**Budget Proposal**

**for the Volt & Pepper System**

Sponsor

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

Last Updated September 30, 2014

**Volt & Pepper Development Team**

**Abstract**: This document thoroughly specifies the initial budget proposal for the Volt & Pepper System. The budget is supported by extensive analysis of all major system components, including decision matrices, selection justifications, requirement tracabilty and risk analysis.

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# Revision History

|  |  |  |
| --- | --- | --- |
| **Date** | **Reason for Change** | **Version** |
| Sep. 30, 2014 | Initial draft of document | 0.0.1 |
| Oct. 2, 2014 | Purpose, abstract, | 0.0.2 |
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# Introduction

## Purpose

The purpose of this document is to propose the initial budget for the Volt & Pepper System (VPS) to the customer. The document demonstrates methods used to analyze quantitative and qualitative data for each item under consideration, as well as a thorough justification for each item that is selected. Further ensuring that all items are needed, each is traced to the specific requirement it will aid in fulfilling and potential risks associated with each item are analyzed.

## Scope

This document is

## Team Roles

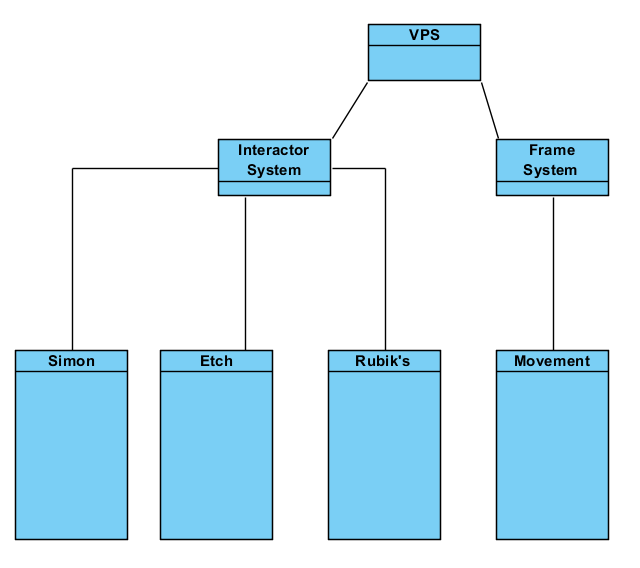
The following table presents all members of the Volt & Pepper System Development Team (VPSDT) and respective role assignments. Each member is accountable for the overesight and advancement of the positions held.

Table 1—Team roles

|  |  |
| --- | --- |
| **Name** | **Role** |
| Nezar Bahksh | Scrum Master  Development Team |
| Greg Carkin | Development Team |
| Gary Roach | Development Team |
| Brittany Rompa | Product Owner  Development Team |

# Decomposition of system

* 1. The VPS is divided into 2 sections. The first section is the frame systems which houses the microcontroller, power supply, and movement system. The second section houses the interactors for each of the challenges. The subsystems of the interactor system are (1) Simon, (2) Etch, (3) Rubik’s. The subsystems of the frame system are (4) movement. The subsystems are depicted below.



The subsystems were defined this way in order to create modularity within the VPS. By breaking the VPS into these subsystems it allows the individual components to be developed separately without having a major effect on the other systems.

* 1. **Simon Subsystem Functionality:**

The functionality of the Simon subsystem is to sense an output sequence, either visual or audio, from the Simon game, interpret the output sequence, then press a button(s) corresponding to the output sequence.

