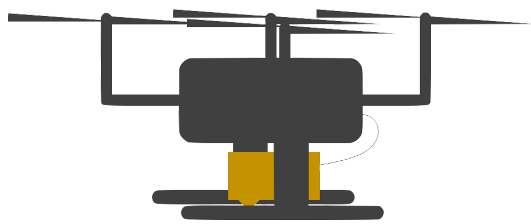
The Next Step in the Printing Evolution



New Mexico Supercomputing Challenge
Final Report
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I. Executive Summary

Space restrictions on current consumer level 3D printing devices make it incredibly difficult for objects of larger sizes to be produced as they have very limited space constraints inside the boxes that house them and on the plate on which they print. Small parts can be printed that can then be assembled to make large products later, however, single larger parts cannot be printed as whole objects. This causes larger things that are built from 3D printed parts to be significantly less structurally sound than they could be if they were made from single, larger, more solid parts.

In our project, we modeled and created a device that is capable of 3D printing objects of much larger proportions. All that a 3D printer really is, at its most basic level, is a device that moves an extrusion point around in three dimensional space and is always either extruding or not extruding. We realized that if the point of extrusion were moved through 3D space in a less constrained way than on rods and stepper motors like current 3D printers, we could make a device that does not have those limitations. We came up with the idea of moving the extruder through space using aerial craft. This would allow objects of technically infinite size to be printed using the same methods of additive manufacturing that 3D printer technology uses today. Throughout the project we further developed this idea and the design of it was particularly challenging, however in the end the aerial craft used was a quadrotor helicopter, or quadcopter. Our project involved building a physical, demonstrative prototype of this device as well as modeling a finished version of the device using Java as well as the visualizing package Java2D.

II. Introduction

3D Printing has been a relatively new frontier in modern technology. It is currently one of the faces for modern innovation, and is breaking down barriers that affect every human being. It has been a medium in which art, technology, and utility has been expressed through. 3D printing does this by bringing advanced manufacturing techniques that have been available in the past exclusively to large factories into the hands and homes of anyone with enough money and interest to purchase one. As the price of 3D printers decreases, the innovations that are coming out of these devices is growing. As the technology reaches more and more people, we will continue to see additional useful things produced by them.

Our project seeks to bring this revolutionary technology further by bringing in our own concepts and innovations that have been developed throughout the project. We believe that the things we have developed could potentially have a very large impact on the field, the technology and the future.

We wish to be able to use two technologies that have been common for quite a long time, but have only recently burst onto the consumer scene, together. These two technologies are small, remote aerial craft and 3D printing. We believe that by using these technologies together, significant advances can be made in the functionality of additive manufacturing. It is important to note that our project is more than simply combining two good ideas. This combination is a result of research, thought, ideas, and decisions. It did not come about in the stroke of a single idea, but through a process of deliberation that ultimately led us to this idea.

In our project we built a simulation of this device in Java, however we were also able to begin work on an actual quadcopter that would do the job. We are working on getting the quadcopter flying, however, it still functions as a model for our purposes. We worked with various boards and programmed them with the Arduino programming language for the actual device as well.

We started by researching all three sides of the problem: flight, extrusion, and programming. To determine whether or not our goal was even feasible, we first needed to research precision aviation techniques. When we had accomplished that we were able to move on to researching extrusion and programming. We decided our goals were feasible and we were able to make decisions about how we should move forward. As we researched, we narrowed down our research and this helped us focus on the details of the project. We decided that a quadrotor copter, or quadcopter, would be the best form for our device. We chose to use a plastic extruder head and ABS plastic as it is the simplest, cheapest and easiest option. We further decided to write a simulation program in Java to help us understand what we would be working with in theory before we physically worked with the hardware.

With this knowledge, we were able to purchase the necessary parts to construct the device. To ensure parts would be compatible with each other, we had to purchase parts in waves. As parts came in, we were able to work with them and connect parts together and determine what other parts we would need. This process was extremely slow but necessary with what we were doing. We purchased a quadcopter frame first and built it. The extruder and plastic were also purchased at that time. We then determined that we would need a controller board for the extruder and found the exact model we wanted to purchase. We purchased the board along with one motor and a motor controller to go with it. We found both the motor and the controller worked so we ordered the other three motors and motor controllers. We also purchased a battery and battery charger that would be able to power our system. We purchased a power distribution board that was incompatible with some of our parts so we modified the board. When the extruder came in, we realized that a connector was needed that could be used to connect the extruder board to the computer. We purchased that as well. We acquired a multiwii board from a person we met with to discuss quadcopters, and we were able to get it to work with our parts. We then purchased a radio reciever and transmitter that we could use to communicate with the quadcopter and do tests with. We realized that our transmitter did not come with a cord that we need to be able to program it to our needs and are now awaiting it's arrival. Until then, no further progress can be made with the quadcopter.

