MULTIPLE COOPERATIVE UAV OBSERVE AND CONTROL SYSTEM DESIGN BASEDED ON TIME DIVISION DUPLEX COMMUNICATION PROTOCOL

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ABSTRACT
To accommodate the cluster operation tactical system of future unmanned aerial vehicles (UAV), and ensure the flight safety, data analysis, success indicators under the premise of increasing the cost and weight limitedly, observe and control system of multi -aircraft cooperative UAV based on the protocol of time division duplex is designed. The time division duplex (TDD) protocol is adopted to resolve the problem that half-duplex communication is transformed to full-duplex communication between data radios zero-costly, then it can realize the application of single carrier full-duplex control mode based on data radio, and it can reduce development cost greatly and adapt to the trend of development of miniaturization observe and control system. In this system the communication mode of time-division multiple address based on heartbeat is designed to reduce the synchronization error, then it can resolve the problem that telemetry data is blocked up during the same frequency channel of many flights, and it can create favorable condition for operation and control of multi -aircraft cooperative UAV on the condition of displaying on the same screen.

CCS Concepts
Hardware~Hardware-software codesign

Keywords
multiple cooperative; time division duplex; observe and control system; time-division multiple address; burst synchronization

1. INTRODUCTION
With the improving of the modern warfare tactics requirements and methods, it has become a new development trend to use multiple UAV completing complex tasks together. We must also monitor and control multiple UAV flying state during the operational research and training. It cannot meet the requirements of flight test only depend on the data of optical and radar, that brings more difficult to the data acquisition, security, fault detection and location, tactical and technical index assessment, cost control and training [1,2]. As a result, the observe and control system of multiple UAV has arisen at the historic moment.

At present, special equipment of professional factory have been mainly selected to structure observe and control system of unmanned aerial vehicle. In these special observe and control systems, frequency division duplex communication methods and frequency division multiple address communication system have been used to realize the full duplex communication of multiple UAV. But the hardware cost of special equipment is higher, and the volume weight of special equipment is larger, that cannot adapt to the demand of low cost and small scale for observe and control system of the multiple UAV [3]. The data station has been selected generally in low cost observe and control system as the hardware platform. But the data radio only supports half duplex communication that cannot meet the requirement of high speed full-duplex communication. Furthermore, two data stations have been loaded at the same time to realize full-duplex communication, but that increases the cost and volume of the hardware [4,5].

The multiple cooperative UAV observe and control system which selects data stations as the hardware platform, based on the time-division duplex (Time Division Duplex, TDD) communication protocol of time division multiple address communication method, is designed. This system can resolve the problem that half-duplex communication is transformed to full-duplex communication between data radios zero-costly.

2. TDD COMMUNICATION PROTOCOL DESIGN
The multi aircraft cooperative UAV observe and control system based on TDD communication protocol is researched in this paper. In the TDD communication protocol, the data is transmitted in the form of a high-speed breaking frame, and special handshake protocol is used to establish burst synchronization between two communication devices. When two devices communicate, one party is calling party, and the other party is called party. When the TDD protocol can ensure the calling party to send data, the called party must receive data. In the TDD protocol the communication equipment alternately is configured to receive or send to complete the full duplex communication [6-8].

2.1 The frame structure of TDD communication protocol
Capture burst frame, idle burst frame and data frame are used in the TDD communication protocol of multiple cooperative UAV

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ICCAE 2019, February 23–25, 2019, Perth, WN, Australia

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ACM ISBN 978-1-4503-6287-0/19/02…$15.00

https://doi.org/10.1145/3313991.3314013

observe and control system. Capturing burst frame and idle burst frame are high speed short frame of three bytes. Data frame can be adjusted according to the user's data length, including the pre code, synchronization code, status code, order code, data information and termination code. The specific structure is shown in Figure 1.

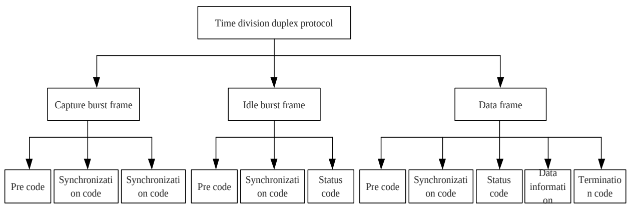

Figure 1. Structure of the TDD communication protocol data frame

The communication frame of TDD communication protocol in multiple cooperative UAV observe and control system contains information as follows:

(1) The pre-code, one byte, the value is 0xAAH, for bit synchronization.

