Funky Town Fancy Pandas Budget Proposal 1.0.0-2014

(Revision October 7, 2014)

**Budget Proposal**

**for Autonomous Panda System**

Sponsor:

The Department of Electrical, Computer, Software & Systems Engineering at Embry-Riddle Aeronautical University

Released:

October 7, 2014

Funky Town Fancy Pandas Development Team

**Abstract:** The budget proposal and functional design is contained in this document in conjunction with the preliminary budget, justifications, and decisions for each of the major components.

# Revision History

Table 1 contains the information regarding the version control for this document, including version, date, and description.

|  |  |  |
| --- | --- | --- |
| **Version** | **Date** | **Description** |
| 0.1.0 | Sept. 28, 2014 | Initial draft of the document |
| 0.2.0 | Sept. 30, 2014 | Continuation of budget proposal |
| 0.3.0 | Oct. 1, 2014 | Formatting |
| 0.4.0 | Oct. 2, 2014 | Continuation of budget proposal |
| 0.5.0 | Oct. 4, 2014 | Adding matrices and continue formatting |

Table . Revision History

**Table of Contents**

[Revision History 2](#_Toc400280054)

[Table of Figures 5](#_Toc400280055)

[1. Introduction 6](#_Toc400280056)

[1.1 Purpose 6](#_Toc400280057)

[1.2 Scope 6](#_Toc400280058)

[1.3 Team Information 6](#_Toc400280059)

[2. Functional Decomposition System 7](#_Toc400280060)

[2.1 High-Level Architecture of System 7](#_Toc400280061)

[2.2 Decomposition of Vehicle Hardware Layer 7](#_Toc400280062)

[2.3 Decomposition of Communication Hardware Layer 7](#_Toc400280063)

[3. Budget Decision Matrices and Justifications 8](#_Toc400280064)

[3.1 Microcontroller 8](#_Toc400280065)

[3.1.1 Items under Consideration 8](#_Toc400280066)

[3.1.2 Decision Matrix 9](#_Toc400280067)

[3.1.3 Justification 9](#_Toc400280068)

[3.2 Sensors 10](#_Toc400280069)

[3.2.1 Items under Consideration 10](#_Toc400280070)

[3.2.2 Decision Matrix 10](#_Toc400280071)

[3.2.3 Justification 10](#_Toc400280072)

[3.3 Motors 11](#_Toc400280073)

[3.3.1 Items under Consideration 11](#_Toc400280074)

[3.3.2 Decision Matrix 11](#_Toc400280075)

[3.3.3 Justification 11](#_Toc400280076)

[3.4 Claw 15](#_Toc400280077)

[3.4.1 Items under Consideration 15](#_Toc400280078)

[3.4.2 Decision Matrix 15](#_Toc400280079)

[3.4.3 Justification 15](#_Toc400280080)

[3.5 Wheels 17](#_Toc400280081)

[3.5.1 Items under Consideration 17](#_Toc400280082)

[3.5.2 Decision Matrix 17](#_Toc400280083)

[3.5.3 Justification 17](#_Toc400280084)

[3.6 Battery 20](#_Toc400280085)

[3.6.1 Items under Consideration 20](#_Toc400280086)

[3.6.2 Decision Matrix 20](#_Toc400280087)

[3.6.3 Justification 21](#_Toc400280088)

[4. Requirements Traceability 24](#_Toc400280089)

[4.1 Microcontroller 24](#_Toc400280090)

[4.2 Sensors 24](#_Toc400280091)

[4.3 Motors 24](#_Toc400280092)

[4.4 Claw 25](#_Toc400280093)

[4.5 Frame 25](#_Toc400280094)

[4.6 Battery 26](#_Toc400280095)

[5. Risk Analysis 27](#_Toc400280096)

[5.1 Microcontroller 27](#_Toc400280097)

[5.2 Sensors 27](#_Toc400280098)

[5.3 Motors 27](#_Toc400280099)

[5.4 Claw 27](#_Toc400280100)

[5.5 Wheels 27](#_Toc400280101)

[5.6 Frame 27](#_Toc400280102)

[5.7 Battery 28](#_Toc400280103)

[6. Total System BudgetAppendix B: Glossary 29](#_Toc400280104)

[Acronyms & Abbreviations 32](#_Toc400280105)

[References 33](#_Toc400280106)

# Table of Figures

Table 1. Revision History 2

Table 2. Team Information 6

Table 3. Items under consideration for the microcontroller 8

Table 4. Decision matrix for the microcontroller 9

Table 5. Decision matrix for the sensors 10

Table 6. Items under consideration for the motor 11

Table 7. Decision matrix for the motors 11

Table 8. Calculations for the price of the motor 12

Table 9. Calculations for the RPM of the motor 12

Table 10. Calculations for the stall torque of the motor 13

Table 11. Calculations for the stall current of the motor 13

Table 12. Calculations for the weight of the motor 14

Table 13. Items under consideration for the claw 15

Table 14. Decision matrix for the claw 15

Table 15. Calculations for the price of the claw 16

Table 16. Calculations for the weight of the claw 16

Table 17. Items under consideration for the wheels 17

Table 18. Decision matrix for the wheels 17

Table 19. Calculation for the price of the wheels 18

Table 20. Calculation for the weight of the wheels 18

Table 21. The items under consideration for the batteries 20

Table 22. Decision matrix for the batteries 20

Table 23. Calculations for the price of the batteries 21

Table 24. Calculations for the discharge rate of the batteries 22

Table 25. Calculations for the voltage of the batteries 22

Table 26. Calculations for the weight of the batteries 23

Table 27. Requirements traceability for the microcontroller 24

Table 28. Requirements traceability for the sensors 24

Table 29. Requirements traceability for the motors 25

Table 30. Requirements traceability for the claw 25

Table 31. Requirements traceability for the frame 26

Table 32. Requirements traceability for the batteries 26

Table 33. Risks and alleviations associated with the microcontrollers 27

Table 34. Risks and alleviations associated with the sensors 27

Table 35. Risks and alleviations associated with the motors 27

Table 36. Risks and alleviations associated with the claw 27

Table 37. Risks and alleviations associated with the wheels 27

Table 38. Risks and alleviations associated with the frame 28

Table 39. Risks and alleviations associated with the battery 28

Table 40. Listing of terms and definitions used throughout this document 31

Table 41. The acronyms and abbreviations used throughout this budget proposal 32

# Introduction

The introduction of this document defines the purpose, scope, and team information for the project.

## Purpose

The purpose of this document is to identify the preliminary budget for the Autonomous Panda System (APS). It is intended to provide the customers of the APS with justifications for major item decisions. These justifications include decision matrices, risk analysis and fulfillment of requirements.

