Magnetic Tape Following Robot

Praveen. D, Bhuvaneswari.B, Nithya sre. N, Hariharan. G

Department of Robotics and Automation Engineering

Manakula Vinayagar Instituite Of Technology

Madagadipet, Puducherry.

Abstract.

 Magnetic tape following Vehicle is an automatic transportation robot with high universality and diversity which can drive and transport goods automatically in the established path, so it is widely used in mass production and logistics industry. In this paper, a tracking system with independent guidance and integrated network control is designed and developed. Firstly, based on the project requirements of some companies and the practical problems, the basic parameters of tracking are determined, and the movement analysis of moving is carried out to obtain its motion characteristic equation for movement control. Then the hardware of the mechanical and electronic parts of the AGV is designed. Arduino is used for software programming. Based on the core PID algorithms, the related algorithms design of AGV path recognition and movement control are presented. Finally, a small AGV capable of carrying a maximum weight of 8 kg is trial-produced and tested. The test data show that the position deviation can be controlled within 15mm and the maximum speed can reach 1m/s. It can communicate with the host computer in various ways. Its expansibility, stability, accuracy, and real-time performance all meet the requirements of the project.

Introduction

Automatic Guided Vehicle (AGV) is a wheeled robot that can be controlled by a variety of sensors, remote controls, networked devices or equipment. It can drive and transport goods automatically in the established path, so it is widely used in mass production and logistics industry as an important part of many intelligent systems. As early in the 1980s, AGV products have been applied in major manufacturing industries in foreign countries, such as hundreds of VOLVO AGVs adopted by many cars and engine manufacturers. Domestic research and application of AGVs have made great progress since 1990. However, the developed AGVs and their corresponding integrated systems are not widely applied in engineering because of the low automation and efficiency and high cost. So there is still a huge room for improvement .

According to the requirements of some manufacturing company and AGV technology development trend, a set of AGV system is designed. We complete the system hardware design, explore and study the AGV control system to improve the traditional control mode. By using Arduino instead of traditional PLC control, the AGV has smaller size, more functions and higher driving accuracy.

1. AGV Integrated Design

Analyzing the project requirements and the basic functions that the control system needs to complete, the basic parameters of AGV are determined, as shown in Table 1.

Table 1. Key performance parameters of AGV.

Performance index	Parameters	Performance index	Parameters
Kerb weight	4 kg	Power source	12V/5200mAH
Payload	5 kg	Continuous running time	6h
Maximum laden mass	8 kg	Driving mode	Two independently driven mid-wheels
Vehicle dimensions	350mm×350mm×180mm	Control mode	PC remote networking/Manual control
Maximum speed	60mm/min	Guidance pattern	Magnetic stripe guide
Kinematic accuracy	±12.5mm	Charging mode	Battery with manual replacement
Minimum turning radius	150mm	Safety protection	Button to stop

Analysis of AGV motion

AGV is driven in various forms; three and four-wheel drive AGV steering accuracy is poor and difficult to control, so the current mainstream AGV driving mode is multi-wheel driving. Multi-wheel driving AGV has a good safety and stability performance and large load, but the disadvantage is that it needs to keep multiple wheels grounded and has high requirements for chassis and tire structure design. An up-and-down slope or uneven road surface may cause wheel suspension or center of gravity deviation instability.The AGV in this project has low speed and a smooth road surface. In addition, in order to increase the load in the future and ensure reliable operation, an eight -wheel structure with two independently driven mid-wheels is adopted. The middle two driving wheels are driven by two motors and turn separately and the other four wheels are universal casters to bear the load. This design makes the AGV flexible and easy to control. The connecting line midpoint of the two driving wheels can be regarded as the geometric center point in eight-wheel AGV structure, shown in Figure 1. Point O_L and O_R represent the midpoints of left and right wheels respectively; V_L and V_R represent the running speed of left and right wheels whose direction is perpendicular to line $O_L O_R$. S is the distance between two driving wheels. XOY is the reference coordinate system, and the counterclockwise motion is positive. Let the coordinates of the point O_P in the coordinate system be (a, b), and the AGV attitude angle is represented by the angle α between the X-axis and V_R, thus the navigation position of AGV can be determined by the vector (a, b, α) in the XOY coordinate system. If $V_L \neq V_R$, there must be a point on the line $\overline{O_L O_R}$ where the velocity is zero, and this point is instantaneous center of revolution O. The driving wheels move in a circular motion around the point O. According to the triangle shown in Figure 1, the turning radius of AGV is:

$$|O_P O| = \frac{S(V_L + V_R)}{2(V_R - V_L)} \tag{1}$$

The linear velocity of AGV is:

$$V_m = \frac{V_L + V_R}{2} \tag{2}$$

The angular velocity is:

