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

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Sponsor: Bo Pollett
Contents

- Description of Competition
- Competition Rules
- Scoring
- Mission Requirements
- Design
- Experiment
- Method of Analysis
- Simulation Design
  - Competition Performance Model
  - Configuration Model
Jerry Sanders Design Competition

- Yearly (March 14-15, 2014) competition held at University of Illinois sponsored by Advanced Micro Devices.
- Objective: Compete with other robots by placing colored cones onto pins to control territories.
- Two airborne entries in entire history
- Cones are located behind a hinged door and upside down tied to a string
Eagle Eye View With Pin and Cone Locations
**Competition Rules**

- Each match will
  - be seven (7) minutes long
  - consist of four or fewer robots
- The team’s color cone is the topmost in the stack of cones for control of a territory
- Teams cannot attempt to control a territory unless it would be contiguous
- Cones will be placed behind hinged doors which must be opened before cones can be accessed.
Airborne Entry Rules

- Quadcopters cannot weigh more than 15 pounds.
- Rotors must be made out of plastic.
- Same battery rules as regular land entries.
  - Batteries must be fully sealed – reduce damage to the course.
  - 5 minutes to replace batteries in between rounds.
- Quadcopter entries must contact the JSDC rules chair with important information.
  - Weight, size, propulsion type, and any other type of information.
Scoring

• Airborne robots have a constant 3x multiplier when scoring cones
  • 5x multiplier for autonomous

• For each contiguous powered territory controlled at the end of match:
  • First level—10 points
  • Second level—30 points
  • Third level—40 points

• Every ten (10) seconds that a team controls:
  • First level territory—1 point
  • Second level territory—3 points
  • Third level territory—5 points

• Completion of an action for the first time will result in ten (10) points being awarded to the team responsible.
2014 JSCDC Competition Video
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Mission Requirements

1. The Quadcopter shall have greater than 50 percent likelihood of winning the competition and at least a 70 percent likelihood of advancing to final round.

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

3. The Quadcopter shall maintain 7 minutes of flight time.
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Design Requirements

- 1.0 The Quadcopter shall fit within a 3’x3’x3’ cube.
- 2.0 The Quadcopter shall weigh no more than 15lbs.
- 3.0 The Quadcopter shall be equipped with a FPV camera.
- 4.0 The Quadcopter shall have a mechanism for picking up Adams Saucer cones with a 2” diameter central hole and 2” height.
- 5.0 The Quadcopter’s propellers shall be guarded such that they cannot damage the netting above the course.
- 6.0 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.
## Traceability Matrix

<table>
<thead>
<tr>
<th>Design Req</th>
<th>MR.1</th>
<th>MR.2</th>
<th>MR.3</th>
<th>Competition Rules</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>2.0</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>3.0</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>4.0</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.0</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>
### Parts List

- AutoPilot Multiplateform
- 3DR Power Module
- Magnometer
- Telemetry Set
- Electronic Speed Control (ESC)
- Video Transmitter
- Pick up Mechanism
- Motors x 4
- Propellers x 4
- Frame 3’ X 3’
- Landing Gear
- Batteries
- First Person View Camera/laptop
- RC Transmitter
# Quadcopter Alternatives

<table>
<thead>
<tr>
<th>Quad-Copter</th>
<th>DC Drones</th>
<th>A.R. Parrot</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cost</strong></td>
<td>$1700</td>
<td>$300</td>
</tr>
<tr>
<td><strong>Tech</strong></td>
<td>Arduino</td>
<td>Linux</td>
</tr>
<tr>
<td><strong>Weight</strong></td>
<td>1000g</td>
<td>420g</td>
</tr>
<tr>
<td><strong>Flight Time</strong></td>
<td>11.5mins</td>
<td>36 mins</td>
</tr>
<tr>
<td><strong>Carrying Capacity</strong></td>
<td>1600g</td>
<td>250g</td>
</tr>
</tbody>
</table>
Weighted Values

<table>
<thead>
<tr>
<th>Category</th>
<th>DC Drones</th>
<th>A.R. Parrot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technology</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Quadcopter Weight</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Flight time with Max Pay</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Carrying Capacity</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>Cost</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Camera</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>

Total Score:
- DC Drones: 95
- A.R. Parrot: 48

Category Weight:
- 5 Very High Importance
- 4 High Importance
- 3 Medium Importance
- 2 Low Importance
- 1 Very Low Importance
- 0 Not Importance

Score Scale:
- 5 Excellent
- 4 Good
- 3 Average
- 2 Poor
- 1 Very Poor
- 0 Does not meet the requirement