While we were working on the physical creation of the device, we were also creating a simulation of it. We wrote a Java program that takes in text files and then runs through a simulation of a device printing the desired object. The details of the object are provided in a text file which the program reads. The simulation has helped us grasp the ideas we would be working with throughout the construction of the physical device and has been extremely useful. We also implemented a graphic representation that demonstrates in 2D what our device will be capable of.

III. Background

The goal of this project is to help progress 3D printing technology by breaking the space barrier 3-D printers currently have. In current 3D printers, the space in which the extruder can travel is severely limited by the size of the build plate and size of the carrying rods. When creating larger 3D printers, the costs and difficulties rise dramatically. To eliminate this problem, a combination of 3-D printer technology and aerial craft could be used.

The printing must be taken care of in three-dimensional space, with no constraints on the directions in which the extruder can be carried. Aerial craft is the exclusive choice to solving this problem as it provides the solution to these necessary items. We initially thought to use a single rotor helicopter based design. We came upon this decision with the knowledge that by design helicopter rotors allow them to hover in the air and therefore would potentially be suitable for accomplishing the necessary tasks. However, we eventually realized that a quadcopter would be a better option. This is because more rotors allow for more precise motion and it also gives the device more thrust. Having all of the extra printing supplies on-board the device will make it heavier than most quad-copters so we had to compensate for this by getting bigger more powerful motors as well as larger propellers.

The part of a 3D printer that actually produces the material is the extruder, which melts the printing material and pushes it out in the form of a thin liquid line, which solidifies almost instantly. The extruder and the programming board are the only parts of a 3D printer that we actually need as all of the other parts of the 3D printer are for moving the extruder around. This is an important thing to note as it becomes clear upon knowing this fact that a quadcopter of relatively small size should be capable of lifting these items. By utilizing these select parts of the printer and building them into an aerial vehicle, the space constraints in 3D printing would be gone because the extruder could be carried very large distances in all directions. This would be a significant imporovement relative to the cubic foot or so of most 3D printers on the market today.

The problem with three-dimensional printing is the size constraints it places on each printed object. Because the 3D printer is a box, with the printing occurring in the inside of the box, the space is limited as well as the size of the finished product to the size of the box. To print larger objects, the printer must print objects that are assembled together after the printing has been finished. However, this compromises the structural integrity of the finished product. Another solution to the size problem is building bigger printers. However, the price of these 3D printers becomes exponentially bigger, and there are still some size restraints on these printers.

To solve this problem, a method had to be thought that was different. The method we decided upon was the use of aerial craft to move the printing part, the extruder, through three dimensional space. This would eliminate virtually any limits on the size other than flight time restrictions, and make the finished product much larger and stronger.

IV. Programming

Our project involved the creation of an accurate simulation of the device we were trying to build. Written in Java, this simulation models the X, Y, and Z axes of the quadcopter, and has the ability to simulate a print based on those. The simulation has a couple of default shapes it can make, but also has the ability to plug in coordinates of different shapes. Our simulation is built so that it takes in coordinates as this is an extremely useful bit of information in printing three dimensional objects. The vertices of a shape would, theoretically, be inputted into the device we are discussing and the device would use this information to print the object. Coordinates are a relatively simple bit of information to collect from a three dimesnional model and also relatively easy to get the quadcopter to move to, therefore, these values serve as an excellent middle ground between the two. For this reason, we used coordinates in our simulation.

By analyzing the program, we were able to make some more connections about our actual model. The different concepts of aerial flight through four rotors was fully understood. This was essential in the building of our model. We were able to finalize how we wanted the user to input personalized details about their project into the computer. How we did this was through the use of the (X, Y, Z) coordinates. The program would then find the RPM's needed for the quadcopter to move to that specific location, and would result in the finished project being the product the user input.
We utilized Java and Java2D for the creation for our simulation. We used Arduino for the work we did with the hardware and Arduino boards.

