2015 AUVSI UAS Competition Journal Paper

Abstract

We are the Unmanned Aerial Systems (UAS) team from the South Dakota School of Mines and Technology (SDSM&T). We have built an unmanned aerial vehicle (UAV) to compete in the AUVSI-SUAS competition. Our goals are successful autonomous flight, communication with a base station, video recording, data transmission, and utilization of computer vision for object detection and color recognition. To meet these goals we have built a custom hexrotor with several unique features including an asymmetrical frame, modular components and extensive use of 3D printed parts. To meet search area thresholds we used a variety of functions from the OpenCV library. This competition will allow our team to demonstrate everything we've learned this year and our ability to put it all together to complete this mission.

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1. Description of the systems engineering approach

1.1. Mission requirements analysis of planned tasks

Our first consideration was flight capabilities - the vehicles ability to take off, land and fly waypoints. We needed a design with ease of flight, stability and good mounting points for equipment. Next we needed to find a flight board to handle communications and a camera and board to record video of the search area. The base station would have to be able to communicate with the flight board, record telemetry data and run code to process the video taken of the search area. Finally we would need a method for identifying objects and determining the color of each target and its alphanumeric.

1.2 Design rationale

In our design process we wanted to create something different, while maintaining stability and fulfilling mission requirements. We chose a less conventional asymmetrical design, for both aesthetic and experimental purposes. We built a hexrotor with offset center plate. This particular design was selected to provide a challenge and allow use to make something we hadn't seen before. The offset design also allows for the positioning of more massive equipment such as the battery at the center point of the motors. The motor configuration did not change from the standard regular-hexagon arrangement of motors. Our rationale was that the flight control board would still be able to accurately control the hexrotor as long the motor arrangement didn't change. Using arms of varying lengths seems to prevent harmonic waves through the frame which reduced vibration and improved performance. Another goal was to have a vehicle that was somewhat modular so that we could test a variety of designs for hardware mounting, blade guards, motors of different sizes, etc. It also allowed for easy repair and replacement in case of damage. We chose to use many 3D printed parts so that we could fully customize them and make changes to improve the designs as we went.

After researching various flight control boards we chose the Pixhawk with Q Ground Control software. The software is based on Ardupilot which we had used in other competitions with very good results. We wanted a separate board with a camera to provide a video stream of the search area. We have been learning to use OpenCV libraries over the last few years, this method was an obvious choice for object detection, as well as shape and color recognition.

All of these goals lead to the production of an off center hexrotor that was extremely stable and could easily be changed to allow continual improvement. The use of OpenCV allows us to make use of advanced algorithms to efficiently search a given area and begin identifying target characteristics. In future years as we become better at using OpenCV it should allow us to meet additional objectives for higher scores.

The flight control board being used did change from the time of the body design, but the rationale used still holds.

The remaining portions of the system were built out of commercially available components for purposes of simplicity and to avoid an overly complex system that an inexperienced team could handle. The intention is to increasingly customize the hardware and software used in the future as the experience level of the team increases.

1.3. Expected task performance

Our vehicle flies very smoothly with great stability whether under manual control or autonomous flight. It has no trouble taking off or flying waypoints. Landing requires the addition of extra waypoints but then it can land without assistance. Video is captured and returned to the base station where we use OpenCV for object detection and identification. Currently we are getting a few false positives when identifying potential shapes but we are finding all of the shapes. We are also having difficulty correctly identifying the specific shape but that is not one of the necessary characteristics for us to complete since we can identify colors. Our code is identifying the color of the shape and the letter with very good accuracy.

1.4. Programmatic risks and mitigation methods

Flight is completely controlled by our Pixhawk board using Ardupilot waypoints. Should it lose contact with the RC controller a failsafe is triggered the vehicle will attempt to return home. If it cannot do that for some reason it will land. Our OpenCV programming doesn't affect the flight path of the vehicle in any way so it does not present any safety risks.

2. Descriptions of the UAS design

2.1 Design descriptions of hardware

Aircraft

The aircraft is a multirotor with six props, more commonly known as a hexrotor or hexacopter. Six motors were selected for the purpose of increasing payload capacity and stability at the cost of energy efficiency. The hexrotor is designed with an offset center-plate that forward of the standard center-plate location. The changing of the center-plate location while maintaining the same motor arrangement required the derivation of equations that can take a supplied offset distance and output the necessary arm angles and lengths.

