Autonomous Quadcopter with Human Tracking and Gesture Recognition

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Abstract—**The goal of this project is to create a quadrotor helicopter (quadcopter) that can autonomously follow a particular human as well as respond to gesture-based commands. A quadcopter is a type of aircraft similar to a helicopter, but has four powered propellers which provide lift. By varying the speed of each propeller, the aircraft can be made to alter its orientation and direction of motion. The quadcopter being used is a Parrot AR Drone 2.0. Initial work was done on the XAircraft X650CF quadcopter, but the AR Drone proved to be a better platform for the purpose of the project. An obstacle avoidance system was set up and working on the XAircraft. The system used 6 ultrasonic sensors to get distance readings from the positive and negative directions of the 3 axes of the quadcopter. However, the AR Drone cannot carry as much weight as the XAircraft. Due to the weight limitations and time constraints, the obstacle avoidance system was not transferred to the AR Drone. Human tracking is done by tracking a red ball with a front facing camera that comes pre-equipped on the AR Drone. The same camera is also used to detect gestures, in this case high velocity horizontal or vertical motion of the red ball. In addition, the quadcopter will have a wifi connection, allowing live video feed and data to be streamed over the Wi-Fi. The video feed and data will then be analyzed and stored on a computer connected to the quadcopter. Once the video feed and data have been analyzed on the computer, the computer will send flight commands back to the quadcopter based on the analysis.**

Keywords-Autonomous Quadcopter; Human Tracking; Gesture Recognition;

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1. Introduction

A “quadcopter” is a type of aircraft similar to a helicopter, but has four powered propellers which provide lift. By varying the speed of each propeller, the aircraft can be made to alter its orientation and direction of motion.

The goal of this project is to create a quadcopter that can autonomously track and follow a particular human as well as respond to gesture-based commands. The human tracking will rely on image processing to find a object the human will be carrying. In addition, the quadcopter will have a wifi connection, allowing live video feeds and data to be streamed over the internet. Autonomous flight will include auto-stabilization, obstacle avoidance, and a low battery landing protocol. As an added safety measure, there will be a WiFi control-based manual override.

Earlier senior projects used the quadcopter platform XAircraft X650CF. However, no successful autonomous flight resulted, therefore, the current project will be a new endeavour. Using an A.R. Drone, block diagram seen in Fig 1, we will design, interface, write software, and run diagnostics for sensors on the quadcopter. The flow of the autonomous code can been seen in Fig 2.

