MECHANICAL STRUCTURE OF AUTONOMOUS DELIVERY DRONE

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ABSTRACT

In this paper, the objective is to design a mechanical structure of drone (quadcopter) capable of carrying a 2-3 kg load in a 2-3 km radius around the pickup point and deliver it autonomously. Therefore, for designing the quadcopter, aerodynamics, stress and strain analyses have been considered in simulations and then hardware has been designed accordingly. This paper focuses in particular on the mechanical design of quadcopter using SolidWorks and the components required for this concept to be brought into reality.

Keywords: Drone, Autonomous delivery, Solid Works.

1. INTRODUCTION

Unmanned aerial vehicle (UAV) known as drone [1], drones around the world are symbolized as the future of all forms of technology, whether it is used as a means of transport for goods or people [2] or by the military to carry out strikes and reconnaissance [3]. The sheer control that we possess over the drones allows us to save key resources such as fossil fuels and human lives that can be utilized to make the world a better place.

Various companies across the world have made drones that can be set to follow a target while responding to their surroundings, gesture control drones for theatrics, autonomous delivery drones such as the ones brought into use by only amazon so far, drones ranging from the size of 10-year old's palm to bigger than a Toyota than people can mount and ride[4]. Moreover, several companies have taking initiative to create racing first-person view (FPV) [5] drones and made a sport out of it, racing drones in patterns and through obstacles.

Drone technology is often classified by generations, the first generation being basic manual control and each generation improving on the previous, adding imaging/video taking, more aerodynamic designs, autonomous flight, safety features and spatial sensors. The continuous growth in this technology will make it safer to use in public areas and push it further into mass production. Drone laws in some countries are quite strict, but as safety features improve, we should see some relaxation on that front as well [6].

The use of drones in autonomous deliveries is of particular interest to us as we see it as the ideal form of item delivery in the future, as it should be able to reduce energy wastage and unnecessary human labour which could be directed elsewhere to improve efficiency and environmental friendliness [7]. The drone we intend to fabricate will deliver items within a limited area, but the technology can be applied to drones with larger fuel capacities for longer distances. Alternatively, if it were possible to set up several recharge points in strategic locations, the range of deliveries can be improved. The uses of these sorts of drones include healthcare emergency drones carrying vital first aid equipment, improving economies through the 'last mile' (last stretch of a journey a product makes) and reducing pollution, since drones can be powered by green technology [8].

In order to maximise efficiency, it is necessary for drones to have minimal mass while maintaining structural strength, so they are often made using carbon fibre and light metals like aluminium, therefore similar materials have been used for the proposed design. The proposed design is used with the base and arms cut from carbon fibre and the connections made with aluminium to increase joint strength. The testing of the proposed model is performed in the 3D modelling software SolidWorks to find weak points and make sure nothing is above the yield strength of the material for each part.

The main contributions are as follows:

- Optimized mechanical design of delivery drone (quadcopter).
- Aerodynamics, stress and strain analyses have been done in SolidWorks.
- The proposed structure is capable of carrying 2-3kg with a servo-controlled claw.

1.1 Literature Review

Drones, particularly autonomous drones initially designed for military use [9] and gradually adapted toward private and consumer needs [10]. Nowadays they are mainly used in every aspect of life ranging from catastrophe situations [11] to recreational purposes [12], in the agriculture sector for monitoring crop's health [13], in an inspection of building rooftops or bridges [14] saving both human effort and time. Use of this equipment can also be included in the transportation of goods or items delivery [15] considering its potential to save fuel and manual labor that can be spent more efficiently to improve industries output. Additionally, low altitude air traffic is not currently a problem, making it ideal for quick transport. One issue that can arise from this, is to have multiple charging points across the city instead of expanding battery sizes. Since having a greater battery size will increase costs and weight. By using an automatic charging station, drone technology can overcome limitations like long distances easily.

Most of the existing research, explored in this paper, revolves around the chassis of the drone where different anomalous shapes were configured and tested in hexacopter or quadcopter variations. Some studies concluded that if a drone is to carry an extra object, it must be aerodynamically efficient to minimize air-wash under the drone chassis and the landing procedure for an autonomous drone shouldn't be dependent on one response system, e.g., just telemetry, instead, it should encompass telemetry, optical feedback [16], laser guidance and a gyro for precision as it operates depends on three axes [17].

In [18], the author explores the special stabilization and autonomous landing of a drone using vision-based landing pad recognition. For this purpose, a method was developed which allows a drone to estimate its relative position and orientation through computer vision, after placing a predefined marker/set of markers on the landing area. This paper was limited by physical hardware, as the experiments were performed in a controlled ROS simulation, and thus do not account for random errors such as wind and limited lighting.

