ASEE 2014 Zone I Conference, April 3-5, 2014, University of Bridgeport, Bridgpeort, CT, USA.

Miniature Wireless Quadcopter

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***Abstract*—A quadcopter is a flying vehicle with four motors driving counter rotating propellers which are mounted in a cross pattern. It is capable of flying around and hovering like a helicopter but with the added stability and maneuverability gained from the extra motors. Making this technology smaller would allow it to serve many useful functions that would be difficult or impossible for other types of vehicles or devices. However, the miniaturization of this technology faces many difficulties and thus we aim to closely integrate the hardware and software in an attempt to design a tiny quadcopter while keeping it functional and useful in a military surveillance capacity.**

I. Introduction

Advances in aeronautics, engineering, and embedded processing have allowed the development of small flying vehicles with a range of functions. One such device is the quadcopter which is similar to a helicopter, except that they utilize four rotors mounted equidistant to the center of mass to achieve lift and maneuverability. Ever shrinking motors and electronics naturally lends itself to making these drones and controlled devices for the military for the purpose of reconnaissance, for researchers for obtaining samples and readings where it would be too dangerous for human beings, and finally for entertainment as a hobby or toy.

So far, most recent developments in the area to serve the purposes listed above have been modular in approach which works against miniaturization. For instance brushless motors offer high power output but require ESC (Electronic State Control) modules to properly drive the rotors. Thus technologies from many different areas (motors, wireless communications, processing, and sensing) are shoehorned into a single device. This is how the majority of quadcopters are designed and built and as such the average quadcopter kit that can be purchased online measures around 22 inches wide. However, since the development of the quadcopter (especially smaller more portable versions) is fairly new and needs much improvement, there is plenty of room for advancement.

The purpose of this study and its contribution to unmanned aerial vehicles is therefore to design a small quadcopter with close integration of technologies in mind during the design process in order to push the current limits of quadcopters involving size, weight, and function. We have set a target size to design a miniature quadcopter to be smaller than 6” wide. The specific function of this design is geared towards a military application of surveillance. This would necessitate designing the software from scratch to tailor it to the hardware in order to discover the possibilities of a developing technology.

Sponsored by University of Hartford UAV Team.

II. Review of Literature

A. Motors

The history of quadcopters is relatively new, but the basic concepts that underlie their elementary operation have been studied for quite a while. The first is the electric motor. Michael Faraday, a scientist and experimenter, was the first to conceive a device which would turn electrical into mechanical energy. [1] Today, this device comes in two varieties, AC or brushless, and DC or brushed. A majority of quadcopters utilize brushless motors due to their high power output to weight ratio. However, driving brushless motors requires an increase in design complexity due to electrical commutation (multiphase) requirements as seen below in figure 1.

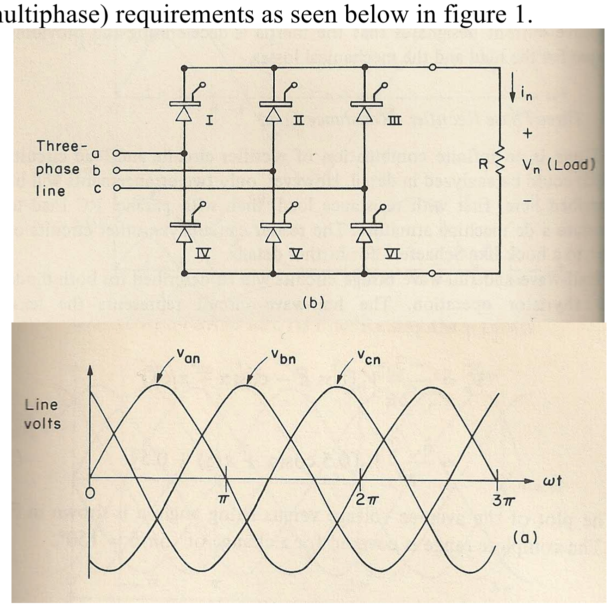


Fig. 1. Three-phase brushless motor control [2]

In the case of the brushless quadcopter this driving circuitry is taken care of through the use of ESC modules (Electronic State Controllers) which can variably drive each motor’s speed independently.

