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

|  |  |  |
| --- | --- | --- |
| **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 formating |

Table 1. Revision History

Table of Contents

[Revision History 2](#_Toc399974138)

[1. Introduction 5](#_Toc399974139)

[1.1 Purpose 5](#_Toc399974140)

[1.2 Scope 5](#_Toc399974141)

[1.3 Team Information 5](#_Toc399974142)

[2. Functional Decomposition System 6](#_Toc399974143)

[2.1 High-Level Architecture of System 6](#_Toc399974144)

[2.2 Decomposition of Vehicle Hardware Layer 6](#_Toc399974145)

[2.3 Decomposition of Communication Hardware Layer 6](#_Toc399974146)

[3. Requirements Traceability 7](#_Toc399974147)

[3.1 Microcontroller 7](#_Toc399974148)

[3.2 Sensors 7](#_Toc399974149)

[3.3 Motors 7](#_Toc399974150)

[3.4 Arm 7](#_Toc399974151)

[3.5 Frame 7](#_Toc399974152)

[3.6 Batteries 8](#_Toc399974153)

[4. Budget Decision Matrices and Justifications 9](#_Toc399974154)

[4.1 Microcontroller 9](#_Toc399974155)

[4.1.1 Items Under Consideration 9](#_Toc399974156)

[4.1.2 Decision Matrix 9](#_Toc399974157)

[4.1.3 Justification 9](#_Toc399974158)

[4.2 Sensors 10](#_Toc399974159)

[4.2.1 Items Under Consideration 10](#_Toc399974160)

[4.2.2 Decision Matrix 10](#_Toc399974161)

[4.2.3 Justification 10](#_Toc399974162)

[4.3 Motors 11](#_Toc399974163)

[4.3.1 Items Under Consideration 11](#_Toc399974164)

[4.3.2 Decision Matrix 11](#_Toc399974165)

[4.3.3 Justification 11](#_Toc399974166)

[4.4 Arm 12](#_Toc399974167)

[4.4.1 Items Under Consideration 12](#_Toc399974168)

[4.4.2 Decision Matrix 12](#_Toc399974169)

[4.4.3 Justification 12](#_Toc399974170)

[4.5 Wheels 13](#_Toc399974171)

[4.5.1 Items Under Consideration 13](#_Toc399974172)

[4.5.2 Decision Matrix 13](#_Toc399974173)

[4.5.3 Justification 13](#_Toc399974174)

[4.6 Frame 14](#_Toc399974175)

[4.6.1 Items Under Consideration 14](#_Toc399974176)

[4.6.2 Decision Matrix 14](#_Toc399974177)

[4.6.3 Justification 14](#_Toc399974178)

[4.7 Batteries 15](#_Toc399974179)

[4.7.1 Items Under Consideration 15](#_Toc399974180)

[4.7.2 Decision Matrix 15](#_Toc399974181)

[4.7.3 Justification 15](#_Toc399974182)

[5. Risk Analysis 16](#_Toc399974183)

[5.1 Microcontroller 16](#_Toc399974184)

[5.2 Sensors 16](#_Toc399974185)

[5.3 Motors 16](#_Toc399974186)

[5.4 Arm 16](#_Toc399974187)

[5.5 Wheels 16](#_Toc399974188)

[5.6 Frame 16](#_Toc399974189)

[5.7 Batteries 16](#_Toc399974190)

[6. Total System Budget 17](#_Toc399974191)

[Glossary 18](#_Toc399974192)

[Acronyms & Abbreviations 19](#_Toc399974193)

[References 20](#_Toc399974194)

# 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

|  |  |
| --- | --- |
| **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 2. Team Information

# Functional Decomposition System

## High-Level Architecture of System

## Decomposition of Vehicle Hardware Layer

## Decomposition of Communication Hardware Layer

# 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.

## Microcontroller

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

Table 3. Requirements traceability for the microcontroller

## Sensors

|  |  |  |
| --- | --- | --- |
| **ID** | **Requirement Text** | **Fulfillment** |
| 4.1.3 | The APS shall monitor the red LED on the floor. |  |
| 4.1.5 | The APS shall follow the line on the floor. |  |
| 4.1.6 | The APS shall remain within the playing board. |  |
| 4.1.7.1 | The APS shall identify the game station. |  |
| 4.1.8 | The APS shall stop moving once the finish line is crossed. |  |
| 4.2.2 | The APS shall play with the Simon Carabiner for 15 seconds. |  |
| 4.2.3 | The APS shall rotate one (1) row of the Rubik’s Cube 180 degrees. |  |
| 4.2.8 | The APS shall pick up one (1) playing card from the stack of cards. |  |

