Design and Implementation of Self-balancing and Navigation Robot Based on ROS System

Guangshang Song[1], Lei Sun[1, 2], Xuetao Yang[2]

1. School of Electrical and Electronic Engineering, Tianjin University of Technology, Tianjin 300384, China
E-mail: sunleiftd@126.com

2. Tianjin Key Laboratory for Control Theory and Complicated Industry Systems, Tianjin University of Technology, Tianjin 300384, China

Abstract: Based on the SLAM (instant location and map construction) technology of monocular vision and multi-sensor information fusion, the following robot self-balancing path planning system is proposed. The system can handle strenuous moving images well, and for scenes with simple description and feature points being scarce, no loss of positioning occurs. In the selection of key frames and the connection of local maps, a variety of algorithm optimization and multi-sensor fusion methods are selected, which makes the drawing faster and more accurate. Path planning uses a more accurate and time-saving bionic algorithm-ant colony algorithm, combined with gyroscope and PID processing feedback information to achieve self-balancing and navigation path planning.

Key words: Path Planning, Ant Colony algorithm, Self-balancing robot.

1 INTRODUCTION

Mobile robots have become an important branch of robotics research because of their broad application prospects in various industries [1].Wheeled, crawler, propulsion, which are classified according to their movement modes. Among them, wheeled mobile robots are widely used because of their low cost, simple structure and control, and high energy utilization.

The earliest research was carried out in the 1950s, and MIT experts designed inverted pendulums. It provides a strong theoretical basis for the attitude of rockets and missiles [4]. In 1986, Professor Kazuo Yama Fuji was the first to design and manufacture a robot that can stand autonomously at the University of Electrical and Telecommunications in Japan. In 2002, Felix Grasser and others from the Swiss Federal University of Technology developed a remote-controlled two-wheel mobile robot Joe through a DSP controller [11]. In the same year, Dean Kaman, a US company called Segway LLC, invented the Segway, which is mainly used for transportation [13]. It is the world's first two-wheeled and self-balancing vehicle. In the past ten years, the research on this subject has been in constant stream, showing a trend of blooming.

2 SYSTEM COMPOSITIONS

The system is a nonlinear, strongly coupled, multivariable control and naturally unstable system.

In order to effectively and accurately collect and maintain the balance parameters, based on the STM32, the gyroscope device and the capture of the encoder are used to accurately measure and monitor the displacement and steering of the car, and then control and realize the self-balancing function.

Analytical indicators such as feature strength and efficiency area are established. Optimize management of features, simplify the number of features, and meet real-time requirements. The monocular stereo vision system is calibrated by the linear calibration method based on the perspective transformation model. The three-dimensional reconstruction method based on linear calibration is applied to reconstruct the three-dimensional matching point pairs to obtain the three-dimensional spatial information of the corresponding object points.

Path planning is implemented by using ant colony algorithm and multi-sensor fusion.

3 SELF-BALANCING WORK PRINCIPLE

3.1 Principle Introduction

The principle of self-balancing is derived from the control principle of the inverted pendulum. The force of the inverted pendulum is as follows:

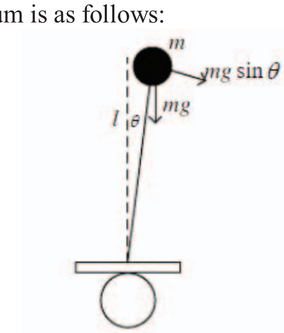


Figure 1.1

When the object leaves the equilibrium position, there will be acceleration in the same direction as its displacement, so the object will accelerate down in this direction. In order to prevent the object from falling down, the wheel can be

Fund Project: National Undergraduate Training Programs for Innovation and Entrepreneurship 201810060009. Key technologies R&D program of Tianjin (18YFZCSF00600 ,18ZXJMTG00160 ,18ZXZNSY0 0270）

accelerated in the same direction as the falling direction. At this time, the wheel has a horizontal acceleration which can be decomposed into the direction of the rod and perpendicular to the direction of the rod.
According to Newton's third law, the object will be subjected to the force opposite to the direction of motion, if the force is equal to the force generated when the object falls, the resultant force of the object points to the center position, and balance can be achieved.

