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Research on the Design of Educational Robot with Four-wheel Omni-direction Chassis

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Abstract. In order to promote the application of mobile robot in higher education, this paper studies the mobile robot composed of omnidirectional wheels. The hardware structure and kinematics of the four-wheel omnidirectional robot are analyzed. The kinematics model and dynamics model of the four-wheel omnidirectional mobile robot are established. The PID control algorithm is used to reduce the error caused by signal jitter and other factors. The feedback control is used to design the kinematic controller of four-wheel omnidirectional mobile robot. The inverse dynamic compensation control is used to design dynamics controller of four-wheel omnidirectional mobile robot. Through the actual motion control test of the four-wheel omnidirectional mobile robot, developed a practical teaching platform for mobile robots the utilization of the motor power is improved, the flexible movement of the robot is realized, and the design of trajectory tracking control system of the four-wheel omnidirectional mobile robot is completed.

Keywords: four-wheel omnidirectional robot, mobile chassis, trajectory tracking

1 Introduction

In view of the social needs of robotics talents, the educational value of robotics platform and the development requirements of remote sharing of equipment resources. Omnidirectional mobile robot with 3 degree of freedom is based on a holonomic system in horizontal plane [1]. Many concept decisions to be made in order to choose a proper solution of each construction aspect keeping in mind often contradictory requirements in design process of a mobile robot [2]. One of the most important is the selection of the chassis type. The first omnidirectional wheel appears at the beginning of the 20th century which can achieve forward and lateral movement [3]. Omnidirectional mobile system has a flexible mode of movement and it can easily go to any two-dimensional position. In order make the platform omnidirectional that mecanum wheels are used, which are driven by separate motors. The main part of the omnidirectional mobile platform is the omnidirectional wheel which includes the hub and the driven wheel. Omnidirectional mobile platform is widely applied to mobile robot to achieve omnidirectional mobile control of robot.

The kinematic and dynamic model of a four-wheel omnidirectional platform has been presented in [4] and [5]. An optimal trajectory generation algorithm for a four-wheel omnidirectional vehicle was proposed in [6]. The biped movement, wheel movement and track movement is included in the movement of mobile mechanical point [7]. The biped movement structure imitates the human's motion but the control is complex and the robot can't meet the requirement of fast moving at any time. Comprehensive consideration, in terms of service robots, the movement system of omnidirectional mobile chassis is chosen. Omnidirectional mobile robot system can achieve three degrees of freedom of movement, and this unique function can achieve the movement of the robot in any direction without changing the direction of the wheel [8].

There are a variety of mobile mechanical chassis structures and the most commonly used is three-

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wheel mobile chassis and four-wheel mobile chassis. Three-wheel mobile chassis usually consists of three Swiss wheels [9]. This system is widely used in soccer robots in robocup. Three-axis mobile mechanical chassis has three wheels. It is not only has power utilization problem, as a result of the contact with ground is triangle, but there is stability issue [10]. In this paper, four-wheel mobile mechanical chassis is studied. Because of omnidirectional movement can be synthesized by the wheel dynamic motion [11].

The objective of this paper is to establish an accurate and adaptive controller for a four-wheel omnidirectional mobile robot considering the effects of static friction, loss of energy due to viscous friction and unknown uncertainties. The remainder sections are organized as follows. Section2 describes motion analysis of omnidirectional mobile platform. The optimization design regarding the circuit structure is described in Chapter 3. The result of research on control of platform is obtained in Section4. Experiment results and conclusion are given in Sections5.

2 Motion Analysis

2.1 Motion Analysis of Three-wheel Omnidirectional Mobile Platform

A three-wheel omnidirectional mobile platform can be simplified as shown in Fig. 1. Three-axis mobile mechanical chassis consists of three separate wheels and each wheel separated by 120 ° apart equidistant. It's velocity is canceled in the x-axis or y-axis direction on the xoy coordinate system in the motion analysis of the three wheels omnidirectional mobile chassis.

