

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 way points to retrieve rings off of 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 outline 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: medium, Large NXT, Large EV3. 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.

2.2 Sensors

The most important sensors available in the kit that we going to use are Ultrasonic sensor, Gyro sensor, and Light (Color) sensor. 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.

The gyro sensor measures the angle and angular velocity of the robot. We did not use it yet, but we may use that when needed later.

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

2.3 Brick

The brick 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.

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

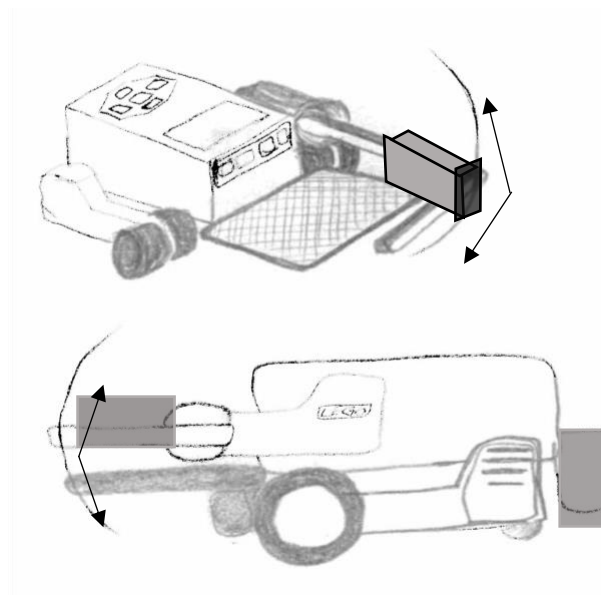
This section describes three of our designs, their sketches, and pros and cons. That will provide a clear overview of our design choices before reached a tentative final design.

4.1 Arm and basket mechanism

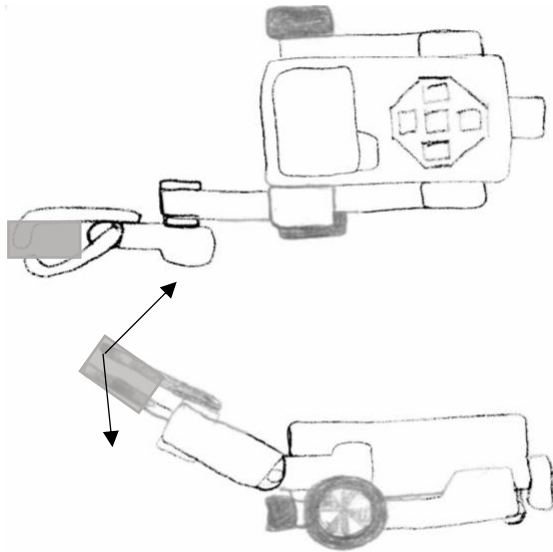
Our first prototype consists of a long arm that can go around the ring and ‘hug’ it. Upon reversing, the ring falls into the basket placed in front of the robot. There is a light sensor placed on the arm to detect the color of the ring.

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

Pros of Design 1	Cons of Design 1
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



4.2 Claw mechanism



The second prototype 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 a long arm that can fold over the robot and extends 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.

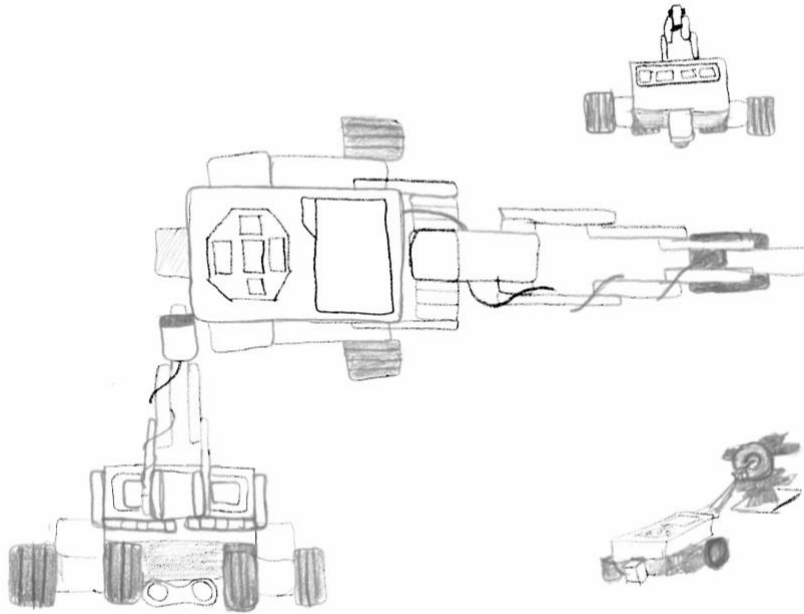
Unlike previously, the ultrasonic sensor is placed between the wheels facing forwards for US localization and obstacle avoidance.

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.

Pros of Design 2	Cons of Design 2
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.
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4.3 Long arm mechanism



The basic mechanical and hardware design of the robot is very similar to the design used in previous labs. The sketch shows a long arm that can fold over the robot and extends forwards to detect the colour 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 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.

