A Testbed for Mini Quadrotor Unmanned Aerial Vehicle with Protective Shroud

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1. Introduction

Potential applications of small rotorcraft unmanned aerial vehicles (UAVs) range from military missions to exploration of the Planet Mars [1]. Tasks such as exploration of unknown territories, formation flying, intelligence gathering etc, require an UAV to be capable of flying very close to other flying or steady objects. Exposed rotary wings limit rotorcraft vehicle's capability to fly in proximity of other objects. In some applications like rescue operation, urban warfare etc, it is highly desirable to cover the exposed blades of UAVs. Many researchers have shown their interest in mini rotorcrafts since last decade. But little or no research work has been done on designing, building and testing of protective shroud for rotorcrafts. This research work proposes a protective shroud for a mini quadrotor UAV to demonstrate the capability of a rotorcraft to continue its flight after a collision with objects such as brick wall. A quadrotor helicopter has been considered as a base vehicle. A protective shroud for the base vehicle has been designed and built to protect rotors against other objects. A proportional and derivative controller has been designed, implemented and tested to ensure the attitude stability of the vehicle in the presence of high frequency noise, vibrations and disturbances. Experiments have been carried out to prove the stability of the quadrotor vehicle after a collision with wall. This study provides the ground work for future work in this direction. Many new applications of rotorcraft UAVs can be explored after a successful completion of this research work.

2. Quadrotor Background

A simplified CAD model of quadrotor is shown in figure 1. It has four rotors attached with electric motor shaft through a pair of gears. The quadrotor can be controlled by only changing the speed of each rotor. The pairs of front/rear and left/right rotors rotate in opposite direction to each other. Roll and pitch angles can be controlled by changing the relative speed of each rotor of front/rear and left/right pairs, respectively. The yaw angle can be controlled by changing the relative speed of front/rear and right/left rotors. The dynamic model has not been presented in this paper due to the space limitation; however, it can be found in [2], [3] and [4]. A quadrotor is simple to build and requires very few components compared to single rotor helicopter. Since, a quadrotor can be controlled by only changing the motor speed, it will be easy to control it compared to conventional helicopters.

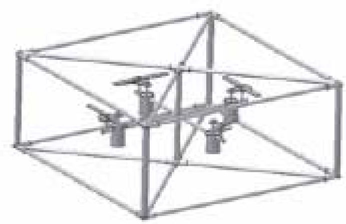

Figure 1. A simplified CAD model of quadrotor with protective shroud.

3. Structural Design of Base Vehicle

Since, choosing the best combination of motors, rotors and battery is the most important task, a dragon flyer vehicle from www.rctoys.com has been purchased and parts from that vehicle have been used for further research work. The structure of the base vehicle including protective shroud is made from carbon fiber tubes. The carbon fibers tubes are very light weight and can resist the impact with brick wall at vehicle speed of 5mph. The current vehicle is capable of flying at 10ft height for 5 minutes, limited by motor heating. A picture of this vehicle is shown in figure 2.

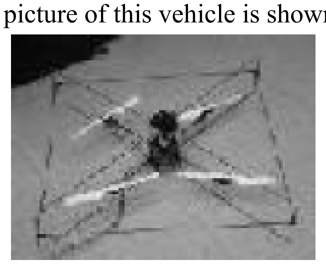

Figure 2. Quadrotor vehicle with protective shroud

4. System Configuration

An overall system configuration is shown in figure 3. It shows the onboard system hardware and the ground station arrangement.

PIC 18F4585 from Microchip Inc, an 8 bit microcontroller, has been used as an onboard controller. The onboard peripherals such as Inertial Measurement Unit (IMU) and Motor Driver Circuit (MDC) have been interfaced with PIC 18F4585. The PIC microcontroller has been programmed using CCS compiler from www.ccsinfo.com.

An IMU, 3DMGX1 from Microstrain Inc, capable of measuring pitch, roll, yaw, angular rates and axial accelerations has been used to measure states of the system. 3DM-GX1 is small in size, light weight, accurate and can be easily interfaced with PIC via serial communication interface (SCI).

