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Verification of Unmanned Air Vehicle Flight Control and Surveillance Using Mobile Communication

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This paper presents a solution of real-time flight control and surveillance for unmanned air vehicles (UAV). To uplink and transmit the flight control commands, a μ P-controlled global system for mobile communications (GSM) circuit is designed using C8051 microprocessor; while to downlink flight surveillance data, an ARM CPU developed general packet radio service (GPRS) circuit is designed in μCLinux to carry out always-connect communication. With system implementation, the mobile communication technologies are introduced into UAV flight control and surveillance application. In this paper, we use a 9 m airship for performance verification. The operation range is tested for 20 km below 1000 ft. The control command delays less than 0.5s through mobile communication, when data transmission is continuously linked through general packet radio service (GPRS) in 9.6 kbps. The operators can monitor the airship on the geographical information system (GIS) with an accurate awareness of UAV flight data. The overall airship flight performance is excellent. The proposed system architecture and validation are completely satisfied to UAV performance requirements for wider range of surveillance and control where mobile communication is covered. Communication infrastructure and fare are also discussed in extremely low cost.

I. Introduction

IN unmanned air vehicle (UAV) flight control, we normally used radio frequency (RF) transmitter to manipulate within visual range. Modern technology is applied to increase the operation range and capability. However, this type of system implementation is limited to military applications only, due to vast investment in communication infrastructure is required as we can find from the AIAA Unmanned Unlimited Systems, Technology, and Operations – Aerospace, Land and Sea Conference and Workshop & Exhibit. In wider demand of UAV operation, flight control and surveillance are two important functions to enhance. We need to operate the UAV beyond visual range with accurate surveillance, but low infrastructure investment for civil applications.

Mobile communication has been developed from the first generation (1G) to the third generation (3G), from analog technology into digital system, from voice only into wideband data transmission. When cell phones become livelihood to the public, its additional values from mobile communication service are potential to study. Mobile communication is a very good means for interactions between any moving individuals or vehicle to communicate with the others from anywhere within base station coverage. Based on these advantages, alternative mobile systems may be studied and developed for different applications.

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In Global System for Mobile communications, 2G (GSM), we can easily establish point-to-point protocol (PPP) between any two mobile stations (commonly called the users or clients) for voice or data exchanges.[1] Under-defined data format, real-time control protocol can be initiated and established. While in General Packet Ratio Service, 2.5G (GPRS), the mobile stations can establish data reporting under Internet addressed transmission control protocol/internet protocol (TCP/IP) to a server center.[2] Real-time surveillance can therefore be constructed for operation.

For UAV flight control, there are two major issues to study: the wireless vehicle flight control, and its surveillance. For vehicle flight control, the manual operator is constrained by their operation ranges. A lot of failures happen due to lost communication, and result in crash or lost vehicle.

When mobile communication becomes widely open to use, its application into UAV control and surveillance becomes optimistic to study. In most UAV design considerations, payload is a great concern for its overall performance. The developing hardware should take weight into serious account.

The technical supports from mobile communication to UAV may consider two categories: to achieve real-time operation using GSM in PPP, and to establish on-line monitor and tracking using GPRS in TCP/IP. Through GSM, the UAV can be operated in wireless control mode; while through GPRS, the UAV can be displayed on the geographical information system (GIS) on-line to track its location and flying condition.

In this paper, we fabricate hardware system for GSM uplink and GPRS downlink to offer the feasibility test for the proposed UAV flight control and surveillance system, design GIS control and surveillance software, and verify the overall performance using an airship. The airship operation range is tested in 20 km distance as high as 1000 ft. The proposed system is useful for UAV applications. Time delays are examined within a few hundred milliseconds.

II. System Description

The proposed airship flight control and surveillance system is shown in Fig. 1. There are three modes in operation. The first mode is control operator using RF controller within visual range during take-off and landing on site. The second mode is operated in real-time interaction to ground operator manually or automatically in computer using microprocessor C8051 through GSM in PPP. The third mode is operated in data reporting for surveillance using an embedded system ARM* CPU through GPRS in TCP/IP. The UAV can be operated through a manual operator on site or a computer operator at the control center. The latter two modes are operated through person computer.