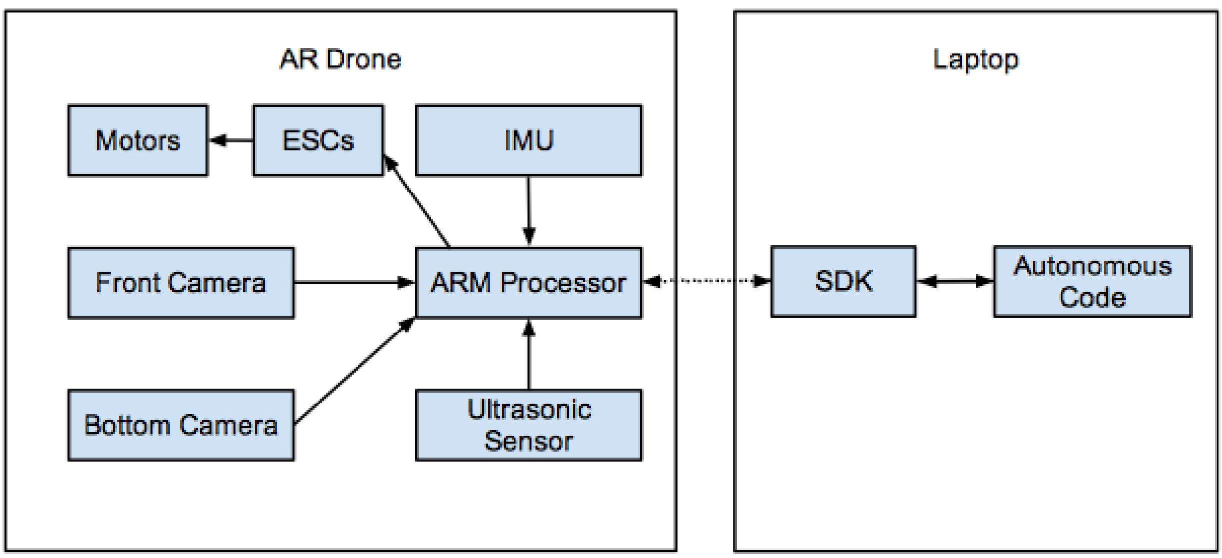

Fig 1.1. A.R. Drone Block Diagram

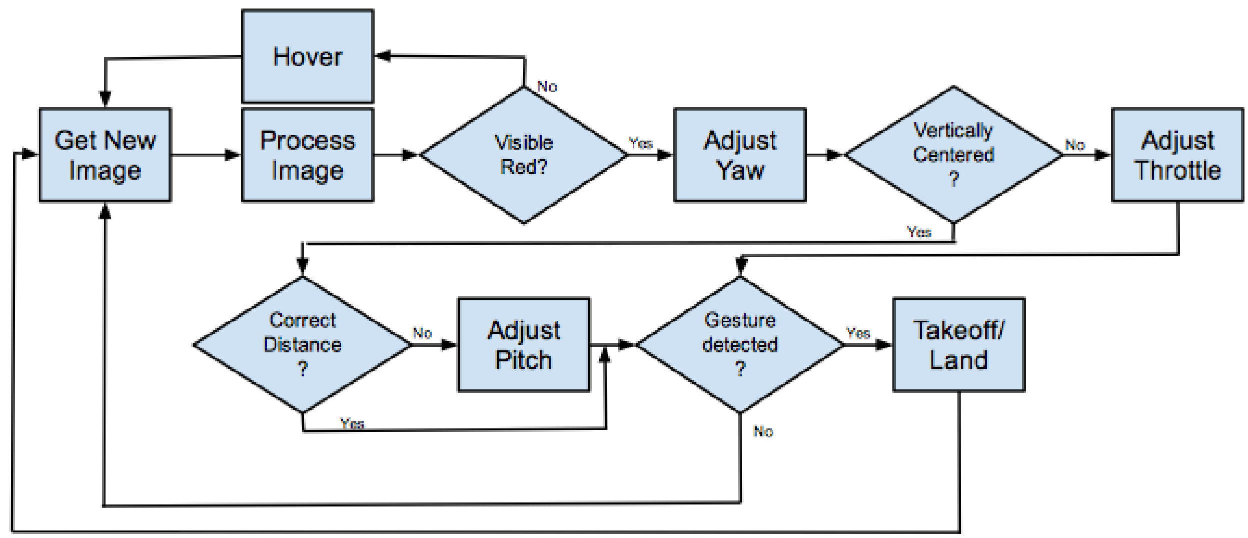

Fig 1.2. Flow Chart of Autonomous Code

Autonomous control will include the following:

- Manual override capability
- Self-stabilization during flight
- Vision-based tracking
- Gesture recognition from a tracked human, allowing intuitive control
- Wifi data connection allowing live video and data to stream to a device

2. Motivation

The use of quadcopters has expanded rapidly in recent years. Applications range from hobbyist quadcopters to military drones. For our project, a quadcopter provides an inexpensive way to safely follow a specific person, record video, and respond to gesture-based commands.

Such a device can be used for hands-free communication or observation with video and audio streaming. Applications could range from watching your child walk to school remotely to following a soldier into battle to see when they may need medical attention.

3. Autonomous Control

3.1 Manual Override Capability

There shall be a manual override, in the form of a PlayStation 3(PS3) controller connected to a laptop, to switch from autonomous control to manual control. The PS3 controller will not have control over the flight path of the quad, but will be able to turn off or on autonomous mode or takeoff or land the quad.

3.2 Self-Stabilization During Flight

All self stabilization will be controlled by the A.R. Drone's on board flight control which was included with the quadcopter when it was purchased.

3.3 Vision Based Tracking

We used vision based tracking to track the human. Specifically, the human being tracked will be carrying a red ball, as seen in Fig 1. The autonomous code will then process images from the quadcopter's front camera to detect the red color of the ball, as seen in Fig 2. From Fig 2., the average X and Y axis values of the white pixels will be found, this average point will then be considered the center point. Based on the images, control signals will be sent to the quadcopter to keep the ball a certain distance away from the quad, while at the same time keeping the center point of the ball, seen in Fig 3, centered in the image.

