

Design and Development of Mechanical Structure and Control System for Tracked Trailing Mobile Robot

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Abstract

Along with the science and technology unceasing progress, the uses of tracing robots become more and more widely. Tracked tracing robot was adopted as the research object in this paper, mechanical structure and control system of robot was designed and developed. In mechanical structure design part, structure designed and positioned were completed, including design of robot body, wheel, underpan, transmission structure and the positioning of batteries, control panel, sensors, etc, and then robot dynamics was analyzed; In control section, M30245 was used as the core, according to the characteristics of tracked tracing robot differential drive, realization scheme of motion control system was put forward, system drive circuit, detection module, control program were developed. System were discussed and checked through test. From this paper tracked tracing robot was researched, and a certain design and experimental basis can be provided in future research.

Keywords: Tracing robot, Structure design, Sensor, Control system, Program design

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1. Introduction

Tracing robot is one of the important branch in robot research field, and along with the rapid development of sensor technology, computer science, artificial intelligence and other related field, mobile robot is marching towards intelligent and diversified direction. Tracing robot, which has self- tracing planning, self-organizing and adaptive ability, can be suitable for vary complex environment. It is composed of sensors, remote manipulator and automatic controller [1].

Since the 1980s, the defense advanced research projects agency (DARPA) special project was built, and set up ground Unmanned Combat Platform strategic plan, the aim was to develop an intelligent vehicle, which could go forward in rugged terrain along the route planning of autonomous navigation and avoiding obstacles, if necessary, it could plan new route. From then on, a comprehensive study of the mobile robot has been started prelude in the world, Such as DARPA "strategic computer" planned autonomous ground vehicles (ALV) plan, intelligence reconnaissance car DEMO II of the United States defense department, and so on [2-3]. Kurisu [4] described a new tracking control method for a tracked vehicle The proposed method is constructed by using a virtual wheeled mobile robot. Ukida [5] proposed an object tracking system using an arm robot and two pan-tilt cameras. Sujan [6] used a metric based on Shannon's information theory; the algorithm determines potential locations of nodes from which to further image the environment. Maekynen [7] used a sensor being capable of measuring 3D positions and orientations in a large working space for interactive teaching of robot paths and environments. Tarokh [8] put forward a simple scheme for multivariable control of robot manipulators. Kwon [9] used a method that mobile robots can track a person in complex environment was presented Based on a particle filter. Suwanratchatamanee [10] used a tactile sensor torch system for robot manipulator and an active sensing technique to realize a 3-D object edge tracking with experimental results. Konukseven [11] presented a cost-efficient, real-time vision-sensor system for identifying, locating and tracking objectst.

2. Tracked tracing robot structure analysis and design

2.1. Structure analysis

Considering the unstructured environment, the mobile robots travelling mechanism must have the following special functional requirements:

(1) Flexible barriers and obstacles avoidance ability. Obstacle avoidance ability requests robot has sensitive and effective navigation and control system; the barrier ability reflected in climbing, resistive overturning and span tunnel ability, it needs robot with flexible body travelling mechanism and perfect motor performance.

(2) Go straight at a rapid speed in the flat ground.

(3) Walk steadily in unflat ground, and has good adaptive ability. When robots move in complex road, especially in the rock around and uneven ground, robots can automatically avoid obstacle, barrier and reset. In the soft ground driving, make robot and ground have large enough contact area in order to generate enough friction help robot forward. These request its walking mechanism has best flexibility, mobility and terrain adaptive ability. At the same time, mobile robot should have all directions driving ability and spiralling ability.

Design principle:

(1) Whole structure should be easy to remove, so that do experiment, debug and repair.

(2) Reserved installation position, including sensor and function components, should be given for function improvement and expansion in future.

(3) Using modular design philosophy.

2.2. Structure design

Robot mechanical structure plays an important role on stability, flexibility and tracing ability. Double motor drive respectively and three section symmetrical layouts are used, shown in Figure 1. Robot main body part can load motor, sensor and some electronic parts, keeping horizontal posture in motion; two drive motor and driving wheel connected, driving wheel driven track moving, and two motor respectively control movement speed and direction, so robot move forward, backward and turn can be realized. Robot has four degrees of freedom (DOF), namely two translational DOFs and two rotation DOFs, motor directly drive track wheel, to change rotatory DOF into translational DOF; In control of system signal, one side of motor speed decreasing, and the other side can realize large radius turning; if it needs small radius turning, rotates one side direction of robot motor.

