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 |
| 0.6.0 | Oct. 5, 2014 | Continuation of budget proposal |

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# 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 were 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 to provide 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 2. 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 behind the selection of the major components. The use of decision matrices was a main method for selecting all the components to be used for the APS. These matrices show the important characteristics of the components and indexed each of them with a weighted score. The Funky Town Fancy Pandas (FTFP) development team scored the characteristic of each component and the average score is calculated. The total score was gathered and the item with the highest total score was 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 (Random Access Memory) 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 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 | A low-cost development platform with running an ARM Cortex – A8 chip. It runs at a clock speed of 1 GHz, contains 512 MB of RAM and 4 GB of on board flash memory. It contains 92 GPIO pins and runs a Linux operating system. It is popular with developers who have some experience. |

Table 3. Items under consideration for the microcontroller

### Decision Matrix

Table 4 depicts the decision matrix used to compare and select the microcontroller. The matrix considered the price, speed of the processor, RAM, Memory, GPIO pins, operating system (OS) or integrated development environment (IDE), and ease of use. The decision matrix describes the specifications of each item considered and computes a total by multiplying the score by a weighted factor for the category being analyzed. The score given to each category was determined by the development team, and the

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **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 4. Decision matrix for the microcontroller

### Justification

The categories considered in the decision matrix were the price, the speed of the CPU, the amount of RAM available, the amount of memory available, the number of GPIO pins, the operating system, and how easy it is to use the device. Each categories was given a score between 1 – 9, 1 being the worse and 9 being the best. This score was determine by ranking each item and their specifications.

Each category was given a weighted score which determined its importance. Using the score and the weighted score we were able to determine the best item for our system.

**Price**

The price of each microcontroller was considered to be the most important factor. The goal is to remain under budget therefor the item price had more importance than other factors. The most expensive item was the UDOO Quad, costing $135.00 therefor it got a score of 9. The cheapest item was the Raspberry Pi costing $38.89 therefore it got a score of 1. The equations used to calculate the score of the Arduino Due and the BeagleBone was where “x” is the price being compared and $38.99 is the best price between all of the items being considered. The Arudino Due costs $40.22 which yield a score of 8.7. That score was rounded down to 8, a valid score. The reason for rounding down was due to the fact that the Arduino Due is slightly more expensive and did not deserve a score of 9 (to be rounded up instead of down). The Beaglebone received a score of 5.3 rounding down to a 5.

**Clock Speed**

## Sensors

The following tables list the categories the sensors were compared over, and the weight given to each category. This decision-making process consists of a decision matrix, requirements traceability, requirements fulfillment, and a risk analysis to decide which part will be used.

### Items under Consideration

The following items listed on Table 5 were considered as the possible sensors for the APS. Each item has a unique ID number and its corresponding vendor. The categories each item will be scored on are: availability, price, OS/IDE, and frames per second (FPS).

|  |  |  |
| --- | --- | --- |
| **Sensors** | **ID** | **Vendor** |
| Pixy Cam | B00IUYUA80 | Amazon |
| CMUcam4 Robot Vision | RB-Sea-05 | Robotshop |
| Raspberry Pi | RB- Ras-01 | Robotshop |
| Minoru 3D webcam | Rb-Pul-01 | Robotshop |

Table 5. Items under consideration for the sensor

### 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 | (1920 x 1080) |  |
| Minoru 3D webcam | Buy it | $37.99 | openCV | 30 | (320 x 240) |  |
|  |  |  |  |  |  |  |
| **Product Weight** | **Availability** | **Price** | **OS** | **FPS** | **Resolution** |  |
| Pixy Cam | 9 | 9 | 9 | 9 | 3 |  |
| CMucam4 Robot Vision | 5 | 1 | 9 | 5 | 4 |  |
| Raspberry Pi | 5 | 8 | 5 | 5 | 9 |  |
| Minoru 3D webcam | 5 | 7 | 5 | 5 | 1 |  |
|  |  |  |  |  |  |  |
| **Weighted** | 0.1 | 0.2 | 0.2 | 0.25 | 0.25 |  |
|  |  |  |  |  |  |  |
| **Product Total** | **Availability** | **Price** | **OS/IDE** | **FPS** | **Resolution** | **Total** |
| Pixy Cam | 0.9 | 1.8 | 1.8 | 2.25 | 0.75 | 7.50 |
| CMucam4 Robot Vision | 0.5 | 0.2 | 1.8 | 1.25 | 1.0 | 4.75 |
| Raspberry Pi | 0.5 | 1.6 | 1.0 | 1.25 | 2.25 | 6.60 |
| Minoru 3D webcam | 0.5 | 1.4 | 1.0 | 1.25 | 0.25 | 4.40 |

Table 6. Decision matrix for the sensors

### Justification

The following describes the process used to justify our decisions over what parts would be used, and the reasoning behind those decisions.

