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Research on Intelligent Disinfection Robot Based on STC89C52 Microcontroller Control System

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Abstract: An intelligent disinfection robot based on STC89C52 microcontroller as the control system is proposed to address the current problems of high cost, scene limitations, and complex control factors. With the assistance of software development, the peripheral circuit of the chip is designed, and the robot can dynamically adjust its path according to its own and surrounding companions' position and motion status. The research results indicate that the various modules of the system can work in coordination, with high accuracy in tracking routes, precise image recognition, timely obstacle avoidance, fast response speed, and safe and reliable system operation. The disinfection robot carried out disinfection and sterilization test on the most common staphylococcus aureus and mold, and the test results showed that the pathogenic bacteria decreased significantly after 2 min, and all bacteria were removed after 3 min, and the killing rate of bacteria was up to>96.0%. This method improves the obstacle avoidance ability and collaborative efficiency of robot systems in complex environments, and can effectively respond to various unexpected situations.

Keywords: Intelligent disinfection robot, STC89C52 microcontroller, circuit design.

1. Introduction

In recent years, the research and application of intelligent disinfection robots have developed rapidly worldwide. At present, most intelligent disinfection robots on the market use ultraviolet disinfection, spray disinfection, and multifunctional disinfection methods, which can effectively kill viruses and bacteria in the air and on the surface[1]. At the same time, by equipping advanced sensors and navigation systems, autonomous path planning can be achieved, obstacles can be avoided, and efficient and accurate disinfection operations can be carried out. Ultraviolet disinfection robots use appropriate wavelengths of ultraviolet light to destroy the substructures of microbial DNA or RNA, causing cell death and achieving the characteristic of sterilization and disinfection for physical disinfection. Moreover, ultraviolet light is an environmentally friendly disinfection method that does not leave any residue on the surface. The ultraviolet disinfection robot is achieved by installing ultraviolet lamp posts on the top of the mobile robot, usually integrated with various sensors used for navigation and target detection, such as cameras, LiDAR, and ultrasound.

Disinfection robots mainly use ultraviolet disinfection methods, represented by UVD Robots and XENEX Light Striker. UVD Robots are autonomous mobile robots, measuring 178 cm in height and weighing 120 kg. Their UV lamps have a lifespan of up to 12000 hours and can emit 254 nm ultraviolet light, killing 99.99% of bacteria within 10 minutes[2]. They can also automatically detect the presence of people in the disinfection area during operation, avoiding harm to human skin and eyes[3]. XENEX LightStriker uses a high-intensity pulsed hernia ultraviolet system that can generate ultraviolet radiation throughout the entire sterilization spectrum (200-315 nm), inactivating pathogens at the most susceptible wavelengths[4]. However, due to the strong enough ultraviolet light to cause damage to human skin and eyes, the room must be vacated during disinfection. To overcome this limitation, Moez Guettari et al. [5] added UVC reflective shielding to surround the UVC lamp, which can reflect the radiation emitted from behind the robot, giving the robot the potential to work safely with humans. In 2022, Conor McGinn et al. [6] used autonomous ultraviolet sterilization and irradiation robots to rapidly disinfect radiation therapy rooms, and evaluated the disinfection program using autonomous UVC robots. The robot disinfection program lasted less than 10 minutes, and the average ultraviolet radiation dose of the samples was 13.01 ± 4.36 mJ/m^2. Automated disinfection programs can shorten the turnover time. In 2023, Michael Rodgers et al. [7] conducted a disinfection experiment using a mobile disinfection robot's UV-C (UV-C) to evaluate its on-site effectiveness. The results showed that the CFU of five different bacterial pathogens decreased by ≥ 5 logarithms in situ. Among the 32 plates placed on UV accessible surfaces, 31 showed a significant decrease in CFU ≥ 5-log. In 2024, R. Mangeant et al. [8] determined the optimal usage conditions for robots in static or dynamic modes by evaluating the distribution of UVC light emitted by HUSKY-UV on wall substrates. With the advancement of artificial intelligence technology, the development hotspot of intelligent disinfection robots is to have stronger self-learning and adaptation capabilities, which can automatically adjust disinfection strategies according to environmental changes and improve disinfection efficiency[9]. In 2024, Zhengyi Chen et al. [10] optimized the coverage sequence by solving CGTSP and proposed a rich BIM scheme for indoor robot coverage path planning, with a disinfection coverage rate of 97.56%. In 2024, Ziwei Liu et al. [11] developed a surface coverage planning algorithm for the disinfection robot based on spray to calculate the path of the fully disinfected surface followed by the nozzle. By selecting the area to be disinfected, the corresponding point cloud is extracted for path planning [12]. In terms of sensor integration technology, disinfection robots mainly integrate disinfection methods such as ultraviolet radiation, ultra dry atomized hydrogen peroxide, air filtration, or plasma disinfection, and can achieve autonomous navigation, movement, and obstacle avoidance in multiple scenarios[13,14]. Based on the characteristics and area of the disinfection area, different disinfection methods are triggered and the disinfection time is automatically calculated to achieve quantitative management of the disinfection process [15]. The multifunctional disinfection robot integrates multiple disinfection methods into one, which can be used individually or in combination, and can play a more powerful role in practical applications.