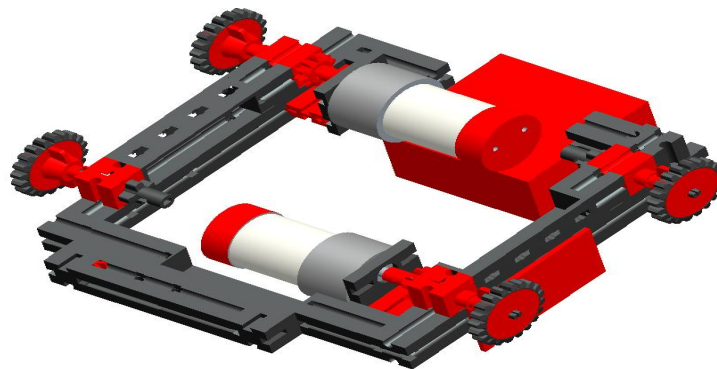


Figure 1. Robot underpan connection diagram modeling

2.2.1. Underpan design

Tracked robot could move on the uneven ground, overcome obstacles, climb stairs that isn't too high, it has better characteristics, including fast running speed (between wheel and legs type), higher bearing capacity and adaptive ability. Combined with the requirements, a double crawler drive structure is selected for underpan of tracked tracing robot, its appearance is

compact. It has 250mm long, and about 30mm wide, the maximum slope it can climb is 30 degrees and cross moat is about 50mm wide. Underpan crawler mechanism is shown in Fig. 2.

Track needs certain tension to ensure that the barrier function and mobile ability, so crawler unit number depends on wheel and the distance between driven pulleys.

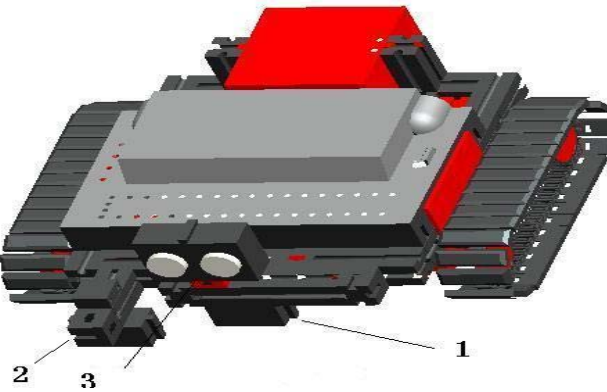


Figure 2. Robot underpan assembly diagram modeling

2.2.2. Sensor positioning design

In this project, color sensor, track sensor and distance sensor are used. Track sensor controls tracing robot advance and steering, so it was installed in the front of robot and to be located on the symmetric axis in order to control robot moving. The function of Color sensor is to identify color, it lets robot stop when red identified and move on when green identified, so it also needs to be installed in front of robot too. Distance sensor feeds back the distance signal between robot and obstacles to single-chip microcomputer (SCM), let it give command to a halt, so distance sensor also need to be installed in front of the robot. And in order to get more accurately identify color and path signal, color sensor and track sensor need to be installed in the distance near ground, it can be shown in figure 2, 1 is track sensor, 2 is color sensor, and 3 is distance sensor.

2.2.3. Overall structure

Robot assembly diagram is shown in figure 3. From the figure, 1 is battery, 2 is dc drive motor, 3 is a tracked, 4 is track sensor, 5 is ultrasonic obstacle avoidance sensor, 6 is color sensor. The structure of mobile robot is relatively simple, robot power is installed on the rear frame; a pair of ultrasonic obstacle avoidance sensor distributed in front. After assembling, the length of tracing is 220mm, width is 216mm and the height is 78.5mm.

