Design of Quadcopter with closed loop control system

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***Abstract*— Quad rotor helicopters are emerging as a popular platform for unmanned aerial vehicle (UAV) research, due to the simplicity of their construction and maintenance, their ability to hover, and their vertical takeoff and landing (VTOL) capability. In this paper an approach for control of autonomously flying Quad rotor which has vertical takeoff and landing capabilities (VTOL) is presented. The embedded control system and its software implementation have been presented. The Vehicle Dynamics has also been presented and analyzed.**

***Keywords*— real-time control; Quadcopter; VTOL; Data Acquisition; quad-rotor; Dynamics;**

I. INTRODUCTION

Quad rotor helicopters are an emerging rotorcraft concept for unmanned aerial vehicle (UAV) platforms. The vehicle consists of four rotors in total, with two pairs of counter-rotating, fixed-pitch blades located at the four corners of the aircraft. Due to its specific capabilities, use of autonomous quad rotor vehicles has been envisaged for a variety of applications both as individual vehicles and in multiple vehicle teams, including surveillance, search and rescue and mobile sensor networks. The rotorcraft is one of the most complex flying robots. Its complexity is due to the versatility and maneuverability to perform many different types of tasks. The classical helicopter is conventionally equipped with a main rotor and a tail rotor, which including the twin rotor helicopter, coaxial rotor helicopter and etc. It requires varying pitch of the rotor blades which is comparatively difficult. In Quad rotors, the control is accomplished by varying the speeds of the four rotors relative to each other. It naturally demands a sophisticated control system in order to allow for balancing flight. It's difficult to operate the attitude of the quad-rotor aircraft flight without any onboard controller by operator.

In this paper, we propose the control strategies of stabilizing a quad-rotor helicopter to test the hardware circuit we developed. Meanwhile, the data acquisition system is proposed. The Motor control algorithm is derived using basic dynamics. Then we suggest a platform with the custom data acquisition system, Radio controller and real-time control system. This paper is organized as follows: Introduction is provided in Section 1. Section 2 presents the design of real-time embedded control system. Section 3 describes the mini quad-rotor aircraft dynamic model and Section 4 explains radio controller and data acquisition system design and following section conclude the paper with conclusion, acknowledgement and references.

II. DESIGN OF REAL TIME EMBEDDED CONTROL SYSTEM

In this section, we describe the real-time control system, which is applied to stabilize the Vertical Take-Off and Landing aircraft. The generalized hardware platform of real time control system of mini quad-rotor helicopter is composed of the microcontroller onboard, the sensors or/and receiver and the actuator, which is shown in Fig. 1. Firstly, the data from the sensors or/and receiver can be sampled and captured continuously by onboard microcontroller. Secondly, these data is processed continuously in microcontroller with certain control algorithm. Finally, the microcontroller sends some control order to the actuators. Like this to complete a cycle of control task.

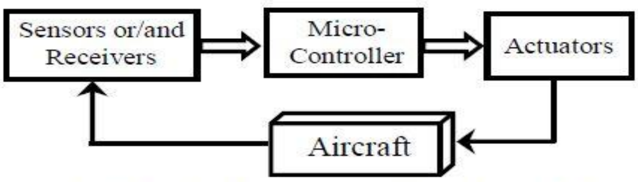

Figure 1. Generalized configuration of the hardware platform

A. General hardware architecture.

This real-time embedded control system uses the 32-bit ARM Controller core. It can run up to 60Mhz and 3.3V I/O, also including 128KB 16bit Flash memory, 16-channel 12-bit

ADC, 6-channel input capture, three 32-bit CPU-timers, 12-channel PWM output, two serial communications interfaces (Standard UART RS232), and 1-channel serial peripheral interfaces (SPI) and watchdog timer module inside.

