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Stabilizing the Bi-copter and Controlling it using Gesture Technology

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ABSTRACT

This paper focused on developing a remotely operated and stabilized Bi-copter which is controlled through gesture. Communication between gesture and bi-copter is done by using wireless communication system. Propellers are rotated using brushless motors which in turn connected to the servo motors. The signals from the transmitter are received by the Multi Wii flight controller and processed. The output from Multi Wii flight controller is given to brushless motors and servo motors. At the transmitter side, gesture glove is used. Flex sensors and accelerometer are assembled using Arduino board. The output signals from Arduino are processed using a micro controller and transmitted. The experiment shows that bi-copter can hover with maintaining it balancing and stability. Maximum operated time of bi-copter is six minutes using 850mAh Lipo battery and operating time can be increased by using larger battery capacity.

Keywords: Bi-copter, Gesture, Multiwii,Flex Sensor, Accelerometer.

1. INTRODUCTION

Bicopters generally use a pair of identical fixed pitched propellers; one clockwise (CW) and one counter-clockwise (CCW). These use independent variation of the speed of each rotor to achieve control. By changing the speed of each rotor it is possible to specifically generate a desired total thrust, to locate for the centre of thrust both laterally and longitudinally and to create a desired total torque, or turning force.

Since the beginning of the 20th century, research efforts have continually pushed the limits to create effective flying machines that offer many capabilities. The tilt rotor aircraft configuration [1] has the potential to revolutionize air transportation by providing an economical combination of vertical take-off and landing capability with efficient, high-speed cruise flight. This makes advanced technology helicopters and civil tilt rotors extremely attractive as corporate/executive transport aircraft and opens the opportunity for designing and commercializing tilt rotor UAVs. Indeed, The Bell Eagle Eye UAV [2] which is based on tilt rotor technology has a large success in the civil and military domains. However, this design brings its own problems, since the degradation in stability is usually observed in high speed forward flight (airplane mode) [3]. Moreover, the involved equations of motion are highly coupled and nonlinear. Gary Gress [4] discovered that the tilt rotor-based mechanism can provide hover stability of a small UAV by using the gyroscopic nature of two tilting rotors. In this paper, we propose an alternative configuration system, where the centre of mass of the UAV is located below the tilting axes, resulting in a significant pitching moment. This configuration is adapted for the miniaturization of the UAV, and it results in a simple mechanical realization. Unlike the full-scale tilt rotors, the propellers can tilt in two directions providing also stability and control in hover. By using this original structure inspired by the ingenious mechanism of Gary Gress [4], required

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lift and control moments are obtained. Therefore, no helicopter type cyclic controls are needed, nor are any other reactive devices. The roll movement is obtained by differential propeller speeds. The yaw angle can be controlled through differential longitudinal tilting. The gyroscopic moments issued from opposed lateral tilting, added to the torque generated by the collective longitudinal tilting allow obtaining a significant pitching moment. In addition, our main contribution is to provide a complete model of the bi-copter and to present control stabilization. This control strategy turned out to be methodologically simple for the proposed system. Hovering vehicles levitated by vectored thrust systems frequently have their centre of mass located above the point of application of the thrust vector, resulting in unstable or neutrally stable open loop attitude dynamics[5]. One type of control device which does not rely on moment arms is the simple gyroscope. It, or rather pairs of them, directly generate the large moments required to change the attitudes of satellites and space stations within short time frames [6]. Rather than adding more rotors, other approaches involve a variety of actuation devices. As usual with aircraft design, key aspects that must be considered are its size and weight. A very effective approach has been shown by Cutler et al [9] using propellers with variable pitch. In their approach, while the authors manage to keep the weight down, they increase the bandwidth of its actuators by almost an order of magnitude. However, the reliability is still an issue, because a failure of an actuator might result in instability. In this paper, the proposed strategy uses dual axis tilting propellers [7], but an approach for controlling the attitude of statically unstable thrust-levitated vehicles in hover or slow translation is explained by the authors [8] and describe such a mechanism in Section III and IV, we present the model of the bi-copter. Finally, we address a strategy for stabilization. Latest technologies like hover bike and stabilization using wall trace locomotion feasibility of bi-copter are included in the reference section [10][11].

