ECE 578: INTELLIGENT ROBOTICS I

Homework # 4: Final report

Marek A Perkowski

Khalid Alkhulayfi – 962247665

Kaa2@pdx.edu

Introduction

In this project I have been asked to control the bending and the rotation motions of the Marie-Curie body. It is a very challenging task since it has more mechanical work than programming. However, working with robotics should involve a lot of mechanical ideas to make the robot work as good as possible.

This report go over all steps into making the bending and the rotating motion of the robot. It also includes all the ideas that I have tested. In addition, it states most of the issues that I have faced during my work, and the solved problems that might benefit whoever is going to do the same work.

Marie-Curie previous design

The robot that I am working on is called the Marie-Curie that you can see in figure#1.

Figure 1 Marie-Curie with old body design

The robot has been built by a lot of materials that is hidden under the dress. Figure#2 shows the materials that are used to build this robot. It has the capability to rotate, but not to bend.

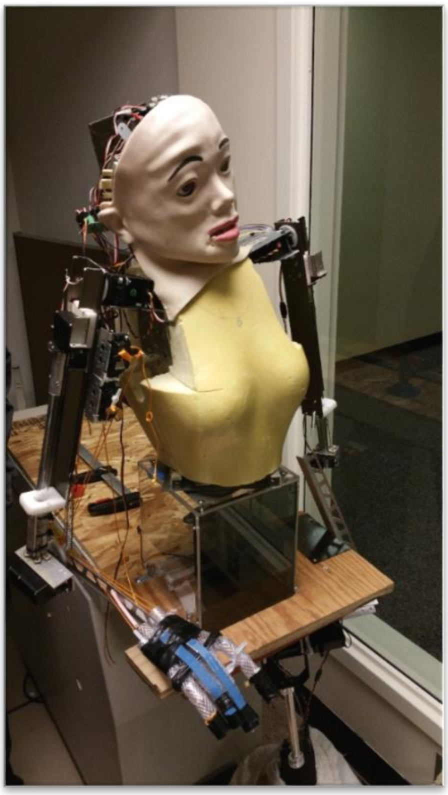

Figure 2 Marie-Curie with old body design – without dress

The project goal

The goal of this project is to build a body that is able to rotate and able to bend to look at the cat. The design should be robust in order to be used for many years.

The starting point

I have spent some time to decide whether I should use the old design that has the rotation motion or I should build the whole robot from the beginning. If I chose to use the old design, I have to find a way to add the bending motion to that old design and fix it to be able to rotate.

Starting from zero is easier than changing a design that is already built to do something else. In addition, building new robot body will have a lot of steps and a lot of details that I have to deal with. However, it will result in having a very robust robot that is capable of doing the tasks that it is designed for. Therefore, I have decided to build a new body that is able to rotate and bend. Moreover, it should be able to carry arms, neck, and head.

Body proportions

Figure#3 shows the proportions of the body and all the other parts in the body.

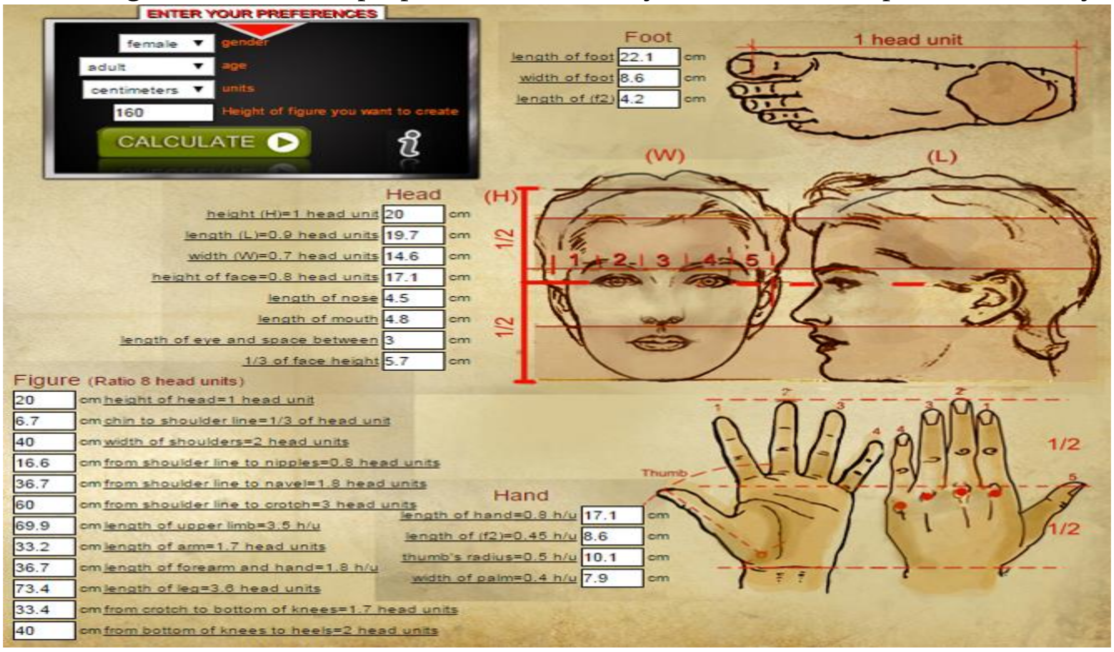

Figure 3 body proportion calculation

Using a dressing mannequin

Figures# 4 and 5 shows a mannequin that I have found to build the robot. It have a very wide space inside that will be enough to fit all wires and boards. It is exactly 60 cm high which is the right proportion of the robot body. In addition, it is separated into three main parts that will make working with the body easier. However, it does not have a strong support (Skeleton) inside the body that will hold arms, neck, and head.

