Design of Autorotation-based Mechanism to Reduce Impact on Drones in Failure

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Abstract - *The project aims at exploring new and innovative method that can be used to increase the reliability and safety of quadcopters and other multi-copters. The Project intends to increase the safety of the quadcopters by developing a crash prevention & impact reduction system that is activated in case of a system failure or other flight errors. The system works on the principle of autorotation which is a commonly used method in helicopters. The autorotation system causes a gyroscopic effect preventing the quadcopter form changing its orientation during vertical fall & also provides drag (both profile drag & due to autorotation) during vertical fall. This system reduces the energy that needs to be absorbed by the quadcopter during impact by converting a part of the kinetic energy of fall to the rotational kinetic energy & also creating a profile normal to the local airflow to produce drag.*

Key Words: Drone Safety, Drone Failure, Auto-rotation, Actuating Mechanism, Impact Reduction.

1. INTRODUCTION

Drones have now been incorporated into the most elite armed forces and are used as target decoys, for combat missions, research and development, and for supervision. This is because drones not only reduce the military cost significantly but also perform an additional function of automation in the execution of high profile and time-sensitive missions.

Due to the above-stated reasons, a crash would need to be avoided in all circumstances. The need of the hour is to fabricate drones that would reduce the impact of crashes and make sure that in the event of any failure, there are mechanisms in place that would ensure that the drone can land safely without any damage to any of the components.

Autorotation is the state of flight where the lift generated here is purely due to the upward motion of air during the descent of the object when there is a rotation induced by the air moving past the rotor. It is called a free spinning rotor. Here there is no power supplied to the rotor, and lift generated is not enough to sustain level flight but helps descend at a slower pace compared to free fall.

The above concept is not used in small scale quadcopter due to its reliance on large diameter blades (while quadcopter have multiple smaller propellers).

This Project explores the idea of implementing a separate retractable blade system that not only gives lift when deployed during descent, but also provides gyroscopic stability.

1.1 LITERATURE SURVEY

Various ideas were explored in order to gain insights into recent developments involving safety and damage reduction of UAVs.

The study [1] focuses on mimicking the nature by taking inspiration from a dragonfly and incorporating the features as cambered flexible blades, which are made by 3D- Printing technology. Experimentally it was found that these have one tenth impact force compared to original plastic blades. This makes sure that blades are unaffected in collision and human safety is ensured but do not provide any safety for components of drone.

Paul E. I. Pounds [2] uses a spinning hoop around the rotor blade, when this rotating hoop comes into contact with any external body changes in the speed of hoop are measured by reflective IR sensors and the blade will stop rotating within 0.06 seconds. Thus, Great safety to the humans but safety of blades and components isn't assured. Concept [3] proposes an idea of making a safe drone capable of avoiding crash even without any power being provided, applying the concept of a hybrid blimp. A large balloon shape with rotors attached. In case of power-loss, the vehicle will gradually descend. Intended in shopping malls etc. Tao Yang [4] designs a system capable of landing safely during the loss of GPS signal or loss of control by the pilot in an unknown environment. This was achieved by using monocular visual simultaneous localization and mapping (SLAM) system, which scans the surrounding and generates grid points of objects around it (Buildings, trees etc.). This date helps create a path for fast and safe landing of the drone autonomously.

Richie Howard [5] invented a protective coveting of a structure which protects the blades of the drone and the components. The elements are made of polypropylene (PP) and these structures are joined together by an elastic joiner to provide stiffness and strength. Cooper [8] uses similar method to shield the entire drone from damage along with protecting it from environmental factors.

Seon Ho Lee [6] provides a method which involves using a parachute system to decelerate the falling drone in event of any malfunction. The parachute which is folded inside a container is forced out by a jet blow that is created inside the container. Similar work with various analysis for the components of parachute is done by another group [7].

Parachutes, if they are made to rotate along its central vertical axis with the help of some extrusions. This rotation gives more drag than conventional parachutes resulting in slower descent known as 'Autorotating Parachutes' are the amongst techniques provided by Fatau [9]. Similarly, R J Gross [11] provides ideas on increasing drag even further with multi layered concept of these radial extrusions on the parachute. David T Barish [10] provide a different method on autorotating parachute is formed of spaced apart flexible flat panels with the peripheral edge of the panels being formed as a succession of arcuate edges. There is slight camber which produces the thrust in rotation and thus leading to decrement of vertical velocity. Tsaliah's method [12] provides safety with an expandable and collapsible parachute assembly having inflatable tubes forming the structure for the parachute.