STC89C52 microcontroller is chosen as the control platform for intelligent robots, and the system adopts a signal detection circuit composed of infrared sensors to monitor the robot's work in real time. The single-chip microprocessor receives and completes all the information collected by the infrared sensor, and then the microprocessor operates it as needed to drive the motor to rotate. Through an obstacle avoidance strategy based on multi-sensor fusion, it can achieve autonomous navigation, movement, and obstacle avoidance in multiple scenarios.

2. System Module and Circuit Design

2.1. Functional modules

2.1.1. Main control module

The STC89C52 microcontroller is chosen as the control chip for the robot. As a microprocessor with low energy consumption, high compatibility, and high performance, it has greater flexibility and faster processing efficiency compared to other microcontrollers. The most important point is the simplification and reliability of the minimal system. The whole machine consists of main modules such as tracking, obstacle avoidance, driving, and disinfection. The axle signal detected by the infrared probe during driving is sent to the main chip, which processes the signal to drive the rotation of the motor, thereby accurately tracking and effectively avoiding obstacles.

2.1.2. Driver module

The drive module is mainly composed of a base plate, a motor, and wheels. In automatic driving, a motor is required to drive the two wheels in front to provide power. The microcontroller uses the path information provided by the infrared tracking probe and infrared obstacle avoidance probe to send driving instructions, and controls the motor speed to achieve intelligent tracking and obstacle avoidance of the robot. In order to provide a stable power source for the robot during operation, this scheme uses four dry batteries as a dry battery pack, reducing the four dry battery packs to 5V and then providing power to the microcontroller and other components.

2.1.3. Infrared obstacle avoidance and tracking module

The infrared wavelength is 750 nm^{-1} mm, with a wavelength between microwave and visible light. The infrared emitted by the infrared emitting device will be reflected by obstacles, and the distance between the robot and the obstacle can be determined by the intensity of the infrared. When the robot is close to obstacles, the infrared light receiving tube receives stronger infrared light, and the voltage on the infrared light receiving tube is also smaller. Use the reverse input terminal of the voltage comparator to control the adjustable potentiometer and adjust the sensitivity of the intelligent robot's obstacle avoidance. The obstacle avoidance system of intelligent robots uses two pairs of infrared receiving tubes and infrared reflecting tubes on both sides of the front of the vehicle to receive corresponding actual data, and then implements the robot's obstacle avoidance function through corresponding obstacle avoidance program feedback, which can also make the robot follow the target object forward.