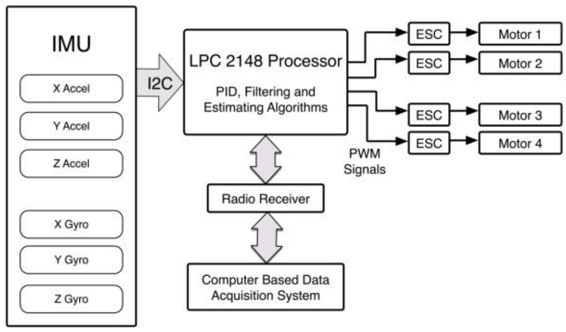

Figure 2. Hardware Architecture

We can get the software and hardware development tools easily from the company's site, furthermore the basic code generation and debugging is obtained from Crossworks software development tools. It can be supported by the ANSI C/C++ language development system and embedded software design. The functional libraries for mathematical operation and the high efficient machine code produced for the application are support by NXP and the third-party.

The other onboard components are:

Inertial Measurement Unit (IMU), which includes three single-axis gyroscope sensors, one dual-axis accelerometer sensor. Actuators, Driver modified for each BLDC motor. Wireless sector includes one indigenous radio command receiver module using zigbee module operating at frequency 2.4GHz.

B. Software Implementation

Because of the ARM Controller (LPC2148) Operational frequency is up to 60MHz and the high efficient code is produced by the development tools. Our application software is exploited using the real-time multiple tasks programming method base on BIOS, with five real-time tasks are described as follows. The block diagram of real-time tasks scheduler of real-time embedded control system is showed in Fig. 3.

The program for the control system begins with the initialization of the registers, variables and that will be used in the program execution. The multitask scheduler is continuously run to execute each of the tasks at required time.

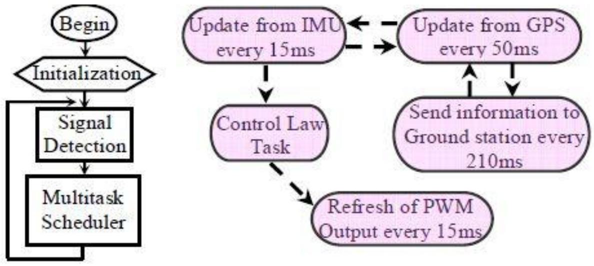

Figure 3. Software Implementation

The first task reads the values of the angular position and angular rate from the gyro sensors and the accelerometer sensor every 15ms. Once the attitude data is obtained, the second task is invoked immediately to compute the control law to stabilize the mini quad-rotor helicopter. The third task reloads the PWM value updated to regulate the motors.

$$PWM_{M_1} = u + \tau_\psi + \tau_\theta$$
$$PWM_{M_2} = u - \tau_\psi - \tau_\phi$$
$$PWM_{M_3} = u + \tau_\psi - \tau_\theta$$
$$PWM_{M_4} = u - \tau_\psi + \tau_\phi$$

Where u is the throttle input τ_ψ , τ_θ and τ_φ is the control input for the yaw, pitch and roll moments respectively.

III. VEHICLE DYNAMICS

The motors are the controlling element through which the stabilization can be achieved. To find out the input for the each motor to be given in order to remove the Roll angle and Pitch angle error, the following mathematical derivation has been done.

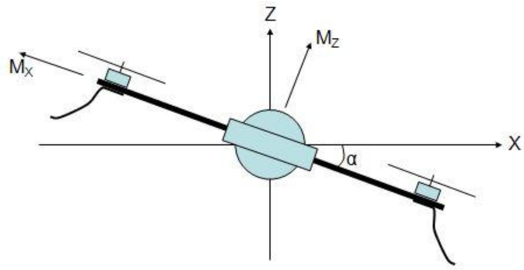

Figure 4: Vehicle Geometry

Let, α degree be the roll angle of the system and T Kg be the thrust developed by each motor according to the pilot input. Since the system is not in hovering position as show in the Figure 4, there will be difference in thrust in left two motors compared to right two by Δt Kg.

From the geometry of the system, the net force upwards is,

$$(T+\Delta t)\cos(\alpha) + (T+\Delta t)\cos(\alpha) + T\cos(\alpha) + T\cos(\alpha)$$

This force must be equal to four times the Thrust given by pilot for system to hover which is 4T.