**Availability**

The availability score for each item was determined by first scoring the items readily available to the FTFP with a score of 9, the highest possible score. The items that had to be ordered and shipped to the FTFP were given a score of 5. The availability category has a weighted value of 10%.

**Price**

The values for the score over the prices of each item was obtained by setting the least expensive item to have the highest score (9), and the most expensive item to have the lowest score (1). Once the minimum and maximum were determined, the scores for the remaining items were calculated by subtracting the price of the item from the price of the most expensive item, dividing it by the most expensive item price, multiplying that by the highest score possible (9), and adding one (1) to the answer. The one (1) is added taking in consideration that the lowest possible value is 1, and the answers are rounded up or down accordingly. Table 7 shows the calculations behind the scores for the price category, with the price category having a weighted value of 20%. The scores for the following items were calculated using the following equation:

|  |  |  |
| --- | --- | --- |
| **Item** | **Calculation** | **Score** |
| B00IUYUA80 | Least expensive item (free) | 9 |
| RB-Sea-05 | Most expensive item ($116.24) | 1 |
| RB- Ras-01 |  | 8 |
| Rb-Pul-01 |  | 7 |

Table 7. Calculations for the scores of the price of the sensors

**OS/IDE**

The scores for the OS/IDE category were based on the previous knowledge and experience of the software engineers at hand. The development team has experience working with Arduino boards and writing and implementing code for Arduino. The items using the OS/IDEs the development team had previous experience with were given the highest score (9), while the items using OS/IDEs unfamiliar to the development team were given a score of (5). The added learning curve of a new OS/IDE or programming language would delay the team and the development of software; therefore a lower score was assigned to those items. The OS/IDE category has a weighted value of 20%.

**FPS**

The frame rate, or frame frequency or frames per second, is the frequency at which the sensor produces unique consecutive images called frames [**reference**]. The values for the score of the FPS category of each item were obtained by giving the item with the highest frame rate the highest possible score of (9). A minimum value could not be set because the rest of the items have the same frame rate. Once the maximum value was determined, the scores for the remaining items were calculated by subtracting the FPS value of the item from the highest scoring item, then multiplying by the highest score possible (9), and adding one (1) to the answer. The one (1) is added taking in consideration that the lowest possible value is 1, with the answers being rounded up or down accordingly. The FPS category has a weighted value of 25%. Table 8 shows the calculations performed to obtain the scores.

|  |  |  |
| --- | --- | --- |
| **Item** | **Calculation** | **Score** |
| B00IUYUA80 | Highest FPS (50) | 9 |
| RB-Sea-05 |  | 5 |
| RB- Ras-01 |  | 5 |
| Rb-Pul-01 |  | 5 |

Table 8. Calculations for the score of the FPS

**Resolution**

The resolution of the sensors is very important to the performance of the sensors. The values for the score of the resolution category of each item were obtained by giving the item with the highest resolution the highest possible score of (9). The item with the lowest resolution was given the lowest possible score of (1). Once the maximum and minimum values were determined, the scores for the rest of the items were calculated by subtracting the resolution value from the highest resolution value, dividing it by the highest resolution value, multiplying it by 9, the highest possible score, and adding one (1) to the answer. The one is added considering that the lowest possible value is 1, with the answered being rounded up or down accordingly.

|  |  |  |
| --- | --- | --- |
| **Item** | **Calculation** | **Score** |
| B00IUYUA80 | 2.8 3 | 3 |
| RB-Sea-05 | 4.12 4 | 4 |
| RB- Ras-01 | Highest resolution (1080) | 9 |
| Rb-Pul-01 | Lowest resolution (320 x240) | 1 |

Table 9. Calculations for the score of the resolution

## Motors

The motors are an essential part of the movement of the APS. Without motors, the APS would not be able to move to complete the tasks. The following categories describe the process in which the decision and justification for choosing the motor.

### Items under Consideration

Table 10 contains the items under consideration for the motors. The items under consideration have been listed below and contains 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 10. Items under consideration for the motor

### Decision Matrix

Table 11 contains the decision matrix of the motor. The motors considered are broken down into categories that are essential for the decision making process. The categories include the price, voltage, revolutions per minute (RPM), stall torque, stall current and weight of the motor.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Product** | **Price** | **Voltage (V)** | **RPM** | **Stall Torque (N-cm)** | **Stall Current (A)** | **Weight (g)** |
| Standard Gearmotor | $24.95 | 12 | 101 | 32.2 | 0.5 | 119.07 |
| Precision Gearmotor | $34.95 | 12 | 90 | 98.01 | 1 | 240.97 |
| 154:1 Metal Gearmotor 20 D x 44 L mm. | $19.95 | 6 | 90 | 84.73 | 3.3 | 32.6 |
| 100:1 Metal Gearmotor 37 D x 57 L mm. | $24.95 | 12 | 100 | 155.35 | 5 | 201.28 |
|  |  |  |  |  |  |  |
| **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 11. Decision matrix for the motors

### Justification

The following describes the process used for 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 12 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 values 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 calculated.

