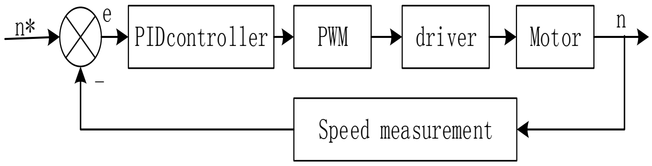


Figure 5. Speed control system with speed feedback.

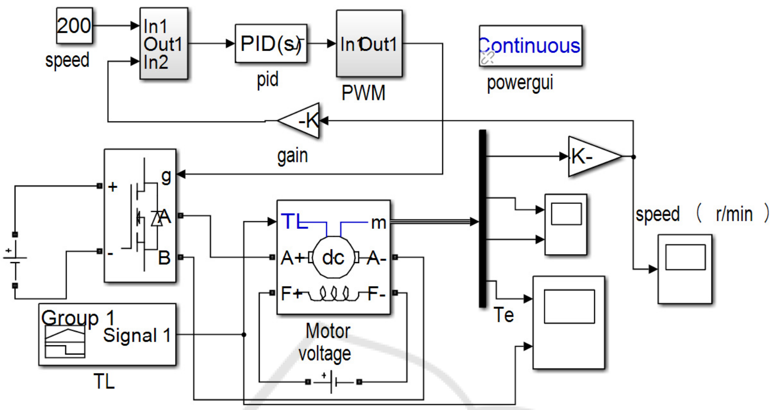


Figure 6. The picture of simulation model.

To simulate motor load changes, the load torque (TL) outputs in step pulse. The initial load torque is set to 4 N. m, and then changes every 0.5 s, as shown in Figure 7.

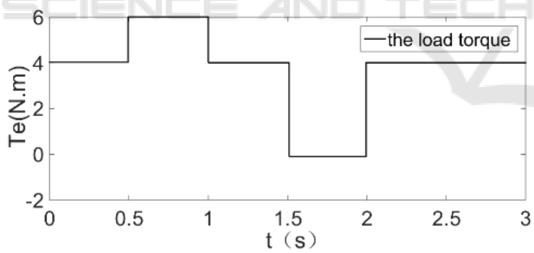


Figure 7. The change of load torque.

Figure 8 is the result of the speed closed loop control system simulation, where in Fig. 8(a) is the torque of the system Fig. 8(b) is the speed of the system changing with simulation time.

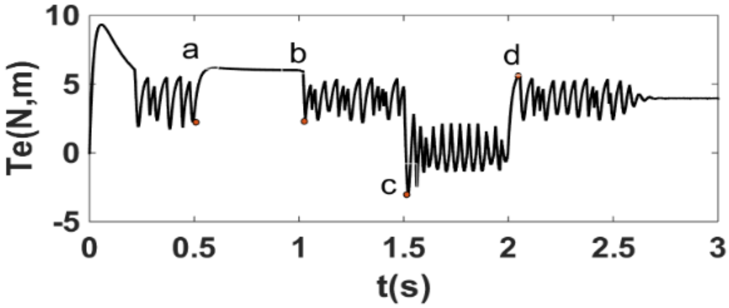
The analysis of simulation results:

As can be seen from Figure 8 (a), the torque at the start of the motor is large, reaching 7.8 N. m, and then stabilized near the set value. And the actual output torque of the motor follows the setting value. At the point of a, the set value jumps from 4 N. m to 6 N. m, the actual output torque of the motor fluctuates greatly.

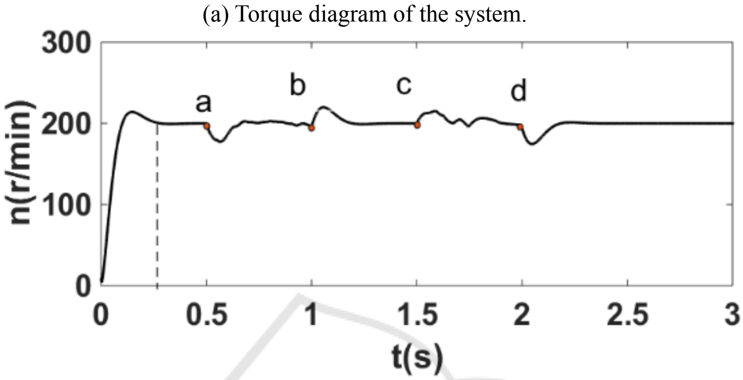
It can be seen from Figure 8 (b) that the speed of the motor is obviously overshoot when the motor starts, and is stable at the set value in 0.2s; When the load torque changes, the motor speed fluctuates greatly, after a certain beating, it can return to the set speed valve.