Figure 4 the mannequin – from side

Figure 5 the mannequin – from front

Building the skeleton

Having a skeleton inside the body is very important to support the body that will carry the weight of the arms, neck, and head. Since the skeleton needs a base to set on, I have started on cutting the base from a think wood. Then I built the skeleton from three pipes that are attached to the base of the body. Next, I drilled two holes in the top of the three pipes to insert the wooden dowels that will hold the arms. Figure#6 to 8 shows the final shape of the skeleton.

Figure 6 the skeleton - from inside the body

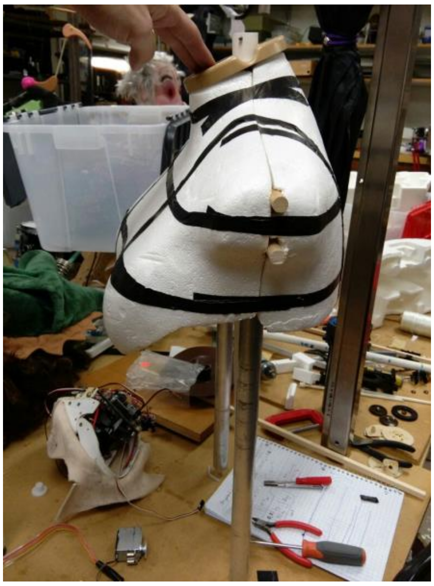

Figure 7 upper body with the skeleton - from the side

Figure 8 upper body with the skeleton - from the front

Rotation design

Since there is a fixed base under the body, I wanted to use it in the rotation motion. The first idea that came to my mind was the way the boat works. It uses a motor at the end of the boat to rotate to the left or to the right. I thought that if I attach a servo to the base of the body, the body will be rotated by using a gear in the fixed base. Figure# 9 shows the two gears A and B where A is the servo gear and B is the gear that is fixed to the wood under the body.

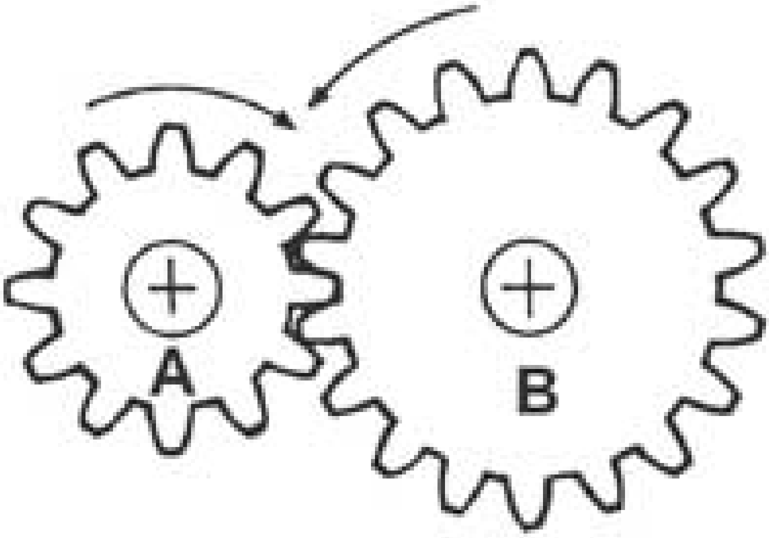

Figure 9 two gears

This idea words very well. However, because I need more space in the body I switched the servo and the gear places. Figure# 10 shows how I fixed the gear under the body.

