MSE 2202: FINAL REPORT

Team #5

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Executive Summary:

This report provides an in depth analysis of the process used to construct a mechatronic device with desirable functions. The major sections include the introduction to the overall goal of the project, discussion of the process, alternative concepts and prototype adjustments, performance of the final design, and recommendations. The general objective of this project was to create a mechatronic device that would autonomously identify and manipulate tesseracts. In order to begin creating a solution, objectives and constraints were formulated. Utilizing the aforementioned designs and constraints a preliminary design was created which would meet the overall goal of the project. During construction a series of iterations were then developed based on feasibility and required functionality of each part. A final prototype was chosen and was adjusted based on various tests that were conducted, resulting in the final design.

Introduction

The overall goal of the project was to build a mechatronic device using a combination of vex, printed and laser cut parts, with the ability to identify and manipulate tesseracts. To meet this goal the group also had to consider if they were following the design objectives and constraints. The device had to be able to operate autonomously, identify and pick up tesseracts, navigate the designated area without collisions, fit inside an MSE locker, and made using materials within the assigned budget. Throughout this report the roles of gravity and torque, sensors and the redesign process are crucial for creating a successful mechatronic device.

The final iteration consists of a round acrylic base which all the components are attached to. Three wheel wells are cut out of the base to allow space for integrated encoder vex motors, which rotate omnidirectional wheels. The Arduino is mounted onto the base on an elevated platform, making room for a battery. The arm is also made out of acrylic and folds to allow the device to reach short and long distances. To operate the arm and hand a cog and chain system is used to reduce the amount of weight on the arm, reducing the moment. Hall Effect sensors are attached to the base which enable the device to identify the tesseracts, while ultrasonic sensors are used to navigate the area and avoid collision. Lines sensors were also used on both the base and the hand to further assist in navigation and placement of the tesseracts. This reports discusses and describe the preliminary design, iterations, final design and why these specific modifications were necessary, and how they would eliminate undesirable results. Knowledge of conservation of gravity and torque allowed for effective refinement of the preliminary design, which will be discussed throughout this report.

This report includes sections discussing the details, evidence, and data needed to understand the development and evaluation of the process. A detailed description of the preliminary design and the iterations that were developed during the construction and implementation of different functionality. Different aspects of the prototype was tested and various adjustments were made during this phase, each having varying impacts on the devices performance, which will be explained. Throughout the following processes many lessons are highlighted, including the use of previous knowledge and performance to redesign a product.

Problem Definition

Problem Statement

Design an autonomous robot that can collect "good" tesseracts and manipulate them for subsequent use.

The team came up with objectives and constraints in order to define the project. These objectives and constraints were used as a guideline to generate several concepts to fit the given criteria. Many of the constraints and requirements were outlined in the project description, however the team came up with additional points in order to generate an optimal design.

Objectives:

The following objectives were used as a guideline while generating concepts and the final design:

I. **Energy Efficient:** The devices should be able to operate within the energy budget of the battery provided. This means that the motors should be able to handle the weight of the robot with the given power that is supplied. Also, this would limit our use of motors and other energy consuming components.

II. **Easy to use:** The device should be easy to use such that it is autonomous and can be easily switched between modes. The device should be coded such that mode 1 and mode 2 can be switched with a push button or a switch.

III. **Feasible to Build:** The device should be designed such that it is feasible to build within the time frame and resources given. It should also be feasible to code with our current knowledge of sensors and electronic components.

IV. **Collision Avoidance:** The device should be able to avoid colliding with the walls of the track and other devices that are operating within the area. This will allow for all the devices to operate smoothly. It will also allow the robot to continue operating as it should without the disturbance of crashing into another device.

V. **Speed:** The robot should move at a moderate speed allowing it to sense the tesseracts accurately as well as other robots. If the speed of the robot is too fast, the sensors may not be able to react quick enough to actually sense the tesseract, An extremely fast robot will also make it hard for the robot to run smoothly and may take up an excessive amount of energy.

VI. **Reliable:** The device should only collect “good” tesseracts that contain a magnet while avoiding picking up “bad” tesseracts. This is the purpose of the robot. The robot should be able to pick up the the tesseracts and deliver them to the given platform. The platform is shown in **APPENDIX.** In mode 2, the robot should also be able to place the tesseract on a vex part that is 43cm above ground.

VII. **Durability/Robust:** The product should be able to last through all of the testing in most environments without needing maintenance. The robot should be made such that it is sturdy. This will add on to the reliability of the device. Also, the robot must be able to complete the given task without needing to be adjusted or fixed.

<u>Constraints:</u>

The following is a set of limitations and restrictions that help shape the design and concepts:

I. **Manufacturing Cost:** The device should not exceed the maximum manufacturing costs of the $50 for the electronic components, $80 for rapid prototyping and $100 for additional components. This was the budget given by the project instructions.

II. **Dimensions:** The device should fit through an opening of 19x25 cm in order to go under the structure and place the tesseract at the top. The structure can be found in **APPENDIX.** The device must also be able to fit Inside the MSE locker with the dimensions of 17cm x 10cm x 18cm. This will allow for easy storage of the device.

III. **Weight:** The device should be lightweight such that it is less than 10lbs. Having a lightweight robot will help save power and help motors run more efficiently. The device must be designed such that the motors are able to withstand the torque.

IV. **Functionality:** The apparatus should pick up at least 3 “good” tesseracts in the time period specified (2-3 minutes). The apparatus must be able to recognize where the “home” position is and deliver the tesseracts accordingly.

V. **Energy Usage:** The device should be able to operate with the 9V battery provided.

Evaluation

Concept generation

The general problem statement for this deliverable was to design an autonomous robot that can collect "good" tesseracts and manipulate them for subsequent use. More specifically, the device was to operate in two different modes; on the first mode the robot had to located "good" tesseracts, pick them up, and place them on a correct slot on a low platform; after collecting at least three, it should switch to mode two, take the tesseracts collected and place them, one by one, on an elevated surface.

After clearly stating the design objectives and goals, the team started developing concepts geared to towards solving the problem. Since the robot was not to exceed 19cm in height, but still be able to reach up to 43cm, it was clear that mode 2 would require some sort of stretching of the robot. This could be achieved in several ways, by moving the device's wheels upward, or having it stretch its arm, etc. Other aspects that was kept in mind throughout the concept generation were the feasibility of the coding of each concepts, as well as how it would navigate inside the provided track.

Out of the twenty concepts that were developed, the top four, most feasible ideas were the following:

a) Non-flexing long arm plus magnet:

This first concept consisted of a 43x15cm rectangular base with a long, rigid, 43cm long arm that lays horizontally across the body of the robot for mode 1, and lifts up 90° from its initial horizontal position for mode 2, so that it is able to reach the raised platform.

At one end of said arm, extruding from the box, it would have a claw as well as a magnet. The magnet would be attached to a retractable flap so that when it is time to let go of the tesseracts, the magnet is pulled away and the magnetic bond is successfully broken. The idea behind having both grips is that the magnet would be responsible for collecting the "good" tesseracts, while the claw would hold on to the blocks, making sure that the magnetic field is further weakened as the flap is moved back. Moreover, having a claw would theoretically add accuracy to the "dropping" phase in mode 1, because, it would be programmed to lay the block at the desired position and gently open its grip to position it in place. The claw was also designed to act as a barrier in between the magnet and the tesseracts, it would be equipped with a stretchable screen along its clippers so that the magnet and the blocks never come directly in contact with each other. This facilitates the removal of the tesseracts.

This concept uses two regular wheels to navigate itself; each of them placed on either side of the rectangular base. The sensors that this device would use to detect the magnets as it moves along the track are Hall Effect sensors. They would be strategically placed at the base of the robot and facing downwards.

b) Foldable arm:

The base for this concept is similar to the one mentioned above. However, it would use an arm with bends instead of a rigid one. The bend would be easier to manipulate as the height does not have to be constrained to a specific length (43cm in height), it is customizable to whichever height is needed. Another thing different with this concept is that it would only have one claw, without a magnetic flap. To make up for the lack of extra grip, the claw would have 360° wrist movement so it can pick-up and drop at any position needed.

To detect whether or not the robot successfully picked up an object, an infrared sensor would be installed on the arm, so that after the collecting motions are done, the claw automatically moves towards the Infrared and positions the object within the sensor's range so that it will make a reading that allows the system to confirm is the mission was successful or not. If it was not, the robot would be programmed to try again.