(2) Synchronization code, one byte, a specific code group, for block synchronization, mark the beginning of a frame data.

(3) Status code, one byte, identify the direction of data transmission, the high four bits identify data sender (source address), the low four bits identify data receiver (destination address), the ground control station address code is zero, UAV address code is n($n \neq 0$).

(4) Order code, one byte, indicate the behavior, process or state of communication terminal (the ground control station/ airborne observe and control terminal). If the source address is zero, the ground control station is the data sender (remote control state), the order code is the instruction code of each remote control/ remote adjustment instruction. If the source address is n ($n \neq 0$), the number n of UAV airborne observe and control terminal is the data sender (remote state), the order code is content number of vice frame in the telemetry data.

(5) Data information, five bytes are remote control status, in which the first four bytes are the remote adjustment data correspond to the remote adjustment instruction. twenty-seven bytes are telemetry status, in which the first twenty-six bytes are telemetry data and the last one byte is data gibberish total (bytes, from order code to the data before gibberish total, are summed along each byte).

(6) Termination code, 2 bytes, the value is 0x0A0D, protect the previous data, mark the end of data information.

2.2 Frame synchronous of TDD communication protocol

During the TDD communication mode used in the multiple cooperative UAV observe and control system, the ground control station and airborne observe and control terminal receive and transmit information alternately, so the two communicating parties must be carried out simultaneously from the time, to ensure the reliability of communication.

In the frame structure of multiple cooperative UAV observe and control system, pre codes and synchronization codes, each one bytes, which are composed of two eight- bit synchronization blocks. The receiver uses two eight-bit shift register to store the current received byte and a received byte ahead. When a new bit has been received, the cyclic shift is carried out, and the current received byte is compared with pre code. If the current received byte is matched with the pre code, then the bit synchronization has finished. And then the next byte is received continually. If the next byte received is matched with the synchronization code, it indicates that the block synchronization is completed and the frame synchronization has been established. The receiver uses a counter to record the operation digits during the next frame synchronization. When the next frame arrives, shift required is carried out, that can read the following data information. If the next byte is not matched with the synchronization code, then it is need to wait for two bytes. If the synchronization code has not been received during this period, then it is pseudo synchronization, and frame synchronization must be restarted to build. Frame synchronization process is shown in Table 1.

Table 1. Frame synchronization process

TDD frame	Pre code	Synchronization code	Data
Bit synchronization completing	Receive register		
Block synchronization completing		Receive register	
Frame synchronization has been established, it receives data directly			Receive register

2.3 The realization of TDD communication protocol

TDD protocol of multiple cooperative UAV observe and control system includes the establishment of burst synchronization, burst synchronization protection and data transmission. TDD protocol of multiple cooperative UAV observe and control system can come to realization by the control of micro controller unit (MCU) processor.

2.3.1 The establishment of burst synchronization

During the initialization, the ground control station and airborne command and control terminal are in the receiving state, waiting for a fixed carrier channel. When one party sends the request, it is called the calling party, and the other party is called the called party. The calling party firstly is in the sending state and begins to send a capturing burst frame to the called party. After the called party detects the capturing burst frame from the calling party, then it is converted to the state of calling party, and it sends the identification capturing burst frame to the calling party. After the calling party detects the identification capturing burst frame from the called party, then it is converted to the state of calling party, and it sends the idle burst frame to the called party. After the called party detects idle burst frame from the calling party, then it is converted to the state of calling party, and it sends the identification idle burst frame to the calling party. After the calling party receives the identification idle burst frame from the called party, burst synchronization between two communication parties has been completed and communication link has been established. In the later burst communication, the calling party sends data to the called party through the data frame and content of data frame is received by the called party, until the called party receives the termination code of data frame, then the communication ends, process is shown in Figure 2.