The tracking function of robots is mainly achieved through the different degrees of infrared light reflection in various colors. Among various colors, black has the weakest reflection of infrared light, while white light has the strongest reflection. The tracking module of the robot is achieved through the use of two photoelectric sensors, RPR220, which include a set of infrared emitting diodes and a set of infrared receiving transistors. Due to the continuous emission of infrared light by the infrared diode, when the infrared light radiates onto the black path, it will produce extremely weak reflection. As the infrared receiving transistor does not conduct, a high level is formed at the in-phase input terminal of the comparator. Similarly, the potentiometer can obtain a low voltage from the inverting input of the comparator, so the potentiometer can adjust the sensitivity of the tracking. When the sensor of the robot is located on the black line, the comparator generates a high level, which is sent to the microcontroller and controls the corresponding indicator diode. The sensor is located below the robot, above the black track on the ground.

2.2. Performance Analysis

2.2.1. Hardware System Reliability Design

In the hardware application of microcontrollers, external interference and internal circuit noise may cause abnormal address bus and even change the working state of the program, resulting in faults. How to take reasonable measures to prevent external interference and eliminate internal circuit noise is a problem that needs to be considered to ensure system reliability. Although the hardware proactive measures to avoid and reduce interference mentioned above are feasible, they cannot fully guarantee the normal operation of the system, and sometimes it is necessary to face technical issues such as monitoring work conditions, managing abnormal situations, and automatically repairing faults after handling them. The most commonly used technology to solve the above problems is the WATCH DOG module. The watchdog system is a timer circuit whose main function is to ensure the normal operation of the system and prevent the generation of life and death loops during the execution process. When the program is working normally, the timer does not overflow, so there will be no reset signal. However, when the system malfunctions, the reset signal will be analyzed and processed by the system before restarting.

2.2.2. Software System Reliability Analysis

To pursue higher stability, reliability, and tracking accuracy of intelligent robots in actual operation, using only hardware watchdogs is far from enough, and software systems should be added to enhance anti-interference performance. By combining software and hardware, dual anti-interference of the microcontroller can be achieved, greatly enhancing its stability. In software, methods such as digital filtering, trap setting, self-detection, and self-recovery can be used to achieve a combination of software and hardware.

2.3. Circuit Design

2.3.1. Main control circuit design

STC89C52RC is a series of microprocessors from ATMEL, which is an eight bit CMOS microcontroller with low voltage and high performance. Its chip includes PEROM and RAM.

STC89C52RC is a complex control system with stronger performance. The STC89C52RC has 40 external pins and 32 external bidirectional input/output interfaces, with the following features: (1) 8k Flash ROM, which can be reused thousands of times; (2) Fully compatible with the MCS51 command system; (3) 8 interrupt sources and 2 external interrupt power supplies; (4) 8 interrupt sources and 2 read-write interrupt lines; (5) Built in memory 256x8bit; (6) Three 16 bit programmable timing/counting interrupts; (7) Serial port interrupts: 2, the serial port is a programmable UART; (8) 32 bidirectional input/output ports; (9) Adjustable clock from 0-24 MHz; (10) Multiple packaging types, such as PLCC, PDIP, PQFP, TQFP, etc., have good adaptability and can meet different needs. The schematic diagram of the disinfection robot control system is shown in Figure 1.