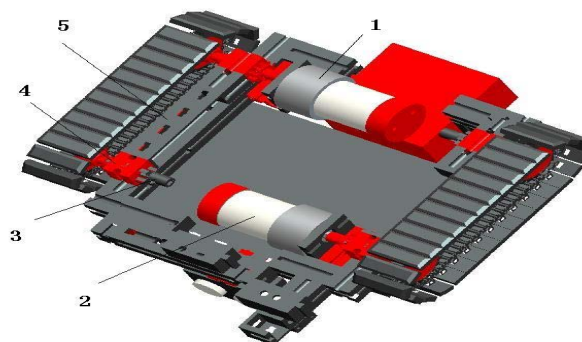


Figure 3. Robot assembly diagram modeling

3. Tracked mobile robot dynamics and kinematics analysis

In view of robot rotary motion, mechanical system dynamics modeling reference coordinate system method is select, through establishing the overall frame of reference and dynamic reference coordinate system, joint reference coordinate system to describe robot relative motion, the relation between ground and robot and vehicle's inertia force, etc., so rigid body dynamics equation can be used to describe robot steering dynamic process.

Vehicle steering plane reference coordinate system XOY is established shown in Figure 4, set vehicle center O as base point, Y axis is vehicle longitudinal symmetry axis, X axis is vehicle lateral symmetry axis, and to establish dynamic base (dynamic reference coordinate system) and vehicle conjoined twin base (Conjoined twin reference coordinate system), that is, make continuum and moving base coincidence.

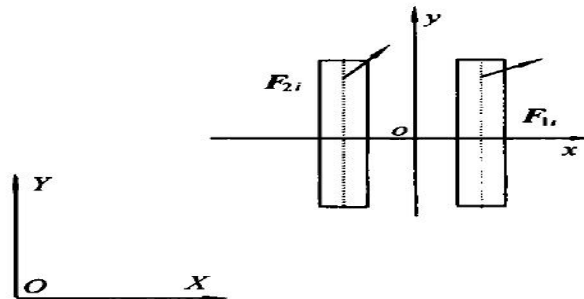


Figure 4. Robot turning plane coordinate system and force analysis diagram

The continuum base relative dynamic base coordinate, $q = [x, y, \phi]^T = 0$, Where ϕ is positive direction angle between moving base x axis and conjoined twin base y axis, because moving base and conjoined twin base always coincidence, so value is 0.

A dynamic base xoy in general base XOY generalized coordinates is defined $Q = [X_0, Y_0, \phi_0]^T$, Where ϕ_0 is positive direction angle between moving base x axis and general base X axis.

Vehicles in steering plane loaded all external force are from ground friction, shown in figure 4, according to model hypothesis, the friction action of track under the concentrated load, i.e., the frictional force F_{1i} , F_{2i} , discretizing distribution in road wheel through track and ground pressure point. The dynamics equation in robot conjoined twin base xoy basis points (center of mass) is

$$\begin{bmatrix} m & 0 \\ 0 & m \end{bmatrix} \begin{bmatrix} \ddot{x} \\ \ddot{y} \end{bmatrix} = \begin{bmatrix} F_x \\ F_y \end{bmatrix} + \begin{bmatrix} F_x^n \\ F_y^n \end{bmatrix} + \begin{bmatrix} F_x' \\ F_y' \end{bmatrix} \quad (1)$$

where m is robot quality, F_x , F_y is coordinates for acting on centroid ground friction force F in moving base; F_x^n , F_y^n is coordinates for acting on centroid ideal binding force F^n in moving base, and $F_x^n = F_y^n = 0$, F_x' , F_y' is coordinates for acting on centroid of inertial force F' moving base.

Dynamics equation for robot conjoined twin base moving base is

$$J\ddot{\phi} = M + M^n + M' \quad (2)$$

where J is moment of inertia for vehicle relative mass center; M is coordinates for friction joint moment M in moving base xoy , it is

$$M = \sum_{i=1}^n (\rho_{1i} \times F_{1i}) + \sum_{i=1}^n (\rho_{2i} \times F_{2i}) \tag{3}$$

where ρ_{1i} , ρ_{2i} is respectively radius vector of low and high speed track side No. i road wheel in moving base, M^n is coordinates for constraint moment M^n in moving base, and $M^n = 0$, M' s coordinates for acting on the centroid ideal constraint moment in moving base.