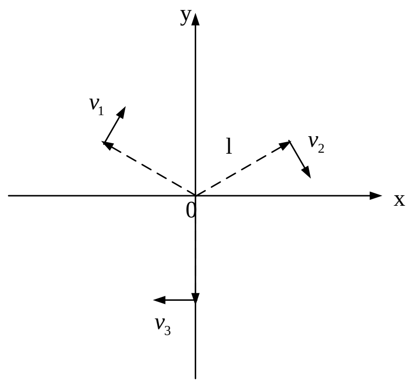


Fig. 1. Motion diagram of a three-wheel omnidirectional mobile chassis

In order to facilitate the calculation, it is assumed that the angle between the robot coordinate xoy and the world coordinate is 0. Take the geometric center as the center of mass and the clockwise direction as the positive direction. Assume that the speed of three drive wheels of three-wheel omnidirectional chassis are v_1, v_2, v_3. The speed of three-wheel omnidirectional mobile chassis on the xoy plane is v_x, v_y and the angular velocity is ω.

$$\begin{pmatrix} v_1 \\ v_2 \\ v_3 \end{pmatrix} = \begin{pmatrix} \cos\frac{\pi}{3} & \sin\frac{\pi}{3} & l \\ \cos\frac{\pi}{3} & \sin\frac{\pi}{3} & l \\ -1 & 0 & l \end{pmatrix} \begin{pmatrix} v_x \\ v_y \\ \omega \end{pmatrix} \quad \textbf{(1)}$$

2.2 Motion Analysis of Four-wheel Omnidirectional Mobile Platform

Although the three-wheel omnidirectional mobile platform can realize omnidirectional movement by using the motion decomposition and synthesis of the omnidirectional wheels. And three wheels can be driven by independent actuators to achieve 3 degrees of freedom movement. However, there is a problem of stability when carrying a payload since the contact area formed when the wheels come into contact with the ground surface is triangle. Especially, the center of gravity becomes higher when driving on the slope. Therefore, four-wheel omnidirectional motion system is a better choice when the system is facing stability problems.

Although there are many improvements in differential and trajectory motion to improve stability, achieving stability in a system using omnidirectional wheels remains a challenging task.

The mobility of the mobile chassis and agility will determine the positioning system efficiency. A four-wheel omnidirectional mobile robot system which can rotate and translate simultaneously is very important in the whole robot service system to avoid these problems.

Four wheels is used to overcome the stability of the mobile platform in this paper. Fig. 2 is the picture of four-wheel omnidirectional mobile chassis.

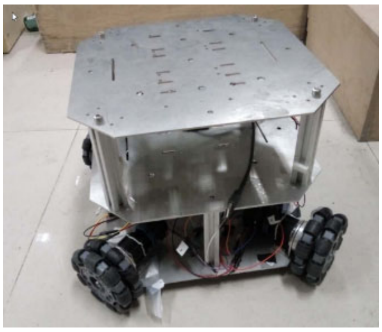


Fig. 2. Four-wheel omnidirectional mobile chassis

Develop motion system of a mobile robot that can rotate and translate simultaneously and basically it can be moved to any direction. This will lay the foundation for the control of mobile control, mapping and positioning of service robots later in this paper.

This experiment utilizes a four-wheel omnidirectional mobile robot platform. As shown in Fig. 3, the omnidirectional mobile robot is consists of four independent drive wheels which is separated by 90 ° equally. It is assumed that the angle between the robot coordinate xoy and the world coordinate is 0. Take the geometric center as the center of mass and the clockwise direction as the positive direction. Assume that the speed of four drive wheels of four-wheel omnidirectional chassis is V_1, V_2, V_3, V_4. The speed of four-wheel omnidirectional mobile chassis on the XOY is V_X , V_Y and the angular velocity is ω.

