Design and Implementation of Communication Control Terminal for Outdoor Intelligent Robot

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Abstract

With the development of society and technology, the working environment of intelligent robot has gradually expanded from indoor environment to outdoor environment, and its communication mode has also expanded from indoor LAN communication to outdoor Wan communication. Therefore, based on stm32f205rgt6 chip, this project develops a communication control terminal which can give control instructions to intelligent robot and collect state data through mobile communication network. At the same time, the communication control terminal realizes the acquisition of global positioning and time synchronization data, which greatly improves the working range and accuracy of intelligent robot, and the data through multi-level cache the communication mechanism ensures the integrity and reliability of the data, and provides a guarantee for the stable work of the intelligent robot.

Keywords*: Communication control terminal; STM32; Robot*

I. Introduction

With the advancements in robotics and network communication technologies, various intelligent robots have been successively designed in recent years, thus having a huge impact on production. Moreover, the environment in which the intelligent robots operate has gradually changed from indoors to outdoors, such as unmanned driving [1]. Consequently, the communication mode has also changed from Wi-Fi to mobile communication network. Therefore, it is particularly important to design a stable communication terminal to satisfy various data storage and transaction processing requirements of intelligent robots.

In this work, we present the design and implementation of an intelligent robot communication control terminal for collecting the required data for the upper-level application of the intelligent robot. The proposed communication terminal performs two-way data communication between the server and the intelligent robot through a mobile communication network. In this way, the robot management system displays the status and data of an intelligent robot in an intuitive and visual manner, and accordingly sends the relevant control commands to the intelligent robot, thereby realizing remote monitoring.

The main contributions of this work are presented below.
(1) The sending and receiving of variable-length data are realized through a DMA double buffering mechanism. This copes with the problem of slower data analysis and transmission speed under complex communication commands [2].
(2) The MicroSD card serves as the local data storage medium, solving the problem of the large size of SD card.
(3) The socket communication protocol for the intelligent robot and the server is designed. This protocol is used to send and receive data of variable-length and has an extensible command structure.

II. The functional requirements and overall design of the system

The purpose of the proposed work is to implement a control terminal that uses the mobile communication network

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to collect the data from the intelligent robot and send commands to it. There are five main modules in the proposed terminal as shown in Figure 1. These include master chip module, serial port commissioning and forwarding module, GPRS and GPS module, MicroSD card module, and communication protocol module. The workflow of the proposed terminal is shown in Figure 2.

(1) Master chip module: This module controls the working of the complete system and implements the logic and data operations, while providing the operating environment for other modules.

(2) Serial port commissioning and forwarding module: This module processes the data from multiple sources in an orderly fashion, enabling clear division and timely analysis between the data streams. Afterwards, this data is transferred to the master chip module for processing.

(3) GPRS and GPS module: This module enables the communication with the server based on the internet of things (IoT) module. It also obtains the GPS and time information of the current module [3].

(4) MicroSD card module: This module stores the acquired GPS and time data on the MicroSD card.

(5) Communication protocol module: This module ensures that the dynamic data between the control terminal and the server is identifiable. In addition, it also expands the protocol content accordingly, when the transactions increase.