## Scope

This document is intended to provide the customers of APS with a list of parts with justification and pricing information. In this list of parts, only major components have been considered. These major components are those with price above $20 [**citation**] and are essential to the early prototyping of the APS. This document also contains a high-level break down of the APS that provides an overview of the initial design of the system.

## Team Information

Table 2 contains the team member names and their corresponding roles.

|  |  |
| --- | --- |
| **Name** | **Role** |
| Kurt Pedrosa | Team Leader/Scrum Master |
| Merissa Roth | Software Leader |
| Mary Luongo | Hardware Leader/Product Owner |
| Luis Bogran | Development Leader |
| Kok Peng Tan | Developer |

Table . Team Information

# Functional Decomposition System

## High-Level Architecture of System

## Decomposition of Vehicle Hardware Layer

## Decomposition of Communication Hardware Layer

# Budget Decision Matrices and Justifications

This section of the document contains the reasoning used during the selection of the major components. The use of decision matrices is main method for selecting all the components to be used for the APS. These matrices show the important characteristic of the component and indexed each of them with a weighted score. The Funky Town Fancy Pandas (FTFP) development team scored each characteristic of each component and the average score is then calculated. The total score is gathered and the item with the highest total score is then selected as the most desirable component for the system.

## Microcontroller

The microcontrollers considered and descriptions of the decision process are described in the following content. The process was tailored to provide the APS with the optimal microcontroller to control all the subsystems.

### Items under Consideration

The following items were considered as the microcontroller used to operate the subsystems of the APS. All of the items have been characterized on Table 3 by item identification name, item ID, vendor, and a description.

|  |  |  |
| --- | --- | --- |
| **Item ID** | **Vendor** | **Description** |
| Arduino Due | Amazon | A microcontroller based on the ARM Cortex-M3 chip. Contains 54 general-purpose input/output (GPIO) pins. It run at a clock speed of 84 MHz. Contains 96 KB of RAM and 512 KB of Flash memory. It is a popular microcontroller for novice and expert developers. |
| Raspberry Pi Modle B+ | Amazon | A microcontroller with a Broadcom BCM2835 chipset, Micro SD storage, and 40 GPIO pins. Contains 512 MB of RAM (Random Access Memory) and a processor speed of 700 MHz It has gain popularity between the novice and experience developers. |
| UDOO Quad | Udoo | A microcontroller based on an ARM Cortex-A9 chip with a clock speed of 1GHz. On-board integration with the Arduino Due Cortex-M3 chip set. It contains 76 fully available GPIO pins, and two Micro USB storage slots. It is not a popular microprocessor within the developer community but has promising features that may satisfy most novice and expert developers. |
| BeagleBone Black | Amazon |  |

Table . Items under consideration for the microcontroller

### Decision Matrix

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Product** | **Price** | **Speed** | **RAM** | **Memory** | **GPIO** | **OS/IDE** | **Ease of use** |
| Arduino Due | $40.22 | 84 MHz | 96 KB | 512 KB | 54 (12 PWM) | Arduino IDE |  |
| Raspberry Pi Model B+ | $38.89 | 700 MHz | 512 MB | SD Card | 40 | Linux |  |
| UDOO Quad | $135 | 1 GHz | 1 GB | SD Card/SATA | 76 | Linux/Aduino IDE |  |
| BeagleBone Black | $65.90 | 1 GHz | 512 MB | 4 GB | 65 | Linux |  |
|  |  |  |  |  |  |  |  |
| **Product Weight** | **Price** | **Speed** | **RAM** | **Memory** | **GPIO** | **OS/IDE** | **Ease of use** |
| Arduino Due | 8 | 2 | 2 | 5 | 8 | 6 | 9 |
| Raspberry Pi Model B+ | 9 | 5 | 5 | 9 | 7 | 8 | 9 |
| UDOO Quad | 3 | 8 | 8 | 10 | 9 | 10 | 5 |
| BeagleBone Black | 5 | 8 | 5 | 7 | 8 | 8 | 7 |
|  |  |  |  |  |  |  |  |
| **Weighted** | 0.2 | 0.2 | 0.1 | 0.25 | 0.1 | 0.1 | 0.05 |
|  |  |  |  |  |  |  |  |
| **Product Total** | **Price** | **Speed** | **RAM** | **Memory** | **GPIO** | **OS/IDE** | **Ease of use** | **Total** |
| Arduino Due | 1.6 | 0.4 | 0.2 | 1.25 | 0.8 | 0.6 | 0.45 | 5.3 |
| Raspberry Pi Model B+ | 1.8 | 1 | 0.5 | 2.25 | 0.7 | 0.8 | 0.45 | 7.5 |
| UDOO Quad | 0.6 | 1.6 | 0.8 | 2.5 | 0.9 | 1 | 0.25 | 7.65 |
| BeagleBone Black | 1 | 1.6 | 0.5 | 1.75 | 0.8 | 0.8 | 0.35 | 6.8 |

Table . Decision matrix for the microcontroller

### Justification

## Sensors

### Items under Consideration

### Decision Matrix

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Product** | **Availability** | **Price** | **OS/IDE** | **FPS** | **Resolution** |  |
| Pixy Cam | Available | $0 | Arduino/C | 50 | (640 x 400) |  |
| CMUcam4 Robot Vision | Buy it | $116.24 | Arduino/C | 30 | VGA (640 x 840) |  |
| Raspberry Pi | Buy it | $29.95 | Raspberry Pi | 30 | 1080 p HD |  |
| Minoru 3D webcam | Buy it | $37.99 | openCV | 30 | 320 x 240 |  |
|  |  |  |  |  |  |  |
| **Product Weight** | **Availability** | **Price** | **OS** | **FPS** | **Resolution** |  |
| Pixy Cam | 10 | 10 | 9 | 8 | 6 |  |
| CMucam4 Robot Vision | 5 | 5 | 9 | 6 | 7 |  |
| Raspberry Pi | 5 | 8 | 6 | 6 | 9 |  |
| Minoru 3D webcam | 5 | 7 | 6 | 6 | 4 |  |
|  |  |  |  |  |  |  |
| **Weighted** | 0.1 | 0.2 | 0.2 | 0.25 | 0.25 |  |
|  |  |  |  |  |  |  |
| **Product Total** | **Availability** | **Price** | **OS/IDE** | **FPS** | **Resolution** | **Total** |
| Pixy Cam | 1 | 2.00 | 1.8 | 2 | 1.5 | 8.30 |
| CMucam4 Robot Vision | 0.5 | 1 | 1.8 | 1.5 | 1.75 | 6.55 |
| Raspberry Pi | 0.5 | 1.6 | 1.2 | 1.5 | 2.25 | 7.05 |
| Minoru 3D webcam | 0.5 | 1.4 | 1.2 | 1.5 | 1 | 5.60 |

Table . Decision matrix for the sensors

### Justification

## Motors

The motors are a crucial part of the APS, as without it, the robot would not be able to move. The categories below describe the items under consideration, the decision matrix, and the justification of the decision made.

