Interim F.E.T.C.H. Report

Kora Barnes, Elliot Dickison,
Brian Lee, Eric Johnston

University of Idaho

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Executive Summary

We, the Foliage Extracting Tele-Controlled Helicopter (F.E.T.C.H) group, are designing a mobile platform to aid the University of Idaho's College of Natural Resources (CNR) sampling of sun foliage (leaves from the tops of trees). The CNR uses sun foliage in studies of climate change. Its current methods of sampling sun foliage are either slow or expensive. Our mobile platform will be a remote controlled quad-copter with a cutting arm extension operable by an individual. It will meet the need to sample branches from the tops of trees up to 22cm long or 2.5cm thick. The quad-copter will be equipped with cut and hold pruners to simplify the cutting and retaining of the sample into one action. The operator can then either land and retrieve the sample or drop it in a clear place. The quad-copter will have two cameras attached with feed to a ground station laptop to assist the user in flight. The flight controller on the quad-copter will have sensors for altitude, orientation, velocity, direction, and location. These sensors will allow the flight controller to help counteract wind and being able to hover. They will also prevent the quad-copter from being lost. The complete quad-copter will be cheap and quick to operate making it the new preferred method for sun foliage sampling.

Background

This project was contracted by the College of Natural Resources (CNR) to help in the gathering of sun foliage. Sun foliage is the leaves at the top of the trees with the most sun exposure. The CNR conducts climate change experiments on sun foliage. Sun foliage is used for its retention of water. The CNR samples at dawn for consistent measurements. Sun foliage is rarely reachable by simple methods. The CNR has three present methods of gathering sun foliage: tree climbers, man lifts, and shotguns. Tree climbers required hiring an experienced tree climber to climb to the tops of the trees and cut the sun foliage sample by hand then climb down. This is a fairly dangerous method. The man lifts method requires trucking in a man lift capable of reaching very high into the air. An operator is required and the equipment is expensive to rent. The area in which trees can be sampled with man lifts is limited by the need for flat ground, and room to maneuver the lift. The shotgun method involves firing at the tops of the trees trying to knock free a sample that can be gathered from the ground. Precautions have to be taken with the types of shot used to prevent danger to any people where the shot may fall. Though cheaper than the previous methods, it is fairly destructive to the trees being sampled, noisy, and slow.

The CNR is seeking a new more efficient, cheaper method of acquiring samples. We are developing a remote-controlled (RC) quad-copter with an extendable cutting arm to meet this need. The proposed quad copter method will be cheap to operate, safe and cause little damage to the trees it samples. It will also require only one operator and very little room to operate. The quad will have some lighting and cameras which will make it easy to operate during dawn and allow gathering of more samples in less time. The samples will be consistent and safely gathered.

Problem Definition

The CNR desires a mobile cutting platform that can gather sun foliage samples from tall trees in failing or good light. Upon request from the CNR, our quad-copter solution is designed so that nearly all the parts are off the shelf. This allows for parts to be purchased and replaced with limited modifications. A manual will explain how each part works and is attached to the quad copter. The quad-copter will take samples up to 20cm in length and 2.5cm in diameter. The samples will be flown to the ground or dropped in a clear place to be gathered from the ground. The quad-copter will require about 2 hours of training to be operable by single person. It will be small enough to fit in a car. The batteries will be rechargeable by the 12 volt system available in any car so it will be usable for many hours at a time with sufficient batteries.

When the project is done a working quad copter and peripherals will be delivered to the CNR with initial training conducted. A training video will be provided for future training. A working quad-copter is defined as capable of collecting sun foliage. The peripherals for the quad will include a transmitter for controlling the quad copter in flight, batteries and charger, and a ground station. The ground station will consist of a laptop for viewing the video feed from the quad-copter. They will also receive documentation detailing safety, repair, usage, setup and storage of the quad copter.

Project Plan

Team Responsibilities:

For this project we initially split into two teams: an arm development team (Eric, Kora and Theora and a quad-copter development team (Brian, Cable, and Elliot). As the semester progressed, we eventually split into three teams so that the computer science majors could focus directly on their project requirements. The resulting groups are given below:

- Cable and Theora – Programmers (Arm extension, light control, web-page)

- Eric and Kora – Arm design (Consulted mechanical engineers, Dr. McCormack)
- Brian and Elliot – Quad copter design (Specific part selection)

Tasks and schedule:

Cable and Theora completed their goals exemplary. They brought a valuable viewpoint to the firmware design. They are leaving us with much of the arm firmware complete allowing next semester to be predominantly verification of their work with regards to arm extension, and lighting.