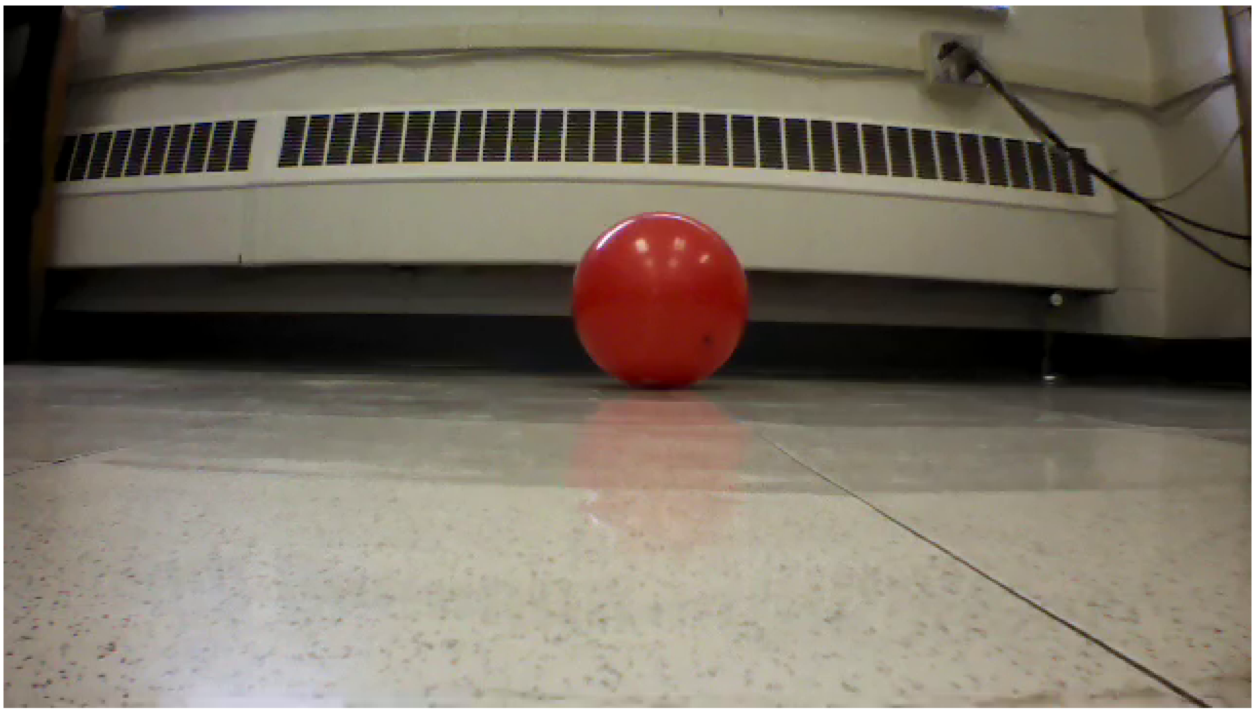

Fig 3.3.1. - Image from quadcopter's front camera

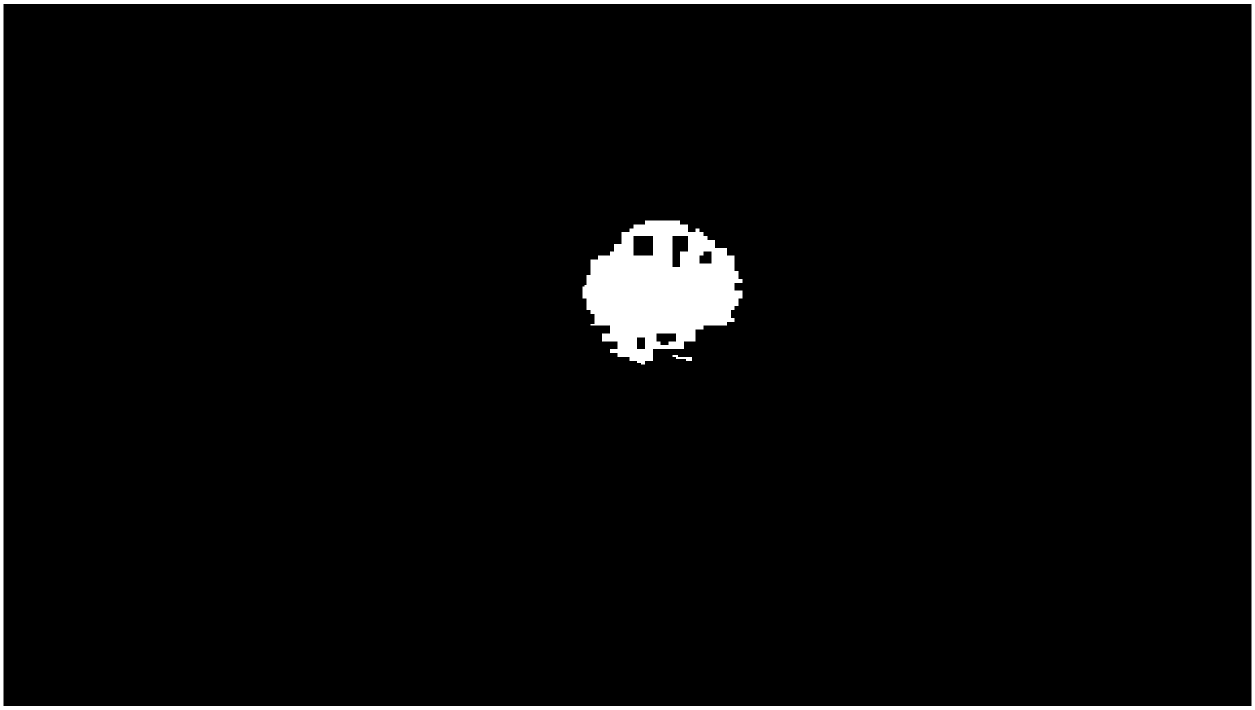

Fig 3.3.2. - Image seen in Fig 3.3.1. after autonomous code has been filtered for the red color of the ball

