Intelligently-Controlled Quadrocopter with Autonomous Navigation using Android

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Abstract— **A quadrocopter is a new kind of unmanned aircraft that has the advantages of novel structure and excellent performance, relating to high, exact and sophisticated technology in many fields. It is of value to practical applications. At first, our team studied a quadrocopter's structure characteristics, attitude algorithm and flight control principle. Then a flight control system was designed which uses LB0 (LB0 employs EP3C10E144C8 of Altera Cyclone Ⅲ as core device) and MPU-6050 as core device and inertial measurement device respectively. The system analyzes the control signal which android mobile phone sends by WIFI, fuses current sensor measurement data, estimates the aircraft's motion attitude and then calculates the motors adjustments. According to the motors adjustments, the system controls the motors to regulate the quadrocopter's flight attitude. It results in a good effect that Euler angles method and Kalman filtering algorithms are adopted to describe and calculate the attitude respectively. At the same time, the data from GPS module is transmitted back to android mobile phone by WIFI and then it helps the system realize autonomous navigation.**

***Keywords*— Quadrocopter; Android, Intelligent Control; Autonomous Navigation; FPGA**

I. Design Survey

A. design intention

The quadrocopter is a micro aircraft, using four rotors as aircraft engine. Because of its small size and lightweight, the aircraft is suitable to carry some certain payloads and possess the ability of autonomous navigation. Thus, it becomes widely available in complex and dangerous situations(e.g. [1]-[3]).

1) Biochemical Detection and Environmental Monitoring: The aircraft can be used to perform tasks in restricted biocheical areas, monitor ecological environment in real time, search for the disaster survivors or harmful pollutants and take civil aerial photo.In addition, according to the different carried sensors, it can also play a major role in traffic control, space exploration and other outdoor adventure.

2) Low-level Detection: The aircraft can perform reconnaissance missions, when it is few meters to several hundred meters close to the target few meters in the air. Especially in the difficult terrain or areas that people cannot reach, it can detect accurately and sent the obtained information back.

3) Military Raid: The aircraft can be used as an offensive weapon to destroy enemy radar and other electronic equipments and to carry weapons for attacking enemy.

4) Communications Relay: The aircraft can be applied to detect and maintain the communication line, saving labor costs.

5) Signal Interference: The quadrocopter also can make interference for the communication equipment in the area of enemy.

In addition, the four-axis aircraft can also be used for recreation, such as playing the piano, augmented reality and other virtual games

In recent years, due to its operating system open source nature, Android smart terminal has occupied most share of the market quickly. The popularity of Android brings the convenience to the App development. As long as you have one Android terminal, you can access the App production. Android and GPS technology are applied to the aircraft in this subject to achieve Android intelligent control and autonomous navigation.

B. Design scheme

The design is based on the DJI chassis and uses FPGA as processing core, combining with MPU6050 modules (three-axis gyroscope + tri-axial accelerometer), WIFI module, GPS module and other peripheral devices to achieve the functions of intelligent control and autonomous navigation, as shown in Figure 1.1.

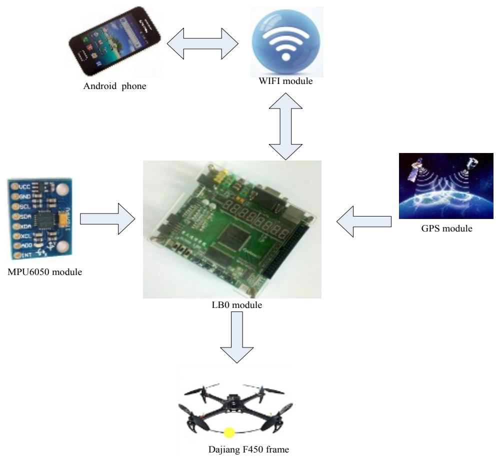

Figure1.1 The system structure diagram of the quadrocopter

The four-axis aircraft in this system can achieve a steady flight in the air. The wireless control of the aircraft is implemented by the communication between Android terminal and WIFI module. During the flight, the aircraft sends location information to Android terminal for display.