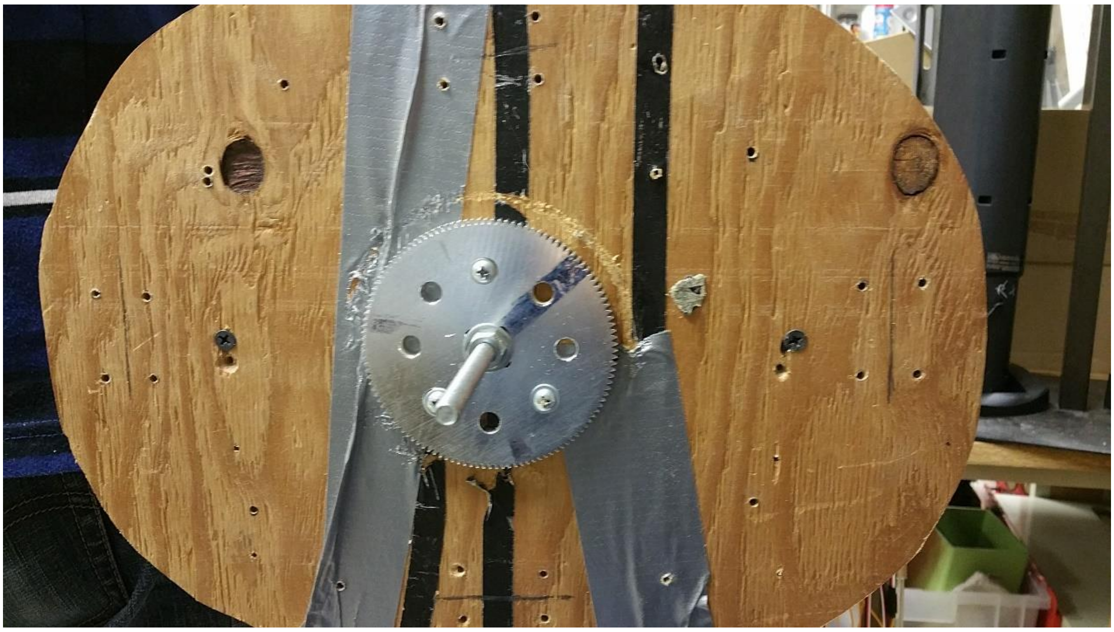

Figure 10 the driven gear under the body

The servo now is fixed to the wood under the body. However, these two components are not enough to make the body balanced. I have used a long screw to hold the gear with washer and nut as shown in figure# 10. This will act as a center when the body rotates. In addition to that, I used four wheels to make the body balanced. Figure# 11 shows the wheels.

Figure 11 the used wheels

However, using four wheels is not as quiet as I thought it is very noisy. In addition, sometimes it blocks the body from rotating. Thus, I found something called Lazy Susan. It is used to make the turntables. Its diameter is 12 inches which makes it capable of carrying up to 1000 pounds. Figure# 12 shows the Lazy Susan.

Figure 12 the Lazy Susan

Attaching the Lazy Susan is a tricky thing to do. Its center should match the center of the body in order to make the body rotate on it. In addition, you should measure where the servo gear should be placed from the center of the Lazy Susan. This is a very important step to make the servo able to rotate the body a full circle rotation. Figure# 13 shows the wood base with the servo and the Lazy Susan.

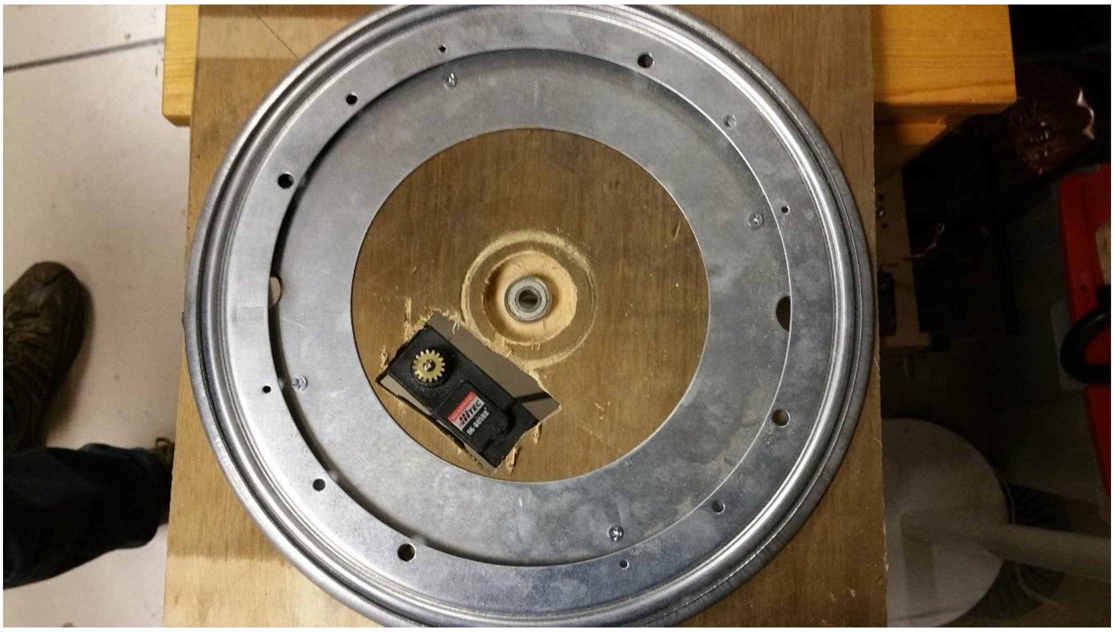

Figure 13 the wood base - from the top

Attaching the body to the Lazy Susan is another tricky thing to do. As soon as you put the body on the basement you cannot screw the Lazy Susan to the body. The solution to that, is to make a hold under the basement where you can screw the Lazy Susan to the body from the bottom. Figure# 14 shows the holes that allows you to screw the Lazy Susan to the body.

Figure 14 the two holes under the wood base

I have used two bearings and nuts to hold the shaft (long screw). This will insure that the two bearings are not going to become too tight or too lose when the body rotates. Figure# 15 shows the space between the body and the basement.

Figure 15 the space between the body and the wood base

Another issue that I have faced during the installation of the Lazy Susan was the very narrow space between the two wood. The space between the two wood should be the same height of the Lazy Susan as shown in figure# 15. In that narrow space I should have the gear and the gear horn of the servo. In fact, it is 5/16 inches (0.3125 inches = 7.9375 mm). That can be solved by using the drill bit forstner which make bigger holes in the wood to put the bearing and the nut as shown in figure# 13. Figure# 16 shows a picture of the drill bit forstner.

Figure 16 the forstner drill bit

Bending design

The goal from bending the body is to make Marie-Curie able to look at the cat. It can happen if Marie-Curie body can bend forward. This can be achieved by using a pulley in the shoulders that will hold the rope that is fixed to the back of Marie-Curie. Then it can be pulled by two winch servos placed under Marie-Curie body. However, this idea might work, but it will miss up the body proportions. In addition, there should be another two winch servos to pull the whole body back. Another issue is can the winch carry the whole body with arms, head, and neck.