C. Rajukar et al. [19] attempt to solve the problem of package security, suggesting two-way communication with the drone along with a GPS to allow it to change its drop-off point in case of unforeseen changes, and a servo-operated combination lock to guarantee that the package can only be opened by the intended recipient. A mobile app to control the drop-off point is proposed as well. The primary issue explored was the lack of security in the current drone delivery systems, specifically how packages are dropped without confirming the presence of the customer, the lack of an option to change the drop-off point, and the lack of measures to prevent against people who are not the customer picking up the package. The researchers were limited by 2D GPS as it does not take into account building heights – using 3D GPS would allow for much more efficient flight path planning. The second limitation was the size and weight of the goods.

An article by Kornatowski et al. [20], describes a drone design that could improve drone flight safety for humans and other animals. Instead of using low-density blade covers which tend to have large holes that humans' extremities may slip through, they suggest making a cage with a tennis racket-like net and having the propellers shrink into it when near humans. They also take into account the increasing global interest in drones as a form of quick, cheap, and efficient transport that can access otherwise difficult-to-reach locations. According to the authors, most contemporary alternatives are limited by the requirements of flat, empty landing areas and landing pads, but the new morphing drone design should be able to deliver in populated areas with fewer requirements of the surroundings. The authors were limited by the production cost and materials available to them. They suggested strengthening the enclosure frames using carbon, aluminum, or titanium alloys, and reducing the frame weight by replacing the plastic grids with larger modules.

The work presented by Abhinav Ajay et al. [21] explores a method of improving drone safety using a transforming frame, this time looking to aspects of Japanese origami for inspiration. Origami is known to be capable of creating shapes that have considerable strength when folded in particular ways, which can be very useful in many fields. The author mainly wanted to discuss issues of safety when flying multirotor drones in populated environments. They recognize the importance of drones in the modern e-commerce and emergency supply industry and desire to give their input on how to improve them in terms of cargo drones. The author designed and made an origami cage for his drone, and tested it in normal flight conditions. They also designed a servo-based dropping mechanism for the package that is activated through an OTP-based system.

K. Nonami [22] in his work proposed guidance, navigation, and control (GNC) of the current standard drone and how it can be improved for beyond visual line of sight (BVLOS) flight. The author deemed that BVLOS technology could revolutionize the logistics industry as well as support disaster relief societies. The limitations of their research included the government's laws on the autonomous flight, such as an autonomous drone having to be below a specific weight to be able to fly in a metropole city, and a license being required to operate such a vehicle.

2. METHODOLOGY

This section presents the mechanical structure, flow chart, and calculations of the proposed design.

2.1 Mechanical Structure

The drone parts were designed and tested in Solidworks. Carbon fibre and fibre glass is selected to use for the arms and base plate, because they are one of the best materials available for flying vehicles, able to withstand high stresses while being very lightweight. They are also relatively easily available in our region, and viable in terms of costs for a one-off project [23]. The air flow analysis around propeller, initial structure and final prototype design are given in Fig. 1-3, respectively.

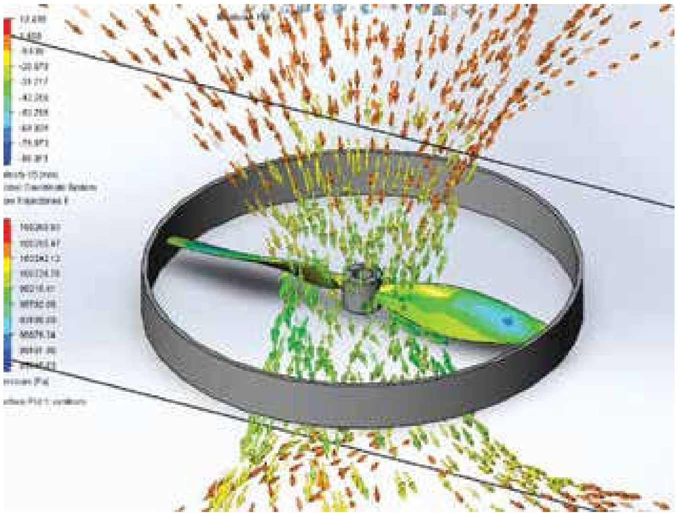

Figure 1: Air flow around propeller

Figure 2: Initial drone design

Figure 3: Final drone design

2.2 Flight Calculations (Prototype)

1045 props, 3S LiPo 3200 mAh
maximum thrust, flight time:

$$F = Pull * g = 0.642 * 9.8 = 6.2916\ N\ per\ motor$$

$$Q = i * t$$

$$t = \frac{Q}{i} = \frac{3.2Ah}{9.5 * 4A} * 60 = 5.0526\ minutes$$

$$F\_total = 6.3 * 4 = 25.2N$$

$$Prototype\ weight \approx 1.42 * 9.81 \approx 13.93N$$

2.3 Flight Calculations (Consummate):

Drone mass≈8.5kg;

