Systems for Flight in Confined Areas for the International Aerial Robotics Competition

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ABSTRACT

Confined areas present a problem for flight systems and controls. The main concern is the margin of error for adjusting to obstacles in confined environments. Therefore, an implementation of a UAV could be a hexacopter with a specific sensor suite that avoids threats and identifies objects of possible interaction. In this case, the mission specifies that the UAV must accomplish tasks without obstacle interference. Specific problems and solutions will be identified and discussed in this paper.

INTRODUCTION

Statement of the Problem

Flight in an open area allows for an increased margin of error and adjustment because there is distance and time to reinstate stability. However, autonomous flight control in confined spaces requires a decreased margin of error. There is less time for adjustment and a higher probability of losing stability. One must account for obstacles both static and dynamic. There will be limitations in the detection of obstacles but these limitations must not interfere with the robot's ability to safely avoid an obstacle within a short amount of time.

Specifically for this mission, the UAV must herd ground robots to a specified boundary within a confined space while avoiding moving obstacles. Therefore, the robot must discern between a target and a threat and implement a decision making algorithm to accomplish the directed task.

Conceptual Solution to the Problem

A proposed solution conceived by the CSUN UAV team is an autonomous hexacopter design using video recognition to identify and analyze its environment. The hexacopter configuration consists of six equidistant motors and rotors. Three motors rotate clockwise and the other three rotate counterclockwise to counteract the rotational torque produced by each motor. All six motors are controlled by a computer using inertial navigation sensors in order to achieve autonomous and stable flight.

Optical sensors are used to dynamically map out a 360 degree view of the environment. Specifically, a system of four cameras is utilized for color and shape recognition. A laser range finder in concert with the camera configuration is used to calculate distances within the arena and distances from objects.

Yearly Milestones

Currently, our team is made up of electrical and computer engineers. We would like to take different perspectives and have other areas of engineering and science participating to expand the overall learning and knowledge of the group. It is our goal to include students from our computer science and mechanical engineering department.

The initial goal was to research material, find parts, and design a functional autonomous aerial vehicle that would accomplish the goals of mission 7. We have a working prototype and are currently testing and improving our initial design as a format for our final hexacopter.

We have a compatible testing structure that incorporates all testing situations. This allows us to gather quantitative data and information on the yaw, pitch, and roll which is needed to formulate stable parameters. The team is momentarily in this phase of testing giving us ideas for improved algorithms.

AIR VEHICLE

Propulsion and Lift System

A hexacopter configuration was the best design for this mission. A hexacopter has more thrust and stability, which is prone to less damage during accidental crashes/collisions. The chosen frame was the Turnigy H.A.L (Heavy Aerial Lift) Hexacopter by Hobby King. The frame is crafted from high quality anodized aluminum which offers greater resilience. The heavy duty alloy skids make this frame ideal for carrying heavy loads such as batteries, cameras, and other electronic components. The H.A.L's motor mounting plates allow for top and bottom mounting of 28-type and 35-type brushless motors.

Figure 1. Turnigy H.A.L Hexacopter frame

The lift system for the hexacopter consists of six brushless 470 kV Navigator motors, six 15-18 amperes brushless ESC's (electronic speed controllers), six 14x4.7 inch propellers, and a 22Ah 14.8V Li-Po battery.

Guidance, Navigation, and Control

The need for an all-in-one approach to flight control hardware was eliminated by using a dedicated flight controller. The approach to the flight controller resulted in the use of a PI controller (single-purpose proportional integral controller) designed specifically for multi-rotor flight. The flight controller chosen was the Hobby King KK2.1 multi rotor LCD flight control board.

