Hardware Design Document of the

Catch and Sweep concept, Version 6.0

McGill University

ECSE 211

Team 20

HARDWARE DOCUMENT

Project: DPM Final Project
Task: Construct a robot that can navigate a closed course to search and retrieve colored rings

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1.0 Abstract

This document provides the high level technical documentation of the mechanical designs proposed for the goals of the navigating through a set of waypoints to retrieve rings off a tree and returning them back to the base. The purpose of this document is to discuss different design ideas that were put forwards by the team and outlines the pros and cons of each concept. It intends to describe the conceptual design of the proposed system and help the team in making a better-informed decision in choosing the final design in conjunction with design activities in later phases of the project.

2.0 Hardware Availability

2.1 Motors

There are total of three kinds of motors available in the kit: Large NXT Figure.1 , Medium EV3 Figure.2 and Large EV3 Figure. 3. Besides the Large NXT is older than Large EV3, the only difference between Large NXT and Large EV3 is the attachment points. The main difference between medium motors and large motors is power and precision, and that will be our premium concern when we decide what job that we will use them to perform. The large motors are more powerful but not the most accurate. In contrast, the medium ones are weaker and much more precise. So, the large motors are suitable for jobs like driving the entire robot around. And the medium motors can be used to perform smaller jobs liking moving a sensor back and forth for more precise detection. The motors will be attached on the top of brick through port A – D.

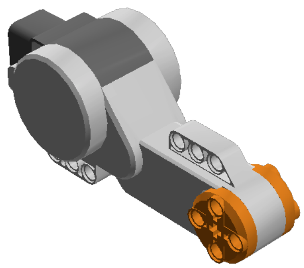

Figure. 1

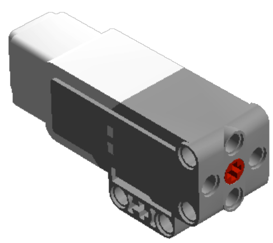

Figure. 2

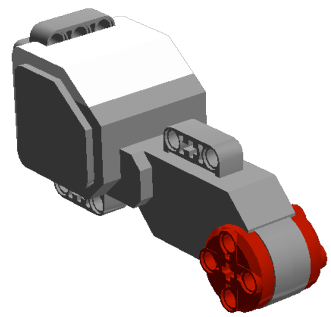

Figure.3

2.2 Sensors

The most important sensors used are Ultrasonic sensor Figure. 4 and Light (Color) sensor Figure. 5. The ultrasonic sensor is used to measure distance by sending ultrasonic waves and measuring how long it takes the wave to echo back. It can be used to detect and avoid obstacles, navigation, and localization. But we will need to test to understand its functionality, and compensate in software for failure.

The color sensor, also referred to as a light sensor, has several modes: RGB, Color ID, etc. It determines color of objects when being placed at appropriate distance from the object. It is more reliable than the ultrasonic sensors if functions properly. It can be used to detect black lines on panel and identify ring colors.

All the sensors will be attached to the ports labelled 1-4 on the bottom of the EV3 brick.

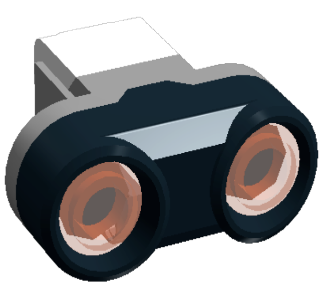

Figure. 4

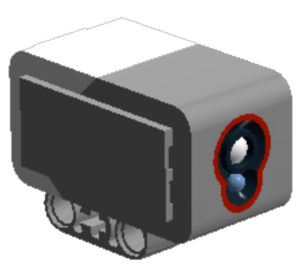

Figure. 5

2.3 Brick

The brick, Figure. 6, in the kit is an embedded system. The brick can be turned on by pressing on the ENTER button for one second or two, and turned off by pressing the ESCAPE button. The brick has features including: LCD screen for display, Speaker for making beeps (will be used in final project when detecting rings), Micro-SD Card Slot for the SD card with leJOS on it, USB type-A for Wi-Fi adapter, USB mini-B for communication with laptop, Ports A-D for connecting motors, Port 1-4 for connecting sensors, and 6 Buttons. The buttons are Enter, Up, Down, Right, Left, and Back button. They can be used to interact with the code.