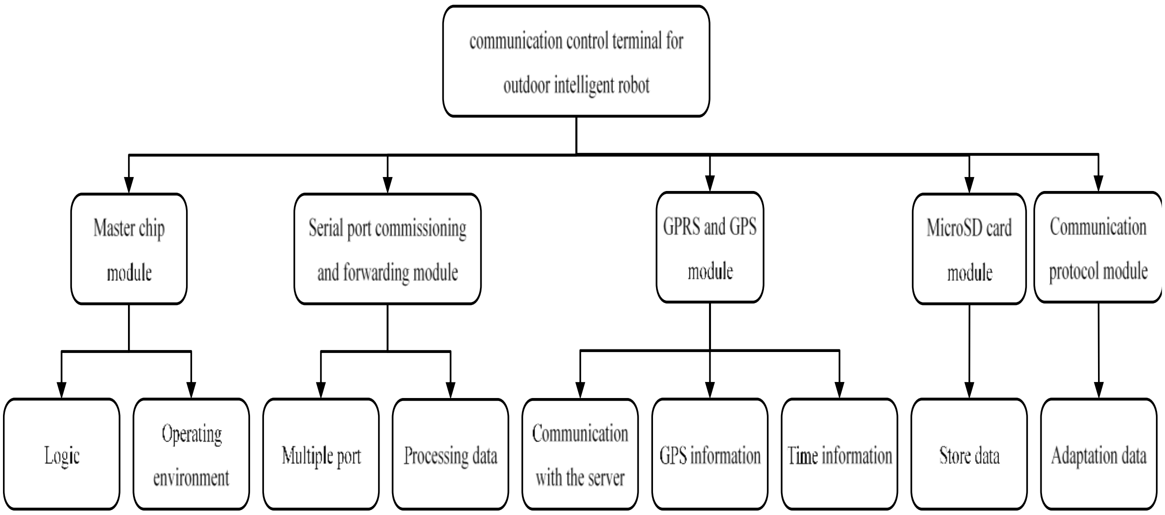

Figure 1. The architecture of the proposed terminal

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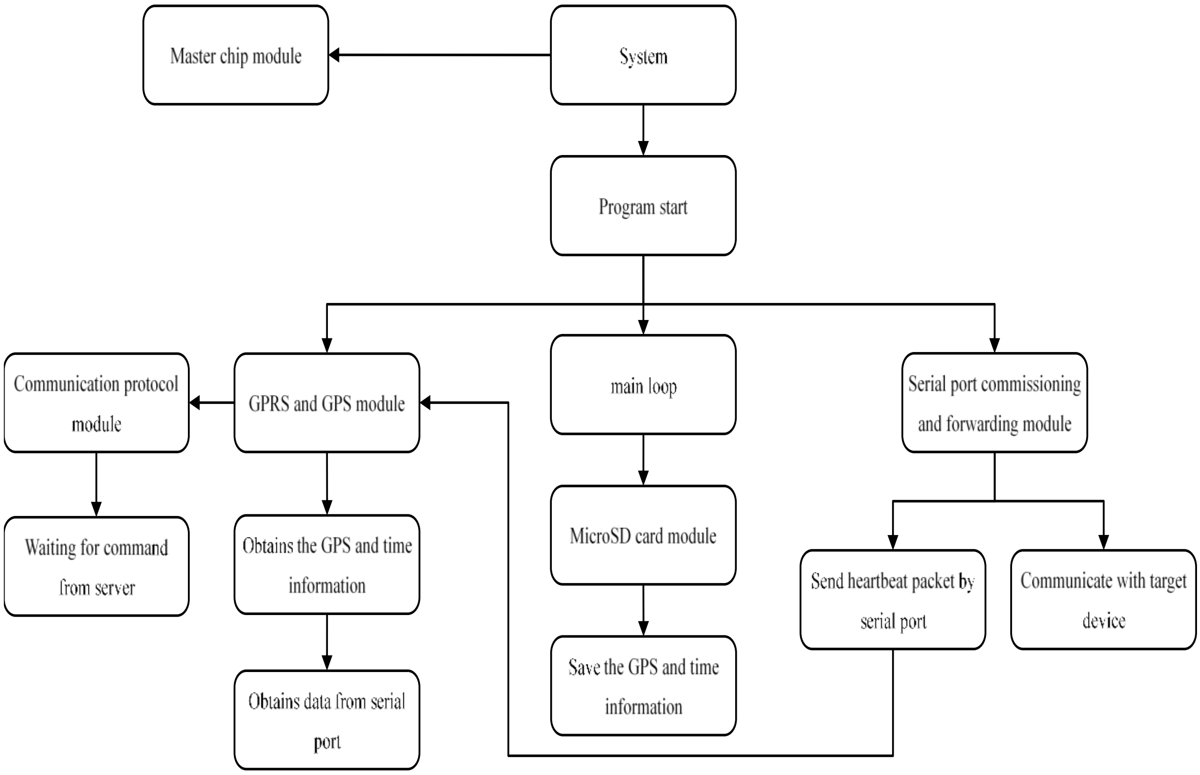

Figure 2. The flow chart of the proposed system.

III. Design and implementation of the master chip module

The master chip module deals with the logic of the entire system and provides an operating environment for other modules. Figure 3 shows the workflow of the master chip module. It has three main aspects, namely, power supply support, selection of the appropriate chip, and program burning support.

(1) Power supply support

The operating voltage of the master chip is 3.3V. In order to ensure the stable operations of the system and meet the power requirements of different modules, the terminal is designed with an external power source of 5V. A 5V to 3.3V conversion circuit is designed to supply power to the master chip. In the serial port circuit, in order to improve the communication security and avoid interference, such as electromagnetic interference, an anti-interference device with an operating voltage of 5V is also used. Please note that the operating voltage of GPRS/GPS module is 3.8V. Therefore, it is necessary to design a 5V to 3.8V conversion circuit.

The power supply uses the ASM1117-3.3 power chip as the core design in combination with the peripheral devices, such as diodes, 10uF capacitors, 100uF capacitors, and 100uH inductors to build a 5V to 3.3V power supply [4]. The schematic diagram of this power supply is shown in Figure 4.

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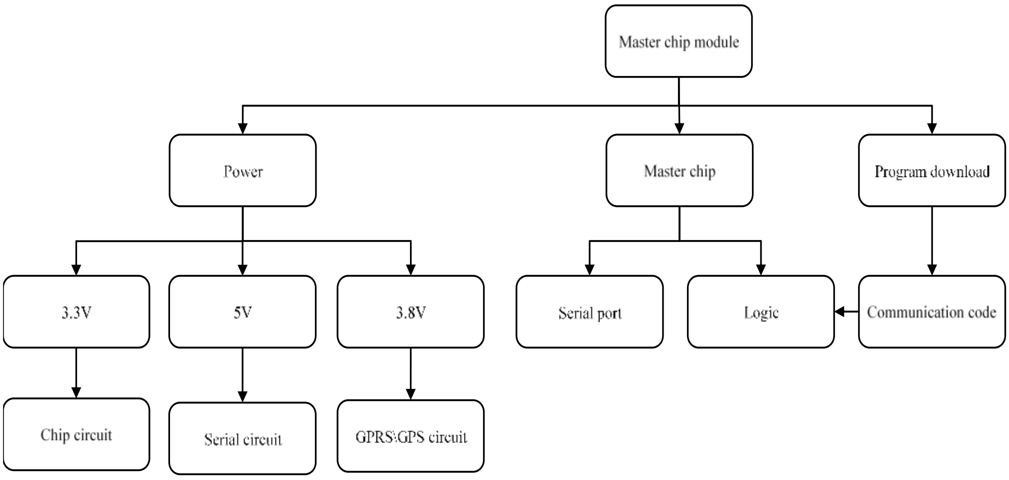

Figure 3. The workflow of the master chip module.

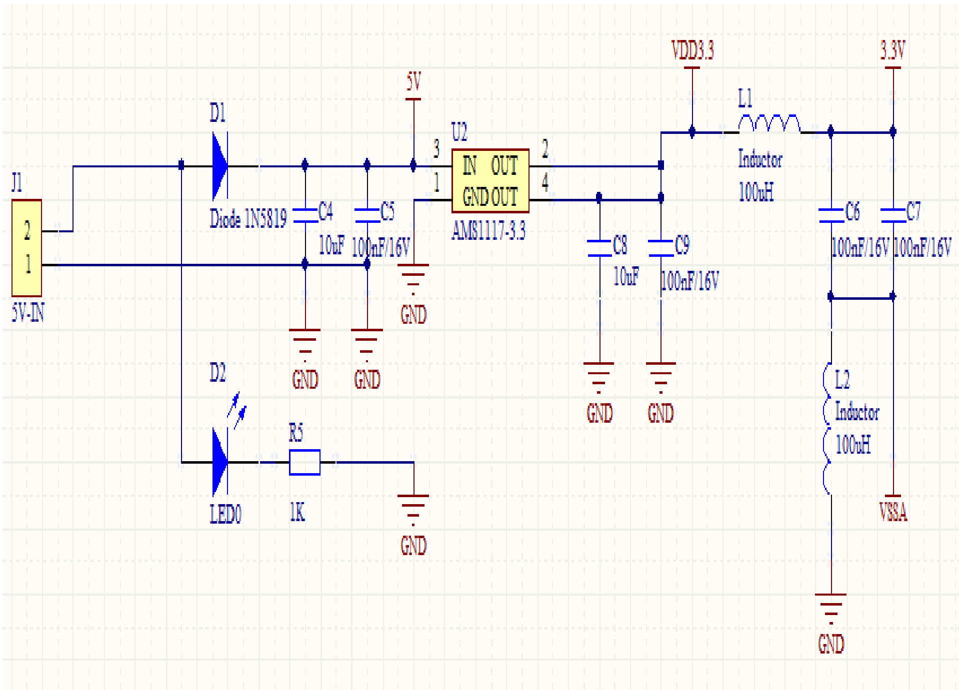

Figure 4. The schematic diagram of 5V to 3.3V supply.

