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Intelligent Remote Search and Rescue Vehicle

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Abstract. This article proposes a design scheme for intelligent equipment for remote search and rescue in the event of a mine disaster. This design uses STM32 and ESP32 as the core for data processing and transmission. Multiple sensors are used to intelligently detect harmful gases, distinguish the presence of human voices, and automatically avoid obstacles. Remote control is achieved through Bluetooth technology, and MIME technology is used for real-time image transmission on site. By detecting signal strength, relative positioning is achieved using hyperbolic positioning method. The intelligent remote search and rescue vehicle based on STM32 can detect the harmful gas content and presence of vital signs at the rescue site while ensuring normal rescue, and collect real-time images of the scene.

Keywords. Intelligent search and rescue; Remote control; Image transmission

1. Introduction

China is a major coal country. In recent years, coal mine accidents have occurred from time to time. According to data released by the National Mine Safety Supervision Bureau, in 2022 alone, there were 367 coal mine accidents, resulting in 518 deaths. Among them, 23 people died from secondary collapses or explosions in mines during rescue activities. The 2.22 Alxa Left Banner coal mine collapse accident that occurred this year resulted in 6 deaths and 47 loss of contact. During the rescue process, one rescue worker was submerged by a landslide and made a heroic sacrifice. Due to the limitations of the mine itself and the complexity of the internal environment, it is impossible to achieve large-scale rescue work after an accident occurs. Therefore, designing a robot that can replace humans to enter the interior of mines for rescue has practical significance [1]. According to data, although traditional rescue robots can detect parameters such as temperature and humidity, they are difficult to complete rescue tasks well due to factors such as their large size, inconvenience in movement, and unstable communication [2].

In response to the above situation, a smart remote search and rescue vehicle is designed, which can replace rescue personnel to enter the scene in the event of a disaster, detect various environmental parameters, and timely transmit real-time data of the disaster scene back to the rescue center, helping rescue command personnel make correct judgments. Whether it is for the lives of rescue personnel or trapped personnel, it is insured. The purpose of this design research is to help search and rescue victims and ensure the safety of rescue personnel.

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2. Overall System Design

This design is an intelligent remote search and rescue vehicle composed of an upper computer and hardware devices. During the operation of the remote search and rescue vehicle, the upper computer can be used to switch the motion mode, and the harmful gas content and human voice can be detected in real-time through sensors. During the movement of the search and rescue vehicle, real-time GPS positioning will be sent to the upper computer to facilitate confirmation of the location of the search and rescue vehicle. The image acquisition module can transmit image signals in real-time during operation, and the entire system can quickly and accurately provide on-site information.The overall framework is shown in Figure 1.

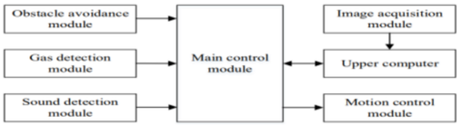

Figure 1. Overall System Framework

This design mainly includes the main control module, obstacle avoidance module, gas detection module, sound detection module, motion control module, image acquisition module, upper computer, etc.

2.1 Theoretical Basis for Measurement Methods

(1) Measurement of harmful gases

Chemical materials are generally used to detect harmful gases, and tin dioxide semiconductor gas sensing materials can react with harmful gases in the air, thereby affecting their surface conductivity. The calculation formula for its resistance value and the concentration of the measured gas in the air is:

$$\log R = m \log C + n \tag{1}$$

Among them, R - resistance value, C - gas concentration, unit: ppm; M - Gas separation rate; N - Gas detection sensitivity.

By adjusting the external resistance and changing its detection sensitivity, the calculation formula is:

$$\frac{2200 R_S}{R_i} = x + 10800 \tag{2}$$

Among them, Rs - sensor internal resistance; Ri sliding rheostat resistance value; X - gas concentration.

Based on the above formula, obtain the voltage values output by different gas concentrations under different resistance values, and the calculation formula is as follows:

$$ppm = 613.9 \times VRL(\frac{R_S}{R_0}) - 2.074 \tag{3}$$

Where ppm - gas concentration; VRL output voltage; RS - Current resistance value; R0- Resistance value in clean air.

The above equation is the theoretical basis, and the current concentration of harmful gases in the air can be determined by the voltage output from the sensor.