Figure. 6

2.4 Other components

Other than brick, sensors, motors, the kit that we are being provided also include other components like wires, batteries, and various LEGO parts. The batteries we have include both AA batteries and a rechargeable battery pack. The battery level is displayed in the top left corner of display screen, the highest it can reach is 8.0V. For better performance, it is good to keep the battery level above 7.0V for all time. We also being provided with USB cables for connection and charging cables. The hardware parts that are available to us are, but not limited to the LEGO parts in the kit. We can also use 3D printer to print more components if needed. The parts will be used to assembly our robot.

3.0 Hardware Design Purpose

The goal of the Hardware Design proposal is to discuss the pros and cons of various concepts so find the perfect design that can accomplish all desired tasks efficiently with the underlying software design. For a detailed overview of tasks, refer to the Requirements Document.

4.0 Design Proposals

This section describes three of our designs, their sketches, and pros and cons. That will provide a clear overview of our design choices before reached a tentative final design.

4.1 Arm and basket mechanism

Our first prototype, Figure. 7 consists of an arm that can go around the ring and 'hug' it. Upon reversing, the ring falls into the basket placed in front of the robot. There is a light sensor placed on the arm to detect the color of the ring.

It includes an Ultrasonic sensor mounted at the front, underneath the basket, for Ultrasonic localization and a light sensor at the back for light localization.

Its pros and cons are discussed in Table.1 underneath.

Table.1

Pros	Cons
• Can catch all the rings in one journey.	• Getting the arm to go around the ring would require a lot of precision.
• Very wide, help lower the center of gravity.	• The size of the basket has to be big so that it can accommodate all the rings but with a basket that size, it would be almost impossible to localize since we need to take 360 turns.
• The mechanism can grab rings at all heights provided.	• Hard to navigate through the tunnel due to increase width

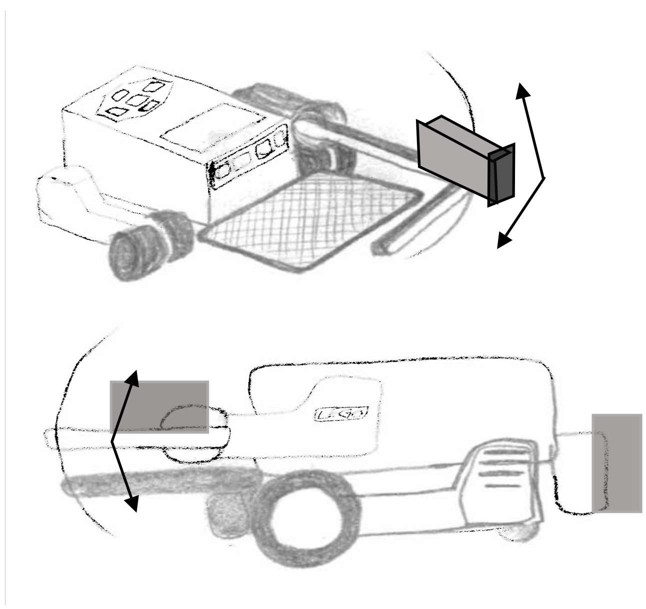

Figure.7

4.2 Claw mechanism

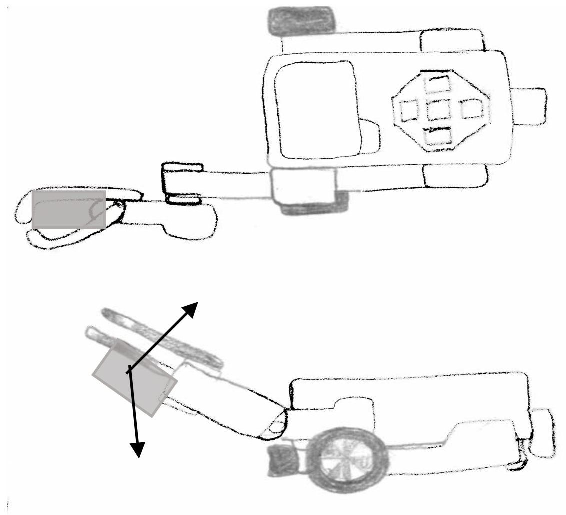

Figure.8

The second prototype, shown in Figure.8, consists of the same basic mechanical and hardware design of the robot is very similar to the design used in previous labs. The sketch shows an arm with a claw at the front that can fold over the robot and extents forwards to detect the color of rings placed on the tree at various heights using a light sensor.