Figure 2.KK.1 controller

Stability Augmentation System

The board contains a PI controller which comes preset with several multi rotor configurations and can output up to eight motors simultaneously. It also contains an on board Atmel 644PA microcontroller, as well as an on-board gyroscope and accelerometer to control stabilization. The KK2.1 board allows the user to change the P-gain and I-gain values so that the user can change the speed of the hexacopter while controlling its stability as well. In order to make this air vehicle autonomous, we are using PWM outputs from the CPU which will be controlled through a separate process involving algorithms and external sensors.

Navigation

To navigate the playing field, the UAV must take in information about itself and its surroundings, perform computations on that data, and signal its motors to act accordingly. This means we must deal with two vastly different tasks: simple but timing-critical I/O and processor intensive general computation. Since our image processing computer runs a Linux kernel (which falls apart in real-time applications), a smaller ARM Cortex M4 processor was added to act as an abstraction layer between the compute tasks and hardware.The secondary CPU takes in data from 4 sources: an MPU-6050 triple axis accelerometer/gyroscope combo, an AK8975 magnetometer, a LIDAR unit salvaged from a Neato robotic vacuum cleaner, and the primary navigation computer. It also outputs navigational data to the flight controller board in the form of PWM signals and positional data to the flight computer over USB. Since these tasks all require different timings, an RTOS (real-time operating system) was implemented to separate each task into its own thread.