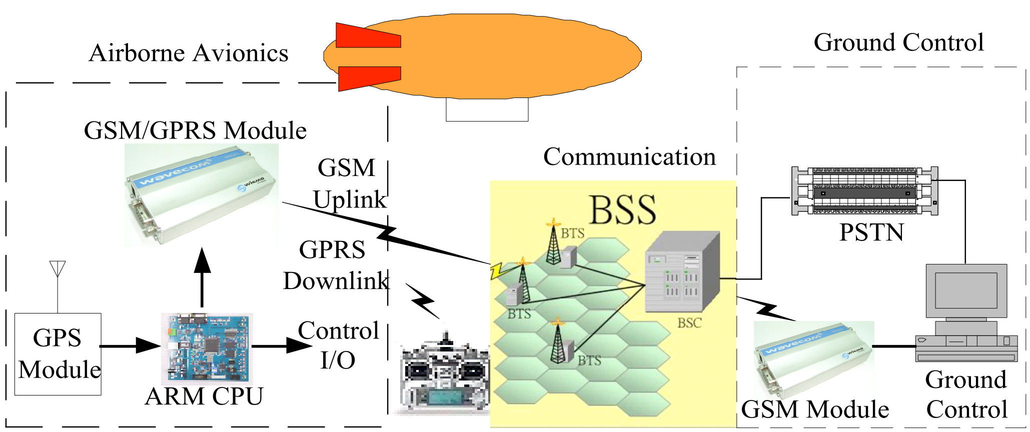

Fig. 1 An airship flight control and surveillance test configuration.

A. Flight Control Unit

In Fig. 2, a UAV is equipped with gyros and sensors as well as control surface actuators. In this paper, an airship is discussed for X wing control. When appropriate flight control model is identified from experiment and calculation, the flight control algorithm is built into read only memory (ROM) in this system. Flight stability is carried out by real-time interrupt routine program in ARM CPU. The on-board flight control handles UAV stability

*A processor with Reduced Instruction Set Computer, low power and high performance.

during flight. Since the payload is installed on the gondola of the airship, system stability is almost dependent and guaranteed by this weight.

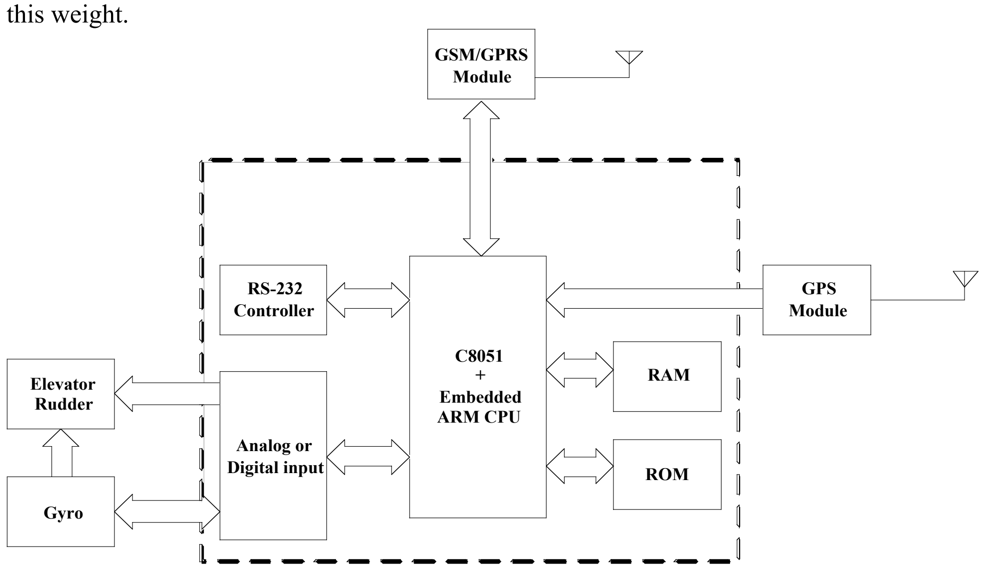

Fig. 2 The proposed UAV flight control system.

