A DMA Interruption Mechanism for Multi-Robot Communication and Location

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Abstract. For multi-robot communication and positioning in a lunar environment, we propose an improved MOBUS-RTU communication networking protocol. The protocol adopts the cooperation mechanism, which includes the sending and receiving of Direct Memory Access (DMA) and idle interruption of DMA. The data length is not limited for communication. Besides, the message is automatically stored in the cache and processed after receiving. This method greatly improves the utilization efficiency of the CPU. Finally, the corresponding communication and positioning test platform is developed based on STM32f103, which shows that the system communication, positioning accuracy, packet loss rate and other experimental tests are carried out. The results show that the design meets the application requirements.

1. Introduction
The research of wireless sensor networks originated from military defense requirements at the earliest stage, and its application needs are constantly expanding. In 1978, with the support of DARPA, Carnegie Mellon University set up a research group on distributed sensor networks, which opened the curtain of wireless sensor networks research. Since the 1990s, with the support of the Natural Science Foundation of the United States and DAPRA, many American universities have devoted themselves to this emerging research field, such as the University of California at Berkeley, the University of California at Los Angeles, the University of Southern California, the Massachusetts Institute of Technology, Cornell University, Georgia Institute of Technology, and so on. Hair and basic theory and key technology research. Soon, some universities and research institutes in Europe, Britain, Japan and other countries also carried out research work in this field.

At present, a large number of in-depth studies have been carried out on wireless sensor networks [1-8]. Each research institution has made a series of gratifying progress in each research direction, including physical layer, data link layer, network layer, transmission layer and application layer. At the same time, on the basis of the Mote node and the corresponding wireless sensor network system, a wide range of application research has been carried out, such as the Duck Island Eco-environmental Monitoring Project launched by the University of California, Berkeley, USA, and the wireless sensor network system on family medical care demonstrated by Intel, etc.

On January 15, 2005, Shanghai Jiaotong University set up the Academy of Aerospace Science and Technology. In April, one of the "spider pedestrian" lunar rovers was shown. The 9-DOF 6-foot omni-directional walking lunar rover proposed by Beijing University of Aeronautics and Astronautics has made great breakthroughs. The ingenious 6-foot walking lunar rover can reduce from 18 DOF to 9 DOF and realize omni-directional walking. The NO.502 of Aerospace Science and Technology Corporation are currently commissioning Harbin University of Technology to develop six-wheel rocker-type lunar rover.
Location of lunar rover is a basic problem in the application of lunar rover. In many previous lunar rover navigation studies, it is assumed that the robot already knows its global position, and only discusses how to plan the path of the robot. With the increasing demand for autonomy of the lunar rover, its communication and positioning problems have received more and more attention [9] - [10].

In view of the above problems, it is necessary to further develop the system integration of multi-robot communication and positioning ground hardware, software and the hardware and software of the overall unit robot prototype, complete the function of multi-robot communication and positioning technology in the principle prototype, and cooperate with the verification of the communication and positioning technology of the robot prototype. Therefore, we design a communication network strategy based on MOBUS-RTU. The protocol adopts the cooperation mechanism, which uses the sending and receiving of Direct Memory Access(DMA)and idle interruption of DMA. The data length is not limited for communication. Besides, the message is automatically stored in the cache and processed after receiving. This method greatly improves the utilization efficiency of the CPU. Finally, the corresponding communication and positioning test platform is developed based on STM32f103, which the system communication, positioning accuracy, packet loss rate and other experimental tests are carried out. The results show that the design meets the application requirements.

2. The Platform Design of Communication and Positioning

The main controller of multi-robot communication and positioning system chooses STM32F103 system, which the communication system between master robot and slave robot chooses CC1310 technology to form a network. The positioning system between master robot and slave robot adopts two wireless modes: (1) The UWB technology is used for short-range positioning. The DWM1000 module is selected and SPI interface is used for controller; (2) The LORA remote networking technology is used for long-distance positioning, and SX1280 communication module is selected and serial interface is used for main controller; moreover, the self-determination of each robot system is adopted. The direction and displacement parameters are obtained by integral calculation using gyroscope and accelerometer. MPU6050 is selected and I2C interface is used to connect with the main controller. The main body of the master robot communicates with the host computer through serial port or USB, while the sub-robot communicates with the host computer through serial port or USB. The hardware block diagram of the main body of each communication platform is shown in Figure 1.
3. Design of MODBUS-RTU Communication Based on DMA Interrupt Mechanism

3.1. The Design of Communication Structure

According to the technical requirements, network communication takes the master robot as the center to form a star network, as shown in Figure 2. When realizing the positioning, both the master robot and the sub-robot can communicate with each other to form a network. This communication module adopts the mode of one master and many slaves, including one host and four slaves. The host computer is connected with the upper computer robot through the serial port line, and the lower computer is connected with the lower computer through the serial port line, and the lower computer is also connected with the lower computer through the serial port line. The communication module communicates between host and slave through wireless mode. The host computer robot can communicate with the corresponding slave computer through the host computer of the communication module. The communication module plays a bridge role in the communication of the ontology robot group.