The main issue that was encountered with this idea was that having a flexible arm plus a moving wrist and claw would require a lot of motors, and would therefore add more weight to the structure, thus making it unable to lift itself up when needed.

c) Box holder plus magnet

This model incorporates a combination of the first two ideas. The base would still be rectangular and use two wheels on each side for its motion. The main difference is again on the arm, this concept has a bending arm that also has wrist movement, however, instead of having a claw, and it works solely with a magnet and a screen that prevents tesseracts from coming into direct contact with it. The main original feature about this idea is that once tesseracts are collected, the claw would drop them into a small container located on the front of the robot. After hoarding the desired amount of objects, it would drive to the platform and collect them from its container to place them on top of the platform.

d) Rigid arm

This concept would work with a single rigid arm that extends upward so it can vertically reach the required 43cm. For this concept the magnet was taken out again, and the wrist movement was also considered an asset, as the hand would need to bend backwards 180° from its initial horizontal position, after it goes through the "H" opening, so that can position the tesseracts correctly.

This model would have a Hall Effect sensor built into the inside of the claw so that it can automatically determine if it successfully picked something up or not. For navigation, an Ultrasonic sensor would be placed on the front of it so that it can detect the wall it is approaching and turn when it is at the appropriate distance. The Ultrasonic sensor would also be used to avoid collisions with any other robots that come in front of it.

Drawing for each concept can be found on Appendix I.

Concept Selection

In order to narrow down the number of concepts from twenty to four, Go/No-Go Screening and a decision matrix were used. The criteria used to assess each of the concepts on the Go/No-Go screening were inspired by the project constraints. Besides being able to sense, pickup, and drop off the tesseracts successfully, the selected concept had to be small enough to fit on the opening of the “H” structure (19x25cm), be able to reach to the top of the structure (43cm high), be feasible and budget friendly to build, plus simple enough to code considering time and skill limitations. All twenty concepts were put through the screening and only the ideas with all “Go” were put through a decision matrix.

For the matrix, the same criteria as before was used, however, before evaluating each idea, each constraint was given a specific weight to determine which one was the most important. The top three, most important ones were that it met the dimensions, can reach to the top of the surface of the platform on mode 2, and that it can sense/pick and drop good tesseracts. After this determination, the concepts were compared to the “Non-flexing long arm plus magnet”, and they were assigned a 1 if they surpassed this concept on the specified category, a -1 if they were not as good, and a 0 if both satisfy the criterion equally. In the end, the “Non-flexing long arm plus magnet” was the winning concept.

A copy of the Go/No-Go Screening and the decision matrix can be found on Appendix II.

Prototype development (Iterations)

Original Concept

As described earlier, the winning concept was the "Non-flexing long arm plus magnet" however once the prototyping stage began, it became clear that the dimensions selected for the original, rectangular base, would become too large and bulky for the "H" opening on mode two as the rest of the components were added. Iterations were not only made to the base, but also to the arm, grip and motion design, as well as the type of sensors that the robot would use. Below is a summary of all the different iterations that the final concept went through.

Base Modifications

After conducting some research, the regular wheels were changed to be Omni wheels. In order to get full benefits of the Omni wheels, the design was changed to use 4 Omni wheels, allowing for multi-directional movement. Further research showed that 3 Omni wheels would be better as they are more reliable on uneven terrain. Another benefit of using 3 Omni wheels, is that there is one less motor being used and one less wheel, this ultimately saves budget and time. This led to our final design of the base. To get the most effective movement, the Omni wheel were situated in a triangular fashion, where each wheel sits at the vertex of an equilateral triangle (120 degrees apart). The triangle was dimensioned such that it would be able to fit inside the opening of the structure that the device must go under in mode 2.

Further modifications were made to the new triangular base, such that the wheels sat under a circular platform. This gave space to put the battery and the microcontroller. It also provided more space to situate the arm on. The circular base

Arm Modifications

After doing some quick testing, it became clear that having a rigid arm was not easy to prototype. It would require precise measurements to ensure that, when lifted 90° from the horizontal, the arm would be at the right distance away from the "H" platform for mode 2 to put the tesseracts on it. Moreover, since the shape for the base changed from a rectangle to a circle, the long arm was now extruding far away from it. It would be challenging to pick up a tesseract that was sensed a few centimetres behind the hand. It was decided that the arm would inevitably need to have bends along it. This would not only facilitate the collection of the tesseracts in mode 1, but it would also give more flexibility of position for mode 2, the robot would no longer need to be exactly at a right position, but it could adapt to different ones.

Each component of the bending arm would have independent motion, therefore a servo motor would be placed at each bend to provide rotation. In total, the arm would have two motors, one to control its lower component, another to control the second component. However, as more motors and parts were added on the furthest end of the arm to create the hand of the robot, the weight surpassed the motor's strength and made it unable to lift it upward. Moreover, the distance of the fully stretched arm generated a larger moment of inertia.

In order to conserve the independent motion of both components of the arm it was necessary to move the extra weight towards the base and away from the robot's hand. To achieve this, sprockets and chains were added to the design. A motor would move a sprocket, which would turn the chain and lift the bottom portion of the arm. A different motor would spin another sprocket which is attached to the second portion of the arm and allows it to move as the chain turns.

Figures 1A-C shows a clear image of the final arm prototype after several iterations.