Figure 1. Arduino Prototyping Board

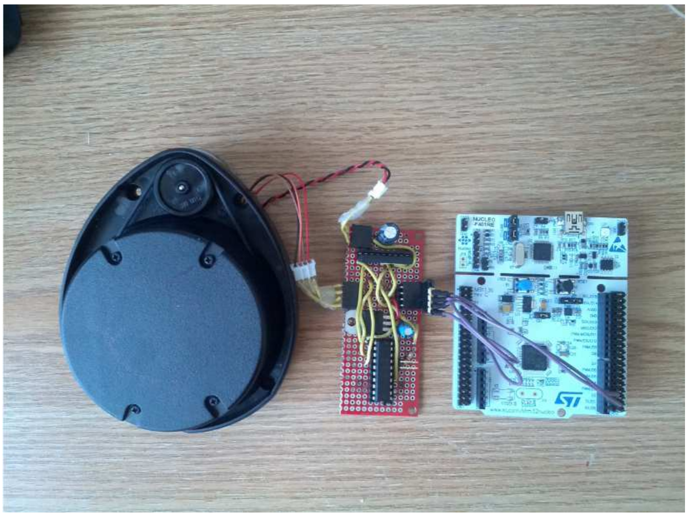

Figure 2. LIDAR Sensor

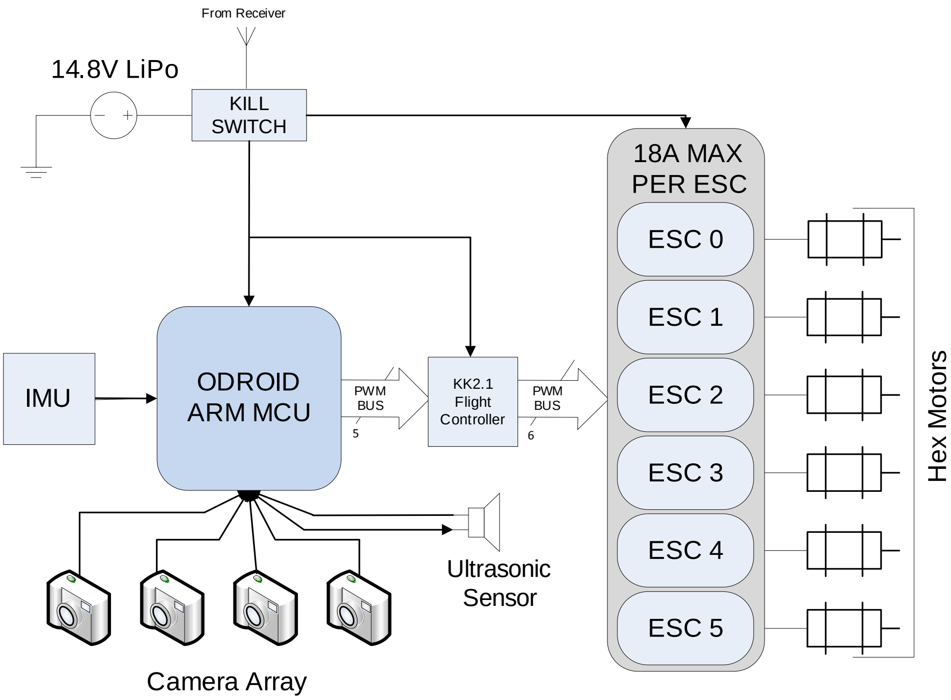

Figure 5. Control System Architecture

Flight Termination System

For the failsafe flight termination system, the safety kill switch that was picked for our air vehicle was the switch encouraged by the IARC. The reason why the team decided to go with the safety switch designed provided by the IARC is because this design has been tested and proven to work in previous missions. This switch when toggled will transmit a signal the receiver located on the aerial vehicle. The signal causes the ground terminal to the battery to disconnect effectively disabling the hexacopter's power.

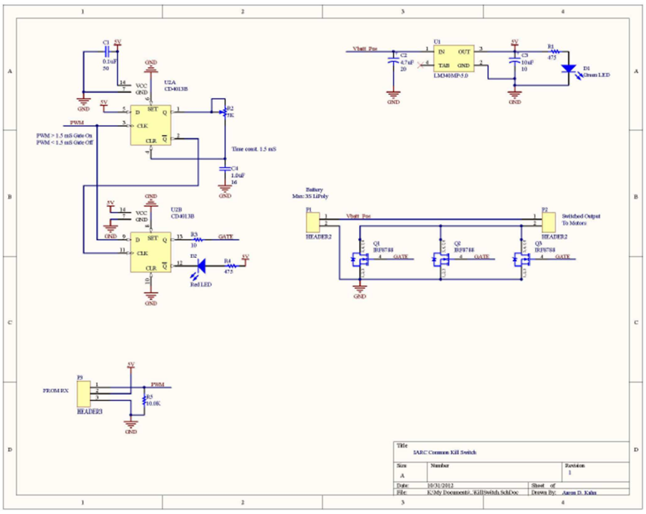

Figure 6. Kill Switch Schematic

PAYLOAD

The payload of this hexacopter will include various boards, sensors, cameras, a battery, flight controller, and the hexacopter frame. Each component has been chosen specifically for this application. Many considerations such as size, functionality, power consumption, price, and expandability have been taken into account before any final decisions were made. Each component will be mounted so that the payload weight is symmetrically distributed to conserve power.

Sensor Suite

Various sensors on the hexacopter will allow it to identify obstacles and targets along with identifying its location and orientation. The Odroid XU, the onboard computer, will receive and interpret the sensory data to prioritize actions and accomplish mission tasks. Each sensor has a specific task and will be tested thoroughly to achieve maximum performance.

GNC Sensors

There are a number of sensors that will help the hexacopter to identify its location and orientation. The hexacopter has to sense acceleration and angular velocity in three axes. Our design calls for the use of the KK2.1 flight control board from Hobby King. This flight controller has a built-in gyro and accelerometer. The flight controller also has a self-leveling mode that can be activated to level the copter using these sensors. These internal sensors will be used in concert with external sensors.

Separate gyros and accelerometers have been implemented from an IMU MPU6050 chip. Unlike the sensors on the flight controller, these sensors can be read externally in real time. The Odroid will take sample values from registers on the IMU chip at a specified sampling rate. These values are given in angular velocity. The integral of these values will produce the actual angles that the hexacopter has moved over a period of time. These sensors will allow the hexacopter to react to movements in three axes and achieve autonomous flight.