* 1. **Simon Subsystem Requirements:**
  2. **Simon Subsystem Hardware to Meet Functionality and Requirements:**
  3. **Etch Subsystem Functionality:**
  4. **Etch Subsystem Requirements:**
  5. **Etch Subsystem Hardware to Meet Functionality and Requirements:**
  6. **Rubik’s Subsystem Functionality:**
  7. **Rubik’s Subsystem Requirements:**
  8. **Rubik’s Subsystem Hardware to Meet Functionality and Requirements:**
  9. **Movement Subsystem Functionality:**
  10. **Movement Subsystem Requirements:**
  11. **Movement Subsystem Hardware to Meet Functionality and Requirements:**

# Budget and Justifications

In the following section, each main component of the VPS will be examined in order to select the most appropriate item. Each component section will contain: (1) specific items under consideration based on results from the respective trade study, (2) all necessary decision matrices, which define and weigh out the relevant qualitative and quantitative specifications for each item, and (3) justifications for the final selection made, which includes an explanation for each category in the matrix and the formula(s) used to calculate scores for each item analyzed.

* 1. Microcontrollers
     1. The following table and justification is a description of the decision making process behind choosing a micro controller for the VPS. The VPS is required to be autonomous; in order to achieve this a microcontroller(s) is proposed. The controller(s) will act as a brain for the VPS which will receive sensory data, and control motors / servos in order to accomplish tasks.
     2. **Items under consideration**

The following are items that were considered as the micro controller for the VPS.

|  |  |  |
| --- | --- | --- |
| Item Name | Vendor | Description |
| Arduino Uno | Already Have | Microcontroller based on ATmega328. The uno has a large amount of support with documentation, and is compatible with other components such as shields and sensors. The controller offers a limited array of I/O pins to work with 6 analog, 14 digital. |
| Arduino Due | Amazon | Microcontroller based on Atmel SAM3X8E ARM Cortex-M3 CPU. The due runs at a lower voltage, and has lower tolerances than other Arduino boards. The board has an increased CPU speed 84 MHz, and higher flash memory compared to other arduino’s. |
| Arduino Mega 2560 R3 | Amazon | Microcontroller based on ATmega2560. The mega has a large amount of support with documentation, and compatibility with other components such as shields, and sensors. The controller offers a wide array of I/O pins with 16 analog, 54 digital. |
| TS-7600 | Technologic Systems | The TS-7600 is a compact embedded computer. It runs Linux 2.6.35 kernel and has a plethora of interfaces. It comes with several on board devices ranging from FPGA, real time clock, watchdog timer, and temperature sensor. The documentation of the TS-7600 is detailed, but outside support for the system is sparse. |
| Raspberry Pi B+ | Amazon | The model B+ is an upgrade over the regular Raspberry Pi B. It supports 40 general purpose pins, 4 USB ports, a micro SD and low power consumption through switching regulators. |

* + 1. **Decision Matrices:**

The following are decision matrices for the items under consideration.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Factor | Cost | Speed | Support | Compatibility | Interfaces | I/O Pins | Shipping |
| Weight | 0.25 | 0.05 | 0.15 | 0.2 | 0.05 | 0.2 | 0.1 |
| Arduino Uno | Free | 16 MHz | High | High | 4 | 6 analog, 14 Digital | have |
| Arduino Due | $37.35 | 84 MHz | Med | Med | 9 | 14 Analog, 54 Digital | 2-3 days |
| Arduino Mega 2560 r3 | $32.35 | 16 MHz | High | High | 5 | 16 Analog, 54 Digital | 2-3 days |
| TS-7600 | $94 | 454 MHz | Med | Med | 13 | 4 Analog, 55 Digital | up to a week |
| Raspberry PI B+ | $38.66 | 700 MHz | Med High | Med | 7 | 40 General purpose | 1-3 days |

After calculating scores for each item.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Factor | Cost | Speed | Support | Compatibility | Interfaces | I/O pins | Shipping | Sum |
| Weight | 0.25 | 0.05 | 0.15 | 0.2 | 0.05 | 0.2 | 0.1 |  |
| Arduino Uno | 9.4 | 0.22 | 10 | 10 | 3.07 | 2.67 | 10 | 7.54 |
| Arduino Due | 5.66 | 1.2 | 5 | 5 | 6.92 | 9.91 | 7.5 | 6.30 |
| Arduino Mega 2560 r3 | 6.16 | 0.22 | 10 | 10 | 3.8 | 10 | 7.5 | 7.99 |
| TS-7600 | 0 | 6.48 | 5 | 5 | 10 | 9.65 | 3 | 4.80 |
| Raspberry PI B+ | 5.53 | 10 | 7.5 | 5 | 5.3 | 8.62 | 8 | 6.80 |