Another color sensor is placed at the back of the robot, facing downwards for Light localization.

Unlike previously, the ultrasonic sensor is placed between the wheels facing forwards for Ultrasonic localization and obstacle avoidance.

This prototype consists of a claw that has one degree of freedom. It can move up and down to grab a ring. Once it grabs one ring it can move take it back to the starting position and come back to grab another one. Its pros and cons are below in Table.2

Table. 2

Pros	Cons
• Probability of grabbing the ring in the first try is high	• With 2 motors at the front, it would, by default move the center of gravity higher and forward.
• Too much weight at the front of the robot by default thus moving the center of gravity higher and forward.	• Would take a lot of time to accumulate all the rings. The more distance the robot travels, the more error is accumulates
• Easy to navigate due to a compact design	• More rounds would reduce battery life so that would increasing change the performance of the EV3.

4.3 Long arm mechanism

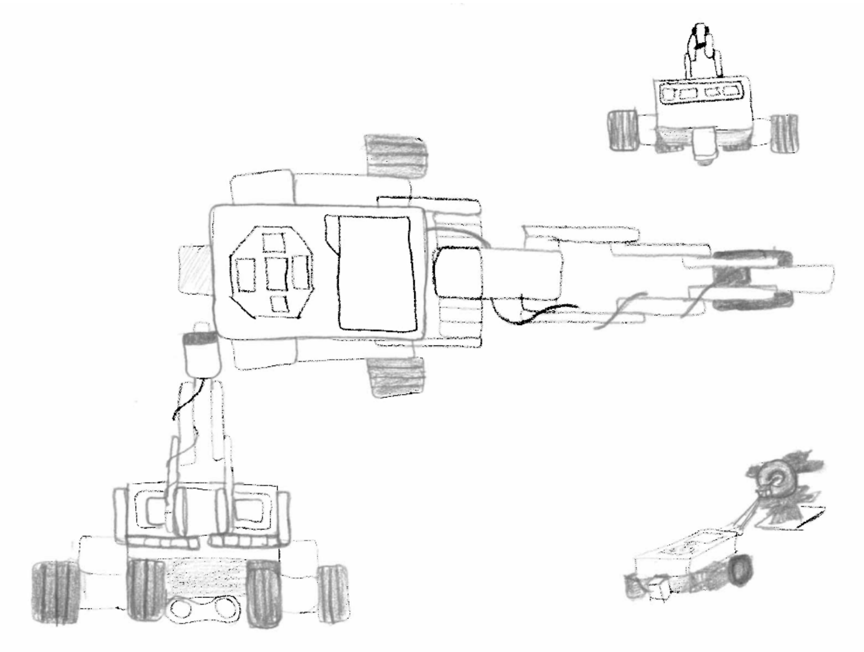

Figure. 9

The basic mechanical and hardware design of the robot is very similar to the design used in previous labs. The sketch in Figure. 9 shows a long arm that can fold over the robot and extents forwards to detect the color of rings placed on the tree at various heights using a light sensor.

Another color sensor is placed at the back of the robot for localization.

Unlike previously, the ultrasonic sensor is placed between the wheels facing forwards for US localization and obstacle avoidance. The arm connected to the motor in front of the wheel base that would provide lateral mobility thereby allowing the arm to carefully lift the ring ~0.5 cm above its resting place. Once lifted the robot will reverse and raise the arm almost vertically to secure the ring at the base of the arm. A light sensor would be connected to the end of the arm in order to detect whatever ring was being lifted. Its pros and cons are below in Table. 3.

Table. 3

Pros	Cons
• The armature can move anywhere we want it. Vertical motion using the motor it is attached to and horizontal motion by changing the heading of the robot.	• If too many rings are added the robot becomes too heavy at the front of the wheels and it pivot at the line of the wheels base.
• Very easy to localize since the armature can be folded over the robot, reducing the footprint of the machine.	• Would require very precise calculation to make sure the arm goes into the ring.
• Easy to navigate through the course especially the tunnel.	• A long arm like this could increase the chances of a collision.

