MicroCART Project Plan

Group: May1630

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1. Introduction

MicroCART stands for Micro-Controlled Aerial Research Team. This is an ongoing senior design project started in 2006 for the Distributed Sensing and Decision Making Laboratory. The current MicroCART quadcopter has much of the hardware needed to have the functionality desired by the advisors of the project. There are the following functionalities that are the overview of the tasks that the May1630 group is planning to accomplish in the 2015 to 2016 school year in order to have more functionality on the MicroCART platform.

1.1 May 1630 Improvement Goals

1.1.1 Fall 2015

- PID Software Redesign
- Tune PID Constants
- Reconfigure MicroCART Demonstration
- Start Implementing a Wi-Fi Module

1.1.2 Spring 2016

- Implement Wi-Fi Module
- Implement Lidar Sensor
- Implement GPS Module
- Test Logging Throughput
- New Ground Station Connection Setup
- Test Outdoor Flight and Ground Station

Figure 1: The Quadcopter

2. Requirements

2.1 Software

2.1.1 Current Software and System

MicroCART is an ongoing senior design project where each year a new team takes the work of an old team and updates it to make it better or serve more functions. Because of this, one necessary goal that our team needs to fulfill in order to be successful is learning the software that MicroCART 2014-15 developed. We must become totally familiar with it in order to update it and make changes to it.

2.1.2 Updating Modularity

Our team will update the current software to be more modular in order to allow new controllers to be placed into the system easily. At the same time, we must make sure not to separate our code too much, so that it is difficult to understand or use. We will make a design that allows a controller developer to create a controller outside of the MicroCART system, and then drop the controller into the system for further testing.

2.1.3 Ground Station

Currently a camera system sends position data to a ground station computer and that ground station computer then routes the data via bluetooth to the FPGA onboard the quadcopter. There are three separate programs that run on the ground station computer during the life of a flight. Our team will condense the three programs into one and also develop a more robust command line interface or GUI for users to interact with by choosing quadcopter setpoints and possibly being able to draw a flight path and have the quadcopter execute the flight path.

2.1.4 PID Software

The quadcopter is stabilized by a PID controller. The base station sends live positional data to the quadcopter and the quadcopter uses that data along with some setpoint or goal position to calculate an error of how far away from the goal the quadcopter is located. And then, based on this error the quadcopter will move itself in the direction of the goal from it’s current position. The software that calculates that error and gets an actuation command for the motors is the PID controller. The current PID controller is slightly flawed in that it sums a flight command from the pilot, to the error. The flight command should be part of the setpoint. Also, the current PID only controls, or stabilizes, the yaw of the quadcopter. Our team will update the PID software to fix the flight command flaw and implement PIDs for roll, pitch, and throttle.

2.1.5 VHDL (Digital logic circuits)

MicroCART uses a Xilinx Zynq 7000 FPGA onboard the quadcopter which is capable of having hardware circuits programmed to it via hardware description language. These circuits are useful because a developer can design and implement IP cores (digital logic circuits) that serve specific uses. The benefit is that one can free up the microprocessor for other operations and also interact with external components via external ports on the board. Currently the quadcopter uses various cores for reading input PWM signals, generating PWM signals, communicating via bluetooth, and reading data from a sensor board (accelerometer, gyroscope, and magnetometer). The PWM related cores were developed by MicroCART 2014-15. That team had the idea to create a "killswitch" within the PWM generator core which shuts the system down in case of emergency or error. Our team will take this concept and implement it into the current PWM generator core using VHDL.

2.1.6 Git Repository

Our team will create a repository that will hold all our coding work and projects. With Git we can safely make changes to our work and revert back to older versions in case something isn't working.

2.1.7 Linux

The Zynq 7000 FPGA has an embedded dual core ARM Cortex A-9 microprocessor. Our team will learn how to run Linux on our platform and then run Linux one of the two ARM processor cores. Linux will eventually be used to communicate via Wi-Fi to the ground station or camera system. The other core on the ARM processor will be used for running the PID control software. The two cores will communicate positional data from the camera system (Linux --> PID).