Works [1,2] not focused on protecting the vulnerable drone components like electronics. The maneuverability is at stake for having a system which assures the safety of the drone, as seen in works [3,10]. While [3]'s shape and buoyant nature limits it to indoor as well as low maneuvering applications. The Protective frame used in work [8] increases the weight of the drone as well as increasing the impact damage on the surrounding in event of crash.

In a work done by Tao Yang [4], system is heavily reliant on constant power supply and optimal functioning of SLAM system along with fully functioning rotors.

As many of the works [6,7,11,12] focus on having parachute as major tool for slower descend which are susceptible to wind making it hard to predict the land location. Such bulky structures also lack stealth and is detected by enemies easily in case of military applications.

This project aims at overcoming these drawbacks as discussed above.

1.2 PROBLEM STATEMENT

The project aims at reducing crash damage on the quadcopter and being able to perform manoeuvres, maintaining high flight efficiency while not relying on constant power supply and optimal rotor conditions during emergency descent.

2. CONCEPT DESIGN AND DETAILS

The following images show the quadcopter that is been designed. The Fig.1. shows a simple quadcopter with 4 arms attached at the vertices of the hub. The motors will be mounted at the ends of each arm. This paper aims at developing a helical surface that is actuated out of the quadcopter arms as shown in fig.2. The helical surface will be created using a fabric that will be stiffened using the actuating arms as shown in the fig.2 and fig.3.

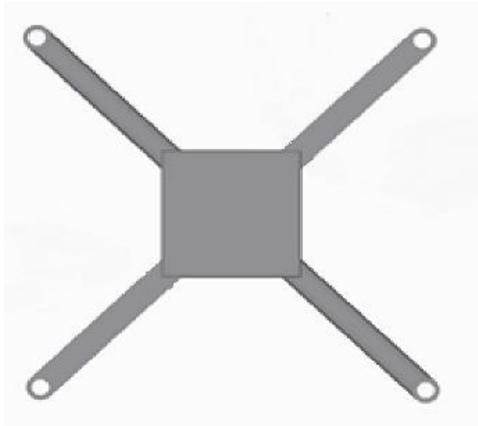

Fig-1: A normal Quadcopter Structure

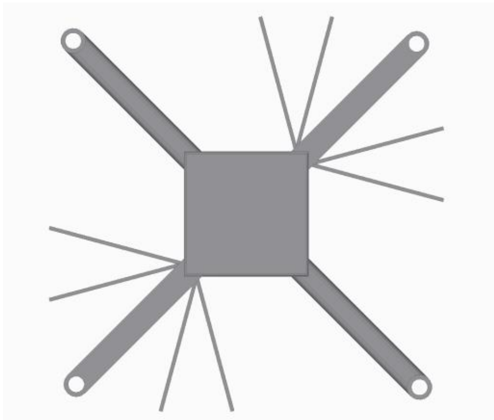

Fig-2: A Quadcopter Equiped with actuating arms.

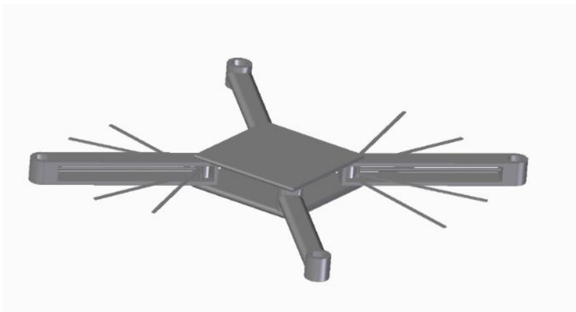

Fig -3: Side View of a Quadcopter with actuating arms.

The actuating arms will be actuated using a servo which in turn will be controlled by an onboard controller unit. The controller unit will deploy the mechanism in case of any failure or malfunction in the system. The controller can be the onboard flight controller or a stand-alone system with a backup power supply that is capable of sensing the failure or operate based on pilot commands.

The thin air tight fabric shown in the fig.4. will be rolled under normal flight condition to keep the aerodynamic drag down and prevent flow obstruction for the rotor downwash. The helical profile of the fabric creates aerodynamic drag during descend a tangential component of which is used to cause autorotation the effects of which will be explained later on in this article.