* + 1. **Justifications:**

The factors taken into consideration for the decision matrices were determined by the needs of the VPSDT. The microcontroller would have to be low cost, but support multiple components and have high support for it through documentation. The total interfaces of the microcontroller were taken into consideration if the VPS were to be upgraded later to use inputs other than pins. The speed was also taken into consideration, but it was not weighted as high because the intended design for the

* + - 1. **Cost**

The cost was considered the most important due to needing to meet the budget for the project. The price factors were based off the comparison between each product’s price, and the product with the highest price.

The score was calculated using: , where Scc is the score for the current controller, ch is the cost of the highest controller, and cc is the cost of the current controller.

The TS 7600 had the highest price of $94 and all other products were compared to that price. The Arduino uno was the best price due to being free since the VPSDT has access to three of them. The Raspberry Pi, Arduino Due, and Arduino Mega all were average on cost.

* + - 1. **Speed**

The CPU speed of the product was considered to have low importance because the VPS’s current design is not CPU intensive. What is needed for the VPS is a micro controller(s) which can monitor sensors, and control motors / servos.

The score was calculated using: , where Sspc is the speed score of the current controller, Sc is the CPU speed of the current controller in MHz, and Sh is the CPU speed of the highest controller.

The Raspberry PI B+ had the best score due to having an exceptionally high clock speed of 700 MHz, compared to the Arduino’s having significantly less at 84 Mhz for the Due and 16 MHz for the Mega and Uno.

* + - 1. **Support**

Support of the product was considered to have moderate importance because the product must be easily programmable. Each of the Arduino’s had high documentation for integration of components, and programing.

The score was calculated using 10 for high, 5 for medium, and 0 for low.

The raspberry pi had similar documentation, but its focus was on a wider variety of components not specifically for sensors and motors. The TS-7600 had a manual, and support documentation provided by the company, but as for third party support there was little to none.

* + - 1. **Compatibility**

Compatibility is of high importance because the product that is chosen must be able to communicate with multiple components. The factor was based off the availability of sensors, motors, servos to communicate with the product.

The score was calculated using 10 for high, 5 for medium, and 0 for low.

After researching multiple sensors, motors, and servos the Arduino Uno, and Mega came out ahead in the score for compatibility. These Arduino’s were capable of communicating with a variety of components, and had several specific components made for it related to the needs of the VPS. The Arduino Due, and Raspberry PI fell short due to not being able to support motor shields as easily.

* + - 1. **Interfaces**

The interfaces of the controllers were of low importance because based off the VPSDT’s current design the complexity of the VPS is low. Thus having a high amount of interfaces is not greatly desired.

The score was calculated using, where Sic is the interface score of the current controller, ic is the amount of interfaces for the current controller, ih is the amount of interfaces for the highest controller.

This category was dominated by the TS-7600 due to supporting multiple busses, serial ports, USB’s and Ethernet. The Raspberry Pi and Arduino Due offered similar amounts of interfaces, while the Arduino Uno and Mega offered a small amount.

* + - 1. **I/O pins**

I/O pin is of high importance because if a product is capable of being reused for additional tasks it will save cost, and space. This factor was based off the amount of total inputs analog, and digital pins. What is needed for the VPS is the ability to communicate with sensors and motors.

The score was calculated using where ITc is the current controllers input total, calculated by where ac is the current controllers analog inputs, wa is the importance weight for analog inputs, dc is the current controllers digital inputs, wd is the importance weight for digital inputs.