In early September we plan to have the arm, the cutting mechanism, and the quad-copter built. We will then proceed to test each individually. By late September we will integrate the arm and the cutting mechanism, and have tested the quad-copter with a payload. October will be dedicated to the integration of the arm and the quad-copter into one cohesive unit. By early November we will have a validated final design. We will then spend the rest of the semester on documentation.

Concepts Considered

Vehicle

We considered several designs that would enable us to access the sun foliage to be sampled. Before we started researching any particular designs, we limited our choices to some sort of remote-controlled (RC) flying vehicle. This was the most efficient, cost-effective, and easily implemented method we could think of.

We knew that any RC vehicle capable of the task at hand would need a high degree of maneuverability in order to collect samples. We also knew that it would need to be able to carry a relatively heavy, possibly asymmetrical load (the sample collecting mechanism along with the sample itself). Based on this we further limited our choices to some type of RC rotorcraft. This left us to consider whether we wanted to use a helicopter or some type of multi-rotor.

We briefly discussed using an RC helicopter. Helicopters are by far the most common type of rotorcraft and there are many types of readily-available, pre-built RC helicopters capable of carrying a significant load. However we decided against using a helicopter because they are extremely complex mechanically and are very prone to failure. We wanted a simpler, more fault-tolerant system. Having ruled out a helicopter we considered several multi-rotor designs, including a tri-copter, quad-copter, hex-copter, and octa-copter.

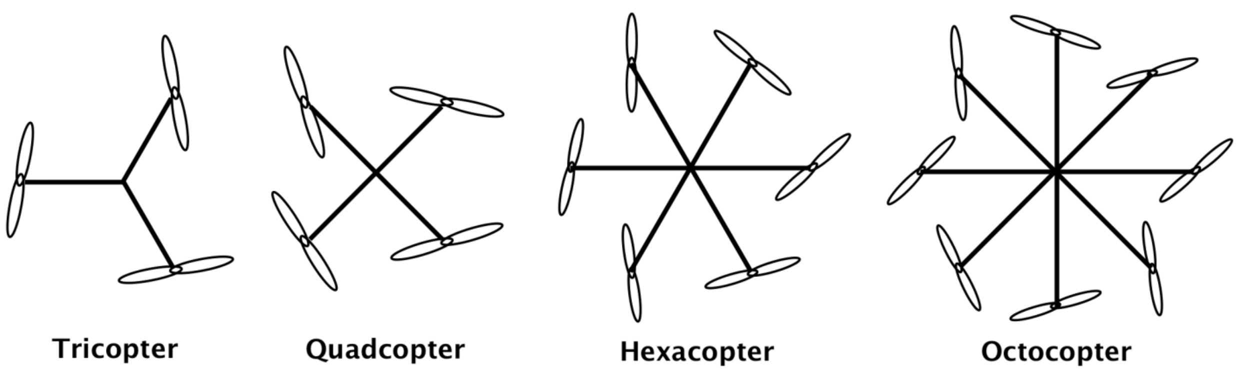

Figure 1: Multi-rotor Diagram

When researching multi-rotors we found several key factors related to the number of propellers used. We found that, in general, the more propellers a multi-rotor has the more stable it is and the more weight it can lift. However we also had to take into account that as you add propellers to a multi-rotor you lower its flight time, raise the cost to build it, and increase its complexity. Based on these facts and the budget available to us we chose to use a quad-copter design for this project.

Quad-copter Orientation

A quad-copter can be oriented one of two ways: an ‘x’ orientation or a ‘+’ orientation. In the ‘x’ orientation the front of the quad-copter is located 45° between two of the arms so that if the front were facing upwards on this page the quad-copter would look like an ‘x’. In the ‘+’ orientation the front of the quad-copter is located along one of the arms. There is very little difference between these two orientations as far as the operator is concerned, but we chose to use the ‘x’ orientation where the power for roll and pitch is distributed between all four motors (as opposed to the ‘+’ orientation where roll and pitch are each exclusive to different pairs of propellers).