1) The advantage to use Altera's devices

a. Flexible and efficient capability of SOC solutions: SOPC (System on a Programmable Chip) consists of a system on a programmable chip, which addicts the Nios II processor, on-chip memory, I / O port and other system functional modules to one FPGA. It has a flexible design of developing custom peripherals and meets the complex requirements of peripherals.

b. The convenience of Nios II soft-core processor: Nios II soft core can be choose from a rich IP core library, depending on user application requirements. That offers a highly user-friendly design and improves effectively the computing ability of system. Nios II software is designed to support user-defined commands that provides an effective way to optimize and speed up the computations, which makes the algorithm commercialization much easier.

c. The powerful capabilities of C2H: The C2H Compiler provided by Nios II is integrated in the Nios II IDE, whose main feature is to converse the software program to the hardware implementation automatically and generate custom Avalon peripherals that is connected to the Nios II system. Nios II C2H Compiler can also enable embedded system developers to improve design efficiency and shorten the development cycle.

2) The advantage of Android platform

Remarkable characteristics of Android platform are that it is an open system architecture and has a very good development and debugging environment. Not only does Android platform provide a good condition for the developers, but also brings benefits to self-development. The popularity of Android smart terminal has brought great convenience to people's life and work. In addition, its portability makes our designed system possess extensive applications.

II. Hardware Circuit Design

Figure 2.1 shows the hardware block diagram of the four-axis aircraft.

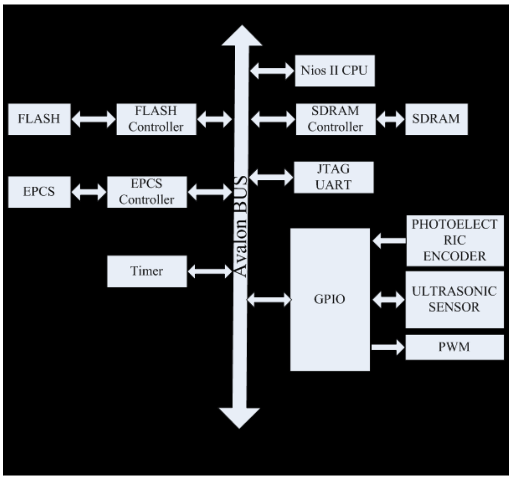

Figure2.1 Hardware block diagram of the quadrocopter

Figure2.2 The prototype image of the quadrocopter

A. hardware performance parameters

1) LB0 performance parameter:

- FPGA: CycloneIIIEP3C
- Memory: SDRAM,two 32-Mbyte SDRAM
  SRAM: one 2-Mbyte SRAM
  Flash Memory: 8-Mbyte flash memory
- Altera EPCS16 Series EEPROM
- Clock Input: 100MHz oscillator

2) Aircraft performance parameters

- Motor: A2212/13T
- ESC: FMT
- Wheelbase: 17.7/450mm
- Batteries: 11.2V (3S1P) 2200mAh

3) The performance parameters of WIFI module

HLK-WIFI-M03

- Hardware: the baud rate range: 1200~115200bps
- Wireless: the frequency range: 2.412~2.484 GHz
- Software: the maximum socket connection is 15

4) GPS Module: ATK-NEO-6M

- Interface Characteristics: TTL, compatible with 3.3V/5V MCU system
- Reception characteristics: 50 channels, GPS L1 (1575.42MHz) C/A code, SBAS: WAAS/EGNOS/MSAS
- Location Accuracy: 2.5mCEP (SBAS: 2.0mCEP)
- Update Rate: the maximum 5Hz

5) MPU-6050

- Gyroscope Measurable Range: ± 250, ± 500, ± 1000, ± 2000 ° / S (DPS)
- Accelerometer Measurable Range: ± 2, ± 4, ± 8, ± 16g

B. Design of the driving circuit of H Bridge

H bridge circuit is a typical DC motor control circuit, as shown in Figure 2.3. When the pair of MOS tubes on the diagonal conduct, the motor will enter the state of turn or reverse. The PWM signal will be first conversed by the H bridge circuit and then drives the DC motors(e.g. [4]).