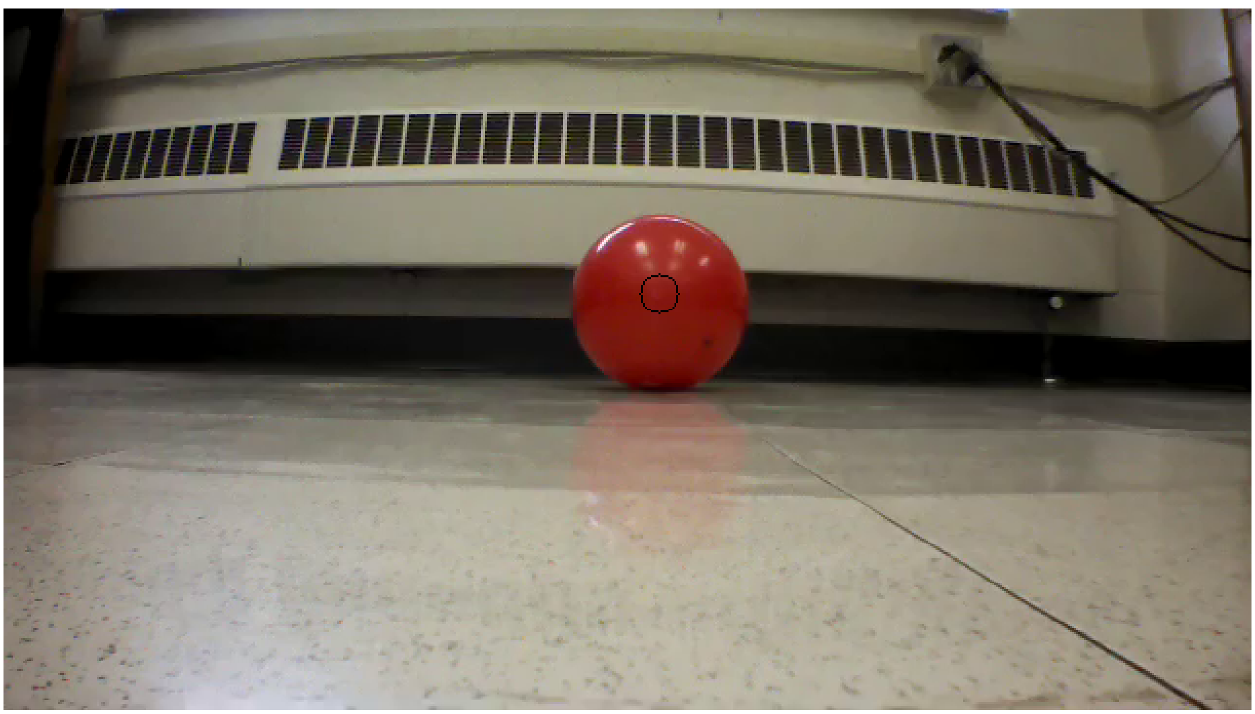

Fig 3.3.3. - Image seen in Fig 3..3.1 with center point of ball shown in image

3.4 Gesture Recognition from a Tracked Human, Allowing Intuitive Control

The tracked human will be able to use high velocity horizontal and vertical movements of the previously mentioned ball to trigger actions in the quadcopter. The actions that are triggered by the signals are land and takeoff. This adds a safety element to the system, allowing the nearby human to influence the quadcopter's behavior. This could be valuable if, for example, the human sees an impending collision that the quadcopter has not noticed. The gestures will be detected by comparing the position of the center point of the ball in the previous image and the current image. If the distance between the center point of the 2 images is greater than 50, but less than 55 pixels in either the x or y axis a horizontal or vertical gesture is detected.

3.5 Obstacle Avoidance

With the initial Xaircraft platform, the obstacle avoidance comprised of six ultrasonic sensors faced outwards in the shape of a cube. With a new propeller guard design, the ultrasonic sensors were mounted onto the guard. The six ultrasonic sensors were chain-linked together to allow for mitigate some of the noise from the environment. Additionally, the firing sequence of the six ultrasonic sensor also help mitigate crosstalk and echos when the quadcopter was near a wall. In the initial design, the ultrasonic sensors were individually controlled by a PID control loop. The signal from the feedback of ultrasonic sensors would adjust the yaw, pitch, and roll as necessary to avoid any objects. When the platformed changed, the object avoidance system didn't get transferred over to the new quadcopter. The weight distribution of the sensors on the new system required further testings that was not pursued further in this project.

3.6 GPS

In our initial design, GPS was used to locate the human while outside. A GPS unit would be placed on the quadcopter while another unit was on the human. The GPS coordinates of the user are sent to the quadcopter. Using the latitude and longitude of the two devices combined with a compass, it is possible to create a vector that points from the quadcopter's current location to that of the human. The vector is then translated into appropriate yaw and pitch. This system has not been transferred to the AR Drone due to weight and time limitations. In addition, the AR Drone platform has been used inside primarily, where GPS is neither regularly accessible nor needed.

3.7 WiFi Data Connection Allowing Live Video and Data to Stream to a Device

The video captured from the camera on the quadcopter and PID error information will be sent via WiFi to a computer connected to the quadcopter. The captured video feed will show how the images gathered from the front camera of the quadcopter and will show the center point of the ball. The error information gathered from the PID controls loop will help us refine the constants we use in the equations.

4. Reason For Switching to A.R. Drone

Our senior project goal is the conversion of an existing quadcopter platform to autonomous operation. The platform we were given was a XAircraft X650CF, block diagram seen in Fig 4. One of the four motors had stopped working last year year. In addition, a second failure had occurred. Both of these issues seem to be the result of the electronic speed controllers (ESCs) not being able to support the current draw of the motors. The existing ESCs supported 10A, while each motor can draw significantly more than this. As a result, the ESCs were failing. In fact, the failure resulted in the ESC briefly igniting.