See Appendix A for more information on the simulation

V. Design of Quadcopter

A) Aerial Flight

The basis of this project is the ability to move the extruder from one place to another in a precise and controlled manner. To effectively eliminate all space boundaries, the extruder must be transported via flight, as ground travel does not completely eradicate vertical frontiers. An essential part of printing is the ability to approach almost any angle from the previous position. This rids any form of airplane as an approach to printing. Helicopters are unique in that they are able to move backwards, forwards, left, right, up, down, and everything in between. By using a combination of these directions, there is virtually no angle left which cannot be flown to directly. Helicopters also possess the desirable characteristic of being able to stay still in the air for any amount of time. To do this, helicopters use a system of rotors to provide both thrust and lift. This rotorcraft can be used in places other aircraft cannot, because it does not need a large amount of space to takeoff. Rotors of a helicopter can be attached vertically to provide horizontal thrust, or horizontally to provide vertical lift.

B) From One to Four

There are many different types of rotors, each designed according to the number of rotors. Tandem rotors are two counter-rotating rotors that are mounted behind the other. One example of these is the Boeing CH-47D Chinook, a famous military tandem helicopter. The two rotors are both vertical, so it uses tilt to compensate for the missing horizontal rotor. The tilt is achieved by a difference in speed of the rotors. [http://www.helicopterpage.com/html/tandem.html] Coaxial rotors are two counter-rotating rotors, one above the other, with the same center. By having one rotor cancel the spin of the other rotor, the coaxial rotor has the benefit of not having software or pilots have to constantly fix the position. [http://web.archive.org/web/20071220021153/http://www.kamov.ru/market/news/petr11.htm] Intermeshing rotors are two counter-rotating rotors mounted close to each other just enough to let the rotors intermesh over the top of the aircraft without colliding. This allows the helicopter to function without a tail rotor, lessening the amount of energy needed for the helicopter to move.[http://www.propilotmag.com/archives/2012/September%2012/A3_Rotor_p2.html] A popular rotor type for models are quadcopters, a multirotor craft that uses four horizontal rotors to provide lift.

Quadcopters are a popular type of aircraft for amateurs to fly, due to their simplicity and ease of flying. The quadcopter uses four rotors, two clockwise and two counter-clockwise, to change maneuver. To move, each rotor changes its RPM, resulting in tilt and movement. Quadcopters were designed in the 1920's, but the difficulty of the pilot to control each motor and stabilize the craft was too much, and resulted in failure. However, with today's computers, quadcopters have become increasingly easier to fly as well as a popular outlets for hobbyists looking for UAV's

(Unmanned Aerial Vehicles). A quadcopter does not require a change in rotor angle for movement, thus simplifying flying. The maneuvering is all done in change of rotor speed. See Appendix B for more information. Because of the presence of more rotors, less surface area is needed per rotor for liftoff and control. Thus, quadcopters present less risk in case of crash, both for the aircraft and the environment. More rotors decreases the reliability of each rotor. For example, a standard helicopter relies on one rotor for vertical lift. If damage is done to that one rotor (which is more likely due to the larger surface area), the helicopter is going down. However, with a quadcopter, the absence of one motor is only a twenty-five percent decrease in lift. Although this is still significant, the statistics are a lot better that the one hundred percent decrease in lift a helicopter accident may occur.

A quadcopter's movement is controlled by the speed of the rotors as well as the tilt. To move a quadcopter vertically, the speed of all four rotors must be increased equally. A quadcopter has a pair of rotors spinning one way and a pair of rotors spinning the other way. Roll is the rotation around the front-to-back axis, pitch is the rotation around the side-to-side axis, and yaw is the rotation around the vertical axis. The power is distributed evenly to the four different motors, and a flight controller tells the motors what to do [see appendix C].

C) Extrusion

3D printing requires the use of extruders, a simple machine that grabs the plastic filament, pushes the plastic through, and melts the plastic so it is able to bend. A standard extruder, also known as the Wade's-like extruder, uses a stepper motor to push the filament into the hot end, which melts and narrows the plastic into the desired width. Many other types of extruders exist, such as the Adrian's or Bowden. The different types of extruders exist because hobbyists constantly make different types to fit their unique needs. Each provides its pros and cons, but they all have a similar characteristic: the hot and cold end. The cold end is the majority of the extruder, and functions to push the filament to the hot end. The cold end is attached to the hot end through an insulator, which is usually made with plastic with stainless steel mechanical supports or a combination of all three. The hot end is the component of the extruder that melts the plastic and extrudes it out. After the cold end pushes the plastic into one whole, the hot end will melt the plastic and push it through the other hole, which is measured for precision and accuracy of the finished product. Around 150 to 259 degrees Centigrade is needed for the plastic to be melted, and this usually takes about 20 Watts. For our purposes, a standard functioning Wades extruder should be fine.