Integrated robot mass center motion equation and attitude motion equation, the robot dynamics equation in moving base can be written as

$$\begin{bmatrix} m\ddot{x}_0 \\ m\ddot{y}_0 \\ J\ddot{\phi}_0 \end{bmatrix} = \begin{bmatrix} \sum_{i=1}^n (F_{x1i} - F_{x2i}) \\ \sum_{i=1}^n (F_{y1i} - F_{y2i}) \\ \sum_{i=1}^n \left\{ -F_{x1i} \left[\frac{L}{2} - \frac{(i-1)L}{n-1} \right] + F_{y1i} \frac{B}{2} - F_{x2i} \left[\frac{L}{2} - \frac{(i-1)L}{n-1} \right] + F_{y2i} \frac{B}{2} \right\} \end{bmatrix} \tag{4}$$

Where L is length of track, B is track center distance.

According to the coordinate transformation relationship, $[F_{x1i}, F_{y1i}]^T$, $[F_{x2i}, F_{y2i}]^T$ is respectively coordinates F_{1i} , F_{2i} in moving base, T is:

$$\begin{bmatrix} F_{x1i} \\ F_{y1i} \end{bmatrix} = \begin{bmatrix} \cos \phi_0 & \sin \phi_0 \\ -\sin \phi_0 & \cos \phi_0 \end{bmatrix} \begin{bmatrix} F_{X1i} \\ F_{Y1i} \end{bmatrix} \tag{5}$$

$$\begin{bmatrix} F_{x2i} \\ F_{y2i} \end{bmatrix} = \begin{bmatrix} \cos \phi_0 & \sin \phi_0 \\ -\sin \phi_0 & \cos \phi_0 \end{bmatrix} \begin{bmatrix} F_{X2i} \\ F_{Y2i} \end{bmatrix} \tag{6}$$

where $[F_{X1i}, F_{Y1i}]^T$, $[F_{X2i}, F_{Y2i}]^T$ is respectively coordinates F_{1i} , F_{2i} in general base.

Because speed direction of F_{1i} , F_{2i} is respectively opposite with velocity $V_{1i'}$, $V_{2i'}$ of moving point $1i'$, $2i'$ in continuum base, Constraint equation for $[F_{X1i}, F_{Y1i}]^T$, $[F_{X2i}, F_{Y2i}]^T$ can be obtained, that is

$$\begin{aligned} -\sqrt{F_{X1i}^2 + F_{Y1i}^2} \cdot \sqrt{v_{X1i'}^2 + v_{Y1i'}^2} &= F_{X1i} v_{X1i'} + F_{Y1i} v_{Y1i'} \\ -\sqrt{F_{X2i}^2 + F_{Y2i}^2} \cdot \sqrt{v_{X2i'}^2 + v_{Y2i'}^2} &= F_{X2i} v_{X2i'} + F_{Y2i} v_{Y2i'} \end{aligned} \tag{7}$$

where $[v_{X1i'} v_{Y1i'}]^T$, $[v_{X2i'} v_{Y2i'}]^T$ is $V_{1i'}$, $V_{2i'}$ respectively coordinates in general base.

And considering friction value in robot joint related with the positive pressure of this point, namely

$$\begin{aligned} \sqrt{F_{X1i}^2 + F_{Y1i}^2} &= F_{1i}\mu \\ \sqrt{F_{X2i}^2 + F_{Y2i}^2} &= F_{2i}\mu \end{aligned} \tag{8}$$

Where F_{1i} , F_{2i} is respectively ground pressure of $1i'$ and $2i'$, μ is frictional factor.

So the differential equation (4) and algebraic equation (5), (6), (7), and (8) could compose tracked robot steering dynamics equations, given an initial conditions can be used to solve steering dynamics equation.

4. Control system program of tracked tracing robot

According to tracked tracing functional requirements, hardware system is designed, including circuit design, drive system design, sensor selection and wiring and other part, the control system comprise motion control systems, sensor systems. Its structure shown in Fig. 5.

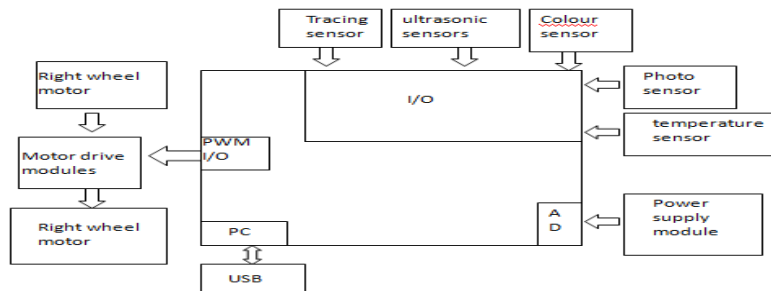


Figure 5. Diagram of control system program

The motion control system includes a control system use M30245 as the core and DC motor drive, the mobile robot can move forward and backward, quick to move freely in a narrow space and rotate around its geometric center to a very small radius.