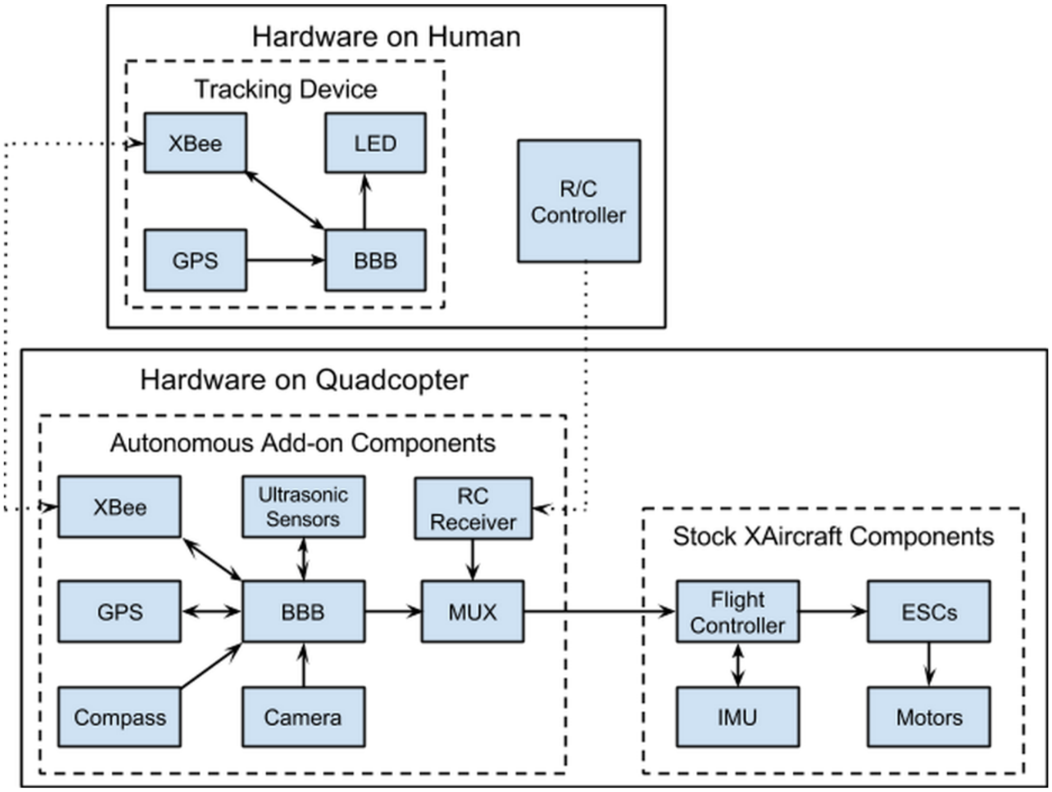

Fig 4.1. Block Diagram of XAircraft

Because of these issues, the existing ESCs were going to be replaced. However, to simply replace them with higher-current versions would have been problematic, as the existing XAircraft flight controller only works with XAircraft ESCs. So to use non-XAircraft ESCs ment that a new controller would have been needed. If we used XAircraft ESCs (rated at higher currents), we would have been investing more money into a system that is difficult to maintain (due to the proprietary nature of the controller/ESC interface from XAircraft). We also had serious concerns about the reliability of products from XAircraft. This is not desirable for a platform that should last for several years. In addition, we had a great deal of difficulty obtaining documentation, datasheets, etc. for the XAircraft components.

Due to price drops over the years since purchasing the X650, switching to a new, more reliable platform rather than investing more money into a system with unreliable components seemed to be a better option. As a result of these issues, we recommend moving to a new platform such as the A.R. Drone, described in more detail below.

5. Proposed Options

The XAircraft X650 CF uses a proprietary communication protocol called UltraPWM between the flight controller (FC1212-S) and the ESCs. For this reason, we could not simply replace the ESCs with standard ESCs. In addition, the XAircraft motors required the use of non-standard propellers made by XAircraft. Not only did the XAircraft propellers cost more, but they are also more difficult to find at typical online distributors.

It is also worth noting that there was a chance that the XAircraft company did not make quality parts and that we would encounter similar failures in the future. The quality and quantity of available specifications and datasheets had made the entire process more difficult than originally anticipated. In regard to the quantity, the main XAircraft website did not have specific manuals or datasheets for the carbon fiber edition. XAircraft had to be contacted directly in order to receive appropriate manuals and documentation. The quality of the translations used in all of their documents was poor, and lacked sufficient details beyond basic I/O connections.

When creating and evaluating our options, we looked closely at material costs, development costs, replacement wait time (i.e., downtime), maintenance costs, and opportunity costs. Specifically, we weighed maintenance and development costs as higher factors for consideration than material costs and downtime. We used opportunity costs as a mean to compare the options with one another.

Our proposed solutions ranked in order of our preference:

1. Purchase a new quadcopter
2. Repair XAircraft with generic components
3. Repair XAircraft with XAircraft components

5.1 Option 1 - Purchase a New Quadcopter

In considering a new quadcopter, we analyzed four different platforms as potential replacements for the XAircraft quadcopter. Among the four (APM:Copter, ELEV-8 Parallax, Parrot's AR Drone, and the DJI Phantom), the group came to consensus that the APM:Copter provided the best platform for both our project and for future use. Though we thought the APM:Copter would have been the best new platform our advisor, Dr. Driscoll, already owned an A.R. Drone and said it would work well for our project so we decided to work with the A.R. Drone.