$$\omega = \frac{V_L + V_R}{2O_P O} = \frac{V_L - V_R}{S} \tag{3}$$

According to equation (2) and (3), when $V_L = V_R$, the angular velocity ω is zero and AGV runs in straight line; when $V_L \neq V_R$, AGV attitude angle $\alpha \neq 0$, there is a turning motion in AGV. Hence the position and attitude angle of AGV are:

$$\begin{cases} x = a + \int_0^t V_m(t) \sin\alpha\, dt \\ y = b + \int_0^t V_m(t) \cos\alpha\, dt \\ \alpha = \alpha_0 + \int_0^t \frac{V_L(t) - V_R(t)}{S} dt \end{cases} \tag{4}$$

where a, b and α_0 are the AGV position and attitude angle in initial time. According to equation (4), given the initial state of AGV, its running route can be tracked and controlled by controlling the speed of driving wheels. Suppose the displacement and deviation angle are Δq and $\Delta \alpha$ in time Δt, the equation of AGV motion state is obtained by differentiating the time variable

$$\begin{cases} d\Delta\alpha = \frac{1}{2O_P O}[V_L(t) - V_R(t)]\, dt \\ d\Delta q = \frac{1}{2}[V_L(t) + V_R(t)]\sin\alpha\, dt \end{cases} \tag{5}$$

The AGV movement line is continuous, and its motion state can be calculated by Laplace transform on time t:

$$\begin{cases} \alpha(s) = \dfrac{1}{2OO_p s}(V_L - V_R) \\[2mm] q(s) = \dfrac{1}{2s}(V_L + V_R)\sin\alpha \end{cases} \qquad (6)$$

Equation (6) determines the relationship between the AGV position and angle deviation and the speed of the two driving wheels, so that the vehicle's running attitude can be controlled by setting speed parameters. Figure 2 shows the motion characteristics of AGV.
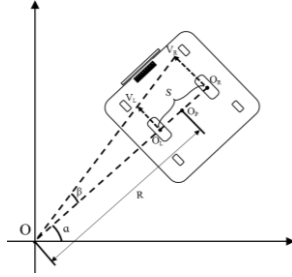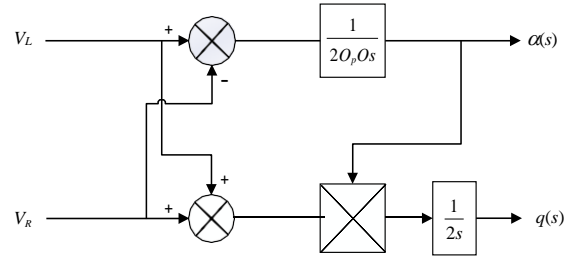

Figure 1. AGV theoretical model of motion.   **Figure 2.** AGV motion characteristics.

1.1 Hardware design
1.1.1 Structure plan

The AGV key structure and components are shown in Figure 3. The AGV body is equipped with fixed boards and other mechanical devices, batteries, various control lines, and circuit boards. Two control circuit boards, one for the control of AGV operation, including magnetic strip acquisition module, drive motor module, ultrasonic module, safety protection module, and Bluetooth transmission module; the other is responsible for communicating with the host computer or server and controlling the display

There is a magnetic navigation sensor fixed on the bottom of the body front by aluminum plate, perpendicular to the magnetic stripe. In order to prevent mutual interference of magnetic fields on the magnetic tape, the distance between the magnetic strip and the magnetic sensor should not be too close, which is set between 150-200mm after testing. The front of the car is equipped with a display screen, which is used to display the current AGV operation status, such as speed, operation time, and specific information of battery power.

1.1.2 Drive motor

When AGV driving, the total resistance is:

$$\Sigma F = F_f + F_w + F_r + F_j \qquad (7)$$

where ΣF is total resistance; F_f rolling resistance; F_w windage resistance; F_r grade resistance; F_j acceleration resistance. $\Sigma F=10.62$N, according to the design parameters and working conditions of the AGV. Brushless DC gear motor adopted for the vehicle is small in both volume and mass and photoelectric encoder is used to measure the time of motor commutation to achieve more accurate control. The power required by the AGV motor is 5.5w, and the maximum speed is 1500rpm. Therefore, the motor model GA25Y370-47 is selected whose rated speed is 2900rpm, maximum speed is 3600rpm, rated torque is 0.52kg•cm, maximum power is 5.6w, weight is 91g, and rated voltage is 12V.
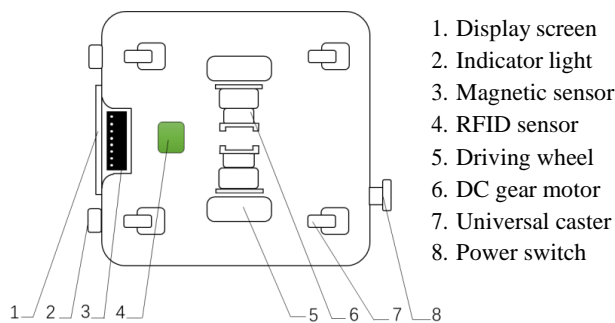
1.1.3 Wheel

The two driving wheels selected are conventional rubber tires that match the motor and are designed to fix the vehicle chassis by a supporting structure processed with boring and spray painting. The material of the supporting structure is Q235 which is low price, good durability, high strength, and rigidity.