The software layer uses the Modbus RTU protocol, and the host and slave set the rules of message processing separately. It can realize the functions of sending data, reading and writing registers from the host computer to the slave computer.

3.2. The Design of Communication Protocol

The transmission of communication message is broadcasting mode, and the specific address resolution is completed in the control chip. In order to improve the transmission efficiency, but at the same time not to occupy more CPU, so that the CPU has more time to deal with other things, the communication module uses the mechanism of cooperation of DMA transceiver and idle interrupt, and the length of communication data is not limited. After receiving the message in the serial port, the message will be silently stored in the cache, waiting for receiving the message to end, and then do the necessary processing. This way can greatly improve the utilization efficiency of the CPU.

In addition, the host and slave communication must set a communication data format, so that both the host and slave can correctly process the corresponding messages. We design and define the following data formats:

- The First bit: the target slave address of the transmission.
- The Second bit: function code 02, sending data; 03, indicating reading slave data; 04, slave mutual ranging; 06, writing slave register; 07, reporting data; 08, stopping reporting data.
- The Third bit: When the function code is 02, the third to the penultimate is the data sent. When the function code is 03, this bit is the first address of the register, and the fourth is the length of the read.
When the function code is 04, it is the slave number of ranging. When the function code is 06, the third place is the register head address. Only address and function code and check bits are used for reporting data and stopping reporting data.

The last two bits are the CRC checks of Modbus, the low is in the front, the high is in the back. The data format is shown in Figure 3.

For example, data 0123456789 is sent to slave No. 2 in the format of 02 02 01 23 45 67 89 F5 25. Which read the two length data of No. 5 from register No. 2: 05 03 02 70 49, and write data 1234:03 06 1234 ED 16 to register 3 of slave 3.

The data format sent from slave to host is the same as that sent from host to slave. The slave responding host only needs to write host address, function code and corresponding CRC verification.

In the process of data transmission, if data transmission errors and CRC verification errors are caused by packet loss or other reasons, error messages will be sent from the opportunity to the host, so that the host can send data again.

3.3. The Software Design of Host
The host receives messages from the host computer, and then parses them and sends them to the slave computer. At the same time, the host receives messages from the slave computer and sends them to the host computer. In order to keep messages in both directions unaffected by each other, the host needs
two buffers, we define U8 DMA_2Master_Buf [DMA_Buf_Len], U8 DMA_2Slave_Buf [DMA_Buf_Len], where the length of the buffer is DMA_Buf_Len, which can be set artificially depending on the maximum number of messages transmitted in a single transmission. The MA_2Master_Buf mainly stores messages sent from serial ports. After receiving the messages, it sends them to PC through the sending foot of serial ports. The DMA_2Slave_Buf is mainly responsible for storing messages sent by serial ports. After receiving, it is also sent to communication chips through serial ports. The working principle of the two buffers is shown in Figure 4.

The host needs to open both serial port 4 and serial port 2 for DMA reception. The receiving buffer of serial port 4 is DMA_2Master_Buf, and the receiving buffer of serial port 2 is DMA_2Slave_Buf. Both serial ports open idle interrupts. When data comes in, the serial port will put the data into the buffer and trigger idle interrupts when data is received. As long as the data to be forwarded is put into the DMA buffer, the DMA will automatically forward. Because the information sent by each robot is broadcast mode, the host first judges the address of the received information. If the host's address is the host's address, the CRC check is carried out to avoid dealing with invalid information. After the CRC is checked successfully, it will be further processed.

The processing of host message is divided into two parts, one is to process the message from the host computer, the other is to process the message from the slave computer. The message from the host computer only needs to be forwarded to the slave computer through the serial port four, and the message from the slave computer needs to judge the function code. According to the corresponding function code, the corresponding feedback information is displayed on the screen.

3.4. The Software Design of Slave
The slave software is similar to the host, but the results of processing messages are different. After receiving messages from the host, it is necessary to determine whether the address matches its own address, and then to process them further. In data format, the second bit is function code, so slave computer has a step to judge function code. Each function code corresponds to a corresponding operation, which is encapsulated in the corresponding function. The flow of processing messages from the slave machine is shown in Figure 5.

In slave software, the idle interrupt of serial port 4 and 2 is opened at the same time, and the DMA reception is opened. When a message comes, the message is stored in the buffer. When the message is transmitted, the data is analyzed and the corresponding function code is operated. The main task of slave computer is to identify the function codes sent by the host computer and operate them according to the function codes. The main function codes are transmitting data, reading slave data, ranging from slave to slave, and writing slave registers.

