Design of a Quadcopter For Winning the Jerry Sanders Creative Design Competition

Jordan Bramble, Harold Merida, Ibtsam Khan

jbramble@masonlive.gmu.edu, hmerida@masonlive.gmu.edu, ikhan5@masonlive.gmu.edu

Abstract **- To win the Jerry Sanders Creative Design Competition, it is necessary to design a "cone transportation system" to transport cones to territories in the arena. There are three tiers of territories that award 1, 3, and 5 points when controlled for 10 seconds. Territories controlled at the end of the match are awarded 10, 30, and 40 points. The cone transportation system includes: (1) a vehicle, and (2) a mechanism for picking up and transporting cones. This project aims to design a quadcopter to pick-up and transport cones, as quadcopters are given a 3x point multiplier. With voltage relationship equations for brushless motors, a simulation was developed to determine optimal quadcopter size and rotor type. Thus, the advantages of using a quadcopter were verified.**

Index Terms – quadcopter, APC, Motor

INTRODUCTION

The Jerry Sanders Creative Design Competition, sponsored by Advanced Micro Devices, and named after their former CEO, is a yearly competition in robotics held at the University of Illinois Urbana-Champaign. The 2014 competition was held March 14th – 15th. Multidisciplinary teams of engineering students nationwide, participate in a game like competition for two days with robots they've designed and constructed. Each year the competition challenges change and require teams to develop innovative mechanisms for successfully scoring points.

DESCRIPTION OF COMPETITION

I. Competition

The competition takes place in a 2000 square foot arena (44.7 x 44.7 ft). For airborne robots, a sloping net is hung above the course that is always approximately 6 feet above the arena floor. The goal of the competition is fostering innovation and creativity within robotics and promoting the engineering disciplines. In last year's competition, 26 teams from six different universities participated in the competition, attempting to pick up cones and place them on pins in order to score points. All of the participating teams hail from universities within Illinois or Indiana. Historically only two airborne entries have competed. During last year's competition, the Northern Illinois University Robotics club entered a quadcopter and they were able to successfully pick up a cone, however they could not accurately place them on

pins and the downward thrust from the propellers would occasionally blow away unsecured cones before they could pick them up. 28 teams entered the 2014 competition, one of which was airborne, and again was not able to score any points.
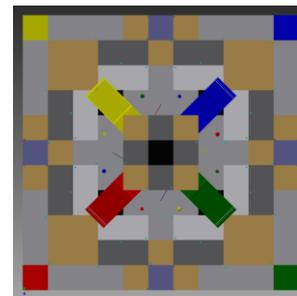

FIGURE 1
EAGLE EYE VIEW OF THE COURSE

The colored boxes in the corners of Figure 1 correspond to each team's starting area; the four colored rectangles represent ramps that lead up to the second level territories. At the base of the second level are small 'soccer' balls that are assigned by color to each team, these balls can be moved to their respective places, around the corner of the second level, in order to change direction of the ramps. The ramps are equipped with conveyor belts initially moving downward, but changing their direction causes the conveyor belt to change direction thus pulling a robot up. The central black box represents the third level territory, and the surrounding 8 boxes represent the second level. All of the other light blue dots represent the pins in the first level. The light purple boxes on each edge are designed to hold cones for each team. There are four hinge doors that must be opened in order to retrieve more cones as seen in figure 2.
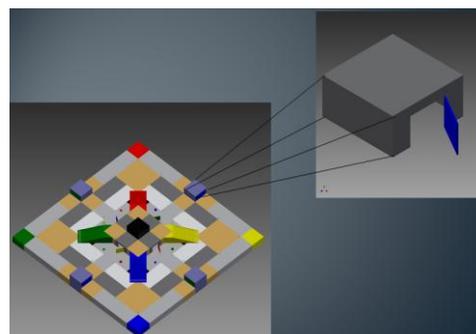

FIGURE 2
LOCATION OF THE HINGE DOOR ON COURT

The competition consists of picking up and transporting cones of a specific color to pins corresponding to territories, where each pin is 1 inch in diameter. This is equivalent to controlling a "territory", and the length of time a territory is controlled determines how many points are awarded.