Flight Controller

We researched several different flight controllers for our quad-copter. The flight controller is an on-board computer that receives input from the RC and from several other sensors and, based on these inputs, flies the quad-copter by distributing the appropriate amount of power to each of the four flight motors. All multi-rotor flight controllers are equipped with a minimum of two specials sensors: a gyroscope and an accelerometer. These sensors tell the flight controller the orientation and velocity of the quad-copter and are essential in keeping the vehicle balanced.

The quality (and price) of a flight controller is largely based off of the quality of these two sensors, as well as any extra sensors that might be included. We ended up choosing a high-quality flight controller (ArduPilot 2.5 Mega) that included three extra sensors: a magnetometer (digital compass) to help the quad-copter automatically hold its yaw (rotation) while hovering, a barometer (atmospheric pressure sensor) to help the quad-copter automatically hold its altitude while hovering, and a GPS to enable the quad-copter to automatically fly to a safe landing location upon losing either battery life or communication with the operator. The benefits gained from the first two sensors are essential to accomplishing the difficult task of hovering accurately enough to collect a leaf sample. The GPS is essential to keep the expensive equipment involved in this project from being lost and damaged.

Frame

There were several requirements we had when looking for a quad-copter frame. We wanted something that was extremely light, strong, and easily repairable. Based on this we decided to look for an off-the-shelf frame (for easy part replacement) made of carbon fiber or wood. We looked for frames with easily detachable arms, as these are the most common point of breakage on quad-copters. We also looked for frames with metal, heat-resistant motor mounts. Eventually we chose the Turnigy Talon V2, a carbon-fiber hobby frame with all of the desired characteristics listed above.

Propellers
We considered several different propeller sizes for our quad-copter. Based on research online we discovered that, in general, larger propellers allow you to lift a heavier load but also reduce the flight time available to you. For our application we considered using either 10” or 12” propellers. Based on some research online and some of our own calculations, we estimated that 10” propellers would give us a total static pull of 2.76kg and a flight time of 19.5 minutes. We estimated that 12” propellers would give us 3.32kg of static pull (0.56kg more than 10” props) but only 11.5 minutes of flight time (8 minutes less than 10” props). In the end we decided to order both propeller sizes and test them in the field.

Cutting Arm Placement
We considered several different arm placement options. We had a number of renditions with the arm positioned in-between two of the rotors. We ruled these options out because of its imbalanced weight for basic flight. Ultimately we decided to go with an arm that would extend straight down from the quad-copter’s center of mass. This limited the chances of the quad-copter flying erratically because of the added weight.

Extension Mechanism

We decided to go with a lattice work, scissor mechanism for the extension of the arm. Extension of the arm therefore requires a linear motion. We originally considered a direct rack and pinion setup for this project. This option was rejected for the need of careful gearing in order to achieve the necessary power and control to extend the arm and have it stop in a particular place. We also considered using a linear stepper motor to provide the motion. We decided against a linear stepper motor due to the large weight and power draw of a stepper motor.

At the suggestion of Dr. McCormack we implemented a worm gear setup as seen in the figure below.

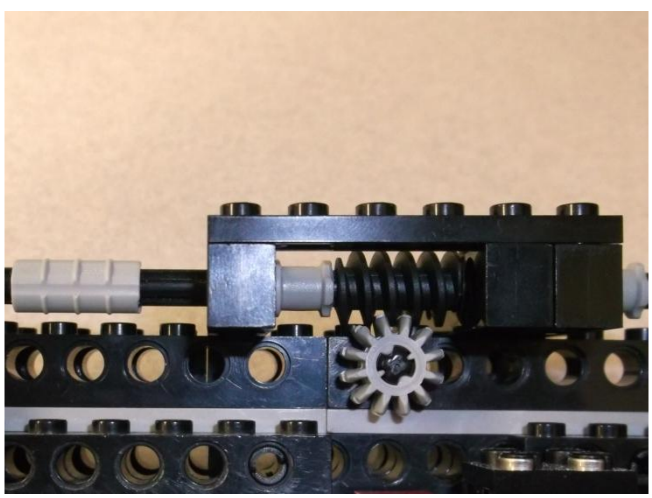

Figure 2: Worm Gear Proof of Concept

The worm gear allowed us to get much more precise control and larger torque without the need for a special motor.