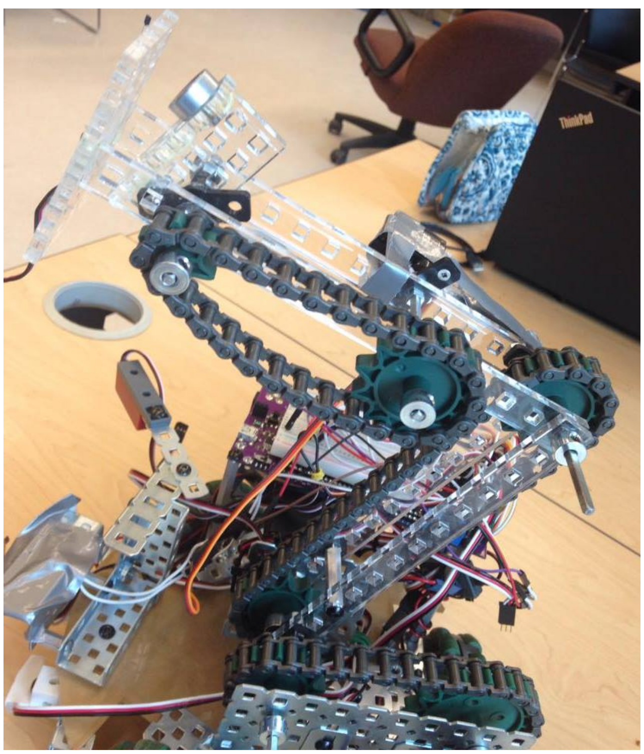


Figure 1A. Arm side view

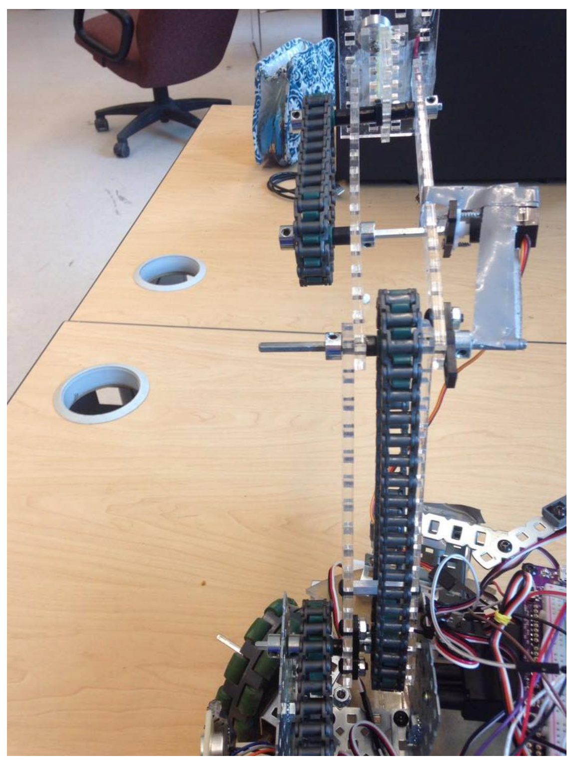


Figure 1B. Arm back view

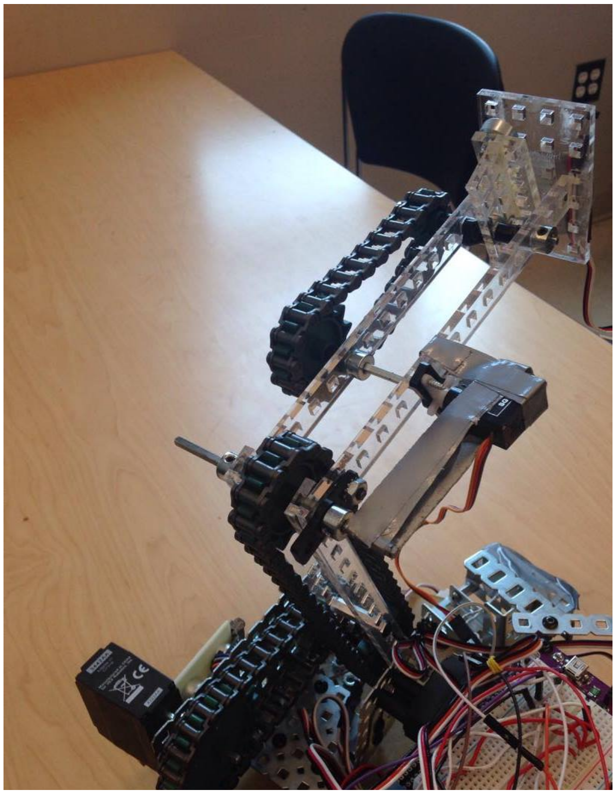


Figure 1C. Arm isometric view

Grip Modifications

The device was originally constructed with a grip that had a claw, a servo motor, a magnet, a screen and a Hall Effect sensor. However, during testing, it was evident that this created too much weight, and the motors could not lift the arm. In order to adjust this, all VEX components of the arm were removed along with the claw and the large servo motors. It was concluded that the claw was not needed and added unnecessary weight because the magnet could do the job of holding the tesseract. Furthermore, the Hall Effect was changed to an infrared sensor so that the magnet would not interfere with the sensory. However, it was later discovered that the infrared had to be 4 cm away from the object and the infrared added too much weight to the grip. As a result, the infrared was changed back to a hall effect. Now, the Hall Effect could be used before the magnet was rotated to pick up the tesseract. The Hall Effect can sweep the ground in order to detect the tesseract, and then the magnet would pick up the tesseract. Finally, a pulley system was added in order to reduce the amount of torque that the servo must create in order to separate the magnet and the tesseract. The pulley system was created with a large gear attached at the motor and a small gear attached at the magnet, this allowed for a greater range of motion.

Figure 2A-C show a clear image of the final grip prototype.

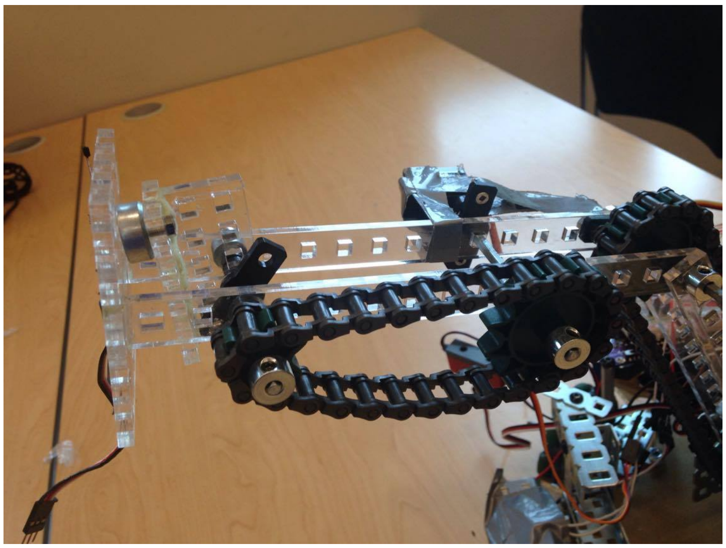


Figure 2A. Grip Side View

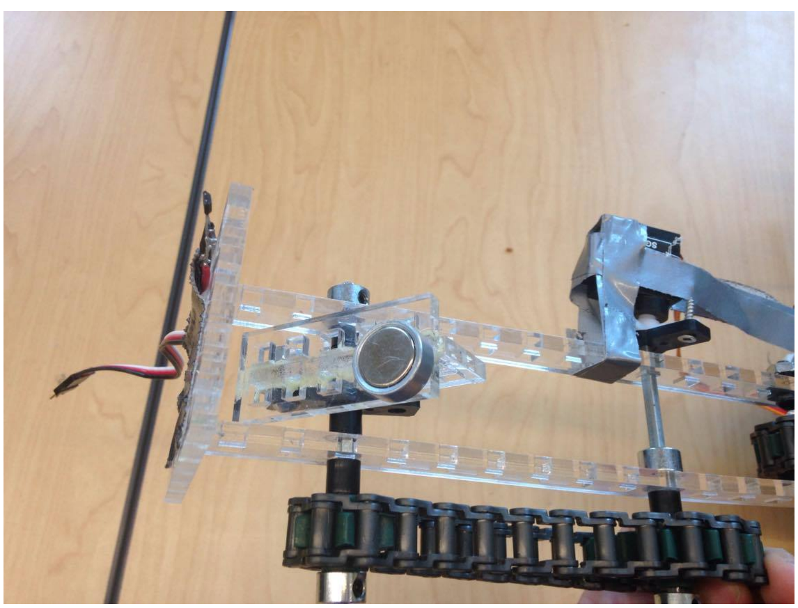


Figure 2B. Grip top view

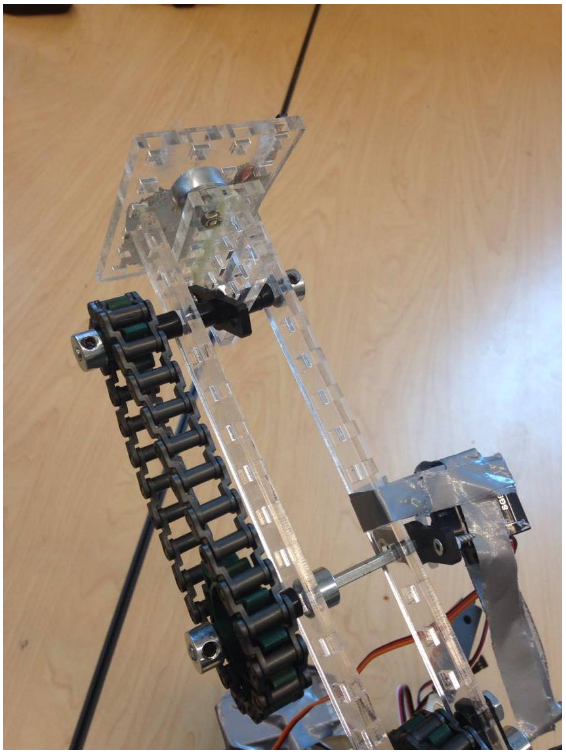


Figure 2C. Grip isometric view

Motion Modifications

The device was to move along the walls of the track and towards the center at first. This was later modified as it would be hard to keep track of the turns as the device got closer to the center and further from the walls. It was therefore decided that the device should always keep contact with the walls, as this is where the ultrasonic sensors get all their information from. This is why the path movement for the robot would be straight from wall to wall, turning left or right, depending on which side of the room it starts moving from. For a clearer image of what the robot's path should look like see Appendix III.

Description of Prototype

Hardware

Driving system

This autonomous device uses omnidirectional wheels which allow it to turn smoothly and with minimum amounts of friction. The perpendicular rollers they possess along the surface make them more efficient than regular wheels, and since bouncy motion could interfere with the handling of the tesseracts (the robot could accidentally drop them), effortless motion is greatly preferred. This also allows for easy multi-directional motion, allowing the device to effectively and efficiently move about the track. The vex wheels used are shown in the figures below.