### Items under Consideration

Table 6 contains the items under consideration for the motors. The items under consideration have been listed below and contain the product ID and the vendor.

|  |  |  |
| --- | --- | --- |
| **Motors** | **ID** | **Vendor** |
| Standard Gearmotor | ROB-12399 | Sparkfun |
| Precision Gearmotor | ROB-12497 | Sparkfun |
| 154:1 Metal Gearmotor 20 D x 44 L mm. | Pololu item #: 1109 | Pololu |
| 100:1 Metal Gearmotor 37 D x 57 L mm. | Pololu item #: 1106 | Pololu |

Table . Items under consideration for the motor

### Decision Matrix

Table 7 contains the decision matrix for the motor. Every item under consideration has been evaluated and broken down into different categories. The voltage is the normalized maximum voltage for the motor. The revolutions per minute (RPM) is the maximum number of revolutions the motor makes in a minute. The stall torque is the maximum amount of force that the motor can move before stalling. The stall current is the maximum current that the motor will need at stalling.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Product** | **Price** | **Voltage** | **RPM** | **Stall Torque** | **Stall Current** | **Weight** |
| Standard Gearmotor | $24.95 | 12 V | 101 | 32.2 N-cm | 0.5 A | 119.07 g |
| Precision Gearmotor | $34.95 | 12 V | 90 | 98.01 N-cm | 1 A | 240.97 g |
| 154:1 Metal Gearmotor 20 D x 44 L mm. | $19.95 | 6 V | 90 | 84.73 N-cm | 3.3 A | 32.6 g |
| 100:1 Metal Gearmotor 37 D x 57 L mm. | $24.95 | 12 V | 100 | 155.35 N-cm | 5 A | 201.28 g |
|  |  |  |  |  |  |  |
| **Product Weight** | **Price** | **Voltage** | **RPM** | **Stall Torque** | **Stall Current** | **Weight** |
| Standard Gearmotor | 4 | 4 | 5.61 | 2.9 | 9.1 | 5.6 |
| Precision Gearmotor | 1 | 4 | 5.00 | 6.7 | 8.2 | 1.0 |
| 154:1 Metal Gearmotor 20 D x 44 L mm. | 5 | 8 | 5.00 | 5.9 | 4.1 | 8.8 |
| 100:1 Metal Gearmotor 37 D x 57 L mm. | 4 | 4 | 5.56 | 10.0 | 1.0 | 2.5 |
|  |  |  |  |  |  |  |
| **Weighted** | 0.15 | 0.1 | 0.05 | 0.35 | 0.3 | 0.05 |
|  |  |  |  |  |  |  |
| **Product Total** | **Price** | **Voltage** | **RPM** | **Stall Torque** | **Stall Current** | **Weight** | **Total** |
| Standard Gearmotor | 0.60 | 0.40 | 0.30 | 1.05 | 2.70 | 0.30 | 5.35 |
| Precision Gearmotor | 0.15 | 0.40 | 0.25 | 2.45 | 2.40 | 0.05 | 5.70 |
| 154:1 Metal Gearmotor 20 D x 44 L mm. | 0.75 | 0.80 | 0.25 | 2.10 | 1.20 | 0.45 | 5.55 |
| 100:1 Metal Gearmotor 37 D x 57 L mm. | 0.60 | 0.40 | 0.30 | 3.50 | 0.30 | 0.10 | 5.20 |

Table . Decision matrix for the motors

### Justification

The following describes the process used in obtaining the scores for the various categories used to rate the motors under consideration in the decision matrix. The data for the motors under consideration was obtained from Sparkfun and Pololu.

**Price**

Table 8 contains the price category scores the price of the motors. The score for the price was obtained by normalizing the price and multiplying the normalized valued by the maximum score of 9 and adding 1. The weighted value of the price category is 15%. The equation below is an example to show how the price score is produced.

|  |  |  |
| --- | --- | --- |
| **Item** | **Calculation** | **Score** |
| ROB-12399 |  | 4 |
| ROB-12497 |  | 1 |
| Pololu item #: 1109 |  | 5 |
| Pololu item #: 1106 |  | 4 |

Table . Calculations for the price of the motor

**Voltage**

The voltage category scores the voltage levels required of the APS for the motors. The maximum operating voltage of all the items are either 6 V or 12 V. They are given a score of 4 for 12 V as it requires more voltage from the APS and they are given a score of 8 for the 6 V requirement. This category is given a 10% weighted value.

**RPM**

Table 9 contains the RPM category scores the RPM of the motors. The motors chosen were around the 90-RPM range to determine the differences in the torque of the different motors. This was done because the motors for each item can come in different RPM, but the torque would change scaling reasonably with the change in RPM. The score for this is determined by dividing the RPM value by 90 and multiplying by 5, as 90 RPM was the arbitrary choice. As this was an arbitrary choice, the weighted value of the score is 5%.

|  |  |  |
| --- | --- | --- |
| **Item** | **Calculation** | **Score** |
| ROB-12399 |  | 6 |
| ROB-12497 |  | 5 |
| Pololu item #: 1109 |  | 5 |
| Pololu item #: 1106 |  | 6 |

Table . Calculations for the RPM of the motor

**Stall Torque**

Table 10 contains the stall torque category scores the stall torque of the APS. This determines the amount of load the APS can move. If the weight of the APS is above the limit, the motor will stall. The equation to determine the stall torque was derived by calculating the normalized stall torque values multiplied by 9 and subtracting that from 10. This determines the load that the APS can carry it is given a weight of 35%.

|  |  |  |
| --- | --- | --- |
| **Item** | **Calculation** | **Score** |
| ROB-12399 |  | 3 |
| ROB-12497 |  | 7 |
| Pololu item #: 1109 |  | 6 |
| Pololu item #: 1106 |  | 10 |

Table . Calculations for the stall torque of the motor

**Stall Current**

Table 11 contains the stall current category scores the maximum current the APS needs to supply the motors when they are in a stall state. The equation used to determine the scores was derived by normalizing the stall current values multiplying them by 9 and adding 1. The weighted value of this category is 30% as it can affect other systems if the current is too high.

|  |  |  |
| --- | --- | --- |
| **Item** | **Calculation** | **Score** |
| ROB-12399 |  | 9 |
| ROB-12497 |  | 8 |
| Pololu item #: 1109 |  | 4 |
| Pololu item #: 1106 |  | 1 |

Table . Calculations for the stall current of the motor

**Weight**

Table 12 contains the weight category determines the weight of each of the different motors. The scores for this category are determined by normalizing the weights of the motors multiplied by 9 and adding 1. The weighted value of this category is 5%.

|  |  |  |
| --- | --- | --- |
| **Item** | **Calculation** | **Score** |
| ROB-12399 |  | 9 |
| ROB-12497 |  | 1 |
| Pololu item #: 1109 |  | 9 |
| Pololu item #: 1106 |  | 3 |

Table . Calculations for the weight of the motor

## Claw

The claw is a crucial part of the APS, as without it, the robot would not be able to complete any of the tasks required. The categories below describe the items under consideration, the decision matrix, and the justification of the decision made.

