Quadcopter

First Semester Report
Fall Semester 2011

- Full report –

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Prepared to partially fulfill the requirements for
ECE401

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Abstract:

The military use of unmanned aerial vehicles (UAVs) has grown because of their ability to operate in dangerous locations while keeping their human operators at a safe distance. The larger UAVs also provide a reliable long duration, cost effective, platform for reconnaissance as well as weapons. They have grown to become an indispensable tool for the military. The question we posed for our project was whether small UAVs also had utility in military and commercial/industrial applications. We postulated that smaller UAVs can serve more tactical operations such as searching a village or a building for enemy positions. Smaller UAVs, on the order of a couple feet to a meter in size, should be able to handle military tactical operations as well as the emerging commercial and industrial applications and our project is attempting to validate this assumption.

To validate this assumption, my team considered many different UAV designs before we settled on creating a Quadcopter. The payload of our Quadcopter design includes a camera and telemetry that will allow us to watch live video from the Quadcopter on a laptop that is located up to 2 miles away. We are presently in the final stages of building the Quadcopter but we still improving our design to allow us to have longer flight times and better maneuverability. We are currently experimenting with new software so that we will not have to control the Quadcopter with an RC controller but will instead operate by sending commands from a remote laptop.

Our project has verified that it is possible to build a small-scale Quadcopter that could be used for both military and commercial use. Our most significant problems to date have been an ambitious development schedule coupled with very limited funds. These constraints have forced compromise in components selected and methods used for prototype development. Our team's Quadcopter prototype is a very limited version of what could be created in a production facility using more advanced technology. Currently our Quadcopter has achieved only tethered flight because it cannot maintain a stable position when flying. Our next step is to fix the software so that we can achieve controllable untethered flight. We are also working on integrating our own Graphical User Interface (GUI) which will allow us to have direct control over all systems. Although there are many enhancements that we could do to the design, we have proven that it is possible to produce a small scale UAV that performs functions of interest to the military as well as commercial/industrial applications.

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Chapter 1: Introduction

UAVs for military use were reduced to practice in the mid-1990s when the Global Hawk [1] and the Predator [2] were developed. These were very large fixed wing aircraft with wingspans in the 50 – 100 foot range. Payloads for these large UAVs included radar, laser designators, cameras, and missile systems. The introduction of these aircraft removed the pilots from harm's way plus added the ability to remain in the target area for many hours at a time. These very successful UAVs represent a fundamental change in the way conflict is managed by the U.S. However, these UAVs are large and very expensive and they beg the question of whether smaller UAVs could also play a role in military applications. Likewise, on the other extreme, there is considerable work in micro UAVs some of which are bio-inspired designs. There are designs modeled after insects and birds, but just as the large military UAVs are too expensive, we felt that these micro-UAVs were too small to be practical and required technology that was not readily available to a senior design project group. It was therefore a vehicle in the one foot to one meter class size that caught our team's interest and is the basis for our project. Specifically, our team is very interested in whether these smaller UAVs can be used not only for military applications but also for commercial and industrial use.

Although most of the large military UAVs are fixed wing aircraft, we felt that a small UAV should have greater maneuverability and versatility since it was likely to be useful for a broader range of applications than the larger or smaller versions. We were also motivated by the DARPA UAVforge [4] challenge which required a vertical takeoff UAV design. We selected the Quadcopter design because of its maneuverability, stability, and large payload capacity. The

UAV that we are building is a prototype unit that could be used for commercial use but is not rugged or robust enough for military use. Although we will meet the goal of producing a small UAV that could perform useful missions in both military and commercial arenas, time and funding constraints forced us to design a UAV to meet our functional requirements but not to meet harsh environmental conditions such as those encountered during military missions. However, our UAV design certainly could be re-implemented with newer and more robust technology which would allow it to be used for military functions.

The Quadcopter configuration UAV will be capable of being remotely controlled to fly specific pre-determined missions. I plan to select a few mission scenarios, in conjunction with my faculty advisor, to show the range of control and monitoring capabilities of such a platform. Such missions might include inspection of a difficult to reach location, rapid deployment video from the location of a fictitious campus incident, or surveillance video from a pre-planned route around campus. As a stretch goal for my project, I will attempt autonomous flight where the UAV must, for example, avoid objects or sustain a flight path in the face of side winds. A scenario requiring autonomous flight would be a search and rescue situation where a building has collapsed and the search route is blocked by unknown objects that must be avoided during the search.

This report is organized into chapters. Chapter 2 contains background on UAVs and motivation for our project. Chapter 3 contains the technical description of the system and subsystems with a discussion of design decisions. Chapter 4 provides a description of the work on this project to date with a discussion of progress, and problems encountered. Chapter 5 presents the target markets that we envision for the UAV, issues related to production for these markets, as well as the ethical issues involved with developing military platforms. Chapter 6 includes the conclusions and future work.

Chapter 2: UAV Background and Project Motivation

UAVs for military use were reduced to practice in the mid-1990s with the High-Altitude Endurance Unmanned Aerial Vehicle Advanced Concept Technology Demonstrator (HAE UAV ACTD) program managed by the Defense Advanced Research Projects Agency (DARPA) and Defense Airborne Reconnaissance Office (DARO). [1] This ACTD laid the groundwork for the development of the Global Hawk shown in Figure (1). The Global Hawk flies at altitudes up to 65,000 feet for up to 35 hours at speeds approaching 340 knots while costing approximately 200 million dollars. The wingspan is 116 feet and it can fly 12,000 nautical miles which is considerably greater than the distance from the U.S. to Australia. Global Hawk is designed to meet domestic needs including homeland security and has been demonstrated in drug interdiction. Global Hawks are also approved by the FAA to fly in U.S. airspace.

Figure 1: Global Hawk

Another very successful UAV is the Predator which was also created in the mid-1990s but has since been enhanced with Hellfire missiles. “Named by Smithsonian’s *Air & Space* magazine as one of the top ten aircraft that changed the world, Predator is the most combat-proven Unmanned Aircraft System (UAS) in the world”. [2] The original version of the Predator, built by General Atomics, can fly at 25,000 feet for 40 hours at a maximum airspeed of 120 knots. In addition to missiles, the Predator can carry cameras, high resolution all weather radar and laser designators. The Predator is a little smaller than the Global Hawk but still has a wingspan of 55 feet.

Figure 2: Micro Air Vehicle

At the very other extreme of size are the Micro Air Vehicles (MAVs) which are an interesting research focus area. There are many designs, some of which are bio-inspired such as the flapping wing version shown in Figure (2). [3] This design is being developed in Germany at the Biomimetics-Innovation-Centre and is inspired by a bird called the swift. Micro air vehicles are also modeled after various insects and generally use exotic designs and materials and are physically small. Additionally, although this design claims to be able to glide, the erratic motion caused by flapping wings could make this a difficult platform to operate a camera from. Although the designs in this class of UAV are fascinating, our interest was in attempting to produce a small UAV which could support a broad mission capability and these MAVs were dismissed as being too small.