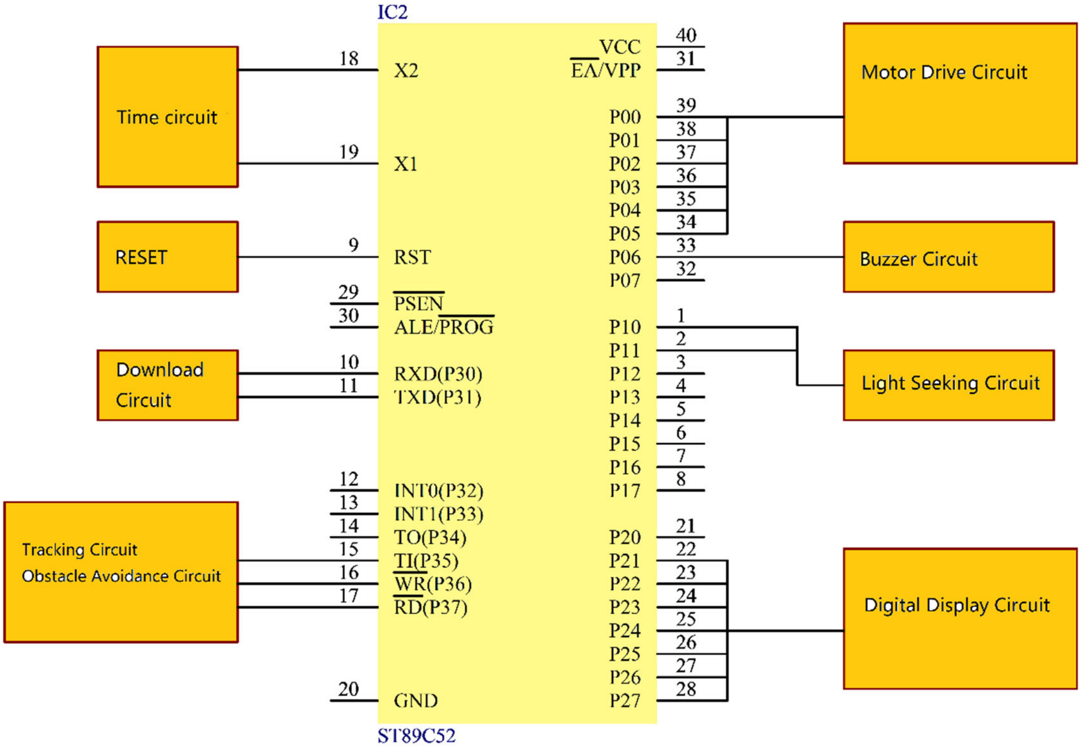

Figure 1. Schematic diagram of disinfection robot control system

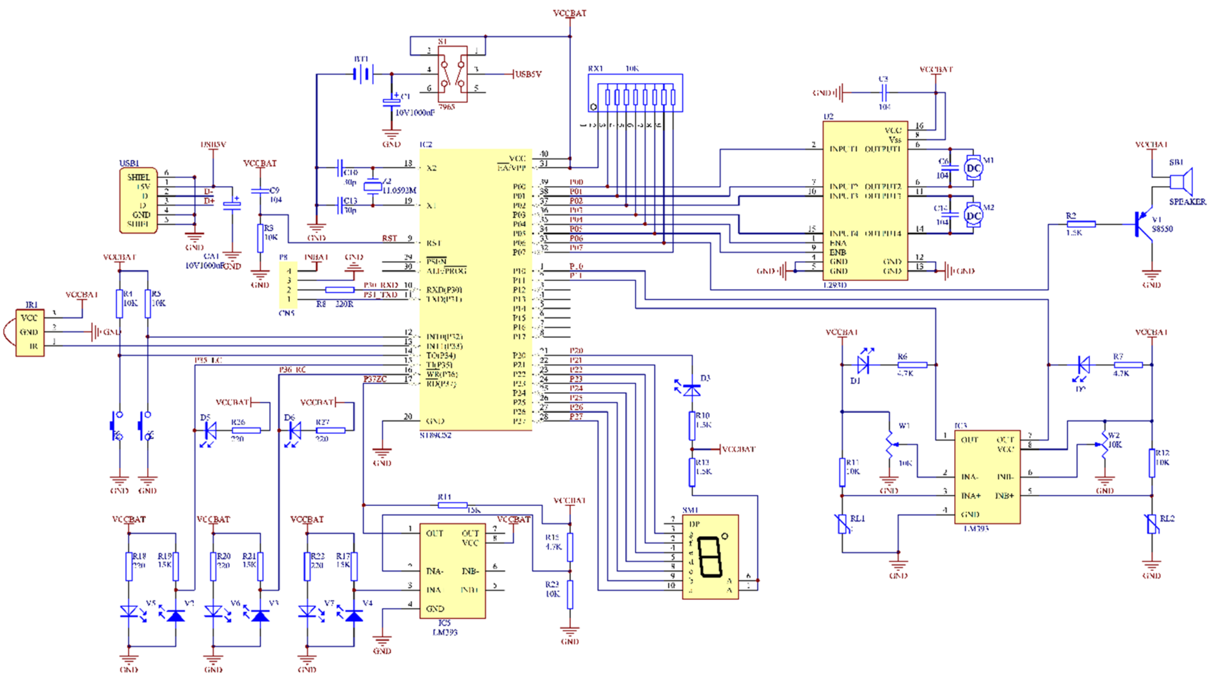

Figure 2. Control System Circuit Diagram of Disinfection Robot

The control system circuit of the disinfection robot is shown in Figure 2. The clock is an important part of the microcontroller, which determines the working speed of the entire microprocessor and completes various instructions through the complex clock circuit of the CPU. The clock signal, on the other hand, has an external input and relies on the difference formed by the oscillation circuit inside the chip. The reset circuit is divided into automatic power on reset and manual button reset. The manual reset of buttons essentially includes two aspects: automatic reset when powered on and manual reset. If the manual switch cannot be turned off, it will automatically reset when powered on. At this point, a path is formed between the external capacitor and resistor and the power supply, allowing the capacitor to automatically recover after charging. There are two types of manual reset for buttons: pulse and level. Among them, the level reset mode is achieved by connecting the RST terminal to the VCC power supply.

2.3.2. Driver Circuit Design

In general, electric motors use H-bridge type drive circuits, but L28N motors use H-bridge type drive circuits, which allows the L28N circuit to drive the motor. By transmitting the PWM modulated PWM signal to the L28N line, the control of the robot's start and stop has been achieved. This scheme uses a four phase six