4.4 Catch and sweep design

This design is best visualized in Figure. 10 below. Our approach was to have two mobile "catchers" that mimic the function of the original "long arm mechanism". Unlike our previous design, we have two arms for, one for the top and one for the bottom ring so no single arm needs to be long enough to reach both. Additionally, the shorter arms are mounted directly above the wheel base thereby reducing the effect of tipping about the wheelbase, similar to the 'long-arm mechanism', the positioning of arm-tip experienced in the previous design. The rotational motion of a single motor mounted above the brick is translated through 6 gears into the "catchers". This mobility of the arms would allow rings to be easily shifted to be near the base by raising the arms and also easily unloaded by lowering the arms.

The "Sweeper" comes in the form of two hooks mounted on a vertical rod with a motor as a base. Once the color of the ring has been detected, the sweeper would rotate counter clockwise sweeping both top and bottom rings onto the catcher for travel. Additionally, using these sweepers in the opposite direction would aid in the dismount of the rings if they happened to get caught while unloading.

In terms of sensors, two light sensors are mounted directly behind the wheel base to read grid lines and adjust the positioning when necessary. A third light sensor was placed at an upward angle on an arm stretching the front left of the robot. With this positioning, the ring being acquired would be in the line of vision of the sensor no matter if it is on the top or bottom. Additionally, not having the color-detecting sensor being placed forward eliminates the possibility of detecting the yellow tree structure as a ring erroneously. Finally, an ultrasonic sensor is placed facing forward for ultrasonic localization.

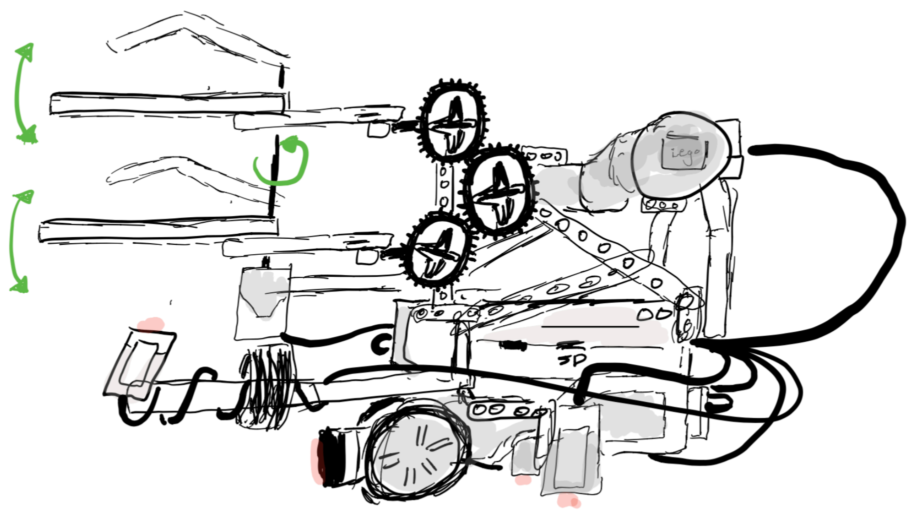

Figure. 10

Table.4

Pros	Cons
• Capable of slightly lifting rings during grabbing process to reduce friction and issues between ring being removed and tree itself.	• Possibility of wrong height causing arms to erroneously poke tree or body of ring rather than threading center.
• Can hold all four rings in one trip.	• The robot is a narrow fit through the tunnel.
• Capable of unloading rings with ease when necessary.	• Variability between distance of arms due to slippage in the gears.

4.4.1 Catch & Sweeper design 1

This design is similar to the one in Figure. 10. Previously we have been using a very similar design but after extensively testing the ‘Catcher and sweeper’ design one major problem we faced was that our after navigating from the start point to the tree, the arms would shake and move out of place such that it was almost impossible for the taco-counter in the actuating motor to keep track of them. There was always some ‘play’ within the gears that would cause misalignment when skewering the ring. Therefore, we decided to eliminate the gear assembly, instead of the arms moving up and down, they are now firmly to the robot.

Now we have firmly attached the catchers to the front of the robot instead of mobile ones. Like our previous design, Figure. 4, we have two arms for the top and bottom ring. The catcher arms are mounted directly above the wheelbase thereby reducing the effect of moments about the wheelbase.

Just as previously, the “Sweeper” comes in the form of two hooks mounted on a vertical rod with a motor as a base. Once the color of the ring has been detected, the sweeper would rotate counterclockwise sweeping both top and bottom rings onto the catcher for travel. Additionally, using these sweepers in the clockwise direction would aid in the dismount of the rings if they happened to get caught while unloading.