In addition to reviewing very large and very small UAVs, we were also intrigued by the requirements of DARPA's UAVforge [4] competition which was posted around the time we started our project. The UAVforge challenge uses crowd sourcing techniques to design and build a micro-UAV that can take off vertically, go to a designated distant location, monitor the location for up to three hours, identify specific objects and then return home. We found this challenge interesting because, since it was a DARPA research project, it represented pushing beyond the limits of what a small UAV had ever achieved. The requirement for vertical liftoff also aligned with our thinking about the optimum form factor for a small UAV. Many of the deployed UAVs are fixed wing aircraft; however, we were looking for something more versatile that we believed could be built in small scale. The Quadcopter, like other helicopter designs, is able to take off without a runway, take video from a fixed hovering position, and finally maneuver through tight spaces as required. The Quadcopter also provides a superior payload capacity when compared to the helicopter and is a more stable platform. Since the Quadcopter was a vertical liftoff design, it aligned well with both our team goals as well as the DARPA UAVforge goals and therefore it became our baseline form factor.

In addition to the military uses of the small UAV, we were interested in evaluating applications in the commercial and industrial sector. Our premise was that if smaller and cheaper UAVs become readily available, new markets and uses will emerge. Potential new markets in commercial and industrial applications include inspecting pipelines or even inspecting dangerous areas like a meltdown site at a nuclear power plant. Disaster relief or crop assessment seems also to be likely areas where small UAVs could be useful. We were also motivated by on-campus uses such as monitoring parking or quick-look video of an incident, or monitoring hard to reach locations, or exploration of a collapsed building or other dangerous location.

The state of the art in small UAVs seems to be a few hand launched vehicles used by the military which are far too expensive to be of interest to our project and the amateur community represented by the DIYdrones [5] website. This community is dedicated to open source development and distribution of information and technology related to UAVs. They have developed control modules, software, and various sensors that can be mixed-and-matched to build a low cost UAV. They also produce a low cost rudimentary Quadcopter system that is available for purchase. The existence of this resource makes a Quadcopter senior project feasible because some of the component parts can be reused instead of reinvented. It would not be feasible for a small three person team to create all the technology required for a Quadcopter for a very limited budget and compressed time schedule. From the perspective of our senior project, DIYdrones provides components for a quick baseline implementation that will allow us to focus on the problems of flight stability, payload management, and mission applications with more resources than if we had to reinvent the base technology. The DIYdrones components are also most importantly very low cost when compared to military alternatives and they are well documented and understood. For all these reasons, we decided to take the DARPA UAVforge as the starting point for performance metrics and the DIYdrones components as the baseline design and then test our hypothesis from that starting point.

Chapter 3: Quadcopter Technology

3.1 Concept exploration:

After deciding to create the Quadcopter, we had to decide what electronics to use and which sensors we would incorporate into it. After a lot of research on the web, we found a couple forums that discussed open source electronic and software components suitable for making a Quadcopter. Also, very basic but highly customizable Quadcopter bodies were available that were suitable for us to use to create our baseline system. The DIYdrones forum provided good information on what was being done in the amateur drone community and provided important information on what would be possible for us to use for our project. Motivated by the UAVforge challenge, we believed that the Quadcopter would be a good design starting point since it could lift off vertically, travel some distance to a specific location, record video of an object, hover if necessary, and return home upon completion. This scenario led us to the conclusion that we would need sensors including gyroscope, accelerometer, compass, GPS, and a battery monitor. We would also need payload components including a camera and a telemetry system to send imagery back to the liftoff site. Furthermore, we would need a control mechanism that would allow flight beyond the line of sight since that was also a requirement. We thought of two approaches for control beyond the line of sight. One was to use the camera and video to allow us to view the flight path from the Quadcopter point of view while guiding it with an RC controller. Second, a more ambitious approach would be to use onboard GPS and guidance and a waypoint system to send commands to the Quadcopter via the telemetry link which the Quadcopter would execute autonomously. We decided to attempt the second goal as a stretch goal for our project. At this point in the design process, we believed that it would be possible to perform most of the maneuvers and tasks required by the UAVforge challenge but we had no idea if the components we would be able to assemble would meet the performance requirements. We also had to realistically scope our project given a very small budget, a small team, and a limited amount of time to complete. We therefore decided to leverage as many commercial components as possible, get a baseline system working as quickly as possible and then focus on problems we encountered in the areas of payload design, body design, system integration, and mission evaluation.

3.2 Flight Platform:

At the start of the summer, Gerad and I began to build the Quadcopter. We started by researching many different types of Quadcopter platforms and looking at current frames in use. We decided that we would use a commercial frame and then build around it with the electronics that we wanted. With the frame, we also got the motors and propellers. These components determined how much room I had for the electronics as well as how much weight I could put on the helicopter and still have lift. The next thing we chose was the microcontroller which was an open source Arduino board which allowed us to put our own software on it. In addition to a microcontroller, we chose a sensor board called the IMU Shield. This board included all of the major sensors that we would need to achieve flight. On the IMU Shield board there is a gyroscope, barometer, compass, and accelerometer which all need to work together to make sure the Quadcopter maintains stable flight while moving or hovering. Finally we purchased a Lithium-ion polymer (Lipo) battery because they have the best ratio of weight to power. The particular battery we chose has been sufficient to complete the design, assembly, and testing of the Quadcopter systems and our experiments have shown that since we have plenty of thrust we can chose a larger battery for our mission flights to improve the flight time. Figure (3) shows the final product of our Quadcopter system.

Figure 3: Quadcopter

We also had to provide a way to control the Quadcopter from the ground. We decided to use an RC controller which is displayed in Figure (4) below. We bought the Futaba 6EX series which has 6 channels and runs at 2.4 GHz. Currently we are using 4 channels for up/down movement, pivot, left/right, and finally forward/backwards. We also can program the other two channels to perform functions such as altitude hold, a takeoff command or control the payload.