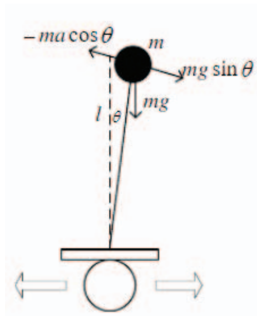


Figure 1.2

In summary, The method of achieving balance: the gyroscope is used to detect the inclination of the vehicle body and the acceleration of the tilt, and the data is sent to the single-chip microcomputer, and the single-chip microcomputer performs the calculation, and the motor speed is adjusted accordingly, so that the vehicle body achieves “Dynamic Balance”.

3.2 Data Collection Unit

The unit is a PCB board containing a micro controller STM32F103 and a gyroscope MPU9250 for collecting and processing the data required by the principle. With this unit module, information such as acceleration and direction can be sent to the two bottom motors. If the measured angle is 0° at the specified level, the motor stops; if it exceeds 0°, the motor advances appropriately, and below 0°, it is appropriately reversed.

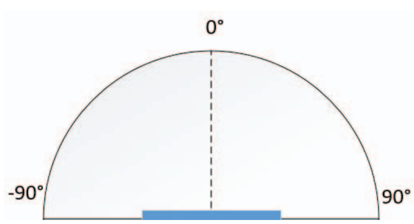


Figure 2.1 Data collection unit board measurement level 0° (flat table)

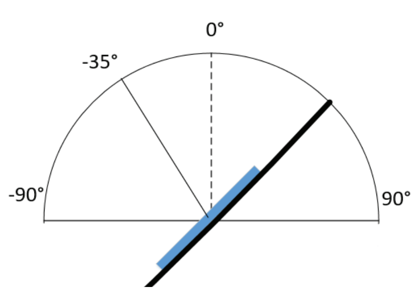


Figure 2.2 Data collection unit rotates -35° (negative direction)along its x-axis

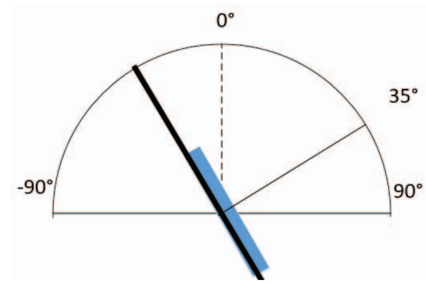


Figure 2.3 Data collection unit rotated 45° (positive direction) along its x-axis

3.3 Implementation of PWM Speed Control System

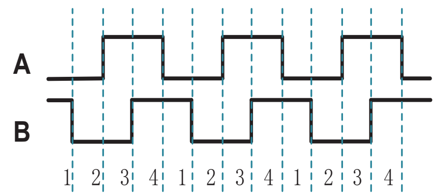


Figure 3.1

Using the incremental Hall encoder, the A and B phases can be used to determine the steering of the motor. Use quadruple frequency technology to increase accuracy by a factor of four.
The code in the program is as follows:
wtemp3=(wtemp3*SPEED_SAMPLING_FREQ)*60/(4*ENCODER1_PPR);//(Average code number*sampling frequency)*60/(4*64)
(When the software is designed, set STM32's Timer 3 to Encoder Mode 3, using quadruple frequency encoding, and each time a pulse is captured, the value of TIM.CNT is incremented by 1.)

3.4 Implementation of PWM Speed Control System

In order to improve the control accuracy, PID control is added. As shown in Figure 4.1

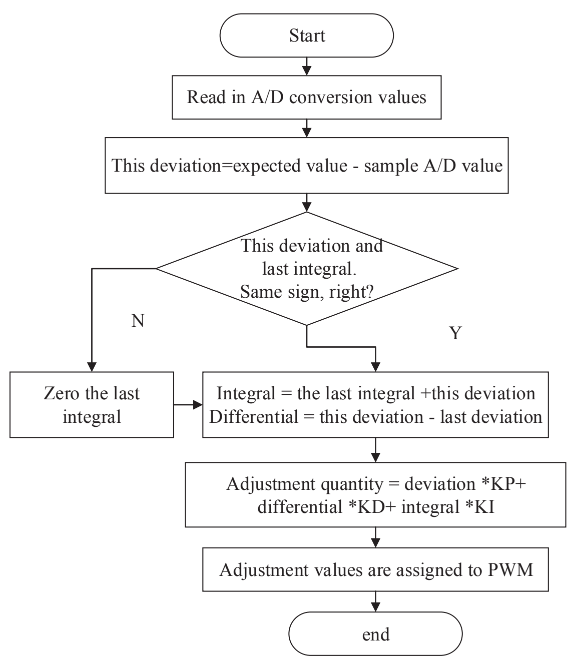


Figure 4.1

The relationship between the input e(t) and the output u(t) is:

$$u(t) = kp(e((t)+1)/T1\int e(t)dt + TD \times de(t)/dt)$$

Note:
The upper and lower limits of the integral are 0 and 1, respectively, and their transfer functions:

$$G(s) = U(s)/E(s) = kp[1 + 1/(TI \times s) + TD \times s]$$

TI is the integral time constant, kp is the proportional coefficient, and TD is the differential time constant.