5.1.1. APM:Copter

The APM:Copter (formerly known as ArduCopter) is part of the open source APM autopilot line of 3D Robotics (3DR). A large community has developed around this platform, and component information is readily available. The 3DR APM:Copter comes either pre-assembled Ready-To-Fly (RTF) or as a kit. The components all use standard interfaces (unlike the XAircraft), and so can easily be repaired or replaced if needed. Our APM platform choice for the project would have been the $623.99 3DR RTF Quad (with GPS), described below.

3DR APM:COPTER QUAD KIT COMPONENTS

- 2 Fiberglass Main frame boards
- 5 Aluminum arms (3 Black, 2 Blue)
- 2 Fiberglass Carrier boards
- Fiberglass Landing gear
- Female T plug - Male XT60 adapter
- Power distribution board, power cables and signal cables for PDB-APM
- Motors (880kv), props (11x47) and SimonK loaded ESCs
- APM 2.6, (Atmel ATMEGA2560 and ATMEGA32U processors)
- Optional Ublox with compass
- Power Module (Deans)
- All hardware needed to assemble the components above

3DR APM:COPTER QUAD KIT MISSING HARDWARE

- Batteries
- R/C system

3DR APM:COPTER QUAD COSTS

- $449.99 3DR APM:COPTER Quad C Frame + Optional Electronics Kit (without GPS)
- $529.98 3DR APM:COPTER Quad C Frame + Optional Electronics Kit (with GPS)
- $623.99 3DR RTF Quad (with GPS)

5.1.2. ELEV-8 Parallax

Known for their BASIC Stamp microcontrollers, Parallax recently developed a hardware kit for a quadcopter. The flight controller is a HoverFly Sport Board that was created by a company called HoverFly. The quadcopter is not yet well known in the community and not many people have done modifications to the quadcopter yet. So one concern with this platform is that we do not know how easy it is to make modifications. The ELEV-8 website stated that 8 hours of assembly time is required for this quadcopter, but it also has two pounds of payload.

ELEV-8 QUADCOPTER KIT COMPONENTS

- 2 - Gem Fan 10x4.5 Composite Propellers
- 2 - Gem Fan Composite Pusher Propellers
- 4 - Gem Fan Plush mount 30A ESCs
- 4 - Gem Fan A2212-13 1000kv motors
- 4 - Anodized 6061 5/8" - .035 aluminum round tube
- HoverFly Sport Board

ELEV-8 QUADCOPTER KIT MISSING HARDWARE

- Batteries
- R/C
- GPS

ELEV-8 QUADCOPTER COSTS

- $599.00 ELEV-8 Quadcopter Kit
- $179.99 ELEV-8 Airframe & Hardware Kit (no electronic components)

5.1.3. Parrot AR Drone

The AR.Drone 2.0, made by Parrot, comes largely pre-assembled and is typically controlled via wireless connection to a smartphone or tablet. Third party software is available to connect the quadcopter to a computer for more advanced control. Because the design is meant for plug-n-play, the payload on the AR.Drone 2.0 is weak, at about 150 grams.

AR.DRONE 2.0 POWER EDITION COMPONENTS

- 3 Sets of Colored Propellers + 1 Set of Standard Propellers
- 2 1500 mAh HD battery
- 720p HD Front Camera
- Outdoor Protective Hull

- Indoor Protective Hull with Guard Rings
- Battery Charger
- Navigation Board
- Main Board
- 4 10-bit ADC Speed Controller
- 4 Parrot brushless 15W motors
- Gears and Shafts

AR.DRONE 2.0 POWER EDITION MISSING HARDWARE

- No Controller (ie. iPad, iPhone, Android, etc.)

AR.DRONE 2.0 COSTS

- $299.99 AR.Drone 2.0
- $369.99 AR.Drone 2.0 Power Edition (longer flight time)

5.1.4. DJI Phantom

The DJI Phantom is the most professional-level RTF quadcopter option that we have seen in this price range (more advanced systems can cost thousands). It comes with its own remote control and LiPo battery as well. The only drawback to such a nice system is its black-box build style that is not easy to modify. While it is a great RTF quadcopter at a very good price, it lacks some of the development options we are looking for.