Utilizing brushed motors, on the other hand simplifies the hardware requirements, shown below in figure 2, at the cost of long term reliability.

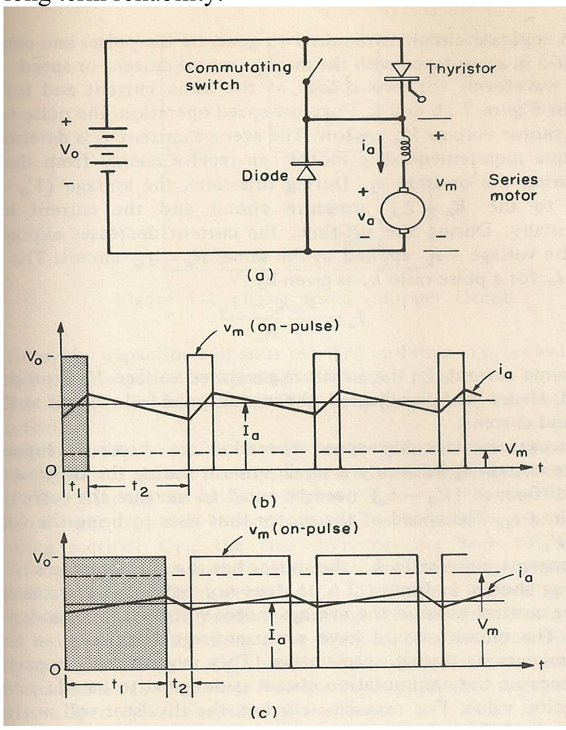
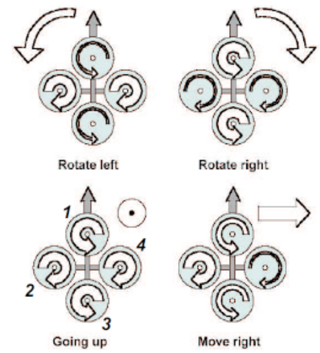


Fig. 2. Brushed motor chopper speed control [2]

In the case of the brushed quadcopter this circuitry can be taken care of by a switching MOSFET (Metal Oxide Semiconductor Field Effect Transistor). Speed control is handled either in software or hardware by what is known as PWM (Pulse Width Modulation) where power is pulsed to the motor and the ratio of on to off time determines rotational speed. [3]

B. *Aerodynamics*

The second major concept in understanding quadcopters is aerodynamics. While the mechanics governing them are relatively simple and robust, it is all the more necessary to understand the aerodynamics. [4] The principle of hovering, climbing, and vertical descent utilized by helicopters works similarly for quadcopters and thus can be applied for stabilization and maneuvering. Air is drawn downward through each rotor to create a vertical channel of air with negative pressure above the plane of the rotor and positive pressure below it while the air outside this channel is relatively undisturbed. This generates a downward thrust which counteracts the force of gravity to enable the vehicle to hover, climb, or descend depending on the power applied to the motor. [3] Having four of these counter spinning rotors allows a quadcopter great control in all three dimensions by independent control of each of its motors. [6] Basic maneuvers utilizing this independent control scheme can be seen in the figure below.



Rotor position and rotation [7]

In terms of choosing the size of the vehicle, Mahony, Kumar and Corke came to the conclusion after analyzing Froude and Mach number similitudes that smaller quadcopters benefit from greater agility due to scaling effects. [3]

C. *Control System*

Finally, the third major concept is control systems and state control. This is the basic system which takes care of generally stabilizing the vehicle through the use of sensor inputs to adjust the motor controls, an example of which can be seen below in figure 3.