In terms of sensors, two light sensors are mounted directly behind the wheel base to read grid lines and adjust the positioning when necessary. A third light sensor was placed on a motor at an upward angle on an arm stretching the front left of the robot. With this positioning, the ring being acquired would be in the line of vision of the sensor no matter if it is on the top or bottom. Additionally, not having the color detecting sensor being placed forward eliminates the possibility of detecting the yellow tree structure as a ring erroneously. Finally, an ultrasonic sensor is placed facing forward and low to the ground allowing for ultrasonic localization at the beginning of the test. The pros and cons in Table.5.

Table.5

Pros	Cons
• The catchers don't wiggle about their position.	• The rings may fall off if there is a sudden change in interia.
• Can hold all four rings in one trip.	• The robot is a narrow fit through the tunnel.
• Capable of unloading rings with ease when necessary.	• The catchers may not fit into the upper part of the rings.

4.4.2 Catch & Sweeper design 2

This design is best visualized in Figure. 11 below. Previously we have been using a very similar design but after thoroughly testing the 'Catch and sweep mechanism 1'one major problem we faced was that our after navigating from the start point to the tree, the arms would shake and move out of place such that it was almost impossible for the taco-counter in the actuating motor to keep track of them. There was always some 'play' within the gears that would misalign with the upper part of the ring. So we decided to completely eliminate the gear assembly and the arms moving up and down and fixed them firmly to the robot. So we moved to the 'Catch and sweep mechanism 2'

After we have firmly attached the catchers to the front of the robot instead of mobile ones similar to 'Catch and Sweep 1'. Like our previous design, we have two arms for the top and bottom ring but this time we relocated the catcher arms slightly below their original position because sometimes due to the varying diameter of each ring, we weren't able to skewer them and the robot would push the entire tree forwards. So we decided to place the catchers slightly below the current level. This way the chances of the rings falling onto the catchers would increase drastically.

Secondly, we placed a light sensor at the front of the robot and it is mobilized. With this positioning, the ring being acquired would be in the line-of-vision of the sensor no matter if it is on the top or bottom. Additionally, not having the color detecting sensor being placed forward eliminates the possibility of detecting the yellow tree structure as a ring erroneously.

In terms of localization, previously, the two light sensors were previously mounted on either sides of the robot next to the wheels to read grid lines and adjust the positioning when necessary. We have now relocated those light sensors to the front of the robot because whenever we passed through a tunnel our light sensors placed on either side of the robot would slightly brush against the tunnel. That slightly tempered with our heading and in some cases one of the tire would start riding the tunnel thus throwing us completely off course. Its pros and cons are displayed in Table. 6

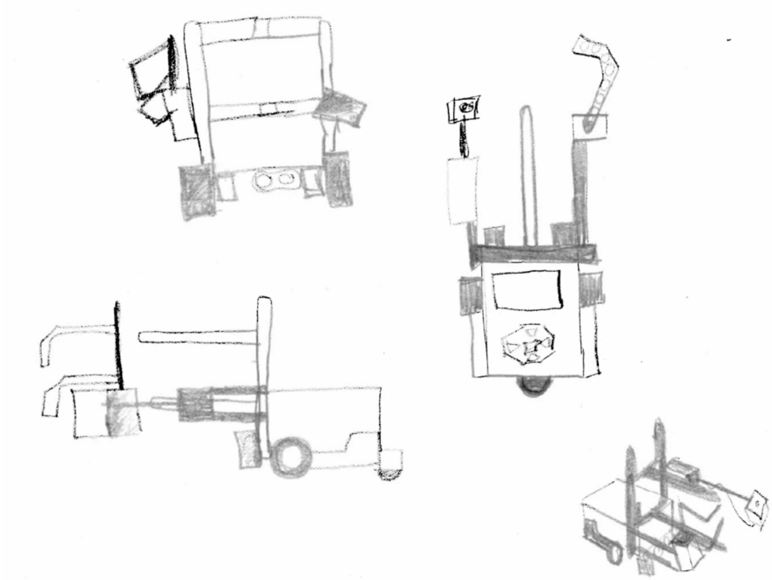

Figure. 11

Table. 6

Pros	Cons
• The catchers always go into the rings i.e. into the lower part.	• Will have to increase mass at the back to counter the mass of the 4 rings after loading the thus leading to reduced battery life.
• The robot has more wiggle room through the tunnel compared to 'Catch & Sweeper design 1'.	• The robot's front rig may hit the top of the tunnel thus altering the heading.
• The rings do not fall off if there is a sudden change in velocity.	• Due to too many motors, the processor is loaded with too many threads thus slowing it down.

