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Design and Development of Remote Controlled Autonomous Synchronic Hexaroter Aerial (ASHA) Robot

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Abstract

Autonomous Aerial Robots have gained their popularity due to economic production, flexibility of launch and variety of applications. In this paper a new approach for development of Autonomous Synchronic Hexaroter Aerial (ASHA) robot is presented. The robot uses six powerful brushless DC motors, high impact resin polymer propeller, electronic speed controller (ESC), a flight controller and a RC controller. The new design is verified on the grounds of structural stability, dynamic analysis, directional flexibility and active controlling which gives a stable flight for longer duration (approximately 25 minutes), hovering effect and improved load carrying capacity up to 3.4kg which broadened its application.

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Keywords: Aerial Robot, Hexacopter, Static and Dynamic Analysis, Payload, Flight Time.

1. Introduction

Aerial robotics is a part of mobile robotics and many researchers have focused on Multicopter like quad-copter [1, 2], hexa-copter [3, 4], octa-copter etc. It has become a popular research area owing to ease of development, adjustment and use in various fields such as military, security and surveillance systems. These systems are often fondly called "eye of the sky". These multi-copters have vertical take-off and landing capability similar to a helicopter in hovering but are relatively easier to control and manufacture because of mechanical simplicity due to fixed pitch propellers and symmetrical design. The simplicity of multi-copters makes them easier to manufacture and

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economic too. The multi-copters use many modern MEMS sensors like gyroscope, accelerometer, magnetometer, barometer etc. and some powerful microcontroller which control brushless motors with the help of electronic speed controllers. Some multi-copters with light load carrying capabilities are commercially available for hobbyists and researchers, for example Parrot AR Drone, Mikrokopter, Draganflayer etc.

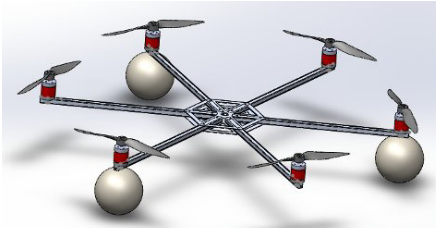

Figure 1. ASHA robot CAD model

Figure 2. Prototype of ASHA robot

This research is mainly focused on ASHA (Figure 1, Figure 2) robot's payload and flight time. ASHA robot is armed with six brushless DC (BLDC) motors, propellers and controllers. The axes of propellers are perpendicular with the propellers fronting upwards. The motor-propeller systems are located on each corner of the hexagon with alternate motors rotating in opposite directions. The control unit is equipped with 3-axis gyroscope and accelerometer which deliver variance feedback to ASHA robot and aid in effective movement. ASHA robot is powered by Li-ion polymer batteries. It can be controlled remotely by the user.

2. Methodology and Designing of ASHA robot

The structure frame of ASHA is made from Aluminium pipes with square cross section and hexagonal Aluminium plates with six internal triangular sections. All the electronic components like controllers, RC receiver, battery etc. are placed at central hexagonal portion. The step by step process of mechanical design, electronic assembly and final algorithm development of the ASHA robot are as follows.

2.1. ASHA Robot Frame Designing and Analysis

The aluminum used for frame of ASHA robot is sufficiently strong and rigid for the purpose and the design of the frame further adds to rigidity and strength. Static and dynamic analysis of the model has been performed using SolidWorks©.

2.1.1. Static Analysis of Aluminum Frame

The hexagonal shaped ASHA robot has six arms of equal length are attached and at the center one hexagonal shaped base as shown in Figure 3.

For simulation on SolidWorks©, the following material properties and structure dimensions are used

- Structure properties at 298k temperature:
  Material used = Aluminium alloy (1060)
  Total mass = 2x0.03 (hexagonal base) + 6x0.02 (arm) =0.18kg
  Volume = 1.06e-5 m^3
  Density = 2705 kg/m^3
- Each motor's thrust using 11"x6" propeller = 1.2 kg [6]
- Weight of each motor = 75 gm
- Length of each arm =28.40cm
- Edge length of centre hexagon = 8.10 cm

To model the system, in SolidWorks©, the central part of hexagonal structure was fixed and a load of 1.125kg (1.2kg from propeller trust - 0.075kg motor weight) is applied at the end of each arm. Load distributions are shown in Figure 4.