As the GPRS/GPS module uses a 3.8V power supply, it uses the MP1482 power chip as the core and is combined with related peripheral devices, such as chip transistors STS3415, and 10K resistors to build a 5V to 3.8V power supply [5]. Its schematic diagram is shown in Figure 5.

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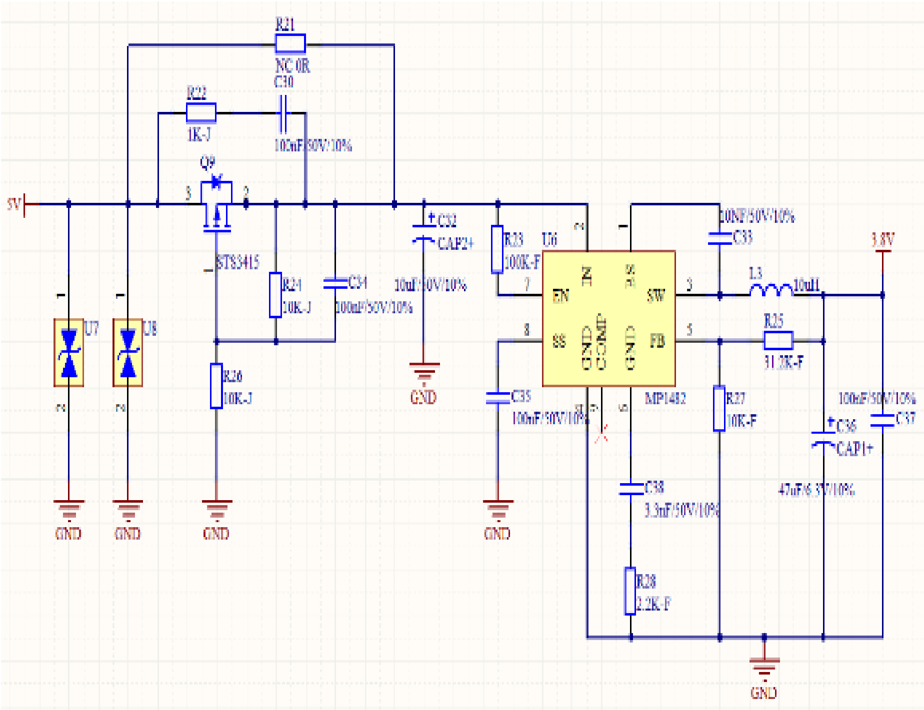

Figure 5 The schematic diagram of 5V to 3.8V power supply.

The MP1482 power chip is used to flexibly modify the output voltage, i.e., the output voltage can be changed by adjusting the resistance of R25. The mathematical expression of the output voltage is:

$$V_{out} = 0.92V \times \left(1 + \frac{R25}{R27}\right) \quad (1)$$

The required operating voltage of the module is 3.8V is calculated using (1).

$$0.92V \times \left(1 + \frac{31.2R}{10R}\right) = 3.7904V \approx 3.8V \quad (2)$$

Therefore, when the resistance of R25 is 31.2R, we obtain the required voltage. Similarly, the resistance can be altered to achieve other voltages.

(2) Selection of the master chip

This system uses STM32F2 series chips (model: STM32F205RGT6), with 1M ROM, and 128k RAM. In addition, this chip supports the use of six serial ports and SDIO reading and writing. This allows us to realize high-speed read and write operation to and from the SD card.

(3) Program burning support

Currently, there are two ways to program the ARM chips, i.e., JTAG and SWD. It is notable that the JTAG has the disadvantage of occupying a large number of pins. Moreover, it has a large size. On the contrary, the SWD only requires four pins, namely, VCC, GND, SWDIO, and SWDCLK, which have a small size and fast speed. Therefore, SWD is usually selected as a program burning method. The circuit diagram of the SWD is shown in Figure 6.