Cutting Mechanism:

We considered multiple different ways to implement the actual cutting of the branch. The first suggestion was to use a rotating saw blade to cut the branches. We decided against that design for multiple reasons. First, implementing a spinning blade would require additional motors as well as quick moving parts, which would increase the weight, power draw, and complexity of the project. Second, when cutting small branches like those in the product specifications, there is the potential for kickback which could cause damage to the arm or even cause the quad-copter to lose control and crash. Third, it would be difficult to retain control of the branch after it had been cut.

The other option we considered and ultimately decided to implement was the use of cut and hold loppers, as shown in the figure below.

Figure 3: Cut and Hold Pruners

These loppers contain an extra attachment on the blade which allows it to retain control of the branch after it has been cut. The use of loppers allows for a much more controlled cutting motion, which could be implemented using either pneumatics or a motor setup similar to the arm extension control above.

Powering the Cutters

The powering and control of the loppers was a more challenging decision than any of the other designs. The two most viable designs are to use pneumatics to control a piston attached to the loppers. The force for this would most likely come in the form of small compressed CO2 canisters. The challenge for this design is our lack of experience in working with pneumatics and that parts for regulating such high pressures are not easy to come by in small sizes.

We also considered powering the loppers with another worm gear/rack and pinion setup, similar to what we are using for the arm extension. The advantage of this setup is that it is using components we are already somewhat familiar with and can model and create easily. The disadvantage of this design is that the addition of another motor on the end of the arm causes weight, strength, and stability issues.

Concept Selection

The two main constraints on our project were the budget and the requirements laid out by our client. With these in mind we came up with our final design through a process of team discussion, brainstorming, researching, and testing.

We started our design process by first discussing the current methods used to collect foliage samples. We learned these methods and their associated problems from our client. As a team we researched and discussed these methods and problems and how we might improve upon them. Each member of the team presented a preliminary idea for collecting the samples. After reviewing these ideas we decided to use some type of remote-controlled (RC) rotorcraft to reach the leaves and some type of RC cutting device on the end of an extendable arm to collect the leaves. At this point we split into two groups, one to research and design the rotorcraft and the other to research and design the arm.

The rotorcraft group quickly decided upon a quad-copter design for several reasons. First, quad-copters are very stable, can hover in place to a relatively high degree of accuracy, and are very simple mechanically. They are also good at carrying relatively heavy loads that may not be balanced perfectly (such as a foliage sample). A quad-copter was also the best multi-rotor option within the team budget.

The cutter-arm group decided upon an extendable lattice arm attached directly beneath the quad-copter. This would allow for some reach without putting the quad-copter off balance. The lattice is also a fairly lightweight, mechanically simple method of extension. The group also decided to use mechanically powered cut-and-hold pruners to actually collect the leaf samples. This would simplify the process of retrieving and storing a sample into one action. It would also provide a stable method of cutting that would not upset the hovering of the quad-copter.

The entire team worked together to research and design the remote communication portion of the project. Ultimately we decided to use a standard 8 channel RC-flyer radio to control the quad-copter, extend the arm, and trigger the cutting. We also decided to include two CCD cameras on board the quad-copter and transmit a live video feed to a laptop for viewing by the operator. These would aid the operator in maneuvering the quad-copter directly over a sample for clipping, as well as in avoiding obstacles such as branches.