4 PATH PLANNING BASED ON ANT COLONY ALGORITHM

Ant colony algorithm is a random search optimization method. As a global optimization algorithm, it has a wide application field. The key problem that needs to be solved is to make the search space of the ant colony algorithm as large as possible (that is, the randomness is large) to find the global optimal path. The prior knowledge (i.e. distance information, heuristic information, and pheromone) is used to converging the system's large probability to global optimality. The essence is to resolve the contradiction between randomness and pheromone strength update. It will be developed from two aspects: search strategy and pheromone update. It can improve the ant's search ability through ant's reentry search strategy.
On this basis, the AIDS search ability can be improved by optimizing the taboo table. Different search strategies through two-way ant groups are adopted. Improve the convergence speed of the algorithm; cross-optimize the path for the concave obstacles to search through different ant colony paths.

4.1 Grid Method to Divide the Environmental Space

For a two-dimensional terrain of arbitrary shape, there are always a finite number of obstacles. Because the obstacle coordinate position is extremely easy to map, it can be regarded as known environmental information, and the grid map can be established by traversing the two-dimensional space.
Regardless of the information of the robot in the height direction, the two-dimensional space of the robot is recorded as AS, and the lower left corner of the robot is used as the coordinate origin, and the conventional rectangular coordinate system TF_0 is established. The maximum values of AS in the x and y axes are respectively x_{max} and y_{max}.
Set the walking step δ of the robot, and divide the x-axis and the y-axis equally at δ to form a grid. The number of raster per column per row is x_{max}/δ. Obstacles are indicated by a black grid.
The serial number method is combined with the Cartesian coordinate method to identify the grid:
Starting from the lower left corner, they are numbered sequentially from left to right and from bottom to top. For example, the grid with the number 1 is recorded as g_1; the grid coordinates of the center point of the grid are defined as grid coordinates, for example, the sequence number is 1. The grid is marked as g (0.5, 0.5)

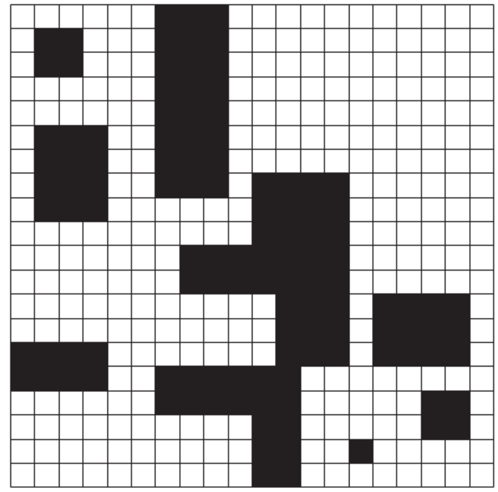


Figure 5.1 Grid environment map

4.2 Description and Definition of Path Planning Problems.

In order to simulate the foraging behavior of the actual ant colony, the robot's starting position g_1 is the ant nest, and the target position g_n is the food source. The robot path planning based on ant colony algorithm is to avoid all obstacles through the interaction and cooperation between ants in the ant colony, and finally find an optimal path from g_1 to g_n.
m: the number of ants;
η_{ij} : The heuristic function.
That is the visibility of the path (i, j).
τ_{ij} : Pheromone trajectory strength on path (i, j).
$P_{ij}^{k}(t)$: Ant k selects the transition probability of grid j and grid i.
k: Ant serial number.
i or j: Grid number.