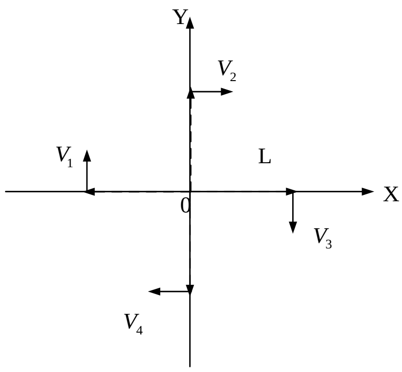


Fig. 3. Analysis of movement of four-wheel omnidirectional mobile chassis

$$\begin{pmatrix} V_1 \\ V_2 \\ V_3 \\ V_4 \end{pmatrix} = \begin{pmatrix} 0 & 1 & L \\ 1 & 0 & L \\ 0 & -1 & L \\ -1 & 0 & L \end{pmatrix} \begin{pmatrix} V_X \\ V_Y \\ \omega \end{pmatrix} \tag{2}$$

3 Circuit Structure

3.1 Hardware Analysis of Four-wheel Omnidirectional Mobile Chassis

The main electrical structure of four-wheel omnidirectional mobile chassis is four motor motion units, drive unit and control unit.

Selection of motor. In this experiment, the gear motor with the hollow cup of the encoder is adopted. The motor has a continuous torque of 17 kg cm and a stall torque of 50 kg cm which can satisfy the service robot's torque requirement.

The speed of the motor is 8100RPM, the working voltage is 12V, the output power is 17W and the deceleration ratio is 64: 1. The motor is A / B dual output and the motor resolution is 12CPR (pulse per revolution).

Driver. The mobile chassis circuit system amplified power with L298N chip. As shown in Fig. 4, we designed the drive circuit of encoder and welded drive circuit independently. And then connect the drive, controller and power to ensure the normal operation of the system.

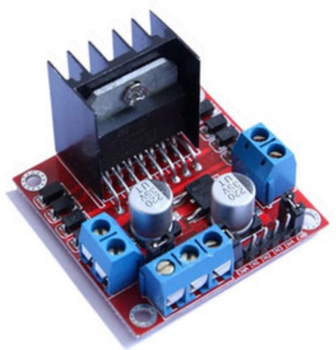


Fig. 4. Motor drive board of L298N

The L298N is a dual H-bridge structure with a voltage of 5V to 35V. It's maximum single bridge threshold current is 2A and it's maximum power is 25W that can meet the drive requirements of a service robot's mobile chassis [12]. The drive module has a strong driving ability, a lower heat during the work and it has a good anti-jamming.

Controller. Service robot's mobile chassis is not only need to achieve the omnidirectional control of the robot but also to get immediate communication with the host computer at any time. And it is also required to perform data operations. Real-time mapping is needed in the process of service robot and through the establishment of the map to achieve the positioning of the robot. At the same time, the real-time motion control of the mobile chassis of the lower computer is realized by the operation decision of the host computer. However, all this requires controller of the lower computer to achieve the decomposition of the movement, real-time calculation and real-time control of each motor. The motor is counted by the interruption of the encoder during operation. The position and motion information of the mobile chassis are transmitted by the lower computer which is needed by mapping of the host computer and the motion of the service robot will be transmitted to the lower computer at high speed. The service robot will send control command to the lower computer at a high speed. Therefore, the choice of controller of mobile robot chassis is very important. So the motor needs high-frequency, fast and so on.

The Arduino Due microcontroller board which is based on the Atmel SAM3X8E CPU is chosen in this paper.

3.2 Circuit Analysis of Four-wheel Omnidirectional Mobile Chassis

The four-wheel omnidirectional mobile chassis of the mobile robot is designed to move in any direction. The host computer and the lower computer can exchange data bi-directionally and the sensor data acquired by the lower computer can help to locate the current mobile chassis, which provides prerequisites for the following robot's mapping and position.

As shown in Fig. 5, the maximum threshold voltage of the controller pin is 3.3V in the omnidirectional mobile chassis system circuit, but the working voltage of encoder of the motor is 5.0V. In order to achieve the normal operation of the controller and the encoder that different voltage values is needed in this circuit system.