2. BLOCK DIAGRAM

The signals are transmitted through the transmitter which is connected to the sensor system and the received signals from the receiver are processed through the Multi Wii controller for which servos and motors are connected. The whole system setup is explained in the block diagram, as shown in Fig.1 and the list of the onboard components is given in Table 1.

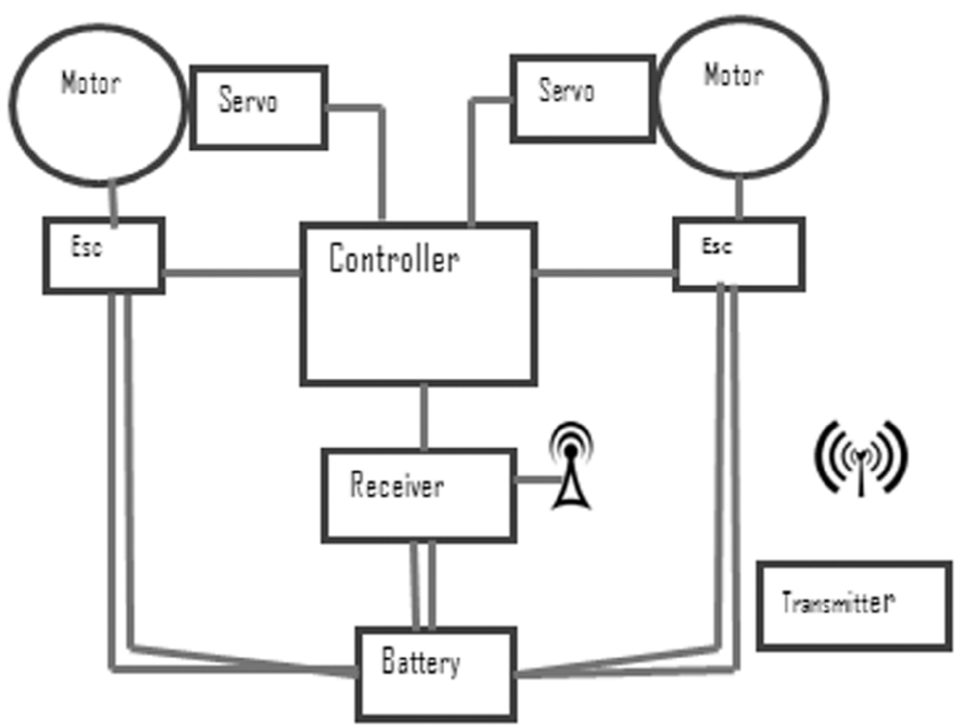

Figure 1: Block diagram of Copter

Table 1
List of Components on board

S.no	*Components*	*Specifications*	*Quantity*
1	Brushless DC Motors	2200KV	2
2	Metal Gear Micro Servo	5V	2
3	ESC	20A	2
4	Multi Wii Lite Flight Controller	2.0	1
5	Propellers	06 × 4.5	2
6	Battery	Lipo 3s	1
7	Receiver	6 Channel	1

3. DESIGN AND IMPLEMENTATION OF COPTER

A Bi-copter has 2 propellers that spin counter-clockwise. By making the propeller pairs spin in each direction, but also having opposite tilting, all of them will provide lifting thrust without spinning in the same direction as. Each rotor produces both a thrust and torque about its centre of rotation, as well as a drag force opposite to the vehicle's direction of flight. Shown in Fig. 2. If all rotors are spinning at the same angular velocity, with rotor one rotating clockwise and rotor two counter-clockwise, the net aerodynamic torque, and hence the angular acceleration about the yaw axis is exactly zero[12], which implies that the yaw stabilizing rotor of conventional helicopters is not needed.

Yaw is induced by mismatching the balance in aerodynamic torques.