2.2 Hardware

2.2.1 Zybo board

Our system will consist of Zybo board on the quad-chassis, 4 ESCs--each connected to a motor with an attached propellor--and Bluetooth/Wi-Fi communication modules. The Zybo board will collect data from a sensor board and communicate data through Bluetooth and Wi-Fi to the ground station. The Zybo board may receive roll,pitch, throttle, and yaw values from an RC transmitter if their is a human piloting the quadcopter. Otherwise, when the quadcopter is running autonomously, data will be collected from the camera system and the Zybo board will decide the roll, pitch, throttle, and yaw based on that received positional data. There will also be a mode made of a combination of human pilot and autonomous control modes where the pilot can decide which axes to have the camera system control.

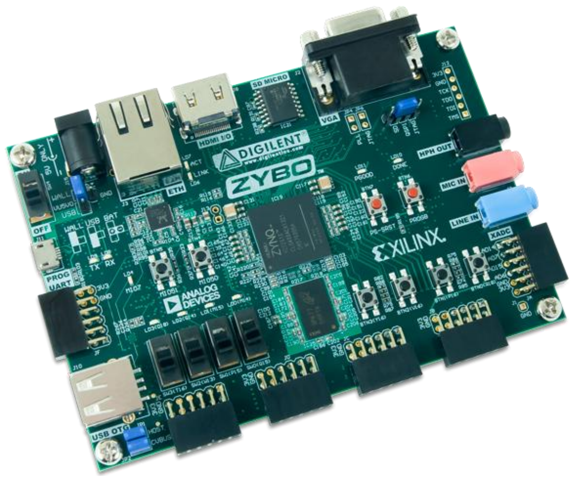


Figure 2: Digilent Zybo board with Xilinx Zynq 7000 FPGA

2.2.2 MicroSD card

The program and hardware configuration will be loaded onto the FPGA via a microSD card when the Zybo is powered on.

2.2.3 System Power

Batteries will plug in the board to power all the components on the quad. Currently the quadcopter uses a 3 cell battery to power the ESCs/Motors and 4 AAs to power the Zybo board. We will create a new circuit that will step down the voltage of a single battery to power the Zybo board so we don't have the inconvenience of replacing AAs. We will also develop a circuit that will protect the quadcopter from damage if someone plugs a battery in the wrong direction (polarity). There will be two team members dedicated to these tasks.

2.2.4 Motors and ESCs

There are four motors on the MicroCART quadcopter each connected to an electronic speed controller (ESC). A motor command signal is sent to an ESC which then supplies enough current to make the motor spin. ESCs make it so the system sending a motor command does not have to supply high levels of current.

Figure 3: 30A OPTO ESC and DJI Brushless Motor

2.2.5 Camera system

The camera system refers the high-speed camera system located in the Distributed Sensing and Decision Making lab (Coover 3050). This camera system collects positional data for the quadcopter via infrared cameras tracking infrared balls attached to the quadcopter. That positional data is then sent to the ground station computer which then relays the data to the quadcopter via bluetooth communication.

2.2.6 RC Transmitter and Receiver

In cases where a human pilot is controlling the quadcopter, an RC transmitter and receiver combination will be used to communicate the control commands. The transmitter we will use is the 6-channel Spektrum DXI6 which will be paired with a Spektrum AR610 6-channel receiver. The receiver converts the PPM generated and sent by the transmitter into 6 PWM waves which will be read by the FPGA, then filtered by the PID controllers, and then mixed into motor commands which will be sent to the motors.

2.2.7 Sensor Board

The quadcopter will be fitted with a sensor board that will report positional data via an accelerometer, gyroscope, and magnetometer. Specifically, the current sensor board is a SparkFun MPU9150 (this may be updated to a higher quality one once we know that our system works). These sensors will be supplemental to the camera system data when flying indoors. They will be more crucial to flight outdoors where a camera system is not available and the quadcopter will have to rely only upon the sensor board's measured positional data.