4.1. Motor drive module design

Mobile robot used around two independent wheels drive, use differential steering mechanism, each wheel is individually controlled by a DC motor. The control of robot motion is primarily by two motor drives, including speed and steering control. The system uses PWM control mode to control a DC motor, changing the voltage on the DC servo motor armature "duty cycle" to change the size of the average voltage, so as to control the speed of the motor, shown in Figure 6.

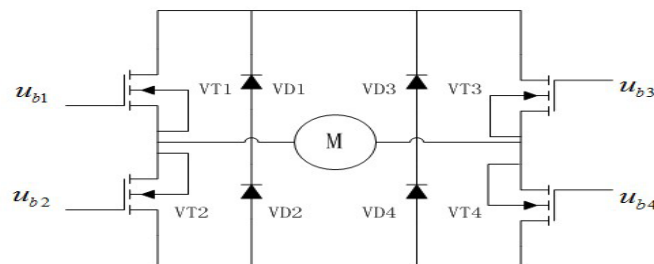


Figure 6. Diagram of H-type drive circuit

4.2. Sensor module design

Environmental, perception awareness is a mobile robot's one most basic ability except movement, the intelligence of a robot is directly depended on, perception ability, and however, perception is determined by the perceptual system. Mobile robot's perception system is a tool to get the external environment information and conduct the internal feedback controls, It is one of the most important part of the mobile robot.

4.3. System software development

The entire control system software is designed in modular way, including the main program module and the sensor subroutine modules. Sensor subroutine modules primarily including the walking tracing module, ultrasonic obstacle avoidance module, color recognition module and photosensitivity and temperature sensing module and other parts, as shown in Figure 7.

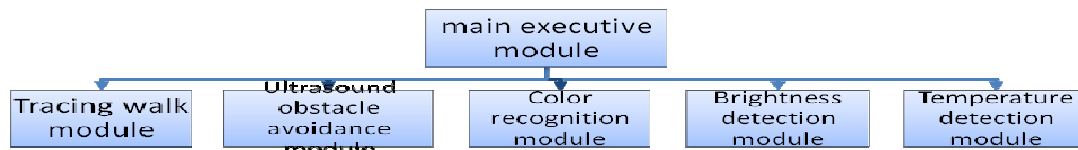


Figure 7. The overall programs of system software

4.4 Program development of main program module

Tracked tracing robot control system is designed to achieve functions as walk along the specified path, avoid obstacles, detects the ambient temperature and brightness. On the basis of the hardware, main program software is designed. The main program contacts walk module tracing procedures, ultrasonic obstacle avoidance modules procedures. together, Adjust the timing of each program, make hardware can give a normal response and make the right behavior. The use of buzz, lighting etc. can identify whether each module give response in response behavior. In the program of motor driver, tracing walking modules and ultrasonic obstacle avoidance modules complete together, so it is very important to coordinate the relationship between these two procedures.

When the program starts, delays one second, then enter into the loop, tracked tracing robot begins to move, looking for black track. When robot find black track, walk along black track automatically. If with 10cm, robot encounters an obstacle, the tracked tracing robot will turn left, go ahead after 1second. Temperature module, brightness module and color module work independently. Program flow chart is shown in Figure 8.

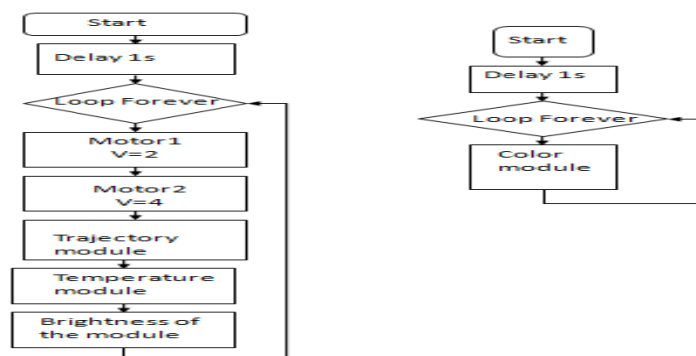


Figure 8. Main program flow

4.5 Tracing walking module design

In this study, use paper with white underside and black track in the middle as experimental site. The tracked tracing robot looks for a black track on a white paper, then walks along the black track. The photoelectric tracing sensor installed on the tracked tracing robot can