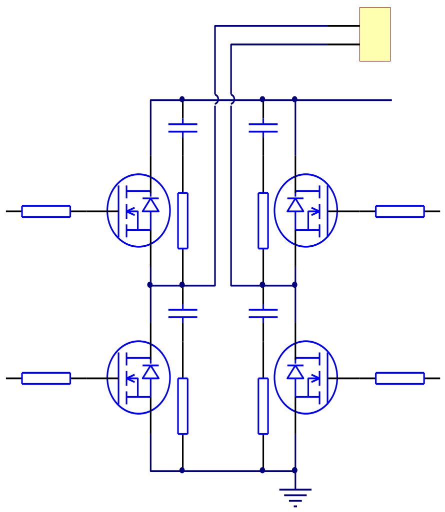

Figure2.3 H-bridge-driving circuit

The MOS tube in this design is IRF3205, whose maximum working current is 16A. As shown in Figure 2.4, the 74LS02 circuit is used in the input signal terminal, whose function is to choose the input signal. If the forward and reverse input signals are high or low at the same time, all of circuit outputs will be low. However, if only one input is high, the corresponding output will be high. Thus, that avoids the situation that two half bridges are connected at the same time and keeps H bridge circuit in working order.

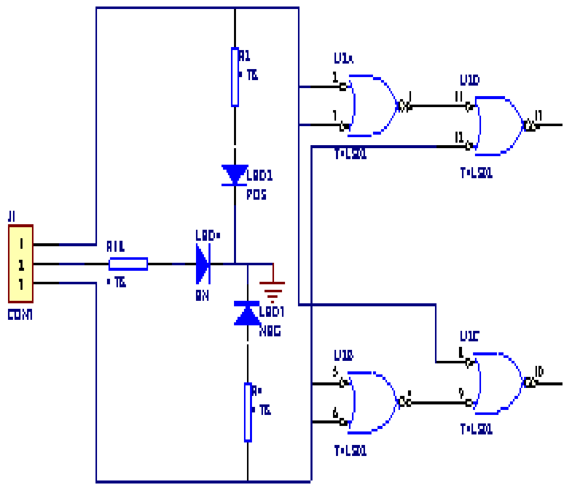

Figure2.4 NOR circuit schematic diagram

C. User-defined modules

1) PWM module

To control the motors of our aircraft, PWM module was designed within the FPGA. Writing data to the register, we will get certain square wave signal that the period is fixed and duty cycle is variable. Then we can manipulate the aircraft flying up and down, front and rear.

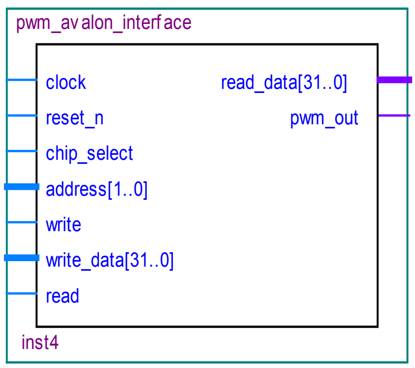

Figure 2.5 PWM module

2) I2C communication module

In our aircraft, MPU6050 is used to detect the real-time gesture. MPU6050 is an I2C slave device, so we need I2C communication module to read data from MPU6050. And then corrected data fusion will generate the real time altitude which is important for following control process.

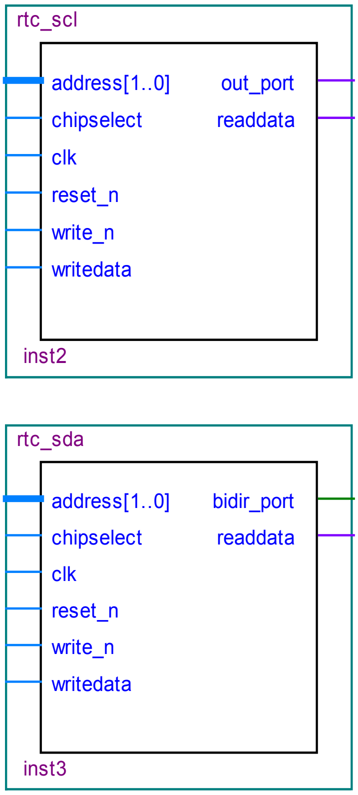

Figure 2.6 I2C communication module

C. *FPGA resource usage*

Figure 2.7 shows the use station of FPGA.

