Snowstorm—Design and Construction of a Electric Recreational Flying Machine

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I. Introduction

Powered recreational locomotion has recently experienced a massive wave of innovation, due to advances in battery and electric motor technology. Electric scooters, inline and coaxial two-wheelers and mono-wheels proliferate and contribute to the quality of life of millions. This project explores indoor flying as a recreational activity. Form the onset, indoor flying requires no or very low local emissions and low levels of noise, which strongly suggests electric propulsion. Considerations of safety and cost lead to a multi-copter design. This abstract describes the design of Snowstorm, an experimental recreational flying machine developed at the National University of Singapore. Innovative features include a conducive propeller, seat and landing gear arrangement, triply-redundant power management, mechanical, electrical and electronic safety measures and a motor control architecture that re-uses proven multi-copter control software and hardware.

II. Motivation

Recreational flying traditionally requires extensive training and preparation. Outdoor airspace is highly regulated and the national aviation authorities enforce adherence to their regulatory frameworks. Large indoor spaces are usually not under the jurisdiction of aviation authorities and thus provide an opportunity to untrained individuals to decide the direction and speed of an aerial vehicle. For recreational indoor flying, performance, cost, simplicity of operation and safety are decisive factors for adoption.

III. Frame Design

Fixed wing aircraft design is out of question for recreational indoor flying, due to the space constraints of indoor venues. This leaves Vertical-Take-Off-and-Landing (VTOL) vehicles as the only viable option. The personal helicopter GEN H-4 (GEN Corporation, 2013) enjoys simplicity of control that might be suitable for indoor flying, provided it can be converted to electric drive. However, the coaxial rotor arrangement would require custom-designed blades, which proved prohibitive for our project. On the other hand, a multi-copter design allows for re-use of proven technology and provides for inherent redundancy.

Figure 1: Personal helicopter GEN H-4

In order to provide sufficient lift with cost-effective, off-the shelf motors, a multitude of rotors would be required. For stable flight, the rotors should be combined in or near a common plane. This design is familiar from popular multi-copters and is under development in the personal VTOL craft VOLOCOPTER (e-volo, 2013).

Figure 2: VOLOCOPTER prototype

For our project, cost considerations led to a hexagonal design, where six radial aluminum beams host one rotor each. The radial beams end in the vertices of a hexagon, attached using carbon fiber connectors. Each vertex hosts one rotor. Finally, each side of the hexagon hosts one rotor in its center. Figure 3 shows the arrangement of 12 beams and 18 motor/rotor pairs in the top plane of the craft.

Figure 3: Top plane of Snowstorm

The goal of conveying an indoor flying experience removes many constraints that commercial outdoor vehicles are subjected to. There is no need for rain or ice protection of the craft or its pilot. The design of the landing gear can assume a flat terrain. Whereas endurance is of critical importance for transport craft, recreational craft can be successful with flight times as short as five minutes. Overall, the indoors recreational use case allows for a much simpler and cost-effective design.

The emphasis on the pilot's flying experience on the other hand gives a critical importance to the clear view by the pilot. The designers responded to this challenge by supporting the top plane with six slanted aluminum beams that connect towards the outer end of the radial beams at the top and radial beams under the pilot seat at the bottom. The landing gear of Snowstorm consists of six aluminum beams that end in 3D printed cups that hold rubber balls for cushioning the impact of rough landings. Figure 4 shows the overall design of the frame.

Figure 4: Design of Snowstorm Frame

For additional thrust, the motors/rotors located on top of the outer beams in the vertices and the sides of the hexagon can be duplicated in a coaxial arrangement. If only the motors/rotors located on top of the vertices are duplicated, the craft will have 24 motor/rotor pairs, and if the motor/rotors on top of the outer beams are also duplicated, the craft will have 30 motor/rotor pairs.

IV. Simulation and Analysis

After constructing the entire structure in SolidWorks, Finite Element Analysis (FEA) was used to calculate stresses under loading with a 70kg person. The simulation results indicate that the maximum stress occurred in the structure is 45MPa, which is significantly below the yield stress of aluminum 6063-T5, 145MPa. Therefore, with a safety factor of 145/45 = 3.22, the structure is safe for flight. Figure 5 shows the color-coded stress on the components of the structure, resulting from FEA.

Figure 5: FEA of mechanical structure

V. Control

Instead of attempting to design a custom-made control system for the craft, the design leverages on the million-fold deployment of existing multi-copter controls. The rotor/motor pairs are grouped into six control groups, based on their physical position. For example, a set of 18 motors can be grouped into 6 control groups of 3 motors each, as shown in figure 5 below. If additional 6 or 12 motors are required, 1 or 2 motors can be added to each control group, respectively.

