**Motors**

This section highlights the different motors utilized in the system and which task they are best suited for. Each motor is then specifically evaluated, through tables and analysis, to determine the best motors to use for each given section of the system. Each motor is compared against their type to determine where they belong in the system, and motors of the same type are compared to motors made by different manufactures.

**.1 Motor Types**

The different motors that will be utilized in the system are stepper motors, dc gearmotors, and linear actuators. Each motor has its unique advantages and disadvantages. The following sections will outline the strengths and weakness of each motor and evaluate their role in the system.

**.1.1 Stepper Motors**

Stepper motors are motors that take a digital signal and convert it into rotation. What makes stepper motors unique from other motors, is that one rotation of the motor is broken down into many equal parts, otherwise known as steps. This is to say that for a 200 step motor, the motor will run through 200, 1.8° steps, for one full rotation. This is useful because it allows the system to define the number of steps for the motor to rotate, allowing for very precise positioning of the motor. Stepper motors also allow for very precise stopping and reversing. This is due to the physical fact that when the stepper motor is not rotating, it is still operating and holding the motor at the current step so stopping is immediate. Stepper motors also allows for easy synchronization between motors. Since each motors speed is dependent on the frequency of the input pulse, setting two motors at the same frequency will allow them to work synchronously (1).

**.1.2 Gearmotors**

Gearmotors are very simple motors which are generally used to drive gears as the name implies. This means that, if we consider the transmission in an automobile, they are capable of producing variable power output by either driving large gears at low speed and high torque or small gears at high speed and low torque. For our application we are interested in a simple motor that will turn at a low speed with high torque. While these motor are not as flashy and complex as servomotors or even stepper motors, they are a cost effective and very efficient.

**.1.3 Linear Actuators**

These motors are set apart from the other motors due to the fact that they produce linear motion rather than rotational motion. Linear Actuating Motors, or Linear Actuators, often provide feedback on position and allow for precise positioning. The one major downfall of the linear actuator is that it also requires some sort of decoder and they are naturally very expensive. They are however the only motor in our list that directly creates linear motion rather than rotational motion.

**.1.4**

(Table ?) shows the purpose for each selected motor.



Table ?: A list of the different motors and their purpose in the system

**.2 Stepper Motors**

These motors will be used to drive the wheels on the robot due to their step properties and ability to synchronize. There will be 4 motors total, one for each wheel.

**.2.1 Considered Motors**

(Table ?) shows the four considered stepper motors.

|  |  |  |
| --- | --- | --- |
| Model | Distributor | Description |
| Soyo SY42STH38-0406B Unipolar Stepper Motor | Robotshop.com | A double shafted, 200 step motor. ± 5% Precioson. Maximum torque 36 oz.-in. Operates at 12V DC (2). <http://www.robotshop.com/en/rbsoy07-soyo-unipolar-stepper-motor.html> |
| Soyo SY42STH47-1684MB RepRap Stepper Motor | Robotshop.com | 200 step high torque motor. Holding Torque 4.4 Kg-cm. ± 5% precision (2). <http://www.robotshop.com/en/soyo-reprap-stepper-motor.html> |
| Wantai 42BYGHM809 | Sparkfun.com, Wantmotor.com | 400 step mdeium torque motor. 48 N-cm holding torque. Rated for 3V. ± 5% precision (5). <https://www.sparkfun.com/products/10846> |
| Wantai 57BYGH420 | Sparkfun.com, Wantmotor.com | 200 step medium torque unipolar stepper motor. Holding trque of 90 N-cm. 1/4 in diameter shaft (5). <https://www.sparkfun.com/products/10847> |

*Table ? : List of all considered stepper motors with the distributor and a brief description*

**.2.2 Decision Matrix**

(Table ?) is the decision matrix for determining which stepper motors to use for the robot. Each motor was scored based upon, price, availability, power output, overall size and precision on a 1 to 5 scale. It is important to note that size is an inverse weighting factor, meaning that a score of 5 actually means it is very size effective or small, and 1 would be very large. The same goes for pricing, 5 is the least expensive and 1 represents the most expensive.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Weight | 0.1 | 0.1 | 0.25 | 0.25 | 0.3 |  |
| Model | Price | Availability | Power | Size | Precision | Total |
| Soyo SY42STH38-0406B Unipolar Stepper Motor | 4 | 1 | 2 | 4 | 3 | 2.9 |
| Soyo SY42STH47-1684MB RepRap Stepper Motor | 3 | 3 | 5 | 1 | 3 | 3.0 |
| Wantai 42BYGHM809 | 4 | 3 | 3 | 2 | 4 | 3.15 |
| Wantai 57BYGH420 | 3 | 1 | 4 | 1 | 3 | 2.55 |

*Table ? : The decision matrix for the stepper motors*

The motor which one the decision matrix was the Wantai ROB-10846 which is highlighted in yellow.