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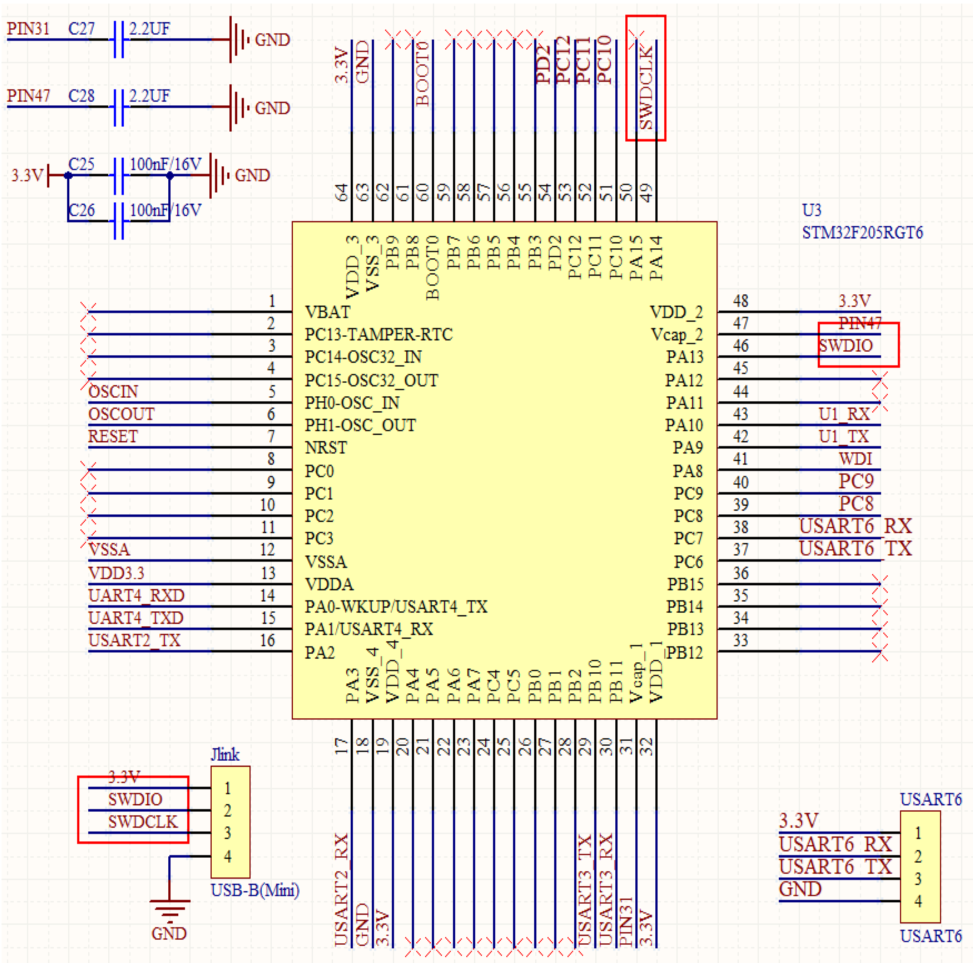

Figure 6. The circuit diagram of the SWD.

IV. Design and implementation of the serial port commissioning and forwarding module

In addition to ensuring the normal SDIO operations, the commissioning and forwarding module also requires four serial ports to realize two-way forwarding of two RS-232 data serial ports, data communication with the GPRS/GPS module, and printing and input of commissioning information. Therefore, this module is divided into two main functional blocks, namely, the commissioning function and the forwarding function.

(1) Commissioning function

In order to implement effective testing with each test point, this module uses a separate commissioning serial port, which provides an effective means for follow-up troubleshooting and code debugging.

(2) Forwarding function

This function is tailored to collect the state data and send commands to the intelligent robots. Please note that the RS-232 is the most commonly used communication method for short-distance communication with target equipment. In addition, in order to ensure that the collected status data is sent to the background service via mobile network, it is necessary for the system to be connected to the serial port used in the GPRS/GPS module. The serial port commissioning and forwarding process is shown in Figure 7.

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Figure 7. The serial port commissioning and forwarding process.

4.1 Hardware implementation of the serial port commissioning and forwarding module

The serial port commissioning and forwarding module has two purposes; commissioning and forwarding. Both of these functions rely on the master chip to complete the tasks. The commissioning function is designed based on the CH340G chip, as shown in Figure 8. The data is displayed by converting the serial port data into a USB signal through the chip. It is notable that the CH340G crystal oscillator should refer to the crystal oscillator parameters configured for the serial port in the master system, otherwise it will not be able to receive the data correctly [6].

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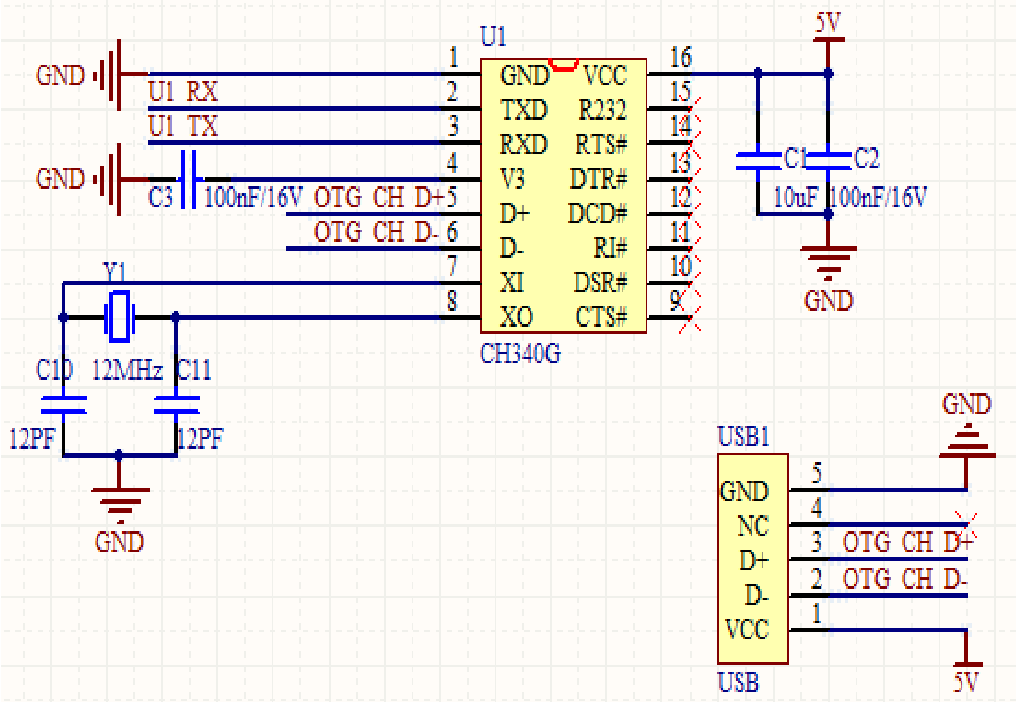

Figure 8. The schematic diagram of the commissioning serial port.

In forwarding function, it is necessary to ensure that the two RS-232 ports realize the data forwarding with the assistance of the master chip, and that they can also forward the data to the GPRS/GPS module through another serial port for realizing the transmission of status data to the server. The design idea is that when serial port 2 receives the data from the target device, the data is forwarded to the serial port 3 in the chip to provide data for the local data processing system. In addition, at the same time, the data of serial port 2 is forwarded to serial port 4 inside the chip for realizing the data upload through the GPRS/GPS module. When serial port 3 receives the external data, it sends the data to the target device, so that the external data interacts with the target device [7]. The schematic diagram of forwarding function is shown in Figure 9.