Figure 3 is a CAD diagram used to measure the distances between territories. The type of territory is color coded.

FIGURE 3
ARENA WITH LOCATION OF TERRITORIES AND NUMBER OF TERRITORIES

Green represents first level territories, of which there are 36. Yellow represents the second level, of which there are 8. Finally, there is one third level territory marked in red. It is also necessary to understand how cones are placed in the course.
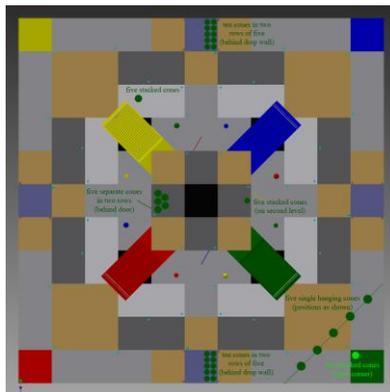

FIGURE 4
CONE LOCATION

For the team starting in the green corner, their cones are arranged as Figure 4. Ten cones are not stacked behind a drop wall that can be opened by pulling out two pins that hold the wall in place. 5 cones are in front of their home territory, hanging from strings. 5 more cones are placed behind a hinged door beneath the second level that must be pulled open. They also have a stack of five cones in their home territory as well as 5 cones stacked at the second level and five opposite of the raised platform. Since the course layout is symmetrical, each other team has their cones located in equivalent positions throughout the course.

II. Scoring

There are many ways to score points. Airborne robots have a constant 3x multiplier when scoring points. For each contiguous powered territory on the first level controlled at the end of the match, a team will be awarded ten (10) points. For each contiguous powered territory on the second level controlled at the end of the match, a team will be awarded thirty (30) points. For each contiguous powered territory on the third level controlled at the end of the match, a team will be awarded forty (40) points. Every ten (10) seconds that a team controls a first level territory will result in one (1) point. Every ten (10) seconds that a team controls a second level territory will result in three (3) points. Every ten (10) seconds that a team controls a third level territory will result in five (5) points. Completion of an action for the first time will result in ten (10) points being awarded to the team responsible. An action consists of opening the doors that hold pins or changing the direction of the ramp. The direction of the ramp can be changed by moving an assigned colored soccer ball at the base of the second territory to its holding area around the corner of the second level. Clearly, airborne robots are given a strategic advantage, and additionally, autonomous robots receive a 5x multiplier.

DESCRIPTION OF COMPETITION RULES

I. Core Rules of Competition

The core rules of the competition are as follows: Each match will be seven (7) minutes long, each round consist of four or fewer robots. The team's color cone is the topmost in the stack of cones for control of a territory and teams cannot attempt to control a territory unless it would be contiguous

II. Airborne Entry Rules

Airborne entries have special specifications. They can weigh no more than 15 lbs. Any rotors must be made out of plastic and should not be able to cut through the safety netting which will be suspended over the course. The same battery rules apply to airborne entries. Since airborne entries could pose a greater safety risk, teams planning on submitting an airborne robot must contact the JSDC Rules Chair and Director by **December 1st** with a description of the expected weight, size, propulsion type, and any other specifications of their robot which will be helpful in determining what kind of risk such an entry might pose to the safety of spectators, competitors, JSDC officials and the game course. After the proposal has been received, the Rules Chair and Director will either approve or deny the entry by January 1st.

REQUIREMENTS

All projects have a set of requirements and they can be divided up into Mission, Functional, and Design Requirements.

I. Mission Requirements

1. The Quadcopter shall compete in the Jerry Sanders Creative Design Competition, and must be competition ready may March 2014.

2. A strategic support tool shall be developed to determine percentage likelihood for winning the competition.

3. The Quadcopter shall have a mechanism to pick up and carry cones, with a mean time of 30 seconds, in order to place them on territories throughout the course.