Flow Status	Successful - Sun Jul 21 20:59:48 2013
Quartus II Version	9.0 Build 132 02/25/2009 SJ Full Version
Revision Name	TestPs2Key
Top-level Entity Name	TestPs2Key
Family	Cyclone III
Device	EP3C10E144C7
Timing Models	Final
Met timing requirements	N/A
Total logic elements	4,976 / 10,320 (48 %)
Total combinational functions	4,306 / 10,320 (42 %)
Dedicated logic registers	2,983 / 10,320 (29 %)
Total registers	3052
Total pins	55 / 95 (58 %)
Total virtual pins	0
Total memory bits	276,352 / 423,936 (65 %)
Embedded Multiplier 9-bit elements	4 / 46 (9 %)
Total PLLs	1 / 2 (50 %)

Figure 2.7 FPGA resource usage

III. SOFTWARE DESIGN AND PROCESS

A. *Nios II software design*

Depending on the system design requirements, system software can be divided into system initialization, data acquisition and processing, network communications, aircraft control by function. The function of each module is showed as followed:

System initialization: Initialize the hardware devices and global variables.

Data acquisition and processing: Read the data stored in the FIFO. And verify the flight path of our aircraft by using the data.

Network communications: According to the system requirements, we need to pack the data and then send it to mobile phones through the Ethernet port. And the data from the mobile can also be received and processed by the system.

Aircraft control: Control the altitude of our aircraft by the command sent by the phone.

The overall system flow block diagram is showed as Figure 3.1.

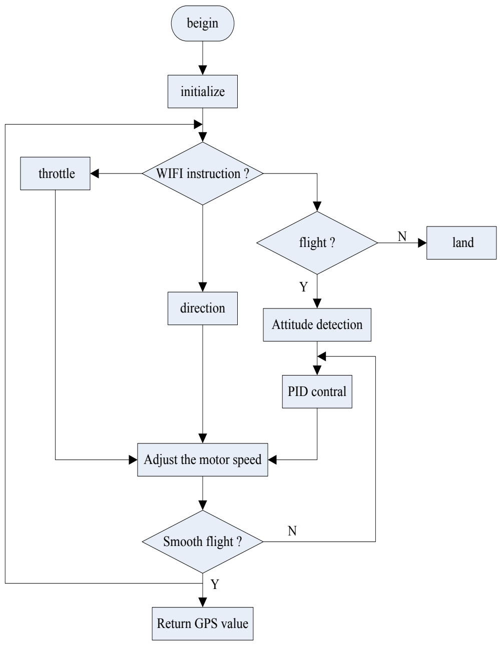

Figure3.1 Overall system flow block diagram

1) *Design of send and receive of network*

The client / server model based on TCP is founded by FPGA and Android phones. And it is realized by the use of the module of WIFI. Phones are used as server and FPGA client.

a. Working principles of WIFI module

WIFI module works with passive serial device networking and serial device networking. WIFI module uses passive serial device networking in our design and the aircraft has been in a state of passive waiting for a connection. It is initiated by the server to connect with the device and make requests or upload data(e.g. [5]).

b. TCP segment format

(1) paragraph format: TCP segment format is used by the system for data transmission, showed as followed

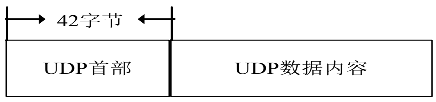

Figure 3.2 TCP segment format

(2) paragraph types: There are two sections in the design，the first is the receive data segment. It is the

control information sent from Android, showed in figure3.3.

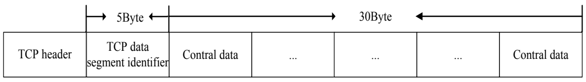

Figure 3.3 receive data segment

The second is transmit data segment，it is the information returned to Android.，showed in the figure 3.4.

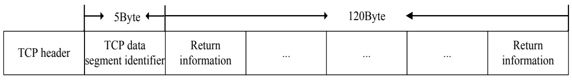

Figure 3.4 transmit data segment

c. Network transceiver process

After power-on initialization, LB0 will continue to send ARP packets and request the MAC address of the phone according to the IP address. After getting the MAC address successfully, LB0 will stop sending ARP packets, and then can communicate with TCP network by the acquired MAC address. The data sent from the phone is processed by LB0. And meanwhile the phone is also processing the data from LB0.

2) Aircraft Control Software Design

In aircraft flight control, the system processes the commands sent by mobile phones and then control the attitude of the aircraft, completing posture self-correcting in flight. Thus the PID algorithm based on feedback control is introduced. In our system, a closed-loop incremental PID control algorithm is applied to control the speed(e.g. [6]).