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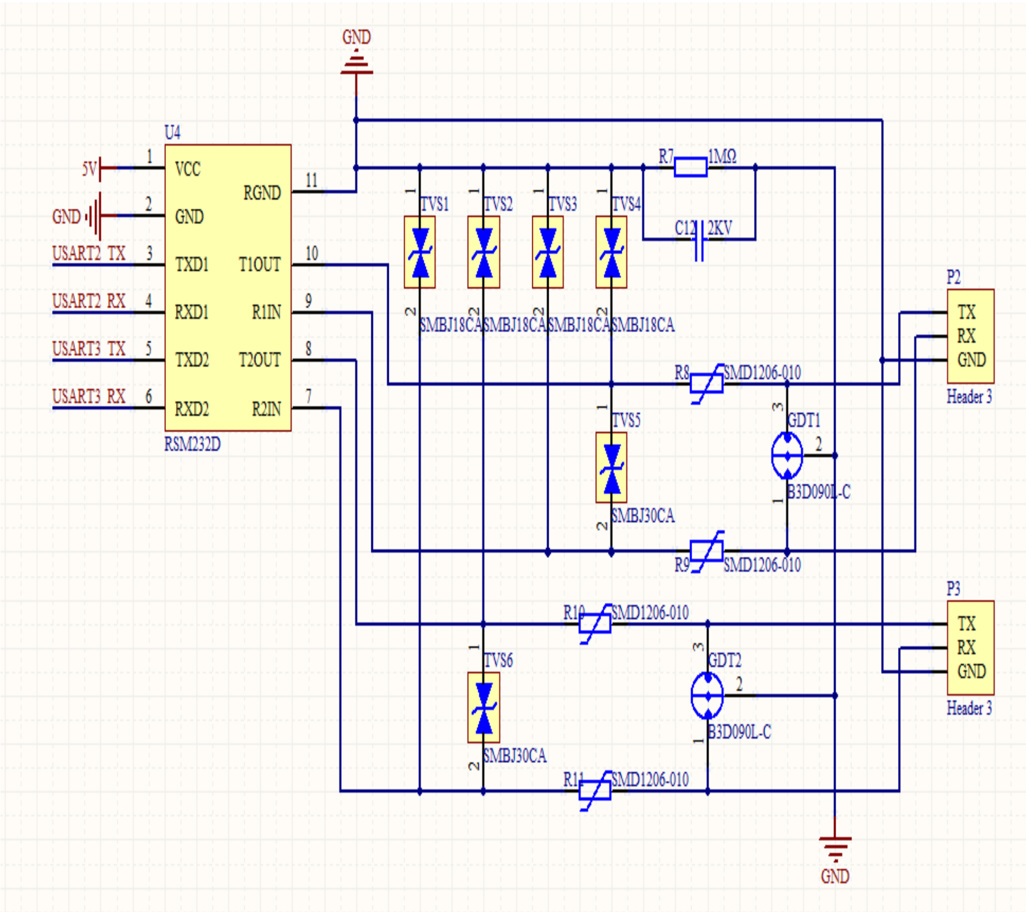

Figure 9. The schematic diagram of the forwarding function.

4.2 Software implementation of the serial port commissioning and forwarding module

In software implementation, the data is sent to a specified serial port by using the serial port function in the HAL library. During testing, the test sentence is added after the function module to assist the system to monitor whether the program is running correctly.
For example, Program 1->Program 2->Program 3.
If "Program 2" does not appear in the printed commissioning information, it means that there is a logic problem from the output of "Program 1" to "Program 3", and the problem can be easily identified using this method. However, in the main loop, DMA double buffering mechanism is used for data processing of multi-serial ports. The flow of the entire serial port module is shown in Figure 10. The key codes are as follows:

```
Serial port interrupts callback function {Stop DMA reception Dma; length=the remaining data length in DMA;
Assign the remaining data to the serial port buffer; Reset the DMA buffer and turn off the half-transfer interrupt;
Mark the completion of receiving a frame of data}
if (serial port 2 receives a frame of data) {Back up data in the operation array; Clear the serial port data and receive the flag bit; Send data to serial port 3}
```

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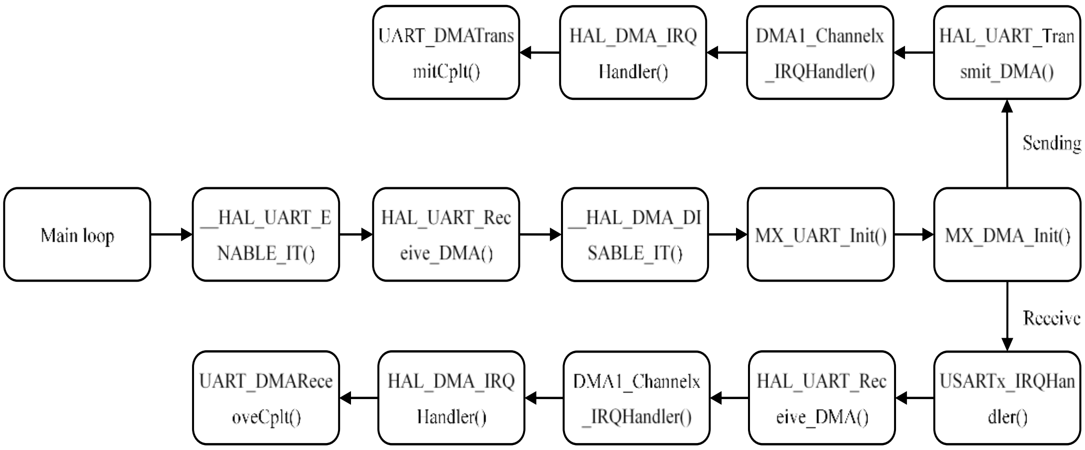

Figure 10. The flowchart of serial port receiving and sending function calls.

IV.Design and implementation of the GPRS/GPS module

In order to enable the back-end service to remotely acquire the status of the device and send related control commands, the system uses the USR-GM3P IoT module to realize the communications with the back-end service. Through the USR-GM3P module, the GPS positioning information and satellite timing data of the intelligent robot is obtained in real time to realize the unification of the intelligent robot and the back-end service [8]. In addition, by analyzing and processing the acquired GPS information, it can be converted into standard latitude and longitude data. This facilitates the back-end service to locate the running track of the intelligent robot. The process of the GPRS/GPS module is shown in Figure 11.