3.1. Frame

We used glass fibre material to build the frame of the copter as it has more tensile strength than most metals and lighter than the most materials used to build frame except carbon fibre which is more powerful than

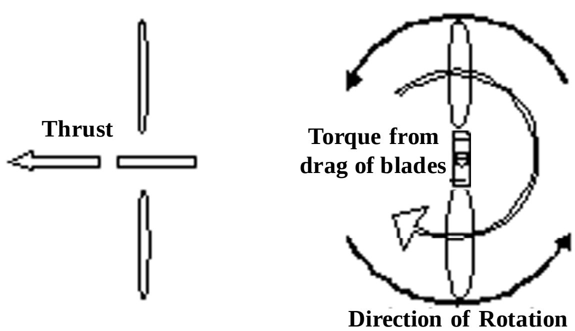

Figure 2: Forces on Propeller

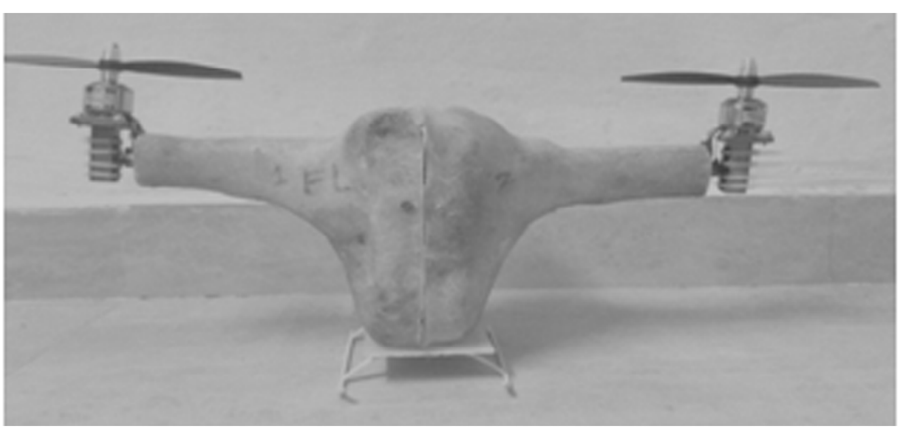

Figure 3: Our prototype

fibre glass but carbon fibre is conductive material where as fibre glass is an insulator. We moulded the glass fibre into the pre designed parts and the parts are assembled together as in Fig. 3.

3.2. Stabilizing the copter

- We have taken advantage of the gravity by adding counter weight at the bottom of the copter. The weight counter acts the upward thrust created by the propellers which lets the copter to stabilize by compensating both forces.
- As the major con of the Bi-copter is the “Pendulum Effect”, we extended the length of frame of the copter so that the angular momentum is very less around the horizontal axis of the copter as in Fig. 4.
- In our prototype servos are arranged to the end of the the horizontal bar which is connected directly to the brushless motors with the help of tilt mechanism that of different from the present system in use as in Fig. 6.

It is estimated that the mechanical energy from the servo to the motor is reduced as we know the increase in length of the shaft connected to the gear decreases the amount of power transmitted to the end of the shaft as in Fig. 5.

3.3. Connections

Multi Wii is connected to Lipo Battery. Servos and ESC are connected to Multi Wii through D ports. Brush less motors are connected to D9, D10 ports and servo motors are connected to D5 and D6 ports. The power