Figure 4: Remote Control

3.3 Payload Components:

The camera which provides surveillance capability for the Quadcopter is a Linksprite JPEG color camera that employs a transistor-transistor-level (TTL) logic signal. The camera has the ability to display a series of images through a serial communication output as well as 30 frames per second (fps) National Television System Committee (NTSC) formatted output. All of the sensors and electronic hardware used in this project communicate over a TTL serial connection, including the wireless telemetry module we are using. The ability to integrate the video over the serial connection seamlessly was the main reason that we chose this camera. Other reasons included the fact that it operated from a 5 V power supply, just like the rest of our sensors, and that the power consumption was low at less than 100 mA. The camera has the ability to capture VGA, QVGA, and QQVGA picture formats as well as allow the image to be compressed with various degrees of compression. This allowed us to shrink the image file size to under 30 kb per image frame which is small enough to allow us to reach a frame rate of about 2.5 fps while transmitting at 115200 bps. This frame rate should be sufficient to guide navigation or to perform surveillance. An image of the camera can be seen in Figure (5). [7] The camera is controlled by the Arduino processor board. A series of hex commands are sent to the camera from the Arduino to initialize and then start a series of image collects. The images are sent from the camera serially in hex format to the Arduino and then transmitted via the XBee-PRO telemetry modules to the ground-based computer for processing.

Figure 5: Linksprite JPEG Color Camera

The XBee-PRO telemetry module is the second payload function on the Quadcopter today. A telemetry module was needed In order to control the Quadcopter from a distance without the use of an RC transmitter. It was also needed to communicate payload camera images back to the ground control computer. The module we chose for the project is a 900Mhz XBee-PRO XBP09. The XBee-PRO modules are capable of deploying point-to-point, peer-to-peer and point-to-multipoint networks. Designed for maximum range, the XBee-PRO is ideal for solutions where RF penetration and absolute transmission distance are paramount to the application. [8] In our setup we use two of the modules. One is connected to the Arduino processor board on the Quadcopter while the other one is connected to a computer on the ground and together they allow communication between the GUI that we are developing on the computer and the Arduino board. The XBee-PRO communicates with the computer serially, through a virtual com port at a baud rate of 57600. An image of the XBee-PRO module can be seen in Figure (6). [9]

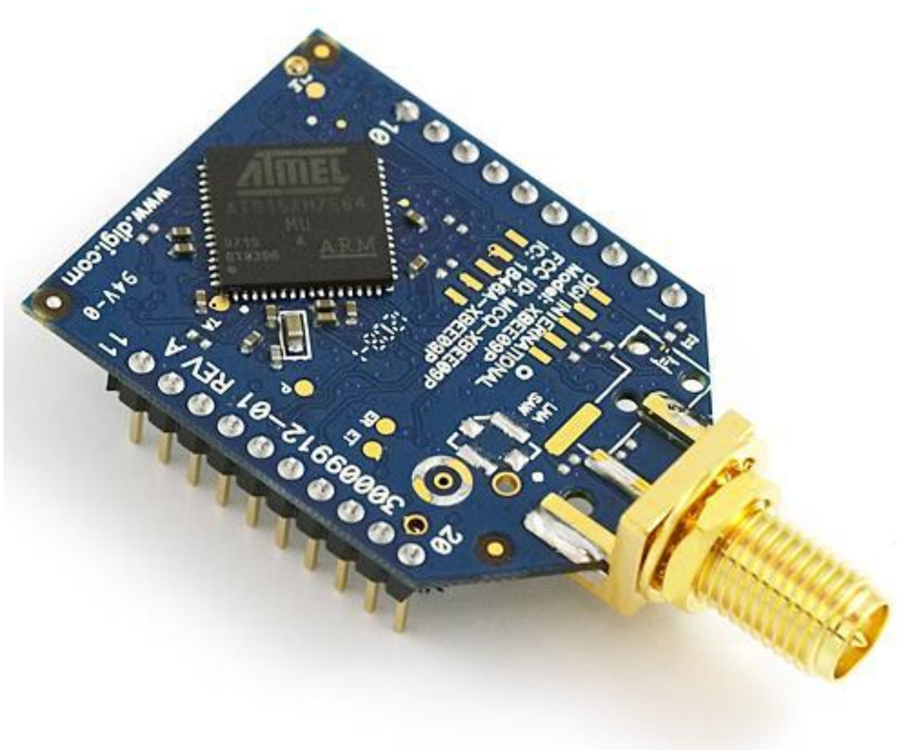


Figure 6: XBee -PRO module

3.4 Graphical User Interface (GUI):

The GUI that we will eventually be using to control flight of the Quadcopter is currently under development. It will be comprised of different tabs all having a specific purpose for the project. It was decided by the team to create a custom GUI so that we could tailor it to our specific environment and needs.

The GUI, shown in figure (7), is comprised of two areas which are the toolbar at the top which will not change and the tab bar which will allow the operator to switch which information he will be viewing. The tool bar at the top of the program will have various status indicators such as a battery level, distance from the base station, signal strength of the XBee system and GPS Lock. As all of these indicators are highly important, so this toolbar will be available at all times during execution time of the GUI. The tabs each have a specific purpose for the project. The tabs were designed to be independent from one another and with different purposes in mind.

3.4.1 Sensors Tab:

This tab was the first to be designed and plays a key role in the setup process of the Quadcopter in that it will be used to upload firmware to the Arduino and calibrate the sensors to set “zero”. Also in this tab we will be able to see the current status of the sensors in near real time and determine if any one part is not working properly.