VI. Applications

The device that we are working towards making could have a profound impact in many different areas. The most basic goal of our project is to create a device that allows for the printing of much larger objects with 3D printing technology. If this is accomplished, it would show that 3D printing can accomplish a lot more than people have previously thought. There are industrial sized 3D printers but these are highly impractical even for large corporations because other forms of manufacturing are much easier and cheaper to use. This method of 3D printing could allow home users of 3D printers print things of much higher quality and size. A lot of 3D printer use is done by people at home who are building things for fun or for unique objects. However, these people often accomplish great things that can impact society a lot in the end. If these people could build larger, more stable parts, they could accomplish more things more easily and thus could allow for greater accomplishments in the future. 3D printers are used in many schools, colleges, and universities around the world. If these educational institutions had access to more capable 3D printers such as ones built in the style we have proposed, this would further advance the education at these facilities. Our technology could also be applied to companies and corporations that use 3D printers. These companies could build larger parts and items using our technology than they could before.

Other, wilder ideas we had were that the printer would be able to construct buildings or building parts. It could make repairs in places that are high up or difficult for people to enter. This would allow for better buildings that are more stable to exist, as well as permitting building in places that were unreachable. Our project would also be practical for use when a natural disaster or impending doom is threatening an area. The quickness as well as the minimization of human danger would be useful in this situation. Another benefit of this project is the introduction of a better system of routing flight patterns and causing certain actions at certain spots. Our program tells the craft where to go and a certain on/off command. An application of this would be firefighting helicopters, where a helicopter would do a routine with the on/off control used to release water. This would allow more people to be on the ground fighting fire, as well as have a more systematic and effortless assistance.

VII. Conclusion and Future Work

The biggest achievement of this project is the creation of our simulation and the vast amount of knowledge we have gained in many different fields and on the particular problem we addressed through completing it. The simulation models our overall goal, and shows the true benefits and amount of practical applications this project can lead to. This simulation gave us a true understanding of the project we were going to handle.

The goal of this project was to be able to build a device capable of 3D printing objects of very large sizes. Our results are that we were able to make a simulation of this quadcopter that 3D-printed, and obtained the parts needed to make the quadcopter. The parts were then assembled and were altered to fit our needs. Then, the programming files for the flight control board as well as the extruder was obtained, modified and used. The simulation of our finished project was a success. While limited in what it is capable of doing, it is a brilliant demonstration of what we are aiming to do and taught us loads of valuable information.

In the future, the model will be functioning similarily to the simulation in behavior. The printing of actual physical objects will occur, and the biggest challenge will be stability. After the printer is able to print parts, the majority of the work will be done to increase flight time and extruding material. To achieve both of these, the weight must be reduced. By adding an actual physics engine that models air flow as well as gravity, the accuracy of the actual product could be improved and it would give a clearer vision of our next steps.

VIII. Acknowledgments

We would like to thank Rob Cunningham for being our mentor in this project. He helped us visualize the project from the very beginning allowing us to go to him with our idea, and come away with a project. He came up with potential problems and through discussion we could develop solutions. Rob Cunningham also connected us with many other people, including Robert Fields, a hobbyist who donated us a flight control board and demoed his quadcopter for us. His Los Alamos National Laboratory connections were very useful in helping find help that we needed.

Nathan Burnside was also a great help to us during the course of the project. A radio control enthusiast as well as an electronics genius, he assisted us in many ways from the start, where he was able to send us on the right track in terms of finding and purchasing the equipment we needed, to helping us figure out how the parts worked (or why they weren't working) and in modifying parts so that they would work.

We talked to many people while developing and working on our project and we would like to additionally thank: Nicholas Dallman, Adam Drew, Drew Einhorn, Robert

Fields, Jannette Rose Frigo, Mark Peterson, Alexandra Saari, Daniel Nathan Seitz, John Singleton, Tom Venhaus, Dawn Venhaus, and Glen Wurden.

