Mechatronics in Aerial Surveilance and Reconnaissance

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ABSTRACT

A growing need for aerial visual superiority for the military and police force is growing rapidly. It can be seen as various companies such as BAE try to create small remote control planes and helicopters to provide visual reconnaissance to ground forces. This demand has been met with remote control airplanes and helicopters, but both have weaknesses and strengths. A better device should be created that has both the altitude and speed capabilities of an airplane and mobility and stability of a helicopter at a cheap and cost effective price. Four ducted fans will provide thrust, stability and direction with the aid of flaps that controlled by servo motors. A 2.4 GHz transmitter allows control of up to a thousand feet. It will incorporate an easy to use remote control that is used for model airplanes. Simple to use remote commands allow the operator to easily operate the device.

Keywords: Experimentation, Vertical and Horizontal, Control, Yaw

1. INTRODUCTION

Advances in technology are allowing smaller and faster products with increased range and mobility to be made. The growing need for aerial reconnaissance in the military and police has sparked the UAV generation where unmanned drones are taking to the sky. This unmanned device will distinguish itself in its innovative retractable wings and rotating ducted fans. The advantage is that it will incorporate a helicopters mobility and stability while also taking advantage of an airplanes speed and altitude. Similar items on the market compose of the Quad copter and small light weight RC airplanes.

Soldiers in the military comprise mainly of young men with countless hours of video gaming experience. This experience is being overlooked while it could be actually harnessed. This device is being designed keeping simplicity of control in mind. Making this device simple will allow it to be used by almost anyone with minimal formal training. The retractable wing feature is meant to allow a longer flight time by creating additional lift with the same amount of thrust. The wings can be retracted in case more mobility is needed in a situation where room is insufficient.

2. BACKGROUND AND FORMULATION

Controlling the Quadrotor involves four different states (Bresciani 2008):

<u>U1 (Upward motion z-direction):</u> (figure 1) with respect to the body. This motion is provided by the thrust generated by all four EDF rotating with the same angular velocity.

U2: Roll motion Φ: (figure 2), this motion is attained by the force differential between the thrust generated by the right and the left fan.

U3: Pitch motion θ: (figure 3), this motion is attained by the force differential between the thrust generated by the front and the rear fan.

U4: Yaw motion ψ: (figure 4), this motion is attained by controlling two sets of flaps placed underneath the side fans to redirect a small component of the normal-to-body thrust force in the horizontal plane. The force components act in opposite directions which create a moment-couple about the vertical axis of the body. The flaps are driven by two servo motors.

All the four motions are set to be controlled independent of each other by a remote control.

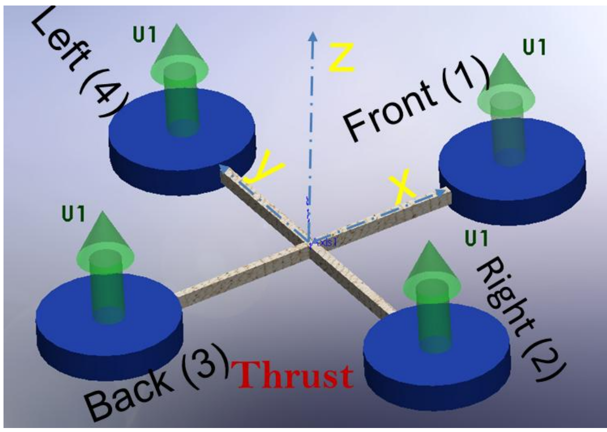

Figure 1: Thrust (normal-to-body motion)