The hexrotor was designed with ½ inch carbon fiber tube arms that are fixed inside 3D-printed PLA arm clamps. Wiring for the motors is run through the arms to avoid the wiring clutter introduced by running wires around the outside of the arms. The motors are placed on the far ends of the arms and are attached through the use of 3D-printed PLA landing gear and blade guards. The landing gear incorporates the lower-half of an arm-clamp and the blade guard incorporates the upper-half of the an arm-clamp. The props are 1047 props meaning they have a 10 inch diameter with a pitch of 4.7

The arm junctions are made from two ⅛ inch aluminum centerplates. The center plates are of a frame-like design to reduce weight, allow easier component access, and to increase airflow past key components.

Power will be provided by two LiPo batteries which will be mounted as close to the center of the motors as possible. These two batteries will be 3S, 5000 mAh batteries. The estimated maximum flight time is approximately 20 minutes.

Autopilot System & Data Link

The processing and communication systems will be comprised of a 3DR telemetry radio operating at 915 MHz, the the 2.4 Spektrum radio receiver, a Pixhawk flight controller, a Basler Dart camera, and an ODroid XU4 on the hexrotor.

Ground Control Station & Data Processing

A laptop is connected to another 3DR telemetry operating at 915 MHz and a Spektrum DX8 2.4 GHz controller on the ground. The laptop will be running QGroundControl which will be used to control the hexrotor and also collect telemetry data. The camera will be controlled by the ODroid and the Pixhawk. The ODroid is connected to the Pixhawk via a telemetry data port and will collect the image feed, but it will not be processing the image data during the flight.

Mission Planning

Mission planning is managed by the Pixhawk and QGroundControl using a flight-path plan specified by the operator.

2.1 Object Detection

Targets will contain (with a few exceptions) saturated colors, while the rest of the aerial image will contain darker greens and browns. Therefore, when looking at a histogram of the image, target colors will be statistical outliers. Target detection finds pixels with these outlier colors by computing the Mahalanobis distance between each pixel and the mean color of the image. Pixels with "rarer" colors have higher values. Besides saturated colors, targets can also contain white and black. To find these targets, thresholding is used to find pixels with color values farther away from neutral gray.

2.2 Background Removal

We used the grabcut function to remove the background and replace it with a bright magenta color that could be ignored later in the color detection function

2.5 Color Detection

We start with an image that has the background changed to bright magenta that we can ignore when evaluating colors. We then transform the image from BGR to HSV format. We set ranges of values for Hue, Saturation, and Value to match each of the colors listed in section 7.2.7.3 of the competition rules. Then we compare each pixel against the ranges of HSV to determine its color. We keep a count of the number of pixels of each color and return the top two colors found in the image which generally correspond to the shape and the letter.

2.5 UAS photograph

3. UAS Performance

3.1. Mission task performance

The UAV flies well and can easily switch from manual to autonomous and back again. It flies waypoints and takes video of the search area. There is good communication between base station and vehicle. The OpenCV code can recognize objects and find colors of both shapes and letters.

3.2. Autopilot system performance

The autopilot system is provided by the Pixhawk control board in combination with QGroundControl which operates on the ground station. This setup provides stable flight with the ability of flying waypoints set by the operator of the ground station. The autopilot system is fully capable of performing autonomous takeoff and landing. Stable flight at forty six meters above ground was achieved and the autopilot system was able to find all points and return to home within fifteen feet of intended landing area. During the entirety of the flight, the ground station was able to communicate, follow, and map the hexrotor throughout its whole flight.

3.3. Evaluation results supporting evidence of likely mission accomplishment.

We are having very good results and expect to complete all mission objectives.

4. Safety considerations

This section outlines the safety criteria for both operations and design of our vehicle as well as some of the potential risks of flying autonomous vehicles and what methods were used to reduce those risks.

8.3.1.5.1. Specific safety criteria for both operations and design
8.3.1.5.2. Safety risks and mitigation methods

The safety risks facing our hexrotor are as follows:

- Flying into a spectator(s)
- Losing communication with the hexrotor
- Crashing

To mitigate these risks the following precautions taken:

1) To minimize the risk of running into a spectator the team has added the ability to manually take control of the hexrotor at anytime. This will allow us to quickly take manual control of the hexrotor and maneuver it out of harm's way before anyone gets hurt.

2) To minimize the risk of damage that can occur as a result of losing communication with the hexrotor, the team has implemented a landing protocol when communications has been interrupted for a certain amount of time. In the event that our ground station has lost communications with the hexrotor, it will attempt to regain connection. If the connection can not be regained after 3 min, the hexrotor will stop what it is doing and land.

3) To minimize the amount of damage done in the event of a crash, the team has designed blade guards to protect the propellers and reduce the possibility of the propellers damaging anything else. The blade guards are made of three 3D-printed PLA parts that are epoxied and friction welded together. The blade guards are designed in such a fashion that they will greatly inhibit the propellers from breaking as the result of a lateral collision. This design will, in turn, also prevent the propellers from cutting people if the hexrotor gets too close to people.