Due to this the Arduino Uno fell short for lack of I/O pins. The Raspberry Pi had a separate setup of pins compared to the others. The usual pins are analog and digital, but the Raspberry Pi has general purpose I/O pins. These pins allow for more flexibility within the system, and let the user determine what the pins are used for.

* + - 1. **Shipping**

The shipping of each product was considered of high importance because the products are needed within 2-4 weeks from writing this report, and the sooner the product is obtainable the better. The optimal time for the product is to have it the same day as when it was ordered, being a 10. Every day beyond that was deducted from the score. This led to the Raspberry Pi having a score of 9, with next day shipping.

* + - 1. **Conclusion**

Based on these factors and the weighted scoring the microcontroller to be ordered is the Arduino 2560 R3.

* 1. Sensors
     1. The following table provides descriptions of possible methods for sensing which the VPSDT considered

|  |  |
| --- | --- |
| Item | Use Description |
| Camera | A camera would receive visual data around the VPS. The data would require a high amount of processing power. |
| Microphone | A microphone would receive audio signals. The signals would require a high amount of processing power. |
| Photocell | A photocell would receive |
| Infrared | An infrared sensor would |
| Color Sensor | A color sensor would |

The following are decision matrices to determine which type of sensors the VPSDT should look consider for use with the VPS.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Factor | Cost | Processing | Documentation | Size | Sensing Capability | Power Needed |
| Weight | 0.3 | 0.25 | 0.2 | 0.1 | 0.05 | 0.1 |
| Camera | High | High | Med | Med | High | High |
| Microphone | Med | High | Med-High | Low | Med | Med |
| Photocell | Low | Low | High | Low | Mew Low | Low |
| Infrared | Low | Low | High | Low | Med Low | Low |
| Color Sensor | High | Low | High | Med | Med | Med |

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Factor | Cost | Processing | Documentation | Size | Sensing Capability | Power Needed | Total |
| Weight | 0.3 | 0.25 | 0.2 | 0.1 | 0.05 | 0.1 |  |
| Camera | 0 | 0 | 5 | 5 | 10 | 0 | 2 |
| Microphone | 5 | 0 | 7.5 | 10 | 5 | 5 | 4.75 |
| Photocell | 10 | 10 | 10 | 10 | 2.5 | 10 | 9.625 |
| Infrared | 10 | 10 | 10 | 10 | 2.5 | 10 | 9.625 |
| Color Sensor | 0 | 10 | 10 | 5 | 5 | 5 | 5.75 |

* + 1. **Justification:**

The factors taken into consideration for the decision matrices were determined by the needs of the VPSDT. It is preferable that the sensors be low cost, require low processing, and have documentation for how to integrate them into the VPS. These factors were weighted highly in order to keep complexity of the system low.

* + - 1. **Cost**

The cost was considered the most important due to needing to meet the budget for the project. The price factors were based off the comparison between each average product price, and the product with the highest average price.

The score was calculated using High is 10, Med is 5, and Low is 0

* + - 1. **Processing**

Processing was considered to be highly important due to the want of simplicity within the system. While there are options which provide a lot of data, cameras and microphones, the processing required to interpret the data is high.

The score was calculated using High is 0, Med is 5, and Low is 10

* + - 1. **Documentation**

The documentation score for the sensors was based off the availability documentation for the sensor with multiple platforms. Those that had high ratings had circuit schematics for connecting with microcontrollers. Med documentation scores were due to documentation of the product limited to specific setups, and vague measurement data.

The score was calculated using High is 10, Med is 5, and Low is 0

* + - 1. **Size**

The size of the sensors was taken into consideration because less intrusive sensors were preferable for the VPS. The higher scoring sensors were small, and easily connected to. The low scoring sensors required either special mounts, or would be much bigger than its competitors.

The score was calculated using High is 0, Med is 5, and Low is 10

* + - 1. **Sensing Capability**

Sensing capability was based off the sensors ability to be used for multiple tasks. A photocell would have a low sensing capability because its task is specific to sensing if light is on it. Whereas, a camera can be used for object detection, color detection, and object recognition just to name a few.