2.2.8 Lidar Sensor

A Lidar Sensor will be used to replace the camera system Z axis when our quadcopter flies outside.

2.2.9 Bluetooth Module

Currently the Zybo board receives its positional data information from the ground station via bluetooth communication. The bluetooth module used currently is the Digilent PmodBT2.

2.2.10 Wi-Fi Module

A Wi-Fi module will be added to the FPGA for higher bandwidth communication. It will replace the currently used bluetooth module. With Wi-Fi capability, the ground station could be taken out of the system and the camera system could send data directly to the quadcopter.

3. Assessment of Proposed Solution

3.1 Outside flight

One of the main goals for this year's MicroCART team is trying to allow autonomous flight for the quadcopter outside of the lab. This requires that the previously implemented camera system be removed from the project and replaced with more universal sensors. To accomplish this, we believe that a combination of a Lidar sensor (for altitude) and GPS based tracking (for latitude and longitude) be implemented. Potential problems include the inability to use GPS while inside buildings and under structures, and the Lidar sensor being damaged in any rough landings with the quadcopter,

3.2 WiFi communications

Currently, the controller (manual and flight directions) communicates to the quadcopter via bluetooth. While this is sufficient for general use, we believe that a wi-fi module would be better suited for the task, as it can allow commands to be sent faster and more reliably. Linux will also be installed to serve as a more universal communications protocol. The only foreseeable downside is that both hardware and software changes will be made, which can cause issues in the debugging process.

3.3 Battery protection / regulation

To allow more efficiency and safety to the quadcopter's power systems, a new battery protection and regulation board will be added. This board will have two main functions. The first is that, in the event that a LiPo pack is plugged in backwards, the electronics will not be damaged from the reverse voltage; and a LED will light indicating this event. Second, it will regulate the LiPo pack's voltage down to a 3.3V line that will power the Zybo board, eliminating the need for supplemental AA batteries. The downside of this is that the LiPo pack will drain faster with the additional load. The question becomes the significance of this increase in power consumption.

3.4 IMU Sensor

The methods of attaching the Inertial Measurement Unit (IMU) Sensor will be analyzed to reduce the noise caused by vibrations in the quad. Experiments will be done to gather the amount of vibration occurring. The current MicroCART setup will have an analysis if a higher end IMU sensor is needed.

4. Validation and Acceptance Test

4.1 Software

4.1.1 Current Software and System

The team members who will be doing the software code should be familiar enough with the code to justify designs for updating or changing the project. Those team members should also be able to draw out a high level diagram of the project for easier explanation.

4.1.2 Updating Modularity

For this requirement to be successfully achieved, a controller developed independently of the current software will be placed into the project and should be abled to be tested on the quadcopter.

4.1.3 Ground Station

The ground station should be combined into one program that is still capable of sending positional data and logging data in its current form.

4.1.4 PID Software

The quadcopter should be able to stabilize itself on the following axes: pitch, roll, throttle, and yaw. Because of these stabilizations, the quadcopter should be able to fly on it's own within the lab (without human pilot controller).

4.1.5 VHDL (Digital logic circuits)

Upon success, the PWM generator killswitch should stop the motors from spinning. To test this a killswitch signal will be sent to the core and the motors should stop.

4.1.6 Git Repository

Our team will be able to revert back to older versions of our project. We must continually update the repository. Test this by downloading old code and running it on our system.

4.1.7 Linux

This will be tested concurrently with the Wi-Fi hardware specification. One test that we will run to isolate just the Linux OS is sending a signal from the Linux processor core to the PID processor core. The PID core will validate that it received data from the Linux core by printing the data to a computer via UART.

4.2 Hardware

4.2.1 Zybo Board

The Zybo board has already been verified capable of our project goals by MicroCART 2014-15. We will continue to test its capabilities during development and testing of the system in general.

4.2.2 MicroSD Boot

A green "DONE" LED will light if the FPGA was successfully booted by the MicroSD card.

4.2.3 System Power

The step down circuit to supply the Zybo board power via one battery, will be tested using a multimeter to test the voltage supply output of the step down circuit before being connected to the Zybo board. A multimeter will also be used to verify that the polarity protection circuit works.