B. Downlink Control

In Fig. 2, the ARM CPU circuit hardware is designed to handle always-connect data reporting from the UAV through GPRS in TCP/IP. (Note: ARM Corporation is the industry's leading provider of 16/32-bit embedded RISC microprocessor solutions.) To the embedded systems, the Linux operation system is the best operation system choice for being free to use, flexible to develop as a module platform, and knowledgeable to promote kernel reliability. Linux is also powerful for Internet capability as UNIX system.

In the proposed hardware system, ARM/Linux is used to design the core system. ARM/Linux is to transplant ARM processor as its core machine and formulate μCLinux into operation core. μCLinux (micro-control-Linux) is specially designed to construct an embedded Linux operation system using micro controllers without memory management units (MMU). The adopted μCLinux is an extension of Linux kernel 2.0 operating system, with some simplification but maintain the appreciated stability of the Linux operation system. The important characteristic of μCLinux for μCKernel memory plus developing tool requires only less than 900 kB. The developing supports from Internet are vast from Internet and easy to access.

The specifications for the ARM CPU circuit hardware contain the following: a) an embedded system hardware and software to establish data conversion and transfer; b) a software to establish GPRS communication in TCP/IP with continuing monitor functions; c) ability to initiate and update global positioning system (GPS) data, store and send with proper format; d) read and send acquired logic, analog and digital data; and e) monitor and control the overall operation with watch-dog for anti-spoofing, default, or lost connection.[3,4] This hardware should match with a PC-based server to: receive all client data from Internet in real time; control surveillance data interval from 2 to 5 s; map and track all clients onto GIS.

The system hardware is shown as Fig. 3, where embedded kernel to access data input and output is programmed. The RS-232 ports are used as component object model (COM)1 for GPS module to capture positioning data, and COM2 for GPRS module to transmit input data to mobile communication system for surveillance purpose. These input data include three types of analog, digital, and logic from any external data acquisition devices.

In our laboratory we have successfully implemented Fig. 3 into practical application hardware, and verified its performance in real-time data surveillance.[4] The hardware design as well as software design is discussed in details.

Referring to Fig 1, the airship reports positioning data and other flight data downlink to the Internet via GPRS. The PC-based server reads data from IP address, and displays the surveillance data on the GIS. The UAV operator can read the UAV location and send control command via GSM uplink.

While the UAV is connected via GPRS, flight data can be sent according the predefined time interval and data format to a designated IP address. In the proposed applications, we require positioning data from GPS, logic, analog and digital data from the UAV. The data format from the client systems will appear like

ID	Log	Lat	Spd	Course	Alt	UTC	Sat	In3	In2	In1	In0	Time	Date

For example,
$GPRS-KGT$GPRMC,082908,A,2259.6952,N,12013.3550,E,10,309,050103,05,2.4,104$62A60FFF.

In0~In3 are down link data of flight performance. The real data for surveillance purpose is estimated from 140~150 bytes depending on GPS conditions.

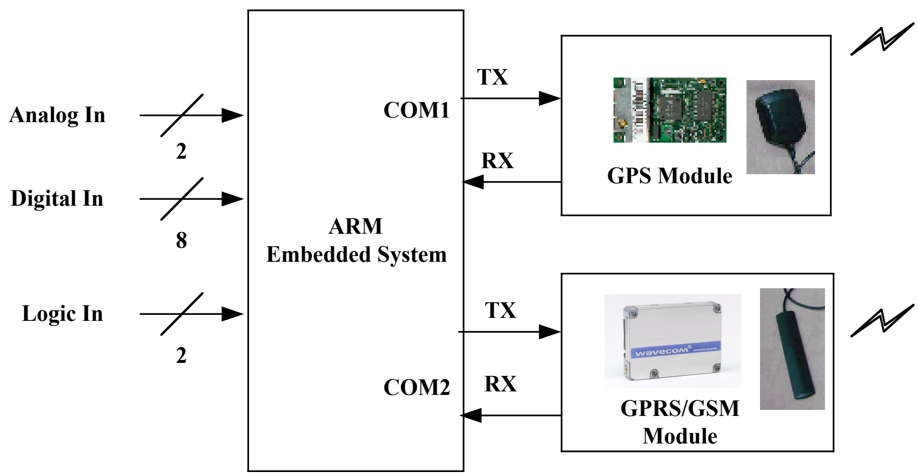

Fig. 3 ARM embedded system hardware.