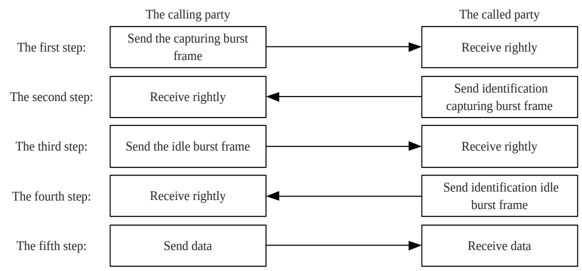

Figure 2. TDD communication protocol implementation process

2.3.2 Burst synchronization protection

The protection of burst synchronization in TDD communication must be considered. If burst synchronization between the ground control station and airborne command and control terminal does not work properly, the new synchronization can timely be established again, so as to avoid the loss of data. Burst synchronization protection scheme: if either of the ground control station and airborne command and control terminal does not detect the correct idle burst frame or the identification idle burst frame, a new process of burst synchronization will be established. State transition can be realized by using the order code of the TDD frame structure. If the called party detects the error of idle burst frame, it will in the next transmission period send appropriate order to inform the calling party and enter the state of out-step. After the calling party reads the appropriate order, it will judge the error of the called party and enter the state of out-step, and in the next transmission period it will send identification idle burst frame and establish the synchronization again. If the calling party receives the error identification idle burst frame, it also will inform the called party through the appropriate order and enter the state of out-step firstly. After the called party receives the error information from the calling party, then it will enter the state of out-step, and both parties will return to the initial state of non-synchronization.

2.3.3 Realization of data radio microprocessor software

Software is written to drive the data radio by microprocessor control module, which mainly contains the control of data receiving and the control of data transmitting and so on. The microprocessor control module of data radio is realized by Borland C 6.0 compiler software. The software controls the system in high real time through the interrupt trigger.

In receiving control process, radio frequency chip firstly must be set to receiving mode, then the data area of radio frequency chip must be initialized. The called party is determined according to the sender of capturing burst frame and identification capturing burst frame, then receiving interruption is triggered and synchronization start. If synchronization is successful, then system begins to receive data and the data is stored in the serial port buffer. When a frame of data has been received completely, then the radio frequency chip is converted from receiving mode to sending mode. The flow of receiving control software is shown in Figure 3.

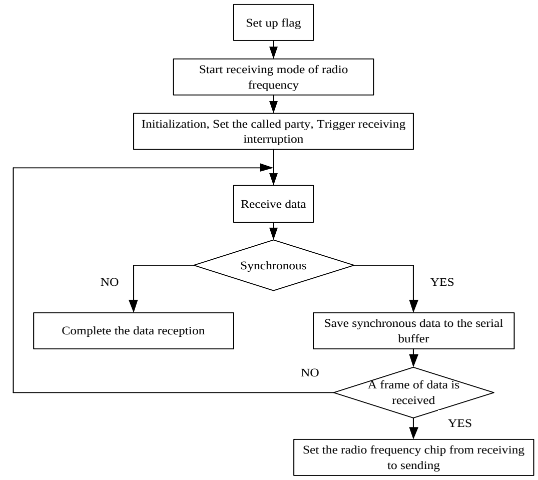

Figure 3. Receiving control software flow

In the process of sending, radio frequency chip firstly must be set to transmitting mode, then the data area of radio frequency chip must be initialized. The calling party is determined according to the sender of capturing burst frame and identification capturing burst frame, then sending interruption is triggered and the data in serial port buffer is sent by radio frequency chip. After a frame of data has been sent completely, then the radio frequency chip is converted from sending mode to receiving mode. The flow of sending control software is shown in Figure 4.

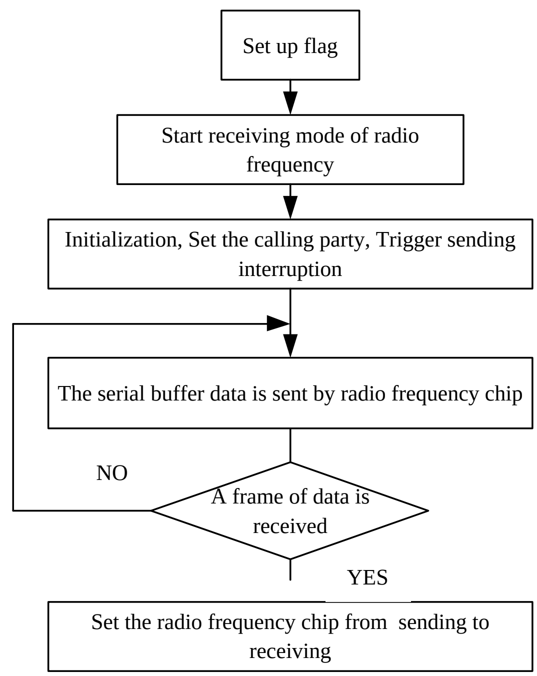

Figure 4. Sending control software flow chart

3. DESIGN OF OBSERVE AND CONTROL MODEL BASED ON TIME DIVISION MULTIPLE ADDRESS SYSTEM

In order to adapt to the use requirement of multiple cooperative UAV, the observe and control system must possess the mode in which multiple UAV is controlled by one ground control station. At present, this observe and control mode of UAV can be realized by some network communication technology, which includes mainly phased array antenna, code division multiple access