### Items under Consideration

Table 13 contains the items under consideration for the claw. The items under consideration have been listed below and contain the product ID and the vendor.

|  |  |  |
| --- | --- | --- |
| **Product** | **ID** | **Vendor** |
| OWI-535 Robotic Arm Edge | OWI-535 | Amazon |
| Stacker 2WD Mobile Robot | RB-Sct-154 | RobotShop |
| AX-12 Dual Robotic Gripper | AX12DUAL\_GRIP | CrustCrawler |
| AL5D Arm Hardware Only - Kit | AL5D-NS | Lynxmotion |

Table . Items under consideration for the claw

### Decision Matrix

Table 14 contains the decision matrix for the claw. Every item under consideration has been evaluated and broken down into different categories. The claw size is how wide the claw will open. The DOF category is the degrees of freedom and how the claw will be able to move.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Product** | **Claw Size** | **Weight** | **Price** | **DOF** | **Controlled** |  |
| OWI-535 Robotic Arm Edge | 2-3 in. | 1.45 lbs. | $44.29 | 5 | RC |  | |
| Stacker 2WD Mobile Robot | 4.25 in. | 3 lbs. | $139.99 | 2 | RC/autonomous |  | |
| AX-12 Dual Robotic Gripper | 9 in. | 2 lbs. | $69.00 | 6 | Autonomous |  | |
| AL5D Arm Hardware Only - Kit | 1.3 in. | 0.6 lbs. | $143.88 | 4 | Autonomous |  | |
|  |  |  |  |  |  |  | |
| **Product Weight** | **Claw Size** | **Weight** | **Price** | **DOF** | **Controlled** |  | |
| OWI-535 Robotic Arm Edge | 4 | 9 | 10 | 8 | 1 |  | |
| Stacker 2WD Mobile Robot | 7 | 5 | 4 | 3 | 7 |  | |
| AX-12 Dual Robotic Gripper | 10 | 6 | 9 | 9 | 9 |  | |
| AL5D Arm Hardware Only - Kit | 2 | 9 | 4 | 6 | 9 |  | |
|  |  |  |  |  |  |  | |
| **Weighted** | 0.25 | 0.15 | 0.15 | 0.25 | 0.2 |  | |
|  |  |  |  |  |  |  | |
| **Product Total** | **Claw Size** | **Weight** | **Price** | **DOF** | **Controlled** | **Total** | |
| OWI-535 Robotic Arm Edge | 1.0 | 1.35 | 1.5 | 2.0 | 0.2 | 6.05 | |
| Stacker 2WD Mobile Robot | 1.75 | 0.75 | 0.6 | 0.75 | 1.4 | 5.25 | |
| AX-12 Dual Robotic Gripper | 2.5 | 0.9 | 1.35 | 2.25 | 1.8 | 8.8 | |
| AL5D Arm Hardware Only - Kit | 0.5 | 1.35 | 0.6 | 1.5 | 1.8 | 5.75 | |

Table . Decision matrix for the claw

### Justification

The following categories justify the decision of choosing the AX-12 Dual Robotic Gripper.

**Price**

|  |  |  |
| --- | --- | --- |
| **Item** | **Calculation** | **Score** |
| OWI-535 Robotic Arm Edge |  | 7 |
| Stacker 2WD Mobile Robot |  | 1 |
| AX-12 Dual Robotic Gripper |  | 5 |
| AL5D Arm Hardware Only - Kit |  | 1 |

Table . Calculations for the price of the claw

**Weight**

|  |  |  |
| --- | --- | --- |
| **Item** | **Calculations** | **Score** |
| OWI-535 Robotic Arm Edge |  | 5 |
| Stacker 2WD Mobile Robot |  | 1 |
| AX-12 Dual Robotic Gripper |  | 4 |
| AL5D Arm Hardware Only - Kit |  | 8 |

Table . Calculations for the weight of the claw

## Wheels

The following tables and justifications give a description of the decision-making process used to select wheels for the APS. The process included analytical, qualitative, and quantitative methods and is shown with the reasoning behind these methods.

### Items under Consideration

The items in Table 17 are considered as different choices for the wheels for the APS. The table includes items from Amazon, SparkFun, and Vex Robotics.

|  |  |  |
| --- | --- | --- |
| **Wheels** | **ID** | **Vendor** |
| Vex Robotics Omni (4 in.) | 217-2584 | Amazon |
| Vex Robotics Mecanum (4 in.) | 217-3644, Right (217-3645, Left) | Amazon |
| Fingertech Mecanum (4 in.) | ROB-11578 | SparkFun |
| Pololu Wheels (42 x 19 mm) | ROB-0889 | SparkFun |

Table . Items under consideration for the wheels

### Decision Matrix

The following tables create the quantitative reasons for the wheels chosen for the APS. Table 18 contains the description matrix, which shows the price, weight, load rating, and holonomic ability for each wheel under consideration.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Product** | **Price** | **Weight** | **Load Rating** | **Holonomic** |
| Vex Robotics Omni | $12.50 | 0.42 lbs. | 200 lbs. | Yes |
| Vex Robotics Mecanum | $15.00 | 0.55 lbs. | 200 lbs. | Yes |
| Fingertech Mecanum | $18.75 | 0.1325 lbs. | 30 lbs. | Yes |
| Pololu Wheels | $3.50 | 0.08 lbs. | Not Found | No |
|  |  |  |  |  |
| **Product Weight** | **Price** | **Weight** | **Load Rating** | **Holonomic** |
| Vex Robotics Omni | 4 | 7 | 9 | 9 |
| Vex Robotics Mecanum | 3 | 9 | 9 | 9 |
| Fingertech Mecanum | 1 | 2 | 5 | 9 |
| Pololu Wheels | 8 | 1 | 1 | 1 |
|  |  |  |  |  |
| **Weighted** | 0.25 | 0.25 | 0.2 | 0.3 |
|  |  |  |  |  |
| **Product Total** | **Price** | **Weight** | **Load Rating** | **Holonomic** | **Total** |
| Vex Robotics Omni | 1.0 | 1.75 | 1.8 | 2.7 | 7.25 |
| Vex Robotics Mecanu | 0.75 | 2.25 | 1.8 | 2.7 | 7.5 |
| Fingertech Mecanum | 0.25 | 0.5 | 1.0 | 2.7 | 4.45 |
| Pololu Wheels | 2.0 | 0.25 | 0.2 | 0.3 | 2.75 |