The four polyurethane universal casters with a diameter of 2mm are installed on the body bottom corners by aluminum alloy connection and can rotate freely in the horizontal direction.
The AGV and its cargo are light, so the body and chassis are made of acrylic sheets, and between them, there is a rigid connection by fastening bolts which is convenient for processing and disassembly.
The AGV 3D model is shown in Figure 3. The overall size of the design meets the basic requirements and related functions. Goods are placed on the body; batteries, control circuit boards and other important devices are placed in the body. The rear part of the AGV body is equipped with a main power switch and an emergency stop button to prevent accidents.

1. Display screen
2. Indicator light
3. Magnetic sensor
4. RFID sensor
5. Driving wheel
6. DC gear motor
7. Universal caster
8. Power switch

(a) AGV chassis parts.
Figure 3. AGV structure.

1.1.3 Control circuit system

The control circuit system of the vehicle is shown in Figure 4. Main control board adopts STM32F103VET6 which is responsible for the button, lighting and motor drive module, and leads to all external circuit interfaces, including magnetic navigation sensor, motor encoder, bluetooth and other communication ports for expansion and debugging. The CPU processes the position signal from the magnetic sensor, and adopts the PID control algorithm to gain the PWM duty cycle signal for given speed, and continuously tracks and corrects the motor speed so that the AGV can move stably on the specified route.

The AGV is powered by a 12V lithium battery and provides 3.3v and 5V voltages for the control through two basic power supply conversion chips, MP1430 and AMS1117-3.3V. L6385D drives the high-power MOS transistor IRF3205 to output a reliable PWM signal. Four transistors form an H bridge circuit to turn the motor positively or negatively. The light part includes power indicator, turn signal and alarm light; switch is for mode switching, emergency stop protection and other operations. The 8050NPN transistor is used to drive high-power light components such as turn signal and alarm lights. Indicator lights are connected with resistors of 10K and 1K respectively, and glow to indicate whether the corresponding power supply is working correctly. The communication module of magnetic navigation sensor adopts RS232 circuit, so that the external magnetic navigation sensor can communicate with the core control circuit reliably and work normally.
Peripheral device interfaces include bluetooth, motor encoder, RFID card reader and other serial communication modules. Bluetooth is responsible for the information transmission, and the serial port is used to assist the other information transmission, or as an extension.

2. AGV Control System Design

C language is adopted to realize the control algorithm of all system modules, and Keil uVision5 to compile. Timer and serial port, I/O interfaces on Stm32F103VET6 chip realize the sensor information collection, motor driving and control of other components to ensure the AGV can work smoothly and achieve the specified tasks.

The AGV on-board software process is shown in Figure 5. The upper computer function includes driving path planning, bluetooth wireless communication and display of AGV operation.
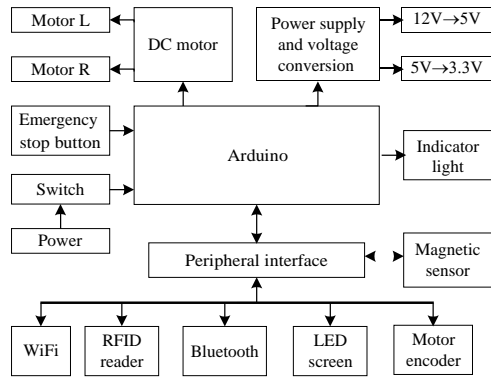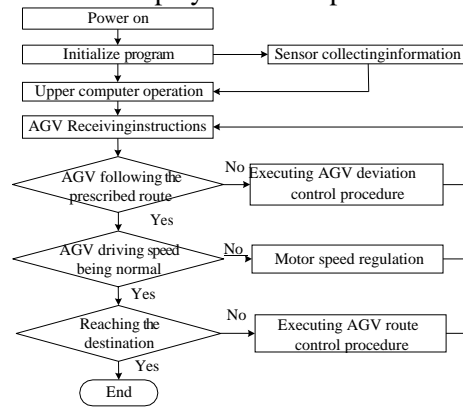

Figure 4. Control circuit system of the vehicle.

Figure 5. AGV on-board software process.

3.3 Design of AGV control algorithm
3.3.1 Steering control

The output value of the sensor is the horizontal distance between the center of the road tape and the sensor, and this information is used to correct steering. If the distance value is 0, no steering correction is required; if the distance value is negative, AGV turns left; otherwise, the AGV turns right. The greater the sensor output, the greater the steering angle.