4.3 Algorithm Application and Improvement

(1) Using Pseudo-random Proportional Rules Instead of Random Proportions for Path Transfer.
In the basic ant colony algorithm, the ant decides the next direction of transfer according to the amount of pheromone on each path and the heuristic information on the path. The state transition rule used is called random ratio. The probability that the ant k of the node i select the node j as the transfer direction is given.

$$P_{ij}^{k}(t) = \begin{cases} 0, otherwise \\ \dfrac{\tau_{ij}^{\alpha}(t)\eta_{ij}^{\beta}(t)}{\sum\limits_{s \in allowed_k} \tau_{is}^{\alpha}(t)\eta_{is}^{\beta}(t)}, j \in allowed_k \end{cases} \quad (3.4)$$

Obviously, under the stochastic proportional rule, ants rely entirely on probabilities for path selection. In order to better and more rationally use prior knowledge, the stochastic ratio is combined with deterministic transfer, and different decision transfer rules are used. The ant at the node r selects the next transition node s by the pseudo-random proportional rule given by formula (3.5)

$$s = \begin{cases} \arg\max_{u \in allowed_k} \{[\tau(r,u)]^{\alpha}[\eta(r,u)^{\beta}]\}, \\ (\text{if } q \le q_0 \text{ chooses the path according to} \\ \text{prior knowledge}) \\ S, \\ (Ohtherwise, \text{ the probability search is} \\ \text{couducted according to formula 3.4}) \end{cases} \quad (3.5)$$

The parameter q_0 introduced in the equation can be used to adjust the ant initiative of the ant to explore the new path, and also to focus the ant's search activity around the local optimal solution.

(2) Limit The Range of Ants that The Ant Travels to The Next Step.

In the basic ant colony algorithm, the next step allows the selected nodes to include all nodes that are not accessed, but in this system, it is limited to free raster that is not accessed in the eight directions adjacent to it.

That is, the ant's next action needs to meet three conditions: ① Adjacent grid of the current grid. ② Grid not accessed by the ant. ③ Free grid.

This restriction allows the ant to quickly bypass the barrier grid to find a continuous optimal path without repeating the grid.

(3) Heuristic Function Redefinition.

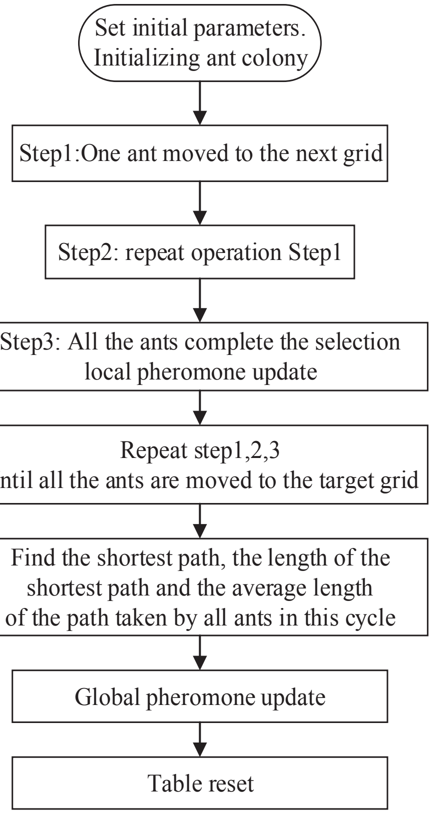
Distance heuristic function in basic ant colony algorithm $\eta_{ij} = 1/d_{ij}$, where d_{ij} is the distance between nodes i and j, but in this system, the grid distance is not 1 or $\sqrt{2}$. The difference is very small, and the guiding effect is not obvious. In order to make the ant transfer the grid closer to the target grid, the probability that the ant will move to the target grid is larger, and the ant will allow the selected grid g_j and the target grid g_n. The product of the distance between the reciprocal = 1 / d_{ij} and a constant C as a heuristic function, take $\eta_{ij} = C/d_{ij}$.

(4) Use Roulette to Select The Next Grid Based on The Transition Probability.

The ant moves from the current grid to the next grid. If the transition probability is always the highest in the allowed grid, the algorithm loses randomness and falls into the local optimal solution. In order to solve this problem, the roulette method is used to calculate the cumulative probability of the ant's next allowed grid transition probability, and a random number of 0~1 is generated. Which random probability the random number falls into is selected. The raster correspond to the cumulative probability.