Pros of Design 3	Cons of Design 3
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

Features

This design is best visualized in figure 2 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 the top and 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 turning the positioning of arm-tip experienced in the previous design. The rotational motion of a single motor mounted above the brick is translated through a total of 6 gears into the “catchers”. This mobility of the arms would allow for 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 and low to the ground allowing for ultrasonic localization at the beginning of the test.

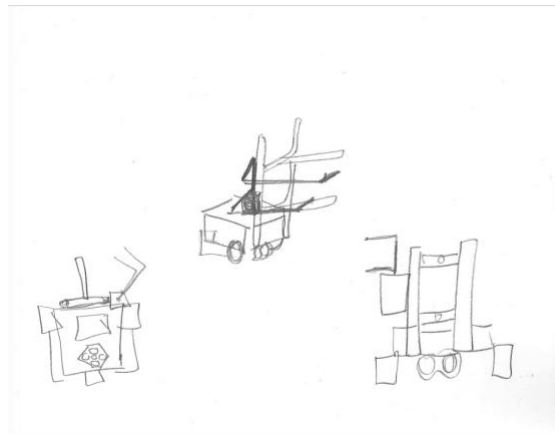


Figure 1: preliminary concept

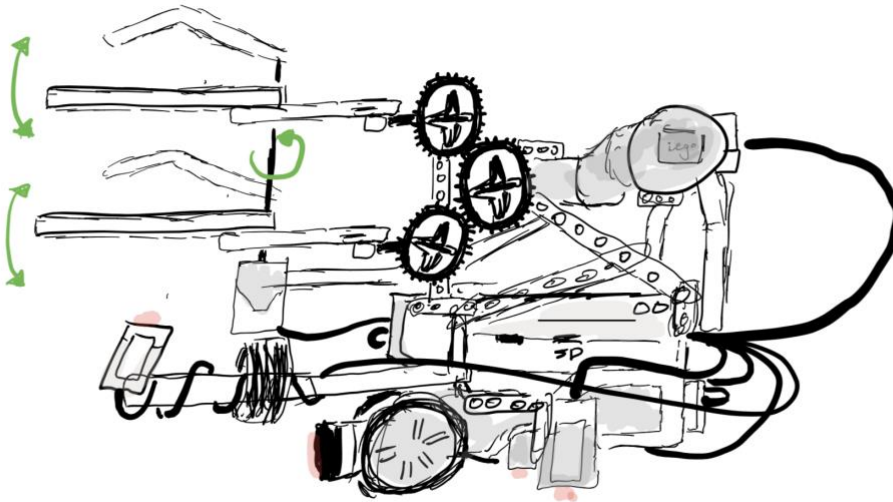


Figure 2: Realistic conceptual sketch

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 best visualized in figure 3 below. 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 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.

Now we have firmly attached the catchers to the front of the robot instead of mobile ones. Like our previous design, we have two arms for the top and bottom ring. The catcher arms are mounted directly above the wheel base thereby reducing the effect of turning the positioning of arm-tip experienced in the previous design.

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.

Pros	Cons
The catchers don't wiggle about their position.	The rings may fall off if there is a sudden change in inertia.
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 4 below. Previously we have been using a very similar design but after extensively 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 during week 4. 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.

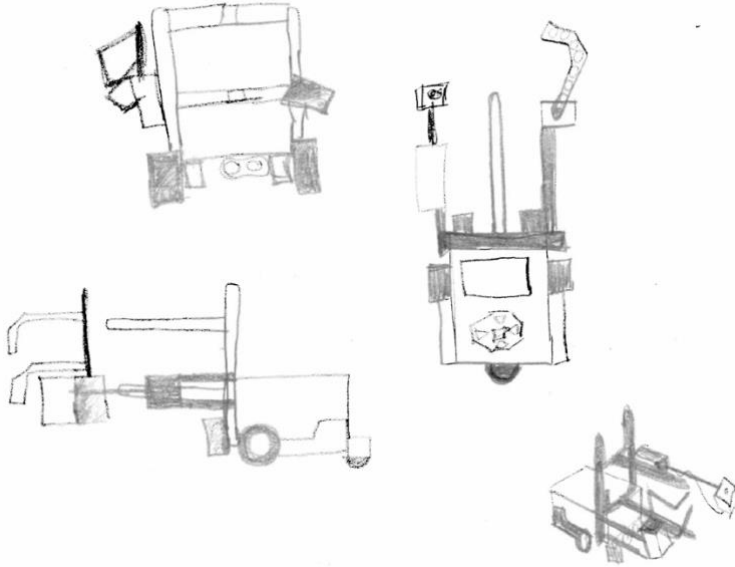


Figure. 4

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.

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 we have placed two arms in front of the robot that are fixed and a sweeper and load and unload the rings.

5.0 Idea selection

5.1 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 from the top of the tree. This inconsistency in results given the most ideal of circumstances caused this idea to be rejected.

5.2 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 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 mobility of the arm is restricted by the ring hitting the ground or other parts of the robot.

Thirdly, the light scanner might get in the way when skewering the rings.

5.4 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 Design 5

Adoption criteria for design 5:

After much consideration we decided as a group that the 'catch and sweep 2' mechanism would be the best approach to take for this task. 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 mobility of the arm be restricted by the ring hitting the ground or other parts of the robot.
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.

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.

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 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.