3.3 The Control System of Current and Speed Double Closed Loop

As shown in Fig.9, the current loop is an inner loop, and the speed loop is an outer loop. The output of the speed regulator (ASR) is the given of current regulator (ACR). The output of the ACR is used to adjust the duty cycle of the PWM signal, thus forming a double closed-loop control system. In this system the set value of the load torque is the same as the single-loop simulation model, as shown in Figure 9.



(a) Torque diagram of the system.



(b) The speed of the system.

Figure 8. The picture of simulation result.

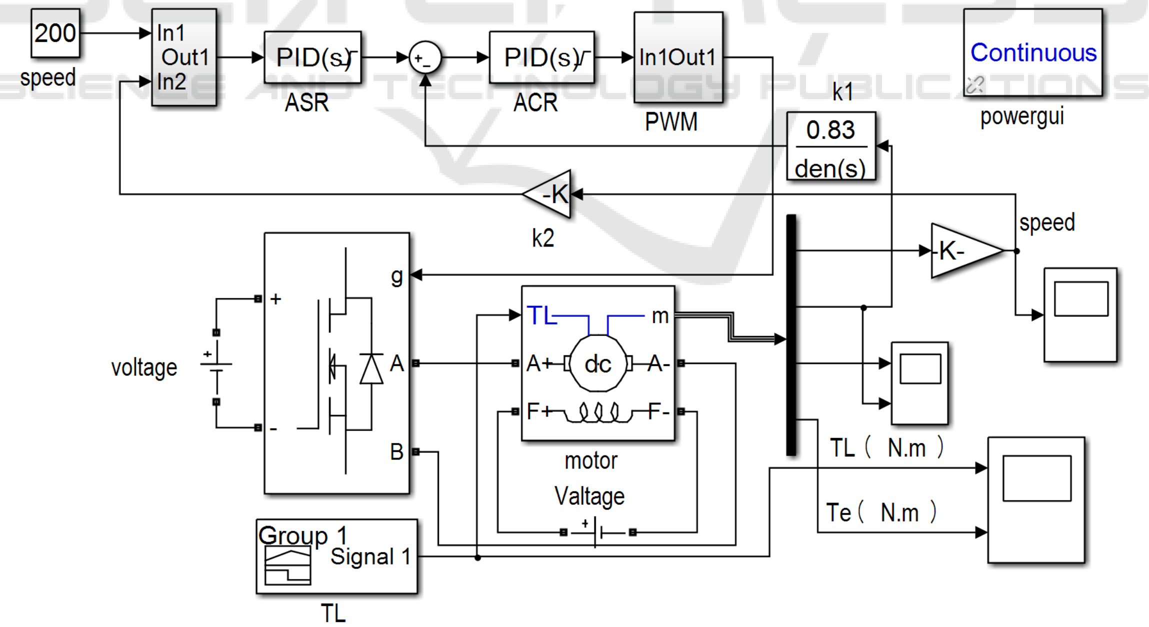
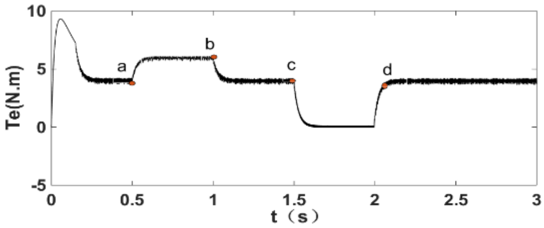
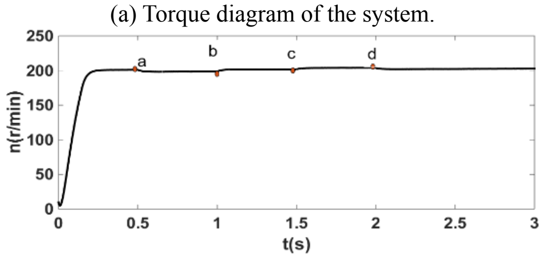


Figure 9. The picture of simulation Model.