Table 4. Requirements traceability for the sensors

## Motors

|  |  |  |
| --- | --- | --- |
| **ID** | **Requirement Text** | **Fulfillment** |
| 4.1.4 | The APS shall start moving when the red LED powers off. |  |
| 4.1.6 | The APS shall remain within the playing board. |  |
| 4.1.8 | The APS shall stop moving once the finish line is crossed. |  |

Table 5. Requirements traceability for the motors

## Arm

|  |  |  |
| --- | --- | --- |
| **ID** | **Requirement Text** | **Fulfillment** |
| 4.2.1 | The APS shall press the middle button on the Simon Carabiner to start playing. |  |
| 4.2.2 | The APS shall play with the Simon Carabiner for 15 seconds. |  |
| 4.2.3 | The APS shall rotate one (1) row of the Rubik’s Cube 180 degrees. |  |
| 4.2.6 | The APS shall draw “IEEE” on the Etch-a-Sketch using the knobs located on the Etch-a-Sketch. |  |
| 4.2.8 | The APS shall pick up one (1) playing card from the stack of cards. |  |

Table 6. Requirements traceability for the arm

## Frame

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

Table 7. Requirements traceability for the frame

## Batteries

|  |  |  |
| --- | --- | --- |
| **ID** | **Requirement Text** | **Fulfillment** |
| 4.1.1 | The APS shall receive power from an independent, on-board, battery. |  |

Table 8. Requirements traceability for the batteries

# 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 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 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 9 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 satisfied most novice and expert developers. |
| BeagleBone Black | Amazon |  |

Table 9. 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 10. 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 following tables and justifications compose a description of the decision-making process that was used to select a motor for the APS. This process includes analytical and quantitative methods as well as reasoning behind these methods documented.

### Items Under Consideration

The following items were considered as possible motors for the APS. Each item in this section has a corresponding item ID (part number or product number) and vendor, which has been compiled.

|  |  |  |
| --- | --- | --- |
| **Motors** | **ID** | **Vendor** |
| Standard Gearmotor | ROB-12399 | Sparkfun |
| Preicision 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 12. Items under consideration for the motor

### Decision Matrix

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **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 |
| Preicision Gearmotor | $34.95 | 12 V | 90 | 98.01 N-cm | 1 A | 240.97 g |
| 154:1 Metal Gearmotor 20Dx44Lmm | $19.95 | 6 V | 90 | 84.73 N-cm | 3.3 A | 32.6 g |
| 100:1 Metal Gearmotor 37Dx57L 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 |
| Preicision Gearmotor | 1 | 4 | 5.00 | 6.7 | 8.2 | 1.0 |
| 154:1 Metal Gearmotor 20Dx44Lmm | 5 | 8 | 5.00 | 5.9 | 4.1 | 8.8 |
| 100:1 Metal Gearmotor 37Dx57L 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 |
| Preicision Gearmotor | 0.15 | 0.40 | 0.25 | 2.45 | 2.40 | 0.05 | 5.70 |
| 154:1 Metal Gearmotor 20Dx44Lmm | 0.75 | 0.80 | 0.25 | 2.10 | 1.20 | 0.45 | 5.55 |
| 100:1 Metal Gearmotor 37Dx57L mm | 0.60 | 0.40 | 0.30 | 3.50 | 0.30 | 0.10 | 5.20 |

Table 13. 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**

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 14. Calculations for the price of the motor

**Voltage**

The voltage category scores the voltage levels required of the APS for the motors. As 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**

The rpm category scores the rpm of the motors. The motors chosen were from around the 90 rpm range so as to determine the differences in the torque of the different motors. This was done as the motors for each item can come in many 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 15. Calculations for the RPM of the motor

**Stall Torque**

The stall torque category scores the stall torque of the APS. This determines the amount of load that 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. As 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 16. Calculations for the stall torque of the motor

**Stall Current**

The stall current category scores the maximum current the APS needs to supply the motors, when they 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 17. Calculations for the stall current of the motor

**Weight**

The weight category determines the weight of each of the different motors. The scores for this category is 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 18. Calculations for the weight of the motor

## Arm

### Items Under Consideration

|  |  |  |
| --- | --- | --- |
| **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 19. Items under consideration for the arm