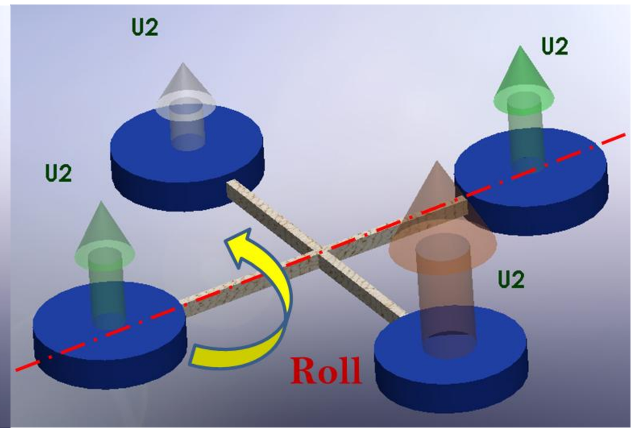

Figure 2: Roll motion

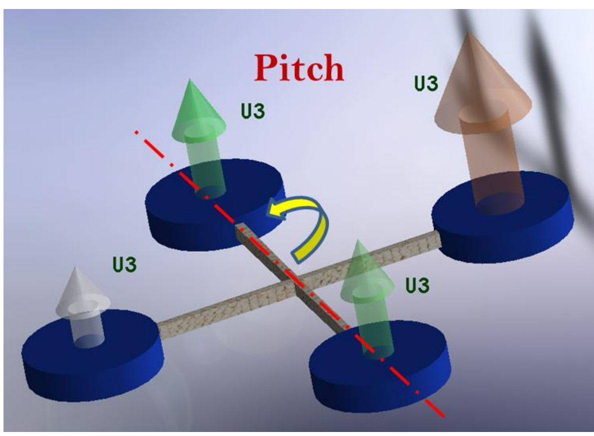

Figure 3: Pitch motion

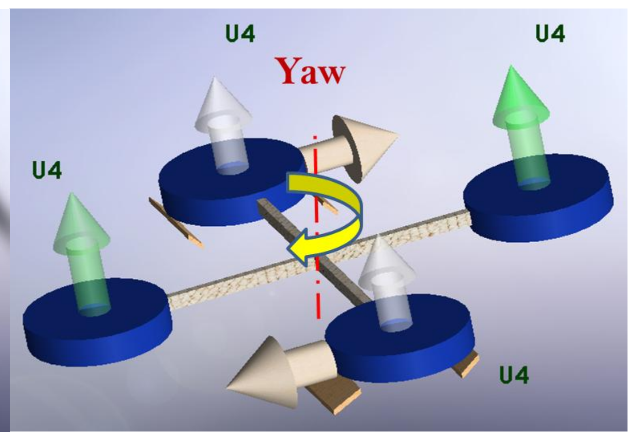

Figure 4: Yaw motion

System Governing Equations:

$$\ddot{Z} = -\mathbf{g} + (\cos\boldsymbol{\theta}\ \ \cos\boldsymbol{\varphi})U1$$

$$\ddot{\varphi} = \frac{U2}{Ixx} \qquad \ddot{\theta} = \frac{U3}{Iyy} \qquad \ddot{\psi} = \frac{U4}{Izz}$$

$\ddot{z}$*: Acceleration normal to the body.*

I_{ii} :moment of inertia about axis i.
T: motor thrust factor.
r: distance from body center to fan center
α*: flaps tilt angle with the vertical plane*

System Control Variables:

$$\boldsymbol{U1} = \boldsymbol{T}[(\boldsymbol{\omega_1}^2 + \boldsymbol{\omega_2}^2) + \cos \boldsymbol{\alpha}\,(\boldsymbol{\omega_3}^2 + \boldsymbol{\omega_4}^2)]$$

$$\boldsymbol{U2} = \boldsymbol{r} * \boldsymbol{T} * \cos \boldsymbol{\alpha}\,(-\boldsymbol{\omega_2}^2 + \boldsymbol{\omega_4}^2)$$

$$\boldsymbol{U3} = \boldsymbol{r} * \boldsymbol{T}\ (-\boldsymbol{\omega_1}^2 + \boldsymbol{\omega_3}^2)$$

$$\boldsymbol{U4} = \boldsymbol{2} * \boldsymbol{r} * \boldsymbol{U1}\ \boldsymbol{sin\,\alpha}$$

3. EXPERIMENTATION

The experimentation procedure of this project was very direct. The main goal was to figure out if there would be sufficient thrust and control. A controlled environment was created by making a guide for the device. The following picture shows the controlled environment that will be used to test the thrust and direction control of the device.