Table . Decision matrix for the wheels

### Justification

The process for the decision making is described in the next paragraphs. The data for these items are found on the websites of Amazon, SparkFun, and Vex Robotics. The wheels are judged based on price, weight, load rating, and the wheels’ holonomic ability.

**Price**

The price of the wheels are valued at 25% of the decision. The wheels are sold by the vendors in multiple pack styles. The Vex Robotics Omni (4 in.) wheels are sold for $24.99 for a two pack. The Vex Robotics Mecanum (4 in.) wheels are sold for $59.99 for a four pack. The Fingertech Mecanum (4 in.) wheels are sold for $74.95 for a four pack. The Pololu Wheel (42 mm. x 19 mm.) wheels are sold for $6.95 for a two pack. Therefore, the decision matrix the price are first divided by the number of items sold to find the price per each item. The prices are then normalized comparing each price to the greatest price. The normalized prices are multiplied by nine and added to one, as shown in Table 19.

|  |  |  |
| --- | --- | --- |
| **Item** | **Calculation** | **Score** |
| Vex Robotics Omni |  | 4 |
| Vex Robotics Mecanum |  | 3 |
| Fingertech Mecanum |  | 1 |
| Pololu Wheels |  | 8 |

Table . Calculation for the price of the wheels

**Weight**

The weight of the wheels are valued at 25% of the decision. The APS has a maximum weight limit of 50 lbs. and therefore the weight of each wheel is important in choosing the wheels for the APS. The wheels should not be too light to hold the APS; consequently the point values were reversed to have the heavier wheels to be rated higher than the low weight wheels. Table 20 shows the calculation to find the score for the weight of each type of wheel. The weight of each type of wheel are normalized to the greatest weight. The score is multiplied by nine and added to one. The final score is subtracted from ten to yield the heavier wheels having a higher rating.

|  |  |  |
| --- | --- | --- |
| **Item** | **Calculation** | **Score** |
| Vex Robotics Omni |  | 7 |
| Vex Robotics Mecanum |  | 9 |
| Fingertech Mecanum |  | 2 |
| Pololu Wheels |  | 1 |

Table . Calculation for the weight of the wheels

**Load Rating**

The APS has a maximum weight limit of 50 lbs., thus the load rating was valued at 20% of the decision. Two types of wheels had equivalent load ratings (200 lbs.) and has the point value of nine as they has the best rating value. One wheel type, Pololu Wheels (42 mm. x 19 mm.), had no load rating available for it, so it has the lowest value possible of one. The other wheel, the Fingertech Mecanum, has the lowest rated value, but larger than the unknown value. Consequently, the value for the Fingertech Mecanum is given as the mid-range value, five.

**Holonomic**

Each wheel type is judged based on whether it has any holonomic ability or not. Each wheel is given either a nine, for yes, or a one, for a no. To minimize the complexity of the robotic arm it was decided to utilize wheels that had holonomic abilities. Therefore, holonomic ability has a value of 30% for the decision matrix.

## Battery

The battery is a crucial part of the APS, as without it, the robot would not be able to function and complete any of the tasks. The categories below describe the items under consideration, the decision matrix, and the justification of the decision made.

### Items under Consideration

Table 21 contains the items under consideration for the battery. The items under consideration have been listed below and contain the product ID and the vendor.

|  |  |  |
| --- | --- | --- |
| **Battery** | **ID** | **Vendor** |
| Polymer Lithium Ion Battery-2000mAh | PRT-08483 | Sparkfun |
| Polymer Lithium Ion Battery-2200mAh 7.4V | PRT-11856 | Sparkfun |
| Turnigy 2200mAh 3S 20C Lipo Pack | T2200.3S.20 | Hobbyking |
| Turnigy 2200mAh 3S 25C Lipo Pack | T2200.3S.25 | Hobbyking |
| Turnigy 2200mAh 3S 30C Lipo Pack | T2200.3S.30 | Hobbyking |

Table . The items under consideration for the batteries

### Decision Matrix

Table 22 contains the decision matrix for the battery. Every item under consideration has been evaluated and broken down into different categories. The capacity is the amount of charge that the battery can safely discharge in an hour. The discharge rate determines the total charge of the battery. The voltage determines the output voltage of the battery.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Product** | **Price** | **Capacity** | **Discharge Rate** | **Voltage** | **Weight** |
| Polymer Lithium Ion Battery-2000mAh | $12.95 | 2000 mAh | 2 C | 3.7 V | 36.00 g |
| Polymer Lithium Ion Battery-2200mAh 7.4V | $13.95 | 2200 mAh | 30 C | 7.4 V | 206.00 g |
| Turnigy 2200mAh 3S 20C Lipo Pack | $8.50 | 2200 mAh | 20 C | 11.1 V | 188.00 g |
| Turnigy 2200mAh 3S 25C Lipo Pack | $10.60 | 2200 mAh | 25 C | 11.1 V | 188.00 g |
| Turnigy 2200mAh 3S 30C Lipo Pack | $13.50 | 2200 mAh | 30 C | 11.1 V | 197.00 g |
|  |  |  |  |  |  |
| **Product Weight** | **Price** | **Capacity** | **Discharge Rate** | **Voltage** | **Weight** |
| Polymer Lithium Ion Battery-2000mAh | 1.65 | 4 | 1.6 | 4 | 8.43 |
| Polymer Lithium Ion Battery-2200mAh 7.4V | 1 | 5 | 10 | 7 | 1 |
| Turnigy 2200mAh 3S 20C Lipo Pack | 4.52 | 5 | 7 | 10 | 1.79 |
| Turnigy 2200mAh 3S 25C Lipo Pack | 3.16 | 5 | 8.5 | 10 | 1.79 |
| Turnigy 2200mAh 3S 30C Lipo Pack | 1.29 | 5 | 10 | 10 | 1.39 |
|  |  |  |  |  |  |
| **Weighted** | 0.15 | 0.25 | 0.3 | 0.25 | 0.05 |
|  |  |  |  |  |  |
| **Product Total** | **Price** | **Capacity** | **Discharge Rate** | **Voltage** | **Weight** | **Total** |
| Polymer Lithium Ion Battery-2000mAh | 0.3 | 1.0 | 0.6 | 1.0 | 0.4 | 3.30 |
| Polymer Lithium Ion Battery-2200mAh 7.4V | 0.15 | 1.25 | 3.0 | 1.75 | 0.05 | 6.20 |
| Turnigy 2200mAh 3S 20C Lipo Pack | 0.75 | 1.25 | 2.1 | 2.5 | 0.1 | 6.70 |
| Turnigy 2200mAh 3S 25C Lipo Pack | 0.45 | 1.25 | 2.7 | 2.5 | 0.1 | 7.00 |
| Turnigy 2200mAh 3S 30C Lipo Pack | 0.15 | 1.25 | 3.0 | 2.5 | 0.05 | 6.95 |