wire stepper motor with L297 and L298N as driving transistors. The STC89C52RC single-chip microcomputer sends drive control signals to pins 17 and 18 of L298N through the I/O port, thereby controlling the speed and direction of rotation of the propulsion motor. The motor drive circuit diagram is shown in Figure 3.

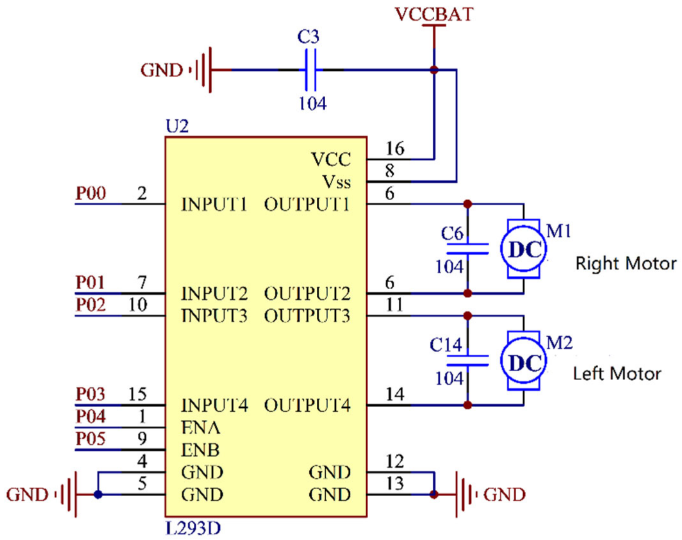

Figure 3. Motor Drive Circuit Diagram of Intelligent Disinfection Robot

2.3.3. Design of power circuit and light seeking circuit

All chips in this scheme are at +5 V, with one section at 1.5 V and four sections at 6 V, which is 6 V higher than the operating voltage of the chips. Therefore, a 7850 type stabilizing chip must be used to reduce this voltage. The output voltage of L7805 is below 1.5 A, which is sufficient to support the operation of the chip. Due to the high rated working voltage and current of DC motors, they can be powered by 6V without voltage reduction.

The light seeking circuit is shown in Figure 4. Two photoresistors are connected in series with a 10k Ω resistor, and the potential at the connection point is compared. When the direction of the robot's movement deviates to the left, the right end experiences a higher light intensity and a lower resistance, resulting in a lower potential at the positive end of the comparator and a low circuit output; When the direction of the car's movement is to the right, the left end experiences a higher intensity of light and a lower resistance, resulting in a lower potential at the negative end of the comparator and a high-level output from the circuit.