Figure 9 is the result of the double closed loop control system simulation, where in Figure 10(a) is the torque of the system Figure 10(b) is the speed of the system changing with simulation time.



(a) Torque diagram of the system.



(b) The speed of the system.

Figure 10. The picture of simulation result.

As can be seen from Figure 10 (a), compared with the speed closed-loop control system, the actual output torque is more quickly stabilized at 4 N.m. The motor output torque varies with load torque and there is a small amount of fluctuation.

It can be seen from Figure 10 (b) that during the starting process of the motor, the motor speed hardly has overshoot and is relatively stable compared with the speed closed loop control system; when the load torque fluctuates up and down, the influence on the motor speed is small.

In summary, the double closed-loop control system has good advantage in speed -following and strong resistance to load fluctuations. The system runs smoothly, with excellent static and dynamic performance. And the PWM pulse width modulation technology directly regulates the magnitude and polarity of the output voltage, which can realize the smooth speed regulation of the system. Considering that the load will change when the dredging robot is working, the control method with double closed-loop is used to weaken the fluctuation caused by the load change, and the speed control of the robot wheel drive system is realized.

4. EXPERIMENT

The test platform is mainly composed of the prototype of pipeline robot, a control system and a simulated pipeline environment, as shown in Figure 12. This experiment has two steps, such as the test of whole machine function and the speed test of the wheel drive mechanism motor.

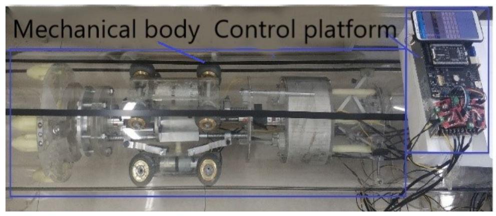


Figure 11. The experiment platform of robot.

4.1 The Test of Machine Function

In order to verify the stability of the control system and test functional modules of the robot are working properly, the function test of the whole machine is carried out firstly. When the robot is placed in the horizontal pipeline, sent the corresponding instruction to test the function realization of the three parts of the robot. Tested that the robot moved stably and each function is according to the design; there is no significant jitter at the moment of start and stop, indicating that the control system is effective and reliable.

4.2 The Speed Test of the Wheel Drive Mechanism Motor

As shown in Figure 5, the wheel drive mechanism motor adopts a double closed-loop control system based on PID algorithm. In order to test whether the motor speed can follow a given change, it sets five values. The speed feedback time interval is 1ms. The actual measurement results are shown in Table 1.

Table 1. The results of measurement.

set r/min	measurement results r/min				error %
160	157	161	163	162	1.8
180	176	181	183	183	1.6
200	196	199	205	203	1.5
220	215	221	224	223	1.3
240	239	241	243	240	1.2

It can be seen that the motor speed average error is 1.48%, and the overshoot is small. The system has good follow-up and dynamic steady-state performance. With the increase of the set speed, the error of the speed is gradually reduced. It can be explained that the double closed-loop speed control system designed has good dynamic-state and steady-state performance. The system can achieve a response fast and a stable output.

5. CONCLUSION

According to the walking mode of the dredging robot, the design of robot control system and the wheel drive motor speed control system was carried out. the simulation analysis and experimental verification were also carried out, the following conclusions were obtained.

(1) It has been verified by experiments that the dredging robot control system has good controllability and autonomy, and can achieve precise control of the robot's operation in the pipeline.

(2) The model of two systems are established in Simulink, which are the control system with single closed loop and double closed loop, and compared the effects of the two control systems. The results show that the double closed-loop control system has good speed follow-ability, strong resistance to load fluctuation and excellent, dynamic performance. It is verified by experiments.

The results show that the control method and speed control system meet the design requirements and can realize the precise control of the speed of the robot wheel drive system.

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