The following table is a qualitative decision matrix

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Weight | 0.1 | 0.1 | 0.25 | 0.25 | 0.3 |
| Model | Price | Availability | Power | Size | Precision |
| Soyo SY42STH38-0406B Unipolar Stepper Motor | $15.34 | Out of Stock | Lowest Torque | Very compact | 200 step |
| Soyo SY42STH47-1684MB RepRap Stepper Motor | $25.91 | In Stock | Highest Torque | Very Large, potentially too big for the robot | 200 step |
| Wantai 42BYGHM809 | $16.95 | In Stock | 3rd highest Torque | Large, however should not be too large | 400 step |
| Wantai 57BYGH420 | $23.95 | Out of Stock | 2nd Highest torque | Very Large, potentially too big for the robot | 200 step |

*Table ?: The qualitative decision matrix for the stepper motors*

**.2.3 Justification**

This section defines how the weighting values were selected for the decision matrix and why each element is important in selecting the proper product.

**.2.3.1 Price**

Since we will be using at least 4 stepper motors for our robot it is important that we consider that this means we will be spending four times the cost of one stepper motor for the whole robot. Each motor was given a score of 1-5 based upon which price range it fell in. (Table ?) shows how points were awarded for the decision matrix.



*Table ?: The price weighting scale for the stepper motors*

The motor selected is the cheapest motor available that also satisfies our power and precision characteristics, other motors that cost more money are overkill for our purpose and often are too large to work with our system which is why a smaller more inexpensive motor is ideal for our system.

**.2.3.2 Availability**

This factor is very easy to calculate. The motor we selected is in stock and ready to ship from sparkfun.com which is why it received an availability score of 3. Those items which are from a distributor and out of stock received a 1 due to the much longer wait for the product to be delivered. Since there are not elements already available to our group no motor in the matrix received a 5 for availability.

Availability is important but since we are currently on schedule it is not as vital to receive the parts immediately. This is why for this iteration of the decision matric Availability has a weighting factor of only 0.1.

**.2.3.3 Power**

For this decision matrix the power score for each motor was awarded based upon the maximum torque output for each motor compared to each other. The selected motor is in the middle of all motors considered in the power rating. Since we have no defined requirement for speed in the current version of the SRS, the torque output of the motor has to be higher than the torque required to turn the wheels which will be used in the system. The torque output for selected Wantai motor is 48 N.cm which is more than enough to drive the largest wheels considered for the system. Relating the power to price, the more torque the motor outputs, the higher the cost generally is. Since there is no need to have excessive amount of torque output from the motor we can save money by purchasing a motor with the required power and not an excessive amount.

Power is very important because if the motor is not strong enough, it will not be able to turn the wheels, and if the wheels don’t move the robot is stationary. Since robot movement is a major component of the system, Power has a higher weighting factor of .25.

Each motor was compared to the other motors so points were awarded based upon where each motor fell in the power rankings, for example the highest power output motor received a 4 and the lowest received a 2.

**.2.3.4 Size**

Since our robot is confined to a one cubic foot area size is very important for the motors driving the wheels. The size of the wheel motors directly translates into the width of the robot. Two motors will be used to simulate an axel, so the length of the motor times two is the amount of space they will occupy. If each motor is six inches long it leave no room for wheels or components to be placed in between the motors. This is crucial to the design of the robot which is why the weighting factor for size is the same as the power factor at .25.

As with the other considerations for selecting our motors, we attempted to choose the smallest possible motor which will still preform the required task efficiently.

**.2.3.5 Precision**

Precision is the most important aspect in the decision matrix. These points were awarded based upon the number of steps in each motor. Every stepper motor has a set number of steps per full rotation. The selected motor has 400 steps per revolution compared to all others in the matrix which only have 200 steps per revolution. This means the precision the 400 step motor in full step mode is increments of .9°, opposed to the 200 step motor which is only 1.8°. This is crucial because in the event of the motor slipping steps, the consequences will not be a dramatic or possibly cause the system to fail. For these reasons the precision category had the highest weighting factor at .3.

Points were given based upon the number of full steps in the motor. So a 200 step motor received 3 points, a 400 step motor received 4 points, and if there was a 600 step motor in the matrix it would have received 5 points.