(2) Ultrasonic Ranging

The principle of ultrasonic distance measurement is based on the propagation speed of ultrasonic waves in the air. The timing starts when the ultrasonic waves are emitted, and stops when the ultrasonic waves are received. The distance between the ultrasonic wave emitting position and the obstacle is calculated based on the interval time. The calculation formula is as follows:

$$S = \frac{340 * t}{2} \tag{4}$$

Where S - obstacle distance; T - Time of ultrasonic reflection.

Based on the above equation, the distance between the ultrasonic sensor and the obstacle in front can be determined for judgment.

(3)Sound Detection

Sound detection is the collection of sound through a microphone, where the sound signal is an analog signal. Through AD conversion, the sound signal is converted into an electrical signal to achieve sound detection.

When sound is introduced, the sound wave vibration simultaneously drives the vibration of the electret film, resulting in displacement. The displacement will change the distance between the electret and the perforated back electrode, causing a change in capacitance. According to equation (5), it can be concluded that the voltage will change in real-time with the capacitance, thereby achieving the process of converting sound into electrical signals.

$$Q = CU \tag{5}$$

2.2 Singlechip Module

Under normal working conditions, this design requires real-time collection of analog values from sensors, with high requirements for data processing speed and ADC sampling accuracy. Therefore, this design requires a high-performance microcontroller for processing and sending processed data. This design selects a data processing module composed of STM32F103ZET6 and peripheral circuits.

This design utilizes Bluetooth and WIFI solutions to establish communication between MCU and upper computer. In figure 2 and 3, it was found that the ESP32-S3-WROOM with Bluetooth protocol stack and WIFI protocol stack was used as the main controller of the data transmission unit. It communicates with STM32 through serial port and is connected to sensors, which consumes IO resources. In order to make it more modular, all the onboard IO of ESP32 was exported. For debugging convenience, a USB download port, CP2102 driver circuit, and reset button were added.

Figure 2. STM32F103ZET6

Figure 3. ESP32-S3-WROOM microcontroller

2.3 Transmission Control Module

This design system requires movement in complex terrain, so the motion control module needs to have good traffic ability and flexible steering function. According to research, the power provided by the four-wheel drive structure can make the search and rescue vehicle more trafficable. This system needs to be equipped with a large number of devices, which requires sufficient installation space for the motion control module. Therefore, this design uses a double-layer structure as the bottom plate of the search and rescue vehicle.

The structure of this search and rescue vehicle requires simultaneous driving of four DC motors. The commonly used motor drive is achieved by adding a basic H-bridge drive circuit and peripheral circuits. After analysis, it is determined that this design uses the L298N of the optocoupler isolation plate as the motor drive, using a total of four sets of motors. Each set of motors requires three IO ports for control. Two of the IO ports control the start and forward/backward rotation of the motor by outputting different high and low levels, and the other IO port is connected to the enabling end to output PWM waves, Used to control the speed at which the motor rotates.

2.4 Detection Sensor and Image Acquisition Module

This design uses three gas sensors, two ultrasonic sensors, and one sound sensor.

(1) Smoke concentration detection sensor

This design selects MQ-2 as the smoke concentration detection sensor that was shown in figure 4, which has good repeatability and stability, short response time, concentration range between 100-10000ppm, high sensitivity, and simple driving circuit.

(2) Carbon monoxide detection sensor

This design uses MQ-9 as a carbon monoxide detection sensor that was shown in figure 5. Its detection range is 10-1000ppm, with a large detection range and an error not exceeding ± 5ppm.

Figure 4. Smoke Concentration Detection Sensor

Figure 5. Carbon Monoxide Detection Sensor

(3) Methane detection sensor

This design uses MQ-4 as the methane detection sensor that was shown in figure 6. MQ-4 is sensitive to methane gas and has a stable output value. In complex gas environments, it can eliminate interference from other gases, and the driving circuit is simple. It can also perform excellent detection tasks in magnetic field environments.

(4) Sound detection sensor

The human voice sensor used in this design is the MK519 high-precision sound sensor that was shown in figure 7, which is equipped with an electret microphone on the module. It can collect the surrounding environmental sound and determine the intensity of the surrounding environmental sound, thus achieving the function of collecting human voice.