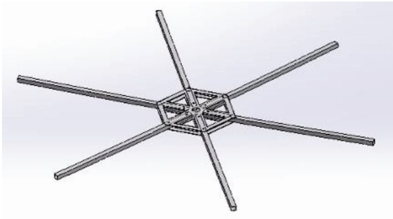

Figure 3. ASHA robot aluminium frame

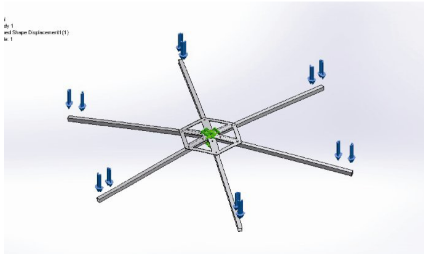

Figure 4. Forces on the structure

The maximum strain, displacement and von Mises stress at given conditions were as shown in Figure 5 to Figure 7:

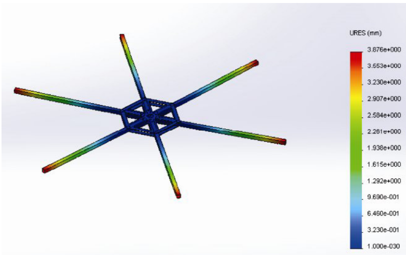

Figure 5. Displacement analysis of ASHA robot structure.

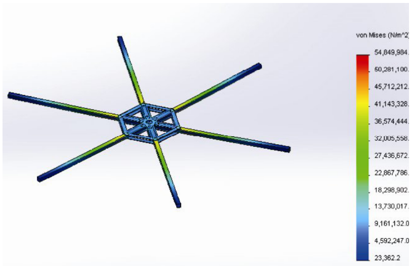

Figure 6. Stress analysis of ASHA robot structure.

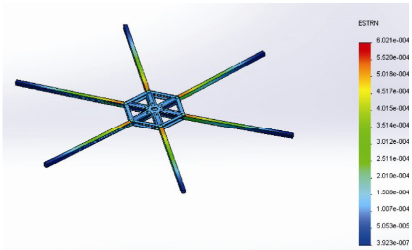

Figure 7. Strain analysis of ASHA robot structure.

The following observations were made from this analysis:

- Maximum displacement of 3.88mm was observed (Figure 5) at the end of arms which is proportionally very small as compared to total length of the structure.
- Maximum von Mises stress was observed as 54.85Mpa (Figure 6) at the location on the arm which is attached to the central hexagonal plate, which is low as compared to the strength of material used. Thus base structure is safe.
- Maximum strain is also observed as 0.60 (Figure 7) at the point where arms are connected to the central hexagonal plate.

2.1.2. Dynamic Analysis of ASHA Robot

To set up a dynamic model and to estimate the acceleration of the ASHA robot all the forces [5] acting on the ASHA robot need to be considered. The different forces are explained below:

- *Mass and Acceleration:*

$$F_{\text{int}} = m_{total} \cdot \begin{bmatrix} \ddot{x} \\ \ddot{y} \\ \ddot{z} \end{bmatrix} \quad (1)$$

- *Gravity:* Gravity is pulling the ASHA robot in positive Z-direction i.e., downwards in the navigation frame. R_{NB} is normal reaction force due to gravity. The gravity force on the body frame in Z-direction can be represented by:

$$F_{gb} = m_{total}.R_{NB}.\begin{bmatrix} 0 \\ 0 \\ g \end{bmatrix} \tag{2}$$

- *Propeller Thrust:* The thrust from the propellers is always assumed to be in positive Z-direction in the body frame hence there will be no thrust in X- and Y-direction. $F_{M1}, F_{M2}, F_{M3}, F_{M4}, F_{M5}, F_{M6}$ are downward forces from individual motors.

$$F_{thrust} = \begin{bmatrix} 0 \\ 0 \\ F_{M1} + F_{M2} + F_{M3} + F_{M4} + F_{M5} + F_{M6} \end{bmatrix} \tag{3}$$

- *Drag Force:* As an object moves in the air, it will experience the drag force same as an object moving in water experiences which will be opposing the motion of the object. This drag force is generated by the friction in the air and it has the same properties of a damping device in a system.

  The drag force is determined by the formula [5]:

$$F_{drag} = ½ .ρ.V^2.S_w.C_D \tag{4}$$

Where: ρ: Air density
V: Velocity
S_W: Reference Area
C_D: Drag Coefficient

- *Disturbance:* Other forces such as Coriolis force from the earth, wind and Euler forces are considered as disturbances and are collectively summarized as F_{dist}.

Total Force: Total force experienced by ASHA robot is described as:

$$F_{total} = F_{gravity} - F_{thrust} + F_{dist} + F_{drag} \tag{5}$$

And total acceleration which provides feedback to microcontroller of flight controller for stable flight.

$$m_{total}.\ddot{r} = F_{gravity} - F_{thrust} + F_{dist} + F_{drag} \tag{6}$$

$$\begin{bmatrix} \ddot{x} \\ \ddot{y} \\ \ddot{z} \end{bmatrix} = \ddot{r} = \frac{1}{m_{tot}}(F_{gravity} - F_{thrust} + F_{dist} + F_{drag}) \tag{7}$$

In the dynamic analysis the total force required to lift the robot from ground is a function of force due to gravity, force due to motor thrust, the opposing drag force of air and the various disturbing forces.