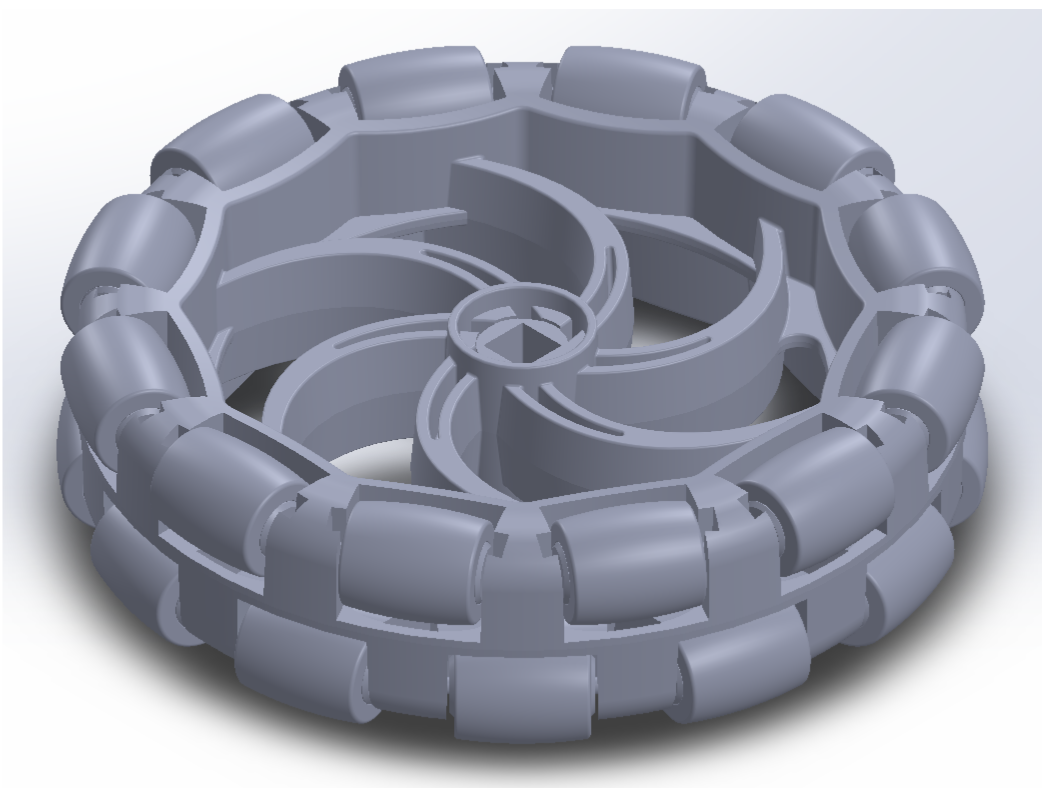


Figure 3A. Omni Directional Wheels

Base

The base for this robot is a circle of 22 cm in diameter; it has three rectangular openings on its circumference that house the Omni-wheels. Each cut is set 120 degrees apart so that the wheels are able to move straight with no issues. The base has 12 holes on one side, this makes it compatible with VEX parts; as a result, adapting and attaching the arm using extra components was not as complicated.

The three motors that power each wheel are located directly under the acrylic base. Because acrylic is stiff, it prevents the wheels from shifting and ensures that they are all properly aligned. The design of the prototype's base is shown in the figures below.

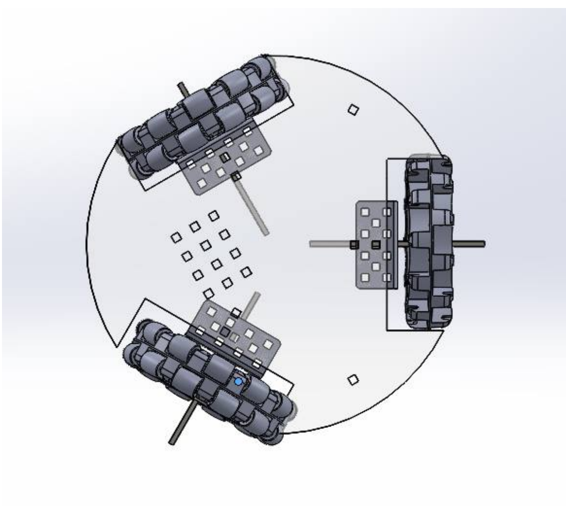


Figure 4A. Base Top View

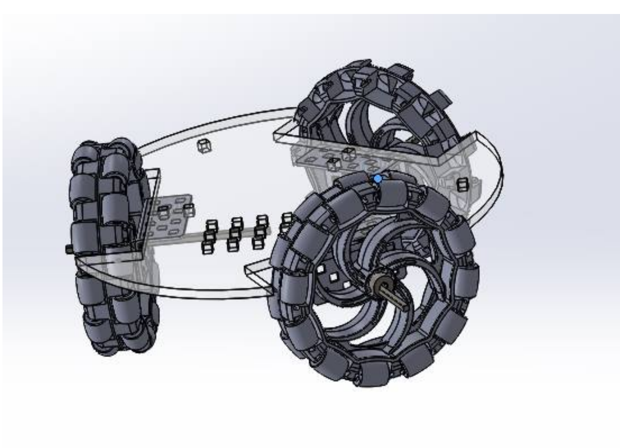


Figure 4B. Isometric view

Arm

The arm is made of acrylic as well as it is a light material but also strong and rigid. Each component of two-bend arm is a rectangle of 190 mm long and 15 mm wide. It is designed to work in collaboration with VEX components which is why they have holes along its surface. A system of chains and sprockets provide movement to the lower part of the arm and another set of these components allow the second part of the arm to move independently from the bottom half. The chain and sprocket allow the motors to be localized at the base which prevents the arm from getting too heavy. The motors used to power the arm movements are VEX EDR 393, with a torque of 1.67 N.m.

In order to maximize the torque from the arm base's motor, a big sprocket was attached directly to the motor and chained to a smaller gear which rotates the base of the arm; the different size sprockets allow for small angle variations from the servo to have a big effect on the arm's motion. In order to keep the length of the chain constant, the sprockets were installed along the arms and fixed into place using square shafts and other VEX components. The arm is shown in figure 5.