C. Uplink Control

The uplink flight control is built in a£gP-C8051 circuit hardware. This circuit diagram includes a microprocessor C8051, GPS receiver and GSM module. C8051* is fully integrated with mixed-signal system on a chip, which includes a 12-bit multi-channel analog to digital converter, two 12-bit analog to digital converters (ADC), a universal asynchronous receiving and transmitting device (UART), four input/output (I/O) ports and watchdog timer. The UART, in full duplex mode, is a serial port capable of asynchronous transmission. The crossbar switch assigns the receiving (RX) and transmission (TX) of UART to GSM or other data by software instruction. The carrier detect (CD) pins of GSM are connected to I/O bits of C8051. The signal levels of UART are converted into proper format.

In the C8051circuit, the cross-bar assigns the selected internal digital resources to the I/O pins and it must be configured before any of these peripherals are accessed. The ADC subsystem for the C8051 consists of a configurable analog multiplexer (AMUX), and a 100k bps, 12-bit successive approximation register. The ADC subsystem is configured with software via the special function registers of C8051. AMUX input pairs can be programmed to operate in either the differential or single-ended mode. The C8051 has two 12-bit digital to analog converters (DAC), each DAC has an output swing of 0 V to V_{ref} -1 least significant bit (*LSB*) for a corresponding input code range from 0x000 to 0xFFF. The 12-bit data word is written from the low byte first and then to the high byte data registers. This circuit is verified in Ref. 5.

Figure 4 shows the detail circuit of C8051 circuit to receive uplink flight command. Left part of this circuit is a C8051 configuration. From the core hardware build by ARM CPU, we have to share COM 1 with GPS to receive uplink data. In Fig. 4, the Universal Asynchronous Receiver Transmitter (UART) handles a switching control to GPS TX and RX. GPS need initialization at start-up or recovery stage to occupy COM 1 in ARM CPU, as shown in Fig. 3. UART switches COM 1 to receive uplink commands from GPRS communication module. The uplink control command is designed in a format as shown in Fig. 5.

*CYGNAL for C8051 specifications available online at http://www.cygnal.com (cited April 2004).

At the up-right corner of Fig. 4, during take-off or landing, this UAV control system is switched into the first mode to operate manually by the RF controller. The RF pulse width modulation (PWM) commands are received and sent into C8051, and converted into proper signal to control X-wing actuators. Flow chart of this commanding process is shown in Fig. 6.