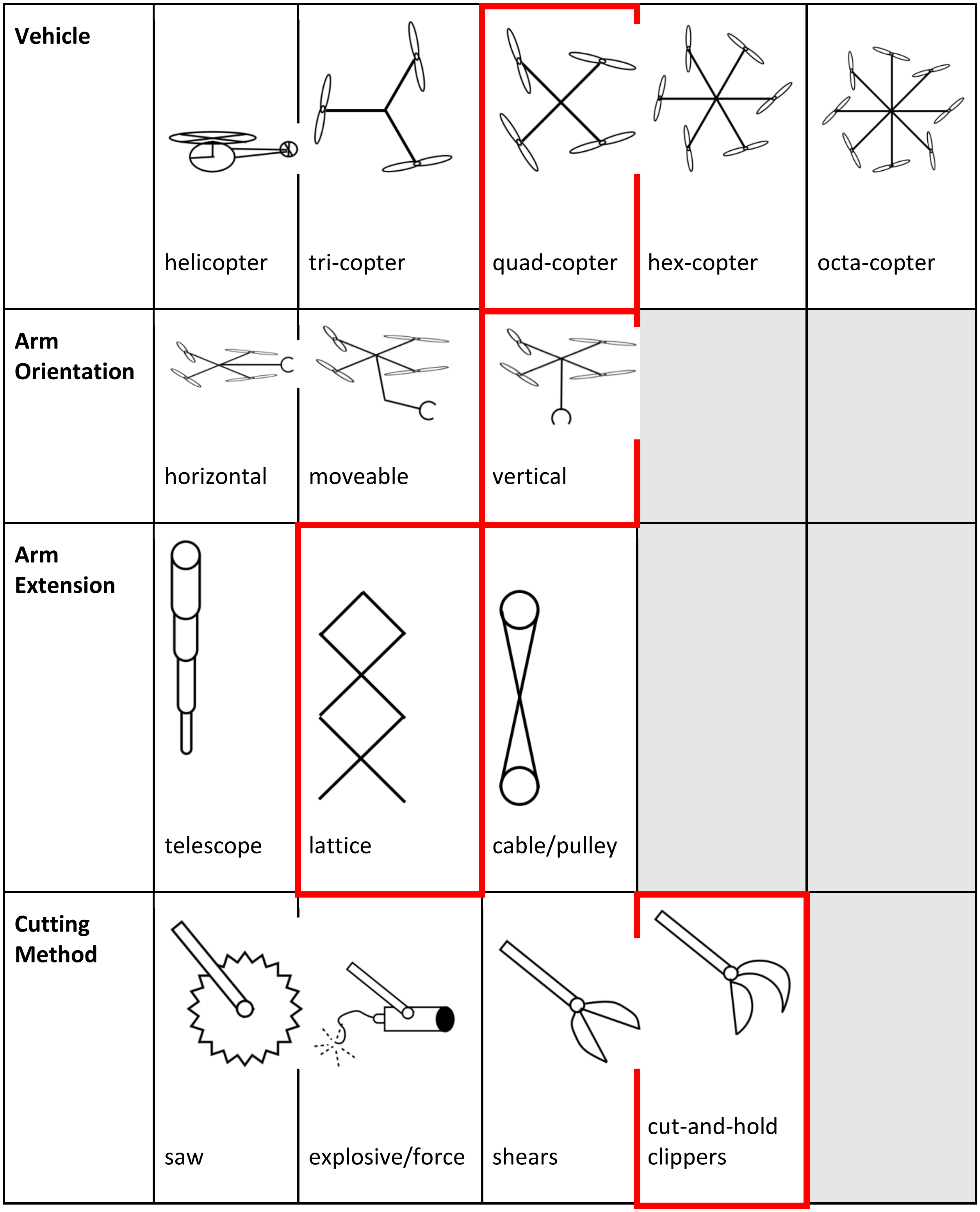

Figure 4: Concept Selection Morphology Chart

System Architecture

Our overall design for the quad copter is demonstrated in the diagram below.