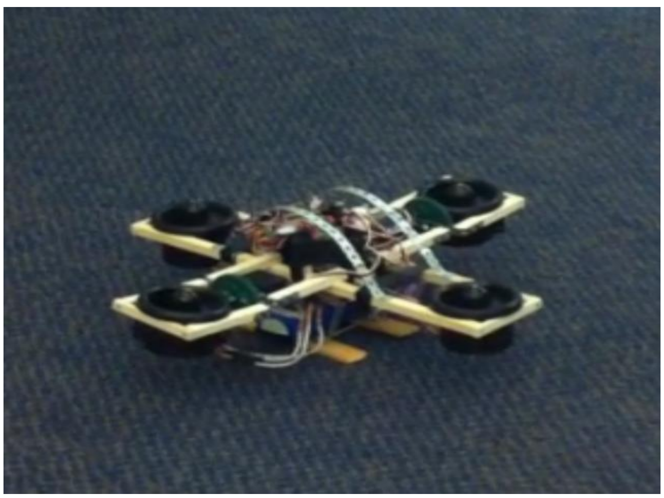

Figure 5: A photo of the quad copter

It will be six feet in height, made up of wood. Four six foot long two by fours will be used to completely make this. A string will be attached from the bottom to the top and will act as a guide. The experimental quad-copter device will have two holes in its center, on the base and on the top. These two holes are used as guide along with this device. This experiment will allow us to directly measure what is the maximum amount of weight this device can carry with a full charge and for how long. This environment will provide only one degree of movement which is up and down; this will greatly help in measuring its velocity as well as timing it.

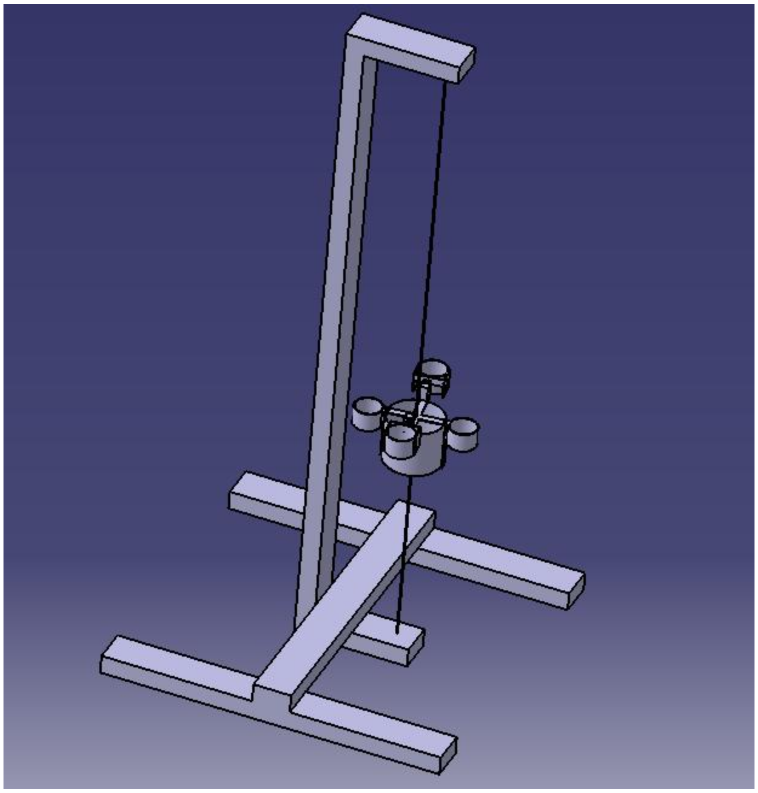

Figure 6: Experimental Environment with Aero-Copter

This experiment is also mainly used for safety purposes. There is a possibility that a ducted fan could malfunction and soar into someone nearby. With all possible scenarios in mind, the project is kept safely harnessed to the support at all time by a guide string. Once the first stage of the experiment is clear in which we test vertical flight, the second stage in which we test horizontal flight begins. The same support can still be used; the main difference is that the Aero-Copter will be attached to the string on the upper end like a tether ball. The section of the string that would be connected to the lower section of the support is cut loose. This will allow for the Aero-Copter to sustain itself in vertical flight while allowing horizontal flight.