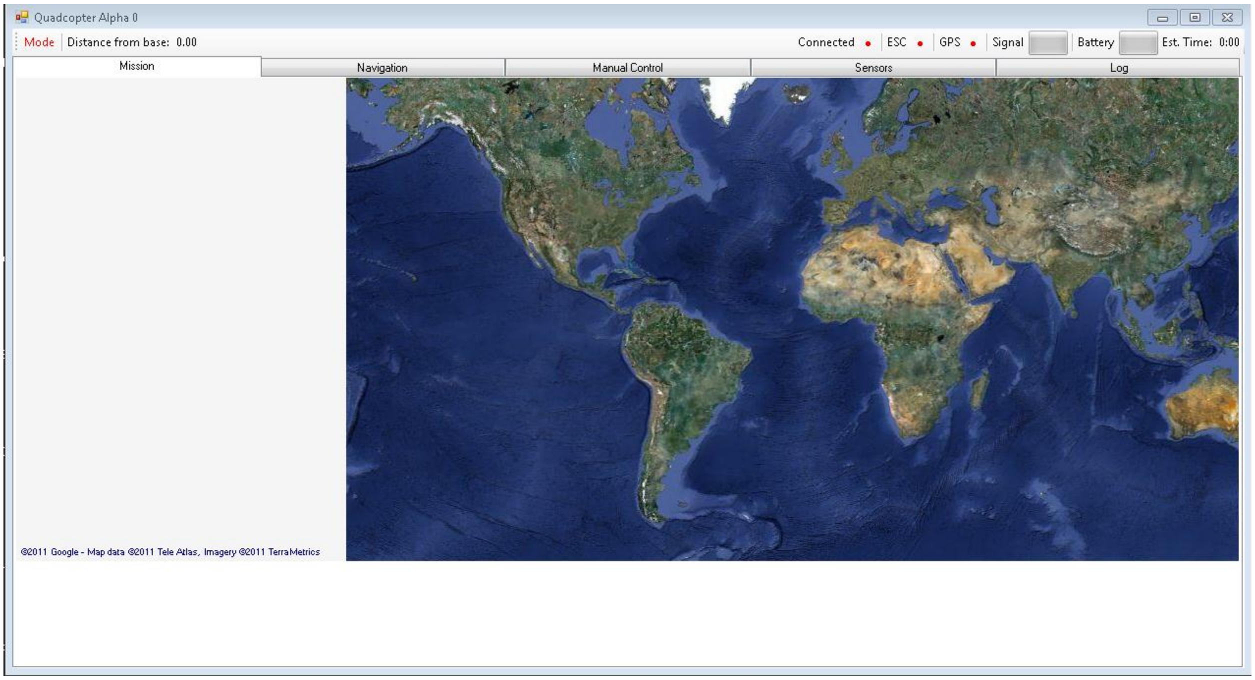


Figure 7: Current GUI

3.4.2 Mission Tab:

The mission tab is one of the most important parts of this program. It is here a user will be able to see the current position of the Quadcopter on a map and also plan out a mission. The user will accomplish this by using waypoints which will be translated into GPS coordinates which will be sent to the Arduino. Upon the start of the mission, the Quadcopter will go to the desired waypoint and complete a task that has been scheduled for that particular point. When complete, if there are more waypoints, the UAV will move on to those or finally come back to the base station.

3.4.3 Navigation Tab:

The navigation tab will play a key role in watching the Quadcopter as it completes missions. In the navigation tab we will be able to see the current position of the copter on top of a map, a live camera feed and the current pitch, yaw, and roll of the Quadcopter.

3.4.4 Log Tab:

The log tab will have the important job of displaying the after-flight logs. It will be able to show the data that was obtained by the onboard logs collected during the flight as well as the flight course on a map.

3.4.5 Manual Control Tab:

In the manual control tab, the operator will be able to take control of the Quadcopter remotely and use the keyboard to control the elevation and position of the copter. This will be the most functional tab for watching the copter in flight as it will have the ability to show video as well as give various commands to the copter including takeoff and land.

Chapter 4: Progress

4.1 Progress to Date:

Our needs analysis determined that we had to design a UAV that had a battery that lasted for an extended period of time, could fly up to two miles, and was able to take surveillance for extended periods of time. After we began the design phase and factored in the constraints of time and budget however, we realized that we would not be able to afford the right technology to achieve the goals of this competition. Although the individual tasks of the competition like vertical take-off and flying two miles seemed feasible with the technology that was within out project constraints, the combined mission was not practical. The endurance was the limiting factor because available battery power compared to the rate of consumption of our motors and electronics limited the expected duration to something on the order of 15 minutes. So, at this point in the project we decided to drop out of the competition but decided to keep the same types of goals at a reduced scale. Our revised goals became a small UAV that would operate for up to a half hour, fly up to two miles, and include a camera payload so we could capture video of targets.

With our new and more realistic project goals we began the project last summer before the fall semester to get a head start on the baseline platform. Gerad a teammate, and I did all the background research for what type of UAV we would develop then we found the parts we needed to build the baseline. We ordered parts from many different companies, physically built the Quadcopter frame and put together main electronics that contained the sensors that the Quadcopter would need to fly. We had to solder all the electronics together as well as produce a power distribution board that would power the entire Quadcopter. We explored forums on the Internet where other groups were using similar components of other projects. With the help of this information we were able to get our basic systems including the distribution of power working correctly. Since our team ordered parts from many different companies, one of our main challenges was integrating all the parts to work together. Our first challenge was figuring out where to fit everything on the frame we had bought. The frame came with generic mounting shelves in the central body which allowed us enough room to mount all of our electronics. However, since the shelves were not designed to mount our specific components, mounting and cable management were a significant problem. We have approached this problem by zip tying all the electronics down as well as their wires to make it a little cleaner.

At the end of the summer we did not have all electronics working on the Quadcopter perfectly, but we were able to get some basic software loaded onto our main control board. With this basic software on the board, we were able to communicate with the Quadcopter through a command prompt interface. This allowed us to calibrate sensors, motors, and Electronic Speed Controls (ESCs). The summer ended with a test flight of the Quadcopter with not all of the electronics working correctly. The Quadcopter never left the ground and immediately flipped over and snapped the protective case around the GPS.

At the start of this fall semester, we therefore began with a long list of problems with the Quadcopter from the summer. Our problems included broken blades, gyroscope not working, battery monitor not working, telemetry not working, and compass not working. Broken blades meant I would have to order new ones from a company in Thailand which would take three weeks to receive. The sensors including gyroscope, battery monitor, and compass were all not working at the beginning of the semester so we had to figure out why those weren't working. Finally the telemetry was not installed because it was not ordered during the summer with the other electronics. We had just ordered the telemetry at the end of the summer so when we got it, it needed to be built and integrated into the Quadcopter.

After the many problems that we had, we wanted to begin testing under more controlled environments. The first test we did was far from controlled as you could see in Figure (11). We had to come up with a better way to test the individual components including sensors and then move on to test flight. For the sensor testing we removed both the control board and the sensor we wanted to work with and hooked them into a computer to make sure the output data was correct. When we were sure that the data was correct, we placed each sensor back on the Quadcopter and hooked that up to the computer. Finally, with the individual components functioning we moved on to flight tests. Our first test required Gerad to hold the Quadcopter over his head while I ran the throttle up for liftoff. By moving the copter around we were able to monitor sensor data and make sure that it had sufficient thrust and level flight so that when released it would actually fly. This method of testing can be seen below in Figure (8).

Figure 8: Early Flight Test

Although our flight is now more stable than before, we are still in the phase of tethered flight as we continue to work flight stability issues. However, we have replaced Gerad by tying the Quadcopter to a table inside so that it is not being affected by outside weather. The Quadcopter flying while tethered can be seen in Figure (9).