**.3 Gearmotors**

These are the motor that will be used to rotate the arm and any arm attachments. There is a currently an expectation for 3 gearmotors. They were selected for their simplicity in operation and the small sizes offered.

**.3.1 Considered Motors**

(Table ?) is a table containing the three considered products, their distributor and a brief description containing the URL for the item.

|  |  |  |
| --- | --- | --- |
| Model | Distributor | Description |
| Micro Metal Gearmotor 30:1 Shenzen Kenmore KM-12FN20-30-06430 | Sparkfun.com | A small gearmotor with a 30:1 gear ratio. Roughly 1in by 1.5 in. Operates at a 430 rpm at 6 V (3).  <https://www.sparkfun.com/products/8911> |
| Micro Gearmotor ROB-12285 | Sparkfun.com | A small gear motor that operates at 45-90 rpms at 6V-12V respectively (3). <https://www.sparkfun.com/products/12285> |
| Cytron 12V 12RPM 166oz-in Spur Gearmotor | Robotshop.com | A gear motor that operates at 12 rpm max with 1.1 N-m output torque (2). <http://www.robotshop.com/en/cytron-12v-12rpm-166oz-in-spur-gearmotor.html> |

*Table ?: A list of the potential Gearmotors, their distributor and a brief description*

.**3.2 Decision Matrix**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Weighting Factor | 0.5 | 0.3 | 0.1 | 0.1 |  |
| Model | Size | Power | Price | Availability | Total |
| Micro Metal Gearmotor 30:1 Shenzen Kenmore KM-12FN20-30-06430 | 1 | 1 | 3 | 1 | 1.2 |
| Micro Gearmotor ROB-12285 | 3 | 2 | 2 | 2 | 2.5 |
| Cytron 12V 12RPM 166oz-in Spur Gearmotor | 2 | 3 | 1 | 2 | 2.2 |

*Table ? : The decision matrix for the Gearmotors*

(Table ?) shows the decision matrix for the potential gearmotors and the highlighted row represents the motor that was selected from the results of the decision matrix. Each category was scored on a scale of one to three. This was done because the specifications of each motor were so close that any sort of scaling would cause each motor to receive and identical total score. For this matrix every motor was ranked according to its relation to the other two motors.

The following table is a qualitative decision matrix

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Weighting Factor | 0.5 | 0.3 | 0.1 | 0.1 |
| Model | Size | Power | Price | Availability |
| Micro Metal Gearmotor 30:1 Shenzen Kenmore KM-12FN20-30-06430 | Smallest | Lowest Power | $9.95 | Out of Stock |
| Micro Gearmotor ROB-12285 | Largest | Middle | $12.95 | In Stock |
| Cytron 12V 12RPM 166oz-in Spur Gearmotor | Middle | Highest Power | $15.48 | In Stock |

*Table ? :The qualitative decision matrix for the gearmotors*

**.3.3 Justification**

This section defines how the weighting values were selected for the decision matrix and why each element is important in selecting the proper product.

**.3.3.1 Size**

When selecting the gear motors for our robot size was determined to be the most important factor. This is because the motors will be used to rotate small components in the arm and claw of the robot so for this scenario smaller is better. This is why the size factor is represents half of the total matrix score. As stated earlier every motor in this matrix is very close in dimensions and specifications so they were ranked according to their relative size to one another. The motor that was selected for our design, the Micro Gearmotor form sparkfun.com, was the smallest and this gave it a large lead over the other motors in the decision matrix and is why it is the motor we selected.

**.3.3.2 Power**

For the selection of gear motors, power was not nearly as important as it was when selecting the stepper motors to drive the wheels of the robot. This is because these smaller gearmotors at most will have to either rotate a Rubik cube row or twist and etch-a-sketch knob which requires much less torque than powertrain of the robot. However it is still important that the motor outputs enough torque that is doesn’t burn itself out when attempting to rotate components of the challenges. This is why the power weighting factor was set a .3 which made is the second most important factor by 20%. All motors in the given selection possess the power required to complete the challenges, however selecting a small motor that has more than enough power is a much better option than selecting a motor that can barely complete the task at maximum output.

**.3.3.3 Price**

As with every component selected for any system, price is always a deciding factor. For each of the motors selected the prices were all within five dollars of each other. This is why they were ranked relative to each other. Gear motors are relatively inexpensive and a single gear motor will cost less than twenty dollars, however we will need multiple gearmotors so the prices is more of a factor.

