**3.4 The Motors for Drive Wheels**

In this section, the process for selecting the motor, that will drive the wheels of the VPS, is explained. 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, the qualitative values and scoring system, for the types of motors, is justified. In section 3.4.3, the torque and RPM requirements, for the VPS, are calculated. In section 3.4.4, specific motors are selected for analysis. In section 3.4.5, the specific motors are analyzed and a motor is selected. In section 3.4.6, the decision matrices, for the specific motors, are justified.

**3.4.1 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. These values come from the trade study performed by the VPDT. The justification for how these qualitative values were assigned is covered in section 3.4.2.

Table X -Motor type raw data

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| 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.

Table XX - Motor type decision matrix, where the chosen motor is highlighted

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| 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 |

According to the decision matrix, in Table **XX**, the DC brushed motor with an encoder is the best option for the VPS.

**3.4.2 Motor Type Justification**

In the following sections, the criterions for analysis are justified and the scoring system is explained.

**3.4.2.1 Efficiency**

The Efficiency of the motor is an important factor to consider when buying a motor. Higher efficiency allows the motor to use less electrical energy to achieve the required mechanical energy[5]. This allows for less wasted energy and longer battery life[5]. During the trade study the VPDT discovered that certain types of motors are more efficient than others[1][3]. As seen in Table **X**, the DC brushless motors are the most efficient, while the stepper motors are the least efficient. The motor types were assigned a value of “high” for most efficient, and “low” for least efficient. The other motors were assigned values in between, such as “low-med”, “med”, and “med-high.” These values were then converted to a numerical score, from 0 to 10, by assigning the “low”, “low-med”, “med”, “med-high”, and “high”, the values of “0”,”2.5”,”5”,”7.5”, and ”10” respectively. The efficiency category was given a weight of 10%, because it affects the battery life of the VPS.

**3.4.2.2 Torque**

The motors torque effects how much tractive effort the VPS can produce[6]. The higher the torque, the easier it is for the motor to turn the wheels of the VPS[7]. During the trade study the VPDT discovered that certain types of motors were capable of higher torques than others[2][3]. As seen in Table **X,** the DC motors are capable of providing the most torque, while stepper motors typically provide lower torque. The motor types were assigned a value of “high” for high torque, and a value of “low” for low torque. These values were then converted to a numerical score, with “0” being “low”, and “10” being “high”. The torque category was given a weight of 20%, because being able to move the robot is extremely important.

**3.4.2.3 Revolutions Per Minute (RPM)**

The motors RPM represents how fast the motor turns, which effects how fast the VPS can move[6]. Having high RPM, combined with having larger wheels, equals a faster robot[6]. During the trade study the VPDT discovered that certain types of motors typically have higher RPM than others[2]. As seen in Table **X**, the DC motors are capable of providing the most RPM, while stepper motors typically provide lower RPM. The motor types were assigned a value of “high” for high RPM, and a value of “low” for low RPM. These values were then converted to a numerical score, with “0” being “low”, and “10” being “high”. The RPM category was given a weight of 10%, because the VPS is competing in a timed competition and should not be slow. This category could of received a higher weight but during the trade study the VPDT learned that by increasing the wheel size we can also increase the speed of the VPS[6].

**3.4.2.4 Position Control**

Position control determines how accurately the motor can position the attached wheel. The more position control a motor has, the more control the VPS will have over its position on the course. During the trade study the VPDT discovered that certain types of motors typically have more position control than others[1][2][3]. As seen in Table **X**, the DC motors with encoders, and the stepper motors, are capable of providing the most position control, while the DC motors without encoders typically provide less position control. Stepper motors have native position control by design, as they rotate in precise steps[1][2][3]. DC motors by themselves have little to no position control. By adding an encoder, the system becomes a closed loop system, and the VPS can use the feedback from the motor to, more accurately, control position[4]. The motor types were assigned a value of “high” for high position control, and a value of “low” for low position control. These values were then converted to a numerical score, with “0” being “low”, and “10” being “high”. The position control category was given a weight of 10%, because the VPS will have to align itself with the games on the course, as well as stay on the line. Other sensors, such as the ones used for line following, will aid in this alignment, otherwise this category would have received a higher weight.