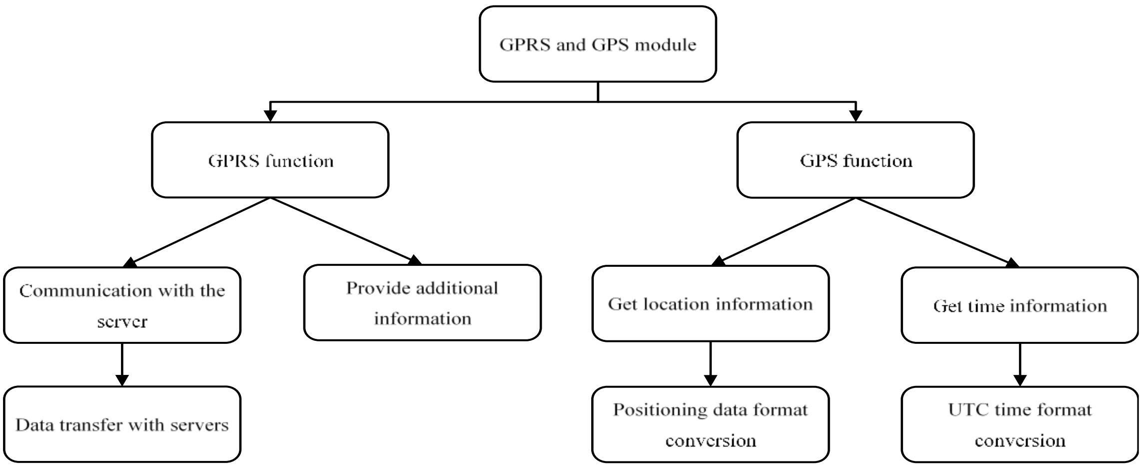

Figure 11. The classification of the GPRS/GPS function.

5.1 Hardware implementation of the GPRS/GPS module

A SIM card is required to acquire GPS positioning information and time information through the USR-GM3P IoT module. In addition, this SIM card also assists in data interactions with the server. Please note that in order to enhance the GPS and GPRS data signals, an external antenna should be added. Moreover, an electrostatic protection circuit is needed to avoid the electrostatic damage to the device. The circuit diagram of GPRS/GPS module is shown in Figure 12.

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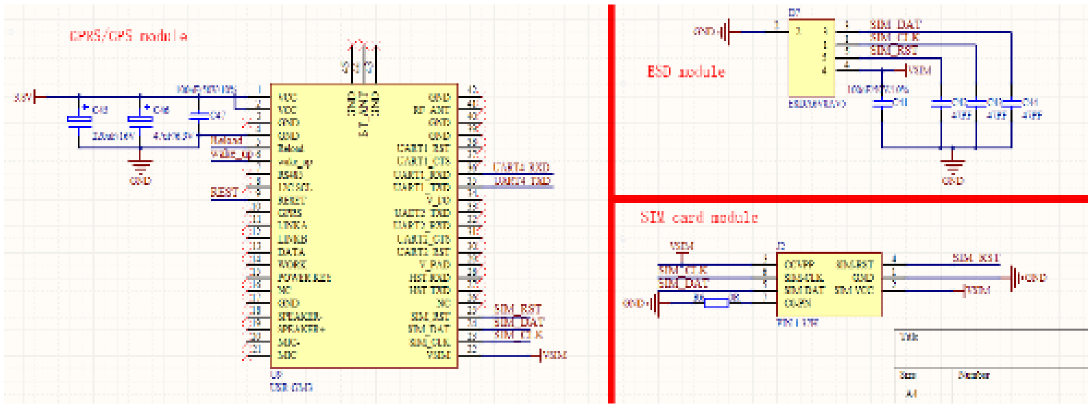

Figure 12. The schematic diagram of the GPRS/GPS module.

5.2 Software implementation of the GPRS/GPS module

The data exchange between the master chip and the USR-GM3P IoT module is performed based on the serial AT commands [9]. After the module is turned on, in order to obtain the GPS and time data, and connect to the background service, it is first necessary to enable the GPS function by using the AT command. Then, the AT command is used to set the address of the background service. In practical applications, it is not always possible to obtain the GPS data directly. However, this data can be obtained indirectly by obtaining the LBS information of the base station [10]. The acquired positioning data is sent to the back-end service through the AT command, so that the back-end service can obtain the position information of the intelligent robot in real time. The workflow of GPRS/GPS module is shown in Figure 13. The initialization code is expressed below:

```
HAL_UART_Transmit_DMA(&huart4,(uint8_t*)"AT+HEARTEN=\"OFF\"\r\n",18);
HAL_UART_Transmit_DMA(&huart4,(uint8_t*)"AT+RSTIM=0\r\n",12);
HAL_UART_Transmit_DMA(&huart4,(uint8_t*)"AT+SOCKA=\"TCP\",\"IP\",PT\r\n",38);
```

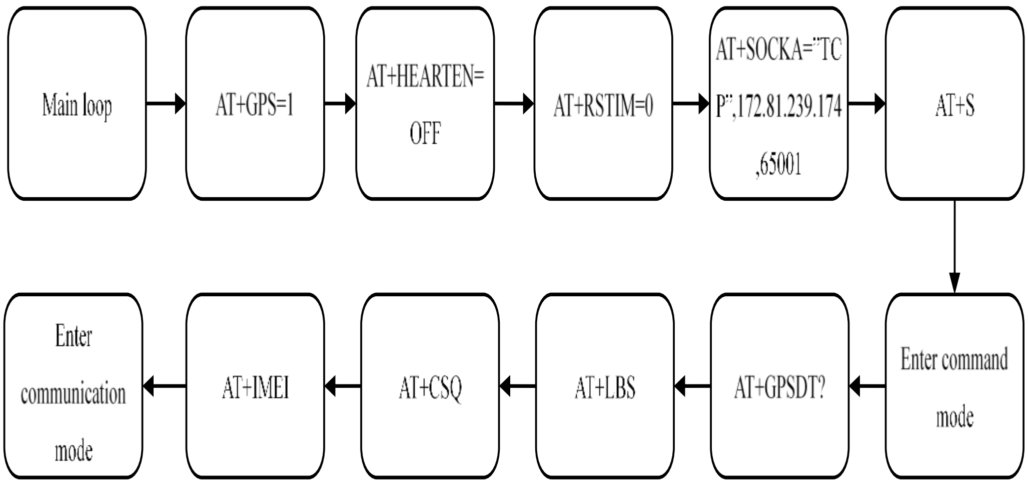

Figure 13. The command call flow chart of the GPRS/GPS module.