**.3.3.4 Availability**

When ranking each motor for availability, they were either given a three is the motor was already in our possession. Unfortunately we do not have any gearmotors in our possession so we will have to order them. If the product was available from a distributor and in stock it received a two and if it was not in stock it received a one. AS mentioned with the stepper motors, availability is important because the faster the motors are available, the sooner prototyping can begin and this ultimately leads to meeting deadlines.

**.4 Linear Actuators**

Linear actuators are motors which electronically drive pistons forward and backward, opposed to the other motors which rotate a drive shaft. These motors are particularly useful for pushing things which is why we decided to use them in the arm of the robot. This will allows the robot to push buttons on challenges and better position the height of the arm.

**.4.1 Considered Liner Actuators**

(Table ?) is a table containing the three considered products, their distributor and a brief description, containing the URL for the item.

|  |  |  |
| --- | --- | --- |
| Model | Distributor | Description |
| Firgelli Technologies L12  Actuator 50mm 210:1  12V Limit Switch | Robotshop.com,  store.firgelli.com | The 50mm stoker length actuator in  the Firgelli line of miniature linear  Actuators. Capable of 5mm/s  movements speed, with no load,  and a peak force output of 45 N (5).  <http://www.robotshop.com/en/firge>li-technologies-l12-actuator-50mm  210-1-12v-limit-switch.html |
| Firgelli Technologies L12  Actuator 100mm 100:1  12V Limit Switch | Robotshop.com,  store.firgelli.com | This motor is in the same series as  the above motor but with a 100mm  stroke length. Capable of 8mm/s  no load speed, and a peak output  force of 23N (5).  <http://www.robotshop.com/en/firge>  li-technologies-l12-actuator  100mm-100-1-12v-limit  switch.html |
| Firgelli Technologies  L16 Linear Actuator,  140mm, 35:1, 12V w/  Limit Switches | Robotshop.com,  store.firgelli.com | This motor is a larger model of the  two previous linear actuators. With  140 mm stroke length and a higher  no load speed of 32mm/s (5).  <http://www.robotshop.com/en/line>  r-actuator-l16-140-35-12-s.html |

*Table ?:A List of the potential linear actuators, their distributor, and a brief description. The selected actuator is highlighted*

For these actuators, and as evident in the (Table ?), Firgelli motors has the most options when it comes to miniature linear actuators at a reasonable price, this is why all of our choices are from Firgelli Technologies. Each motor has a price of $70 USD.

**.4.2 Justification**

For these linear actuators there is no decision matrix. Since every motor is the same motor with varying size, this is the only thing we have to choose our motor. Each motor costs exactly the same amount and they are all available and in stock form both Roboshop.com and directly from Firgelli Technologies. The specifications for force output and speed of the actuators is directly related to the stroke length of the motor which is why there is some variation in speed and force output of the motors. Ultimately the only deciding factor in selecting our linear actuator was size.

**.4.2.1 Size**

Initially these three motors were considered for our project, however upon further consideration, it was determined that the 100mm and 140mm actuators would just be too large to fit the system. If a decision matrix were to be created the weighting factor for the size of the motor would have to be the main consideration and essentially remove the two larger motors form the selection process.

Our robot arm is intended to hover above the challenges and operate by moving up and down to complete the nectary tasks. The 100mm motors and 140mm would not allow us any room to raise the arm. This is because the resting length of the motor is the stroke length. This means that the 100mm stroke length motor, cannot retract more than 100mm but can extend out to 200mm. When we consider that this is nearly eight inches, and our robot cannot be taller than one foot, it drastically reduces the amount of space we have to work with and would physically not fit in the system. And if the 100mm motor is too large than the 140mm motor is also too large for the robot.

**.4.2.2 Price and Availability**

All three linear actuators go for the exact same price at both distributors. This is another reason why we decided not to complete a decision matrix. Considering how expensive linear actuators are price was a very important factor in choosing our linear actuator, however, the Firgelli motors were the most cost effective motors and also happened to provide everything we need. Almost all of the more expensive motors were way to large and output too much power.

Since they are all the same cost that row of the decision matrix would be null and void anyway. This also goes hand in hand with availability because they are all sold by the same company and distributor and are all in stock they all have the same cost and availability.

**.4.2.3 Power**

The L16 linear actuator is the only actuator that has a larger driving motor out of the three selected however as mentioned earlier its size eliminated it from use in the robot. The two other actuators, the 50mm and the 100 mm L12 actuator, both have the same driving motor, it is the piston length and weight that causes differences in the output speed and force. Since we selected the smallest motor the shaft length is the shortest translating into the highest output force. This also means that it has lower speed, but for this project speed is not as necessary as power. Fortunately, the smaller actuator which fits the robot design has the higher force output.