4.4.3 Catch & Sweeper design 3

This design can be best visualized in Figure. 12 below. Previously, we have been using a very similar design but after extensively testing the 'Catch and sweep 2'mechanism throughout Week 5. The problem we faced was that while the robot is navigating the course, sometimes while going through narrow turns the catcher arms would collide against the walls or other obstacles nearby. The would alter our course because a slight change in the heading of the robot results in error accumulation that would eventually throw it off course. So we moved to the 'Catch and sweep 3' mechanism.

Like our previous design, we have two arms, one for the top and one for the bottom ring but this time we relocated the catcher arms but now to solve the problem at hand, we have moved the catcher arms backwards by about 4cm. Thus, our rig now rises directly above the center of the brick. Like previously, the arms skewer the rings and the sweeper pulls them onto the catcher arms.

Secondly, we pushed the Ultrasonic sensor backwards underneath the EV3 brick because we need more space so that the rings can easily rest at the 'brick end' of the catcher arms.

Naturally, the light sensor placed in front, to detect the ring's color, is moved slightly backwards. So is the sweeper. With this positioning, the ring being acquired would be in the line-of-vision of the sensor no matter if it were on the top or bottom. Additionally, not having the color-detecting sensor placed forward eliminates the possibility of detecting the yellow tree structure as a ring erroneously.

Like previously, the two light sensors are in front to avoid brushing against the tunnel and to avoid tempering with the heading throwing it completely off course. Pros and cons discussed in Table. 7.