Since using pulleys is not going to be as good as I want, I thought of using a gear with a rack. As shown in Figure# 17, the gear is going to be the servo horn, and the rack is going to act as a ladder. The gear is going to move the servo up and down on the rack. Since the servo is attached to the bottom of the body it will carry the body up and down. The problem with this design is that it does not have enough torque to carry the body up.

Figure 17 gear with a rack

The last idea to bend the body was the Monster Torque that can generate a lot of torque. Figure# 18 shows how it look like.

Figure 18 the Monster Torque

After I found out how it works and I knew that it is very expensive, I decided to build it by myself. However, I should make sure first that the body is bendable. To make that happen I added the universal joints to the three pipes in the skeleton. Figure# 19 shows the universal joints.

Figure 19 the universal joints

Next, I took the skeleton out and started cutting the pipes. Then I inserted the universal joints and screw them in each pipe. Figure# 20 and 21 shows how each pipe should bend.

Figure 20 the pipe with the universal joint - straight

Figure 21the pipe with the universal joint - bended

Putting all three pipes together will make the body bend forward. Figures# 22 and 23 show how the three joints should look like when I bend it forward.

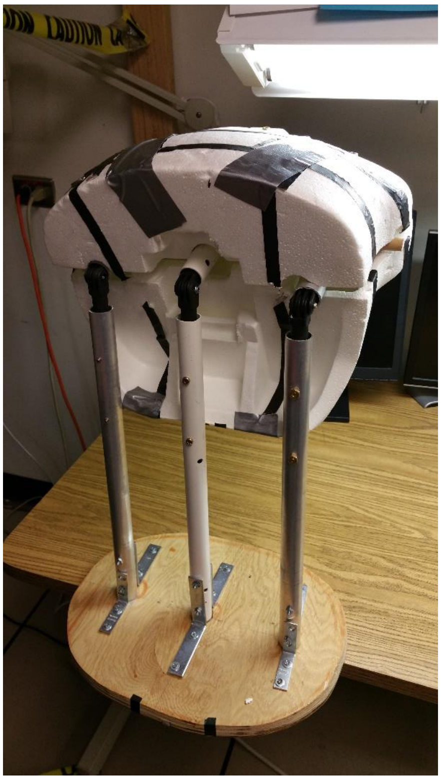

Figure 22 bending the body forward – the upper part

Figure 23 bending the body forward - full body

Designing the Monster Torque

The Monster Torque is a device that uses a servo with gear to increase the servo's torque. By understanding how it works I can make it to carry as much as I need. The first step to make it is to measure the weight of all the components that are going to be attached to the body. However, because my team are working with the arm and the neck in parallel, I could not measure their weight. Therefore, I will consider the worst case, and try to calculate the weight of them in that case.

From my experience on working on the leg, the weight is approximately 2 kg. The head of Marie-Curie is ready and its weight is about 1.5 kg. However, the neck is not ready, but my teammate knows what is going to be on it. Therefore, I calculated the weight of every item and I got a total of 1 kg. Thus, the whole weight that the device should carry is 6.5 kg.

The next step is find where the weight is going to be applied. I have designed the arms to be carried by two wooden dowels. This means that the weight is going to be applied in between the two wooden dowels as shown in figure# 24. The first wooden dowel is 6.6 cm far from the center of the gear, and the second one is 10.6 cm. Thus, the average of the two distances is 14.05 cm.

Figure 24 the space between the two wooden dowels

To calculate the actual torque that is needed to carry 6.5 kg I had to do some research and experiment the calculation. I concluded that in order for the device to move the whole weight, I have to double that weight and calculate the torque for it. In this case the device will carry the 13 kg without dropping it. This means that the device is able to move the 6.5 kg very easily without losing speed. Using the following equation, I calculated the torque of the device.

$$Torque = Force * Distance * Sin\theta$$

$$Torque = 13\ kg * 14.05\ cm * Sin\ 90 = 182.65\ kg.cm$$

After I know that the device should carry 182.65 kg.cm in order to move the upper half of the body up and down, I have to choose a servo and calculate the gear ratio for the two gears. I found that the most powerful servo in the lab is the HS-805BB it has 24.7 kg.cm at 6 v and 19.8 kg.cm at 4.8 v. Now, I can use the following equation to calculate the gear ratio.

$$Device\ Torque = Gear\ ratio * Servo\ torque$$

Substituting for the torque by 182.65 kg.cm and servo torque by 24.7 kg.cm I will get 7.4 ratio of the two gears. Since the gear on the servo is the one that moves the larger gear it is called the driving gear and the bigger one called the driven gear. The ratio of the two gear should not be less than 7.4, and it is calculated by dividing the number of teeth of the bigger gear by the number of teeth of the smaller gear.

In the lab I found a gear with 120 teeth, and I had to look for a horn gear that fits the servo and has at least 16 teeth. I found exact number of teeth on a gear horn that also have the same pitch number of the big gear. The pitch for both of them is 32.

As soon as I knew the gear ratio, I could calculate the speed of the device. It depend on the speed of the HS-805BB servo at 6v which is 0.14 sec/60° as shown in the following equation.

$$Device\ Speed = Servo\ speed * Gear\ ratio$$

$$Device\ Speed\ at\ 6 = 0.14\ sec/60° * 7.5 = 1.05\ sec/60°$$

I have made an excel file that do all the calculation to get the number of teeth in the big gear which is the driven gear. You only need to enter the weight that you want to carry, the distance where the weight is going to be applied from the center of the driven gear, servo torque and speed at low and high voltage, and the number of teeth in the driving gear (the servo gear). The next table shows how the excel file look like.