4.4 Algorithm Implementation Steps

In the grid environment with a total number of grids n, the steps of the ant colony algorithm to implement the robot path planning are:



(1) Initialization:

Including the path start raster g_1, the target raster g_n to make the number of loops $N_c = 0$, set the maximum number of loops $N_{c}\_\max$, setting the pheromone heuristic factor α, the expectation heuristic factor β, the pheromone volatilization coefficient ρ, the constant Q, and the initial pheromone on the path between the grids $\tau_{ij}(0) = const$ ($const$ is a constant). Setting $routh-best$ used to record the shortest path obtained per loop, $length\_best$ record the shortest path length obtained for each cycle, $length\_average$ record the average length of all paths obtained in each iteration. Place m ants at the starting point g1 and add g1 to the taboo table $tabu_k$ (k=1, 2, 3... m)

(2) Local Pheromone Update:

Pheromone gradually evaporates over time, with $1-\rho$ Indicates the degree of volatilization

$$\tau_{ij}(n+1) = (1-\rho)\tau_{ij}(n) + \rho\Delta\tau_{ij}^{k} \quad (3.6)$$

In the middle $\Delta\tau_{ij}^{k}$ There are many different methods of seeking, and under the premise of guaranteeing the performance of the algorithm, $\Delta\tau_{ij}^{k}$ is a constant, $\tau_{\min} \le \Delta\tau_{ij}^{k} \le \tau_{\max}$.

(3) Global pheromone update:

At the end of each cycle, global pheromone updates are performed according to equations (3.7) and (3.8).

$$\tau(r,s) \leftarrow (1-\alpha)\tau(r,s) + \alpha\Delta\tau(r,s) \quad (3.7)$$

$$\Delta\tau(r,s) = \begin{cases} 1/L_{gb}, (r,s) \in \text{Global optimal path} \\ 0, \quad \textit{Otherwise} \end{cases} \quad (3.8)$$

Where α is the pheromone volatilization coefficient, and L_{gb} is the global optimal path so far.
The taboo table is cleared:
Cycles $N_c = N_c + 1$
If $N_c \le N_{c}\_\max$, go to step1;
If $N_c > N_{c}\_\max$, jump out of the loop and output the optimal path and its length.

4.5 Simulation Study

To verify the effectiveness of the algorithm, a simulation experiment was performed on the computer using matlabR2016a.
Figure 6.1 shows the convergence curve of the basic ant colony algorithm.
Figure 6.2 shows the convergence curve of the improved ant colony algorithm.
Figure 6.3 shows the final path planning simulation diagram based on matlabR2016a.