Figure 4: Showing Length of the frame

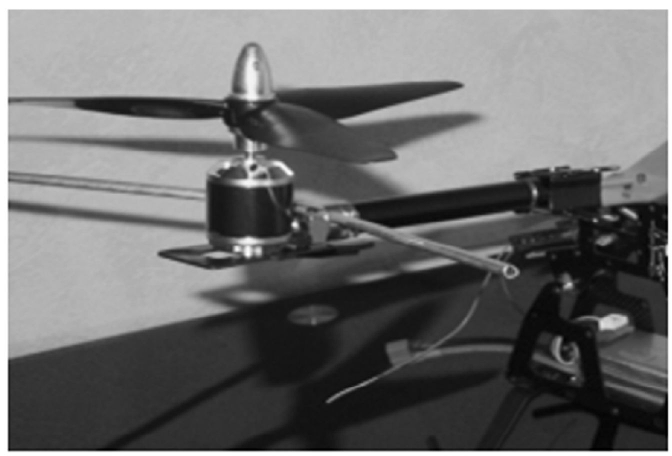

Figure 5: Existing mechanism

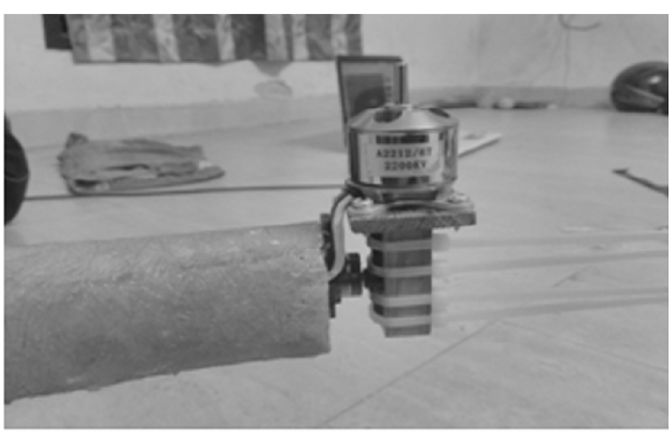

Figure 6: Our mechanism

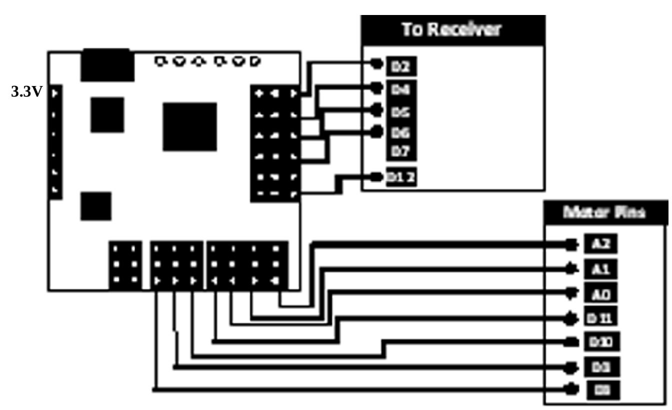

Figure 7: Connection diagram of Multi Wii flight controller

supply for ESC to drive motors is provided by the Lipo battery. Pins at another end of the ESC are connected to brushless motors and after configuring transmitter and receiver, the channels from Multi Wii are connected to the receiver

The power supply is given to the receiver and each channel of receiver is allocated to each parameter i.e., throttle, pitch, roll, yaw, aux1, aux2 where aux1 and aux2 are optional as in Fig. 7.

4. KINEMATICS OF COPTER

In order to properly model the dynamics of the system, we need an understanding of the physical properties that govern it as in Fig. 8. We will begin with a description of the motors being used for our bicopter, and then use energy considerations to derive the forces and thrusts that these motors produce on the entire bicopter. Both motors on the bicopter are identical, so we can analyze a single one without loss of generality. Note that adjacent propellers, however, are oriented opposite each other; if a propeller is spinning "clockwise", then the adjacent one will be spinning "counter-clockwise", so that torques are balanced if all propellers are spinning at the same rate.

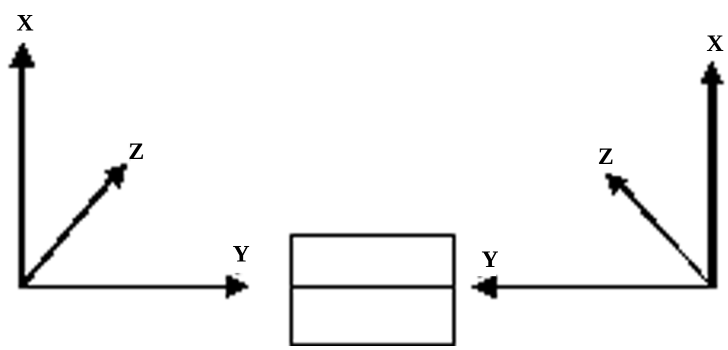

Figure 8: Axis Diagram

4.1. Motors

Brushless motors are used for all bicopter applications. For our electric motors, the torque produced is given by

$$\tau = K_t\left(I - Io\right) \tag{1}$$

Where τ is the motor torque, I is the input current, I0 is the current when there is no load on the motor, and Kt is the torque proportionality constant. The voltage across the motor is the sum of the back-EMF and some resistive loss:

$$V = VR_m + K_v\omega \tag{2}$$

where V is the voltage drop across the motor, Rm is the motor resistance, ω is the angular velocity of the motor, and Kv is a proportionality constant (indicating back-EMF generated per RPM). We can use this description of our motor to calculate the power it consumes. The power is

$$P = IV = \frac{\left(\tau + K_t I_o\right)\left(K_t I_o R_m + \tau R_m + K_t K_\vartheta \omega\right)}{K_t^2} \tag{3}$$