4. The Quadcopter shall have a 25 percent likelihood of winning the competition and at least a 70 percent likelihood of advancing to final round.

II. Functional Requirements

- The Quadcopter shall have the ability to transmit a live video feed to a laptop.
- The Quadcopter shall be able to remain in flight for at least 7 minutes at a time. A 3 minute buffer is desirable.
- The Quadcopter's batteries shall be rechargeable between rounds.
- The batteries shall provide sufficient power such that, the flight time and consistent thrust to carry necessary payloads can be achieved.
- The Quadcopter shall lift the cone to a sufficient height, at least 2 feet above the ground.
- The Quadcopter shall place cones on a 1 inch diameter 8 inch long pin.
- The Quadcopter shall have the ability to collect cones semi-autonomously.
- The Quadcopter shall be able to fly beneath a 6 feet net at all times, and have the ability to fly as low as 2 feet for an extended period, totaling no more than 20 seconds.
- The Quadcopter shall have a carrying capacity of at least 1kg, for a camera, cone acquisition mechanism, and cone.
- The Quadcopter shall be transportable, able to meet requirements to be checked onto a plane, or in the trunk of a sedan.
- The Quadcopter's Arduino system shall be compatible with stability (fly-by-wire) software modules.

III. Design Requirements

- The Quadcopter shall fit within a 3'x3'x3' cube.
- The Quadcopter shall weigh no more than 15lbs.
- The Quadcopter shall be equipped with a FPV camera.
- The Quadcopter shall have a mechanism for picking up Adams Saucer cones with a 2'' diameter central hole and 2'' height.

- The Quadcopter's propellers shall be guarded such that they cannot damage the netting above the course.
- The Quadcopter shall be equipped with a mechanism for concentrating the thrust such that it will not blow cones away when attempting to pick them up.

TRADE OFF ANALYSIS

Quad-Copter	DC Drones	A.R. Parrot
Cost	$1700	$300
Tech	Arduino	Linux
Weight	1000g	420g
Flight Time	11.5mins	36 mins
Carrying Capacity	1600g	250g

		DC Drones		A.R. Parrot	
	Category Weight	Score	Weighted	Score	Weighted
Technology	3	4	12	2	6
Quadcopter Weight	4	3	12	4	16
Flight time with Max Pay	5	5	25	0	0
Carrying Capacity	5	5	25	1	5
Cost	3	3	9	4	12
Camera	3	4	12	3	9
Total Score:			95		48

TABLE 1
TRADE OFF ANALYSIS FOR 2 ALTERNATIVE KITS

Table 1 shows the different alternative kits. Three different options for Quadcopter kits are in consideration, which will likely need to be heavily modified. The first is manufactured in China and sold by the DC Area Drone Users group. It is essentially identical to the 3D Robotics model, but has a cheaper frame and may not provide the stability that we are looking for. The second model is the A.R. Parrot Drone. This drone offers a very long flight time and is built on an open source android Operating System, however it cannot carry anywhere close to the payload that will be necessary for this competition. The 3D Robotics ArduCopter, though more expensive, offers a reliable shipping time and stable frame. It also can carry 60% more than our necessary payload, and is highly customizable.

The weights were chosen based upon the nature of the competition. Flight time and carrying capacity are highly important, and keeping weight of the robot down is also important to ensure a lengthy flight time. The abilities of the technology such as autopilot and camera are less important as they are only needed in this competition for lower level tasks, and most of the flight time will completed manually. Because all options are reasonably priced, cost is only of medium importance to us. The DC drone user groups, imitation ArduCopter is clearly the best choice.

DESIGN OF EXPERIMENT

In order to conduct a simulation and also analyze and compare potential strategies for winning the competition, it is necessary to conduct experimental trials to determine the performance attributes of a potential quadcopter that would

be used in competition. Two experiments were conducted to determine horizontal and vertical velocity.