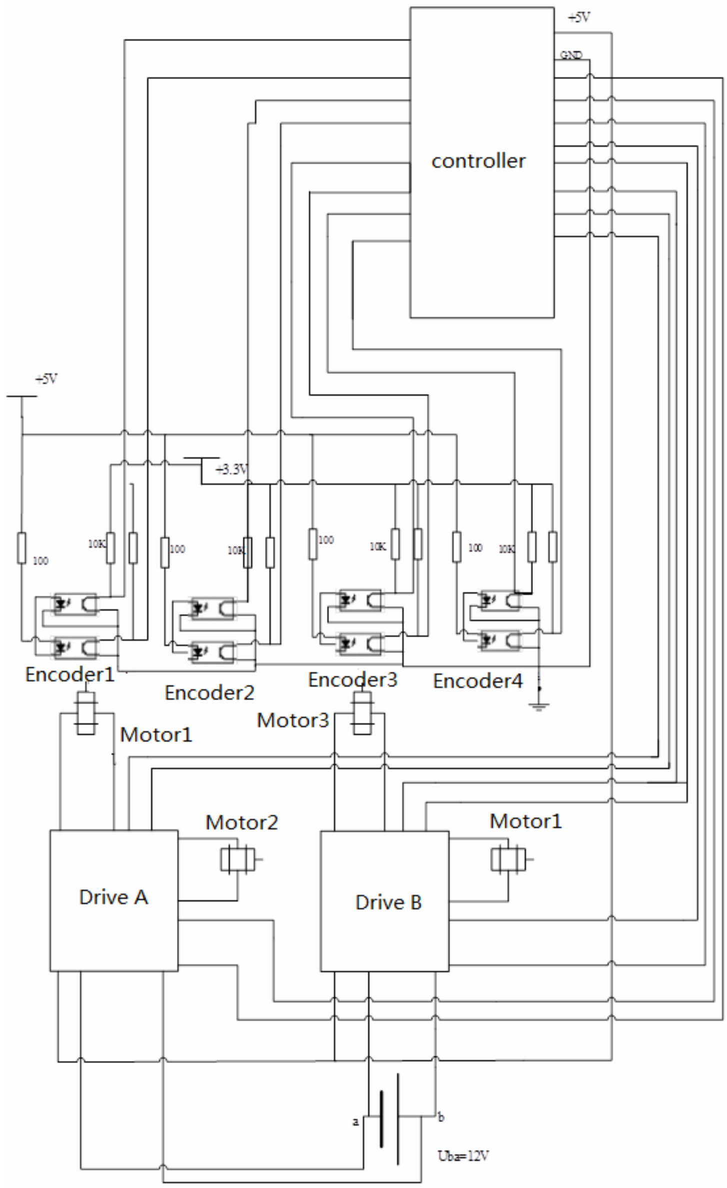


Fig. 5. Circuit graphic of a four-wheel omnidirectional mobile chassis system

The transmitter is the basic element of the formation of the field. Relatively low weight and smaller size are the advantages of the transmitter. It can emit sectoral laser and gating pulses with fixed angles. The transmitter has the following characteristics: wide range of applications, simple and convenient maintenance, high measurement accuracy, strong adaptability in harsh environments.

The materials of the beacon are reflective patches which does not consume any energy but been set on the ceiling to reflective lasers. Each beacon has a unique identification number (ID) that identifies the robot’s position and direction information which is stored in the robot in advance. By comparing the received signal with the stored data, robot could determine its location in the room. The beacon ID is encoded as shown in Fig. 3.

4 Research on Contorl of Platform

4.1 Mobile Robot Path Planning Method

The controller of the motion is first initialized when the mobile platform is running. The system continuously returns the movement information of the mobile robot, including the speed of each motor and the value of the encoder that can help the host computer to analysis and judge the motion. Therefore, the host computer can carry out mathematical operations and algorithm analysis to determine the location and direction of mobile robots. At the same time, the host computer will give precise control information of each motor through algorithm fusion so that the 2D map can be established smoothly. The baud rate used in this system is 576000. As shown in Fig. 6 is the flow graphic of the omnidirectional mobile platform that worked properly.