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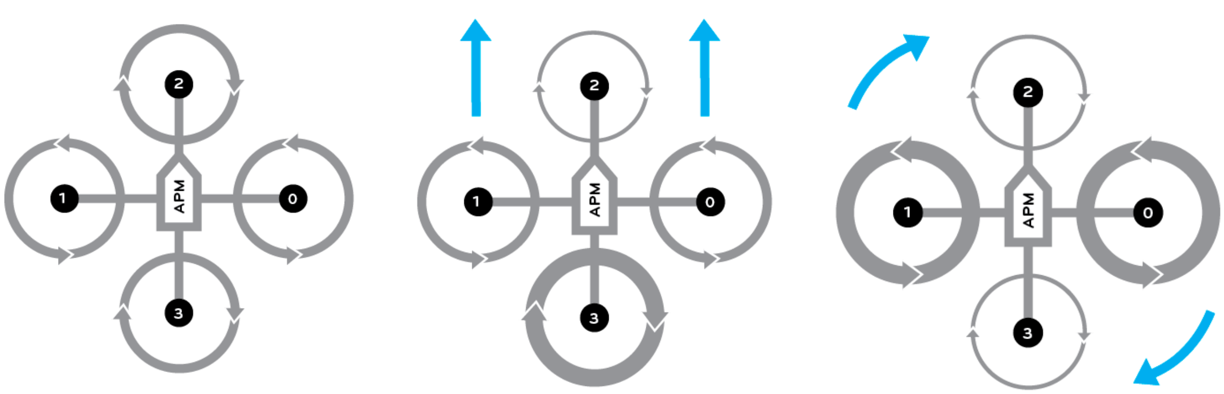
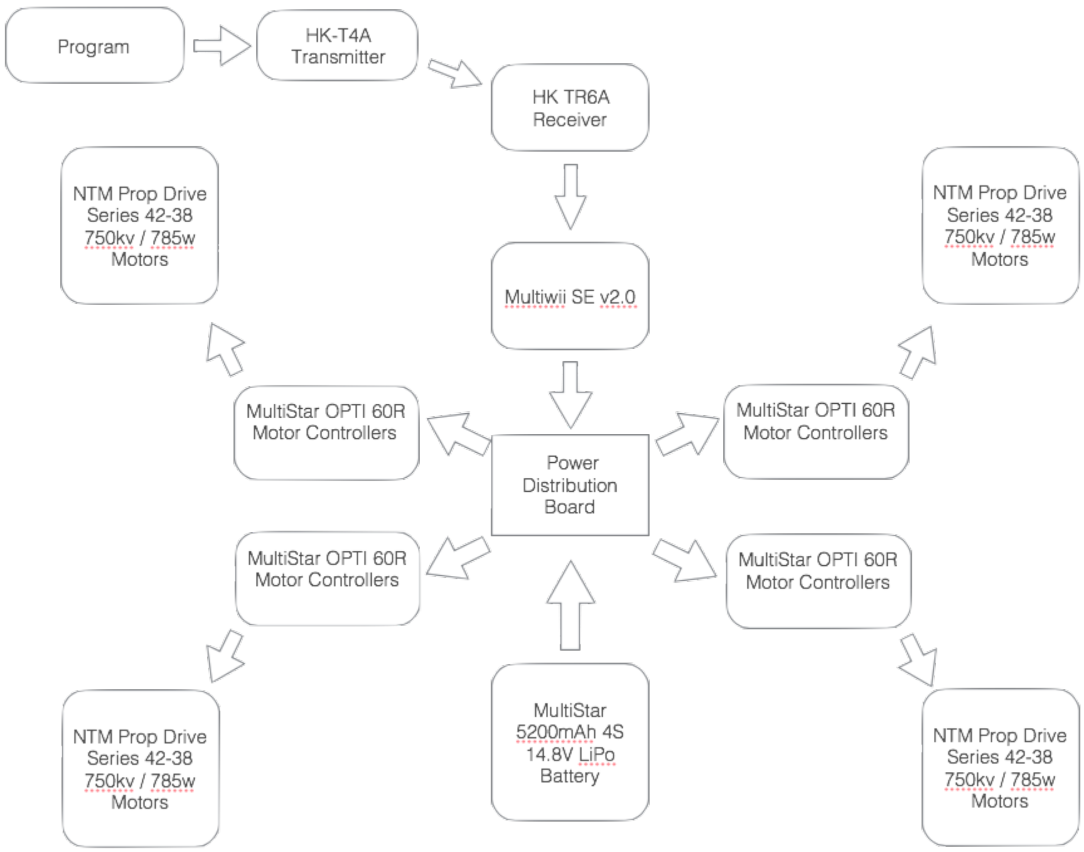
X. Appendices