I. Experiment 1: Horizontal Velocity

The first experiment measured horizontal velocity over three separate distances, both taken from measurements of *figure 3* that roughly corresponds to territory locations of the arena. The quadcopter was already hovering when the tests were conducted. The pilot would fly the quadcopter back and forth between the given distances of 20.5, 30.7, and 47.7 feet. Each time an observer watched the quadcopter travel the given distance the time would be recorded. These times, over 36 trials for each distance, were modeled as distributions using Arena's input analyzer. *Figure 5* shows that the resulting distributions were Beta or 20.5 feet, and normally distributed for the distances of 30.7 and 40.7 feet.
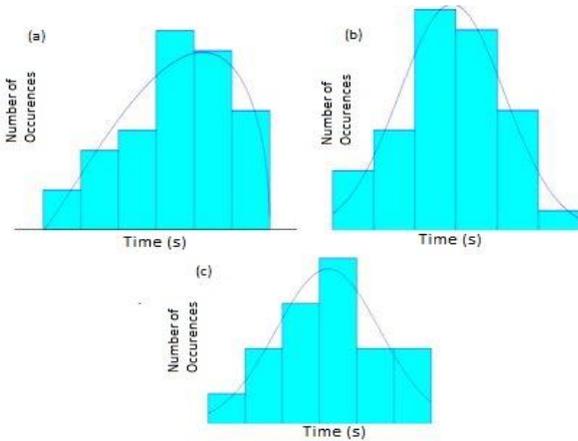

FIGURE 5
VERTICAL VELOCITY DISTRIBUTION, (A) 20.5 Feet (B) 30.7 FEET (C) 40.7 Feet

II. Experiment 2: Vertical Velocity

The second experiment measured ascending velocity at 4.5 feet. Due to time constraints in the facility where tests were being conducted, only 20 trials were conducted for the 4.5 feet height. The main reason the 4.5 feet tall experiment was the only one included in this experiment was the 6 foot high ceiling net and it would make no sense to have the quadcopter hover at the planned 5.5 feet. However, the means for each distribution were very close together. The experiment was conducted by marking the distances on a wall and mounting a laser to the quadcopter. The laser was aligned with the wall in order to measure the vertical altitude of the quadcopter. *Figure 6* shows the resulting distribution for the 4.5 feet vertical velocity was Beta.
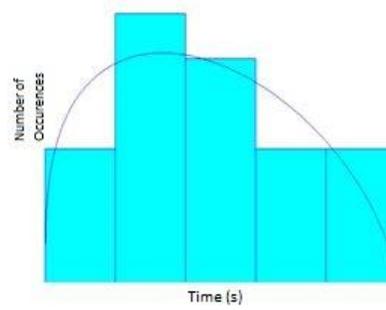

FIGURE 6
HORIZONTAL VELOCITY DISTRIBUTION FOR 4.5 FEET

III. Equations of Quadcopter Dynamics and Kinematics

In order to determine an optimal combination of battery and motors, it is necessary to understand the relationships that relate their properties. Newtons' laws indicate that in order for the quadcopter to hover in place, the thrust must equal the weight of the platform being elevated, and in order to ascend to a certain height or descend an acceleration must occur which will also require some change in thrust given by newton's laws.

When thrust is known, the rpm's of the motor can easily be determined as follows:

$$rpm_{ideal} = \left(\frac{2}{\pi}\right)^{1/2\omega} \left(\frac{g^{3/2}m^{3/2}}{\alpha D\sqrt{\rho}}\right)^{1/\omega} \quad (1)$$

Alpha and omega are power coefficients given by every propeller. For APC 6 x 4 propellers, these are .015 and 3.2. Rho is the density of air that the propeller is rotating in. Each motor is given a constant Kv rating that corresponds to rpm/volt. So once rpms are known, the real time voltage drawn can be calculated. Power is as follows:

$$P = IV = \alpha * rpm^{\omega} \quad (2)$$

the rpm value used is the rpm/1000. So a battery with 10000 rpm's using APC 6 x 4 propellors draws .015*10^3.2 = 24W. From power and voltage, the current can be calculated. The current relates to flight time as follows:

$$time \ (minutes) \ = ((Battery \ Capacity)/I \ )*60 \quad (3)$$

The most commonly used batteries for quadcopters are Lithium Polymer (LiPo) batteries, because of a large capacity and negligible affect on weight coupled with excellent discharge capabilities.