Both stages will be used to clear the experimentation phase of the Aero-Copter. Once the experimentation phase is complete, the free flight test will begin. This will allow us to further study its control and vibration without being supported at any point. The quad-copter's main feature is its moving flaps design allowing improving yaw control. The device will be flown in an open environment to test all of its features. The weight of the materials and electronics used were carefully recorded to make sure that the thrust created would be enough to lift the quad-copter vertically.

The quad-copter is designed to weigh around 2000 grams at its max. Each of the fixed ducted fans which are located on the front and back of the quad-copter produce 2023 grams of thrust. The movable ducted fans produce 1100 grams of thrust apiece for stability and directional control.

The following table gives a brief description of each part that was used on this project.

Table 1: Brief Description of the system components (Ref. 3)

Name	Description
EDF89 with D3468kv Motor & Heat-sink	The EDF89 with d3468kv motor will be used to lift the aero-copter vertically into the air.
Hobby King SS Series 70A ESC	This part is used to control the current flow to the EDF89 with d3468kv motor. The more current that passes through the ESC the more power is generated to create lift.
Hobby King SS Series 50A ESC	The SS Series 50A ESC is used to control the current flow to the EDF68 with 2836kv motor. The more current that passes through the ESC the more power is generated to control the direction of flight while in air.
Turnigy 5000 mAh 4 cell Li-Po	The Turnigy 5000mAh 4 Cell Li-Po pack is what we are using to power our aero-copter and all the electronics on board.
EDF68 with 2836kv Motor & Heat-sink	The EDF68 with 2836kv is used just as the EDF89 with D3468kv to lift the aero-copter and primarily used to direct the aero-copter in any direction.
IMAX B8+ Charger/Discharger 1-8 Cells	The IMAX B8+ charger is used to charge the Turnigy 5000 4 Cell Li-Po, and also discharge the Li-Po when it’s time to recharge.
HobbyKing Multi-Rotor controller	The HobbyKing Multi-Rotor controller will be used to stabilize the aircraft during flight. To do this it takes the signal from the three on board gyros (roll, pitch and yaw) then passes the signal to the Atmega168PA IC microcontroller.

4. VERTICAL AND HORIZONTAL

The experimentation phase completes the necessary requisites to begin “Stage 1”. The body will be made of light materials that are used in remote control airplanes and helicopters. This allows for easier modification since some structural parts can be found in your everyday hobby store.

The design consists of two forms. The main difference between both forms is the position of the aspect of control. In the first stage, the focus is given to establish upwards motion (U1).

In the second stage, the focus is given on the directional control of the vehicle, particularly the yaw direction which is controlled by the flaps installed beneath the right and the left fans. The material used to construct the flaps are foam blocks and thin carbon fiber rods. This allows light weight and strong wings to be used. This will increase flight time using the normal amount of thrust normally used without wings. The wings will be attached to a gear mechanism that is light which will allow the ninety degree motion required for both wings.