Motor Thrust $= 2 * Load = 2 * \frac{8.5}{4} = 4.25kg$

ESC Current Rating $= \frac{P_{motor}}{V} = \frac{1750}{22.2} = 78.83A$

∴ 80A is sufficient

Prop rating: 18x6 (experimentally found)

2.4 Battery Calculations (Consummate):

$$\frac{1750W}{22.2V} = 78.8288A$$

$$15\ minutes = 0.25h$$

$$78.8288A * 0.25h = 19.7072Ah$$

$$78.8288A * 4 = 315.3152A\ total$$

$$22000mAh\ available$$

$$\frac{315.3152A}{22Ah} = 14.3325\ h^{-1}\ minimum$$

2.5 Flow chart

The basic flight control of the proposed method has been given in Fig. 4.

Nonlinear Dynamic models and control systems have been developed and reviewed by many researchers [24-25], with altitude control being possible with a simple PID controller [26]. Flight control software has been used and adding to it for our purposes, including the addition of control for a claw to hold a box containing the package to be delivered.

According to the sources, 6-12s batteries would be ideal for proposed design, with matching speed controllers and motors that can withstand high voltages, to reduce wire currents. Lower currents reduce losses due to heat and allow us to use thinner wires, which also helps reduce weight, along with heating losses.