Figure 6. Methane detection sensor

Figure 7. Sound Detection Sensor

(5) Selection of ultrasonic distance measurement sensors

This design performs automatic obstacle avoidance movement in complex environments, requiring sufficient accuracy of the ultrasonic sensor that was shown in figure 8. The detection accuracy of the HC-SR04 module can reach 2mm, which can meet the requirements of this design.

(6) Image acquisition module

This design requires the ability to collect images in real time during normal system operation and upload the collected images to the upper computer in real time that was shown in figure 9. Due to the large amount of data required to transmit images, in order to ensure real-time transmission of images, the operation of uploading to the upper computer uses the WIFI scheme for communication. In order to control system power consumption, the ESP32-CAM with relatively small volume and power consumption was selected when selecting the image acquisition module. In order to adapt to the camera, the input voltage of 5V is converted into 1.2V and 2.8V that can be used for camera power supply when designing the circuit. In order to capture clear images in relatively dark environments, an LED light was added to the circuit design to supplement the light. ESP32-CAM uses a serial port for program download, so when designing a circuit, connect the resources of the serial port to the pins for easy download and debugging.

Figure 8. Ultrasonic distance measurement sensor

Figure 9. Image Acquisition Module

2.5 Power Module

This design requires the power supply to be able to provide voltage to each module stably for a long time to support long-term search and rescue work. Lithium batteries have a large capacity and their output voltage is a fixed value. When supplying power to different modules, voltage sharing operation is required. The current of lithium batteries is relatively high, and even if a single lithium battery supplies power to the entire system, there will be no shortage of current. Therefore, this design chooses lithium batteries as the system power supply.

3. System Software Design

The upper computer of this design uses Java to process video streams and Bluetooth instructions, uses Bluetooth and WIFI technology for data exchange, and uses HTTP protocol for streaming video streams.

For the intelligent search and positioning technology of search and rescue vehicles, the WIFI signal strength is obtained through the Bluetooth callback function provided by Android. The WIFI signal strength can be obtained on ESP32 and transmitted to the mobile phone through the Bluetooth channel. The control end of the search and rescue vehicle and the transmission end of the WIFI are fixed, and the characteristics of the WIFI signal waveform are generally used to directly estimate the distance to the access points (APs), so the signal strength can be used for positioning, However, there may be deviations in individual positioning. According to the hyperbola, the two can be combined to compensate each other for the RSSI values of the two channels. Although sometimes this compensation may fluctuate, it can achieve simple relative positioning.The overall program design of this design software is shown in Figure 10.

3.1 Sensor Programming

The number, type, function, and communication interface of sensors MQ-2, MQ-4, MQ-9, HCSR-04, and MK519 are shown in Table 1.

Table 1. Sensor Description.

Sensor	Number	Function	Type	Interface
MQ-2	1	smoke detection	analog signal	ADC
MQ-4	1	methane detection	analog signal	ADC
MQ-9	1	carbon monoxide detection	analog signal	ADC
HCSR-04	2	ultrasonic distance detection sensor	analog signal	ADC
MK519	1	sound intensity detection	digital signal	single-bus

STM32 filters and processes the digital quantity of MQ series sensors after AD conversion, forwards the data to ESP32, and calls the relevant interface to push the data to the Bluetooth channel. Afterwards, the upper computer will monitor these channels and display the data on the APP. In order to send data to the upper computer, this design uses Bluetooth technology to set warning signs for carbon monoxide concentration, methane concentration, smoke concentration, excessive concentration, and life detection signs in the feature values of the service. Detect these characteristic values in the upper computer, obtain relevant parameters of the gas, and display them on the UI. When the life threshold and gas threshold exceed the set range, the front desk can activate a vibration warning and make a warning display in the UI. The indicator lights for 'discovering vital signs' and' exceeding gas concentration 'will be marked red, respectively. The sensor program design is shown in Figure 11.