(CDMA), frequency division multiple access (FDMA) and time division multiple access (TDMA) [9]. In phased array antenna system, CDMA and FDMA, the observe and control equipment is required specially, and the cost of hardware is higher, therefore the function is difficult to be realized by low-cost data station [10,11].

The network communication technology of observe and control system designed in this paper, is TDMA based on fixed interval. Time is divided into fixed interval cycles, and each cycle is divided again into downlink cycle and uplink cycle. Downlink cycle is divided into two time intervals: in the first time interval the ground control station sends remote control information to the UAV, and the second interval is the protection interval. Uplink cycle is divided into N time intervals (N=2 * n, n is the number of UAV, n>1): in the first time interval the first aircraft sends the remote telemetry information, and the second interval is the protection interval, and in third time interval the second aircraft sends the remote telemetry information, and the fourth interval is the protection interval,......, and in the N-1 time interval the n aircraft sends the remote telemetry information, and the N time interval is the protection interval. Time cycle of TDMA is shown in Figure 5.

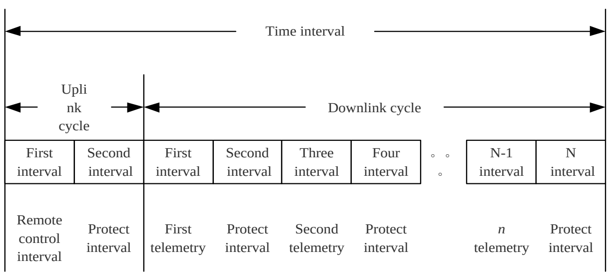

Figure 5. Time cycle of TDMA

In TDMA, the synchronous between ground control station and unmanned aircraft fleet is very critical. When the synchronization error is greater than the protection interval, the ground control station may receive multiple UAV remote telemetry information waves at the same time. But under the same carrier frequency, the telemetry information can not be separated from each UAV by the ground control station, which may cause the telemetry data block. The synchronization error is mainly composed of clock error and wireless transmission time error. Wireless transmission distance can be calculated by the latitude and longitude from ground control station and UAV real-time. Then Wireless transmission distance is divided by radio transmission rate, which can calculate wireless transmission time error. In according to this calculation formula, the synchronous error can be corrected.

Because of individual differences of timekeeping clock between the ground control station and unmanned aircraft fleet, the clock error accumulation will increase over time, and the larger synchronization error can be brought. The ground control station periodically sends a heartbeat synchronous order in this project, which can make the clock between each UAV and ground control station keep synchronous. Specific method is described as follows: every other minute the ground control station sends heartbeat order including three bytes through the remote control downlink time interval, using the broadcast protocol. After the UAV in the system receives heartbeat synchronization order, wireless transmission time error is corrected firstly, then the timing clock is adjusted to the ground control station clock.

4. THE DESIGN OF MULTIPLE COOPERATIVE UAV OBSERVE AND CONTROL SYSTEM

The multiple cooperative UAV observe and control system in this paper is composed of ground and airborne equipment. Ground equipment includes remote control / telemetry car, data radio, antenna, remote control command keyboard and industrial control computer. Airborne equipment includes data radio, antenna, data acquisition and record management computer. The component of the multiple cooperative UAV observe and control system is shown in Figure 6.