Table . Decision matrix for the batteries

### Justification

The following describes the process used in obtaining the scores for the various categories used to rate the batteries under consideration in the decision matrix. The data for the batteries under consideration was obtained from Sparkfun and Hobbyking.

**Price**

The score for the price was obtained by normalizing the price and multiplying the normalized valued by the maximum score of 9 and adding 1. The weighted value of the price category was 15%. Table 23 contains the calculations for the price of the battery.

|  |  |  |
| --- | --- | --- |
| **Item** | **Calculation** | **Score** |
| PRT-08483 |  | 2 |
| PRT-11856 |  | 1 |
| T2200.3S.20 |  | 5 |
| T2200.3S.25 |  | 3 |
| T2200.3S.30 |  | 3 |

Table . Calculations for the price of the batteries

**Capacity**

The capacity category scores the different capacities of the batteries. As the capacities of the batteries do not vary much, 2200 mAh for four of the batteries under consideration and the last one at 2000 mAh. A score of five was given to the 2200-mAh batteries and a score of four was given to the battery with 2000 mAh. As the capacity determines the capacity of the battery, it was given a weighted score of 25%.

**Discharge Rate**

The discharge rate, C rating, of the batteries scores the discharge relative to the battery capacity, a 100-mAh capacity at a 5 C rate will have a total capacity of 500 mA. The equation to determine the score was derived by normalizing the C rating multiplied by 9 and subtracting that from 10. As the discharge rate determines the total capacity of the battery, it was given a weighted score of 30%. Table 24 contains the calculations for the discharge rate.

|  |  |  |
| --- | --- | --- |
| **Item** | **Calculation** | **Score** |
| PRT-08483 |  | 2 |
| PRT-11856 |  | 1 |
| T2200.3S.20 |  | 5 |
| T2200.3S.25 |  | 3 |
| T2200.3S.30 |  | 3 |

Table . Calculations for the discharge rate of the batteries

**Voltage**

Table 25 contains the voltage category scores the voltage output of the battery. This determines the normalized voltage output of the battery. The equation to determine the score for the voltage was to normalize the voltage multiply by 9 and subtract that from 10 to get the score. The weighted value of this category is 25%.

|  |  |  |
| --- | --- | --- |
| **Item** | **Calculation** | **Score** |
| PRT-08483 |  | 4 |
| PRT-11856 |  | 7 |
| T2200.3S.20 |  | 10 |
| T2200.3S.25 |  | 10 |
| T2200.3S.30 |  | 10 |

Table . Calculations for the voltage of the batteries

**Weight**

Table 26 contains the weight category determines the weight of each of the different batteries. The scores for this category are determined by normalizing the weights of the motors multiplied by 9 and adding 1. The weighted value of this category is 5%.

|  |  |  |
| --- | --- | --- |
| **Item** | **Calculation** | **Score** |
| PRT-08483 |  | 8 |
| PRT-11856 |  | 1 |
| T2200.3S.20 |  | 2 |
| T2200.3S.25 |  | 2 |
| T2200.3S.30 |  | 1 |

Table . Calculations for the weight of the batteries

# Requirements Traceability

The following items describe the how each requirement in the FTFP’s System Requirement Specification (SRS) traces to the parts needed to build the APS. The following tables will refer to the IEEE SoutheastCon 2015 Hardware Competition (SHC) rules for requirements traceability purposes.

## Microcontroller

Table 27 contains the requirements related to the microcontroller and how each requirement will be fulfilled.

|  |  |  |
| --- | --- | --- |
| **ID** | **Requirement Text** | **Fulfillment** |
|  |  |  |

Table . Requirements traceability for the microcontroller

## Sensors

Table 28 contains the requirements related to the sensors and how each requirement will be fulfilled.

|  |  |  |  |
| --- | --- | --- | --- |
| **ID** | **Requirement Text** | **SHC Rules Traceability** | **Fulfillment** |
| 4.1.3 | The APS shall monitor the red LED on the floor. | Once the signal in shut off the timer is started and the round begins. | The Pixy Cam uses hue and saturation as its primary means of images detection. |
| 4.1.5 | The APS shall follow the line on the floor. | Drive on the white line (must cover the line all of the time). |  |
| 4.1.6 | The APS shall remain within the playing board. | The competition round will end if any part of the robot leaves the playing board. |  |
| 4.1.7.1 | The APS shall identify the game station. | Each toy will be placed in a white block. |  |
| 4.1.8 | The APS shall stop moving once the finish line is crossed. | The competition round will end when the robot crosses the finish line. |  |
| 4.2.2 | The APS shall play with the Simon Carabiner for 15 seconds. | Play Simon for 15 seconds. Correctly match the lights and sounds. |  |
| 4.2.3 | The APS shall rotate one (1) row of the Rubik’s Cube 180 degrees. | Twist one row 180 degrees on the Rubik’s Cube. |  |
| 4.2.8 | The APS shall pick up one (1) playing card from the stack of cards. | Pick up one card from the deck and hold it to cross the finish line. |  |

Table . Requirements traceability for the sensors

## Motors

Table 29 contains the requirements related to the motor and how each requirement will be fulfilled.

|  |  |  |  |
| --- | --- | --- | --- |
| **ID** | **Requirement Text** | **SHC Rules Traceability** | **Fulfillment** |
| 4.1.4 | The APS shall start moving when the red LED powers off. | Once the signal in shut off the timer is started and the vehicle will have a maximum of five minutes navigate and play each of the games. |  |
| 4.1.6 | The APS shall remain within the playing board. | The competition round will end if any part of the robot leaves the playing board. |  |
| 4.1.8 | The APS shall stop moving once the finish line is crossed. | The competition round will end when the robot crosses the finish line. |  |