For the purposes of our simple model, we will assume a negligible motor resistance. Then, the power becomes proportional to the angular velocity:

$$P \approx \frac{\left(\tau + K_t I_o\right) K_\vartheta \omega}{K_t} \tag{4}$$

Further simplifying our model, we assume that $K_t I_0 >> \tau$. This is not altogether unreason- able, since I_0 is the current when there is no load, and is thus rather small. In practice, this approximation holds well enough. Thus, we obtain our final, simplified equation for power:

$$P \approx \frac{K_v}{K_t} \tau\omega \tag{5}$$

4.2. Forces

The power is used to keep the bicopter aloft. By conservation of energy, we know that the energy the motor expends in a given time period is equal to the force generated on the propeller times the distance that the air it displaces moves.

$$P.dt = F.dx \tag{6}$$

Equivalently, the power is equal to the thrust times the air velocity.

$$P = F\frac{dx}{dt} \tag{7}$$

$$P = T\vartheta_h \tag{8}$$

We assume vehicle speeds are low, so ϑ_h is the air velocity when hovering. We also assume that the free stream velocity, ϑ_∞, is zero (the air in the surrounding environment is stationary relative to the bicopter). Momentum theory gives us the equation for hover velocity as a function of thrust,

$$\vartheta_h = \sqrt{\frac{T}{2\rho A}} \tag{9}$$

Where ρ is the density of the surrounding air and A is the area swept out by the rotor.

Note that in the general case, $\tau = \vec{r} \times \vec{F}$; in this case, the torque is proportional to the thrust T by some constant ratio K_τ determined by the blade configuration and parameters. Solving for the thrust magnitude T, we obtain that thrust is proportional to the square of angular velocity of the motor:

$$T = K\omega^2 \tag{10}$$

Where k is some appropriately dimensioned constant. Summing over all the motors, we find that the total thrust on the bicopter (in the body frame) is given by

$$T_{Bi} = \sum_{i=1}^{2} T_i = K\begin{bmatrix} 0 \\ 0 \\ \sum w_i^2 \end{bmatrix} \tag{11}$$

4.3. Torques

Now that we have computed the forces on the bicopter, we would also like to compute the torques. Each rotor contributes some torque about the body z-axis. This torque is the torque required to keep the propeller spinning and providing thrust; it creates the instantaneous angular acceleration and overcomes the frictional drag forces. The drag equation from fluid dynamics gives us the frictional force:

$$F_D = \frac{1}{2}\rho C_D A \vartheta^2 \tag{12}$$

Where ρ is the surrounding fluid density, A is the reference area (propeller cross-section, not area swept out by the propeller), and C_D is a dimensionless constant. This, while only accurate in some in some cases, is good enough for our purposes. This implies that the torque due to drag is given by

$$\tau_D = \frac{1}{2} R\rho C_D A(\omega R)^2 \tag{13}$$

$$\tau_D = b\omega^2 \tag{14}$$

Where ω is the angular velocity of the propeller, R is the radius of the propeller, and b is some appropriately dimensioned constant. Note that we've assumed that all the force is applied at the tip of the propeller, which is certainly inaccurate; however, the only result that matters for our purposes is that the drag torque is proportional to the square of the angular velocity. We can then write the complete torque about the z axis for the motor:

$$\tau_z = b\omega^2 + I_M \dot{\omega} \tag{15}$$

where I_M is the moment of inertia about the motor z axis, $\dot{\omega}$ is the angular acceleration of the propeller, and b is our drag coefficient.