emit infrared to the walking road space, and the installed will be received by receiver module through the background reflectance of the road surface, Control system determine the strength of the received to achieve recognition function. The track sensor is digital sensor, and the tracked tracing robot use one pair of track sensors, which contains two emit and two receive device connecting the sensor to the digital input and 9V power supply terminal.

The sensor should be away from detected surface 5mm-30mm, if it is white or bright, show a value of 1; if encounters black, show a value of 0, because the light is absorbed and little reflection. If two values are displayed as 0, indicates that black track is found, and then the robot will walk along the black track, program flow chart shown in Figure 9.

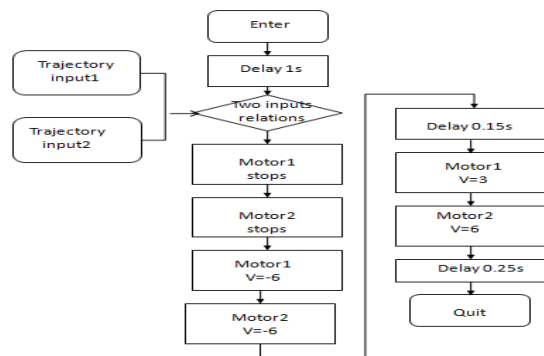


Figure 9. Tracing walking module program flow

After the program starts, delay 1s firstly, track sensors start work, judge whether two digital input values are 0, if both are 0, in order to let the tracked tracing robot drive on track more accurate, two drive motor should stop quickly at the same time, then two drive motor go back at the speed of 6, delay 0.15s, now, the robot can return the front the black track, then turn left, the left motor at the speed of 3 while the right motor at the speed of 6. The robot goes ahead until it walks along the track.

4.6 Ultrasonic obstacle avoidance module design

We use Ultrasonic sensors to detect the distances of obstacles, reflecting the distance between the sensor and the obstacle, in order to protect the robot, When the obstacles are in front of the robot, it will stop or turn left. The ultrasonic sensor is an analog sensor that can measure the distance from 0 to 400mm. The corresponding detection value shows on the program detection interface in cm.

Ultrasonic obstacle avoidance sensors are installed at the front of the robot body, input 10, if the robot is in front of obstructions and away from the obstacle less than 10mm, the motor 1 speed of left wheel is 3, the motor 2 speed of right wheel is 6. Underpan makes the robot turn left by differential. The flow char of Ultrasonic obstacle avoidance module is shown in Figure 10.

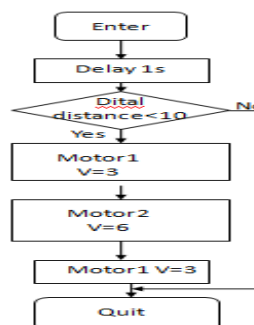


Figure 10. Ultrasonic obstacle avoidance module flow

After starting, the program delays 1 second, then the Ultrasonic sensor begins to detect the analog value. First, detect whether there are obstacles in the front of robot at 10cm, and if there is, the speed of left motor is 3, the right motor speed of Left rotation is 6, and delay 1s. If not, the underpan-drive continues in accordance with the trajectory walking program.

4.7 Color recognition module design

Color sensors to identify the different colors can be used in industry for detecting product's color. This can be used to detect orbit which has different colors, so that we can light of different colors to display the results of the identification. Surfaces of the different colors have different wavelengths of reflected light, they can be exported in the form of 0 ~ 10V voltage. The strength of the reflected light is relevant to and ambient light, surface roughness and the distance from the object to the sensor.

The color sensor is an analog sensor, the range of values is 0 to 1000. One end of the sensor receives signal A1 or A2 side, the other end to the 9V power supply side and public side. Since the sensor's analog value is different for different colors. Here simulated experiments have encountered the red value is about 90, so set 80 < analog value < 150 as the red value; the green value is about 160, so set 150 < analog value < 180 as the green value; the blue value is about 220, so set 220 < analog value as the blue value. In order to debug robot better, we show the color identified by the color recognition module with the lights of different colors. The program flow chart of color recognition module was shown in Figure 11.