	Monster Torque motor calculation	Values	
input using high voltage	The weight that you are trying to move	6.50	kg
	The distance between the center of the gear and the force	14.05	cm
	The torque of the used servo at high voltage	24.70	kg.cm
	The speed of the used servo at high voltage	0.14	sec/60
	The number of teeth in the servo horn	16.00	Tooth
calculations using high voltage	Torque at the distance that the motor should carry	13.00	kg
	The motor torque	182.65	kg.cm
	The gear ratio for the two gears at high voltage	7.39	
	The motor speed for the servo at high voltage	1.04	sec/60
	The number of teeth in the driven gear at the high voltage	118	Tooth
input using low voltage	The weight that you are trying to move	6.50	kg
	The distance between the center of the gear and the force	14.05	cm
	The torque of the used servo at low voltage	19.80	kg.cm
	The speed of the used servo at low voltage	0.19	sec/61
	The number of teeth in the servo horn	16.00	Tooth
calculations using low voltage	Torque at the distance that the motor should carry	13.00	kg
	The motor torque	182.65	kg.cm
	The gear ratio for the two gears at low voltage	9.22	
	The motor speed for the servo at low voltage	1.75	sec/61
	The number of teeth in the driven gear at the low voltage	148	Tooth

In the above table, I made it very easy to just enter the fields that are colored by blue. Then you should see the calculations in the green field. The only thing you should care about is the orange field which is the number of teeth that the driven gear should have.

In some cases, the number of teeth in the gear is too high. You might not able to find it or it is too big to your project. In that case you should play with your inputs. You can try to make the load less heavy or decrease the distance between the center of the gear and the load point. Another thing that you can do is to find a more powerful servo.

The most effective way is to increase the gear ratio. You can do that by finding a smaller gear horn for the servo. This will increase the gear ratio which eventually is going to allow you to have the same torque with smaller gears. Adding more gear is a bad idea because the gear which you are going to use between the driving gear and the driven gear is going to ensure that they rotate in the same direction. However, it is not going to affect the gear ratio. In fact, using more gears means that you are going to increase the gear friction which is going to reduce the power. This is called gear train as shown in figure# 25.

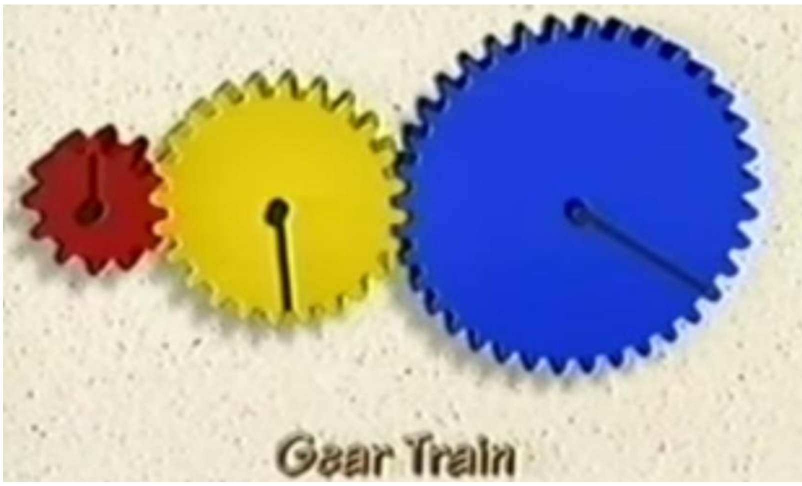

Figure 25 gear train

However, if you used a different gear train called compound gear train, you can increase the gear ratio significantly. Figure# 26 shows how the compound gear train look like.

Figure 26 compound gear train

Building the Monster Torque

Building the Monster Torque by myself gave me a lot of experience in using the tools in the shop. I had to use the right tools to get the best result. Figure# 27 and 28 shows the final shape of the device.