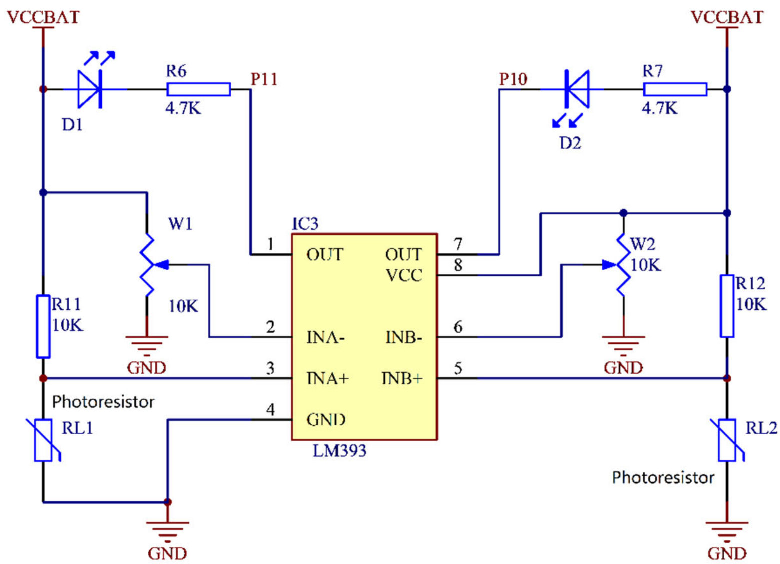

Figure.4. Design of the Light seeking Circuit for the Intelligent Disinfection Robot

2.3.4. Input and output channel design

The input channel, also known as the forward channel, is used to collect information from different sensors; In microcontrollers, the information channel used for monitoring and collecting controlled targets is called the "forward channel", which includes: when sensors convert measured displacement, position, acceleration, pressure and other data into electrical energy, and convert it into digital signals (AD); The advantage is that it can be converted into numbers, but it does not match the digital level of the microcontroller and needs to be converted into TTL digital signals received by the single-chip function. The more parameters are measured, the less I/O. Forward channel expansion involves two technical issues: one is to transform the signal, and the other is to increase the number of input signal channels. The forward channel refers to the transmission method of all input and control systems, even microcontrollers, which can be converted through AD in most cases. According to the type of signal being processed, the input channel can be divided into digital input channel and analog input channel, while the output channel can be divided into digital output channel and analog-to-digital output channel.

The output channel is also known as the backward channel. In the design of the backward channel, the interface problem between the microcontroller and the driver module needs to be solved. At this time, a series of problems such as data conversion (due to being connected to the actuator, digital signals need to be converted to analog signals for easy reception by the actuator, that is, DA conversion), isolation, and output channels are discovered. Simply put, the backward channel is a signal input to the actuator by a numerical microcontroller and other controllers. The signal identified by the microcontroller is converted into a voltage or current analog signal identified by the actuator.

3. Design of Control Program

In the design of microcontroller control systems, both hardware and software design should be considered. As a car based on intelligent tracking and obstacle avoidance, the diversity of its functions is the key to its design. The two basic types of software design systems are data processing and process control. Data collection, digital filtering, and scaling conversion are all part of data processing. Process control refers to the operation and output of a microcontroller based on existing algorithms to achieve production control. The software architecture of the control system adopts a modular structure design, consisting of a main control module, a motor drive speed regulation module, an obstacle avoidance module, a tracking module, etc.

3.1. Driver Process

The functions that the driving module needs to implement include: being able to receive infrared commands from the remote control in remote control mode, adjusting the rotation speed of the left and right motors of the robot through data conversion processing to change the operating state of the robot, so as to make straight, backward, left turn, and right turn operations. In obstacle avoidance mode, the robot travels forward and sends obstacle avoidance commands when the obstacle avoidance module detects obstacles ahead. The two drivers of the robot change their speed to achieve left or right turn obstacle avoidance. In tracking mode, the two motors are adjusted according to the instructions sent by the tracking module to achieve the purpose of tracking.