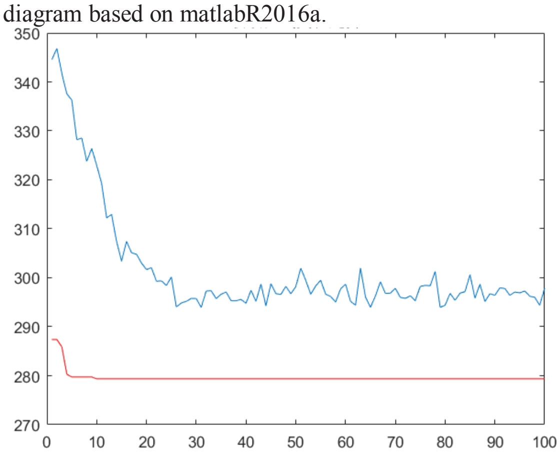


Figure 6.1 Basic ant colony algorithm convergence curves

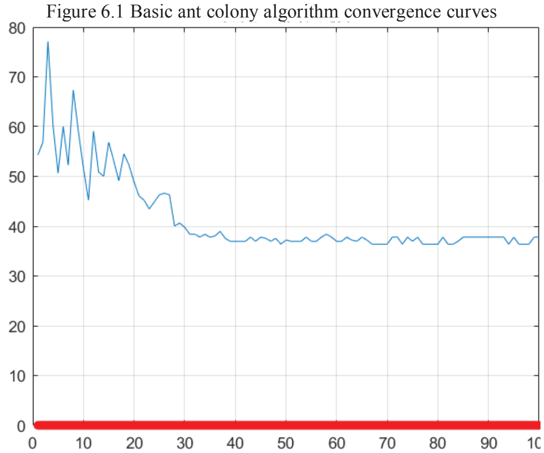


Figure 6.2 Improved ant colony algorithm convergence curves

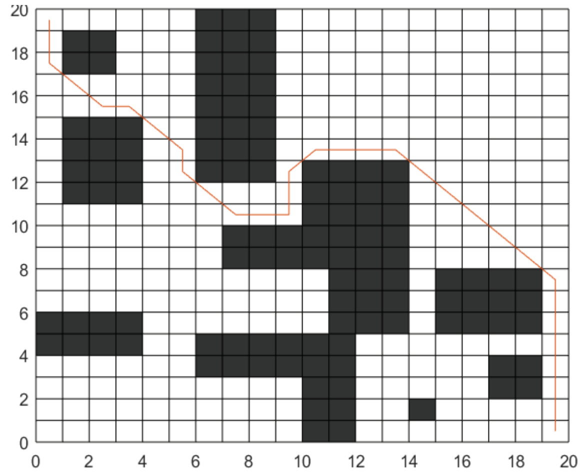


Figure 6.3 Simulation diagram of the final path planning of the robot

5 CONCLUSION

Based on the ROS architecture, the STM32 is the processor's data acquisition board as the lower computer. Control the overall balance and travel of the robot, and retreat; use the Raspberry Pi-3B+ as the host computer to control the entire system for path planning and map navigation. Based on the mathematical model of basic ant colony algorithm, combined with the characteristics of mobile robot path planning problem, the modified ant colony algorithm is applied to the robot and the simulation research is carried out. After a lot of experiments, the real machine balance and action functions are available, and the path planning algorithm works well.

REFERENCES

[1] Zhang Zheng. Design and Implementation of Two-Wheeled Mobile Robot by variable structure Sliding Mode Control [A]. China Automation Society Control Theory Committee, China Systems Engineering Society. 35th China Control Conference Proceedings (D) [C]. China Automation Society Control Theory Committee, China Systems Engineering Society: 2016: 5.

[2] Li Shanshou, Fang Qiansheng, Xiao Benxian, Qi Dongliu.Environmental Modeling Based on Improved Viewable Method in Global Path Planning[J].Journal of East China Jiaotong University,2008(12):73-77

[3] Zhang Qi. Research on path planning and positioning technology of mobile robots [D]. Harbin Institute of Technology, 2014.

[4] Oommen B,Iyengar S,Rao N,Kashyap R.Robot Navigation In Unknown Terrains Using Learned Visibility Graphs[J].IEEE Journal of Robotics and Automation,1987,3(6):672-681

[5] Zhang Qi. Research on path planning and positioning technology of mobile robots [D]. Harbin Institute of Technology, 2014.

[6] Li Meiyan. Design of DC motor speed control system based on single chip microcomputer [J]. Electronic Design Engineering, 2016, 24(22): 158-160.

[7] Xie Zhengxia. Design and research of two-wheel self-balancing electric vehicle control system [D]. East China Jiaotong University, 2015.

[8] Li Li. Anti-backlash and synchronization control method for dual motor drive servo system [D]. Tianjin Polytechnic University, 2017.

[9] Li Yanlong. Design and implementation of USB camera driver under Linux [D]. North China University of Technology, 2015.

[10] Xia Gaoyu. Design and Practice of Intelligent Camera Based on OpenCV [D]. Hangzhou University of Electronic Science and Technology, 2016.

[11] Felix Grasser, Aldo D'Arrigo, Silvio Colombi, Alfred c. Rufer. JOE; A Mobile,

[12] Inverted Pendulum. IEEE Transactions on Industrial Electronics. 2002, 49(1): 107~114

[13] Li hongmei, li zhi, gao fei Balance Masterpiece - Segway HT two-wheeled Platform Electric Vehicle. Electrical industry. 2002, 6:19 ~ 21

[14] Li Pingzhou, Wu Yang. Research on M/T method of motor speed measurement based on microcontroller [J].Electronic Science and Technology, 2017, 30(05): 76-79.

[15] Zijian Yang. A design of the two-wheeled selfbalance vehicle [A]. International Engineering Technology Publishing Association. Abstracts of the 2016 International Conference on Advanced Materials, Structures and Mechanical Engineering (ICAMSME 2016) [C]. International Engineering Technology Publishing Association: 2016:1.

[16] WANG Ke,JIA Songmin,LI Xiuzhi,et al.The Monocular Visual Mileage Calculation Method of Mobile Robot Based on Ground Features[J].Acta Optica Sinica,2015,35(05):245-251.

[17] Zhang Zheng. Design and Implementation of Two-Wheeled Mobile Robot by variable structure Sliding Mode Control [A]. China Automation Society Control Theory Committee, China Systems Engineering Society. 35th China Control Conference Proceedings (D) [C]. China Automation Society Control Theory Committee, China Systems Engineering Society: 2016: 5.

[18] Wen Shuangyun. Research and optimization of two-wheel self-balancing trolley control algorithm [D]. Jilin University, 2017