### Decision Matrix

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **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. | .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 | 1.35 | 1.5 | 2 | 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 20. Decision matrix for the arm

### Justification

## Wheels

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

### Items Under Consideration

The items in Table 21 were considered as different choices for the wheels for the APS. The table includes items from Amazon, SparkFun, and Vex Robotics.

|  |  |  |
| --- | --- | --- |
| **Wheels** | **Part number** | **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 21. Items under consideration for the wheels

### Decision Matrix

The following tables create the quantitative reasons for the wheels chosen for the APS. Table 20 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 | 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 | 2.7 | 4.45 |
| Pololu Wheels | 2 | 0.25 | 0.2 | 0.3 | 2.75 |

Table 22. Decision matrix for the wheels

### Justification

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

**Price**

The Price was valued at 25% of the decision. The wheels are being sold by the vendors in multiple pack styles. The Vex Robotics Omni (4 in.) wheels are being sold for $24.99 for a two pack. The Vex Robotics Mecanum (4 in.) wheels are being sold for $59.99 for a four pack. The Fingertech Mecanum (4 in.) wheels are being sold for $74.95 for a four pack. The Pololu Wheel (42 x 19 mm.) wheels are being sold for $6.95 for a two pack. Therefore, for the decision matrix the price was, first, divided by the number of items sold to find the price per each item. The prices were then normalized comparing each price to the greatest price. The normalized prices were multiplied by nine and added to one as shown in Table 21.

|  |  |  |
| --- | --- | --- |
| **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 was valued at 25% of the decision. The APS has a maximum weight limit of 50 lbs. and therefore the weight of each wheel was 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 22 shows the calculation used to find the score for the weight of each type of wheel. The weight of each type of wheel was normalized to the greatest weight. The score was multiplied by nine and added to one. The final score was 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 had the point value of nine as they had the best rating value. One wheel type, Pololu Wheels (42 x 19 mm), had no load rating available for it so it has the lowest value possible of one. This left the Fingertech Mecanum as the lowest rated value, but larger than the unknown value. Consequently, the value for the Fingertech Mecanum was given as the mid-range value, five.

**Holonomic**

Each wheel type was judged whether it had any holonomic ability or not. Each wheel was 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.

## Batteries

The following tables and justifications compose a description of the decision-making process that was used to select the batteries that will be used for the APS. This process includes analytical and quantitative methods as well as reasoning behind these methods documented.

### Items Under Consideration

The following items were considered as possible batteries for the APS. Each item in this section has a corresponding item ID and vendor, which has been compiled in Table 23.

|  |  |  |
| --- | --- | --- |
| **Motors** | **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 25. The items under consideration for the batteries

### Decision Matrix

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **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 | 0.6 | 1 | 0.4 | 3.30 |
| Polymer Lithium Ion Battery-2200mAh 7.4V | 0.15 | 1.25 | 3 | 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 | 2.5 | 0.05 | 6.95 |

Table 26. 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%.

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

Table 27. 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%.

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

Table 28. Calculations for the discharge rate of the batteries

**Voltage**

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 29. Calculations for the voltage of the batteries

**Weight**

The weight category determines the weight of each of the different motors. The scores for this category is 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 30. Calculations for the weight of 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 29 details the risks associated with the microcontrollers.

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

Table : Risks and alleviations associated with the microcontrollers

## Sensors

Table 30 details the risks associated with the sensors.

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

Table 32. Risks and alleviations associated with the Sensors

## Motors

Table 31 details the risks associated with the motors.

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

Table 33. Risks and alleviations associated with the motors

## Arm

Table 32 details the risks associated with the arms.

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

Table 34. Risks and alleviations associated with the arm

## Wheels

Table 33 details the risks associated with the wheels.

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

Table 35. Risks and alleviations associated with the wheels

## Frame

Table 34 details the risks associated with the frames.

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

Table 36. Risks and alleviations associated with the frame

## Batteries

Table 35 details the risks associated with the batteries.

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

Table 37. Risks and alleviations associated with the batteries

# Total System Budget

# Glossary

# Acronyms & Abbreviations

|  |  |
| --- | --- |
| **Entry** | **Expanded Phrase** |
| FTFP | Funky Town Fancy Pandas |
| DOF | Degrees of Freedom |
| APS | Autonomous Panda System |
| LED | Light-emitted Diode |
| IEEE |  |
| 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