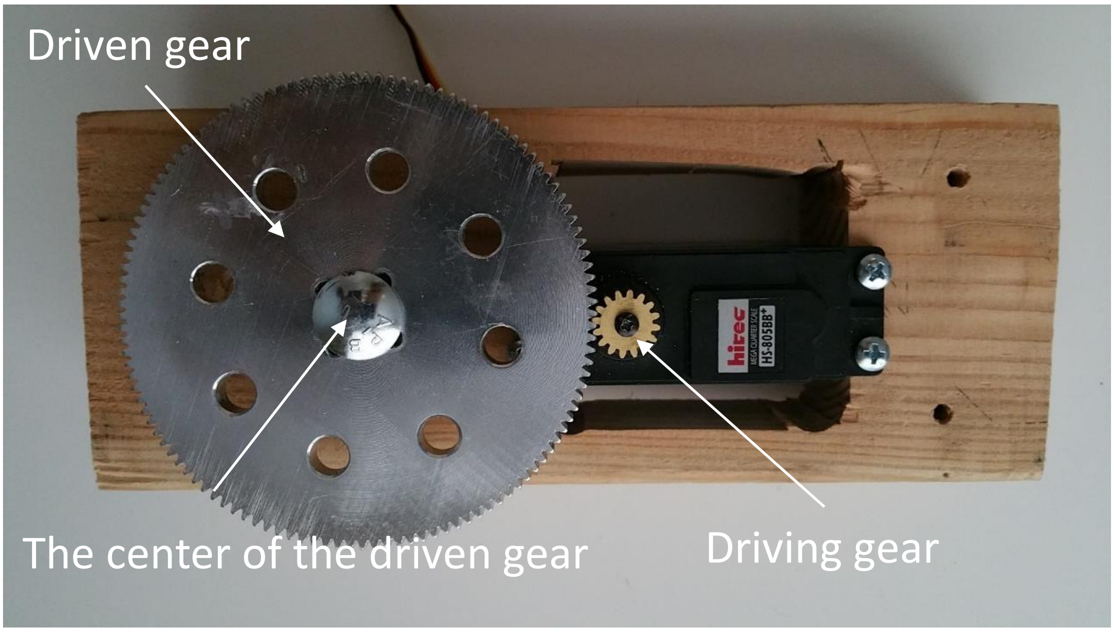

Figure 27 the Monster Torque - from the top

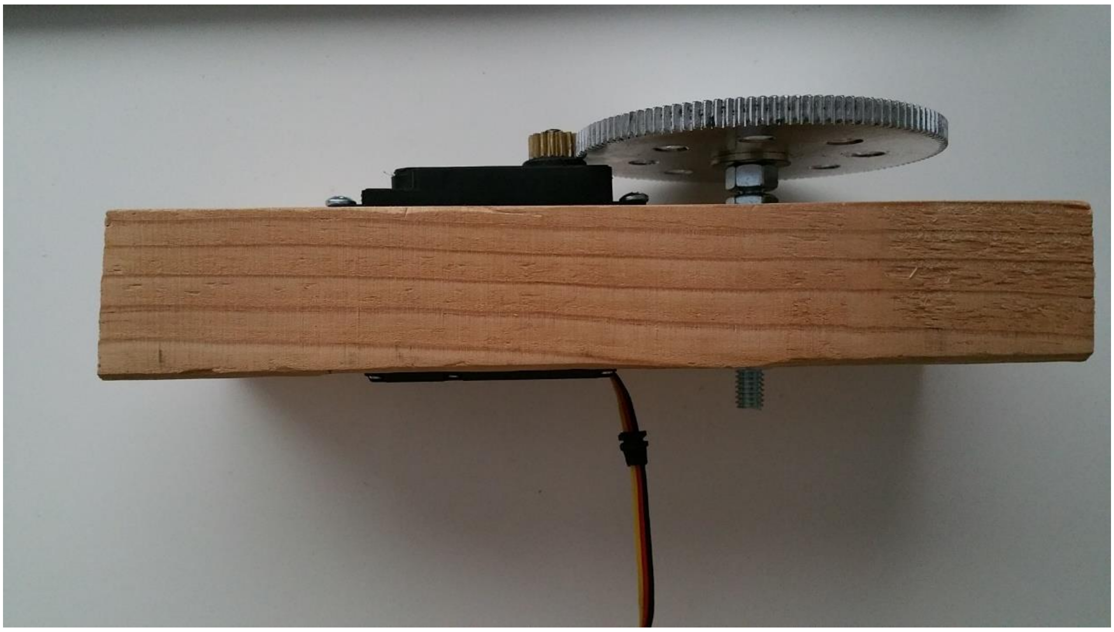

Figure 28 the Monster Torque - from the side

First, I start making the hole for the servo and I made it very wide in case I need to change the servo position. Then I made a wide channel for the gear shaft, so it can move back and forth. Making the channel this wide, helped me to change the servo. In addition, it allows me to increase the tension between the two gears. Figure# 32 shows the shape of the channel.