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

Table 12. Calculations for the price of the motor

**Voltage**

The voltage category scores the voltage levels required for the APS from 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. It was given a score of 8 for the 6 V requirement. The weighted value of the voltage category is 10%.

**RPM**

Table 13 contains the RPM category scores the RPM of the motors. The motors chosen were approximately 90-RPM. This is used to determine the differences in the torque of the different motors. The motors for each item may have a 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. The weighted value of the RPM category is 5%.

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

Table 13. Calculations for the RPM of the motor

**Stall Torque**

Table 14 contains the stall torque category scores the stall torque of the APS. This determines the amount of load the APS can move. If the load of the APS is above the limit, defined by the stall torque, the motor will enter a stall state in which it is unable to move. The equation to determine the stall torque was derived by calculating the normalized stall torque values multiplied by 9 and subtracting 10 from it. This determines the load that the APS can carry. The weighted value of the stall torque category is 35%.

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

Table 14. Calculations for the stall torque of the motor

**Stall Current**

Table 15 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 the stall current 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 15. Calculations for the stall current of the motor

**Weight**

Table 16 contains the weight category determines the weight of the different motors. The scores for this category were determined by normalizing the weights of the motors, multiplying it by 9 and adding 1. The weighted value of the weight category is 5%.

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

Table 16. 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 17 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 17. Items under consideration for the claw

### Decision Matrix

Table 18 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 (in.)** | **Weight (lbs.)** | **Price** | **DOF** | **Controlled** |  | |
| OWI-535 Robotic Arm Edge | 2-3 | 1.45 | $44.29 | 5 | RC |  |
| Stacker 2WD Mobile Robot | 4.25 | 3 | $139.99 | 2 | RC/autonomous |  |
| AX-12 Dual Robotic Gripper | 9 | 2 | $69.00 | 6 | Autonomous |  |
| AL5D Arm Hardware Only - Kit | 1.3 | 0.6 | $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 18. Decision matrix for the claw

### Justification

The following categories justify the decision of choosing the AX-12 Dual Robotic Gripper. This also describes why certain parts were chosen over others.

**Claw Size**

The claw size was a major component of the decision matrix. The claw must open a minimum of 3 in. to meet the requirement of twisting one row of the Rubik’s Cube 180 degrees. A Rubik’s Cube is 3 in. in length, width, and height. A claw that opened less than 3 in. was still considered under the assumption the width would be fabricated later in the term. However, a claw already having an opening of 3 in. or more was given a better score than one that did not. The weighted value of the claw size category is 25% because of the importance to play all of the games using the same claw.

**Price**

|  |  |  |
| --- | --- | --- |
| **Item** | **Calculation** | **Score** |
| OWI-535 Robotic Arm Edge | Least expensive item ($44.29) | 1 |
| Stacker 2WD Mobile Robot |  | 1 |
| AX-12 Dual Robotic Gripper |  | 5 |
| AL5D Arm Hardware Only - Kit | Most expensive item ($143.88) | 9 |

Table 19. 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 20. Calculations for the weight of the claw

**Controlled**

As stated by the IEEE SoutheastCon 2015 Hardware Competition, the robot must move autonomously at all times. Having a claw that was remote controlled (RC) would not be eligible for this competition. How the claw was controlled was scored higher if it was autonomous, lower if it was an RC, and in the middle if it was both autonomous and RC. The weighted value of the controlled category was 25%.

## 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 21 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 mm. 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 22 contains the description matrix, which shows the price, weight, load rating, and holonomic ability for each wheel under consideration.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Product** | **Price** | **Weight (lbs.)** | **Load Rating (lbs.)** | **Holonomic** |
| Vex Robotics Omni | $12.50 | 0.42 | 200 | Yes |
| Vex Robotics Mecanum | $15.00 | 0.55 | 200 | Yes |
| Fingertech Mecanum | $18.75 | 0.1325 | 30 | Yes |
| Pololu Wheels | $3.50 | 0.08 | 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 22. Decision matrix for the wheels

### Justification

The process for the making certain decisions are 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 have a weighted valued of 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, with two wheels per package. The Vex Robotics Mecanum (4 in.) wheels are sold for $59.99, with four wheel per package. The Fingertech Mecanum (4 in.) wheels are sold for $74.95, containing four wheels per package. The Pololu Wheel (42 mm. x 19 mm.) wheels are sold for $6.95, containing two wheels per package. For the decision matrix, the price are divided by the number of items sold to find the price per each item. The prices are normalized by comparing each price to the greatest price. The normalized prices are multiplied by nine and added to one, as shown in Table 23.