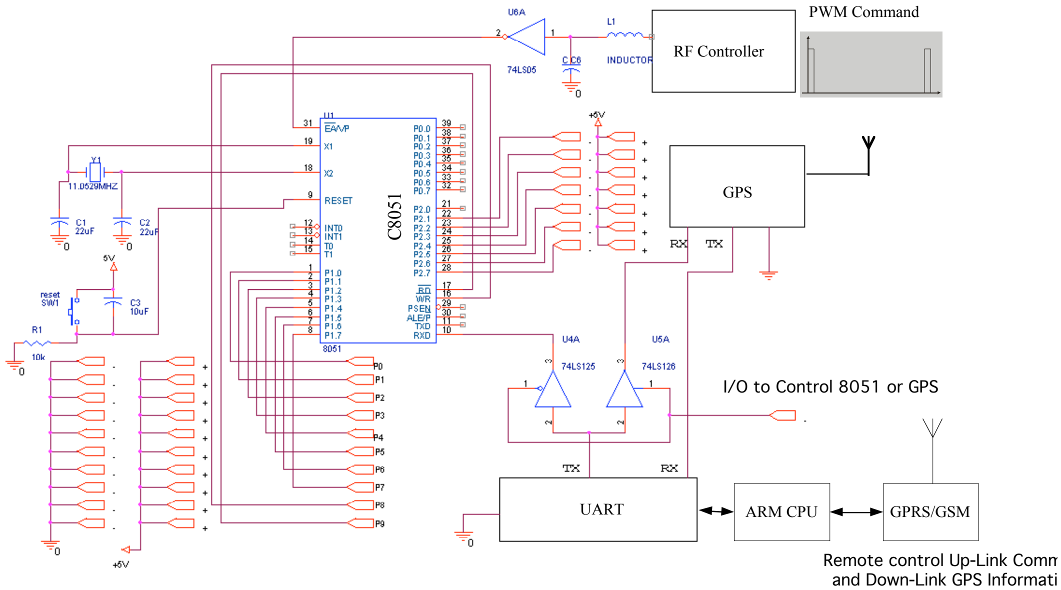

Fig. 4 C8051 circuit to receive uplink flight command.

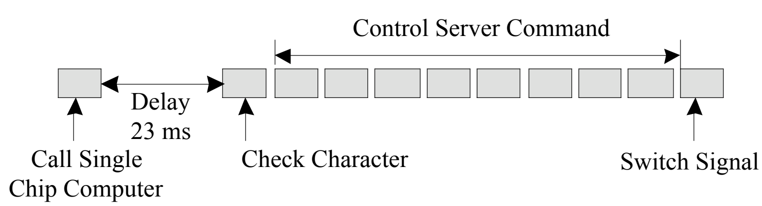

Fig. 5 Uplink control command format.

D. Ground Operation

In the proposed system, a ground operation center is designed using GIS with digital map under World Geodetic System-1984 (WGS-84) specification developing from MAP X. All real-time positioning data will be mapped onto GIS. In this software system design, we include UAV flight data on the display together with digital map. Fig. 7 shows design feature of the ground operation center display in our test flights. The lower-left corner shows the flight data, including heading, altitude, speed, pitch, roll, and other information. The most important data we used are speed and attitude (roll and pitch) while operating the test airship.

On the GIS display, we keep three position data for this controlled target. The red one shows the most update position, and the other two dots show past track data. The software can increase to 4 past track points to get better view of the operated UAV. However, when many UAVs under surveillance, the past track data will cause certain degree of confusion. On this demonstration of Fig. 7, the airship is making a right turn from past track, while the airship attitude is carrying a roll-to-right performance shown at its left corner. The flight data and the attitude data offer the operator a very good sense to control this airship. Several additional control functions are created at the lower display.