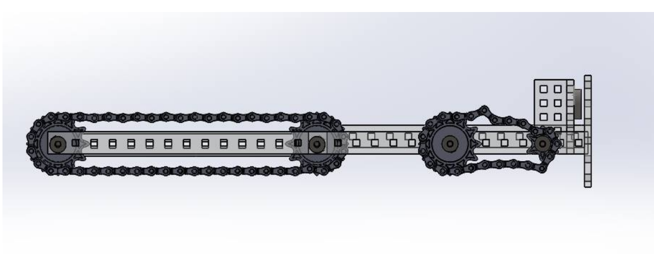


Figure 5A. Arm side view

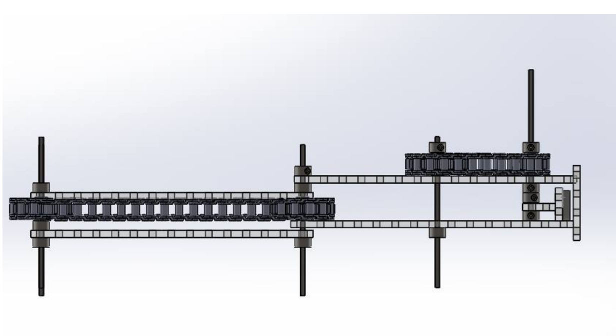


Figure 5B. Arm front view

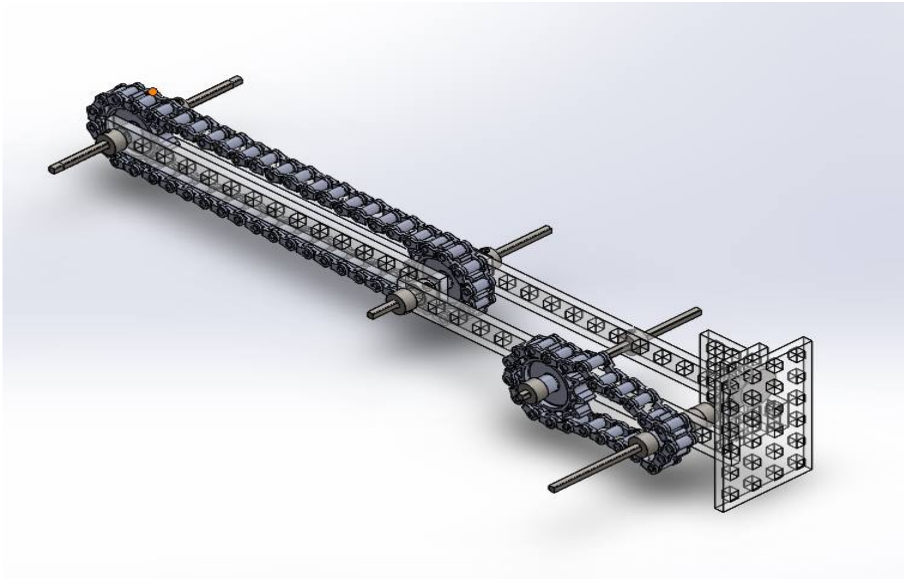


Figure 5C. Arm isometric view

Grip

The grip of the devices serves as the component that picks and drops the tesseract. It is designed with acrylic parts, a rare earth magnet, a mini SG-90 9G servo and a pulley system. An acrylic rectangle is attached at the end of the arm. The acrylic rectangle is 75.6 mm by 50.4 mm. The acrylic rectangle was cut and designed to be VEX compatible so that future iterations could be made if more components needed to be added using VEX. It serves as a barrier between the magnet and the tesseract. This allows the magnet to be pulled away from the tesseract, separating the two components when necessary. The acrylic material is light and also significantly reduces the force between the magnet and the tesseract, allowing for easy separation between the two. This allows the design to use a weaker, but lighter servo (the mini SG-90 9G servo). Having the lighter servo helps the overall design of the device because it reduces the torque that the motors at the base must create. To further reduce the torque needed, a pulley system was used with a large gear attached at the servo and a small gear attached at the magnet. This allowed for a greater range of motion and reduced amount of torque needed. The magnet is also screwed to an acrylic material designed with VEX dimensions. The magnet has a force of 9lb allowing it pick up tesseracts from a distance of about 2 inches with the acrylic barrier between the two. Other specifications of the magnet can be found in APPENDIX IV. All the acrylic material was attached together using resin bond. The design of the grip is shown in figure 6.

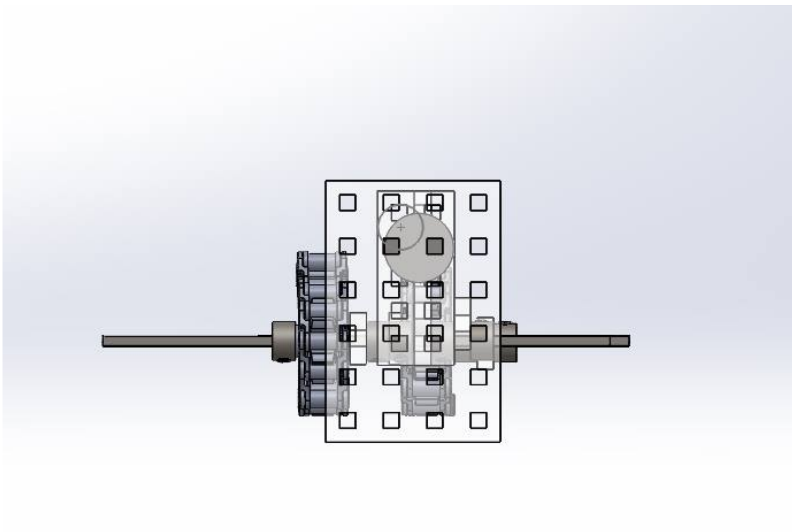


Figure 6A. Grip front view.

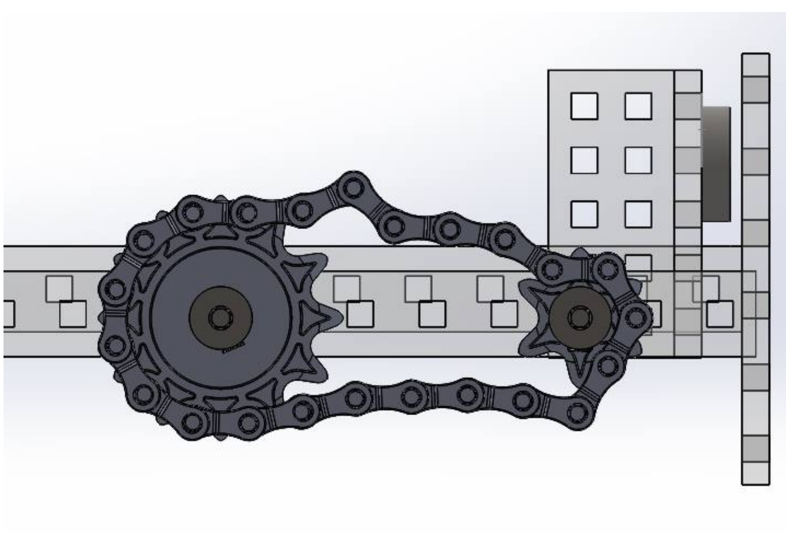


Figure 6B. Grip Side view

Software and Circuitry

Sensors

Hall Effect:

The device is equipped with a total of four Hall Effect sensors to determine the proximity of magnets. Three of said sensors are located at the front of the robot and attached at the base. Their job is to locate and inform the system of the presence of magnetic tesseracts for their recollection. The range of these sensors is about one inch, therefore they must be as close to the ground as possible for them to successfully detect the magnets.

Another Hall Effects can be found at one side of the acrylic screen at the device's hand. The function for this sensor is to inform whether a tesseract was retrieved or not. If the Hall Effect sense a change in magnetic flux, then it will experience a change in its voltage, thus confirming that a "good" tesseract has been collected. The placement of the Hall Effects are shown in figure 7.

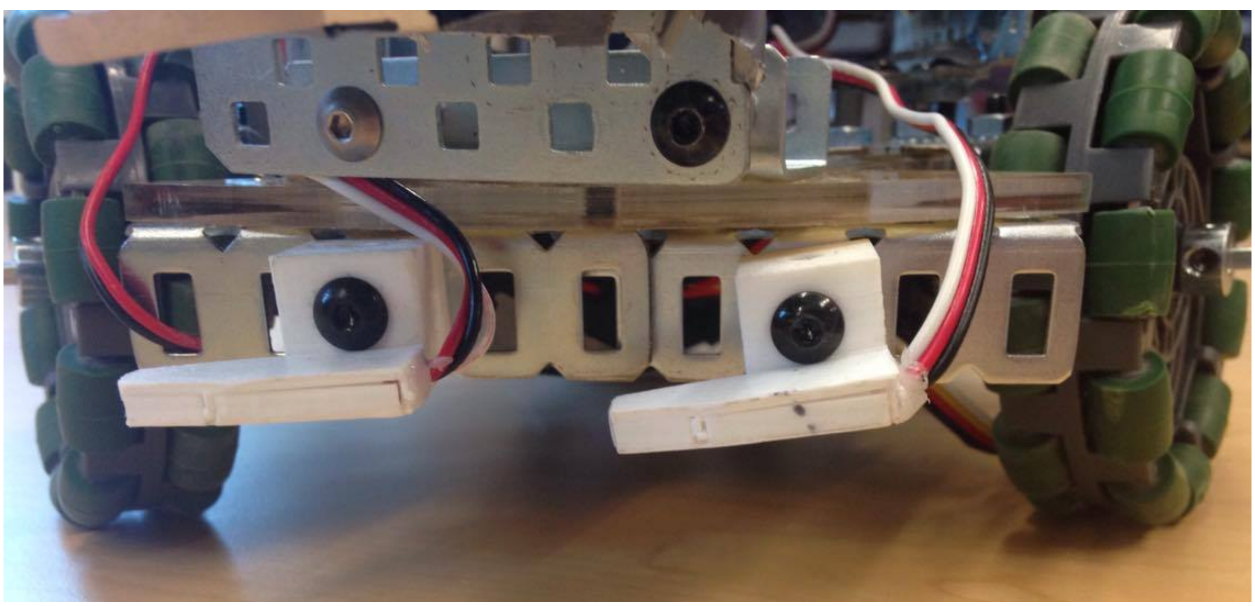


Figure 7. Hall Effect sensors at the front of the robot.

Ultrasonic

The ultrasonic sensors are placed at the front and the left side of the device. This is used to understand the position of the device relative to the wall. Since the the motion of the the device is circular (it drives around the perimeter, getting closer to the centre each revolution about the track), the ultrasonic sensor on the left side will always be facing one of the walls. Knowing the distance away from the wall, the device is able to straighten itself, allowing it to move along a straight path by keeping the distance between the device and the wall constant. The ultrasonic sensor at the front of the robot will prevent the robot from crashing into other robots and the wall in front of it. It will also allow the device to know when to turn right. The placement of the ultrasonic are shown in figure 8.