4.2.4 Motors and ESCs

One way to simply test a motor is by observing its reaction when sent a signal--it should spin. For more accurate motor and ESC condition testing we will consult the graduate students who are providing advice and help on this project.

4.2.5 Camera System

The camera system will be tested by observing what it sees via the Tracking Tools software that interfaces with the camera system, and verifying that we can see our quadcopter being tracked. We will also test the camera system by observing the positional data output on the ground station computer.

4.2.6 RC Transmitter and Receiver

The RC transmitter can be tested by increasing or decreasing pitch, roll, throttle, and yaw and observing the motors' rotations. There is also a "binding successful" LED that lights solid orange on the receiver when it is connected to the transmitter.

4.2.7 Sensor Board

The sensor board can be tested by sending the output via UART and displaying the data on screen of a computer.

4.2.8 Lidar Sensor

The Lidar sensor can initially be tested by comparing its measured Z-axis data to the camera system's measured Z-axis concurrently. This means that we will have to test the Lidar sensor inside the lab before using it outdoors.

4.2.9 Bluetooth

The bluetooth can be tested by sending a test message to the Zybo board from the ground station computer and having it reply to the ground station computer with a received confirmation message.

4.2.10 Wi-Fi Module

The Wi-Fi module will be tested in a similar fashion as the bluetooth module--by sending a specific test message to the Zybo. The difference is that with the Wi-Fi module, the Zybo should not reply to the camera system computer, but instead blink an LED to confirm the specific message was received.

5. Project Schedule

5.1 Fall Semester

Our project schedule for the fall 2015 semester consists mainly of getting up to speed with the project by understanding MicroCART 2014-15's tasks and accomplishments and also improving specific design features that will make expanding functionality of the quadcopter easier for the spring semester. More specifically, the first third of the semester is dedicated to reading documents, understanding existing code, and doing research about quadcopter flight mechanics and physics to understand the project as a whole. This will involve a lot of collaboration as a team to make sure each person understands at least 90% of the project at all times, but each person will also be an expert in his or her specific task. Practicing flying quadcopters is an essential part of this project as well because without knowing how to fly the quadcopter, there is no demo.