There is an issue with these sensors that still needs to be addressed. The sensor readings from the gyro and accelerometer have some error that can cause the copter to drift in any of the three axes over a relatively short period of time. These errors in angular velocity are due to sensitivity levels in the register values for these sensors. To correct these errors, two more GNC sensors will be implemented.

An integrated magnet on the IMU chip will be used to negate any errors in the X and Y axis. This means that the hexacopter will not drift or yaw to the left or right. This could potentially be a problem if not corrected because the hexacopter will orient itself incorrectly and potentially travel outside of the playing field.

The last type of GNC implemented will be a laser range finder. This laser range finder will measure the altitude or height of the hexacopter at any given time. This will stop the copter from gradually gaining or losing altitude caused from the inherent errors from the accelerometer and gyro. The distance values calculated from the laser range finder will also be used to calculate distances from the playing field grid lines and boundaries as well as the targeted ground robots and other obstacles.

Mission sensors

The onboard cameras will play a major role in sensing objects and targets while accomplishing the objectives of this mission. We plan to be able to visually identify the ground crawling robots and the other flying vehicle in the playing field.

Target Identification

Detection of lines and circles will be crucial to this project since moving ground robots have a circular shape and the borders of the 20x20 meter field are lines. Color detection is another important task, since it is needed to distinguish between each side of the field by detecting the specific color of the boundary which can be white, green, or red.

In order to detect objects, an array layout of four cameras will be arranged adjacent to each other on the bottom side of the hexacopter. This configuration was decided upon to cover and evaluate the whole field. The cameras needed will be chosen for their fps (frames per second) and their intelligent auto focus which many cameras do not implement as a feature.

To accomplish many of these tasks OpenCV is used. OpenCV is an image recognition library aimed at real-time image processing. CvCapture is a function used for capturing the incoming video signal. A signal from a camera is needed to be captured before it could be processed. Here is an example of code used:

CvCapture* cvCreateCameraCapture(int index). This is used for initializing to capture a video from a camera.

```
int main( int argc, char** argv ) {
   VideoCapture cam(-1);

   if ( !cap.isOpened() )    {
cout << "Cannot open " << endl;
     return -1;
   }
}
```

The code above demonstrates the use of capturing a video signal from a webcam. The test statement returns an error and a message if the webcam is not recognized.

For the detection of lines, Hough line transform is used. The standard Hough line has the following arguments: output of the edge detector, vector to store parameters, resolution and threshold. The function is represented by HoughLines(). The probabilistic Hough line transform is a more effective operation and it is represented by HoughLinesP(). For the detection of circles, Hough circle transform is used. The function is represented by HoughCircles(). The input image is converted into grayscale before it is processed. The arguments for this function include input image, a vector that stores three values, x,y, and r, resolution, and minimum and maximum radius of the circle. Since we can set how big of a line and circles we want to detect, they are ideal for use of circular robots and field boarder lines. Color detection uses a color filter function to detect the desired color. In the code the arguments of the function InRange are user inputs from track-bars.

```
inRange(tmp, Scalar(hlow,slow,vlow), Scalar(hhigh,shigh,vhigh), tmp);
```

OPERATIONS

Flight Operations

The flight preparations for each full flight run include an operational checklist and a safety checklist. The operational checklist includes checking structural integrity of removable components, propeller alignment, battery security, battery voltage levels, and an orientation test. The safety checklist includes checking the propeller shields, kill switch test, safety parameter, and main battery connections. These checklists have been developed over time to ensure the aerial vehicle's integrity and the safety for those in the general vicinity.

Man/Machine Interface

The design of this hexacopter does not call for a ground station, but a ground station will be used for displaying status updates during the mission. All of the processing will be performed on board by the Odroid XU computer. The only other man to machine interface will be the wireless operation of the kill switch. This kill switch will be operated by a low power transmitter and receiver. The transmitter has a switch that will activate the kill switch which will disconnect the battery from the motors. This will instantaneously cut the power to all the hexacopter's components in case of a potentially hazardous departure of the mission objective.