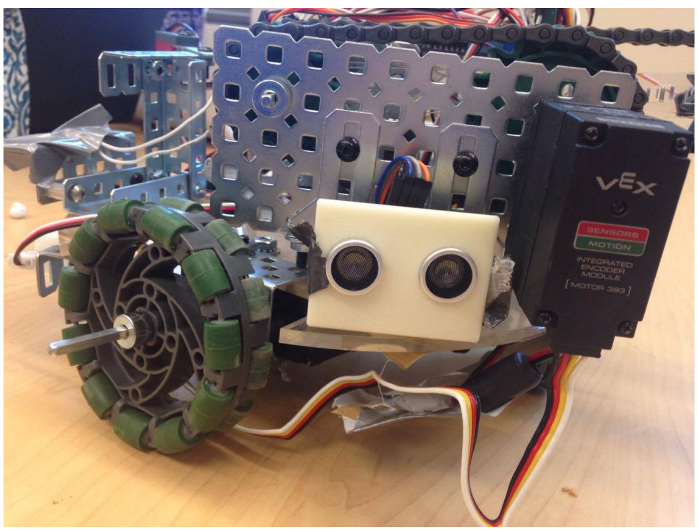


Figure 8A. Right Side Ultrasonic

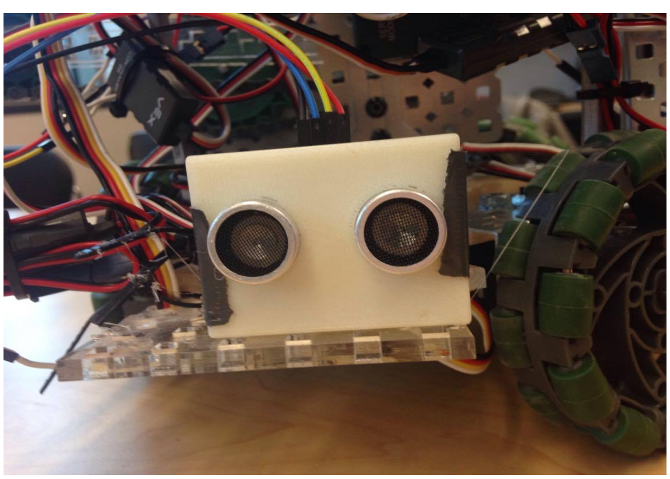


Figure 8B. Left Side Ultrasonic

Line detecting sensor

In order to determine where exactly to drop off a tesseract once it has been collected, a line detecting sensor was incorporated on this design. It is located at the base and extends forwards so that it can lay over the walls of the track and get a reading. If the line sensor recognizes the black line on the platform, the robot will be programmed to release the tesseracts at a location about 50mm away from the line. **Figure 9 shows the exact location of this sensor in more detail.**

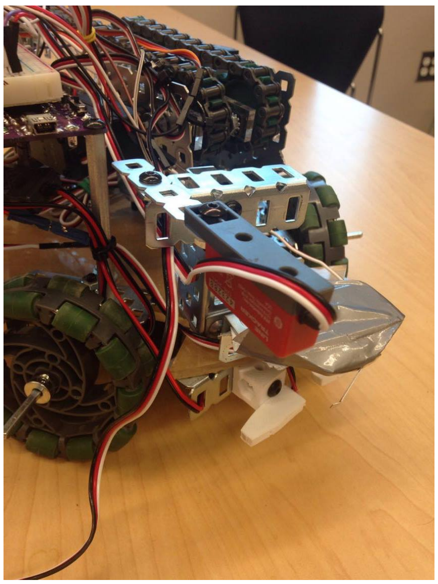


Figure 9. Line tracking sensor facing forwards

Mode 1:

Motion/Drive

The robot will start by moving along one side of the track. The ultrasonic at the front will keep track of the distance it is away from the wall it is driving towards and once it is **-----cm** away from it, the device will automatically stop, and then move back diagonally to the right for a few seconds and stop. Immediately after stopping, the robot will drive backwards and towards the wall it started from. Before hitting the back wall, the robot should stop, move forwards, diagonally to the right for a few seconds and stop. Immediately after, it should start moving forwards towards the front wall again. The process repeats until the whole track has been scanned. Reference appendix III for motion schematic.

Tesseract Pick Up

As the robot drives along the track, the Hall Effect sensors will constantly take readings to detect changes in magnetic flux. The device is programmed to stop moving once the Hall Effect's readings are altered, as this would indicate that there is a tesseract very close by.

After stopping, the robot should then lower its arm and magnetic flap to pick up the tesseract.

<u>Go Home and drop tesseracts</u>

A few seconds after lowering its flap, the robot should start driving towards the closest wall detected by the Ultrasonic sensors. Once the bumper switch it hit against the wall, the device should turn to the right, if the right Ultrasonic was being used, or left, if the left Ultrasonic was beings used. After turning for the first time, it should continue driving straight until the bumper switch hits another wall. From here the robot should turn towards home, and continue driving until the bumper switch is hit again. At this point, the robot will turn toward the tapes, and drop the tesseract after moving a certain amount of encoder counts. The amount of encoder counts is varied depending on the amount of tesseracts picked. This works because the tapes are always a constant distance away from the wall and the same distance away from each other.

Mode 2:

<u>Pick Tesseract</u>

The robot starts facing the platform where the tesseracts are located. The robot drives straight until the bumper switch is activated by the platform. Immediately after the state of the switch changes, the robot is programmed to lower its arm and use the Hall Effect sensor on its hand to detect the tesseracts on the platform. The robot should sweep left to right until the change in flux is large enough; once it detects the location of the greatest change in magnetic flux, the device will stop and lower the magnet flap to attract the tesseract. A few seconds after it lowered its flap, the robot will assume it successfully grabbed a tesseract and will proceed to turn.

<u>Go Under the Structure and Drop the Tesseract</u>

Once the tesseract is sensed, the robot will turn towards the structure. Next, it will back up and extend its arm completely in order to go under the structure. After driving straight, under the structure, the robot will turn its arm 180 degrees backwards, allowing it to position the magnet screen and the tesseract directly under the structure. Once positioned, the magnet flap will lift back, detaching from the tesseract which will stick onto the metal of the tall frame.

Description of Final Design

For the final design the use of an aluminum trapezoid base was implemented to reduce the amount of material required, while keeping the material lightweight and robust (Materials, n.d.). When comparing different potential materials for the base, the properties of strength and density were examined. We considered the materials of iron and aluminum, however aluminum has the density of 2.7g/cm^3 whereas iron has a density of 7.87g/cm^3, making aluminum the more lightweight material (Density, n.d.). To compare the strength of the materials considered, the property of Yield Strength was examined, with Aluminum having a Yield Strength of 95MPa opposed to Iron's yield strength varying from 120-150MPa (Modulus, n.d., Iron, n.d.). From this data we can see that Aluminum is weaker, yet significantly lighter than Iron, making it the favourable material.

Ultrasonic sensors were added on the sides and front to ensure collision free navigation, and to assist in movement correction. A front panel made out of cardboard was added to the front going as low as a couple centimeters from the ground, angled inwards to allow for the redirection of nearby tesseracts towards the device. Hall Effect sensors are implemented behind this front panel to allow for detection of tesseracts that have been acquired. Upon detection a folding arm constructed from a series of aluminum rods, once again ensuring a lightweight yet durable design, will pick up the tesseract. A combination of a large integrated encoder vex motor and a smaller servo located directly on the arm, will allow for successful retrieval and manipulation of the tesseracts. On the end of the arm will be an electromagnet wrapped with Styrofoam ensuring the tesseract only attaches to the tip, an electromagnet will minimize the weight required to manipulate the tesseracts. Additionally a light sensor and a hall effect sensor will be located midway on the second section of the arm to detect when a tesseract has been acquired, and where the guiding lines for tesseract storage are located. To navigate this course 3 integrated encoder motors are being used in combination with Omni directional wheels to allow the device to better navigate turns and angles.

Conclusion

The overall prototype was designed to meet all the objectives of the project. The design uses sensors in a way which allows the robot to autonomously run through a track to find tesseracts and return home. This is done using the ultrasonic and Hall Effect sensors as described through the report. The ultrasonic is used for mapping, while the Hall effects are used to find "good" tesseracts. The robot was also designed to run in mode two. The arm was made such that it would be able to reach low enough to the ground to pick up tesseracts in mode 1 and also drop off tesseracts 43cm above ground. The design of the robot made it theoretically feasible to complete all the objectives of the project. However, realistically, many factors were not taken into account while designing the prototype.