Table . Requirements traceability for the motors

## Claw

Table 30 contains the requirements related to the arm and how each requirement will be fulfilled.

|  |  |  |  |
| --- | --- | --- | --- |
| **ID** | **Requirement Text** | **SHC Rules Traceability** | **Fulfillment** |
| 4.2.1 | The APS shall press the middle button on the Simon Carabiner to start playing. | The timer starts and points are earned when the robot presses the center button on Simon. |  |
| 4.2.2 | The APS shall play with the Simon Carabiner for 15 seconds. | Play Simon for 15 seconds. |  |
| 4.2.3 | The APS shall rotate one (1) row of the Rubik’s Cube 180 degrees. | Twist one row 180 degrees on the Rubik's Cube. | The AX-12 Dual Robotic Gripper has 6 DOF allowing it to rotate the row 180 degrees. |
| 4.2.6 | The APS shall draw “IEEE” on the Etch-a-Sketch using the knobs located on the Etch-a-Sketch. | Draw “IEEE” on the Etch-a-Sketch. |  |
| 4.2.8 | The APS shall pick up one (1) playing card from the stack of cards. | Pick up one card from the deck. |  |

Table . Requirements traceability for the claw

## Frame

Table 31 contains the requirements related to the frame and how each requirement will be fulfilled

|  |  |  |  |
| --- | --- | --- | --- |
| **ID** | **Requirement Text** | **SHC Rules Traceability** | **Fulfillment** |
| 5.2/5.3 | The APS shall fit within a 1 ft. x 1 ft. x 1 ft. area before and after the competition begins. | The vehicle must fit in a 1 ft. x 1 ft. square and may not be taller than 1 ft. |  |

Table . Requirements traceability for the frame

## Battery

Table 32 contains the requirements related to the battery and how each requirement will be fulfilled.

|  |  |  |  |
| --- | --- | --- | --- |
| **ID** | **Requirement Text** | **SHC Rules Traceability** | **Fulfillment** |
| 4.1.1 | The APS shall receive power from an independent, on-board, battery. | It must be self-propelled, autonomous and may not be remotely controlled in any manner. |  |

Table . Requirements traceability for the batteries

# Risk Analysis

Each component has an amount of risk in its use on the APS. This section details some risks associated with each component used as part of the APS. The quantitative value of each risk was determined by personal experience and research of each component. The chance that the risk could occur is rated in a range of one to nine. One is the least likely for that risk to occur and nine being the most likely to occur. The severity of each is risk is rated in the same scale of one to nine; one being the least severe and nine is the most severe.

## Microcontroller

Table 33 details the risks associated with the microcontrollers.

|  |  |  |  |
| --- | --- | --- | --- |
| **Risk** | **Probability** | **Severity** | **Risk Mitigation** |
|  |  |  |  |
|  |  |  |  |

Table . Risks and alleviations associated with the microcontrollers

## Sensors

Table 34 details the risks associated with the sensors.

|  |  |  |  |
| --- | --- | --- | --- |
| **Risk** | **Probability** | **Severity** | **Risk Mitigation** |
|  |  |  |  |
|  |  |  |  |

Table . Risks and alleviations associated with the sensors

## Motors

Table 35 details the risks associated with the motors.

|  |  |  |  |
| --- | --- | --- | --- |
| **Risk** | **Probability** | **Severity** | **Risk Mitigation** |
| Motor burns out |  |  |  |
|  |  |  |  |

Table . Risks and alleviations associated with the motors

## Claw

Table 36 details the risks associated with the claw.

|  |  |  |  |
| --- | --- | --- | --- |
| **Risk** | **Probability** | **Severity** | **Risk Mitigation** |
| Claw falling off | 3 | 9 |  |
| Damage to claw | 4 | 8 |  |

Table . Risks and alleviations associated with the claw

## Wheels

Table 37 details the risks associated with the wheels.

|  |  |  |  |
| --- | --- | --- | --- |
| **Risk** | **Probability** | **Severity** | **Risk Mitigation** |
| Damage to the wheels |  |  |  |
| Loss of a wheel |  |  |  |
|  |  |  |  |

Table . Risks and alleviations associated with the wheels

## Frame

Table 38 details the risks associated with the frames.

|  |  |  |  |
| --- | --- | --- | --- |
| **Risk** | **Probability** | **Severity** | **Risk Mitigation** |
| Frame falling apart | 3 | 9 |  |
| Bolts falling off | 5 | 9 |  |
|  |  |  |  |

Table . Risks and alleviations associated with the frame

## Battery

Table 39 details the risks associated with the battery.

|  |  |  |  |
| --- | --- | --- | --- |
| **Risk** | **Probability** | **Severity** | **Risk Mitigation** |
| Battery unable to hold charge |  |  | Ensure that battery is not damaged |
| Battery explodes |  |  | Ensure that battery is not damaged |
|  |  |  |  |

Table . Risks and alleviations associated with the battery

# Total System BudgetAppendix B: Glossary

|  |  |  |
| --- | --- | --- |
| **Entry** | **Definition** | **Aliases** |
| \* | At any time throughout a use case. |  |
| Autonomous | Behavior independent of any outside commands or authority. Moves and performs tasks by itself without human interaction past powering the APS on. |  |
| Edges | The boundaries of the playing board. |  |
| Error Margin | The range of suboptimal data for a specific set of data. |  |
| Etch-a-Sketch | Small, travel version of the toy, Etch-a-Sketch.  By: Ohio Art – “R” Web# 636061, SKU: FD79DD3F, UPC/EAN/ISBN: 026511051508 [1]. |  |
| Finish Line | A line signifying the end of the course. |  |
| Game Station | White box, 1 ft. x 1 ft. in size, on the playing boards where the objects are sitting. |  |
| Line | White lines painted on the playing board defined by painter’s tape.  Scotch Blue 0.94 in. x 60 yds. Painter’s Tape; Home depot: Model# 2090-1J Store SKU # 958999 [1]. |  |
| Middle Button | On the Simon Carabiner, there are three (3) round buttons that control the game setting, the round button in the middle is referred to as the middle button. |  |
| Navigational System | A subsystem controlling direction, speed, and maneuvering of the APS. |  |
| Object | The game as per IEEE SoutheastCon 2015 Hardware Competition rules [1]. |  |
| One Playing Card | A single card from the standard 52-card deck. |  |
| Operational System | A subsystem controlling all functions related with the interaction of the APS with each of the objects. |  |
| Pattern | The random sequence of lights to be repeated by pressing the corresponding buttons on the Simon Carabiner. |  |
| Play Simon Says | Game that challenges the user to repeat a pattern of flashing lights and sounds using the Simon Carabiner. |  |
| Playing Board | A 5/8 in. x 4 ft. x 8 ft. sanded pine plywood surface as defined by IEEE SoutheastCon 2015 Hardware Competition rules [1]. |  |
| Position | A location within the playing board. |  |
| Power Off | A state in which no current or voltage is being supplied to the system. |  |
| Power On | A state in which current and voltage is being supplied to the system. |  |
| Real-Time events | Any event that requires a system response bound by time. |  |
| Rubik’s Cube | “R” Web# 374846, SKU: DAD09D9E, UPC/EAN/ISBN: 714043050273 [1]. |  |
| Sensory System | A complex collection of input/output (I/O) devices. |  |
| Simon Carabiner | Small, travel version of the game Simon Says.  “R” Web# 351215, SKU: 226CE810, UPC/EAN/ISBN: 014397018500 [1]. |  |
| Stack of Cards | Multiple playing cards stacked on top of each other from the standard 52-card deck. |  |
| Standard 52-Card Deck | Toys “R” Us# (TBD) [1]. |  |
| System | A collection of parts that make up one (1) single unit. |  |
| Task | Specified interaction mandated by rules defined by IEEE SoutheastCon 2015 Hardware Competition [1]. |  |
| Two-Man Lift Rule | 50 pounds or more must be carried by two (2) people as per the Occupational Safety and Health Administration (OSHA) materials handling regulations [3]. |  |