**3.4.2.5 Speed Control**

Speed control determines how accurately the motor can control the speed of the attached wheel. The more speed control a motor has, the more control the VPS will have over its position on the course, as well as how fast it’s going. During the trade study the VPDT discovered that certain types of motors typically have more speed control than others[1][2][3]. As seen in Table **X**, the DC motors with encoders, and the stepper motors, are capable of providing the most speed control, while the DC motors without encoders typically provide less speed control. Stepper motors have native speed control by design, as they rotate at precise speeds[1][2][3]. DC motors by themselves have some speed control, but factors such as wheel slippage and orientation of the motor can cause speeds to vary[8]. By adding an encoder, the system becomes a closed loop system, and the VPS can use the feedback from the motor to, more accurately, control speed[4]. The motor types were assigned a value of “high” for high speed control, and a value of “low” for low speed control. The other motors were assigned values in between, such as “low-med”, “med”, and “med-high.” These values were then converted to a numerical score, from 0 to 10, by assigning “low”, “low-med”, “med”, “med-high”, and “high”, the values of “0”,”2.5”,”5”,”7.5”, and ”10” respectively. The speed control category was given a weight of 25%, because the VPS will have to overcome inconsistencies in the speed of each wheel to remain on the line. The speed control will also aid in making sure the vehicle maintains the correct speed to complete the course in the desired time.

**3.4.2.6 Cost**

The VPDT is required to remain within a certain budget; therefore the cost of the motor is a major decision factor. During the trade study the VPDT discovered that certain types of motors typically cost more than others[1][9][10][11][12]. As seen in Table **X**, the DC brushless motors with encoders cost the most, and the brushed DC without encoders cost the least. The motor types were assigned a value of “high” for highest cost, and “low” for lowest cost. The other motors were assigned values in between, such as “low-med”, “med”, and “med-high.” These values were then converted to a numerical score, from 0 to 10, by assigning the “low”, “low-med”, “med”, “med-high”, and “high”, the values of “0”,”2.5”,”5”,”7.5”, and ”10” respectively. The cost category was given a weight of 25% because motors are one of the most expensive items that are required for the VPS.

**3.4.3 Calculations for Required Motor Specifications**

Before selecting specific motors for consideration, the torque and RPM required to move the VPS need to be calculated.

**3.4.3.1 Assumptions**

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[6][13]:

* The VPS will weigh no more than
* The VPS will weigh no less than
* The maximum speed will be
* The maximum acceleration will be
* The VPS will have two drive wheels
* The weight on each drive wheel will be ¼ of the total weight of the VPS (This is because the VPS will have two drive wheels and two casters)
* The radius of each wheel, mounted to the motor, will be approximately
* The operating surface will be on a flat plane (i.e. the maximum incline will be )
* The rolling resistance coefficient between the wheels and the wood operating surface will be approximately 0.001[14]
* The coefficient of friction between the wheels and the wood operating surface will be approximately 0.6 [15]

**3.4.3.2 Tractive Effort Calculation**

In order to calculate the torque needed from the motor, first the total tractive effort required to move the VPS at the desired speed and acceleration needs to be calculated.

|  |  |
| --- | --- |
|  | Equation(**Y)[6]** |
|  |  |

Where is the total tractive effort (), is the force necessary to overcome rolling resistance (), is the force required to climb a grade (), and is the force required to accelerate to max velocity ().

Expanding Equation(**Y**),

|  |  |
| --- | --- |
|  | Equation(**YY)[6]** |
|  |  |

Where is the force necessary to overcome rolling resistance (), is the gross vehicle weight (), and is the rolling resistance coefficient.

|  |  |
| --- | --- |
|  | Equation(**YYY**)[6] |
|  |  |

Where is the force required to climb a grade (), is the gross vehicle weight (), and is the max incline ().

|  |  |
| --- | --- |
|  | Equation(**YYYY**)[6] |
|  |  |

Where is the force required to accelerate to max velocity (), is the gross vehicle weight (), is max vehicle speed (), 32.2 is the acceleration due to gravity (), and is the time it takes to reach ().