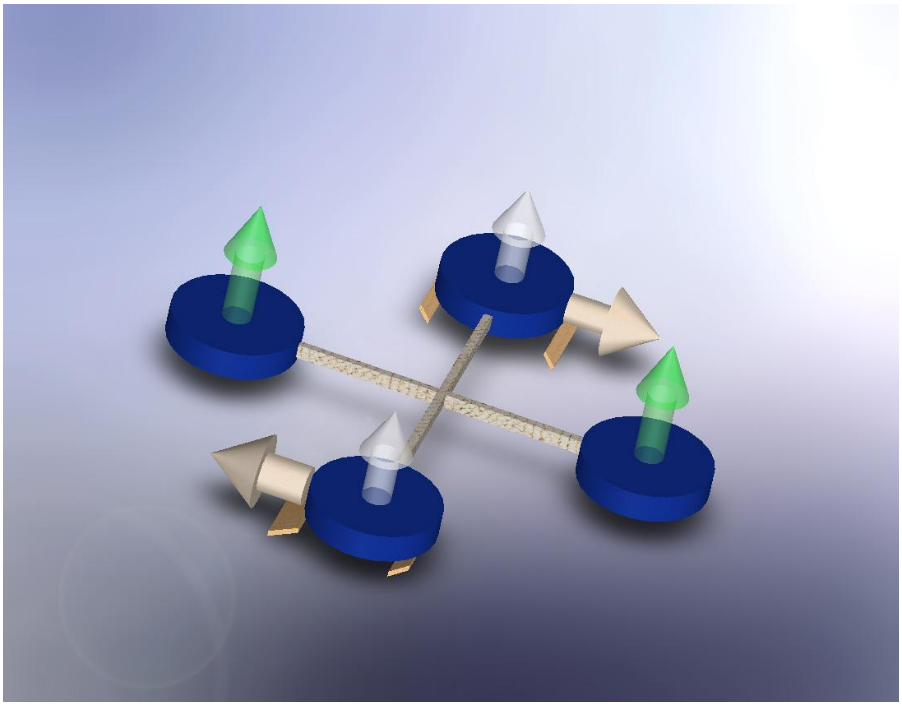

FIGURE 2: FLAPS mechanism FOR QUAD-COPTER YAW CONTROL

The flaps function will be added on the quad-copter once all the necessary stages are complete. The flaps will be detachable for easy installation and maintenance. The installation process will include four small bolts and four small nuts to secure the wing setup. Once one is spun, the other will spin the opposite direction. A servo will be attached to the flaps system in which it will move linkage system to control the flaps. There will be two settings that include fully open and fully closed. Since the main purpose of the flaps are to improve the control of the yaw control.

Both flaps are initially placed on a neutral position that will not interfere with the thrust the ducted fans will be producing. The wings will also have room to close and open to prevent any clashes of parts during operation. The flaps can be made of shaped foam or thin carbon rods that can be found in your local hobby store.

The servos are secured in place with a thin and lightweight aluminum piece of sheet metal. By creating a truss shape, this will give us the appropriate strength needed to maintain the servos in the proper position instead of bending inward due to the moment and torque produced by the fans. The ducted fans will be secured in place using the following device.

This device will secure the ducted fans and allow for rotation to balance and control direction.

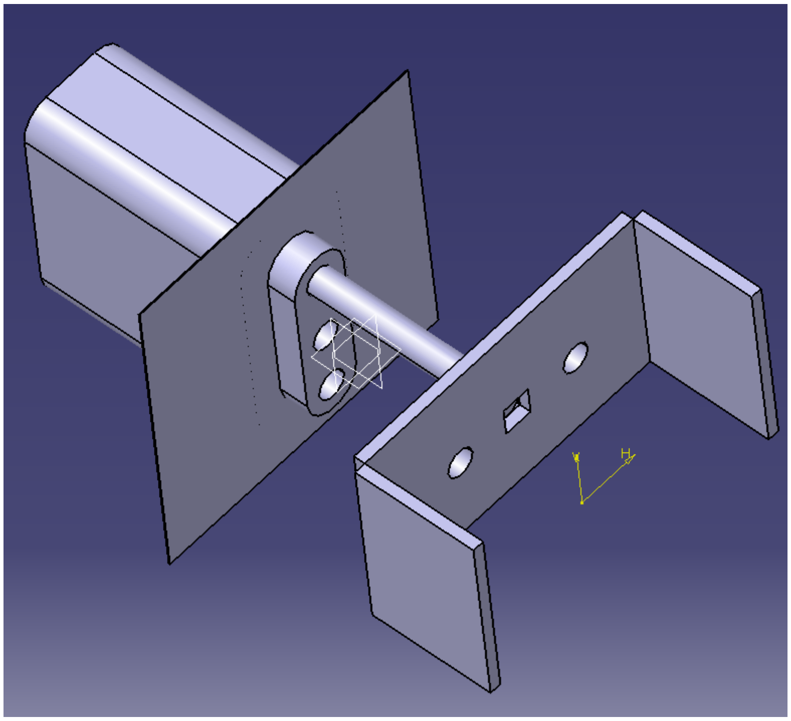

Figure 3: Bracket for ducted fans support

5. CENTER OF GRAVITY AND MOMENT BALANCE CALCULATIONS

A moment balance analysis (FAA 2007) is conducted pre experiment stage. In this analysis the weight and position of all the quadrotor components are identified and manipulated to obtain moment equilibrium.