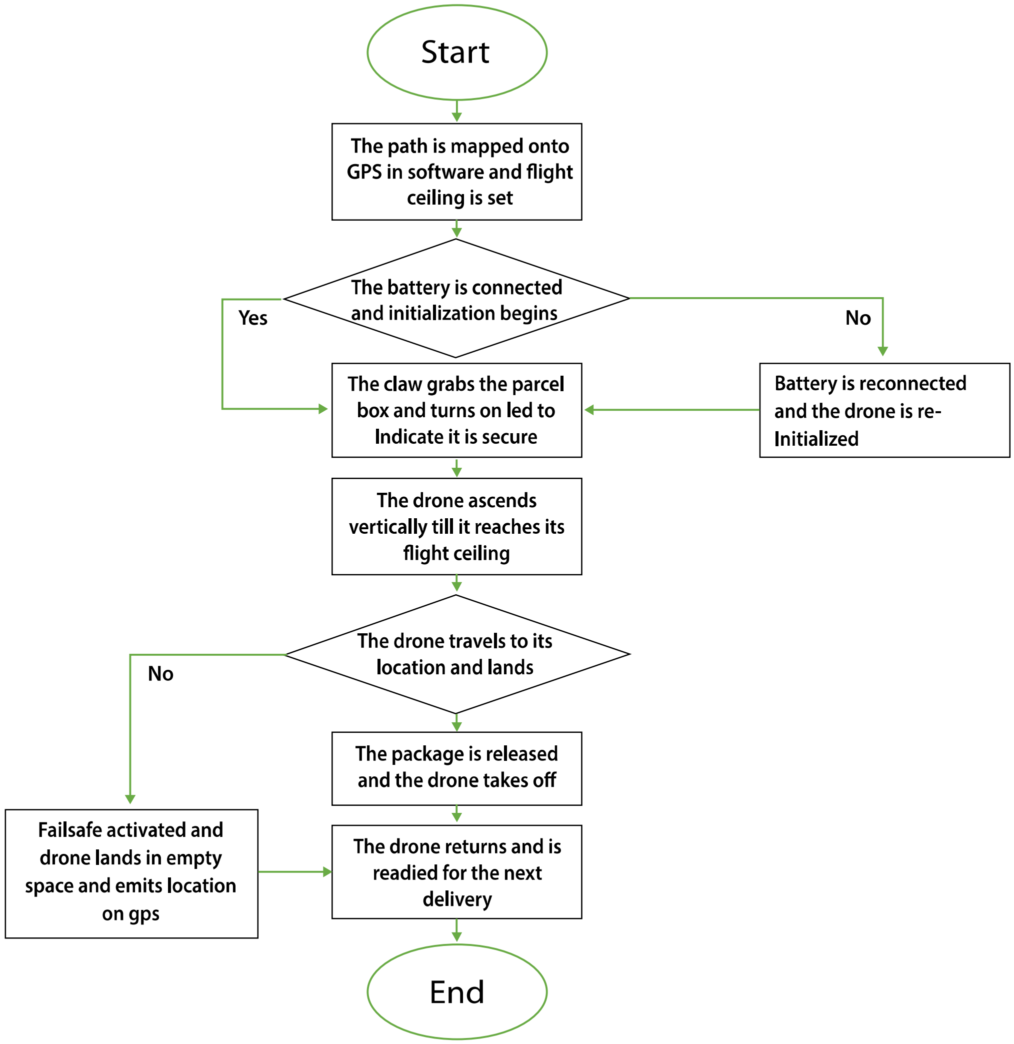

Figure 4: Flow chart of proposed model

3. RESULTS

In this section, stress and strain analyses of the proposed design are shown using Soliworks. The results of the stress analyses showed no issues with the parts at the specified loading conditions (total drone + package mass: 8.5kg). Maximum stress in the arms and base plate are a large margin below yield strengths of the materials. The stress and strain analyses are shown in Fig. 5-7.

Figure 5: Stress test of arm

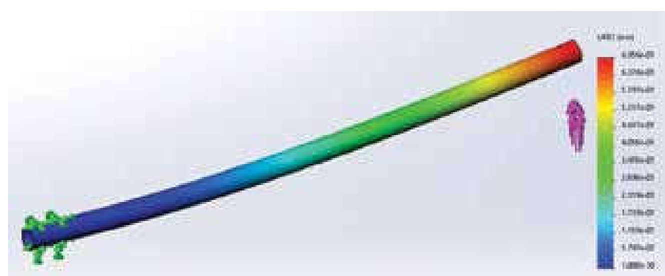

Figure 6: Strain test of arm

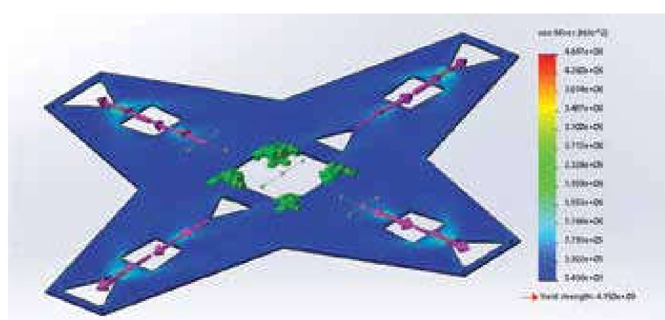

Figure 7: Stress test of base plate

Now, the different claw designs are tested to hold the package are shown in Fig. 8-10.

Figure 8: Claw design 1

Figure 9: Claw design 2

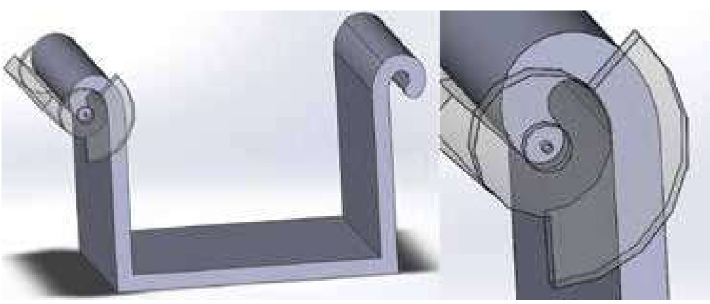

Figure 10: Claw design 3

Above are three conceptual ideas for mechanical claws to hold the package in place. Design 1 is made using sticks and it is the basic design to check the stability, Design 2 has the largest range of motion which makes it easier to implement but less stable due to the long, thin parts. Design 3 attempts to simplify the task to two servo motors and reduce the movement range, while preventing the box from moving from side to side.

The final design will be a combination of Claw Design 2 and Claw Design 3, with further improvements that make it more suitable for a specific box size and more stable during flight.

4. CONCLUSION

In this paper, we designed a quadrotor UAV for package delivery purposes. Our drone's mechanical design performed very well in simulations; however, it may be possible to optimise it for better aerodynamics, and the consummate drone with high-power electronics has yet to see in-flight testing

As the world continues to make progress in this field and computer engineering therefore the foreseeable future of drones is filled with artificial intelligence and more size and battery efficiency. An Unmanned Aerial Vehicle will be used in all fields of life from emergency services to military utilisation and more civil employment, we plan to continue down the same path and use image feedback as a form of input to the FLC, along with integrating SMC (slide mode control) into the FLC which will allow the drone to manoeuvre to a safe position in case a sensor or actuator fails. SMC allows the FLC to input pulses to the motor which causes them to work in short bursts allowing the drone to bounce across the air, in a manner referred to as 'sliding' in one direction on any two axes. We plan to incorporate a lighter and smaller claw improving the overall efficiency of the drone and allowing more weight to be transported.

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