Category Weight X Score = Final Score

Category Weight (0-5): | Score (0-5): | Final Score (0-150): |
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Experiment 1 – Horizontal Velocity

- Three distances
  - 20.5 feet, 30.7 feet, 47.7 feet
- 36 Trials per distance
- 108 trials total
- Velocity (ft/s) = Distance (ft) / Time (s)
- Average Velocity and Std Dev:
  - 20.5 Feet: $\mu = 3.75$ ft/s $\sigma = 0.57$
  - 30.7 Feet: $\mu = 5.19$ ft/s $\sigma = 0.97$
  - 47.7 Feet: $\mu = 6.50$ ft/s $\sigma = 1.09$
20.5ft Horizontal Velocity

Distribution Summary
Distribution: Beta
Expression: 2.26 + 2.51 * BETA(2.16, 1.49)
Square Error: 0.004660

Chi Square Test
Number of intervals = 5
Degrees of freedom = 2
Test Statistic = 0.756
Corresponding p-value = 0.685

Kolmogorov-Smirnov Test
Test Statistic = 0.0803
Corresponding p-value > 0.15

Data Summary
Number of Data Points = 36
Min Data Value = 2.471
Max Data Value = 4.56
Sample Mean = 3.75
Sample Std Dev = 0.572

Histogram Summary
Histogram Range = 2.26 to 4.77
Number of Intervals = 6
30.7ft Horizontal Velocity

Distribution Summary
Distribution: Normal
Expression: NORM(5.19, 0.961)
Square Error: 0.002755

Chi Square Test
Number of intervals = 4
Degrees of freedom = 1
Test Statistic = 0.176
Corresponding p-value = 0.697

Kolmogorov-Smirnov Test
Test Statistic = 0.0849
Corresponding p-value > 0.15

Data Summary
Number of Data Points = 36
Min Data Value = 3.13
Max Data Value = 7.13
Sample Mean = 5.19
Sample Std Dev = 0.975

Histogram Summary
Histogram Range = 3 to 7.53
Number of Intervals = 6
40.7ft Horizontal Velocity

Distribution Summary
Distribution: Normal
Expression: NORM(6.5, 1.08)
Square Error: 0.007691

Chi Square Test
Number of intervals = 4
Degrees of freedom = 1
Test Statistic = 0.729
Corresponding p-value = 0.421

Kolmogorov-Smirnov Test
Test Statistic = 0.0808
Corresponding p-value > 0.15

Data Summary
Number of Data Points = 36
Min Data Value = 4.08
Max Data Value = 8.22
Sample Mean = 6.5
Sample Std Dev = 1.09

Histogram Summary
Histogram Range = 4 to 8.64
Number of Intervals = 6
Horizontal Velocity
Experiment 2 – Vertical Velocity

- Three vertical distances
  - 2.5 feet, 4.5 feet, 5.5 feet
- 20 Trials per vertical distance
- 60 trials total
  - Laser used to determine height.
- 4.5 Feet data was used in simulation
- Velocity (ft/s) = Vertical Distance (ft) / Time (s)
4.5 ft Vertical Velocity

Distribution Summary
Distribution: Beta
Expression: \(0.67 + 1.07 \times \text{BETA}(1.32, 1.63)\)
Square Error: 0.008975

Chi Square Test
Number of intervals = 2
Degrees of freedom = -1
Test Statistic = 0.068
Corresponding p-value < 0.005

Kolmogorov-Smirnov Test
Test Statistic = 0.0819
Corresponding p-value > 0.15

Data Summary
Number of Data Points = 20
Min Data Value = 0.76
Max Data Value = 1.65
Sample Mean = 1.15
Sample Std Dev = 0.268

Histogram Summary
Histogram Range = 0.67 to 1.74
Number of Intervals = 5
Vertical Velocity
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Time Intervals for Controlling Territories

- Mean ascending velocity for 4.5 feet: 1.15 ft/sec
- Assumption: it takes a mean time of 30 seconds to pick up and drop a cone
- Time to acquire a territory:
  \[ t = \frac{2d}{\mu_h} + \frac{4 \times 4.5}{\mu_v} + \text{Norm}(30,10) \]
- \( d = \) distance from home territory to pin.
- Need 7 contiguous territories to control 3rd level.
- 420 seconds in a match.
- Expected # of cones: 12
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<table>
<thead>
<tr>
<th>Problem</th>
<th>Problem Addressed By Simulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) No current understanding of quadcopter performance in this</td>
<td>(1) Determine the expected number of points attained in</td>
</tr>
<tr>
<td>competition</td>
<td>competition</td>
</tr>
<tr>
<td>(2) No ideal combination of battery type and motor size that gives</td>
<td>(2) Determine quadcopter motor size and battery type.</td>
</tr>
<tr>
<td>optimal results</td>
<td></td>
</tr>
</tbody>
</table>
Model Assumptions

• Teams will attempt to enter the third territory 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.