4.4. Rotational Force

In the inertial frame, the acceleration of the bicopter is due to thrust, gravity, and linear friction. We can obtain the thrust vector in the inertial frame by using our rotation matrix R to map the thrust vector from the body frame to the inertial frame. We derive the rotational equations of motion from Euler's equations for rigid body dynamics.

$$\dot{\omega} = \begin{bmatrix} \dot{\omega}_x \\ \dot{\omega}_y \\ \dot{\omega}_z \end{bmatrix} = I^{-1}\left(\tau - \omega \times (I\omega)\right) \tag{16}$$

We can model our bicopter as two thin uniform rods crossed at the origin with a point mass (motor) at the end of each. With this in mind, it's clear that the symmetries result in a diagonal inertia matrix of the form

$$I = \begin{bmatrix} I_{xx} & 0 & 0 \\ 0 & I_{yy} & 0 \\ 0 & 0 & I_{zz} \end{bmatrix} \tag{17}$$

Therefore, we obtain our final result for the body frame rotational equations of motion.

$$\dot{\omega} = \begin{bmatrix} \tau_\theta I_{xx}^{-1} \\ \tau_\varphi I_{yy}^{-1} \\ \tau_\varnothing I_{zz}^{-1} \end{bmatrix} - \begin{bmatrix} \frac{I_{yy} - I_{zz}}{I_{xx}} \omega_y \omega_z \\ \frac{I_{zz} - I_{xx}}{I_{yy}} \omega_x \omega_z \\ \frac{I_{xx} - I_{yy}}{I_{zz}} \omega_x \omega_y \end{bmatrix} \tag{18}$$

5. SENSORS

5.1. MEMS Gyroscope

A MEMS Gyroscope can be used to measure rotational motion. It is not affected by translational motion. A MEMS gyroscope uses the Coriolis Effect, as shown in Figure 2.1, to measure the angular rate [13]. Consider a mass (m) moving in direction $x\rightarrow$ with angular rotation velocity Ω_z applied as in Fig. 9. The mass will experience a force in the direction of the arrow as a result of the Coriolis force.

The resulting displacement caused by the Coriolis force is then found using a capacitive sensing structure.

A tuning fork configuration is common to most available MEMS gyroscopes. The two masses shown in Fig.10 oscillate and move constantly in opposite directions. Under the influence of an applied angular velocity, the Coriolis force acting on each mass will also act in opposite directions, resulting in a change in capacitance. This capacitance difference is proportional to the angular velocity &!z. This capacitance is then converted into either a output voltage for analog gyroscopes or a binary number for digital gyroscopes.

Under the influence of a linear acceleration, the two masses move in the same direction, resulting in no capacitance difference. As there is no output under this condition it shows that the MEMS gyroscope is not sensitive to linear effects or vibration.

MEMS = Micro-Electro-Mechanical Systems

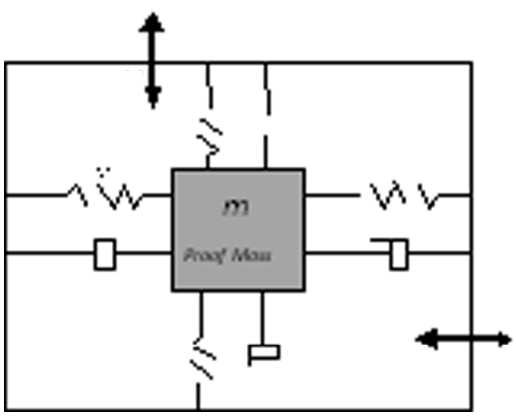

Figure 9: MEMS Gyroscope

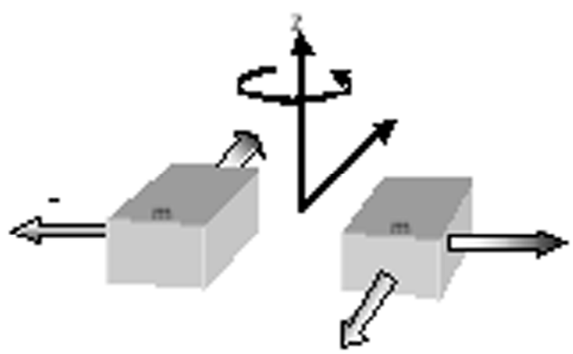

Figure 10: Coriolis Force

6. DESIGN AND IMPLEMENTATION OF GESTURE

A combination of accelerometer and Flex Sensors are replaced with the transmitter (controller) to control the copter. The flex sensors and accelerometer are connected to Arduino board analog pins and is programmed according to the required output which is obtained by the resistance which varies as the flex sensors are bent in certain angles. The list of the components used is given in the Table 2.