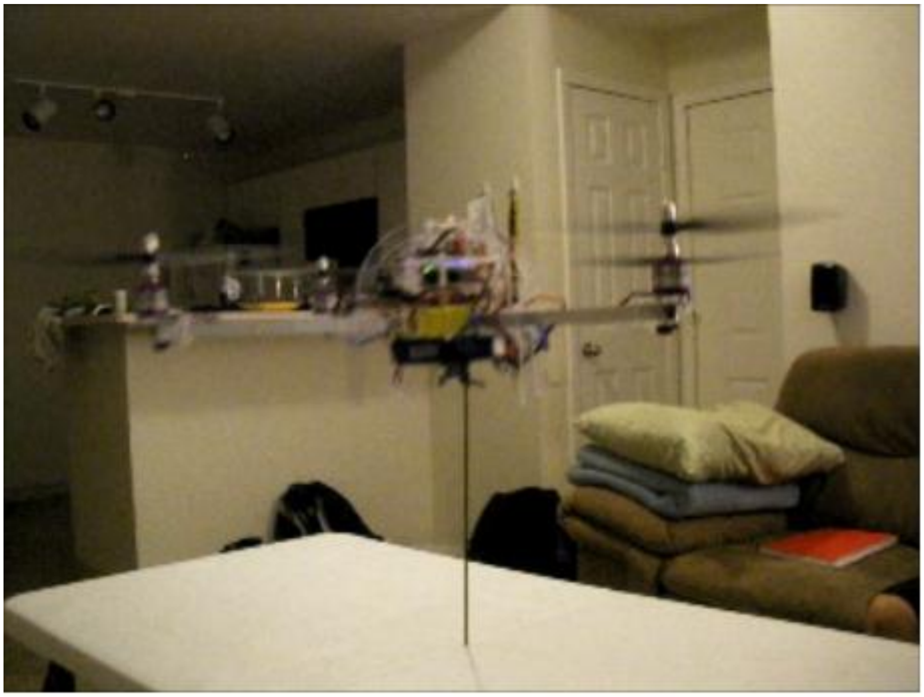


Figure 9: Indoor Tethered Flight

We allow the Quadcopter to lift a couple of inches off the ground but without enough slack to tip enough to break the blades. We continue to do testing this way to make sure that all the sensors will work during flight. We currently are seeing that one of the wings is dipped which will cause the copter to drift in that direction instead of hovering. We have also attempted an outdoor tethered flight where we provided a 5 foot slack line. This outdoor tethered flight can be seen in Figure (10). This test was successful but again it drifted to one side so we will have to fix that before we can do untethered flights.

Figure 10: Outdoor Tethered Flight

In addition to flight testing, payload integration also began this fall semester with the delivery of the telemetry component and the camera. Each of these electronics components had to be connected into the main board so that the program contained there could use them. Our Arduino board had a few extra serial connections which allowed us to connect the sensors. We just got the telemetry and sonar to work correctly through two of the serial connections on the board. Currently we are working on getting the camera to work through another one of the serial connections. The biggest problems we encountered are discussed in the next section.

4.2 Development Challenges:

Although we have encountered many difficulties during this project, we have fixed most of them. The big difficulties we have had include the gyroscope not responding, telemetry not working, random power failures, and finally radio control not working correctly.

The gyroscope was probably our biggest problem; the helicopter would not receive data from the gyroscope fast enough for it to compensate for the slight differences in motor speeds that resulted in non-level flight. During takeoff there is always one motor that spins faster than the others which causes the Quadcopter to tilt. When the Quadcopter tilts, the gyroscope is supposed to sense the tilt and signal the computer to slow down that motor while speeding up the opposite side motor to make the Quadcopter level. This tilt problem is apparent in Figure [11] shown below. We discovered that the Gyroscope was getting powered incorrectly and would not work if power cables were connected in a certain sequence. We remedy this by plugging in the battery monitor first and then plugging in the battery itself.

Figure 11: First Test

Earlier in the development process, when we had just finished putting together all the basic electronics, we were having random power failures throughout the entire Quadcopter.

This was worrying us because it could have meant that one of the components on the main boards had failed which would be very expensive to fix. We finally discovered it was a loose connection on a power distribution board that just needed to be re-soldered. We were delighted to discover this simple fix and fortunate that there were no damaged components.

With the power distribution problem solved, we began to try to communicate with the Quadcopter from an RC controller radio. Initially, we had trouble getting our radio to communicate with the Quadcopter correctly. First, our throttle was set in the reverse direction so pushing up on the throttle would mean that the motors would power down. This problem was easy to fix because the radio provided a polarity switch for this purpose. We also had problems with the motors not spinning up until the throttle was advanced 2/3 of the way. This offset meant that only a tiny movement in the throttle would have a big effect on the motor speed. This also meant that when the motors started, they started very fast and the helicopter would jump into the air without any control. We were able to remedy this problem also through control settings on the radio where we were able to scale the throttle. We had to set the minimum throttle to about 45% and the max throttle to 100%. This gave us a lot larger range of throttle which allowed for a more controlled take off and better control of the Quadcopter.

Our most recent problem was the telemetry not working at all. We attempted to test the individual components to make sure the right software was loaded on the modules, but we could not communicate with the boards. We figured out that I had soldered the Xbee module incorrectly which caused it not to work. We had to strip the module connector, order new pins, and re-solder the chip. After the re-soldering, we were able to communicate with each board.

We just recently hooked up one Xbee to a computer and the other to the Quadcopter and were able to receive data wirelessly.

We have had many problems with the Quadcopter but that is to be expected during a project like this. We are very lucky that we have been able to figure out and fix all of these problems allowing us to continue our work and get closer to a final project demo that will be presented at the end of May.

4.3 Current problems:

At the moment we have only a few unresolved problems. The main one is that the Quadcopter will not liftoff in level flight. We have done some testing and have determined that non-level liftoff occurs when the throttle is not advanced to the maximum. The liftoff seems to be more level when the throttle is set to maximum but with maximum throttle the Quadcopter leaps into the air so quickly that it is difficult to control. We are working and researching on how to fix it so that it will try to self- level at any throttle setting. At the moment we think the problem might be the communication between the motor, the ESC, and the board not sending the right information. The software algorithm may also be a factor in this instability problem, so we are looking into software solutions as well.

The only other difficulty we are currently experiencing is creating our GUI. Our GUI is going to have a lot of functions as explained above and the problem we are facing is integrating all those functions in one place. Currently we do not have a lot of documentation on integrating outside open source programs like the Google maps API which would allow us to use their satellite images for determining a route. This is an ongoing challenge but it is not presently in the critical path of our project.

In summary, there are few current problems that we are all working on as a team but there appear to be no “show stoppers”. We also know that there will continue to be unanticipated problems and obstacles between now and our May demo.

Chapter 5: Markets, Challenges Ahead, and Ethics

5.1 Target Markets:

The Quadcopter is proving to be a versatile tool that appears likely to support a number of markets and missions. Military missions, of course, are beyond the scope of our current project so we evaluated potential missions in the commercial and industrial sector that would be appropriate for the Quadcopter that we are building. For example, we were thinking that the local police here on campus that have to spend many hours looking at parking permits on cars could send the helicopter out to fly down the car line and allow an operator to watch the onboard camera to see the permits. This would cut down on man hours as well as not wasting gas by driving around to inspect cars. Additionally, the Quadcopter could be used during a campus incident to assess a dangerous situation without putting officers or first responders in harm’s way.