A motor driving circuit using FETs and a PWM co-processor has been designed, tested and built. This MDC is capable of handling four motors (12v-24v, 40A). The PWM co-processor, from www.awce.com, is capable of generating 8 PWM channels and can be easily interfaced with the PIC microcontroller via SCI, which makes the PIC free from additional computing power required to generate four PWM channels.

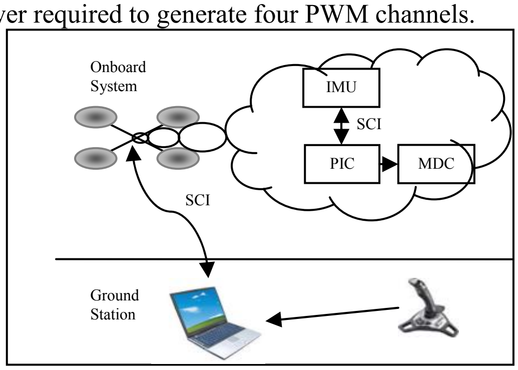

Figure 3. Overall System Configuration

The most important issue while designing an UAV is the stability of the vehicle. An attitude stability controller is required to have stable flight, since the dynamic of quadrotor has low damping rate [5]. The additional disturbances from flexible plastic joints, carbon fiber tubes and impact with wall may affect the overall stability of the vehicle. So far, various approaches like classical control [2], LQ control [2], H_∞ [3] and neural network [4] have been considered for the stability of vehicle. Assuming only small angular deviation in roll, pitch, and yaw, a classical Proportional Derivative (PD) controller has been designed to address the attitude stability problem. The stability controller keeps the vehicle stable before, during and after an impact with wall. It makes flight easy and allows pilot to do other maneuvering without taking care of vehicle stability. The controller also lets the vehicle fly while maintaining continuous contact with the wall. This capability adds a great advantage to the vehicle to continue flying even after a small hit with the wall, where other vehicles fail and turn hostile.

This attitude stability controller is programmed in Real Time LabVIEW 7.1, a graphical programming platform from National Instrument Inc. The Real Time module comes with a dedicated Pentium III processor card, which makes the system CPU free from any addition computation required to perform vehicle stabilization. A standard Pentium IV Desktop with Microsoft Windows XP and LabVIEW 7.1 has been used as a ground station. The ground station has been interfaced with vehicle via standard serial communication channel. Manual control of flight will be performed via standard analog transmitter.

5. Experiments

The main aim of this research work was to design and build a UAV which has striking ability with the brick wall and other similar vehicles. The velocity of the vehicle at the time of impact was assumed to be of 3mph. This research work was partially supported by URCA, Wichita State University. The UAV was built and experiments were carried out at 116 Wallace Hall. A few test flights have been carried out in tethered mode to prove the stability of vehicle before, during and after an impact with brick wall. The PD controller provably assures attitude (roll, pitch, and yaw) stability.

The authors encourage readers to log on to www.chiragapatel.com, and click on the gallery link.

6. Conclusion

A quadrotor mini rotorcraft with protective shroud has been designed, built and tested to prove its capability to survive after an impact with brick wall or other similar vehicle. A vehicle can hover while maintaining contact with brick wall. A better control law, using advanced mathematical tools, can be designed to give better stability after an impact.

[1] Patrick C. O'Brien, "Using a Robotic Helicopter To Fuel Interest In And Augment The Human Exploration Of The Planet Mars" Journal of the American Institute of Aeronautics and Astronautics, September 2003, Long Beach, California.

[2] Samir B, Andre N. and Ronald S. "PID vs. LQ Control Techniques Applied to an Indoor Micro Quadrotor" Proceedings of IEEE/RSJ International Conference on Intelligent Robots and Systems, September, 2004, Sendai, Japan.

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[4] Dunfield, M. Tarbouchi, G. Labonte, "Neural Network Based Control of a Four Rotor Helicopter" IEEE International Conference on Industrial Technology, 2004.

[5] Scott D. Hanford, Lyle N. Long, and Joseph F. Horn. "A Small Semi-Automated Rotary-Wing Unmanned Air Vehicle" AIAA September, 2005.