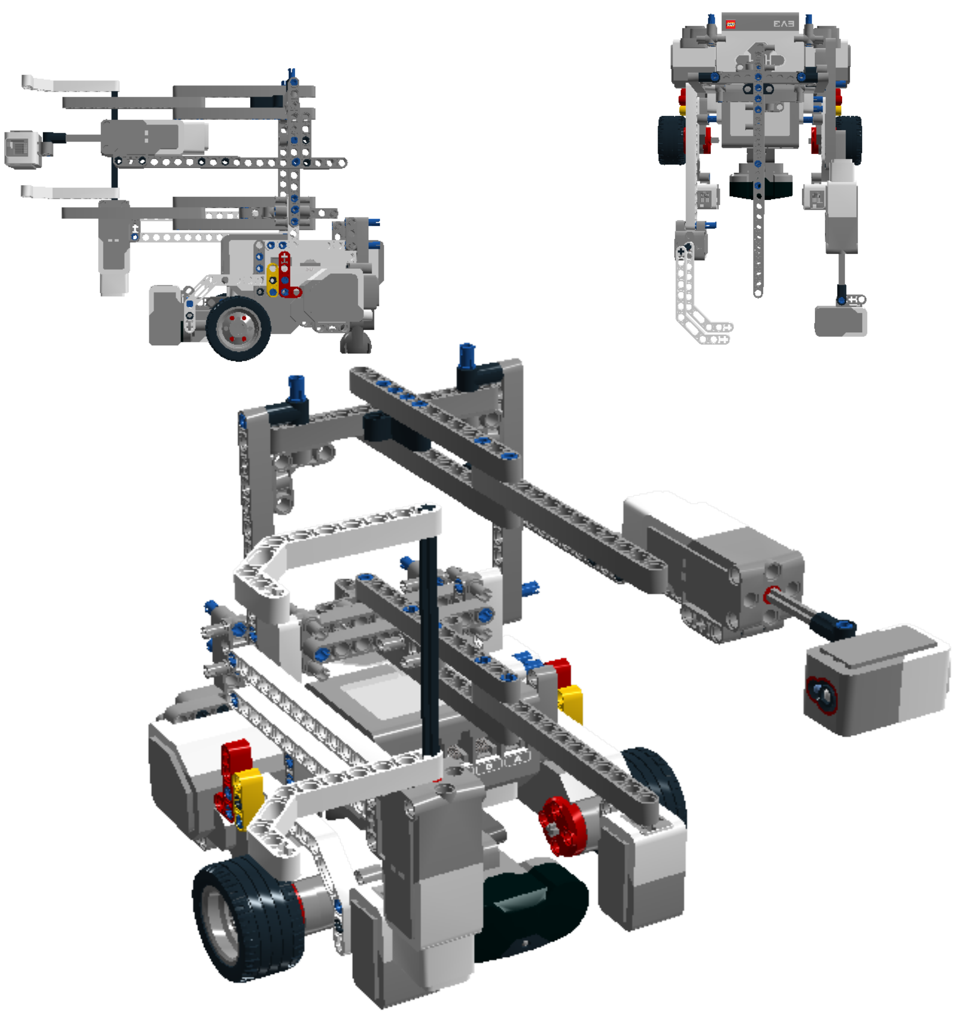

Figure. 1

Table. 7

Pros	Cons
• The catchers always go into the rings i.e. into the lower part.	• Will have to increase mass at the back to counter the mass of the 4 rings after loading the thus leading to reduced battery life.
• The robot has more wiggle room since it is much more compact now.	• The robot's front rig may hit the top of the tunnel thus altering the heading.
• The rings do not fall off if there is a sudden change in velocity.	• Due to too many motors, the processor is loaded with too many threads thus slowing it down.

Justification

Previously we had proposed that we can pull the rings from the tree and they would automatically fall on a basket placed in front but in that case, it would be very hard to unload the rings after retrieving them. Then we decided to construct a long arm that would skewer the rings but making the arm point directly into the ring was very difficult.

Now, after rigorously testing the 'catch and sweep' concept for three weeks. We have concluded that it is statistically the most reliable design for the task.

5.0 Idea selection

5.1 Arm and basket(Design 1)

Rejection criteria for design 1:

First off, the basket was a great idea but when attempting to execute it we realized that the sheer thickness of the rings would cause them to stack high enough to disable gathering more than two rings at a time as they would obstruct the sweeper. Secondly, unloading the basket would be extremely difficult if not impossible.

Finally, even when using our hands to control the robot we found it difficult to have a ring land in a basket when dropped form the top of the tree. This inconsistency in results given the most ideal of circumstances caused this idea to be rejected.

5.2 Claw Mechanism(Design 2)

Rejection criteria for design 2:

The reality of creating a functional claw on the end of an arm long enough to reach top and bottom while having the mobility to do so would be very complicated. In addition, the reward of completing this complicated design would only be the capture of a single ring whereas both other designs have the potential to gather multiple. The complexity of this design is simply too great for the result it achieves.

5.3 Long arm Mechanism(Design 3)

Rejection criteria for design 3:

First off, the ‘long arm’ mechanism seemed like a great until we started testing it. The main question that came to mind was how long would the arm have to be handle the weight of 4 rings and how exactly would we calibrate the arm to make sure that its tip goes into the ring. This would require the heading of the robot to be very precise, with the current motors that we have, it would be very difficult if not impossible.
Secondly, once a ring is acquired, the ring hitting the ground or other parts of the robot restricts the mobility of the arm.
Thirdly, the light scanner might get in the way when skewering the rings.

5.4 Catch and sweep 1 (Design 4)

Rejection criteria for design 4:

After much testing the ‘catch and sweep 1’ mechanism would not be the best approach to take for this task. The possibility of grabbing multiple rings is low because sometimes due to the varying diameter of each ring, we weren’t able to skewer them and the robot would push the entire tree forwards.

So we decided to place the catchers slightly below the current level. This way the chances of the rings falling onto the catchers would increase drastically.

5.4 Catch and sweep 2 (Design 5)

Rejection criteria for design 5:

After much consideration we decided as a group that the ‘catch and sweep 2’ mechanism would be a decent approach to use for the course but due to the arms extending out too far ahead, sometime they hit the walls or the course obstacles and it tempers the heading of the robot. So we altered the design and it is described as the ‘Catch and sweep 3’ mechanism.

5.5 Catch and sweep 3 (Design 6)

Adoption criteria for design 6:

For the final design, we decided as a group that the ‘catch and sweep 3’ mechanism would be the best approach to take for this task. We have slightly altered the ‘Catch and sweep 2’ design so that our robot maybe more compact. We have do so by moving the catcher arms slightly backwards. This way the possibility of grabbing multiple rings at once with such a simple design would help achieve the highest score possible with the greatest simplicity of hardware/software design.

If we could achieve a functional ring detector/retriever with such a simple design, the debugging process would become infinitely simpler and would allow for more time spent on navigation towards and around the tree.