STRATEGY ANALYSIS

Given the fact that a team can only control a territory that is contiguous to theirs, the heuristic approach is that their contiguous path will not be able to intersect with another teams until the second level at least. Once a team

controls, the third level territory then all second level territories are contiguous to them, and they can then attempt to play defense by placing cones on top of any territories in the second level that become controlled by the other team. Thus the optimal strategy is one that allows a team to reach the third level first, and control it as long as possible. In order to do this, one must consider the placement of the cones on the course, and pick up cones such that they will have the shortest mean time between cone placements.

Using the distances to each territory mapped out in *figure 4,* we can use the mean times from our velocity distributions to determine an expected number of territories that can be controlled in a 7 minute period as well as the number of points that this would attain in a situation where there was no competition. The mean horizontal velocity was 3.75 ft/sec, mean ascending velocity is 1.15 ft/sec, and the time to acquire a territory can be modeled by the following equation:

$$t = 2d/\mu_h + 4*4.5/\mu_v + 30 \qquad (4)$$

This equation for time accounts for the time there and back motion between territories as well as ascending and descending. This equation incorporates an assumption that picking up and dropping off a cone requires 15 seconds. This is optimistic; it may take as long as 45 seconds. D is the distance in feet to territories in the arena. The time to gain control is estimated from the equation above. These distances represent the territories needed in order to control the third level. It takes 234.1 seconds to control the third level, out of a total of 420 seconds in the match. The remaining time can be used to play defense and prevent other players from entering the second level. The mean time to control a territory is 33.4 seconds, which leaves time for four more territories to be controlled in a 7 minute period. Thus, the expected number of cones is 12. In summary, because territories must be contiguous to other controlled territories, the strategy is to always approach the nearest territory. Once the third territory has been controlled, a defensive mode will be assumed; placing cones on top of other teams controlled territories if and when they enter the second level. Executing this strategy, without any competition taken into consideration yields 1908 points.

A mean time of 33.4 seconds to control a territory may be too optimistic. If it takes 30 seconds to pick up and drop a cone, then the mean time to control a territory is 48 seconds, which is enough to control 8 or 9 territories. This means the third level can be controlled, with two cones remaining to use defensively. In this case, the final score, not considering competition, is 1,281. In actuality, it likely takes a longer amount of time to control territories, and longer times are used in the competition.

SIMULATION

There is no current understanding of quadcopter performance in competition and no ideal combination of parts and components that give optimal results. The simulation will address these problems by determining the number of points attained in the competition and determining the quadcopter size and rotor types.

I. Simulation Design

For determining ideal parts, three alternatives were evaluated for motor and two for battery. An 850Kv, 1100Kv, and 1220Kv motor were tested. For batteries a 10,000mAh and 5,000 mAh battery were tested, each in combination with all three motor alternatives. The simulation models the dynamics of a quadcopter by calculating the neccesary thrust to move maneuver and transport cones through the course in order to enter the third level territory.

After cones are placed in the third level, the average thrust is used to determine average rpm's and ultimately the average current drawn across the motor. This average current is used to calculate an expected flight time. Additionally, it should be noted that the cost differential for each of these batteries and motors is less than one dollar, if purchased through many vendors however, the flight times can vary significantly.

Now that experiments have been conducted, in order to model horizontal velocity and vertical takeoff velocity, these distributions will be used in the simulation trials, alongside the distances of cones and territories to be controlled in order to determine expected number of territories that can be controlled, and output the number of points. The landing accuracy distributions will factor in to determining error potential for picking up cones as well as estimating the time to pick up a cone.

During the simulation, user error and precision can be combined with a random number to determine whether or not a cone is picked up or not. These stats can be used to determine a maximum amount of cones a robot can pick up.