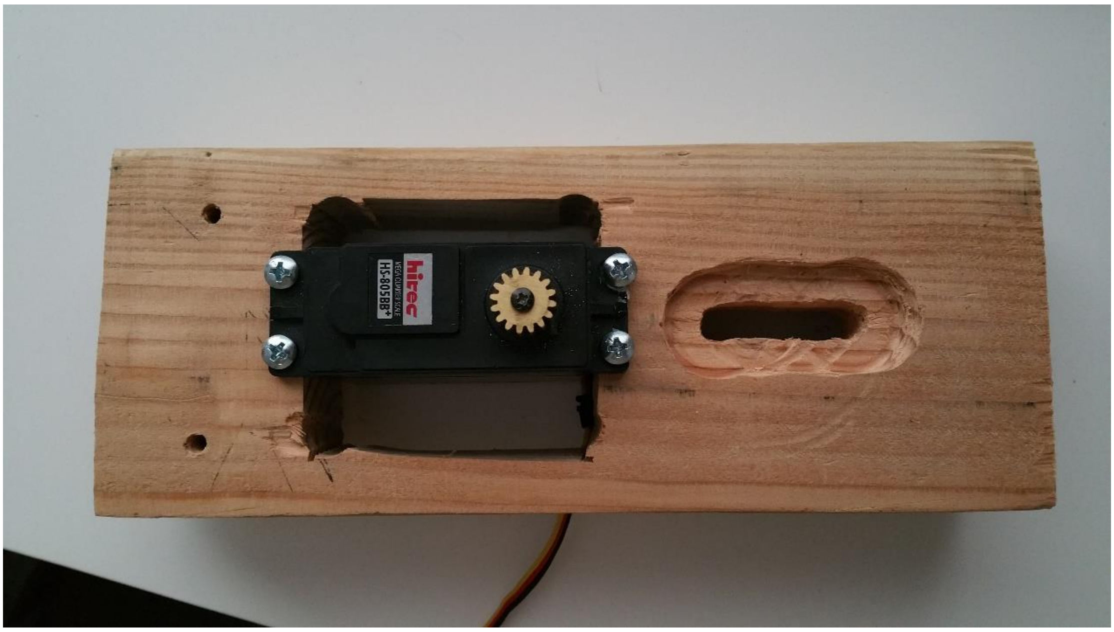

Figure 29 shaft channel

After the base of the device is done, I started making the driven gear. I inserted the long screw into the gear. Then I hold it with a washer and nut. Next, I used two nuts and two bearings to hold the gear to the base. Figure# 30 shows how I sorted them in the shaft.

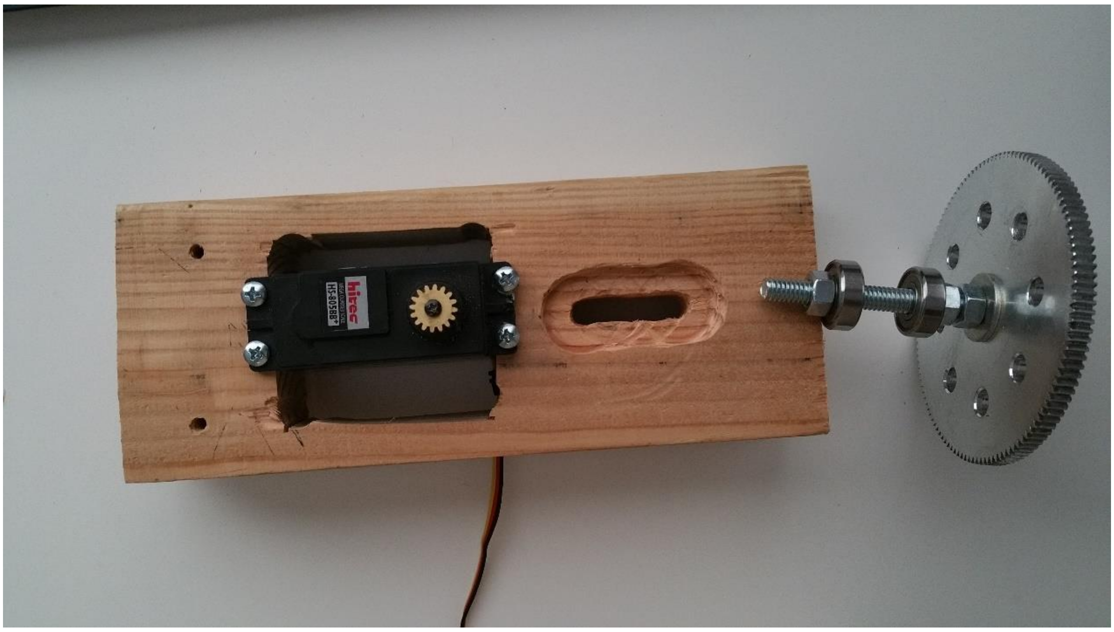

Figure 30 the shaft of the driven gear

Using the bearings is very important to allow the shaft to move without changing the place of the nuts. Without the bearings the two nuts will change their places, and they might make the shaft lose or more tight to the base and prevent the gear from rotating.

Another thing that might affect the smooth transfer of power from the driving gear to the driven gear is the gear pitch. The two gears must have the same pitch number in order for them to transfer the full power. Sometimes the two gears will not fit if they have different gear pitch number. Figure# 31 shows the point where the two gear transfer the power. This might not be possible if you have to gear with different pitch numbers.