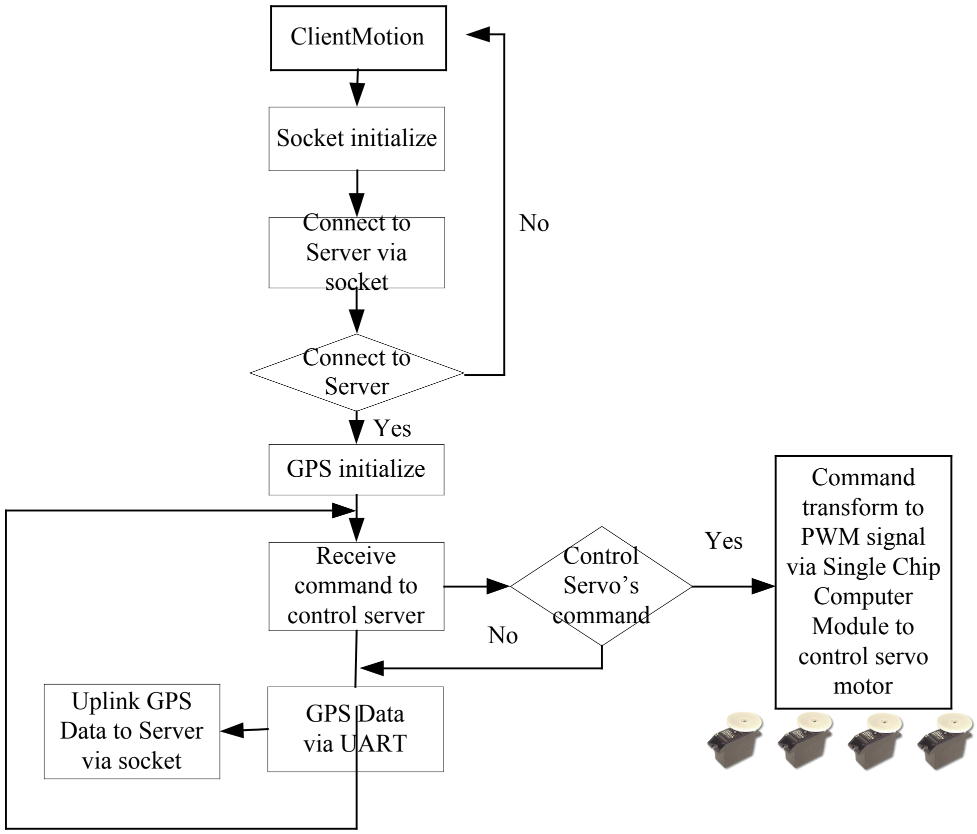

Fig. 6 Uplink flight control commanding process.

III. Verification Tests

Under system implementation, a hybrid circuit is fabricated for tests. The functions are specified that P GSM hardware handles airship flight control operation in PPP, and the ARM GPRS hardware carries data exchange for surveillance in TCP/IP.

The airship is equipped with system configuration as shown in Fig. 1. We use radio frequency (RF) controller to start the flight control manually during take-off and landing. Since the airship may fly beyond visual range, for safety concern, we have an ultra-light aircraft accompanying to watch its remote flight operation in the air. Fig. 8 shows the airship in cruise flight at low altitude within visual range.

From Fig. 2, the data surveillance plays an important function to the airship flight test. The ARM CPU handles GPS data in 20~60 s periodically and downlinks to IP address via GPRS. The actual position and track of the airship is monitored on a GIS display. The flight operator is controlling the airship using the flight control computer as shown in Fig. 7. In the flight tests, the RF operator and the computer operator were talking through cell phone communication to hand-over flight operation.

Table 1 shows the delay time test and statistics for airship flight control surveillance using mobile communication in GSM and GPRS. Both GSM command and GPRS data are tested from outdoor unit to laboratory computer. Time delay condition varies depending upon the test area of base station coverage and operating altitude of availability. The transmission delay for a GSM control command uplink is measured about 300 milliseconds. The transmission time of a 150-byte packet for a GPRS surveillance data downlink is about 425 milliseconds. The overall GSM and GPRS communication efficiency is satisfied to airship flight operation. The GIS display conversion time delay is about 1 second. The overall surveillance and control delay should be calculated by [GSM uplink delay + GPRS downlink delay + GIS access delay] = 1725 milliseconds in this airship flight application. This means, once the operator finds any problem the actual response requires 1.725 s to get complete awareness. This time delay is definitely satisfied to airship flight performance. In our flight tests, the stability and reliability of mobile communication infrastructure is excellent at all cruise flight levels under 1000 ft.

Table 1 Delay time test and statistics

Function	Samples	Maximum[a]	Average[a]	Minimum[a]
GSM uplink	1150	320	300	275
GPRS downlink	2000	460	425	375
3kB data	110	1200	1100	950
150 B data	97	220	200	160
GIS access	2000	2500	1000	900

[a]Data shown in milliseconds.