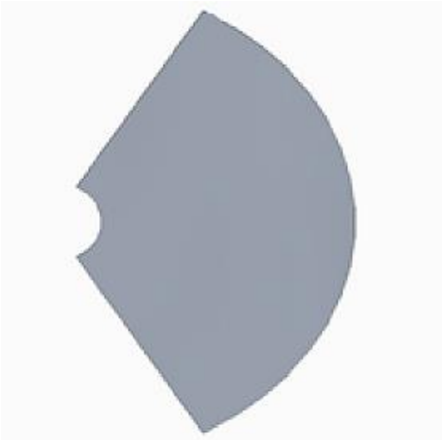

Fig -4: The shape of Fabric in opened position

In case of rolling the rectangular fabric one can use a cylindrical body to roll the fabric around it. But here, the fabric being used is in the shape of circle's sector. Only a cone can be used to roll this fabric. The cone needs to be reverse engineered based on length and a frustum to be obtained, which is based on the two diameters as shown in following Fig -5.

Fig -5: Element to Roll the Fabric

2.1 CALCULATIONS

Terminal velocity is the equilibrium velocity with which an object falls over a constant acceleration (like gravity) over a viscous medium (like air).

V_t is the terminal velocity of the quadcopter while descending through the atmosphere through the action of gravity.

The rotor drag coefficient of auto-rotating discs in descent is given by the following formula [13].

$$C_{Dr} = \frac{L}{\frac{1}{2}\rho V^2 \pi R^2}$$

$$C_{Dr} = 1.1$$

where L is the upward force generated by autorotation and profile drag.

Considering V_t = 40 m/s as a baseline for terminal velocity of an object of this size (typical 25cm arm length) and mass (roughly around 1 kg including structure and additional payload)

$$\rho = 1.225 \text{ kg/m}^3 \text{ (of Air)}$$

$$R = 20 \text{ cm} = 20 \times 10^{-2} \text{ m}$$

Solving for upward force generated by quadcopter falling at this speed V_t (=40m/s)

$$L = 135 \text{ N}$$

Assuming the weight of the quadcopter is 9.8 N (that is 1 Kg force). hence it is not in its equilibrium state and will decelerate to equilibrium velocity.

Equilibrium velocity is given by,

$$V = \sqrt{\frac{2mg}{\rho A C_D}}$$

here lift = weight.

Substituting and solving for V,

$$V = 10.75 \text{ m/s}$$

Compared to 40 m/s for conventional Quadcopter. Further optimizations can be carried out to reach a desirable descent velocity by varying other dependent parameters such as weight and fabric area.

2.3 HELICAL NATURE OF FABRIC AND ROTATIONAL EFFECTS

The rotational effect is induced by a pair of forces acting coaxially on the extended structure in opposite directions that cause a rotary effect. The rotary effect is related directly to the tangential force created by the aerodynamic effect and the mass moment of inertia value of the entire structure.

This is shown by the following image Fig-6 in order to visualise the kind of forces that will be created when the structure is falling with fabric in extended position.

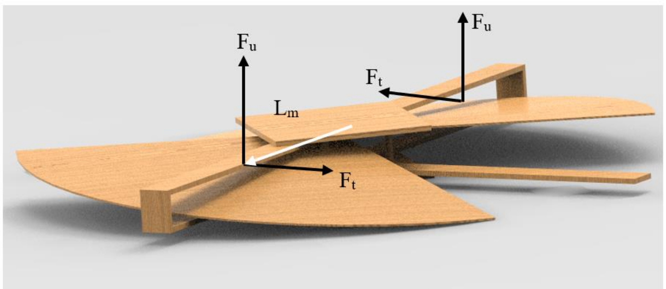

Fig.- 6: Forces acting on the structure

It can be seen from the above figure that F_u is acting upwards which is produced by the drag of the fabric during downward fall. As the air hits the fabric and pushes it upwards this force called as 'Drag' is obtained.

The Inclination is provided by the Fabric as can be seen from above Fig -6. This force which is acting perpendicular to the arm on horizontal plane concentrated at a distance L_m from the hub will create a couple to a system, which is from both front and back side of fabric. This results in rotation can be called "Autorotation". The main advantage of having this Autorotation is that during the fall the quadcopter will have a rotational stability, this will make sure the quadcopter doesn't flip and lands horizontally and avoids cross landings or upside-down landings which could be cause severe damages to the structure.

3. CONCLUSIONS

From the proposed design and calculation, it can be concluded that an autorotation-based actuation system will be able to provide enough drag to decelerate the drone (quadcopter) during fall in case of any malfunction. Further work needs to be done in order to precisely determine the benefits of the proposed system which will require simulation using CFD and FEA tools. The results from the CFD and FEA analysis can be used to further optimize the proposed design in order to completely eliminate the chances of structural failure and safeguard the onboard components during crashes.

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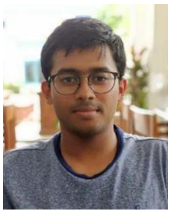

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