Table 2
List of components used for gesture glove.

S. no	Component	Quantity
1	Flex Sensor	4
2	Accelerometer	1
3	Arduino MEGA	1
4	Power Supply	-
5	Glove	1

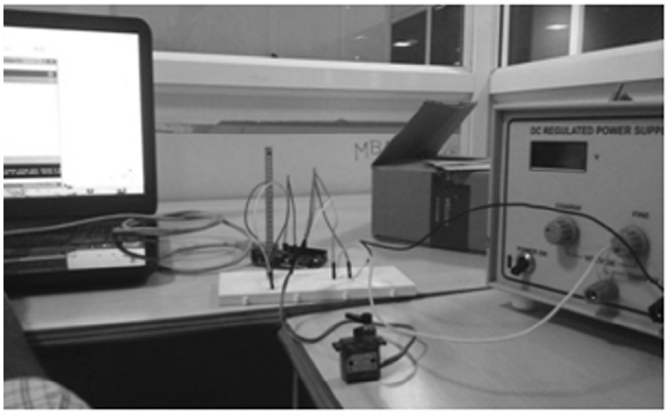

Figure 11: Controlling servo with flex sensor

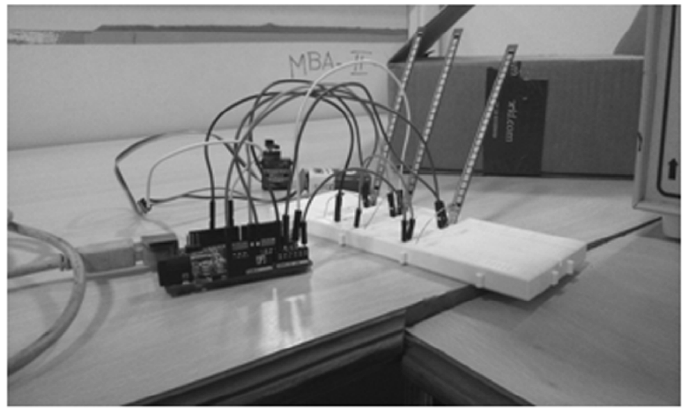

Figure 12: Testing of flex sensors

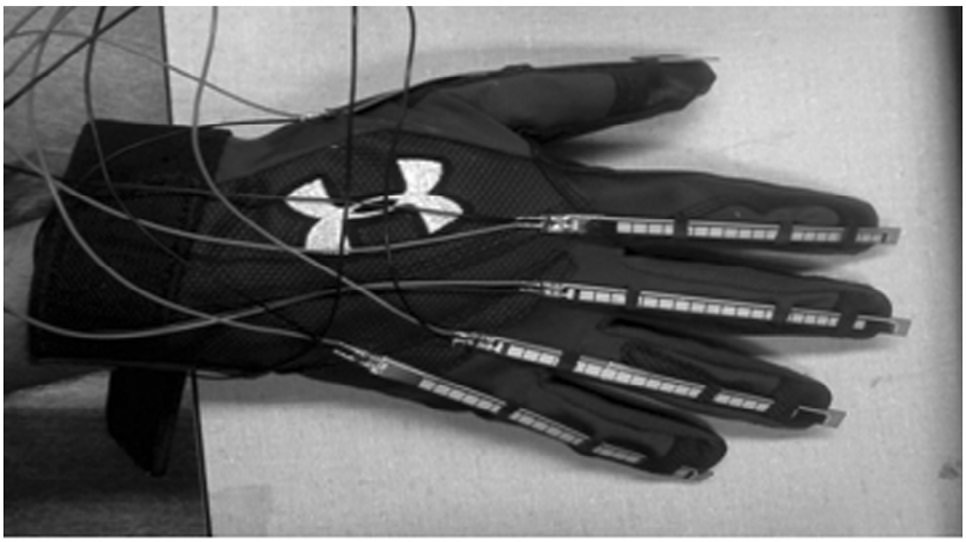

Figure 13: Gesture Glove Connections

We connected all the flex sensors and accelerometer to a hand glove which is easy to operate but our main challenge was to control the copter as efficiently as the 6 channel controller which we use for general purpose and tested shown in Fig. 11, Fig. 12, and Fig. 13.