2.2. Electronic System in ASHA Robot

Electronics of any robot are very important for stable flight of the robot. In ASHA robot different electronic devices available in open market source (with known specifications [6]) are used. The electronic components are chosen based on the desired load and flight time requirements and mutual compatibility. The main concentration was towards increasing flight time and payload, accordingly the motor-propeller pair capable of delivering the desired thrust while consuming less power was chosen [6]. Other major parts have been selected as follows:

- Brushless DC Motor: Six 890kv of BLDC motors are mounted on ASHA robot. And weight of each motor is 75gm. Thrust of each motor with 11”x6” propeller is 1.2kg. This motor uses electrical commutation system.
- Propeller: 11”x6” propellers made from high impact resin polymer are used. The chosen propellers are aerodynamically designed to have very low noise.
- Electronic speed controller (ESC): ESC is an electrical circuit which is used to vary speed of BLDC motor. The speed that is produced depends on the received frequency from controller board. The burst current of each ESC is 30amp with 25gm of weight.
- Flight controller: KK2.0 multicopter controller board which has an integrated gyro and accelerometer has been used. Atmel ATmega324u 32-bit microcontroller is used in this board. Total weight of this board is 5.1g. The integrated accelerometer and gyroscopic sensors give feedback to the controller in order to make flight more stable.
- Remote controller: The Hobbykings T6A 2.4 GHz radio control systems is an entry level transmitter offering the reliability of 2.4 GHz signal technology and a 6 channels receiver with a range of 100m. This transmitter requires a PC to modify any of the channel variables including mixing and servo reversing.
- Battery: For this research, 4S2P high discharge and light weighted lithium-ion polymer batteries with 13.2 and 8400mAh of capacity were used. The maximum discharge capacity of this battery is 30C.

2.3. Final Assembly

The components for robot frame and the electronic components were purchased from open market as per the above mentioned specifications and assembled into the prototype.

3. Analysis of Final Assembly

The ASHA robot has six motors with alternate motors rotating in different directions, i.e. one motor in clockwise direction and adjoining anti-clockwise direction, as shown in Figure 8. This is required for the effective net angular acceleration to be zero for the configuration. If the effective angular acceleration is not zero then it will lead to spinning of the ASHA robot. Take for instance if all the motors are rotating in clockwise direction then the ASHA robot will be rotating in clockwise direction and similarly for anti-clockwise direction. Same thing can be observed if the all the three clockwise motors are halted then because of effective angular acceleration due to other three anti-clockwise motors the ASHA robot will be spinning in anti-clockwise direction.

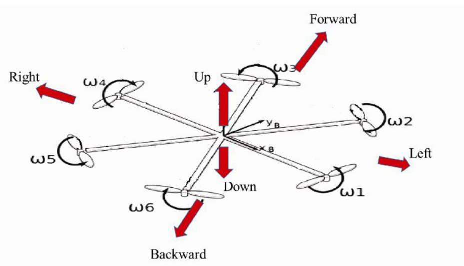

Figure 8(a). Direction and rotation of ASHA robot

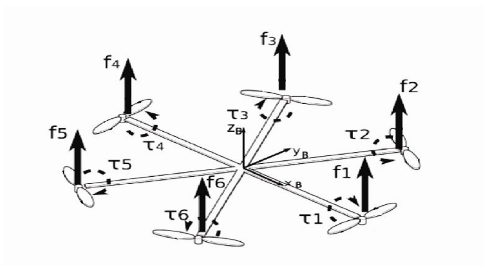

Figure 8(b). Forces of ASHA robot

Where:
ω: It shows the positive direction of rotation of the motor.
f: It shows the thrust of a motor with direction.
τ: It shows the torque with direction.

Robot control logic and its direction controls are shown in Table1. Refer to Figure 8(a) for notation.

Table 1.Direction controlling of ASHA Robot

Direction	Motors speed increase	Motor speed decrease
Up	ω1, ω2, ω3, ω4, ω5, ω6	-
Down	-	ω1, ω2, ω3, ω4, ω5, ω6
Left	ω3, ω4, ω5, ω6	ω1, ω2
Right	ω1, ω2, ω3, ω6	ω4, ω5
Forward	ω1, ω5, ω6	ω2, ω3, ω4
Backward	ω2, ω3, ω4	ω1, ω5, ω6

3.1. Total Weight and Thrust

Total weight of the ASHA robot is combination of mechanical and electronic assemblies with following quantities (Table 2):

Table 2.ASHA robot assemblies

Component	Weight (gm)	Quantity	Total weight (gm)
BLDC Motor	75	6	450
Carbon fibre propeller	16.25	6	97.5
ESC	32	6	192
Flight controller	20	1	20
RF receiver	20	1	20
Li-poly battery	1045	2	2090
Structure	700	1	700
Total	-	23	3569.5

Thrust from single 890kv BLDC motor with 11’x6” propeller is 1.2 kg, so total thrust from six motors is 1.2x6 = 7.2 kg.