Equating both,

$$(T+\Delta t)\cos(\alpha) + (T+\Delta t)\cos(\alpha) + T\cos(\alpha) + T\cos(\alpha) = 4T$$

i.e, $4T(1-\cos(\alpha)) = 2 * \Delta t * \cos(\alpha)$

Solving the above equation, we get,

$$\Delta t = 2T(\mathrm{Secant}(\alpha)-1)$$

Above equation is helpful in finding out change in thrust that should be made to left two motors in order to make the system change its angle by α degree.
The same relation exists for Pitch angle ϕ. Hence taking both roll angle and pitch angle into account, we get ,

$$\Delta t,roll = 2T(\mathrm{Secant}(\alpha)-1) \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{(Eq 1)}$$

$$\Delta t,pitch = 2T(\mathrm{Secant}(\phi)-1) \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{(Eq 2)}$$

Once we get the Δt,roll and Δt,pitch, then for making the system to hover, we can calculate the input that should be given to each motor as follows:

Thrust	**α>0 and ϕ >0**	**α>0 and ϕ <0**	**α <0 and ϕ >0**	**α <0 and ϕ<0**
Front Right Motor	T+Δt,roll +Δt,pitch	T+ Δt,pitch	T+ Δt,roll	T
Front Left Motor	T+ Δt,pitch	T+Δt,roll +Δt,pitch	T	T+ Δt,roll
Back Right Motor	T+ Δt,roll	T	T+Δt,pitch +Δt,roll	T+Δt,pitch
Back Left Motor	T	T+ Δt,roll	T+ Δt,pitch	T+Δt,roll+ Δt,pitch

Table 1: Thrust to be given to different motors for maintaining hover

IV. RADIO CONTROLLER AND DATA ACQUISITION

Unlike other projects being performed in other universities, this aims at better performance and low budget construction. This pushes to build indigenous radio controller to control the dynamics of the quadcopter. Diagram shown below illustrates the block diagram for the radio controller developed. As it is evident, two joysticks are used for controlling the direction of motion and other turntable switch, built using a potentiometer with a cap, is used to control the throttle/ amount of average current flowing to each motors. A ZigBee XBee[17] module is used as RF transceiver module and the design and selection of components allow us to use it for a maximum range of 300m.

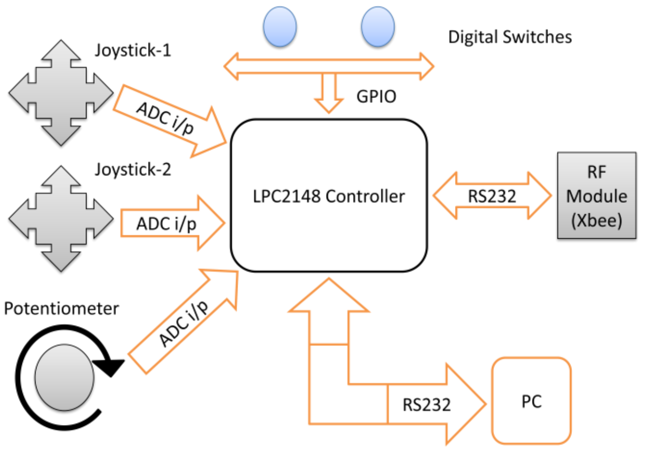

Figure 5: Radio controller Block Diagram.

As mentioned repeatedly in this paper, main concern is to develop a platform for research in the quadcopter area. Hence it is of paramount importance for any researcher to know the behavior of sensors and actuators in real time systems. This aids to develop optimized system with excellent performance. Keeping this as aim, an GUI is developed in LabVIEW[16] to display sensor values in real time. Figure 5 illustrates block diagram of Radio controller and Figure 6 illustrates an example of GUI frontend developed in LabVIEW.

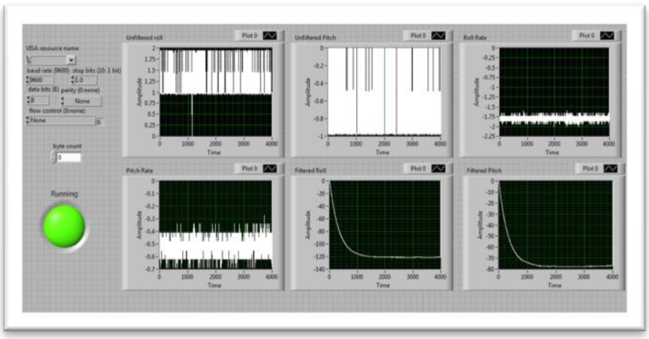

Figure 6: GUI Developed in LabVIEW.