Solving Equation(**YY**), using the weight range of to , and the rolling resistance of 0.001 (values from assumptions above),

|  |  |
| --- | --- |
|  | Max |
|  | Min |

Solving Equation(**YYY**), using the max incline angle of (values from assumptions above),

|  |  |
| --- | --- |
|  |  |

Solving Equation(**YYYY**), using the weight range of to , of , and of ,

|  |  |
| --- | --- |
|  | Max |
|  | Min |

Substituting solved Equations **YY**, **YYY**, **YYYY**, back into Equation(**Y**),

|  |  |
| --- | --- |
|  | Max |
|  | Min |

**3.4.3.3 Torque Required From the Motors**

Now to find the torque required from the motors to achieve the calculated in section 3.4.3.2,

|  |  |
| --- | --- |
|  | Equation(**YYYYY**)[6] |
|  |  |

Where is the total torque required from all motors, is the total tractive effort from Equation(**Y**) (), is the radius of the wheel (), is the resistance factor. The resistance factor accounts for the frictional losses between the caster wheels and their axles and the drag on the motor bearings. Typical values range between 1.1 and 1.15 (10% to 15%).[6]

Solving Equation(**YYYYY**), using the range of to , the wheel radius of , and the of 1.15,

|  |  |
| --- | --- |
|  | Max |
|  | Min |

Since the VPS has two wheels this value is divided by two to get the torque required for each wheel,

|  |  |
| --- | --- |
|  | Equation(**YYYYYY**)[6] |
|  |  |
|  | at max weight |
|  | at min weight |

As seen above, whatever motor is selected, for the VPS, must be able to generate a torque of at least .

**3.4.3.4 Calculate Wheel Slippage**

The next step is to make sure the VPS won’t experience wheel slip at the assumed conditions,

|  |  |
| --- | --- |
|  | Equation(**YYYYYYY**)[6] |
|  |  |

Where is the max tractive torque (), is the friction coefficient between the wheel and the ground, is the weight on one wheel (), and is the radius of the wheel ().

Solving Equation(**YYYYYYY**), using of 0.6, as , and as 3,

|  |  |
| --- | --- |
|  | Max |
|  | Min |

The wheels will not slip if the following condition is satisfied,

|  |  |
| --- | --- |
|  | Equation(**YYYYYYYY**)[6] |
|  |  |

Solving Equation(**YYYYYYYY**), using the from Equation(**YYYYY**), the from Equation(**YYYYYYY**), and two wheels,

|  |  |
| --- | --- |
|  | At Max Weight |
|  | At Min Weight |

As seen, above wheels will not slip at any weight of the VPS between to .

**3.4.3.5 Calculate Required RPM**

The next and final step is to calculate the RPM required to achieve the desired speed,

|  |  |
| --- | --- |
|  | Equation(**YYYYYYYYY**)[16] |
|  |  |

Where is revolutions per minute, is the maximum speed, and is the radius of the wheel.

Solving Equation(**YYYYYYYYY**), using the of , and of ,

|  |  |
| --- | --- |
|  |  |
|  |  |

As seen, above the motors for the VPS must be capable of , to achieve the desired speed.

**3.4.4 Items Under Consideration**

Now that the required specs of the motor have been calculated, in section 3.4.3, and the most appropriate type of motor has been determined, in section 3.4.1, specific motors can be analyzed to determine the exact motor to drive the wheels on the VPS. To recap, the motor chosen must be capable of producing a torque of at least and . It was also decided in section 3.4.1, that DC brushed motors with encoders are best for the VPS. The following table houses several choices that meet these criteria.

Table XXX - Items under consideration

|  |  |  |
| --- | --- | --- |
| Item ID | Vendor | Description |
| RB-Pol-123 | Robot Shop | The motor is geared with a gear ratio of 19:1. At 12V the motor is capable of 500 rpm and has a stall torque of 5.25 lb\*in. The encoder has an accuracy of 1216 counts per revolution.[17] |
| RB-Cyt-83 | Robot Shop | The motor is geared with a gear ratio of 60:1. At 12V the motor is capable of 58 RPM and has a stall torque of 9.01 lb\*in. The encoder has an accuracy of 180 counts per revolution.[18] |
| RB-Pol-125 | Robot Shop | The motor is geared with a gear ratio of 50:1. At 12V the motor is capable of 200 rpm and has a stall torque of 10.63 lb\*in. The encoder has an accuracy of 3200 counts per revolution.[19] |
| Parallax 28819 | Microcontroller Shop | This motor is geared with a gear ratio of 30:1. At 6V the motor is capable of 82 RPM and has a stall torque of 24.78 lb\*in. The encoder has an accuracy of 1920 counts per revolution.[20] |

**3.4.5 Motor Decision Matrix**

In the following table, the motors from Table **xxx** are analyzed to determine the best type of motor to drive the VPS. The areas of evaluation include position and speed accuracy, stall current, height, length, and community support. With the exception of community support, the values for the categories came directly from the motors data sheet. The qualitative values for community support, were assigned based on how much documentation and example code is available for controlling the motor and encoder.