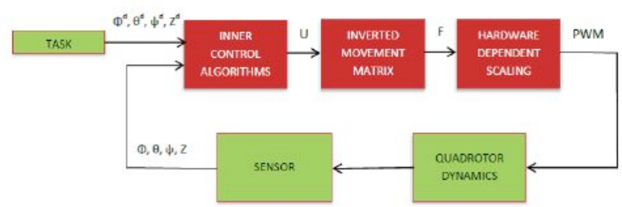


Fig. 3. Control block diagram [6]

An IMU (Inertial Measurement Unit) consisting of a gyroscope, accelerometer, and magnetometer provides the sensing but is sensitive to vibrations. [3] In the end a pilot can supersedes control with manual input all the while that autostabilization provides minute corrections. [4]

III. Methods and Materials

The quadcopter as described above consists of the following major components:

- Microprocessor
- Brushed Motors
- MOSFETs
- Accelerometer
- Lithium Ion Battery
- Voltage Regulator
- Wireless Transceiver

A. *Processing*

One part of the quadcopter contains all of the digital control and feedback components. The microprocessor acts as the brain of the quadcopter. It reads the accelerometer, makes adjustments as necessary to the brushed motors which are driven by PWM signals applied to control MOSFETs, in order to auto stabilize flight. The accelerometer converts the acceleration experienced in the X, Y, and Z directions into an analog value which can be filtered and read. The thrust characteristics for each motor is experimentally found and stored in permanent memory which is used to control the thrust strength of each motor independently. When an external control signal is received (in the form of serial data from the wireless transceiver), the microcontroller gives priority to the received signal over the auto stabilization routine to perform the required maneuver by manually increasing thrust to the motor in the desired direction.

B. Power Supply

The other major block is the power supply management. This is accomplished by the voltage regulators. Since the lithium ion battery supplies a voltage in the range of 4V, and the system requires 3.3V for the logic, a regulator is necessary. The digital logic supply is generated by a low drop out regulator that insures a steady 3.3V rail to the microprocessor, accelerometer, and wireless modules so that they can function reliably. The analog supply is tapped directly from the battery to drive the motors. The two supply rails must be independent from each other to insure that any fluctuation caused by throttling the motors does not feedback and reset the microprocessor, or interrupt normal function.

C. Software

The 'C' software written for the PIC16F886 processor describes a superloop structure which contains four main tasks. The top level simply calls each task successively and loops. Global variables are utilized to pass data from one task to another.

The first task is a software based implementation of a four output 8 bit resolution PWM driver. A call to the function PWM(a,b,c,d) will write the four eight bit values a, b, c, and d to the motors with proportional duty cycles. It must be periodically called each iteration to ensure that the motors are continuously being driven.

The second task is the hardware UART initialization, transmission, and reception code. These functions allow communication through the wireless xbee modules. The serial port is initialized to 19200 Baud by calling uart_init. To send a string, the function uart_txt(string) sends each character in the string until the entire message has been sent. To receive a character, rxd() checks the port to see if the buffer contains received data and returns it if so.

The third task is the ADC (Analog to Digital Converter) software which utilizes the hardware peripheral build into the PIC to measure an analog voltage and return its corresponding digital value. The function adconvert(dir) handles initializing the feature to read the x, y, or z accelerometer values depending on the argument 'dir'. It returns a 12 bit value proportional to the measured voltage.

The final task is the auto correction algorithm which has the important job of deciding how much thrust each motor should receive. It does this by comparing its current measured x, y, and z velocities with pre-defined constants to determine whether current thrust should be increased or decreased (and by how much) to compensate for roll in any given direction. The pre-defined constants were measured by leveling the accelerometer and taking baseline values and adding a margin to calculate a max and min to prevent the software from causing oscillation. These parameters were programmed to the prototype quadcopter and tested to see the effects and trimmed until stable flight was achieved. In addition, the auto correction algorithm checks to see if a wireless command was given. If so then it gives priority to the command over auto stabilization by momentarily thrusting in the direction of the command. It recognizes the command characters 'u' (up), 'd' (down), 'l' (left), 'r' (right), 'f' (forward), 'b' (backward),'h' (halt/disarm), 'a' (arm).

ACKNOWLEDGMENT

The authors would like to thank the University of Hartford UAV team and Tom Lavoie for design help and funding.

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