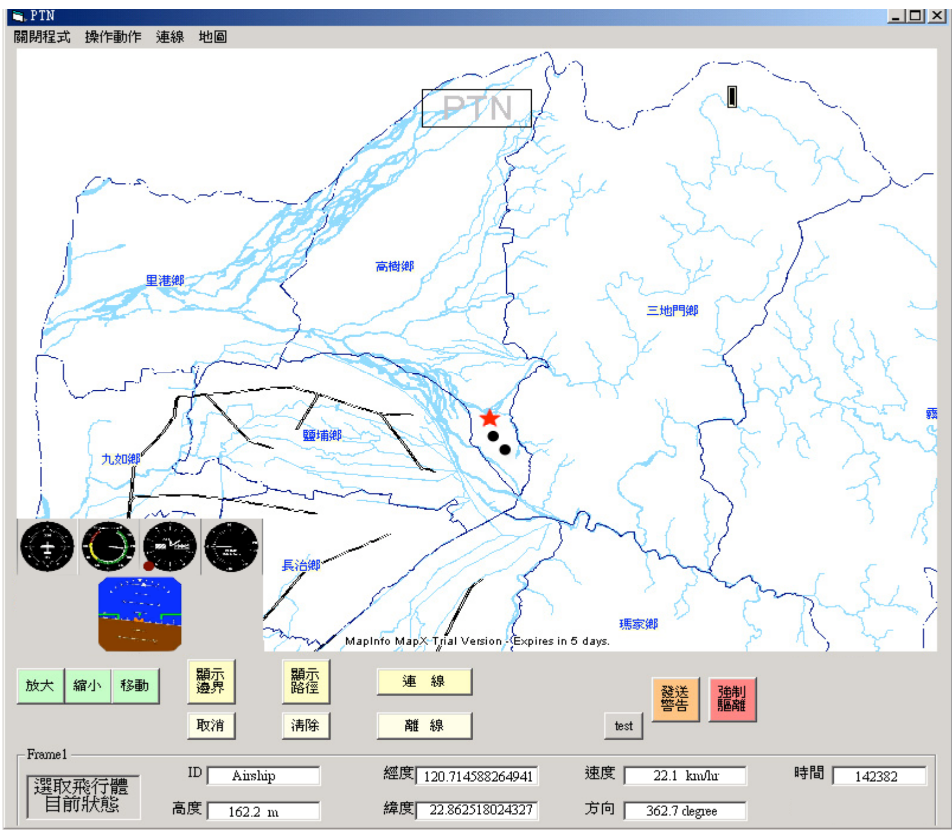

Fig. 7 Ground operation center display.

Fig. 8 The airship in cruise flight test.

IV. Conclusion

In this paper, we verify the capability of a real-time UAV flight control and surveillance system using GSM and GPRS mobile communication. The proposed system is a hardware circuit design using C8051 microprocessor to build a GSM point-to-point protocol (PPP) communication for flight control commands, and using ARM CPU embedded system to build a GPRS IP addressed transmission control protocol (TCP/IP) for data surveillance downlinks. Both GSM and GPRS communication protocols are operating in real time. Data accuracy and efficiency are verified in many flight tests. Apparent time delays are examined to be acceptable to operators in performance.

The advantages of the proposed system architecture and configuration are concluded as follows:

1) The proposed system has no distance limit to fly a UAV, wherever mobile communication service is available.

2) The UAV operators can exactly be aware of the location, attitude and flight data of the controlled UAVs, in real time with less than 2 s delay.

3) The proposed system is low cost in hardware fabrication with high technology implementation.

4) The mobile communication infrastructure is almost free to use. Only regular mobile service charge is required. We have a good deal with local system provider for GPRS fare at (New Taiwan Dollar) NT$ 300 per month, and GSM fare at NT$ 0.01 per second. (Currency exchange rate NT$ 35.0 = US$ 1.0)

5) The mobile service coverage can be as high as 1000 ft in Taiwan where base station cell size is 550 meters. Higher coverage for larger cell size is expected, such as in the USA for over 2000 ft.

6) Mobile communication has experienced to transmit complete data for moving clients as high as 250 km/h speed.

7) Each mobile base station can handle at least 15 GPRS and 15 GSM subscribers (users) simultaneously, or 60 subscribers in time division/demand multiple access (TDMA) time-sharing frame and slot protocol.

8) Mobile communication is very available, reliable, and stable in Taiwan. The system design includes a watchdog to detect system lost connection status and restart system connection within 15~20 s.

9) Software design can be enhanced to add more functions for operators from GIS display.

In Fig. 7 we have built the ground operation into personal computer. The left lower part of airship attitude can be moved to a second display that the operator can get better awareness of flight situation of the airship, i.e. the operated UAVs.

In this paper we propose that UAV stability should be airborne. In our airship test, the stability control is not difficult due to the gondola has payload to keep the center of gravity to a steady low position. Other UAVs will need different considerations in flight control design.

For a better look to the controlled UAVs, the GIS display offers very good overall operation sense to the operator remotely. In our tests, this time delay is acceptable to airship flight performance, but further verifications and efforts would be required to other UAV characteristics.

Acknowledgment

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