The desired angle is called setpoint (SP). The difference between the angle measurement and the setpoint is the error (E). The incremental PID controller is an improved vision of the PID controller, and the discrete incremental PID control algorithm is as follows:

$$U(k) = K_P E(k) + K_I \sum_{n=0}^{k} E(n) + K_D[E(k) - E(k-1)]$$

(1)

where k is the sample number(k=0,1,2,……), *U(k)* is the output at *k* step period, E(k) means temperature errors at *k* step period, K_P is proportional gain, K_I is integral gain, and K_D is derivative gain. We can get $U(k-1)$ according to recursive method:

$$U(k-1) = K_P E(k-1) + K_I \sum_{n=0}^{k-1} E(n) + K_D[E(k-1) - E(k-2)]$$

(2)

Let formula (1) and formula (2) make subtraction, we can get formula (3):

$$\Delta U(k) = K_P[E(k) - E(k-1)] + K_I E(k) + K_D[E(k) - 2E(k-1) + E(k-2)]$$

(3)

Where Δ *U(k)* is the incremental output, and it will be added to the last output *U(k)*, that is,

$$U(k) = U(k-1) + \Delta U(k)$$

This is the principle of incremental PID algorithm.

The output is incremental, so the malfunction has little effect on the output. We can use logic methods to eliminate the influence. Besides, the incremental output is only relevant with the last three samplings, so it can be weighted to obtain better attitude control results(e.g. [7],[8]).

B. Android Software Design

The mobile phone control site is based on android platform and designed with the android developer tools named eclipse.

Figure 3.5 welcome screen

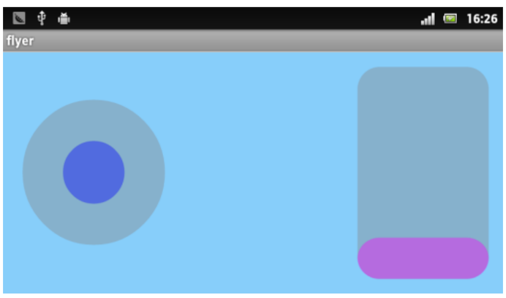

Figure 3.6 control interface

To meet the demand of the man-machine interaction, the functions of mobile phone site contain receiving and sending information, which are implemented through the network protocol TCP. The information that mobile phone receives is mainly current location of the quadrocopter. And the control information that phone sends contains direction and speed parameters of the quadrocopter in sensor mode. Mobile phone interfaces are shown as figure 3.5 and figure 3.6. As figure 3.6 shows, the round rocker in left screen controls the quadrocopter's direction and the rounded rectangle rocker in right controls the speed(e.g. [9]).

IV. THE DIFFICULTY AND INNOVATION

A. The Research Difficulty

1) Aerodynamics: Helicopter rotor is a divergent system and the quadrocopter has four rotor wings that interfere with each other. That poses a problem for dynamic analysis of the quadrocopter and causes it difficult to set up an accurate dynamic model. While the quadrocopter is in the air, laminar air flowing which causes considerable forces and moments plays a leading role. So it needs a three-dimensional aerodynamic analysis method.

2) Stability Control: The quadrocopter has four rotor wings that interfere and differ with each other. The aircraft is sensitive to external environment because of its small volume. Thus, it puts forward higher requirements in terms of stability and aircraft must pose rapid response capability and the ability of timely adaptive adjust to ensure the quadrocopter's stable attitude.

B. The Research Innovation

1) Android Intelligent Control: This design uses android smart terminal to intelligently control the quadrocopter by WIFI. The popularity and portability brings good experience to aircraft control personnel.

2) GPS autonomous navigation: The quadrocopter with a GPS module in this design can realize autonomous navigation and makes the aircraft controlled more conveniently.

V. SUMMARY

After several months of learning and exploration, we have a profound understanding of FPGA. We encountered many problems in the system development process. With unremitting efforts, a series of difficulties have been overcame, and the system basically reaches the expected function. The process of solving difficulties witnesses the growth of our team. In the problem-solving process, we fully appreciate the importance of experience. Rich experience in the design will promote to choose a good plan in the beginning of system design stage, as well as the rich experience in hardware and software debugging will greatly speed up the progress of the project.

Finally, our team would like to thank the contest organizing committee for giving us a rare opportunity to practice, as well as teachers and classmates for their guidance and assistance in the development process.

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