Total payload provided by ASHA robot is subtraction of total thrust provided by motors and total weight of ASHA robot.

Payload = Total Thrust – ASHA robot Weight
Payload = 7.2 – 3.5695 = 3.6305 kg

So 3.6305 kg of payload can be carried by the ASHA robot. This load can be in the form of extra accessories or some kind of small mobile robot.

3.2. Battery and Flight Time Analysis

In ASHA robot lithium-ion polymer battery is used for high discharge current. This is the analysis for the maximum safely pulled current by the ASHA robot from battery.

Maximum Discharge current from the battery:

$$I_b = \text{Normal Discharge x Capacity/hour} \quad (8)$$

$$I_b = 30 \text{ x } 1600\text{mA} = 480\text{A}$$

Maximum pulled current by motor:

$$I_m = \text{No. of Motor x Maximum current pulled by single motor} \quad (9)$$

I_m = 6 x 25A = 150A

Hear we found that $I_b > I_m$ so battery will be safe while running.

The estimation of maximum flight time using one motor averaged pulled current is 5 amp. This is obtained from real time test.

Flight time (In hour) = Maximum Current (In Ah) / Pulled Current (In A) (10)
Flight time = 16Ah / 30A
Flight time = 0.53 Hour = 31 minutes 48 second

By using high capacity Lithium-ion Polymer battery, the flight time of the robot has been significantly improved to 31 minutes 48 second.

4. Flight Testing and Controlling

Each and every motor plays a significant role in controlling the hovering of the ASHA robot and its motion in any specific direction. The ASHA robot will keep hovering in the configuration shown in Figure 8. It can be made to move or spin in any specific direction by the virtue of changing the speed of the motors. The ASHA robot can be made to move in X-direction by just reducing the speed of motor M1, the net thrust will be such that it will guide the ASHA robot effectively in Y-direction. To move in Y-direction we need to reduce the speed of motors M2 and M3 so that effectively the thrust will be in Y-direction and ASHA robot can move in that specific direction.

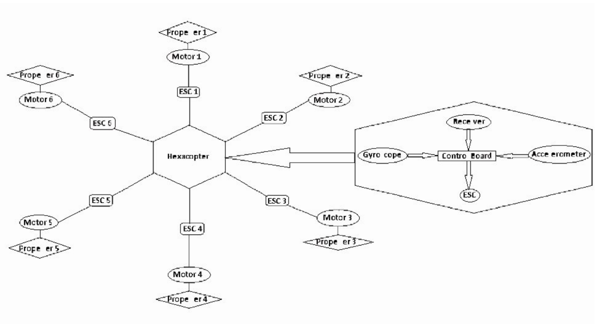

Figure 9. Flow-diagram of ASHA robot

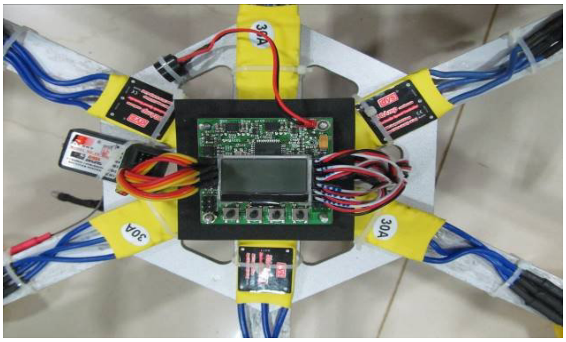

Figure 10. ASHA robot connections

The above figure (Figure 9, Figure 10) shows the complete flow diagram of our ASHA robot. The central board consists of Receiver, Gyroscope, Accelerometer and Control board. The control board takes signal from receiver which is sent to it through transmitter by the user, it takes necessary data from the other sensors and then combine the inputs and processes it and then gives the signal to different ESCs which in turn controls the speed of motor + propeller.

5. Conclusion

This paper presents the design and fabrication of a hexa-copter along with its static and dynamic analysis. The ASHA robot is capable of carrying a payload of up to 3.4kg, a total flight time of up to 25 minutes through experiments which is in line with the theoretical flight time of about 30 minutes. The direction and altitude are easily controllable using a Remote controller due to aid of onboard flight controller and feedback system. The sturdy design of robot enlarges the scope of future adaptation and development in regards with the application in various fields such as defense, surveillance, and rescue operations.

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