Other ideas include inspecting a pipeline. Our Quadcopter would easily fly down a pipeline and allow an operator to watch the onboard camera and check for problems in the pipeline. Pipelines often pass through rugged terrain with very poor roads and using a Quadcopter would mean they wouldn’t have to drive the entire route. They should be able to fly down the pipeline a lot faster and also they would be able to maneuver the Quadcopter when they needed to inspect a certain area in closer detail or even from other angles. It might also be possible to fly an infrared imager on the Quadcopter to look for areas of different temperature which might indicate a spill or a weakness in the pipeline.

During the recent week of presentations, we were also approached by someone who worked with Xcel Energy. He had seen us demonstrate the Quadcopter and he had mentioned that the Quadcopter would be very helpful for the company. We learned that they have to inspect the power transmission lines on a regular basis which takes a lot of man hours. They would use our technology by flying the Quadcopter down the power line while video recording the flight so an operator can go over the footage to make sure there are no problems. This was a neat idea because there are many power lines all over the United States and it must cost a lot of money just to inspect them. Also, this is a great application because the lines are difficult to access and they are dangerous for humans to approach.

So, even though we did not get to compete in the UAVforge competition with DARPA, we still know that there are many interesting uses for this technology.

5.2 Challenges Ahead:

The identified challenges that we have ahead include increasing battery life, integrating the hardware into our new GUI, and getting everything to work together correctly for flight. For the battery life challenge, we will be looking at alternative larger capacity batteries so we will have a longer sustained flight. Fortunately, this relatively simple solution is feasible because our experimental results so far indicate that we have plenty of thrust and can accommodate the added weight of a high capacity battery. Our fallback is to keep the battery we have and demo the Quadcopter with a shorter flight time. The GUI development challenge is mostly a matter of resources. The coding of the GUI is mostly being done by Gerad but I will be assisting him when he needs it. Coding the GUI and integrating the hardware into the GUI is going to be difficult. The way we will approach this is by integrating one sensor at a time and we will use references from other projects to help us. Trying to get everything to work correctly at the same time to sustain a flight is the grand challenge and will not happen until we are able to get everything to work on its own correctly. This will be one of the most difficult parts of the flying the Quadcopter because so many little things can go wrong. If any one thing goes wrong on the Quadcopter, it will cause it to malfunction and most likely crash. Our fallback for GUI development is to drop some features if we believe that the resource limitations are going to prevent us from completing this task.

Although production is beyond the scope of our current project, there are several challenges that would be faced by someone wishing to produce the Quadcopter. Our prototype is an evolving project consisting of components and subsystems from many different sources tied together in a manner sufficient for demonstration of concept mission support. Basic electronics subsystems could be built and delivered in large quantity but the Quadcopter would have to be redesigned to accommodate rapid assembly and test, and better sensor payload interfaces would have to be created to make customization easier. Also, the UAV technology base is rapidly changing because of the significant interest in this field. This rate of change results in rapid component obsolescence and makes technology freezes difficult.

However, at least for the challenges we have identified for ourselves, I believe that we are well prepared to get through them. We are also aware that anything can go wrong and that we will have to use our resources wisely to get through them to our final goal of a flying Quadcopter that can perform missions.

5.3 Ethics:

Ethics is becoming a more important aspect of engineering as research moves closer to impacting humans in fundamentally new ways, such as genetic engineering of crops or human organs. The National Academy of Engineering maintains a website [10] for the discussion of ethics issues related to engineering. Topics like energy, climate, and synthetic biology all receive significant attention since they are topics where ethics guidelines are being formulated. There are also codes of ethics for performing research which apply to all engineering projects and disciplines.

Our specific project on UAV design is not at the center of any of the current ethics controversies but two potential issues come to mind. Both cases involve the use of UAVs and not the design itself.

The first issue is a privacy issue. As the number of sensors and sensor platforms increases, citizens are concerned about their privacy rights. UAVs, including the ones we are constructing, could certainly be used to invade the privacy of individuals by tapping into phone conversations or video recording. We are specifically building a platform that can be used for many applications and as such we believe that any ethical concerns lie with those who might apply a UAV in such a way that it violates privacy. There is nothing specific in the design that either enables or inhibits that use.

The second issue relates to the use of a UAV as a weapons platform. There are certainly legitimate ethical discussions about this topic. The UAV we are building could not be used for such a purpose although it might be conceivable that a small UAV could be designed to carry a small weapon. Again, this ethical issue rests with others who might try to create such a weapons platform.

Chapter 6: Conclusions and Future Work

6.1 Future work:

This coming semester is going to be filled with many tasks our team still needs to accomplish before Engineering Day in May. We will want to complete the coding and integration of the GUI so that we can achieve full control with a computer rather than an RC control. We will be working on optimizing power consumption as well as looking at alternatives to the current battery system that we are using now. One of the biggest steps we will have this coming semester is getting a completely stabilized flight that will allow the Quadcopter to hover untethered in a single location. With the stabilized flight, we will also be working on getting untethered flight around a local area like the park nearby. The next step after untethered flight in a local area is to give it remote way points where it will have to go on its own to a location and come back. Once we have achieved the ability of the Quadcopter to reach a target location and then return home, we will be almost completely done with this project. We will also be researching alternative bodies that we can use to protect our Quadcopter as well as looking at upgraded hardware if we receive donations from outside sources. There are certainly a lot of tasks remaining but we will be prepared and on schedule to show a demonstration of this project in May.

6.2 Future risks:

Future risks are a great concern for our team because we want to make sure we are done by the end of next semester. We have to anticipate problems and dedicate time in the schedule to make sure we can resolve unanticipated problems. One future problem discussed in the Challenges section is the integration between the GUI and the Quadcopter. The GUI will be running everything from sensor calibration and logs of flight data to manual control of the helicopter. We will mitigate this risk by software module re-use and by being flexible in the number of features we support in the GUI as time constrains us.

The only other risk that we have thought of is pushing the Quadcopter beyond its limits without having a failsafe function. An example of this risk is failing to notice that there is insufficient battery life to safely complete a mission, resulting in the Quadcopter being in the air when all systems shut down. The Quadcopter will then fall to the ground, and most likely break. We also have to watch out for weather conditions as well as altitude ceiling to prevent similar destructive results. We have not begun to design fail safes but we do plan on including features that will try to predict as many different risk factors as we can think of and design the Quadcopter to auto respond appropriately, such as make a decision to land safely to the ground.