3.2. Tracking Program

In the application of microcontrollers, the running software of the system is likely to be affected by external interference or internal circuit noise indicators, resulting in confusion of the address bus and changes in counting. In order to improve the stability of the system, it is necessary to effectively control the noise of the system. In order to ensure the stability of the system, it is necessary to avoid and reduce external disturbances and built-in circuit noise, as well as monitor the system's working condition in real time, handle abnormal situations, and address technical issues related to automatic fault repair. Under this requirement, we can also use certain hardware devices to assist, and the design and use of monitoring timers is currently one of the most common and cost-effective ways.

The monitoring timer is essentially a dedicated timer, which always comes from the inside and outside of the microcontroller. Through reasonable programming, it is ensured that a large amount of data will not be generated during operation. The timer initializes it periodically. If something abnormal happens in the program, it will cause the counter to fail to clean up in a timely manner, resulting in overflow of the counter and causing the entire system to malfunction. Import the CPU into error diagnosis and processing, so that it can be restored to normal working state. The monitoring timer allows it to automatically repair in case of emergency, and its software and hardware are easy to implement, so it is widely used, and this technology is also called WATCH DOG [31]. Generally, the following methods are used to implement a hardware "watchdog": (1) using a microprocessor monitoring device; (2) Adopting monostable 74LS123; (3) Use a counting chip with a built-in oscillator.

3.3. Obstacle Avoidance Procedure

To make the obstacle avoidance ability of intelligent robots more accurate, there are six sensors in the obstacle avoidance circuit, four of which are sensors that can detect close range at the front of the car, and the other two are used to detect obstacles farther away. This design uses four reflective infrared detectors JY043W to reduce external interference and ensure the accuracy of the robot's evasion. On this basis, it can optimize the detection circuit and improve the signal processing speed. Due to the short range of lateral obstacle detection and weak external interference, direct current drive is used. LM393 was compared with an external circuit with an output voltage of 25 V/160 Ω=0.156 W. The intermittent comparison power supply of LM393 was adjusted by an R20 potentiometer. A comparator provides a voltage of 0-5V, which is read out through the microcontroller port. The I/O port detects a high level 1 indicating the presence of a signal (obstacle), and 0 indicating the absence of a signal (obstacle). When there are obstacles ahead, the detection range is relatively small and may be interfered by surrounding light. Therefore, it is necessary to use an AC modulation working party with high anti-interference ability. By changing the NPN transistor at the transmitting end, the LED can output frequencies ranging from 50 Hz to 500 Hz. To suppress the interference of external light, a 0.01 u filter is introduced on the receiver. The system uses LM358 integrated operational amplifier to amplify the output, which is read out by the data acquisition port of the microcontroller.

4. System Function Testing

4.1. Control System Testing

Necessary experiments are still required for the completed microcontroller system. At present, various microprocessors need to undergo the following tests:

(1) Testing the integrity of software functions in the microcontroller system: mainly testing whether the software within the microcontroller system is written correctly and completely.

(2) Power on and power-off tests: Ensure the reliability of the robot's power supply by repeatedly turning on and off the power supply.

(3) ESD and EFT testing: By using various interference devices to simulate and generate disturbance signals, which directly affect the operation of the microcontroller system, the reliability of the microcontroller system can be tested. For example, classical simulators are used to generate interference signals when detecting anti-static ESD capabilities; Detecting EFT through high-speed anti-interference will use spike noise simulation to generate interference signals, etc.

(4) Testing instruments: Measurements are made using electronic signal generators, multimeters, oscilloscopes, DC stabilized power supplies, and other instruments.

(5) Testing method: Use a multimeter to measure parameters such as voltage, current, forward and reverse resistance, and transistor operating status of the robot during operation; The signal waveform is tested using an oscilloscope, and the signal is generated by a signal generator to simulate the signals formed by various hardware circuits and sensor circuits, or to detect the signals formed by them; Charge each system under test with a DC stabilized power supply; Detect the various modules of the robot.