• Time to control cone \( t = \frac{2d}{\text{random.normal}(\mu, \sigma)} + \frac{4 \times 4.5}{\text{random.uniform}(\mu, \sigma)} + \text{random.normal}(30,10) \)
# Simulation Breakdown

<table>
<thead>
<tr>
<th>Model</th>
<th>What Is Addressed</th>
<th>Language</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expected Performance</td>
<td>Passes in distribution data gathered experimentally, in order to output expected distribution of points scored</td>
<td>Python</td>
</tr>
<tr>
<td>Optimal configuration</td>
<td>Determines the ideal quadcopter battery type and rotor size, with relation to weight and battery life</td>
<td>Matlab</td>
</tr>
</tbody>
</table>
Simulation Diagram

Priority Queue of Territories
Current Cone Distances
Competition Cone Placement

20.5 ft Horizontal Dist.
30.7 ft Horizontal Dist.
20.5 ft Horizontal Dist.
4.5 ft Vertical Dist.
Pick up Time Dist.

Points in the Round of Competition
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• Territories contained in shortest path priority queue leading to third territory, as well as surrounding second level territories 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.
• chance of opponent capturing controlled cone in second or third level, if contiguous paths overlap
• Output is a distribution of points scored over 111 simulation trials.
### Competition Simulation Results

**Distribution Summary**
- Distribution: Normal
- Expression: NORM(555, 154)
- Square Error: 0.019862

**Chi Square Test**
- Number of intervals = 6
- Degrees of freedom = 3
- Test Statistic = 13.5
- Corresponding p-value < 0.005

**Kolmogorov-Smirnov Test**
- Test Statistic = 0.16
- Corresponding p-value < 0.01

**Data Summary**
- Number of Data Points = 111
- Min Data Value = 291
- Max Data Value = 1.04e+003
- Sample Mean = 555
- Sample Std Dev = 155

**Histogram Summary**
- Histogram Range = 291 to 1.04e+003
- Number of Intervals = 10
Results

• Highest Single Round Score was 932 points for first place, 430 points for second place.
• Winning team averaged 866 points per round
• 80% chance of runner up, only 2% chance of victory
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Rpm’s generated under a given thrust \( \omega \), and \( \alpha \) are power coefficients given by the propeller manufacturer \( \omega = 3.2 \), \( \alpha = .015 \) for APC 11x4.5 propellers

\[
\text{rpm}_{\text{ideal}} = \left(\frac{2}{\pi}\right)^{1/2\omega} \left(\frac{\frac{g^{3/2}m^{3/2}}{\alpha D \sqrt{\rho}}}{\omega}\right)^{1/\omega}
\]

\[P = IV = \alpha \times \text{rpm}^\omega \]

\[\text{Time (mins)} = \frac{\text{Battery Capacity}}{I} \times 60\]
## Data of motors

<table>
<thead>
<tr>
<th>Motor (Kv)</th>
<th>Battery (mAh)</th>
<th>Mean amps (4x)</th>
<th>Flight Time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>850</td>
<td>5000</td>
<td>6.97</td>
<td>11.95</td>
</tr>
<tr>
<td>1100</td>
<td>5000</td>
<td>15.91</td>
<td>5.24</td>
</tr>
<tr>
<td>1220</td>
<td>5000</td>
<td>22.16</td>
<td>3.76</td>
</tr>
<tr>
<td>850</td>
<td>10000</td>
<td>6.97</td>
<td>23.9</td>
</tr>
<tr>
<td>1100</td>
<td>10000</td>
<td>15.91</td>
<td>10.48</td>
</tr>
<tr>
<td>1220</td>
<td>10000</td>
<td>22.16</td>
<td>7.52</td>
</tr>
</tbody>
</table>
Results of Flight Time Tradeoff Simulation

• An 1100 kv motor with 10000 mAh provides the longest flight time
• 850 Kv motor will yield high flight times but demand high voltage to do so.
Recommendations

• To win the competition quadcopter needs to be designed with:
  • Mechanism that picks up cones quicker
  • Implementation of autonomy

• To maximize flight time and strength of motors, 1100 kv motor with a 10000 mAh LiPo battery should be used

• Continue further research to develop more effective designs of claw pick up mechanism in order to reduce mean time to pick up and place cones from 30 seconds to 6 seconds.
Questions?