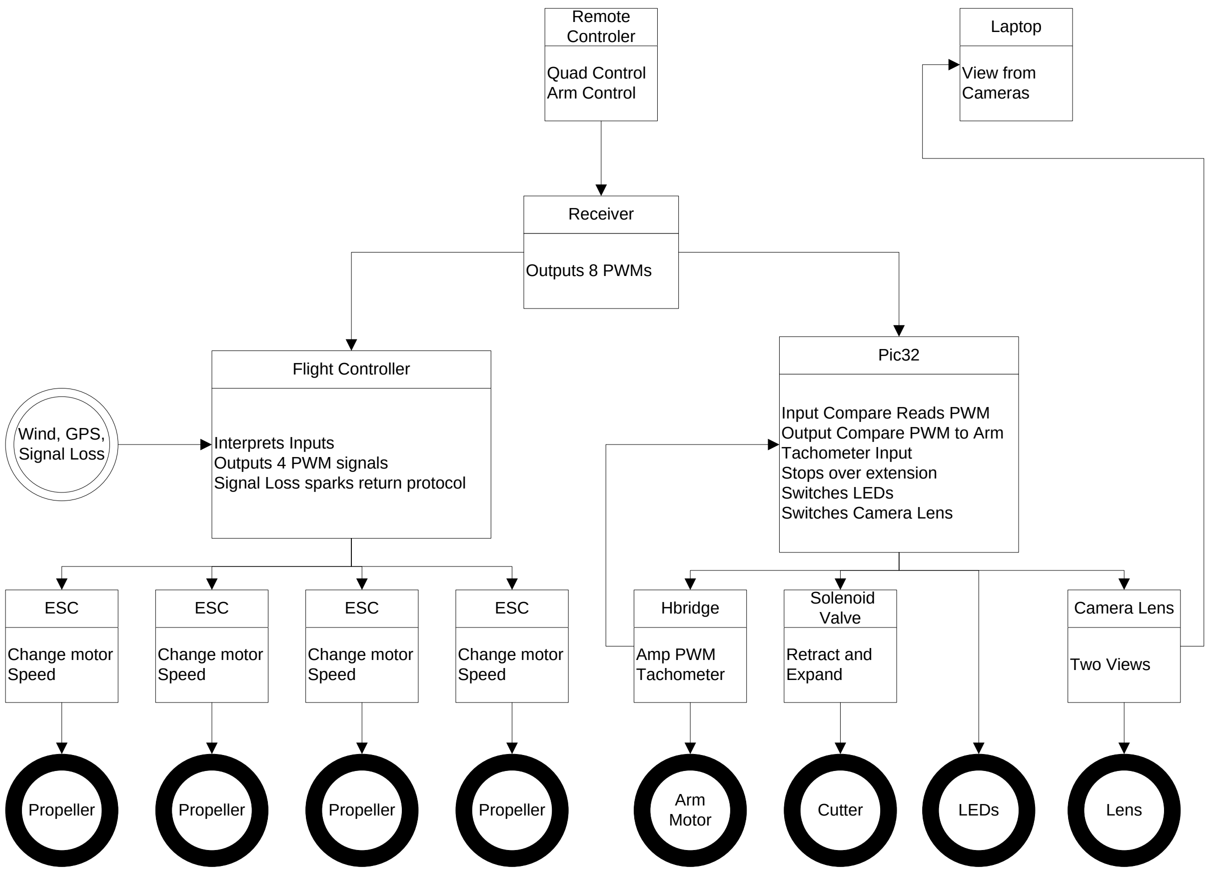

Figure 5: Control Flow Chart

The arm control will primarily be managed by the PIC32, which will receive signals via the remote controller and receiver. These signals will be interpreted by the PIC32 which will then send various control signals to the arm and light components on the quad copter. This will allow for precise speed and position control on the arm extension, as well as allow the PIC32 to monitor the extension of the arm and prevent over extension. Additionally, allowing the PIC32 to directly control the arm allows it to retract the arm safely, should it ever loose contact with the remote controller.

The direct interactions between components are given in the table below.

		Table 1: Component/Entity Dictionary		
Name	**Directly Interface?**	**Purpose/Function**	**Dependencies**	**Subordinates**
Remote Controller	Yes	User Control	None	Receiver
Receiver	No	Translates wireless signals	Remote Controller	PIC32, Flight controller
PIC32mx3CK (PIC32)	No	Arm/LED Control	Receiver/tachometer	Arm Motors, LED, Camera, Solenoid
H-Bridge	No	Converts PIC32 signals for Arm Motor	PIC 32	Arm Motor
Arm Motor	No	Move Arm	H-Bridge	None
Solenoid Valve	No	Provide Cutting Force	PIC 32	None
Cameras	No	Provide Video Feed	PIC 32	Laptop
Laptop	Yes	Receives video feed	Cameras	None
Flight Controller	No	Stabilizes flight, controls movement	Receiver	ESC
Electronic Speed Control (ESC)	No	Control Flight Motor Speed	Flight Controller	Flight Motors
Flight Motor	No	Provides Lift, turns propellers	ESC	Arm Motor

The advantage of this setup is by utilizing non-flight-control channels on the remote control, we will be able to perform direct control of the arm movements and actions without the need for an additional controller or transmitter, cutting down on cost and complexity. Beyond this dependency it allows for a modular set up. The arm, cutter, and quad-copter can be designed and developed separately, then integrated. The entire design will be run off rechargeable batteries, allowing for multiple runs to be made in one outing.

Future Work

The fall semester holds further refinement of our design. We have ordered the components for the quad-copter and arm. As the parts come in over the summer they will be picked up and stored. Early next semester we will be configuring the flight controller and programming the cutting mechanism. The quad-copter and arm will be run through several tests in order to find and eliminate any possible bugs present in either part. Then integration will occur. Further testing will be done to verify the unit as a whole. Throughout the semester documentation will be preformed, such that final documentation will not be as optimal and complete as possible.