There is also the risk with any UAV of losing the control link to the aircraft. Witness the recent problem of the U.S. stealth drone losing communication and crashing in Iran. Our approach to this particular risk is to monitor the control link and have the copter either land or return home if the link is broken

6.3 Conclusion:

The project is presently in the final design stages and we have completed several tethered test flights. We have resolved several issues encountered in this project to date, and we continue to work on outstanding issues. Although a lot of work remains, we continue to be optimistic that we will complete the project on schedule. When the basic flight control systems are complete, the Quadcopter will be ready for experimental missions. At that point the project could go in a variety of directions since the platform seems to be as flexible as we initially intended. As a team, we can completely change what function it performs and we are able to integrate any technology that would prove to be useful. This project will clearly demonstrate the goals of proving that small scale UAVs are useful across a broad range of applications.

Appendix:

UAVforge:

Details of the UAVforge provided below are copied from the UAVforge website. The two figures below shown a concept drawing of the proposed challenge course as well as a summary of the performance requirements for the competition.

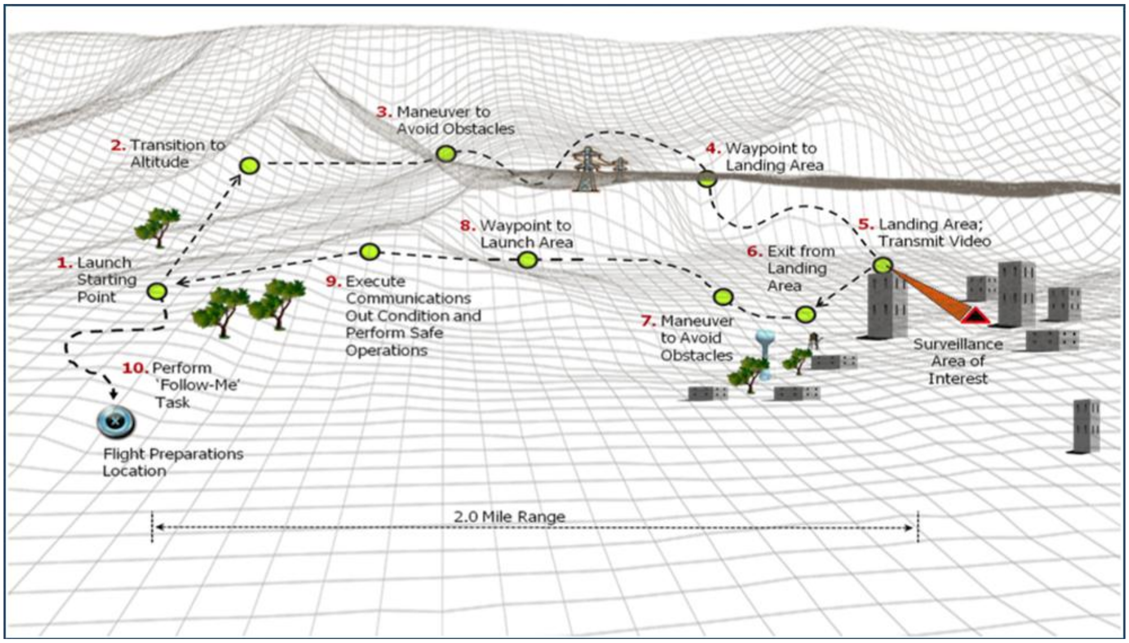


Figure 12: DARPA Competition

Technical Performance

Below are elements of the performance criteria that will be used as guidelines for judging the air vehicle systems. However, the ultimate determinant of a winning system will be the successful completion of the competition fly-off course to include evaluation by DARPA and SSC Atlantic.

- The complete air vehicle system must fit in a rucksack carried by a single person
- The air vehicle must take off vertically from a starting location, fly out to an observation location, perform observations, return to an ending location that is different from the starting position, and land vertically
- The air vehicle system must be able to fly and operate successfully with winds up to 15 miles per hour (mph)
- Without previous detailed knowledge of the observation area, the air vehicle system must perform observations for up to 3-hours at a location up to 2.0 miles beyond line of sight from the starting location
- At the observations area, the air vehicle system must be able to identify persons or activities of interest up to 100 feet away
- The air vehicle system must send real time video or pictures from its observation area back to the operator (a distance up to 2.0 miles)
- The vehicle design must consider noise reduction features to make it as quiet as possible so as not to attract undue attention
- The air vehicle user interface and vehicle controls should be simple and intuitive

Appendix A:

1. UAV (Unmanned Ariel Vehicle)
2. GUI (Graphical User Interface)
3. HAE UAV ACTD (High altitude Endurance Unmanned Ariel Vehicle Advance Concept Technology Demonstrator)
4. DARPA (Defense Advanced Research Projects Agency)
5. DARO (Defense Airborne Reconnaissance Office)
6. UAS (Unmanned Ariel System)
7. DIY (Do It Yourself)
8. GPS (Global Positioning System)
9. IMU(Inertial Measurement Unit)
10. TTL (Transistor – Transistor – Level)
11. NTSC (National Television System Committee)
12. FPS (Frames Per Second)
13. BPS (Bits Per Second)
14. ESC (Electronic Speed Controller)
15. Lipo (Lithium ion Polymer)

Appendix B:

Table 1: Buget

object	cost	reason
futaba 6 channel 2.4GHz transmitter and reciever	199.99	to control the heli
battery charger and balancing board	89.99	this charges the battery and makes sure the cells are charged at the same rate (battery last longer)
	5.95	connector for the battery to the power distribution board
Double sided tape (vibration)	2.89	this was put on the bottom of the board to help prevent vibration
Soldering tip (1/64)	6.45	needed a lot finer tip in order to do the soldering on the board
solder	2.89	needed solder
electrical tape	2.19	for wires that the rubber could not cover
x 10 header female 08POS .1"	12	
1x20 right Angle Pin headers	1	
3x8 right angle pin headers	1.99	
2x arms for the body	9	
2x propeller set	12	
4x motor	72	
ESC (power the motors)	72	
Xbee Telemetry kit	150	
Full ArduPilot Mega kit	250	
Lipo battery 2200 MAH	22.88	

2x4 wood	6.06	needed wood to solder the button connectors correctly
Dean connectors (male)	3.75	
gps	29.99	
soldering iron	149.99	
servo leads (longer cables)	5.9	spare parts
2S-3S	5.39	to get battery level prediction working
camera	54.96	to have a camera.....
1x motor	18	
1x ESC	18	
2X propeller	12	
6X propeller	45	
sonar / propellers	80	
cables	7	
Total cost so far	1349.26	

We planned a budget of 1000.00 dollars when we started. We have gone past this as you can see in table 1. We received a 100 dollar donation from Dan Ferguson at Agilent. We have paid for 1049.26 on our own, 200 from the ECE department and 100 from Agilent. We have had to order all these parts from Thailand which incurred many shipping costs. All of our costs are included above in the table.