In order to achieve the best accuracy and response time, we adopt the complete PID control algorithm, using the proportion, integral, and differential linear parameters to allocate and determine the parameters of different proportions according to the actual road conditions. The principle is simple, feasible robust, and easy to adjust the parameters. By setting the relevant parameters, the system obtains excellent stability and response speed.

3.3.2 Fork and merging of road control

The system always thinks that the ground has two tracks. When tracking single track, the two tracks are regarded as overlapping. When going into the fork, the distance between the left and the right gets wider; on the contrary, when two tracks are close to the merger, the distance between them decreases, as shown in Figure 6. The AGV automatically selects the correct path according to the system instructions.

3.3.3 AGV Positioning Control

RFID tags are adopted to determine AGV position, which are located on the left or right side of the tracks. There is no power supply inside RFID tag. After receiving the signal and electromagnetic energy from the sensor on the AGV, the data in the preexisting tag will be transmitted to the AGV. RFID tag provides a simple and low-cost method to determine the position of the AGV in track. The relevant data are tracked and fed back by the upper computer in real time. We use the RFID tag on the left or right to indicate the AGV to turn left or right or drive in a straight line at a fork ahead. In addition, the RFID tag can also provide an indication of the stop position for the AGV, as shown in Figure 7.
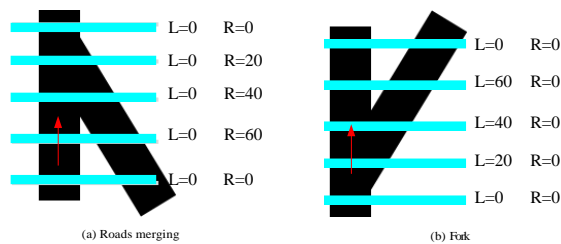

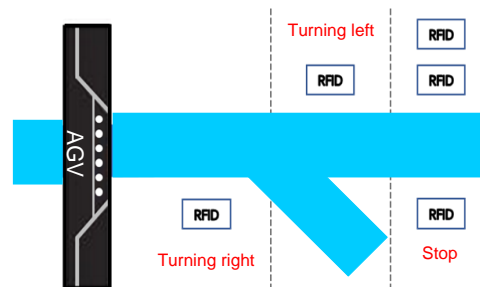**Figure 6.** Fork and merging of road code.

Figure 7. RFID positioning.

Figure 8. AGV application.

4.Software Program

https://dl.kristyxx.workers.dev/0:/ARDUINO%20CODE%20FOR%20MAGNETIC%20TAPE%20FOLLOWING%20ROBOT.pdf

5.Engineering Application

The trial production of AGV is completed, as shown in figure 8. The vehicle is equipped with a camera to test the ability of tracking guidance. Through the video information from the camera, the AGV position points are recorded every 50mm and connected to obtain its continuous driving route. In this way, the actual driving path can be compared with the tape guiding path to obtain the deviation of AGV driving route.

Setting AGV different speeds, the average driving deviations are obtained, as shown in Table 2, taking AGV driving to the left as positive and to the right as negative. The test results show that the AGV can correctly trace the track and read the tags, and transport the goods to the designated place stably and accurately within the specified error. The maximum driving deviation shall not exceed 15mm.

Table 2. AGV driving deviations.

No	AGV speed (m/s)	Position		(its initial position is 0)		
1	0.2	0	-2.9	+4.5	+4.6	-1.0
2	0.4	0	+4.3	+5.4	-4.2	-3.5
3	0.6	0	+2.7	+7.5	-6.4	+5.6
4	0.8	0	+7.4	-10.1	+11.3	-4.8
5	1.0	0	-6.5	-13.5	-12.7	+6.1

6.Conclusion

A small AGV is designed which can carry up to 8kg. The position deviation can be controlled within 15mm and the maximum speed can reach 1m/s. It can communicate with the host computer in various ways. Its expansibility, stability, accuracy and real-time performance all meet the requirements of the project. AGV is a multi-disciplinary and interdisciplinary complex system. In order to achieve better performance, further optimization should be made from the following aspects.

1. The chassis can be optimized. Eight -wheel structure requires a high geometric dimension of the vehicle, and the improperly geometric parameters will result in jack-up, contact, or tail failure on complex roads. Therefore, a more flexible four-wheel structure, including a double drive wheel and double load-bearing wheel, can be considered, but the four-wheel structure needs to be strengthened.

2. AGV guidance mode technology and the requirement of software and hardware are developing. In the future, AGV will integrate information fusion and artificial intelligence technology, such as fuzzy control, deep learning, and neural network algorithm, so that AGV does not need a lot of manual intervention, it can complete self-learning, self-training according to the specific environment to achieve the best decision-making and real-time response.

7.References

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