The battery voltage detection uses Keil software to start the "check" file located in the "battery voltage detection program" and generate a check. Hex target file. Turn on the power control switch of the intelligent robot, supply power to the robot, and use STC download software to download the speed. Hex file to STC89C52RC. After downloading, let the two wheels of the robot leave the ground, and after turning on the power switch, observe the rotation status of the robot's wheels.

There is an infrared remote control interface installed above the intelligent robot, which can receive commands from the remote control. When the robot is adjusted to mode 3, it is in remote control mode and the robot motor starts to operate. Then start testing the execution of the robot's four commands: forward, backward, left, and right. Adjust the robot to mode 3 and perform forward, backward, left, and right steering operations.

4.2. Tracking and obstacle avoidance test

The front of the intelligent robot is equipped with an infrared tracking module. When the control mode of the robot is adjusted to 1, the robot will automatically perform tracking. The robot's tracking probe will automatically search for the black tracking belt around the robot and perform tracking operations based on the tracking belt. Place the robot adjusted to Mode 1 on the black tracking belt and observe whether the vehicle is performing tracking operations. Adjust the robot to mode 1, place the robot on the tracking belt, and conduct a tracking test.

There are four infrared sensors installed on the front of the intelligent tracking robot. When the robot is adjusted to mode 2, it will automatically move forward to avoid obstacles. When the robot is adjusted to mode 2, it moves forward and adds obstacles in front of it to observe whether the robot can successfully avoid obstacles. Adjust the robot to Mode 2, prevent obstacles on the robot's path, and conduct obstacle avoidance tests.

4.3. Disinfection Test

Bacterial count detected after disinfection: Immediately after disinfection is completed, culture dishes are placed at the monitoring desk, treatment desk, and bedside table in each ward for air sampling. After 15 minutes, they are collected and sent for testing; Three points were randomly selected from the monitoring desk, treatment desk, hospital bed, and bedside table in each ward for surface sampling using throat swab wiping. The front section of the throat swab was placed in nutrient broth and immediately sent for testing. The disinfection qualification rate is based on the 100000 level purification standard, and the air monitoring qualification standard is that the bacterial count is ≤ 4 CFU; The qualified standard for surface disinfection of objects is that the total number of bacterial colonies should not exceed 5 $CFU \cdot cm^{-2}$, and pathogenic microorganisms should not be detected.

Statistical methods were used for data analysis using SPSS 22.0 software. Quantitative data were expressed as mean ± standard deviation ($\bar{\chi} \pm S$) and compared using *t*-test; Count data is expressed in frequency (*n*) and percentage (%), and compared using χ^2 tests. P<0.05 indicates a statistically significant difference. After disinfection using two different methods, the surfaces and air of two groups of objects were tested 50 times each, with 150 samples collected from each group. Comparison of disinfection results between two disinfection methods listed in Table 1. The qualified disinfection rate of the observation group was higher than that of the control group, and the difference was statistically significant (P<0.05). The qualified rate of air disinfection in the observation group was higher than that in the control group, but the difference was not statistically significant (P=0.073).

Table 1. Comparison of disinfection results between two disinfection methods [*n* (%)]

Group	Number of cases	Qualified rate of surface disinfection of objects	Qualified air disinfection
Control group	50	46 (92%)	47 (94%)
Observation group	50	48 (96%)	49 (98%)
χ^2		63.12	1**7.002**
P		<0.001	0.081

5. Conclusion

STC89C52RC microcontroller was selected in this research and infrared tracking and obstacle avoidance modules were added to the motherboard to achieve robot tracking and obstacle avoidance. Adopting dual motor drive, the robot can flexibly perform forward, backward, left, and right steering operations. The robot program is set with modes including remote control, tracking, obstacle avoidance, and disinfection. The modes can be adjusted by pressing buttons, and the robot's mode status can be displayed through LED lights. There are expansion interfaces left on the robot motherboard, which can be installed with corresponding modules according to the requirements of the robot's work in the future. Remote control robots enter the ward for autonomous mobile disinfection, which has a good disinfection effect on the surface of objects, can kill pathogenic microorganisms on the surface of objects, improve the quality of hospital infection control management, and reduce the workload of nurses. It is worth further promoting and applying.

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