Through the testing phase of the product development, it was discovered that many iterations needed to be made. Most specifically, the arm of the prototype was too heavy to be lifted with the vex servo motors. At this point, many changes to the design began to occur. Pulley systems using gears and chains were incorporated to help reduce the torque that the servo motors must create. Moreover, the initial design with the claw was discarded, because it added unnecessary weight and performed a redundant task. The prototype did not need both the claw and the magnet in order to pick up the tesseract. During the design phase, acrylic was chosen to be the design material because it was light weight and cost effective. However, press wood is even lighter weight and more cost effective. More research of the the material needed to be done to make an effective design.

Recommendation

A big constraint for this project was time, scheduling, setting, and meeting deadlines was of vital importance to complete this task. Trial and error was not a good way of approaching this problem, as it was soon discovered, making iterations on the chassis took a lot of time away from the programming of the device which was a major part of this task. Making use of programs like SolidWorks can impact the outcome of the project positively, because modelling the concepts before actually starting to build the prototype, makes it more clear how all of the parts mate together, and how they will behave once they are assembled. In this manner, it is easier to identify mistakes and correct them without wasting too much time building and rebuilding.

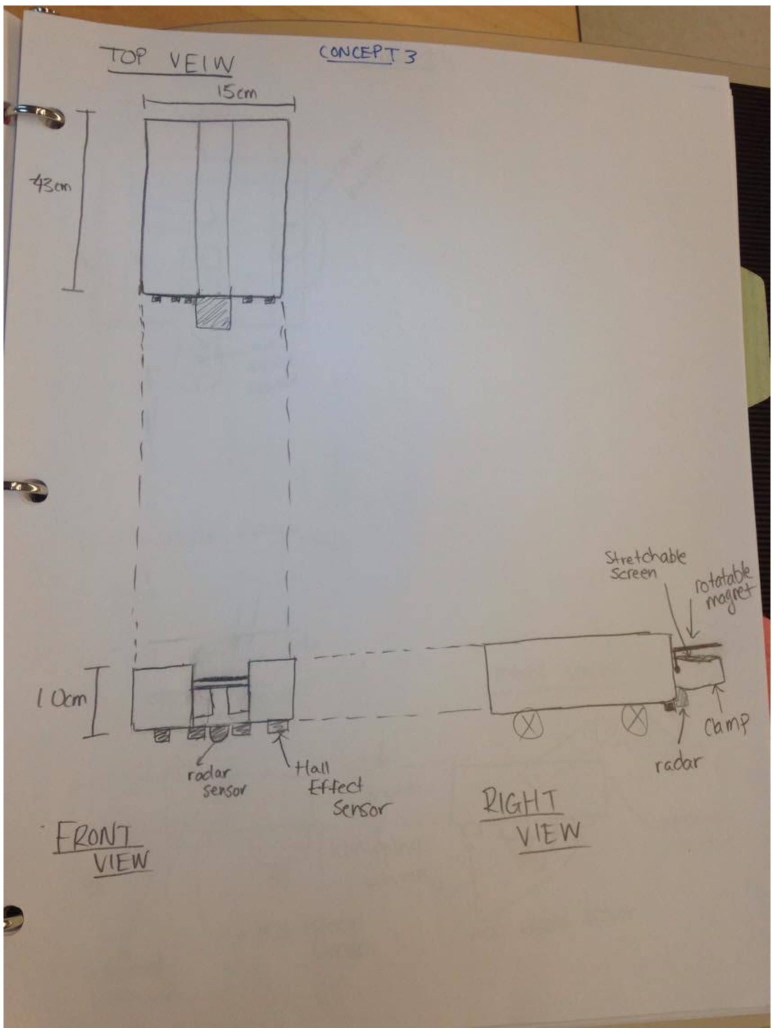
For the design prototype itself, if the project were to start again, one thing that should change is the material of the arm, pressed wood is by far less heavy than acrylic and but still sturdy enough that it can perform just as well. Also, using servos configured to have a greater torque instead of a greater speed would be ideal for the arm movements, to ensure that it will be strong enough to lift all the different components.

Another aspect of the design process that could be improved was the selection of the movement along the arena. The goal was to achieve perfect straight motion, using Ultrasonic sensors plus encoders, the robot was supposed to accomplish this task. Too much time was put into this part of the program, and as it was no easy to achieve, other important tasks were neglected, resulting in an incomplete mission. The robot was not constrained to straight motion and yet this was the preferred method, since it is the most intuitive.

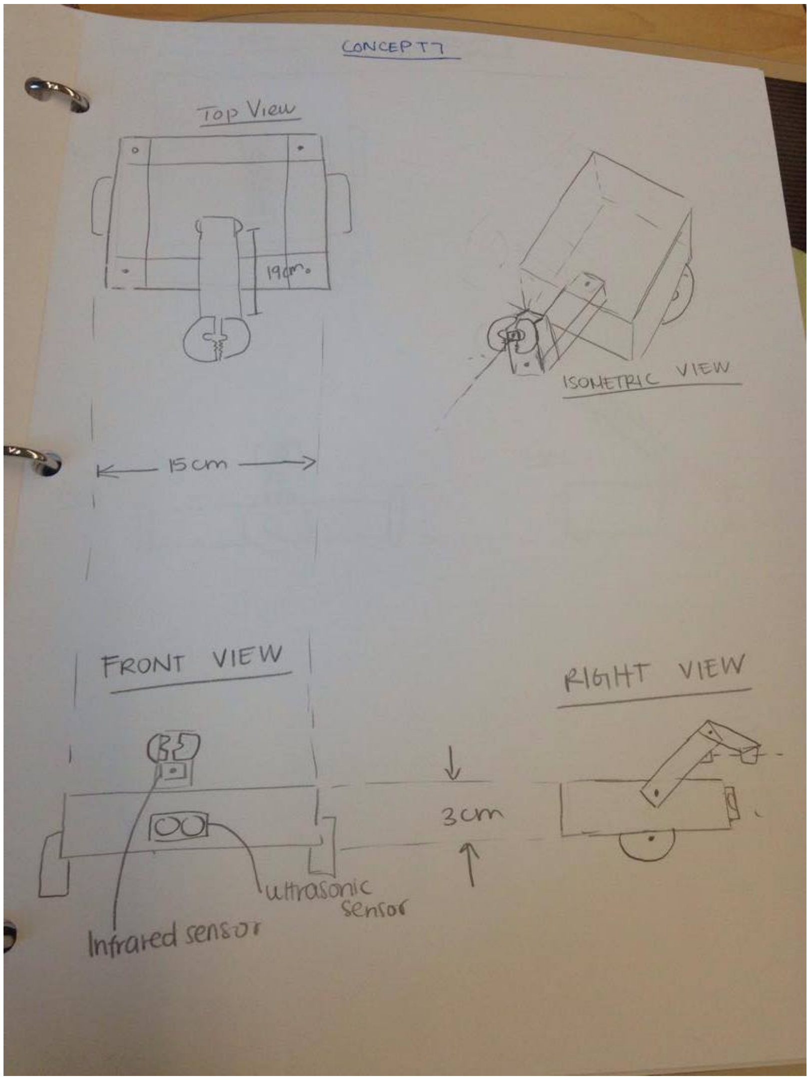
Overall, the task assigned was attainable, however more cautious and strict planning was required in order to achieve it within the time constraints.