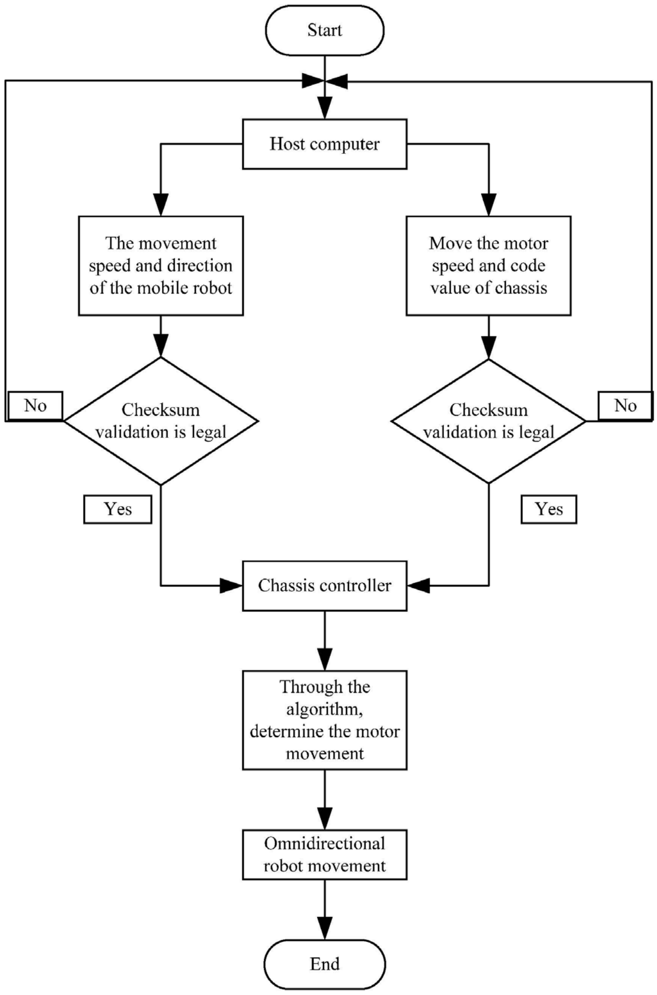


Fig. 6. Omni-directional mobile platform in the normal work flow chart

After the robot is powered on, the host computer provides the mobile robot with an initial motion speed and direction according to the input target position, and then determines whether the speed and direction are legal. If legal, the speed value and direction are transmitted to the chassis controller, otherwise, the upper computer re-assigns, and judges whether the motor speed and the code wheel value of the mobile chassis are equal. If they are equal, the motor speed value is transmitted to the chassis controller. Otherwise, a feedback command is sent to the host computer to re-determine the speed value of each motor. Finally, The chassis controller monitors the motion of each motor in real time through an algorithm as well as controls the movement of the robot.

4.2 Control Algorithm of Mobile Platform

There are open-loop control, closed-loop control and other control methods in control system. PID control algorithm is utilized in this service robot mobile chassis. It is very important to monitor the movement path of the mobile chassis during the working process of the robot due to positioning, mapping and other reasons. So the moving speed of the mobile chassis of the service robot is an important control parameter. The relative position of the mobile robot in the coordinate system can be determined by the relative position and direction of the coordinates of the mobile platform [13]. The speed of the moving chassis of the service robot can be obtained from the code disk of the wheel.

The moving direction of the mobile chassis can be obtained from the result of the data processing of the MPU 6050 by DMP (Digital Motion Processing). DMP can convert the original data directly into the quaternion output, and then you can easily calculate the Euler angle and get pitch, roll, yaw. It doesn’t have to get on attitude calculation to the chassis controller by the utilization of built-in DMP, to a certain extent, it reduces the burden on the MCU which has more time to deal with other events and improve system real-time.

This method avoids the tedious filtering process and is simple and effective. The attitude direction is used to determine the direction of the synthesis velocity of important parameters in the all-wheel mobile platform. The angular signal of the gyroscope will be used as the feedback signal of the platform dead reckoning compensation control. The feedback signal of the wheel encoder, the speed of the platform and the signal of the MPU6050 are used together as a feedback signal for the platform control compensation. This method can also be used to estimate the dead reckoning of the platform. Fig. 7 shows the control flow chart of the robot mobile chassis.