The score was calculated using High is 10, Med is 5, and Low is 0

* + - 1. **Power Needed**

The power needed by each sensor was of low importance because it is preferred that the sensors have a low power consumption, but

The score was calculated using High is 0, Med is 5, and Low is 10

* + - 1. **Conclusion**

Based off the weighted scores for the factors the infrared and photocell sensors will be used as a baseline within the initial prototypes. This is primarily due to their low cost, and low processing requirement.

* + 1. Simon Game
       1. Items Under Consideration
       2. Decision Matrices
       3. Justification
    2. Navigation
       1. Items Under Consideration

|  |  |  |
| --- | --- | --- |
| **Item ID** | **Vendor** | **Description** |
| Pixy CMUCam5 | Amazon |  |
| QTR-3A | Pololu |  |
| QTR-3RC | Pololu |  |
| QTR-8A | Pololu |  |
| QTR-8RC | Pololu |  |
|  |  |  |
|  |  |  |

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| |  |  | | --- | --- | | Camera | Pixy CMUCam5 | | Pan/Tilt Mech Kit Pixy | Pan/Tilt Kit | | IR LED | COM-09349 | | Analog IR Sensor Array (3) | QTR-3A | | Photodiode (IR Receiver) | TSOP38238 | | Photo resistor LDR | KE-10720 | | IR LED | OFL-5102 | | IR LED | RB-Spa-463 | | Analog IR Sensor Array (8) | QTR-8A | | Digital IR Sensor Array (8) | QTR-8RC | | Ultrasonic Range Finder Sensor | LV-EX4 982 | | 38 kHz IR Proximity Sensor | Pololu-2460 | | IR Sensor Array (5) | SKU17637 | | Reflectivity IR Sensor Pair | VUPN6320 | |

* + - 1. Decision Matrices
      2. Justification
  1. Navigation Motors

In this section we explain the process in which we selected the motor that will drive the wheels of the VPS. The process involves several critical steps. In section 3.4.1, the different types of motors are analyzed to determine the best type of motor to drive the VPS. In section 3.4.2, specific motors are selected for analysis, using the results from section 3.4.1, as well as the required torque and rpm calculations from section 3.4.4.1. In section 3.4.3, the specific motors are analyzed and a motor is selected. In section 3.4.4, all the calculations, formulas, and qualitative reasoning for analysis are justified.

* + 1. Motor Type Decision Matrix

In the following table different types of motors are analyzed to determine the best type of motor to drive the VPS. The values in this table are not for any one specific motor, but generalized to represent the norm for the type of motor. The justification for how these qualitative values were assigned is covered in section 3.4.4.2

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| motor type | efficiency | torque | rpm | position control | speed control | cost |
| Stepper | low | low | low | high | high | med |
| DC Brushed | med-high | high | high | low | low-med | low |
| DC Brushless | high | high | high | low | med | med |
| DC Brushed w/encoder | med-high | high | high | high | high | med-high |
| DC Brushless w/ encoder | high | high | high | high | high | high |

The above table is then normalized by assigning these qualitative values with a numerical score from 0 to 10. The areas of interest are then given a weight based on how much that area should affect the choice. These weights are then multiplied by the numerical score and summed together to give the total score for the motor type (Shown in the table below). The justification for choosing these weights and scores is discussed in section 3.4.2.2.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| motor type | efficiency | torque | rpm | position control | speed control | cost |  |
| weight | 0.1 | 0.2 | 0.1 | 0.1 | 0.25 | 0.25 | Total |
| Stepper | 0 | 0 | 0 | 10 | 10 | 5 | 4.75 |
| DC Brushed | 7.5 | 10 | 10 | 0 | 2.5 | 10 | 6.875 |
| DC Brushless | 10 | 10 | 10 | 0 | 5 | 5 | 6.5 |
| DC Brushed w/encoder | 7.5 | 10 | 10 | 10 | 10 | 2.5 | 7.875 |
| DC Brushless w/ encoder | 10 | 10 | 10 | 10 | 10 | 0 | 7.5 |