Appendix A - Simulation:

The programming for the simulation of our project was kept in a github repository allowing for collaborative work to be done on it more easily. This repository



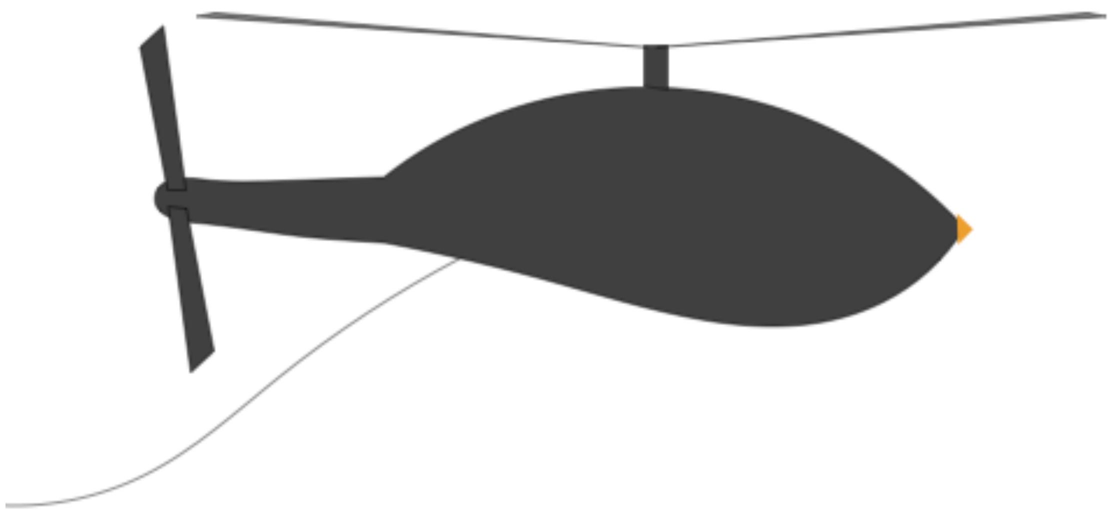
can be found here along with a ReadMe detailing how the project is organized and how it can be run: https://github.com/SupercomputingProject/simulation

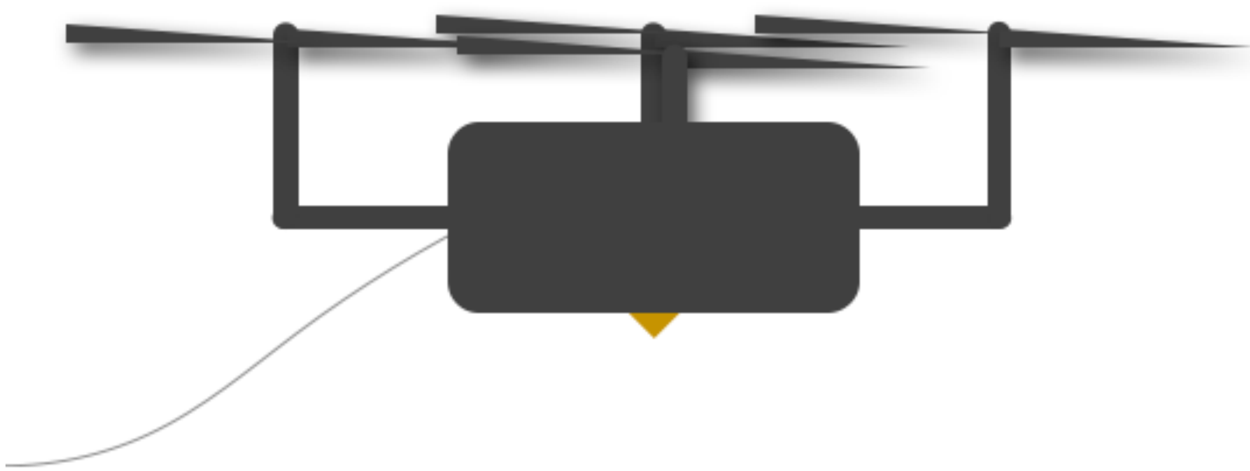


Appendix B - Quadcopter Movement

Images found at: http://blog.oscarliang.net/build-a-quadcopter-beginners-tutorial-1/

Appendix C - Quadcopter System Chart:





Appendix D - Design Visual Aid:

Appendix - Website:

Information contained in this document is also available along with more information can be found on our website: http://www.supercomputingproject.github.io