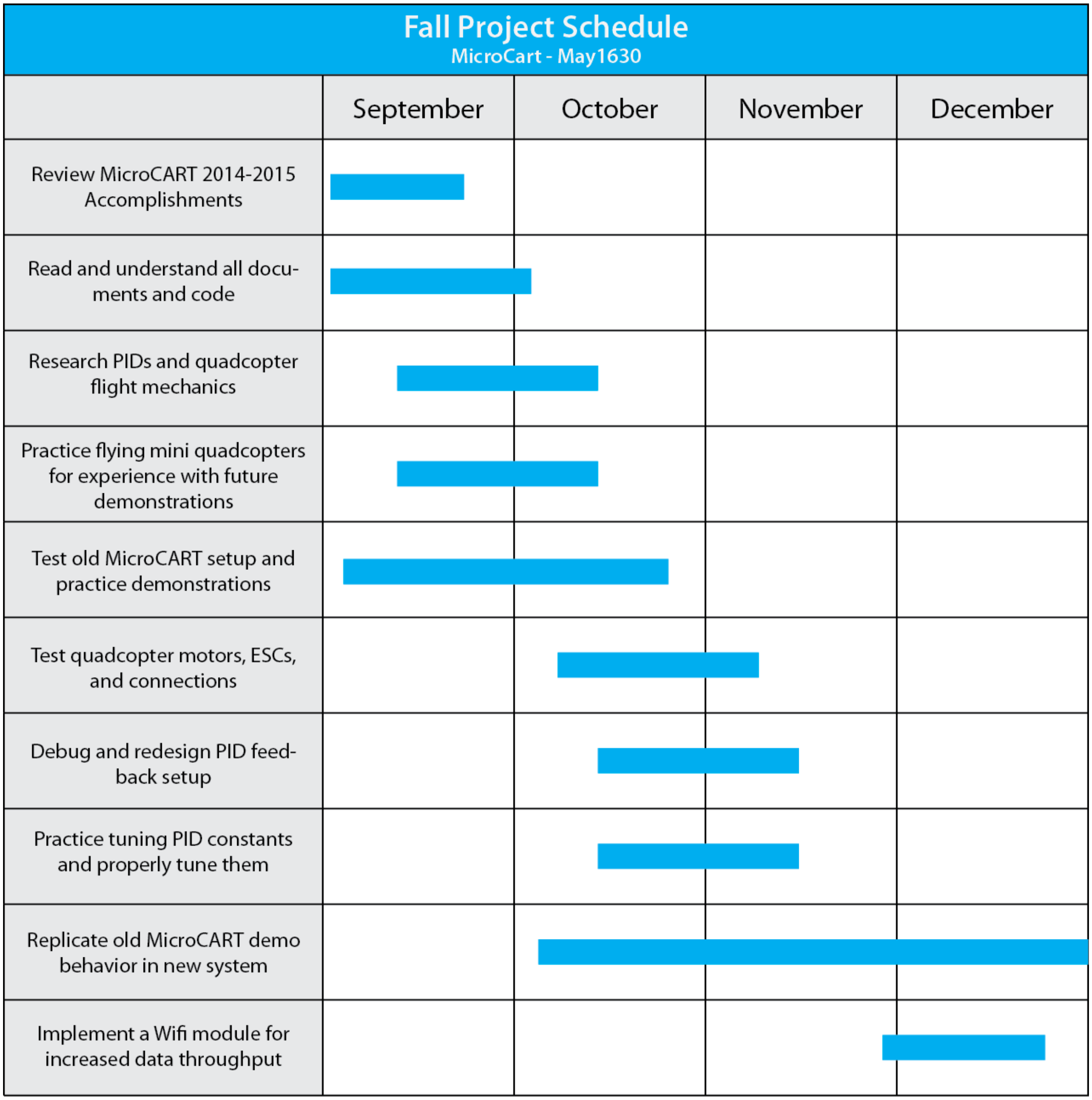
As the team becomes more versed and comfortable, we will begin hashing out necessary tasks outlined in the diagram below. An overlying task that has been a top priority for several years is to make the code more manageable by moving towards a modular design. We will have made considerable changes to the code by the end of the semester.

One of the first tasks was to get one of the older senior design MicroCART projects running to accomplish two things: 1.) to have something to demo by November 2nd for the ISU IT Expo, and 2.) to have a working system to model the newer MicroCART system on (what most of the work will be done on). Other tasks related to this goal would be to test the current motors and electronic speed controllers (ESC) to ensure they are working as expected and will not need to be replaced.

The next step is to work with the new MicroCART quadcopter to replicate the functionality of the old quadcopter. Our goal is to have this completed by the end of the fall semester. This step involves intricate steps, including debugging and development to implement pitch and roll into the system. This will allow the quadcopter to hover in a stable manner without human interaction.

If all goes to plan, we will also implement a Wi-Fi module to increase throughput of data for logging. This will begin much later in the semester with no concrete deadline until the second semester.