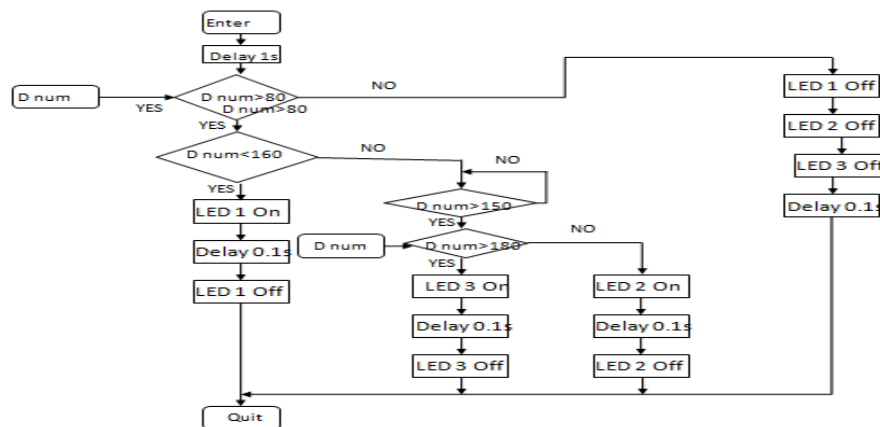


Figure 11. Flow chart of Color recognition module

5. Experiment

Tracked tracing robot walks along the black track in the corner is shown in Figure 12, and the color sensor encounters a red object and red light lights is shown in Figure 13.

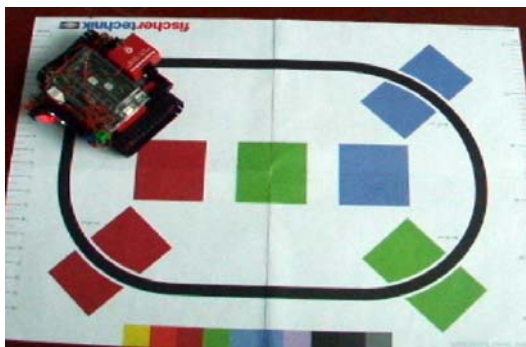


Figure 12. Robot at the corner

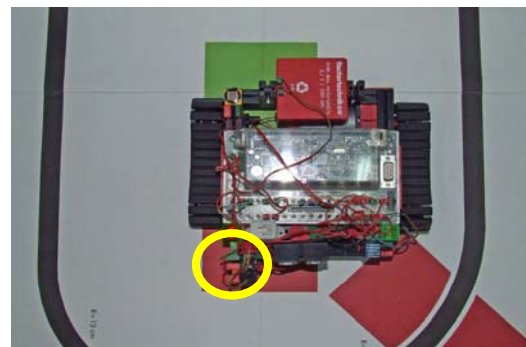


Figure 13. The red lamp lights

6. Conclusion

In this paper, tracked tracing robot was selected as the research object, mechanical structure and control system of robot was designed and developed. In mechanical structure design part, structure designed and positioned were completed, including design of robot body, wheel, underpan, transmission structure and the positioning of batteries, control panel, sensors, etc. The structure of mobile robot is relatively simple, robot power is installed on the rear frame; a pair of ultrasonic obstacle avoidance sensor distributed in front. After assembling, the length of tracing is 220mm, width is 216mm and the height is 78.5mm.

From the robot dynamics analyzing, the steering dynamics equation can be solved by the differential equation, algebraic equation and the given initial conditions.

In control section, M30245 was used as the core, according to the characteristics of tracked tracing robot differential drive, realization scheme of motion control system was put forward, system drive circuit, detection module, control program were developed. The track sensor, ultrasonic obstacle avoidance sensors, optical sensor, temperature sensors, color sensors are chosen in system. On the basis of hardware design, software system including five modules to achieve tracing walking, ultrasonic obstacle avoidance, color recognition, brightness and temperature detection are designed, and tests system more than once to improve the system's hardware and software design, so that the Tracked tracing robot have has a good performance. From this tracked tracing robot researching, a certain design and experimental basis can be provided in future research.

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