V. CONCLUSIONS

Quadrotor helicopters are popular as test beds for small UAV development, but their aerodynamics are complex and need to be accurately modeled in order to enable precise trajectory control. Although many good control results have been reported in previous work, these have focused primarily on simple trajectories at low velocities, in controlled indoor environments.

In this paper, we proposed the real-time embedded control system for the quad-rotor aircraft with the vehicle dynamics. In addition, the multitask programming method is adopted in software design to carry out the computation of control law, data processing and correction output along with radio controller and data acquisition system to get the satisfied results.

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REFERENCES

[1]. A. L. Rodriguez, L. M. Parrilla, A. Simón-Muela and M. M. Prats.: '*Real time sensor acquisition platform for experimental uav research*', Digital Avionics Systems Conference, IEEE/AIAA Spain – 2009.

[2]. Xiaojie LIU, Xiaohui ZHAO, Haijun GU, Anand SANCHEZ.: '*Application and Design of Real-time Control System for the Quad-rotor Helicopter',* 2009 International Conference on Measuring Technology and Mechatronics Automation, China.

[3] Markus Achtelik, Tianguang Zhang, Kolja Kiihnlenz and Martin Buss,: '*Visual Tracking and Control of a Quadcopter Using a Stereo Camera System and Inertial Sensors*', Proceedings of the 2009 IEEE, International Conference on Mechatronics and Automation, August 9 - 12, Changchun, China

[4] Gary Fay, Derivation of the aerodynamic forces for the mesicopter simulation, IEEE International Conference on Robotics and Automation, Barcelona, 2005 .

[5] McKerrow, P., Modelling the Draganflyer four-rotor helicopter, Proceedings of the IEEE International Conference on Robotics and Automation, Vol.4, 2004, Pages: 3596 – 3601.

[6]Vedran Sikirik, Control of Quadrocopter, School of Electrical Engineering,Royal Institute of Technology, Year 2008.

[7] Peter Kunz, Gary Fay, Shelley Cheng, Tibor Fabian, Chad Partridge, The Mesicopter: A Miniature Rotorcraft Concept, Stanford University, November 2001.

[8] Lara, David Sanchez, Anand Lozano, Rogelio Castillo, P. "Real-time embedded control system for VTOL aircrafts: Application to stabilize a quad-rotor helicopter", IEEE International Conference on Control Applications, Computer Aided Control System Design, 2006.

[9] Tommaso Bresciani, Modelling, Identification and Control of a Quadrotor Helicopter, Department of Automatic Control, Lund University, October 2008.

[10] Peng Kemao, Dong Miaobo, Chen Ben M, Cai Guowei, Lum Kai Yew, Lee Tong H, Design and Implementation of a Fully Autonomous Flight Control System for a UAV Helicopter, Proceedings of the 26th Chinese Control Conference, 2007.

[11] Guowei Cai, Ben M. Chen, Kemao Peng, Miaobo Dong and Tong H. Lee, Modeling and Control System Design for a UAV Helicopter, 14th Mediterranean Conference on Control and Automation, June 2006, Pages 1– 6.

[12] Gabriel M. Hoffmann, Haomiao Huang, Steven L. Waslander, Claire J. Tomlin, Quadrotor Helicopter Flight Dynamics and Control: Theory and Experiment, IEEE Conference on Robotics & Automation, 2009.

[13] LPC 2148 Datasheet: http://www.nxp.com/documents/data_sheet/LPC2141_42_44_46_48.pdf

[14] ITG3200 Datasheet: http://www.sparkfun.com/datasheets/Sensors/Gyro/PS-ITG-3200-00-01.4.pdf

[15] ADXL345 Datasheet: http://www.analog.com/static/imported-files/data_sheets/ADXL345.pdf

[16] LabVIEW Documentation: http://www.ni.com/pdf/manuals/320999e.pdf

[17] Xbee documentation: http://ftp1.digi.com/support/documentation/90000976_G.pdf

[18] RCToys, http://www.rctoys.com.

[19] Silverlit. http://www.silverlit.com.

[20] Microdrones GmbH. http://www.microdrones.com.

[21] MARV, http://www.enae.umd.edu/research/index.html