Table 1: Fall Semester Schedule



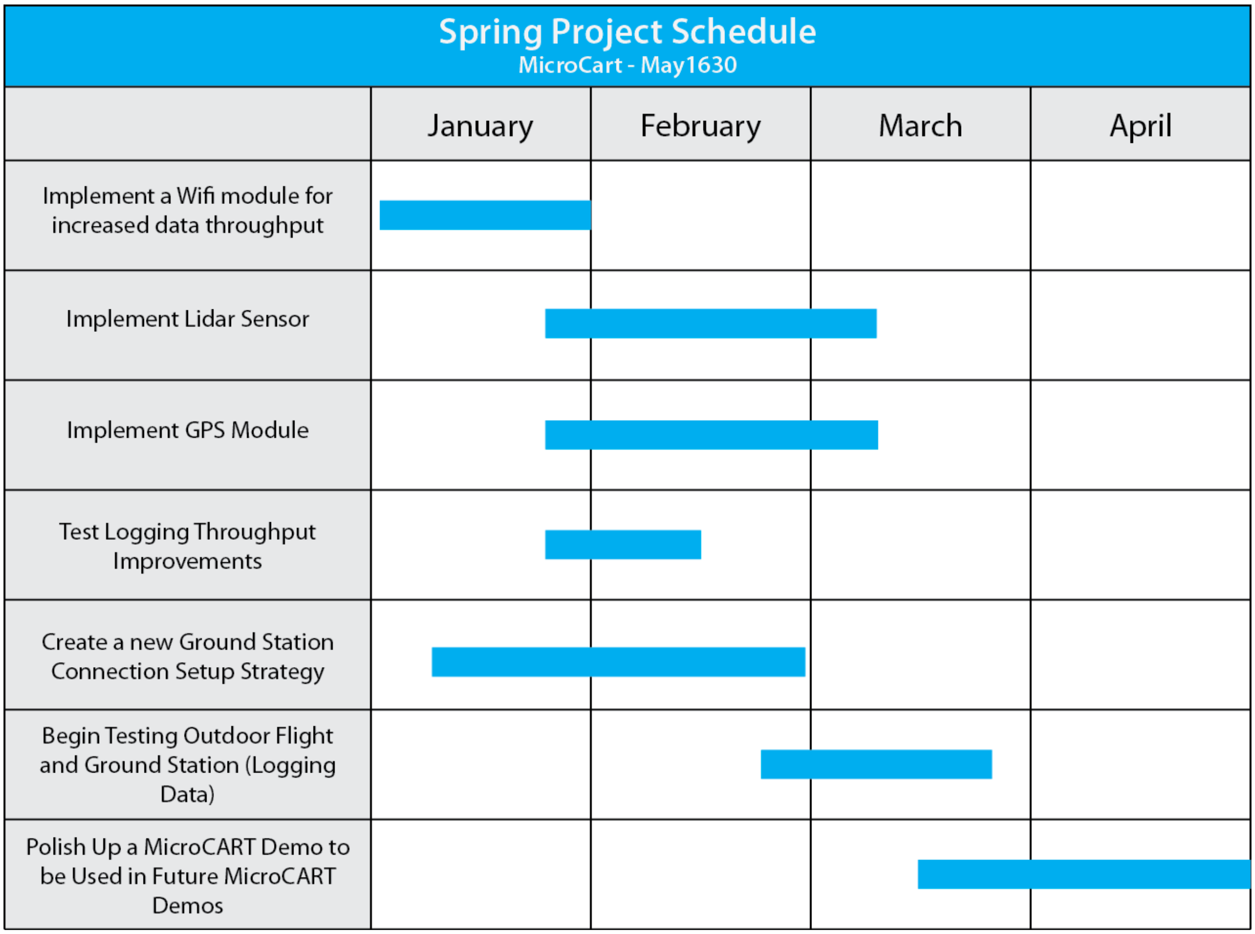
5.2 Spring Semester

The spring semester will bring on more challenges related to adding new functionality and improving the demonstration. One of our main goals for the second semester is to allow the quadcopter to fly outdoors without the restraint of relying on the camera system for tracking.

This means that a few things will need to happen: a Lidar sensor needs to be implemented, GPS needs to be implemented, and a Wi-Fi module using SPI to begin with will be added. Each of these has a crucial role in allowing outdoor flight. The Lidar sensor will determine the Z axis, GPS will be used for X and Y axis positioning, and Wi-Fi will be utilized for improved communication with the base station (since the demo will need to run outside, a new system for running the ground station will need to be improvised.

Overall, finishing the year with a polished demo for use with future systems will take some time, but is something the future MicroCART teams need to have. Having a concrete setup scenario and a simple, yet interesting demo to show to capabilities of the quadcopter is our goal.