Since a quadcopter will only be picking up cones that are in one of the three stacks, the time to pick up and drop off a cone will be the same. However for competing robots, it will take different lengths of time to pick up cones on strings and behind doors. Accurate estimations of this time will be factored into the simulation.

Simulation trials will be ran against 4 competitors, and all of their possible choices for cone placement and choices of cones to pick up in order to see the outcomes. In the simulation, whichever team is currently in control of the third level territory will assume a defensive role in order to prevent the other team from controlling the third level.

II. Description of Simulation and Results

The data for mean current drawn for each battery/motor combo is as follows:

motor(kv)	Battery(mAh)	Mean amps(4x)	Flight time(min)
850	5000	6.97	11.95
1100	5000	15.91	5.24
1220	5000	22.16	3.76
850	10000	6.97	23.9
1100	10000	15.91	10.48
1220	10000	22.16	7.52

TABLE 2
FLIGHT TIME FOR DIFFERENT CURRENT BATTERY
COMBINATIONS

The 5000 mAh battery is the only one which fulfills the 7 minute flight time with an 850Kv motor. A 10000 mAh battery will always guarantee at least 7 minutes of flight time. However, the 1220Kv barely clears the 7 minute threshold and the 850kV motor, while offering a long flight time may be unreliable when a mechanism for picking up and transporting cones is attached, since it may have difficulty generating the necessary thrust.

For the simulation for expected points, cones are contained in a list structure of the shortest path to the third level. Also, surrounding second level cones are stored in a list. The time to proceed to each cone is determined by using the sciPy library to generate random numbers from the distributions determined experimentally. Controlled cones accumulate points according to the rules. Random chance of opponent capturing controlled cone in second or third level. Output is a distribution of points scored over 111 simulation trials. The result was a normal distribution with mean of 555 and a standard deviation of 154. The top two competitors in the 2014 competition scored an average of 866 points per round and 430 points per round. By assuming both teams points were normally distributed, and comparing them. The result is an 80% chance of coming in second place, after 3 rounds of competition, and less than a 2 percent chance of coming in first place.
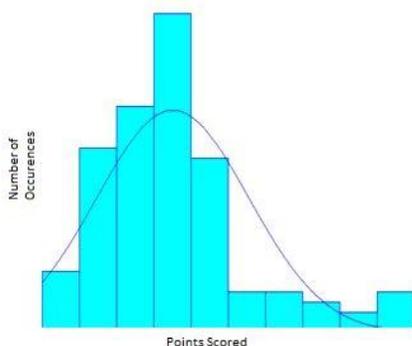

FIGURE 7
PRELIMINARY COMPETITION RESULTS

III. Assumptions

The following assumptions had to be made when constructing the simulation:
- Teams will attempt to enter territory three as soon as possible
- The teams' paths will not come into contact until level two
- No team will sabotage another team
- Cone transportation takes about 30 seconds, and is normally distributed.

IV. Recommendations

In order to maximize the flight time, as well as the strength of motors for transporting objects, it is recommended to use an 1100Kv motor in combination with a 10000mAh LiPo battery. In the competition, it is clear that the first place team, a ground robot was performing at a level well beyond the rest of the competition. The advantage is that, even though a quadcopter is much faster and has a 3x point multiplier, picking up cones with a quadcopter is unreliable and takes a lengthy amount of time on average compared with ground robots. Results show that most of the time for a quadcopter to gain control of a territory is spent attempting to pick up a cone. Whereas for ground robots, most of the time is spent navigating the arena. Therefore, in order to win the Jerry Sanders Creative Design competition, a quadcopter must be designed, with a mechanism that can pick up cones in significantly less time. In the past two years, no airborne entry has been able to score points, and simulation shows that, using existing technology, a quadcopter is not able to achieve a high likelihood of winning the competition.

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AUTHOR INFORMATION

Jordan Bramble, Student, Department of Systems Engineering and Operations Research, George Mason University

Harold Merida, Student, Department of Systems Engineering and Operations Research, George Mason University

Ibtsam Khan, Student, Department of Systems Engineering and Operations Research, George Mason University