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

Table 23. Calculation for the price of the wheels

**Weight**

The weight of the wheels have a weighted valued of 25%. The APS has a maximum weight limit of 50 lbs. Therefore the weight of each wheel is important in choosing the wheels for the APS. The wheels support the entire body of the APS; consequently the point values were reversed to have the heavier wheels to be rated higher than the low weight wheels. Table 24 shows the calculation to find the score for the weight of each type of wheel. The weight of each type of wheel is 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 24. 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 holonomic ability or not. Each wheel is given either a nine, for yes, or a one, for a no. The team made a collective decision to utilize wheels having holonomic abilities. The weighted value of the holonomic category is 30%.

## Battery

The battery is an essential part of the APS. Without the battery, the APS would not be able to function. The following categories describe the process in which the decision and justification for choosing the battery.

### Items under Consideration

Table 25 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 25. The items under consideration for the batteries

### Decision Matrix

Table 26 contains the decision matrix of the battery. The batteries considered are broken down into categories that are essential for the decision making process. The categories include the price, capacity discharge rate, voltage, and weight of the battery.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Product** | **Price** | **Capacity (mAH)** | **Discharge Rate (C)** | **Voltage (V)** | **Weight (lbs.)** |
| Polymer Lithium Ion Battery-2000mAh | $12.95 | 2000 | 2 | 3.7 | 0.079 |
| Polymer Lithium Ion Battery-2200mAh 7.4V | $13.95 | 2200 | 30 | 7.4 | 0.45 |
| Turnigy 2200mAh 3S 20C Lipo Pack | $8.50 | 2200 | 20 | 11.1 | 0.41 |
| Turnigy 2200mAh 3S 25C Lipo Pack | $10.60 | 2200 | 25 | 11.1 | 0.41 |
| Turnigy 2200mAh 3S 30C Lipo Pack | $13.50 | 2200 | 30 | 11.1 | 0.43 |
|  |  |  |  |  |  |
| **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 26. Decision matrix for the batteries

### Justification

The following describes the process used to obtain 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 found 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 27 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 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. The weighted value of the capacity category is 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 it from 10. The weighted value of the discharge rate category is 30%. Table 28 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 28. Calculations for the discharge rate of the batteries

**Voltage**

Table 29 contains the voltage category scores of 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 the voltage 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**

Table 30 contains the weight category to determine the weight 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 the weight 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

# 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 31 contains the requirements related to the microcontroller and how each requirement will be fulfilled.

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

Table 31. Requirements traceability for the microcontroller

## Sensors

Table 32 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 32. Requirements traceability for the sensors

## Motors

Table 33 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 33. Requirements traceability for the motors

## Claw

Table 34 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 34. Requirements traceability for the claw

## Frame

Table 35 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 35. Requirements traceability for the frame

## Battery

Table 36 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 36. Requirements traceability for the batteries

# Risk Analysis

Each component has an amount of risk in its use on the APS. This section details some of the 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 37 details the risks associated with the microcontrollers.

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

Table 37. Risks and alleviations associated with the microcontrollers

## Sensors

Table 38 details the risks associated with the sensors.

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

Table 38. Risks and alleviations associated with the sensors

## Motors

Table 39 details the risks associated with the motors.

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

Table 39. Risks and alleviations associated with the motors

## Claw

Table 40 details the risks associated with the claw.

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

Table 40. Risks and alleviations associated with the claw

## Wheels

Table 41 details the risks associated with the wheels.

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

Table 41. Risks and alleviations associated with the wheels

## Frame

Table 42 details the risks associated with the frames.

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

Table 42. Risks and alleviations associated with the frame

## Battery

Table 43 details the risks associated with the battery.

|  |  |  |  |
| --- | --- | --- | --- |
| **Risk** | **Probability** | **Severity** | **Risk Mitigation** |
| Battery unable to hold charge | 3 | 6 | Ensure that the battery is charged in the right manner. Removing the battery from the charger when the charger indicates that it is done charging. |
| Battery catches fire | 2 | 9 | Abusing the battery in ways such as physically damaging it and short circuiting the battery will damage the battery. |
|  |  |  |  |

Table 43. Risks and alleviations associated with the battery

# Total System BudgetAppendix A: 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 44. 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 45. The acronyms and abbreviations used throughout this budget proposal

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