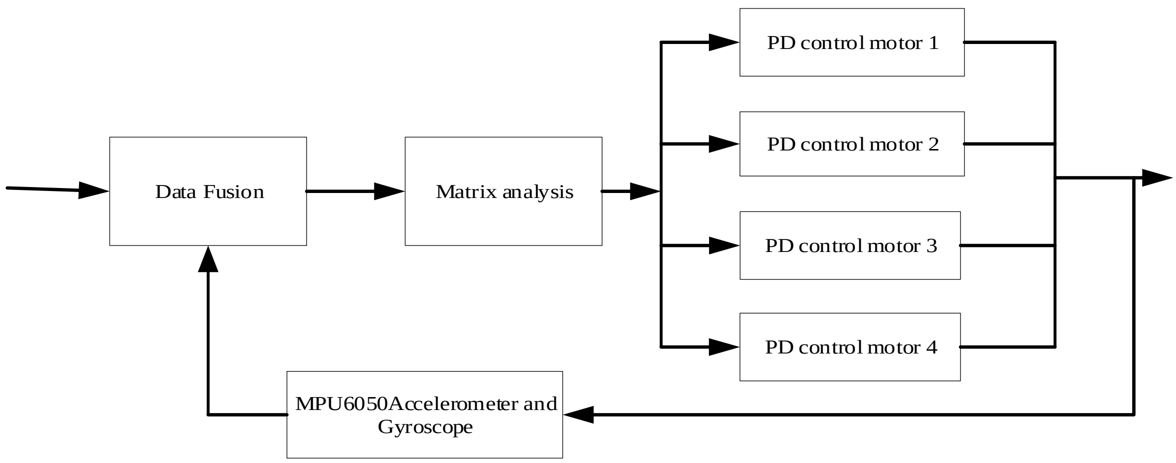


Fig. 7. The control flow chart of the robot mobile chassis.

Service robot’s mobile platform built-in gyro sensor provides mobile the platform with additional gesture feedback for the platform. The gyroscope provides speed commands that correct the rotation speed feedback of the platform. It can reduce the roughness of the road surface and the loss of encoder feedback signal that can disturb the direction of platform. On-line adjustment is made for the speed of each wheel in the control system of the mobile chassis. This is called the core speed compensation. Because the motion platform of these four wheels has nonlinear complex dynamic behavior. So it will increase the deviation due to external disturbances. The steady-state error can be reduced and the stability of mobile chassis can be improved by this algorithm [14].

PID algorithm is the most extensive control method in the actual scene and it’s control algorithm is simple, effective and very mature.

Because it is a digital controller of the program control in practice so that digital PID control algorithm is adopted. PID control algorithm can be divided into position PID and incremental PID. Mobile chassis control of the motor is used in absolute value rather than incremental. So position PID is adopted.

The integral and the differential are discretized in the positional PID.

$$u_k = K_P\left(e_k + \frac{T}{T_I}\sum_{j=0}^{k} e_j + T_D\frac{e_k - e_{k-1}}{T}\right) \quad \textbf{(3)}$$

$$u_k = K_P e_k + K_I\sum_{j=0}^{k} e_j + K_D\left(e_k - e_{k-1}\right) \quad \textbf{(4)}$$

In the formula, e_k is the deviation and $e_k = r_k - y_k$, K_P a is the proportional coefficient, T_I is the integral time constant, T_D is the differential time constant, K_I is the integral coefficient, and K_D is the differential coefficient.

The PID control motor is shown in Fig. 8.