VI. Design and implementation of the built-in SD card function

The built-in SD card is used to locally store the status, GPS, and time information of the intelligent robot in order to facilitate the data compensation in the background service. For reading and writing from and to the SD card, it is necessary to mount the file systems to provide low-level support for the SD card. In this system, the data is saved daily in a file named after the date, and the data of the current day is written into the file. In order to avoid data duplication, the system scans all the data files during start-up to check if the file exists. If the file exists, the system opens it and shifts the data pointer to the end of the file, and starts writing new data. Contrary, if the file does not exist, the system creates a new file, and shifts the data pointer to the end of file, and starts writing new data, as shown in Figure 14.

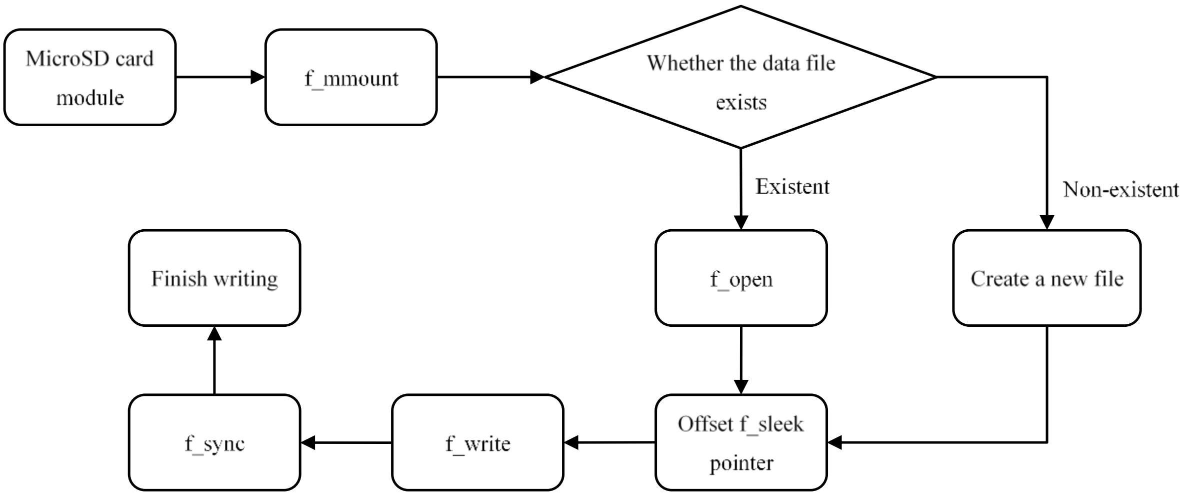

Figure 14. The process flowchart of the built-in SD card.

In the built-in SD module, the built-in FatFS file system is used to read, write, and create files. First, the module initializes the SDIO-related configuration of STM32. Then, it uses the file system functions to complete the operation. The resulting saved data is shown in Figure 15. The pseudocode for reading and writing from and to the SD card are as follows:

If (it is able to write data) {Mount a file system}
If (the current date file does not exist) {Clear the write file pointer offset; Open or create a new file and offset the pointer variable}
If (data writing is performed successfully) {Clear the cache and save the new pointer offset}

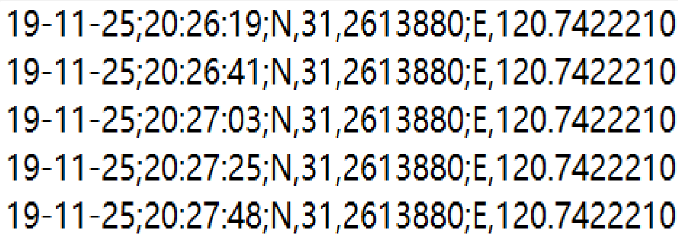
19-11-25;20:26:19;N,31,2613880;E,120.7422210
19-11-25;20:26:41;N,31,2613880;E,120.7422210
19-11-25;20:27:03;N,31,2613880;E,120.7422210
19-11-25;20:27:25;N,31,2613880;E,120.7422210
19-11-25;20:27:48;N,31,2613880;E,120.7422210

Figure 15. The resulting data saved in the file.

VII. Design and implementation of the communication protocol function

In this module, the communication protocol comprises six parts, including frame header, frame length, device ID, command word, command content, and check code [11]. Please note that it is necessary to arrange all the fields in a big-endian manner, as shown in Table 1.

Table 1. The format of the communication protocol.

Frame header	Frame length	Device ID	Command type	Command content	Checksum
2 Bytes	2 Bytes	4 Bytes	2 Bytes	N Bytes	1 Bytes

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(1) Frame header: fixed as 0x53 0x54.
(2) Frame length: the number of bytes from the start of the command word to the check code.
(3) Device ID: the command reported by the unregistered devices is fixed to 0xFF 0xFF 0xFF 0xFF;
(4) Command word: setting the command type of communication.
(5) Command content: N bytes of command content.
(6) Check code: the single-byte cumulative sum of all the bytes from the beginning of the frame to the check code.

During communication, after receiving a command, the system first determines whether the frame header is correct, and then obtains the total length of the command according to the frame length. In order to distinguish between multiple terminals, the background service assigns a unique ID to each terminal. When receiving a command, the service conducts a match with the current terminal ID to determine whether the command is sent to the current device. Then, the command type is determined by the server based on the command word, and the command content is the parameter of the command. Finally, the checksum is used for data verification.