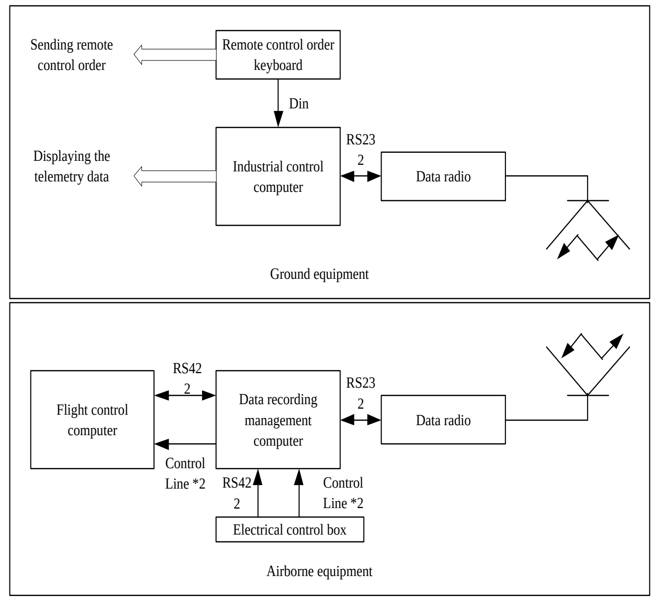

Figure 6. Component of the multiple cooperative UAV observe and control system

Ground remote control / telemetry car is converted into standard shelter by self-designed. One communication cabinet and two observe-control cabinets are installed in the shelter. In the shelter, there are one communication command seats and two flight operation seats. And two MDS 2710A/C data radios and one signal distributor are installed in the communication cabinet (mutually standby). One industrial control computer and one remote control keyboard are installed in the observe-control cabinets. One MDS 2710A/C airborne data radio and data acquisition and recording management computer is mounted in the fairing of the UAV head, and the antenna is mounted in the UAV vertical tail, as far as possible to reduce the effect of the original airborne equipment.

The industrial control computer is connected to the keyboard through the DIn input of discrete quantity plate, which can sample the real-time discrete input and generate the corresponding remote-control order sent to the serial signal distributor, then forward the order to the data station and send out. After airborne data station receives the remote-control order, the order is sent to the data acquisition and recording management computer, and is two-time coded, lastly is forwarded to the flight control computer.

5. RELIABILITY ANALYSIS

In the TDD protocol, the communication equipment alternately is configured to receiving mode or sending mode, in order to complete the full duplex communication. For users, whether the data will be able to complete bidirectional transceiver under the transmission rate meeting system demand, is only cared about. So as long as data transmission rate is greater than the sum of transmission rate of two communication equipment, data radio can be considered to work in full duplex operation mode. The observe-control data code of certain UAV is selected to calculate and analysis the reliability and data refresh rate of full-duplex communication.

5.1 Reliability analysis of the full duplex communication

The length of telemetry data is 32 bytes and the refresh rate is 20Hz, so the required transmission rate is 6400bps. The length of remote-control order is 10 bytes and the refresh rate is 5Hz, so the required transmission rate is 500bps. If the data radio transmission rate is 9600bps> (6400+500) bps, multi aircraft cooperative UAV observe and control system can achieve full duplex communication within the required transmission rate.

5.2 Analysis and calculation of data refresh rate

In the theory the transmission time of remote-control data is 10.4ms, the downlink time interval of the actual remote control is 10msn, and the protection time interval is 10ms. In the theory the transmission time of remote observe data is 33.3 milliseconds, the uplink time interval of the actual remote control is 35 milliseconds, and the protection time interval is 10 milliseconds. The downlink cycle of TDMA is 20 milliseconds, the uplink cycle is (45 * n) milliseconds, and the total time is ((45 * n) + 20) milliseconds. Because one station can control four airports at most, namely n is 4, uplink period is 180 milliseconds, the total time is 200 milliseconds. Furthermore, every 200 milliseconds, one airport sends out a set of new telemetry data to ground control station, and update rate is 5Hz. If N is bigger, telemetry update rate of airport is lower.

6. CONCLUSIONS

In this paper, the time division duplex protocol is adopted to resolve the problem that half-duplex communication is transformed to full-duplex communication between data radios zero-costly, then it can realize the application of single carrier full-duplex control mode based on data radio, and it can reduce development cost greatly and adapt to the trend of development of miniaturization observe and control system. In this system the communication mode of time-division multiple address based on heartbeat is designed to reduce the synchronization error, then it can realize the mode in which multiple UAV is controlled by one ground control station., and it can create favorable condition for operation and control of multi -aircraft cooperative UAV on the condition of displaying on the same screen.

Under the premise of meeting the UAV observe-control function, performance and reliability, the volume of the UAV is small and the weight of the UAV is light. The volume of the UAV is only one-sixth of professional observe and control equipment, at the same time the cost of the UAV is only one-twentieth of professional observe and control equipment costs. Furthermore, this system reduces the development cost of the UAV and has higher application value.

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