In table 2, the weight of each component is listed in the first column, the distance from the center of gravity in the second column, and in the third column is the moment contribution of each component

TABLE 2: MOMENT ABOUT THE CENTER OF GRAVITY OF EACH COMPONENT

Item	Weight - grams	Distance inches	Moment
A ESC 70A	80	-1	-80
B ESC 70A	80	1	80
C Motor	295	6	1770
D Motor	295	-6	-1770
E Battery	552	0	0
F Receiver	10	1	10
G Servo	43.5	3	130.5

H Servo	43.5	-3	-130.5
I Bracket	8	-4	-32
J Bracket	8	4	32
K Gyro	15	-2	-30
L Putty	10	2	20
	Total Weight =1440		Total Moment=0
Datum is 0 at center of Cylinder frame			

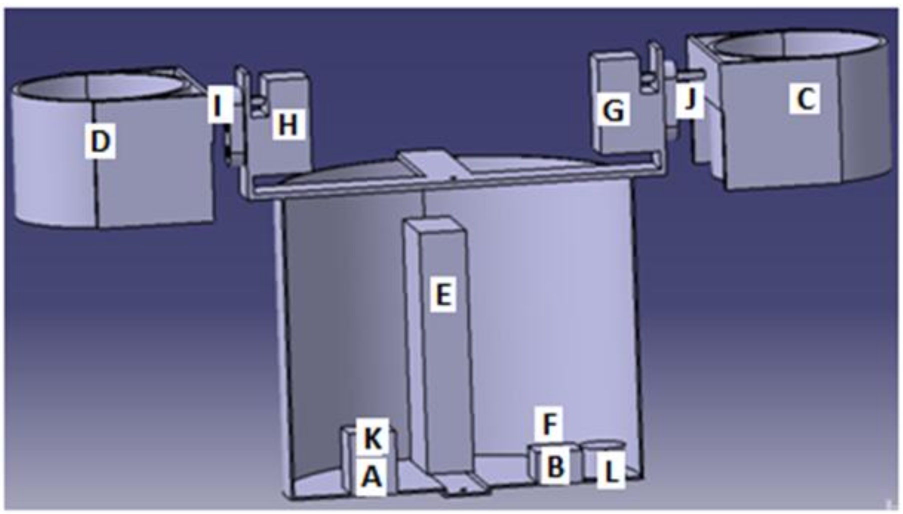

FIGURE 4: COMPONENTS USED TO CALCULATE THE MOMENT ABOUT THE CENTER OF GRAVITY

6. CONTROL

The control system is being designed to be responsive to quick maneuvers, meaning that it will incorporate three gyroscopes. All gyroscopes are connected to a microprocessor that is connected via PWM to the electronic speed controllers which are connected to the ducted fans. This allows the microprocessor to correct any imbalance while in flight and not interfere with the operator's control. The purpose of this gyroscope is to balance out the quadrotor in flight by sending signals from the gyroscopes to the microprocessor which measure pitch, yaw and roll. Since the microcontroller is also connected to the receiver, whenever the operator sends a command, the microprocessor processes the incoming signals and either increases or decreases power to the fans. The name of the chip used on this gyroscope system is Atmega 168PA.

7. CONCLUSION

The quad-copter will provide vital information to the operator which can be relayed to military and police officials. This could possibly save lives or prevent harm to someone. The normal price of a military grade spy-robot is normally tens of thousands of dollars apiece. This project is being designed to deliver a workable robot at a relatively cheap price. It is also being designed to be operated easily similar to video games since most police officers and military personnel are young adults. Modification on the quadrotor typical control would provide a great benefit of better maneuverability and faster response. However, weight proved to be a major constraint for any addition to the system. Therefore weight optimization is greatly needed to obtain the desired objectives.

8. REFERENCES

[1] FAA Aircraft Weight and Balance Handbook, 2007.
[2] "Modeling, Identification and Control of a Quadrotor Helicopter", T. Bresciani, Lund University, 2008.
[3] http://www.hobbyking.com

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