Appendices

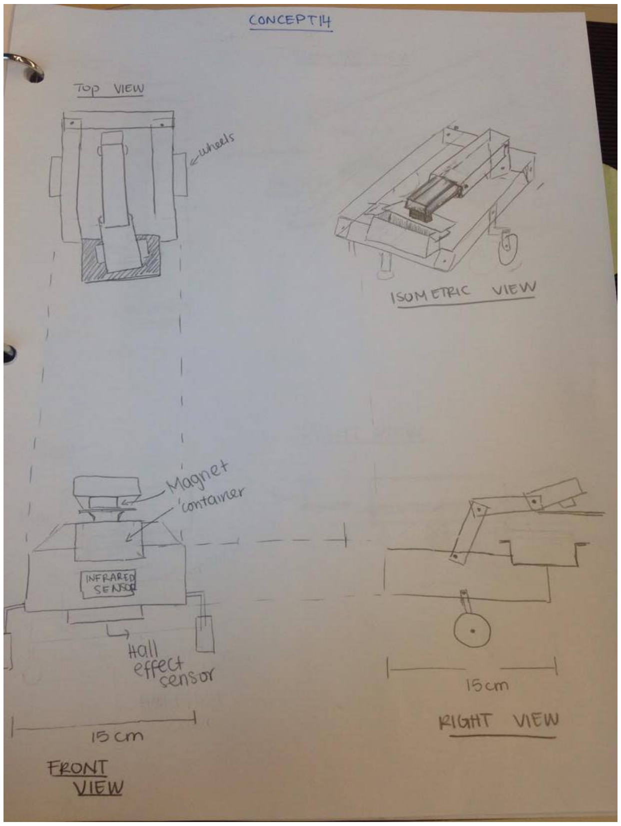
Appendix I: Concepts generated



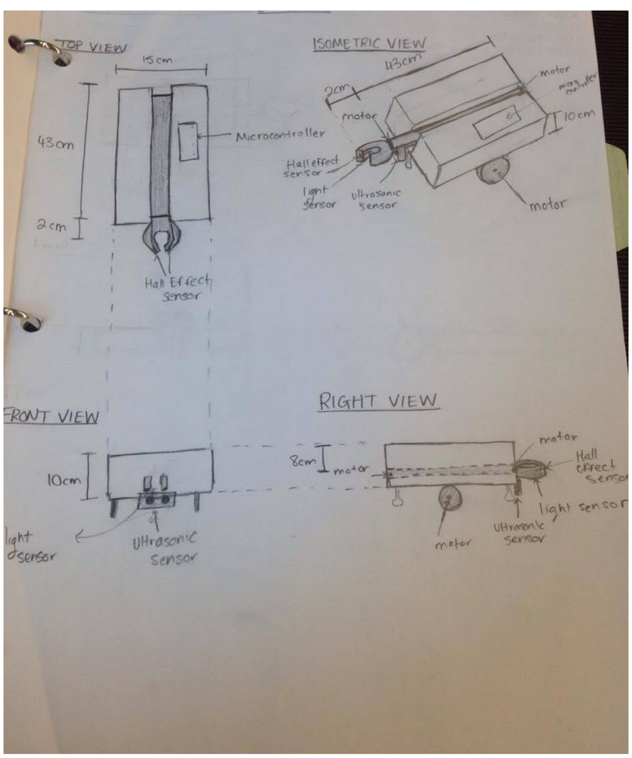
A) Non-flexing long arm plus magnet



B) Foldable arm



C) Box holder plus magnet



D) Rigid Arm

Appendix II: Concept selection matrices

Go/No-Go Screening

	Within Budget	Fits in Opening of Structure (19x25cm)	Can sense and pick up tesseracts	Can drop off tesseracts onto platform (between pieces of tape)	Can reach the top of the structure	Feasible to build considering time and skill	Feasible to code considering time and skill
Concept 1	Go	No-Go	Go	Go	Go	No-Go	No-Go
Concept 2	Go	Go	No-Go	No-Go	No-Go	No-Go	No-Go
Concept 3	Go	Go	Go	Go	Go	Go	Go
Concept 4	No-Go	Go	Go	Go	Go	No-Go	No-Go
Concept 5	Go	Go	Go	Go	Go	No-Go	No-Go
Concept 6	Go	Go	Go	No-Go	No-Go	Go	Go
Concept 7	Go	Go	Go	Go	Go	Go	Go
Concept 8	Go	Go	Go	Go	Go	Go	No-Go
Concept 9	Go	Go	Go	No-Go	No-Go	Go	Go
Concept 10	Go	Go	Go	No-Go	Go	No-Go	No-Go
Concept 11	Go	Go	No-Go	Go	Go	Go	Go
Concept 12	Go	Go	Go	No-Go	No-Go	Go	Go
Concept 13	Go	Go	Go	Go	Go	No-Go	No-Go
Concept 14	Go	Go	Go	Go	Go	Go	Go
Concept 15	Go	Go	Go	Go	Go	Go	Go
Concept 16	No-Go	No-Go	No-Go	No-Go	No-Go	No-Go	No-Go
Concept 17	No-Go	Go	Go	Go	Go	No-Go	No-Go
Concept 18	Go	Go	Go	No-Go	No-Go	No-Go	Go
Concept 19	Go	Go	Go	No-Go	Go	Go	Go
Concept 20	Go	Go	Go	No-Go	No-Go	No-Go	No-Go

Decision Matrix

A) Weighting of Constraints

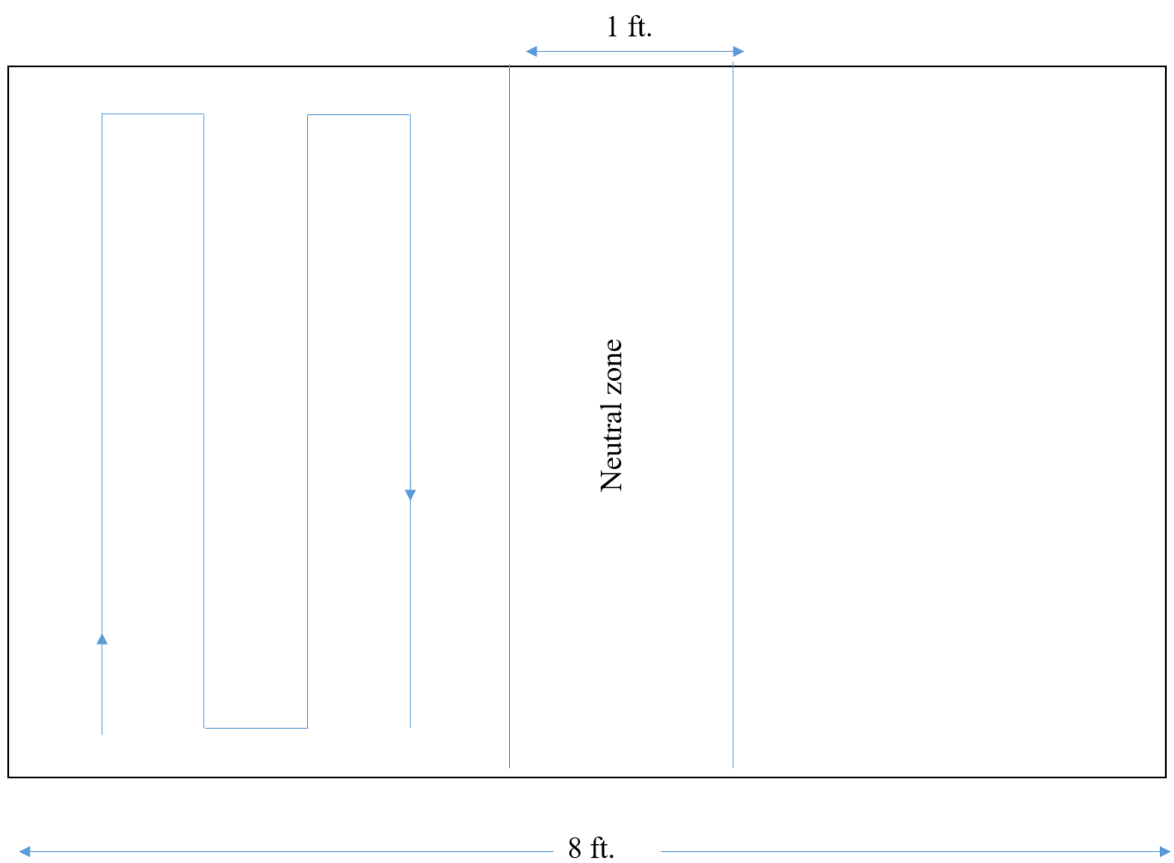
Column1	Within Budget	Meets Dimensions	Can reach top surface	senses good tesseracts	Durable	easy to build	total	weight
within budget	1	1/3	1/2	1/3	1	1/3	3.50	0.04
meets dimensions	3	1	1/2	1	2	3	10.50	0.11
can reach top surface	2	2	1	1	3	3	12.00	0.13
senses/picks/drops good tesseracts	3	1	1	1	3	2	11.00	0.12
Durable	1	1/2	1/3	1/3	1	1	4.17	0.04
easy to build	3	1/3	1/3	1/2	1	1	6.17	0.07
							47.33	

B) Concept Assessment

Concept 3	Concept 7	Concept 14	Concept 15
0	1	-1	0
0	0	0	0
0	0	0	0
0	-1	-1	-1
0	-1	0	0
0	-1	-1	0
0.00	-0.38	-0.43	-0.23
Winner			

Appendix III: Motion Schematic

Mode 1



Appendix IV: Grip Magnet Specifications

Specification	Description
Size	1/2 x 1/8 inches
Strength	9lb
Type	Rare Earth magnet
Shape	Cylindrical

Source: http://www.leevalley.com/en/wood/page.aspx?p=32065