Table XXXX - Motor raw data

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Motor | Position/Speed Accuracy (Counts Per Revolution) | Stall Current (A) | Height (in) | Length (in) | Community Support | Cost ($) |
| weight | 0.05 | 0.2 | 0.1 | 0.15 | 0.1 | 0.4 |
| RB-Pol-123 | 1216 | 5 | 1.46 | 2.52 | Med | 39.95 |
| RB-Cyt-83 | 180 | 1.8 | 1.46 | 2.24 | High | 22.58 |
| RB-Pol-125 | 3200 | 5 | 1.46 | 2.52 | Med | 39.95 |
| Parallax 28819 | 1920 | 3.5 | 0.48 | 4.32 | Low | 24.99 |

The above table is then normalized by assigning these values 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 (Shown in the table below). The justification for choosing these weights and scores is discussed in section 3.4.6.

Table XXXXX - Motor decision matrix

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Motor | Position/Speed Accuracy (Counts Per Revolution) | Stall Current (mA) | Height (in) | Length (in) | Community Support | Cost ($) | Total |
| weight | 0.05 | 0.2 | 0.1 | 0.15 | 0.1 | 0.4 |  |
| RB-Pol-123 | 3.8 | 3.6 | 3.3 | 8.9 | 5 | 5.7 | 5.3 |
| Cytron SPG30-60 | 0.6 | 10 | 3.3 | 10.00 | 10 | 10 | 8.9 |
| RB-Pol-125 | 10 | 3.6 | 3.3 | 8.9 | 5 | 5.7 | 5.6 |
| Parallax 28819 | 6 | 5.1 | 10 | 5.2 | 0 | 9 | 6.7 |

According to the decision matrix, in Table **XXXXX**, the Cytron SPG30-60 motor is the best option for the VPS.

**3.4.6 Motor Justification**

In the following sections, the criterion for analysis is justified and the scoring system is explained.

**3.4.6.1 Position/Speed Accuracy**

Position and speed accuracy is a measure of how precise the encoder is. The accuracy is measured in counts per revolution of the motors drive shaft. The counts per revolution were converted to a score from 0 to 10 using the following formula:

|  |  |
| --- | --- |
|  | Equation(**YYYYYYYYYY**) |

Where is the accuracy score of the current motor, and is the accuracy score of the highest motor.

The weight for the position and accuracy category was determined to be the least important and was given a weight of 5%, because all the motor encoders have acceptable accuracy.

**3.4.6.2 Stall Current**

Stall current is the current the motor will draw when at max torque. Large amounts of current draw are not desired, because it drains the battery faster and could cause damage to the system. The motor with the lowest stall current is most desirable for this category. Because of this, the lowest stall current score was calculated using the following formula:

|  |  |
| --- | --- |
|  | Equation(**YYYYYYYYYYY**) |

Where is the stall current of the current motor, and is the lowest stall current.

The weight for the stall current was given a weight of 20%. Since all motors being considered meet the minimum specs to move the VPS at the desired speed and acceleration, it was decided that the stall current category should be weighted fairly high to help weed out motors that are just too powerful. Having a motor that is too powerful can make the system very difficult to control[3][4].

**3.4.6.3 Height**

The height of these motors is equivalent to the diameter of the motor since these motors are cylindrical in shape. This category was taken into consideration in an attempt to maximize the space usage on the VPS. Because of this the lowest height was considered the best value, and was calculated using Equation(**YYYYYYYYYYY**):

Where is the height of the current motor, and is the lowest height.

The weight for the height was given a weight of 10%. This is due to the fact that the heights are relatively small compared to the max allowed size of the robot. Although the VPDT would like the motor to be as small as possible, the height does not affect the space as much as the length.

**3.4.6.4 Length**

Much like the height, this category was taken into consideration to maximize the space usage on the VPS. Because of this the lowest length was considered the best value, and was calculated using Equation(**YYYYYYYYYYY**):

Where is the length of the current motor, and is the lowest length.

The weight for the length was given a weight of 15%. The way the motors will be orientated to drive the wheels forces them to protrude into the center of the VPS. These motors are fairly long compared to the available space and so were weighted higher than the height category.