6.0 Evolution of Design

6.1 Week 1:

During the first week we had no concrete concept for the hardware design yet. We took the week to understand the restrictions and capabilities of our so that in subsequent weeks we could create a functional prototype that follows all guidelines.

6.2 Week 2:

Although we agreed upon the selection of the design, our brainstorming raised a few questions about how the physical model would actually function.

Worries and Questions from the team:

1. How will an arm of such length handle the weight of 4 rings?
2. Once a ring is acquired, will the ring hitting the ground or other parts of the robot restrict the mobility of the arm.
3. If the tip of our arm is so far from the center of rotation when extended, pinpointing the center of the rings may require a level of accuracy our wheels motors aren't capable of.
4. The light scanner might get in the way when skewering the rings

The physical model was created and tested at a basic level to assess its physical capabilities. Upon the first test it was proven that this design caused more issues than solutions in terms of the problem at hand.

Practical issues with the Long arm mechanism:

1. Raising a ring caused the center of gravity to shift making the robot tilt forward even when only one ring was on the arm
2. Thickness of the ring caused the arm to not be able to reach down far enough to unload the rings
3. The ring measured almost 20 centimeters causing any turn of the robot at the wheel base to cause drastic change in the positioning of the arm tip.

We deemed our prototype unfit for further testing and decided to attempt a completely new design for the retrieval of the rings. Below is the description of the new design and a summary of its structure.

6.3 Week 3:

Due to our design failure in week 2 we needed to reassess the approach we were taking and consider the possibility that none of our three designs were ideal to move forward with. As a group the "Catcher & Sweeper" design was created became our best option for hardware design.

6.4 Week 4:

After thoroughly testing our 'Catcher & Sweeper' design this week. One major problem we faced was that our after navigating from the start point to the tree, the arms would shake and move out of place such that it was almost impossible for the taco-counter in the actuating motor to keep track of them. There was always some 'play' within the gears that would misalign with the upper part of the ring. So we decided to completely eliminate the gear assembly and the arms moving up and down and fixed them firmly to the robot.

Instead what we have implemented is that our hook rotates counterclockwise to load the rings onto the arms and they move clockwise to unload them at the base. This way our robot achieves all the tasks necessary without any over complicated designs.

Now, instead of the arms aiming directly for the top part of the rings loop, they're placed such they aim for the lower part of the loop. This way even if the arms are misaligned, the chances of them catching the ring have greatly increased.

6.5 Week 5:

After testing our new design that we came up with during the 3rd week, we realized that even after immobilizing our catchers at the front, sometimes due to the varying diameter of each ring, we weren't able to skewer them and the robot would push the entire tree forwards.

Therefore, we decided to place the catchers slightly below the current level. This way the chances of the rings falling onto the catchers would increase drastically.

Besides that, we previous encountered the problem of the rings falling off the catchers due to sudden changes in velocity. To counter that problem, we have placed a small connector at the front of each catcher so that rings do not fall off due sudden changes in velocity.

Thirdly, whenever we passed through a tunnel our light sensors placed on either side of the robot would slightly brush against the tunnel. This slightly tempers with our heading and in some cases one of the tire would start riding the tunnel thus throwing us completely off course.

To fix that issue, we placed our light sensors at the front. This also helped with light localization since the robot would require less area of localize.

6.6 Week 6:

Finally after thoroughly testing the capabilities and limitations of our 'Catch and Sweep' concept that we came up with during the 3rd week, we realized that even after immobilizing our catchers at the front, sometimes due to the varying diameter of each ring, we weren't able to skewer them and the robot would push the entire tree forwards.

Therefore, we decided to place the catchers slightly below the current level. This way the chances of the rings falling onto the catchers would increase drastically.

Besides that, we previous encountered the problem of the rings falling off the catchers due to sudden changes in velocity. To counter that problem, we have placed a small connectors at the front of each catcher so that rings don't fall off due sudden changes in velocity.

Thirdly, whenever we passed through a tunnel our light sensors placed on either side of the robot would slightly brush against the tunnel. This slightly tempers with our heading and in some cases, one of the tire would start riding the tunnel thus throwing us completely off course. To fix that issue, we placed our light sensors at the front. This also helped with light localization since the robot would require less area of localize.
For the week, as placing the robot through every situation, we observed that the catcher arms would hit the walls of the course while taking tight corners. Therefore, we moved the entire rig backwards such that it now rises above the center of the EV3 brick. This way the robot is compact without altering any of the capabilities.