* + 1. Justifications

Several assumptions need to be made in order to make appropriate calculations for the motor's minimum required specifications. These assumptions are based on research of similar robots (citations needed):

The VPS will weigh no more than 40 pounds

The maximum speed will be 1 ft/s

The maximum acceleration will be 0.5 ft/s^2

The radius of each wheel, mounted to the motor, will be no longer than 3 inches

The operating surface will be on a flat plane (i.e. the maximum incline will be 0 degrees)

The static coefficient of friction between the wheels and the wood operating surface will be approximately 0.6 (<http://www.engineeringtoolbox.com/friction-coefficients-d_778.html>)

The rolling resistance coefficient between the wheels and the wood operating surface will be approximately 0.001 (<http://www.engineeringtoolbox.com/rolling-friction-resistance-d_1303.html>)

The calculations

* 1. Servos
     1. Items Under Consideration
     2. Decision Matrices
     3. Justification
  2. Power Supply
     1. Batteries

This section covers all the detailed steps we took in order to choose the most suitable battery for the VPS. Section 3.6.1 covers the different types of batteries under consideration for the VPS by analyzing averaged critical specs within each battery type. 3.6.2

* + 1. Battery types decision matrix

As mentioned above this section analyzes critical specs for different types of batteries. This is the first step we took toward finding the most suitable battery for the VPS. Table 1 holds all the critical specs and their values for all the battery types under consideration. VPDT formulated Equation (1) to calculates the price per cell normalized to 1000 mAh. The VPDT applied Equation (1) for 5 or more popular products for each battery type and averaged it to form column 6 of Table 1, all the calculations done for Column 6 can be seen in section 3.6.3 Table X.

Equation (1)

1. Table 1 Critical specs of batteries[29][30][32]

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | Gravimetric Energy Density(Wh/kg) | Cycle Life (to 80% of initial capacity) | Cell Voltage nominal | Safe Load Current | Average | Memory effect |
| **NiCd** | 45-80 | 1000 - 1500 | 1.25 V | can reach 15C or more | $1.77 | Yes |
| **NiMH** | 60-120 | 300 to 500 | 1.25V | <1C | $1.12 | No |
| **Lead Acid** | 30-50 | 200 to 300 | 2V | <1C | $0.51 | No |
| **Li-ion** | 110-160 | 500 to 1000 | 3.6V | <1C | $2.69 | Minor |
| **Li-po** | 100 to 130 | 300 to 500 | 3.6 | can reach 15C or more | $3.74 | No |

Things to consider here, batteries have an extremely large band of types, within these types there is also a second large band of specs. The VPDT gathered the most accurate data up to this day by thoroughly researching the web.

Now that we have Table 1 with all the detailed specs, we are ready to weight each column in favor of the specs that concern the VPS most. Table 2 on the next page carries a new column of weight. These weights were completely unbiased toward any particular battery type. These weights are further disscussed in section XXXXX [justification]

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  | Gravimetric Energy Density(Wh/kg) | Cycle Life (to 80% of initial capacity) | Cell Voltage nominal | Safe Load Current |  | Memory effect | Total |
| **Weights** | 0.35 | 0.05 | 0.1 | 0.05 | 0.3 | 0.15 |  |
| **NiCd** | 4.63 | 10 | 3.47 | 10 | $2.88 | 0 | 3.8315 |
| **NiMH** | 6.67 | 3.2 | 3.47 | 5 | $4.55 | 10 | 5.9565 |
| **Lead Acid** | 2.96 | 2 | 5.56 | 5 | $10.00 | 10 | 6.442 |
| **Li-ion** | 10 | 6 | 10 | 5 | $1.90 | 5 | 6.37 |
| **Li-po** | 8.52 | 3.2 | 10 | 10 | $1.36 | 10 | 6.55 |

1. Table 2 Battery types decision matrix

Our clear winner from Table 2 are the Lead Acid battery and the Li-po. Now that we have 2 winners we are ready to take the second step toward finding our ideal battery hiding within these two enormous battery families.