**3.4.6.5 Community Support**

The community support category is a measure of how much documentation is available for the motor in question. To receive a score of high community support the motor had to have a datasheet for the encoder and the motor, as well as example control code for the specific motor and encoder. Motors were given a score of medium community support, if they had a datasheet for the motor and the encoder, but little to no example code. Motors with no datasheet, or datasheets that didn’t include encoder instructions, received a score of low community support. These qualitative scores were converted to numerical scores by assigning values with a score of “high” the value “10”, “med” the value “5”, and “low” the value “0”. The weight of this category was given a weight of 10%. Knowing how to use the components is important to the VPDT. Having the extra support of the community will make it easier to get things up and running.

**3.4.6.6 Cost**

The cost score was computed in such a way that the lowest price received the highest score. Using Equation(**YYYYYYYYYYY**):

Where is the cost of the current motor, and is the lowest cost.

The VPDT weighted the cost category at 40%. The motors are one of the most expensive components of the VPS. In an effort to stay within budget the VPDT decided that cost should be the most important category when choosing a motor, especially since all the motors considered meet the minimum requirements to move the VPS.

**3.5 Servos**

In this section, the process for selecting the servos, that will be responsible for moving the various interactors of the VPS, is explained. The process involves several critical steps. In section 3.5.1, specific servos are selected for analysis. In section 3.4.2, the specific servos are analyzed and a servo is selected. In section 3.4.6, the decision matrices, for the servos, are justified.

**3.5.1 Servos Under Consideration**

|  |  |  |
| --- | --- | --- |
| Servo | Vendor | Description |
| Parallax #900-00008 | adafruit.com | continuous |
| TowerPro SG92R | adafruit.com | 180° |
| TowerPro SG-5010 | adafruit.com | 180° |
| Fitec FS90 | robotshop.com | 180° |
| Fitec FS90R | robotshop.com | continuous |
| Dagu RS001A | robotshop.com | 180° |
| TowerPro MG90S | amazon.com | 180° |

References

[1]<https://learn.adafruit.com/adafruit-motor-selection-guide>

[2]<https://www.modmypi.com/blog/whats-the-difference-between-dc-servo-stepper-motors>

[3]<http://robotoid.com/howto/choosing-a-motor-type.html>

[4]<http://www.ikalogic.com/closed-loop-speed-and-position-control-of-dc-motors>

[5]<https://engineering.purdue.edu/ResearchGroups/DEAR/web/papers/icra_energy>

[6]<http://www2.mae.ufl.edu/designlab/motors/EML2322L%20Drive%20Wheel%20Motor20Torque%20Calculations.pdf>

[7]<http://www.physics.uoguelph.ca/tutorials/torque/Q.torque.intro.html>

[8]<http://www.pololu.com/docs/0J21/5.c>

[9]<http://www.robotshop.com/en/gear-motors-with-back-shaft.html>

[10]<http://www.robotshop.com/en/dc-motors.html>

[11]<http://www.robotshop.com/en/bldc-motors.html>

[12]<http://www.robotshop.com/en/stepper-motors.html>

[13]<http://www.robotroom.com/Jet.html>

[14]<http://www.engineeringtoolbox.com/rolling-friction-resistance-d_1303.html>

[15]<http://www.engineeringtoolbox.com/friction­coefficients­d_778.html>

[16] <http://www.societyofrobots.com/mechanics_dynamics.shtml>

[17] <http://www.robotshop.com/en/pololu-12v-19-1-gear-motor-encoder.html>

[18] <http://www.robotshop.com/en/12v-58rpm-60-1-gear-motor-encoder.html>

[19]<http://www.robotshop.com/en/pololu-12v-50-1-gear-motor-encoder.html>

[20]<http://microcontrollershop.com/product_info.php?products_id=6714&gclid=CJPbloz5kMECFS1k7AodVxsABQ>

[21] http://www.adafruit.com/products/154

[22] http://www.adafruit.com/products/169

[23] http://www.adafruit.com/products/155

[24] http://www.robotshop.com/en/9g-micro-servo-motor-4-8v.html

[25] <http://www.robotshop.com/en/9g-continuous-rotation-micro-servo.html>

[26] <http://www.robotshop.com/en/dagu-micro-servo-motor.html?gclid=CjwKEAjwkrmhBRD49Mbm_MvruWsSJAAEDt13G-69Z3vuZIxbYOs7jOm8PM4qXak4UsvN_YxHLPje_xoCkQTw_wcB#Dimensions>

[27] <http://www.amazon.com/MG90S-Micro-Servo-Helicopter-Plane/dp/B006VRWV1W/ref=sr_1_3?ie=UTF8&qid=1412333109&sr=8-3&keywords=servo>