Table 2: Spring Semester Schedule



6. Risk and Feasibility Assessment

In general this project is of low risk, the system we are implementing is based off the design of previous years MicroCART projects. Our goals are reasonable for the team's skill level and the time given to complete them. Specifically we aim to build off the 2015 MicroCART teams work on the new MicroCART platform, which was a completely new platform from prior years. Based off what features we wish to deliver being

- A modular design capable for real experimentation application
- The ability to work with custom controllers
- Full camera control as well as fully camera free control (aka outside)

6.1 General Risks

6.1.1 Time Constraint

If any of the features take longer than a projected timelines, then our project is at risk of not being delivered on time. This is especially true for features that are dependent on other features being finished.

6.1.2 Cost

- Cost outside of our expected cost will be any components that become damaged throughout project.
- Any flight critical part that need replacement may hinder the progress of our work, particularly during the testing phase.

6.1.3 Safety

- As we are working with a quadcopter system, there is a risk of losing control of the quadcopter.
- A bystander could be injured if the system collides with them, thus in our test the MicroCART system must be tethered to the ground of our workspace when in flight.

6.2 Risks in Required Features

6.2.1 Platform for experimentation bottlenecks

1) Ability to plug in custom controllers
    - This is crucial if the MicroCART system is to be a real research tool.

2) Full camera control:
    - Currently only one axis is controllable
    - The other 3 axes must be camera controllable on time
3) Camera free control:
    - This is a goal we wish to fulfill, but it is not linked to point number 2 so it not as much of a risk. This is related to related to both of the previous bottlenecks. The system will have to be able to use controllers that are built for a variable amount of controlled axis ranging from all six to zero.

6.2.2 Final Demonstration Risk

Besides our clients requirements the timely completion of above features factors into our ability to prepare a sound demonstration for our industry panel at the end of the second semester.

7. Cost Considerations

Includes a realistic estimate of project's costs. Allows for contingencies

Item	Approx. Cost	How will the team obtain the item?
Lidar Sensor	$200	Provided by Client
USB Wi-Fi Module	$7	Provided by Client
IMU Sensor	$650	Provided by Client
Self-Tightening Propellers (x4)	$30	Provided by Client
DJI E300 2212 Brushless Motor (x4)	$116	Provided by Client
AAA Batteries	$10	Provided by Client

Throughout the year, we will be adding and replacing parts on the quadcopter. The replacement parts will depend on the outcome of testing the quadcopter motors and ESCs. The AAA Batteries will be necessary in the first part of the fall semester to practice flying the mini quadcopters. The controllers take 4 AAA batteries.

One of our stretch goals for this semester is to add Wi-Fi functionality by adding support for a Wi-Fi module. This will allow the quadcopter to relay information at a faster rate to the ground station computer for improved logging.

For improvements later in the year (most-likely in the spring semester), we will be incorporating a Lidar sensor for detecting the quadcopter's height in an attempt to remove its dependency on the camera system.

8. Market and Literature Survey

There are many projects similar to MicroCART. A few projects include:

8.1 Flying Machine Arena

The Flying Machine Arena is a lab located in Zurich Switzerland. The lab contains a high-precision camera system for tracking motion of flying objects like quadcopters. These flying machines run software that automates flying which is used to test advanced algorithms and experiment with controls and estimation. The flying machines communicate with other components via a wireless network.

8.2 MultiWii

MultiWii is a software project that controls hobby RC flying objects. It implements an optional PID controller for stabilizing roll, pitch and yaw. Traditionally, MultiWii software is run on a version of an Arduino with an Atmel ATMega2560 processor.

9. Conclusion

The MicroCART project in the 2015 to 2016 school year will make the improvements to hardware and software to have a completely autonomous demonstration with the current system and be able to fly outside. Some of the features needed to allow these two tasks to happen include controlling all axes of motion with the camera system, doing some PID software redesign, updating the demonstration, implementing a Wi-Fi module, implementing a Lidar sensor, and implementing a GPS module.

Appendix A: References

Picture References
30A ESC www.house4hack.co.za
DJI Brushless Motor www.photodrone.co.nz