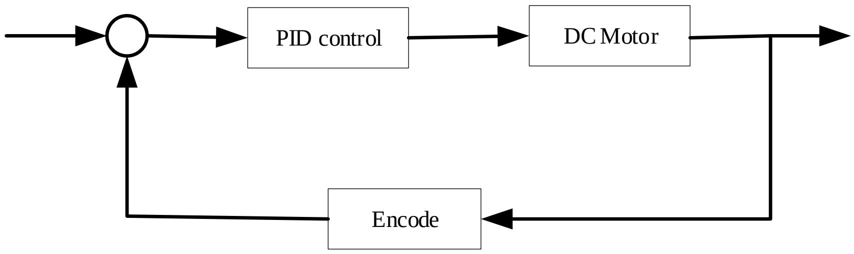
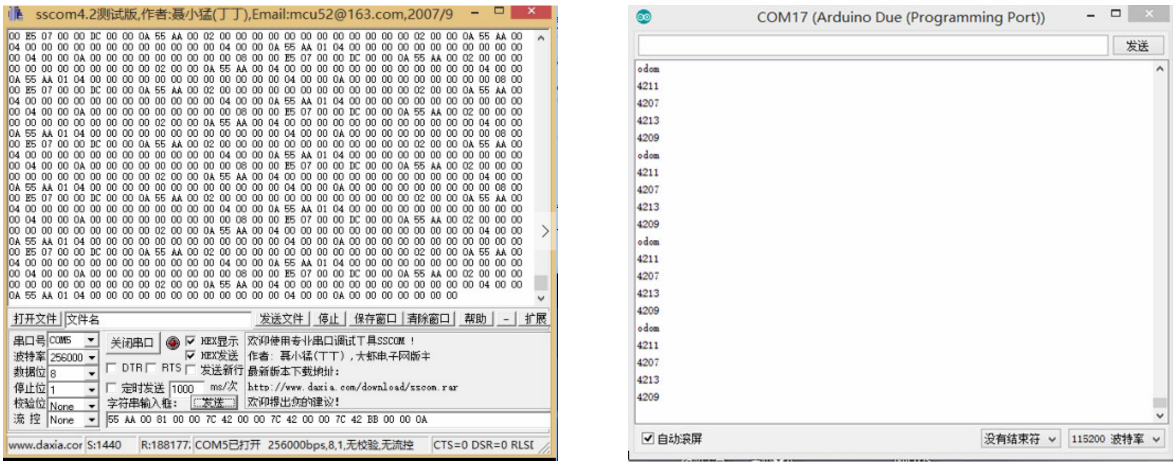


Fig. 8. The structure of the PID control motor

4.3 Experimental Results

In this section, the motion analysis of the four-wheel omnidirectional mobile chassis is carried out, and the motion model is established, thereby realizing the control of the mobile chassis. In the control process of the mobile chassis, the PID motors are used to control the motors of the mobile chassis. Fig. 9(a) shows the control value when the host computer controls the speed of each motor of the mobile chassis. As shown in Fig. 9(b) is the encoder speed value. So each motor encoder return value is basically the same through the serial debugging assistant to drive each motor. Each motor can be driven by the serial port debugging assistant, and the return values of the individual motor encoders are basically equal.



(a) Control value of host computer (b) Speed value of encoder counting

Fig. 9.

During the movement of the mobile chassis, the upper computer calculates the movement mileage of the mobile chassis through the return value of the code wheel. The floor of each floor is 0.6m, as shown in Fig. 10 for the actual distance of the floor. Actual distance of the floor

Fig. 10. Actual distance of the floor

Fig. 11 and Fig. 12 are the physical map of the initial position during the movement of the mobile chassis and the counting mileage obtained by the host computer. Fig. 13 and Fig. 14 are the physical map of the final position and the counting mileage obtained by the host computer. It can be seen that the plane coordinate of the robot at the initial position is x=0; y=0; the coordinates of the robot at the final position are x=0.597m, y=0.02m; therefore, the PID control algorithm can adjust to obtain a more accurate control effect.