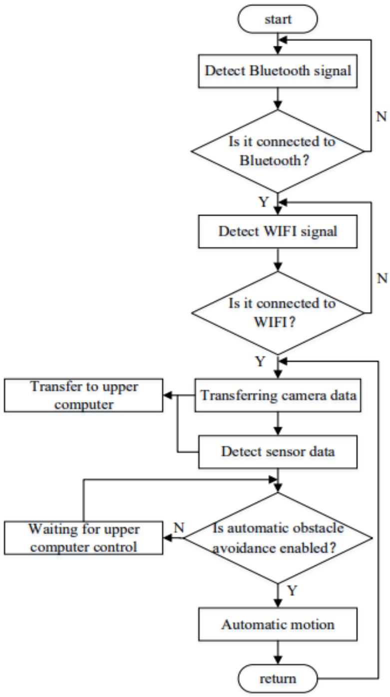

Figure 10. Overall Program Design Diagram

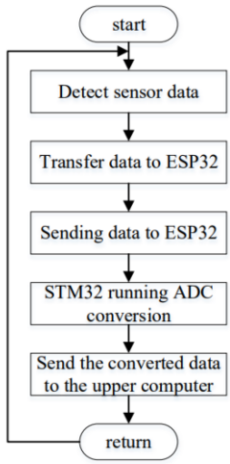

Figure 11. Sensor Program Design Diagram

3.2 Motor Control Program Design

The motor drive module L298N has three control pins. When the two control pins are dual high or dual low levels, the motor does not work, and the other control pin controls the PWM output to control the speed of motor movement. The working status is shown in Table 2.

Table 2. L298N pin status control

A control pin	B control pin	Motor Status
0	1	foreward
0	0	Stop rotating
1	0	reversal
1	1	Stop rotating

In manual control mode, it is necessary to achieve forward, backward, and steering functions. The logic for implementing forward and backward is to simply control the levels of pins A and B, with a duty cycle of 0. The left and right turns carried out during operation can be matched with the high and low levels of the pins and the duty cycle of PWM to achieve left or right turns.

In automatic tracking mode, the ESP32 system determines the direction of movement based on the distance between the ultrasonic sensor and the obstacle. The switch for automatic tracking is located on the upper computer, which provides the switch for automatic tracking. The program flow is shown in Figure 12.

3.3 Video Streaming Push and Receive Program Design

In ESP32-CAM, use fb_ The capture interface can obtain a frame of image data from the CAMRE sensor, encoded in JPEG format. The collected data can be directly sent out through the HTTP protocol and its MIME format can be configured as image. In the upper computer, the HTTP packet sent by ESP32 can be parsed into image data through HTTP service parsing, and displayed in the ImageView control of the upper computer, thereby achieving the push and receive of video streams. The program flow is shown in Figure 13.

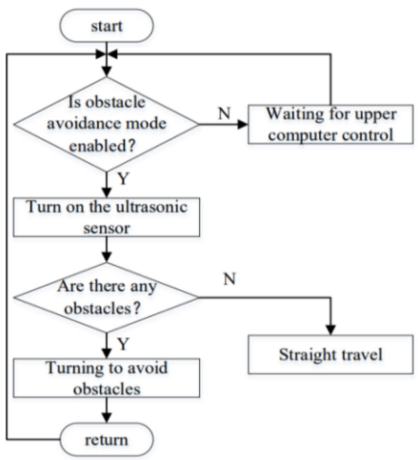

Figure 12. Design diagram of motion control program

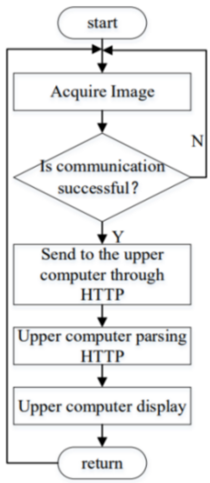

Figure 13. Design diagram of image transmission program

4. Conclusion

This design completes the basic functions of a remote intelligent search and rescue vehicle, using the upper computer to switch the movement status of the search and rescue vehicle. After activating the automatic obstacle avoidance mode, the search and rescue vehicle will automatically move according to the on-site situation, and the upper computer can monitor the on-site situation in real-time; When not turned on, the upper computer can be used to control the movement of the search and rescue vehicle based on the transmitted image information; The gas sensor and sound sensor will work continuously. If harmful gas exceeds the limit or human voice is detected, the upper computer will receive a prompt signal. In the complex environment of mines, more functions can be expanded on the basis of this design in the future, such as improving the detection of vital signs, long-distance transmission, etc. Data can also be considered to be transmitted to the cloud for big data analysis to evaluate the overall risk of the disaster environment.

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