Since the base station has a link control mechanism, it is necessary to add a heartbeat packet to ensure the stability of data communication. Both position information and time information of the intelligent robot are added to the heartbeat packet and sent to the background service. This is depicted in Figure 16.

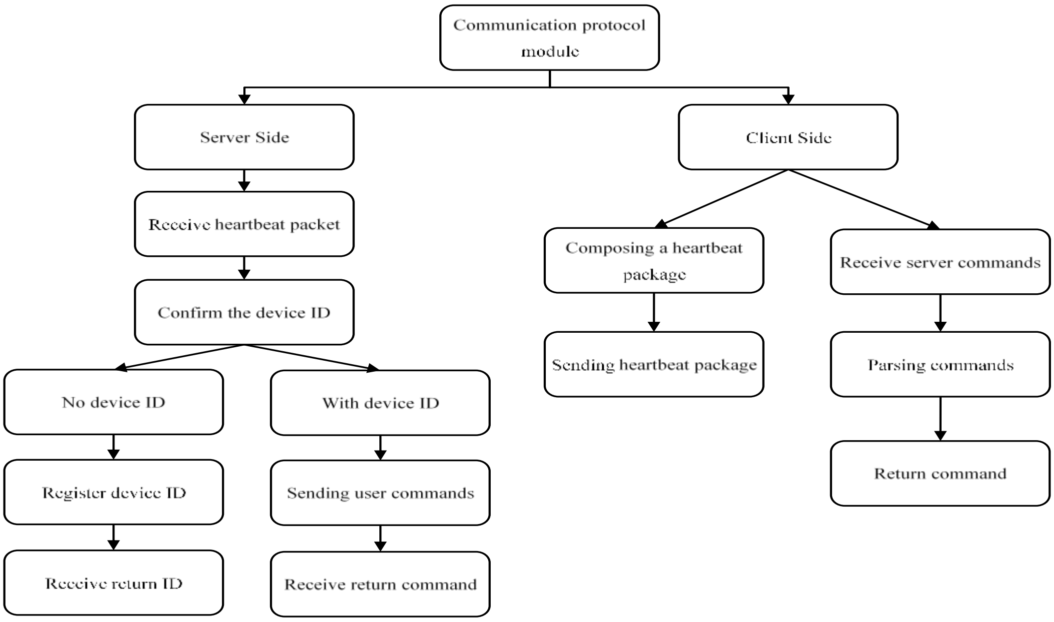

Figure 16. The flowchart of the communication protocol function.

During the communications between the communication control terminal and the back-end service, since the back-end service is unable to obtain the connection and working status of the communication control terminal, when the user sends a command, the command is first saved in the database. After the heartbeat packet is received, the command is sent to the communication control terminal. At the same time, if an external device sends the data while the communication control terminal is collecting data, the system will interrupt the data collection of the heartbeat packet and switch to external data handling. Meanwhile, the system suspends the transmission of heartbeat packet and will not send it until there is no new external device data for a certain period of time. In this way, it is possible to prevent losing commands due to the communication control terminal being busy. This process is presented in Figure 17.

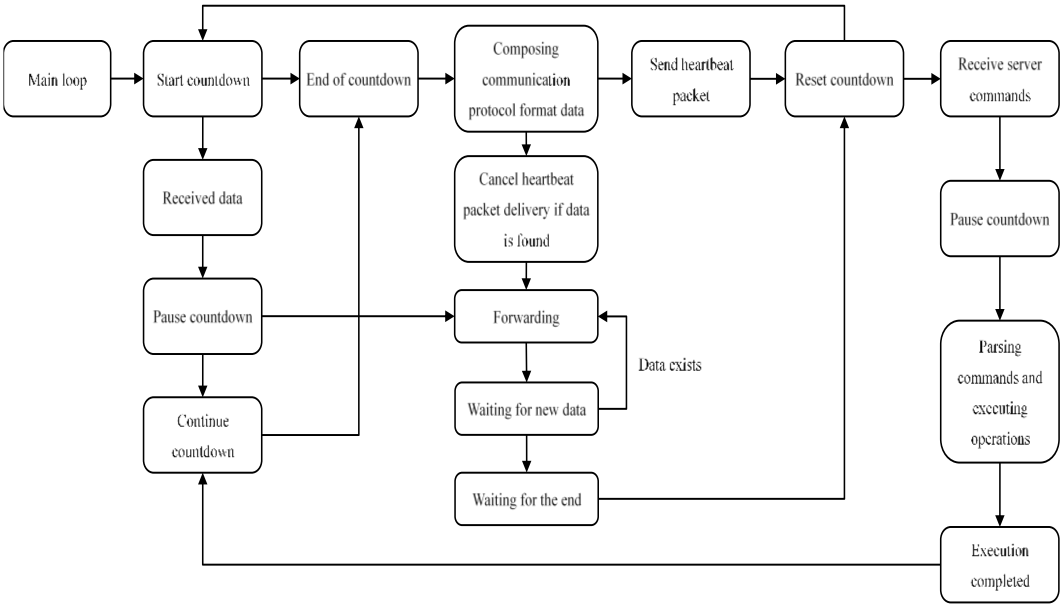

Figure 17. The flowchart of the communication protocol.

VIII. Conclusions

In this work, the proposed system uses the STM32F205RGT6 chip as the master controller of the intelligent robot communication control terminal to perform actions in an outdoor environment. The proposed terminal uses the mobile communication network for data communication, sending commands, and uploading real-time position information. In addition, the data from different sources is processed by using the double buffering mechanism of DMA, which makes the system robust. The proposed system has been used in multiple robots, including outdoor disinfection robots and agricultural plant protection robots. The analysis performed on the data acquired from multiple sources shows that the synchronization of the intelligent robot has been significantly improved after the terminal is used. The reasonable selection of components ensures that the communication control terminal has a higher stability and a reasonable price range. The proposed system is an effective solution for remote operations and detection of outdoor intelligent robots. It is also helpful in the development of intelligent robots.

Acknowledgement

[1] Jiangsu Qing Lan Project ([2020] 10). [2] 2020 Jiangsu Provincial Education Science “13th Five-Year Plan” (D/2020/03/50). [3] This research was funded by Special Equipment Safety Supervision Inspection Institute of Jiangsu Province, grant number FMZ202018.

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