Fig. 11. Moving the initial position of the chassis

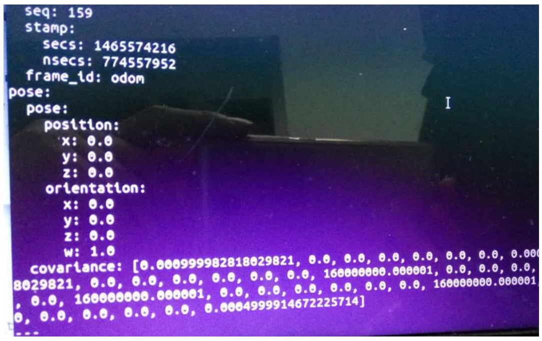


Fig. 12. Counting mileage obtained by the host computer at the initial position

Fig. 13. Physical map of the final position of the mobile chassis

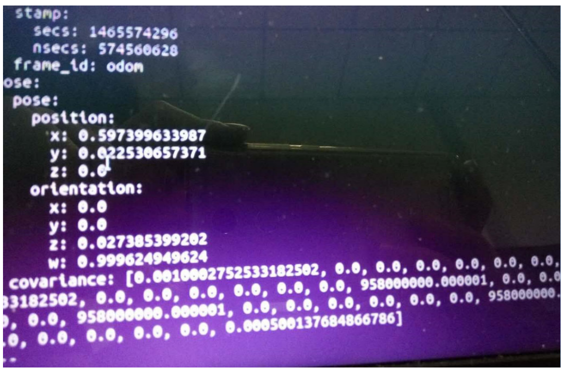


Fig. 14. The final mileage obtained by the host computer

Adjust the proportional coefficient K_P, integral coefficient K_I, differential coefficient K_D in the PID algorithm to improve the dynamic performance of the motor and reduce the steady-state error in the process of the motor, and then achieve the stability of the motor work.

Taking into account the actual work of the motor, the trial and error method to adjust the $K_P / K_I / K_D$ in this paper is adopted. Write down the parameters at this time when K_P reaches the target size, then multiply this parameter by 0.6 to 0.8. And then adjust K_I, and finally to adjust K_D. Table1 shows the actual value of each parameter in the adjustment process. The initial speed of a motor is 33r / min.

Table 1. The actual value of each parameter in the adjustment process

K_P	K_I	K_D	Range of return values of the motor encoders
3	0	0	23~27
4	0	0	25~28
5	0	0	26~31
6	0	0	26~32
7	0	0	25~33
8	0	0	27~40
5.6	1	0	26~36
5	10	0	28~37
4.5	10	0	31~35
4	10	0	31~35
4	12	0	31~35
3.8	12	0	31~35
3.8	14	0	31~35
3.9	14	0	31~35, 31/32/33 is more
3.9	20	0	31~35,32/33is more
3.9	30	0	31~34,30/35 is few
3.9	25	0	32~33,31/35 is few
3.9	25	0.005	32~33,31/34 is few and it's hard to achieve stability
3.9	25	0.05	32~33,31/34 is few and steady-state error and dynamic characteristics is more appropriate
3.9	25	0.5	32~33, 31, 34, 35 is few and dynamic characteristics is good

Steady-state error is small but dynamic characteristics is not very good when K_P=3.9 / K_I=25 / K_D=0.005; Steady-state error is vulnerable but dynamic characteristics is good when K_P=3.9 / K_I=25 / K_D=0.5 . Steady-state error is small and dynamic characteristic is good when K_P=3.9 / K_I=25 / K_D=0.05. So take K_P=3.9 / K_I=25 / K_D=0.05 in the program.

5 Conclusion

This paper constructs a practical teaching system for educational robots, and carries out robot education and research to train and train the innovative ability of engineering students. In this brief four-wheel omnidirectional mobile chassis is analyzed and the motion model is established. Based on the kinematics and dynamics model of four-wheel omnidirectional mobile robot, this paper proposes an inverse dynamic compensation control strategy combining classical PID control and sliding mode control. The experimental results verify the trajectory of the four-wheel omnidirectional mobile robot. The validity of the tracking shows that the strategy can meet the rapidity and stability requirements of the trajectory tracking control of four-wheel omnidirectional mobile robots. The results also conclude that continuous change in magnitude of disturbances with time does not decrease the efficacy of the controller to satisfy the sliding mode condition. Moreover it is also capable of reducing the chattering effect.

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