An off-the-shelf multi-copter flight controller using a hexa-copter configuration is then utilized to control each control group independently through sending a PWM signal to each control group. For each control group, the same PWM signal is split and sent to each individual Electronic Speed Controller (ESC), which controls 1 motor each.

Hence, although there are 18 rotors, the controller operates as if it is actually controlling a 6-rotor multicopter aircraft. Figure 6 shows the control structure of the craft.

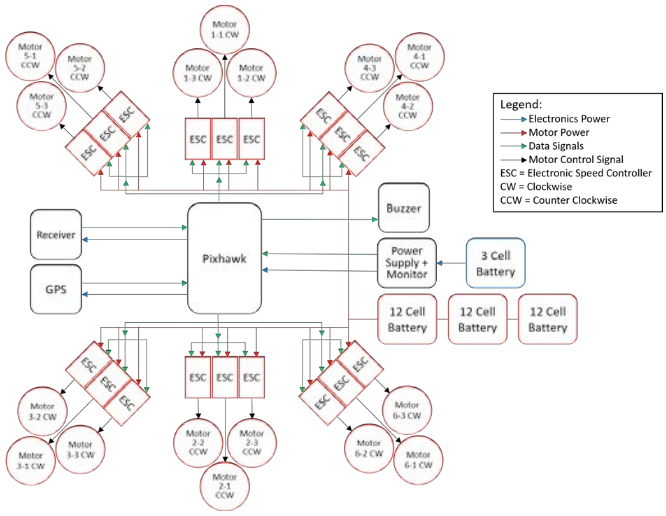

Figure 6: Control structure of Snowstorm

In this arrangement, the failure of individual signal wires, ESCs, rotors and motors means that the affected group of rotors experiences a reduced power output, a situation that the control software can easily compensate for.

VI. Power

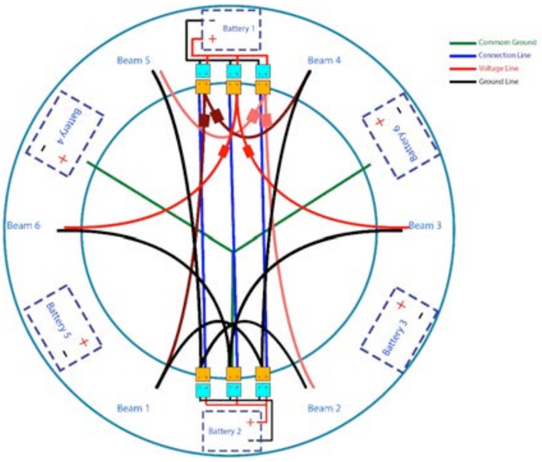

Figure 7: Power distribution

The power distribution system is orthogonal to the control system, see Figure 7. Six LiPo batteries of 22.2V each (nominal), located under the pilot seat, are arranged in opposing pairs and connected in series (since 44.4V is required to power the motors), each pair supplying power to six (or eight or ten) motors. In the basic configuration of 18 motor/rotor pairs, this geometry ensures that the failure of one battery system only affects one of the three motors in each control group. Experiments have proven that controlled landing is possible in this case.

VII. Testing and Results

The machine is currently equipped with 24 brushless DC motors (Wilson, Trickey, 1962) of 2.2kW each, powering propellers with a diameter of 76cm. Three sets of two 6-cell Lithium Polymer batteries provide 22Ah each, allowing the craft to fly with a light person for about 5 minutes.

The personal flying machine Snowstorm flies stably using off-the-shelf multi-copter controllers operated using a standard remote control set with a light person of 60kg on board. In addition to the triply redundant power supply and failure resistant control, safety features include a 5-point seatbelt, depicted in Figure 8, and an onboard emergency switch.

Figure 8: Snowstorm at E2Festa 2015 in Daegu, Korea

Figure 9: Snowstorm flying with a thrill-seeker participant at a media event in Singapore (Straits Times, 2015)

VIII. Conclusion

We propose the design of an electrical Vertical-Take-Off-and-Landing craft for recreational indoor use, based on established multi-copter controls. The indoor use case affords ultra-light design and a cost of a fraction of outdoor personal aircraft. We envision indoor flying parks that offer machines like Snowstorm to the general public. For this use case, advanced flight monitoring and automatic fail-over in case of operator mistakes will be desirable.

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