DJI PHANTOM QUADCOPTER COMPONENTS

- Phantom Frame
- GoPro camera mount
- 2200mAh LiPo Battery
- Battery Charger
- USB cable
- Remote Control Unit
- 6 Propellers
- Digital Compass
- DJI built in ESCs
- DJI built in Flight Controller

DJI PHANTOM QUADCOPTER COSTS

- $479.00 DJI Phantom RTF

5.2. Option 2 - Repair XAircraft with Generic Components

An alternative solution to purchasing a new quadcopter was to modify the current quadcopter. The intent is to use generic (non-XAircraft) ESCs with the existing motors and replace the flight controller with one that is able to communicate with the ESCs, and is also better-suited for research and development. We considered this method because of the existing carbon fiber frame structure and assumed working motors with propellers. However, the alteration of the quadcopter changes the initial specifications to unknowns (ie. payload, maneuverability, performance, etc.) and would require extensive testing outside of the scope of our project. Additionally, we still faced the same problems in regards to the propellers being keyed to the XAircraft motors and a lack of information on the XAircraft motor specifications (ie. rpm, current draw, power consumption, voltage characteristics, etc.).

COST OF MODIFYING QUADCOPTER

- $54.04 = 4 x $13.51 Hobbyking YEP 30A (2~4S) SBEC Brushless Speed Controller
    - $239.98 = 1 x $239.98 APM 2.6 Set (external compass)
- $294.02 = Total Cost for Modification

5.3. Option 3 - Repair XAircraft with XAircraft Components

The most straightforward solution to the replacement of the 10A ESCs is to purchase higher rated ESCs. Unfortunately, XAircraft's ESCs are only compatible with the XAircraft flight controller. The 30A ESCs are intended for use with the current XAircraft models and a lack of information raises questions about whether or not the ESCs are compatible with their older quadcopter models. Although replacement of the ESCs is the least expensive option in the short term, it is a costly investment for the future. Not only are we making assumptions about the ESCs and flight controllers working, but we are also assuming the motors are still in working condition.

Most importantly, a generic ESC costs about $18.00 in comparison to the XAircraft ESCs at $28.99 each. If any failure occurs through manufacturing defects or human error, it would cost nearly twice as much to replace the ESCs.

As a consideration of future expenses, the XAircraft X650 propellers are specially keyed to the XAircraft motors. If the propellers broke during a test flight as a result from a crash, the replacement propeller must be obtained from the XAircraft company. As a comparison of the cost of propellers, generic propeller brands are about $6.00 for a set of 4 whereas the XAircraft's propellers costs $20.00

MINIMUM COST OF REPAIRING QUADCOPTER

- $115.96 = 4 x $28.99 XAircraft x650pro x650 PRO parts E7007 brushless 30A ESC
- $9.89 = 1x $9.89 XAircraft X650 parts E1009 usb link
- $125.85 = Total Cost for Repair

WORST CASE SCENARIO COST OF REPAIRING QUADCOPTER

- $9.89 = 1x $9.89 XAircraft X650 parts E1009 usb link
- $19.98 = 1 x $19.98 XAircraft X650 v4 v8 x450p parts p3001 v1 brushless motor
- $115.96 = 4 x $28.99 XAircraft x650pro x650 PRO parts E7007 brushless 30A ESC
- $280.00 = 1 x $280.00 XAircraft X650 v4 v8 x450p parts -- Fc1212-P and AHRS-S V2 combo
- $425.83 = Total Cost for Repair

COMPONENTS STILL MISSING IN COMPARISON TO A RTF QUADCOPTER

- GPS unit

6. Conclusion

Initial work was done on the XAircraft. We managed to get GPS communication working between the human and quadcopter. We also built and implemented an ultrasonic sensor obstacle avoidance system on the XAircraft. Later on, we discovered that the XAircraft would not work as the quadcopter platform for our project. We then switched the the Parrot A.R. Drone. Though we did not have time to switch our previously completed work form the XAircraft to the AR Drone we did implement new components of the autonomous control. Human tracking is done by, with image processing, looking for the specific color of a ball the human will be carrying and following that color. Gesture recognition is done by looking for high velocity changes in the center point of the ball.

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