Appendix C:

Letter to Dan Ferguson, Agilent:

Dan Ferguson
Agilent Technologies

QuadCopter
Team: Matt Parker, Gerad Bottorff, Christopher Robbiano
Supervisor: Bill Eads
http://www.engr.colostate.edu/ece-sr-design/AY11/quadcopter/index.shtml

We are a senior design team at Colorado State University in the Electrical Engineering department. We are under the tutelage of Professor Bill Eads for the development and construction of an Unmanned Aerial Quadcopter (UAQ). Our team is comprised of three members. Matt Parker, a senior in Electrical Engineering is the team leader and responsible for all of the physical hardware that resides on the UAQ. Gerad Bottorff, a junior in Computer Science is in charge programming the firmware for the UAQ. Christopher Robbiano, a senior double majoring in Electrical Engineering and Physics is in charge of the wireless video and communications systems.

The final goals of the UAQ are autonomous flight, waypoint missions and video surveillance up to two miles. A practical application for our UAQ would be the inspection of remote locations, such as a tall rooftop or pipeline, to prevent human endangerment. There are a number of components/sensors that send signals to the UAQ's onboard microcontroller, which processes these signals and controls the motors appropriately. The sensors include two accelerometers, two gyroscopes, a barometer, a compass and the electronic speed controllers (ESC). The UAQ has attained tethered level flight that lasts for a maximum of five minutes.

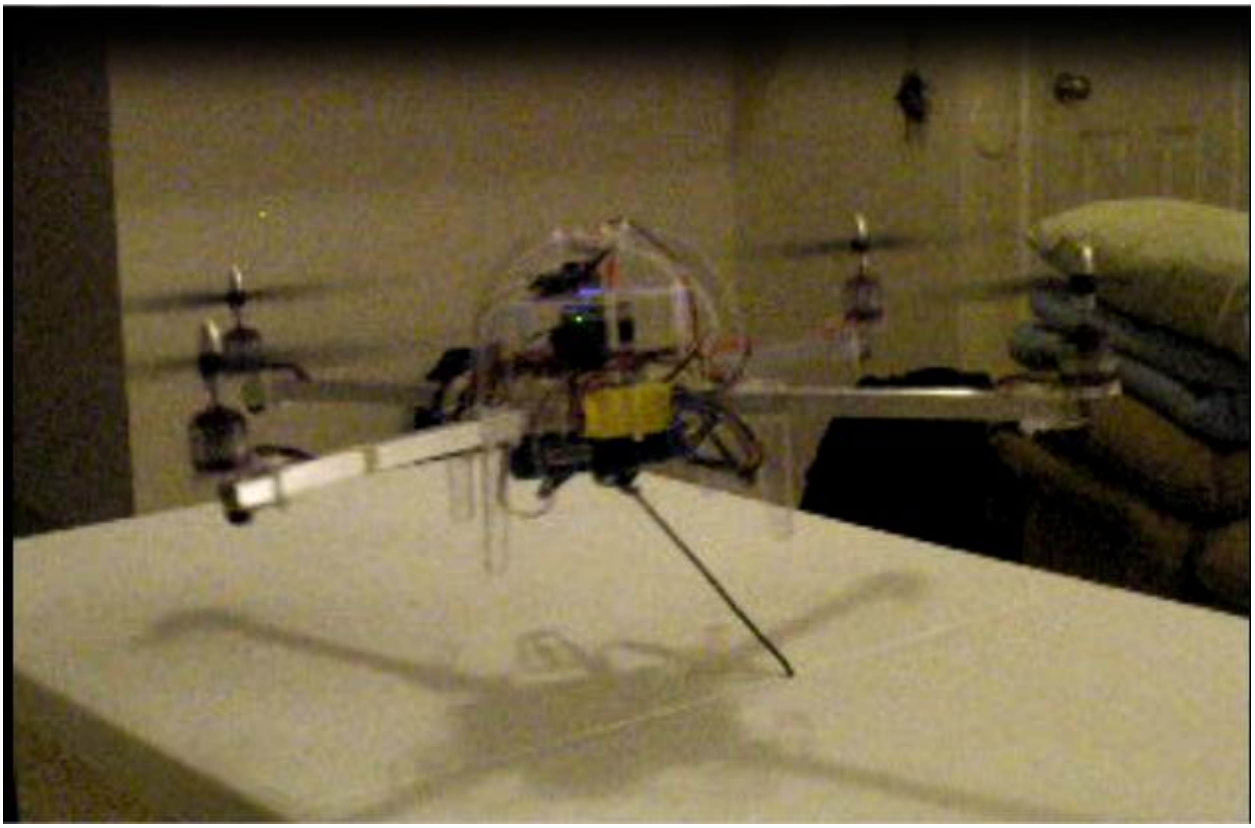
Each week the team spends a minimum of 18 hours on the project. This includes performing test flights, writing software to integrate all of the hardware together as well as testing the wireless communications system.

We have spent $1300 on this project from personal funding but to achieve our end goals we need additional funding of $800. This would include the following:

- Carbon fiber shell $200
- Sonar $150
- Spare parts (props, motors, screws, servos, etc) $100
- Battery $100
- Foam for body $100
- Camera mount $50
- IR Camera $100

Total: $800

This money would be used to purchase the items listed above and used in the following manner. The carbon fiber will be shaped around the foam to create a rigid, but light weight body that will allow us to keep all of the electronics contained. Sonar will assist with obstacle avoidance during autonomous flight. Spare parts will be used in testing and as replacements for broken parts. A larger battery will provide the UAQ with a longer sustained flight time and additional power for the video surveillance system. We will use servos to control a camera mount which will provide us with the ability to change the camera viewing angle and direction, allowing focus to maintain on target while the UAQ moves.
We appreciate that you have considered us for a donation, and would like to thank you for spending the time reading our inquiry. We look forward to hearing from you.



Regards,

Matt Parker

Gerad Bottorf

Christopher Robbiano

Acknowledgements:
We would like to thank Bob Parker for most of the funding.
We would like to thank Dan Ferguson for donating some money towards our project.
We would like to thank the ECE department for their contributions.
We would like to thank Bill Eads for accepting to advisor our project.
We would like to thank those who have shown support for our project.

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4. http://www.uavforge.net/
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6. http://www.helikraft-rchelicopters.com/store/1909/futaba/6ex-2-4g-airp-heli-radio-set-no-servo-with-r617fs-6ex-ss.html (picture of RC controller)
7. http://dlnmh9ip6v2uc.cloudfront.net/images/products/10061-01b_i_ma.jpg
8. http://www.digi.com/products/wireless-wired-embedded-solutions/zigbee-rf-modules/point-multipoint-rfmodules/xbee-pro-xsc#overview
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10. http://www.onlineethics.org