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Mechanical Design

A quadcopter consists of four basic parts: the frame, arms, motor brackets, and skid. The frame is the central material which holds all electronics including sensors, batteries, electronic speed controllers, and microprocessors (Arduino UNO R3 and Raspberry Pi). The frame will be multiple levels connected by standoffs to provide more mounting area. Carbon fiber, aluminum, and acrylic are possible frame materials. The arms connect the motors and brackets to the frame. The arms can also be used for wire management if they are hollow. Most likely, the arms will be aluminum or carbon fiber tubing. The motor brackets connect the brushless motors to the arms. The motor brackets will be designed in Solidworks and 3D printed. Skids provide a stable base to land and launch the vehicle. Skids also protect any electronics mounted to the bottom of the chassis, such as the camera module. Landing gears can either be on the arms and motor brackets or the fuselage. Small diameter carbon fiber tubing and 3D printed adapters can be used to create the skid. It is also possible to include a protective frame or propeller guard in a quadcopter design. This frame surrounds the propellers to reduce damage to the quadcopter and prevent damage caused by the propellers. Most quadcopters do not have a protective frame. It is useful during testing to prevent damage caused by collisions or crashes, but it increases cost and weight. By implementing a simple system to attach and detach the protective frame, the frame can be utilized during testing without harming final performance.

The final design goal is to utilize the most efficient manufacturing processes and materials. Most likely, a fully 3D printed design will be used. FDM 3D printing is appealing because of the ease of construction and its future possibilities. 3D printing also allows rapid prototyping. During testing, design flaws can discovered and fixed quickly. The Solidworks models can be easily changed and then a new part can be printed immediately to replace the flawed part. As 3D printing technology increases, its accessibility and usefulness will increase greatly. Designing to utilize this technology will allow for future growth and experimentation. The largest downside of 3D printing is the relatively limited material choice compared to other manufacturing methods. Most 3D printers can only print with ABS and PLA. Other materials include HDPE, nylon, ceramic, and some metals.

Solidworks will be used to design and analyze the model. The design will be tested in Solidworks and after construction to see the effect of alternative designs and material choices. Testing in Solidworks will include stress, flow, and finite element analyses. Physical testing will focus on mass, center of mass, and force produced by the motors. The relationship between thrust and current will be crucial to test in order to have sufficient data for programming and the PID algorithm.

The major components are brushless motors, propellers, electronic speed controllers, and batteries. Brushless motors provide more efficiency than the equivalent brushed motors. Propellers are classified by their diameter and pitch. For multirotor applications, a large diameter, small pitch propeller provides the best results. Pitch is the distance the propeller would travel during a full revolution under no load. Large diameter, small pitch propellers provide more torque and lower speeds. The motor produces torque which causes yaw, or rotation along the XY plane. To stop the constant rotation, two clockwise propellers and two counterclockwise propellers are used. The same propellers are oriented diagonally from each other to result in a net force of zero. Electronic speed controllers control brushless motors and are commonly used in RC planes, helicopters, and multirotors. The ESC has three connections to the motor, two to the power supply, and three, similar to a servo, to the flight controller. The ESC will receive power from a LiPo battery and receive signal from an Arduino UNO. The Arduino controls the ESC similarly to a servo. By utilizing the servo library and digital PWM output, the speed of the motor can be controlled. For power, there will have to be two different power sources because the motor and ESC require high voltage, provided by the 4 cell LiPo battery, while the electronics require a lower voltage which will be provided by a 9v NiMH battery or four AA NiMH batteries.

The flight controller is another integral component which incorporates a microprocessor and sensors to stabilize the vehicle and provide accurate control. Many premade flight controllers are available such as the ardupilot, MultiWii, and the HobbyKing KK2.0. These controllers are generally accompanied with flight planning software. To reduce cost and allow for customization, we will design and build our own flight controller. A printed circuit board (PCB) will designed using CADSOFT's free PCB design program, Eagle. The PCB will incorporate an Arduino UNO R3 as a processor and a 10DOF IMU breakout for sensors. The 10DOF IMU contains a L3GD20 3-axis gyroscope, a LSM303 3-axis compass, a LSM303 3-axis accelerometer, and a BMP180 barometric pressure/temperature.

An estimate of the vehicle mass was calculated to be 2000 grams. This is based off of the proposed components and a general Solidworks model of the quadcopter. Different motor/propeller combinations yield different thrusts, while drawing different currents. As thrust increases, larger propellers and motors are needed. To support larger motors, higher amp rated ESCs are needed, as well as larger batteries. So, as thrust increases, weight and cost also increase. Several different component combinations can be seen below. The combination that provides high thrust, low cost, and low mass will be chosen. A general rule is to choose a motor, ESC, and propeller combination that provides two times more thrust than mass. By always having more than double the necessary thrust, the vehicle is able to accelerate more rapidly and maintain precise control. Because the vehicle will not run under ideal conditions, actual thrust will be less than calculated thrust; consequently, the design will have to be optimized to minimize mass.

Electrical testing will also be a focus, in order to ensure efficient circuitry. One major design goal is to increase flight time. On average, flight times range from four minutes for nano-quadcopters to fifteen minutes for mid-sized quadcopters. With such short flight times, the applications of quadcopters are crippled. Optimizing the battery, mass, and other characteristics of the quadcopter can increase flight time. Another alternative would be to develop a charging station. This provides a significant challenge because it would be most useful if the quadcopter remained autonomous throughout the entire flight. The vehicle would have to monitor battery life, distance to the nearest charging station, distance to the objective, and flight conditions. Based on projected battery life under current flight conditions, calculations would be made to see if it could reach its objective or if it had to stop.

Another focus will be incorporating principles of the Taguchi method, also called the robust design method. The Taguchi method improves the fundamental function of a product by designing with noise and cost in mind. Noise is any uncontrolled variable that affects the product. In the case of this project, noise most heavily affects sensors. Noise skews sensor values, which could lead to collisions or inaccuracies in positioning. Noise can be reduced electronically and mechanically. Small capacitors can reduce noise by reducing spikes in current and are a common solution to reducing noise. Also, a voltage regulator and BEC (in the ESCs) will control voltage to stop errors caused by increased voltage. Mechanically, noise is primarily produced by vibrations from the motors. These vibrations can be reduced by balancing the propellers. Material choice also affects noise. Some materials reduce it by dampening the vibrations. Also, mounting electronics on rigid foam may reduce noise. These possible solutions will be tested to see their effect on flight and the electronics.

Project Objective

- Optimize mechanical design to increase flight performance
- Investigate different manufacturing techniques
- Increase flight time
- Prepare for and earn CSWP
- Learn Eagle to design PCBs for the flight control board