* + 1. Finding the VPS's ideal battery

Section 3.6.1 compared 6 extremely popular types of batteries with critical average specs. Although this was extremely useful in aiding us toward our decision, it is not enough. In order to find an ideal battery for the VPS we need three extremely important values. Voltage, and capacity.

* + 1. Voltage

As mentioned above voltage is one of the three crucial unknown values we need in order to select our ideal battery. As mentioned in section [SERVO MOTOR]. section [MIcroo] and section [LINE]. All of our electronic components operate on 4.5 V to 6 V except for our encoded DC motor which operates on 6 V to 15 V. Here we reach a design decision since different components of our robot demand different voltage ratings, Table 3 will provide the factors we took under consideration then Table 4 provides our decision matrix for voltage.

Pre defined term for Table 3

High V: 11.1 V or 12 V

Low V: 6 V or 7.2 V

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Voltage | Step down regulator | step up regulator | charging more than 1 unit | Current flexability | Efficiency | price |
| 1 High | High | Low | Low | medioum | Low | medioum |
| 1 Low | Low | High | Low | Low | Low | medioum-low |
| 1 High & 1 Low | High | High | High | High | High | High |

1. Table 3

Table 4 on the next page extends Table 3 by adding weights to each column, furthermore on XXXXXXX

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Voltage | Step down regulator | step up regulator | charging more than 1 unit | Current flexibility | Efficiency | price | total |
| Weight | 0.05 | 0.05 | 0.35 | 0.2 | 0.1 | 0.25 | 1 |
| 1 High V | 0 | 10 | 10 | 5 | 0 | 5 | 6.25 |
| 1 Low V | 10 | 0 | 10 | 0 | 0 | 7.5 | 5.875 |
| 1 High V & 1 Low | 10 | 10 | 0 | 10 | 10 | 0 | 4 |

Table 4

Based on Table 4 our design is best equipped with a single battery of either 11.1 V Li-po or 12 V Lead Acid. We still didn't solve the problem of having different components with different operating voltage, in order to solve it we created Table 5 that compares different solutions.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Solutions | Efficiency | drop out voltage | needs heat sinking | price |
| Linear Regulators | Low | Low | High | low |
| Switching Regulators | Hight | High | low | high |

Table 5

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Solutions | Efficiency | drop out voltage | needs heat sinking | price | Tottal |
| Weight | 0.2 | 0.3 | 0.1 | 0.2 |  |
| Linear Regulators | 0 | 0 | 0 | 10 | 2 |
| Switching Regulators | 10 | 10 | 10 | 0 | 6 |

Table 6

* + 1. VPS maximum current

Now that we reached a decision to have 1 battery with switching regulators its time to find our second crucial value . In order for us to find we analyzed the current drawn by VPS in different states of operation. After carefully studying all these states, we reached a conclusion that is drawn by the VPS when moving. When moving the VPS has both the encoded DC motors operating in conjunction with the line following sensors, in this state we know that the only component drawing currents are the DC motors and the microcontroller, therefore can be calculated using the following mathematical formula Equation (2).

Equation(2)

Where is the maximum current the VPS draws, is the maximum current the DC motor draws and is the maximum current the microcontroller draws.

[34] (i)

Equation(3) [33]

From (DC motor section), we reached a decision of using XXX product. XXX product datasheet provide us with the following values [XXXXX].

410 mA

2 A

.14 lb.inch

2.26 lb.inch1

can then be calculated using Equation (3)

Equation(3) [33]

1.21 A (ii)

Where is the VPS maximum current consumption, is the free running current when no load is experienced by the motor, is the maximum current consumption by the motor when stalled, is the torque required in order to move the VPS and is the torque at which the motor stalls.

combining (i) and (ii) we get the following:

1. Capacity

Section 3.6.2.1 & section 3.6.2.2 gave us the 2 of the crucial values we need in order to decide what battery to buy. Now all we need is the capacity, in order to correctly choose an appropriate capacity we had to make a decision on how long the robot can operate continuously before running low on power.