**.4.2.4 Final Decision**

As already mentioned the only feasible linear actuator is the Firgelli 50mm L12 linear actuator, due to its compact size and relatively high pushing force. Due to a lack of vendors that sell affordable, miniature linear actuators, all of the considered motors were from the same family of Firgelli Technologies miniature linear actuators, removing the need for a decision matrix. In conclusion the only linear actuator we found that will satisfy all our needs is the Firgelli Technologies L12 Linear Actuator 50mm.

**.5 Requirements Traceability**

Several of the requirements for our robot pertain directly to the functionality of the motor. (Table ?) lists the requirements and how the system will validate the corresponding requirement.

|  |  |  |
| --- | --- | --- |
| **ID** | **Requirement Text** | **Fulfillment** |
| **3.1.1** | **The system shall move in the two-dimensional playing field** | **The stepper motors will rotate the wheels of the robot giving it mobility across the playing field** |
| **3.3.3** | **The system shall play the Simon carabineer** | **The linear actuator and the gearmotors in conjunction will create an arm with rotating and horizontal movement, allowing the robot to push all button on the Simon Carabineer** |
| **3.3.4** | **The system shall twist one row of a Rubik’s cube 180 degrees** | **The linear actuator will lower a claw onto the row of the Rubik’s cube and a gearmotor will then rotate the claw with the single row of the Rubik’s cube** |
| **3.3.5** | **The system shall draw “IEEE” on a Pocket Etch-A-Sketch** | **The linear actuator will lower claw like devices onto the knobs of the etch-a-sketch allowing the robot to turn the knobs and draw on the etch-a-sketch** |
| **3.3.6** | **The system shall collect a single playing card** | **The Linear actuator will give the arm the ability to press down on the top card of the deck where an adhesive will grab the card and, then the actuator will move the arm back up so the card can be carried** |

*Table ?: A table identifying how requirements pertaining to the motors will be handled. The ID is the requirement number from the SRS, followed by the actual requirement text and how the motors will validate the requirement.*

**.6 Risk Analysis**

As with any part in a moving system, there is a possibility that the components may fail either catastrophically or otherwise. (Table ?) defines several of these cases assigning each a probability and severity score from 1 to 10, 1 being the lowest and 10 being the highest. It also provides ways to mitigate the associated risks.

It is important to note that for (Table ?) the severity score references the damaging effects to the system and how hard it will be to correct. Although there are some physical risks involved they are very minor if the proper precautions are taken. The following table is not intended to evaluate these circumstances

|  |  |  |  |
| --- | --- | --- | --- |
| **Risk** | **Probability** | **Severity** | **Mitigation of Risk** |
| **Overheating** | **5** | **6** | **If a motor is run too long or it drawing too much current, the physical temperature of the motor will increase and could potentially cause the motor to fail or a fire hazard. In order to reduce the probability of the motors overheating, and potentially creating a fire hazard, it is most important to ensure that the motor is wired correctly into the system. This prevents motors form drawing extreme amounts of current and causing the motor to overheat. Since stepper motors constantly draw current it is unavoidable that they will heat up, by ensuring they are only on when in use we can mitigate the probability of catastrophic overheating** |
| **"Burning out" a motor** | **3** | **7** | **If the motor is forced to drive a load that is too large or the motor is physically blocked from rotating, the internals of the motor will fail and it will no longer function properly. In order to reduce this risk we will calculate all loads for the motors prior to assembly and ensure that each motor can handle the load that it will be driving. We will also test extensively to ensure that all components are free to move and there are no errors in programing that would force a motor through an invalid range of motion. If this were to happen the only way to fix it is to replace the motor with a working motor.** |
| **Becoming Askew** | **6** | **2** | **While the robot is moving or during construction, it is very possible that a motor could be knocked askew. This will cause many problems. If the wheels are not aligned there will be slipping and the precession of motion will be decreased. If the actuators or the gearmotors in the arm become askew, the robot may not be able to complete a challenge or complete a challenge incorrectly. If this happens it is very simple to fix because we will simply remount the motor in the correct position. WE can mitigate this risk by securely mounting all motors and ensuring that they do not interfere with one another** |

*Table ?: A table describing the risk analysis cases for the motors, with a probability and severity score ranging from 1 to 10. 1 being the lowest and 10 being the highest. The table also includes ways to mitigate each risk.*