Table 40. Listing of terms and definitions used throughout this document

# Acronyms & Abbreviations

|  |  |
| --- | --- |
| **Entry** | **Expanded Phrase** |
| APS | Autonomous Panda System |
| DOF | Degrees of Freedom |
| FPS | Frames per Second |
| FTFP | Funky Town Fancy Pandas |
| GPIO | General-Purpose Input/output |
| ID | Identification |
| IDE | Integrated development environment |
| IEEE | [The] Institute of Electrical and Electronics Engineers |
| LED | Light-emitted Diode |
| OS | Operating System |
| OSHA | Occupational Safety and Health Administration |
| RAM | Random Access Memory |
| RC | Remote Control |
| RPM | Revolutions per Minute |
| SHC | SoutheastCon 2015 Hardware Competition |
| SRS | System Requirement Specification |

Table . The acronyms and abbreviations used throughout this budget proposal

# References

Arduino Uno

<http://arduino.cc/en/Main/arduinoBoardUno>

Raspbarry Pi

<http://www.raspberrypi.org/products/model-b/>

UDOO

<http://shop.udoo.org/usa/product/udoo-quad.html>

Vex Robotics. Mecanum Wheels [Online]. Available: http://www.vexrobotics.com/vexpro/wheels-and-hubs/mecanum-wheels.html

Vex Robotics. Omni Wheels [Online]. Available: http://www.vexrobotics.com/vexpro/wheels-and-hubs/omni-wheels.html

SparkFun. Mecanum Wheels - 4 pack [Online]. Available: https://www.sparkfun.com/products/11578

SparkFun. Wheel 42x19mm [Online]. Available: https://www.sparkfun.com/products/8899

Fingertech. FingerTech Mecanum Wheels (Set of 4) [Online]. Available: <http://www.fingertechrobotics.com/proddetail.php?prod=ft-mecanum-set-v2>

Standard Gearmotor -101 RPM (3-12V) Available: <https://www.sparkfun.com/products/12399>

Precision Gearmotor -90 RPM (6-12V) Available: https://www.sparkfun.com/products/12497

154:1 Metal Gearmotor 20Dx44Lmm Available: http://www.pololu.com/product/1109

100:1 Metal Gearmotor 37Dx57L mm Available: http://www.pololu.com/product/1106

Polymer Lithium Ion Battery-2000mAh Available: https://www.sparkfun.com/products/8483

Polymer Lithium Ion Battery-2200mAh 7.4V Available: https://www.sparkfun.com/products/11856

Turnigy 2200mAh 3S 20C Lipo Pack Available: http://www.hobbyking.com/hobbyking/store/\_\_8932\_\_Turnigy\_2200mAh\_3S\_20C\_Lipo\_Pack.html

Turnigy 2200mAh 3S 25C Lipo Pack Available: http://www.hobbyking.com/hobbyking/store/\_\_8934\_\_Turnigy\_2200mAh\_3S\_25C\_Lipo\_Pack.html

Turnigy 2200mAh 3S 30C Lipo Pack Available: http://www.hobbyking.com/hobbyking/store/\_\_9394\_\_Turnigy\_2200mAh\_3S\_30C\_Lipo\_Pack.html

Battery information: http://web.mit.edu/evt/summary\_battery\_specifications.pdf

[1] Nova Southeastern University & Broward College. (2014, March 19). *SoutheastCon 2015 Hardware Competition Rules (DRAFT*) [Online]. Available: https://docs.google.com/file/d/

0B8nHHJOB5RWcUFPQVlXdngyTVk/edit?pli=1

[2] *Embry-Riddle Aeronautical University 2014-2015 Student Handbook*, ERAU, Daytona Beach, FL, 2014.

[3] B. Besser. (n.d.). *Materials handling: heavy lifting* [Online]. Available:

https://www.osha.gov/SLTC/etools/electricalcontractors/materials/heavy.html

[4] Toys R Us. *Pocket Etch A Sketch* *- Red* [Online]. Available: http://www.toysrus.com/product/

index.jsp?productId=2395954&cp=2255960.2256553&parentPage=family

[5] Toys R Us. *Rubik’s 3x3 Cube* [Online]. Available: http://www.toysrus.com/buy/

brain-teasers/rubik-s-3x3-cube-wm5027-29224016

[6] Toys R Us. *Simon-Carabiner* [Online]. Available: http://www.toysrus.com/buy/

card-puzzlegames/ simon-carabiner-1850-3839349

[7] Dreamstime. *Deck-Cards* [Online]. Available: http://thumbs.dreamstime.com/z/

deck-cards-18545272.jpg

[8] *IEEE Editorial Style Manual*, vol. 6, Mar. 2014

[9] *IEEE guide to software requirements specifications*, ANSI/IEEE Standard 830-1984, 1984.

[10] C. Larman, *Applying UML and Patterns: An Introduction to Object-Oriented Analysis and Design and Iterative Development,* 3rd ed. Westford, MA: Pearson, 2005.

[11] J. Straus, *The Blue Book of Grammar and Punctuation*, 11th ed. Indianapolis, IN: Wiley,

2014.