The VPDT choose that it would be most suitable if the robot operated for 2h continuously for prototyping purposes. Therefore the capacity is calculated in units of mAh down using Equation (4)

Equation(4)

1. VPS ideal battery

Finally we reached our ideal battery, this is the most suitable battary for the VPS prototyping. Specs can be show below in Table 7.

|  |  |
| --- | --- |
| Voltage | 11.1 V or 12 V |
| Current discharge | 1.61 A |
| Capacity | 3220 mAh |

1. Table 7

/////////////

THIS SECTION STILL NEEDS WORK AS WELL AS THE ABOVE SECTIONS

1. Battery products decision matrix

This section will capture X products from the Lead Acid family of battery and X products from the Li-po family of battery and compare all of them using different weights to filter out that one special battery for us.

All the weights were given by votes from the entire VPDT where we honestly tried to be as unbiased as we could be. The highest weights were given to Column 2 (Gravimetric Energy Density(Wh/kg)) and column 6 ( ). We felt these two specs hold the most vital specs we are looking for, which is low cost, low weight and high capacity.

//////////////////////

* 1. Shields
     1. Items Under Consideration
     2. Decision Matrices
     3. Justification

# Requirements Traceability

The following section

|  |  |  |
| --- | --- | --- |
| **Requirement No.** | **Requirement Text** | **Requirement Fulfillment** |
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# Total System Budget

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| --- | --- | --- | --- | --- | --- | --- | --- |
| **Item Description** | **Part No.** | **Fulffilled By** | **Qty** | **Unit Price** | **Shipping** | **Replacement Cost** | **Cash Otlay** |
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# Requirements

# Functional Requirements

The robot shall traverse the course.

The robot shall remain on the white line, which marks the path of the course, at all times.

The robot shall move to the next challenge once the current challenge is complete.

The robot shall move to the finish line once all challenges are complete.

The robot shall cross the finish line.

The robot shall complete all four challenges, defined as: Simon, Etch A Sketch, Rubik’s Cube and playing card.

The robot shall complete each challenge once.

The robot shall keep track of progress on a challenge.

The robot shall complete the challenges in a sequential matter.

The robot shall execute the challenges one at a time.

The robot shall complete the Simon challenge.

The robot shall press the activation button on Simon.

The robot shall obtain a pattern from Simon.

The robot shall press the buttons on Simon in a pattern corresponding to the obtained pattern.

The robot shall complete the Etch A Sketch challenge.

The robot shall print “IEEE” on an Etch A Sketch.

The robot shall complete the Rubik’s Cube challenge.

The robot shall rotate one row of a Rubik’s Cube 180 degrees.

The robot shall complete the playing card challenge.

The robot shall obtain one playing card from a deck of cards.

The robot shall complete the course with the playing card.

## Nonfunctional Requirements

The robot shall fit within 1 ft3.

The robot shall be autonomous.

The robot shall remain on the course for 5 minutes.

The robot shall interact with Simon for exactly 15 seconds.

The robot shall complete the challenges in sequence.

The robot shall execute all requirements within 5 minutes.

The robot shall press the buttons on Simon before Simon outputs an error tone.

The robot shall fulfill the competition safety regulations.

The robot shall contain nonflammable substances.

The robot shall not damage the course.

The robot shall do no harm.

The robot shall shut off in case of emergency.

The robot shall operate with an on-board power supply.

# A. Appendicies

## A.1. Appendix A

# Supplement

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| --- | --- | --- |
| **Entry** | **Definition** | **Alias** |
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# Acronyms & Abbreviations

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| --- | --- |
| **Entry** | **Expanded Phrase** |
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