So, we combined the gesture glove with a 6 channel transmitter circuit where all the parameters are defined and can be controlled by varying the bend angles of flex sensors and the movements of the accelerometer with respect to the three axis coordinate system.

7. SOFTWARE

The Multi Wii is programmed by Arduino software. All the components given to Multi Wii are defined properly. The parameters for each component are given accurately.

To maintain the stability of copter PID are important. We can check the current PID values of the copter using Multi Wii configuration tools. We can change PID values from there. Multi Wii configuration programme can also run in Multi Wii flight controller.

8. SIMULATION

We simulated the conditions we created using MATLAB and the results were promising as shown in Fig. 14 and Fig. 15. Here are simulation plots: dt = 0.0001, first 1300 points. This result obtained for constant 5

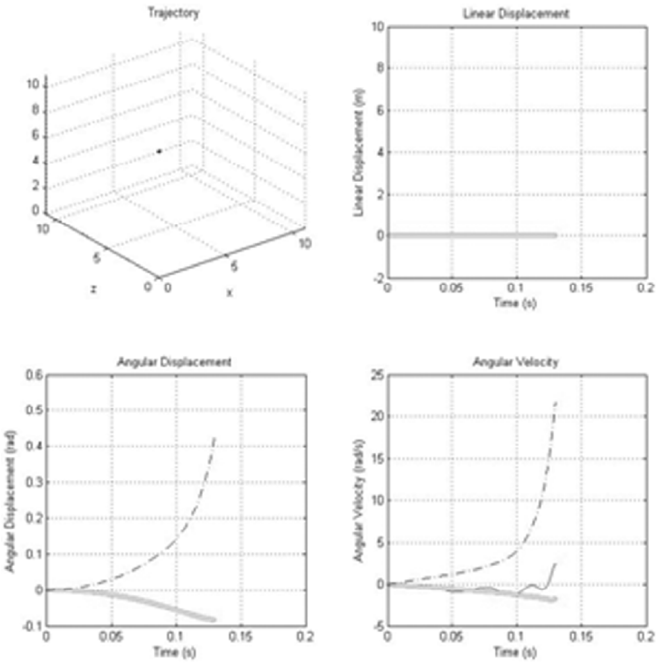

Figure 14: Simulation of bi-copter

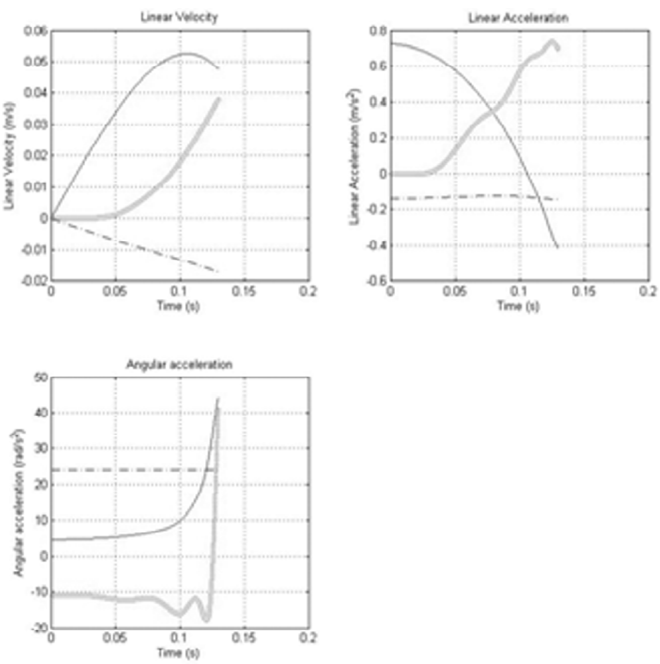

Figure 15: Simulation of bi-copter

degree tilting angle for one of the motors and equal motor speeds. Angular acceleration just grows to the infinity in less than 1 second.

9. CONCLUSION

The proposed model in this paper gives promising results when simulated using MATLAB and tested on prototypes. The stability of the copter appears to be effective and practical.

The proposed controlling system using a combination of long range transmitter and gesture glove is proved to be efficient based on the tests conducted by our team. However, in order to validate the proposed strategy more rigorously, further tests and analysis of the performance based on collected data are required.

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