4. The Test
The system testing needs to be carried out in an open and non-interference environment. The host and slave computers are connected to the computer by serial lines, the computer opens the serial debugging assistant, and adjusts the baud rate of 115200, stop bit 1, data bit 8, and no parity check. The computer connected by the host computer can act as the upper computer function, while the computer connected by the slave computer can act as the lower computer function.

The host computer sends the corresponding data from the serial port to the host computer. The slave computer receives the corresponding data and returns the successful message from the opportunity. Conversely, if the data transmission is wrong in the middle and there is packet loss, the slave will return the error message and need to be retransmitted. The test range of outdoor communication is from the library roof to Huanglong Mountain. The testing tool is a notebook computer in Win10 environment, and the debugging assistant is used in XCOM serial port.

4.1. The Testing of Sending Data
The function code of sending data is 0x02. With the address and check code to be sent, the data can be sent to the corresponding lower computer.

We test the communication between PC and slave No. 2. The data is 0123456789, which should be sent to slave No. 2 in the format of 02 02 01 23 45 67 89 F5 25. The first 02 is slave number 2, the
second 02 is function code for sending data, and the last two are CRC-16MODBUS check. The lower is in the front, the higher is in the back, and the middle is data. We input the message directly into the serial debugging assistant, click Send, the serial debugging assistant will display the message returned from the machine. The return message 01 02 81 E1 indicates that No. 2 received the message from the slave. The first bit 01 is the host address, the second bit is the function code to send data, and the last two are the check code. If a check code error is sent, an error prompt is returned. The lower computer will display the data directly after receiving the message, and the display result is: 02 02 01 23 45 67 89 F5 25.

4.2 Transmission Rate and Packet Loss Test
The transmission rate mainly refers to the total amount of data sent per unit time. Its unit time is defined as the time it takes for a message to be sent from the host to receive a return message.

When the amount of data is small, the system takes up a large proportion of the time to process messages, so the bandwidth display is small; when the amount of data is large, the corresponding bandwidth will be closer to the true value, but if the amount of data is too large, the packet loss rate will increase, resulting in transmission failure. After many experiments, the amount of data transmitted in a single time should not be more than 300 bytes, and the transmission interval should not be less than 100 ms. Rate test only needs to send data to slave computer. The host LCD screen will automatically display the bandwidth. The test results are shown in figs. 6 and 7. The data loss testing is shown in Table 1.

Figure 5. The flow of processing messages

Figure 6. The display of computer
Figure 7. The bandwidth of host

Table 1. Data Packet Loss Rate

| slave | Send packet | Receive packet | Packet Loss Rate % |
|-------|-------------|----------------|--------------------|
| 1     | 800         | 795            | 0.625              |
| 2     | 800         | 794            | 0.75               |
| 3     | 800         | 796            | 0.5                |

Table 2. The test results of Lora positioning

|          | 1(m) | 2(m) | 3(m) | average(m) | error(m) |
|----------|------|------|------|------------|----------|
| slave2   | 1608 | 1609 | 1610 | 1610       | 1        |
| slave23  | 1610 | 1607 | 1608 | 1608.3     | 1.7      |
| slave24  | 1609 | 1606 | 1606 | 1607       | 3        |
| slave25  | 1609 | 1607 | 1607 | 1609.3     | 2.02     |

The average packet loss rate of the designed network is 0.63%, which meets the application requirements of the system.

4.3. Accuracy Test of Effective Communication Distance

In order to realize multi-robot communication and positioning, it is necessary to have high-precision long-distance communication and positioning capabilities. We have carried out an effective communication distance test around the campus of Wuhan University of Engineering. We set the transmitting power of the node to 5 dBm, and send a set of data in a cycle. The host computer is located on the top of the 8th floor of the library of Wuhan University of Engineering, and the slave computer is located on Huanglong Mountain. The distance measured by Google Map is 1610m, as shown in Figure 8. Each record is an average of 15 times, three times respectively. As shown in Table 2, the test accuracy is within 3 meters, which meets the application requirements of the system.

Figure 8. The Distance Measurement based Google Map
5. Conclusion
Aiming at the communication and positioning of multi-robot in lunar environment, system scheme demonstration, algorithm research and hardware implementation are carried out. An improved MOBUS-RTU communication network protocol is designed. The protocol communication module adopts the mechanism of cooperation of DMA transceiver and idle interrupt, and its communication data length is not limited. This method can greatly improve the utilization efficiency of CPU. The corresponding communication and positioning test platform is developed based on STM32 platform. The experiment verifies the feasibility of the system and meets the application requirements.

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