During testing leading up to the competition, there is another user interface through the second auxiliary channel of the transmitter that will stop the run and automatically enter a landing algorithm. This interface is implemented to prevent unnecessary damage to the hexacopter during controlled testing runs.

RISK REDUCTION

Vehicle Status

The KK2.1 Board has a status LED that turns on when the hexacopter has been armed and ready to fly. A loud tone will also go off when the copter is originally armed. Currently in process, a ground station will be created in order to monitor information of the copter such as the battery life and its current location on the field. This information will be used in order to monitor if any malfunctions occur and to monitor if the kill switch needs to be used.

Shock/Vibration Isolation

In order to withstand shock and damage to the hexacopter most of the frame was designed using carbon fiber. This was used because carbon fiber is light weight and stronger than the original design of aluminum. A polymer damper was put under the KK2.1 in order to minimize the amount of vibrations. This was needed in order to prevent inaccurate measurements by the on-board gyroscope and accelerometer.

EMI/RFI Solutions

Our components are designed to shield themselves from EMI and RFI therefore shielding solutions were not needed.

Safety

Safety to both the surrounding environment and the hexacopter itself was one of our top priorities. The hexacopter will be equipped with propeller guards in order to protect the propellers from breaking when it hits an obstacle and in order to protect bystanders when the hexacopter is in flight.

A kill switch as required by the competition rules was constructed in order to manually shut the power from the battery to the hexacopter. The kill switch produced was the one provided by the IARC however it was modified to be used with a 4-Cell Li-Po battery by using only two N-MOSFET devices. The kill switch will only be used if the hexacopter gets out of control or exits the field of play.

Testing

Since the image processing and the design of the hexacopter were done in parallel, testing for the line and circle detection were simulated by both still images and live video feed. Still images were first used in order to make sure that the algorithms used would distinguish both lines and circles. Once the results were satisfactory, a web cam was used to simulate actual usage on the hexacopter. Different angles and movements of the camera and a circular object were used to test the limit of the algorithms as well as the capacity of the cameras. Adjustments such as different filtering and blurs were used to improve the results.

As for the hexacopter, it was first flown under pilot control in order to test the stability and to make sure every motor was working properly as instructed. A testing structure was created in order to test autonomous movement. This structure will test minute movements in every direction such as taking off, moving left, moving right, and landing. The advantage of using this structure is that it will limit the movement of the hexacopter so that it does not accidentally crash when testing and will protect those operating it.

CONCLUSION

Our team’s main objective is to complete a highly competitive UAV. In the process of striving for this goal, all our members will be sharing information and enacting methods for innovation. The implementation and development process will be rooted in our modeling, testing, and algorithms in order to improve the current platform.

References

HobbyKing Kk2.1.5 Board. n.d. 8 April 2014. <http://hobbyking.com/hobbyking/store/__54299__Hobbyking_KK2_1_5_Multi_rotor_LCD_Flight_Control_Board_With_6050MPU_And_Atmel_644PA.html>.

International Aerial Vehicle Competition. “Mission 7 Rules.” n.d. 8 April 2014. <http://www.aerialroboticscompetition.org/downloads/mission7rules_100314.pdf>

ODROID | HardKernal. n.d. 8 April 2014. <http://www.hardkernel.com/main/products/prdt_info.php?g_code=G137510300620>.

“T18 - ESC- T-Motor.” n.d. 8 April 2014. <http://www.rctigermotor.com/html/2013/esc_0916/82.html>.

OpenCV| OpenCV. n.d. 8 April 2014. <http://opencv.org/>.

MN3110. n.d. 8 April 2014. <http://www.rctigermotor.com/html/2013/Navigator_0910/35.html>.

“Motors and prop combos | FPK UK.” n.d. 8 April 2014. <http://www.fpvuk.org/things-explained/motors-and-prop-combos-explained/>.