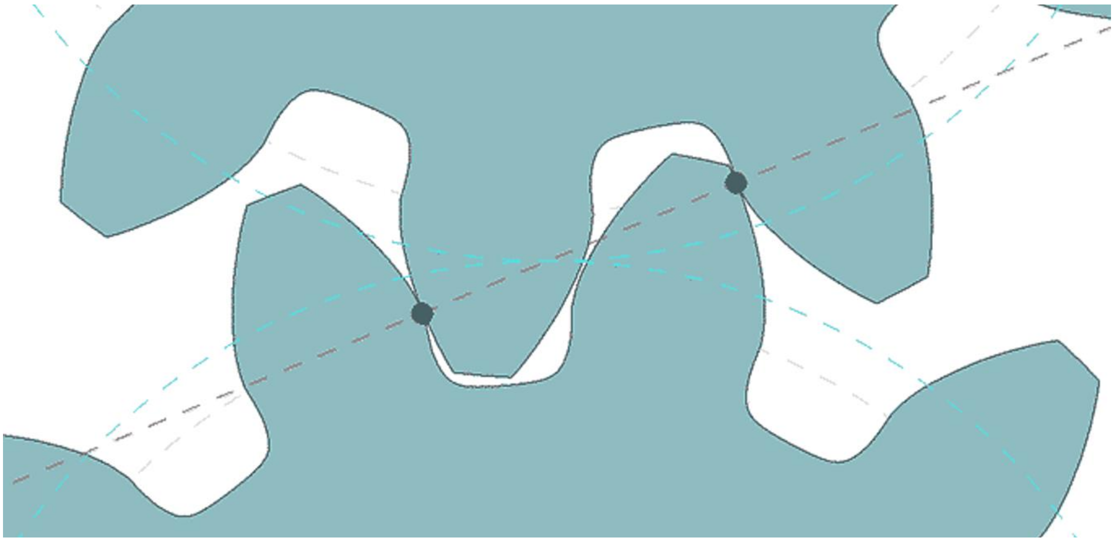

Figure 31 the points where the two gears contact

In my design of the Monster Torque, the driven gear has 120 teeth and the driving gear has 16 teeth. This means that the driving gear is going to rotate 7.5 times to complete one rotation of the driven gear. This can only be accomplished by using continues rotation servo. This made me to open the servo and cut the piece of plastic that blocks the servo from having a full rotation. In addition, I had to adjust the servo potentiometer to the center to let the servo brain think that the horn is in the middle. Figure# 32 shows the servo gears from inside.

Figure 32 the servo gears - from inside

Before buying the horn gear for the servo, you should have a look of the type of the spline gear in the servo. For the HS-805BB the gear type is 1D Heavy Duty Spline. Figure# 36 show the different types of gears.

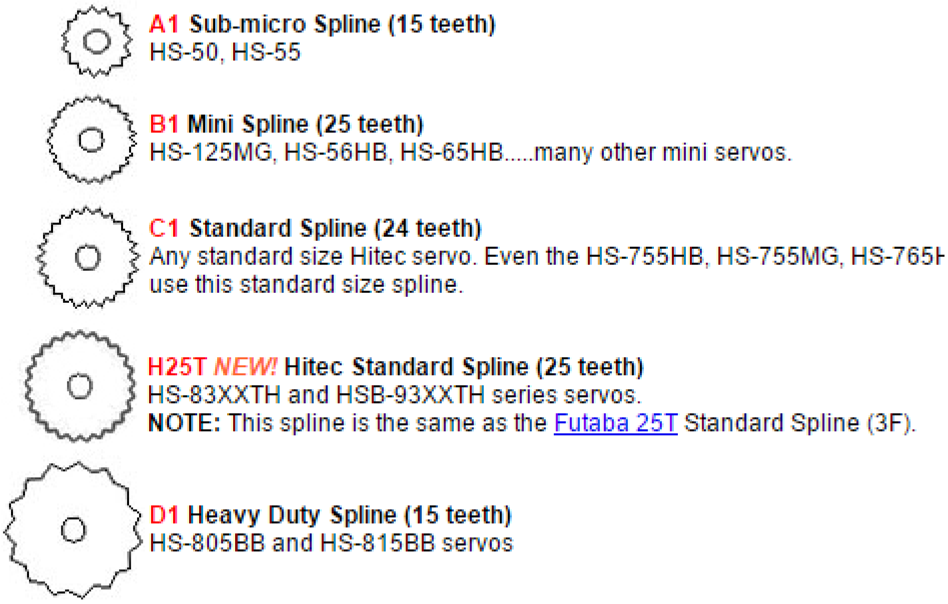

Figure 33 the different types of gear spline

Bending the body using the Monster Torque

Integrating the Monster Torque with the body is more complicated than I thought it would be. I started with a pipe holder and my hand to hold the device in place as shown in figure# 37.

Figure 34 first use of the Monster Torque in the body

The problem with attaching the driven gear to the pipe in this way is that the gear is tending to push forward from one side and backward from the other side. This made the device work very weekly since the two forces are cancelling each other. The solution for that is to use two consecutive holes in the gear. Therefore, I used wood with zip-ty to hold the gear, and using another type of pipe holder to hold the device as shown in figure# 35.

Figure 35 using the Monster Torque in the body with wood and zip-ty

Using zip-ty made the pipe very lose and a lot of the power were lost because of it. In addition, the base of the device was not been held in place very well. It pushes the pipe back. Therefore, I used screws to hold the gear and wood from each side of the pipe. However, it broke down after the first test because of high torque that in device generate. Figure# 39 shows how the wood broke.

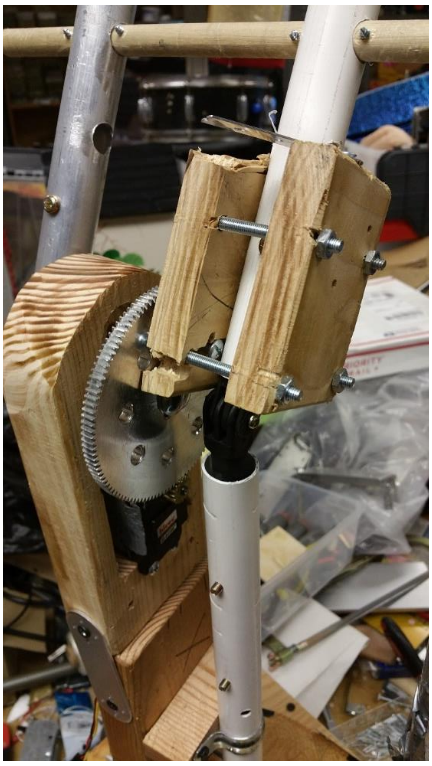

Figure 36 using the Monster Torque in the body with wood and screws

To fix that, I used a plastic to hold the gear to the pipe. In addition, I used another long 2 by 4 wood that will hold the device from moving backward. To make the body very rigid, I connected the three pipes with each other in two different points using long threaded rods. Figures# 37 to 42 shows how the skeleton look like after I fixed it.

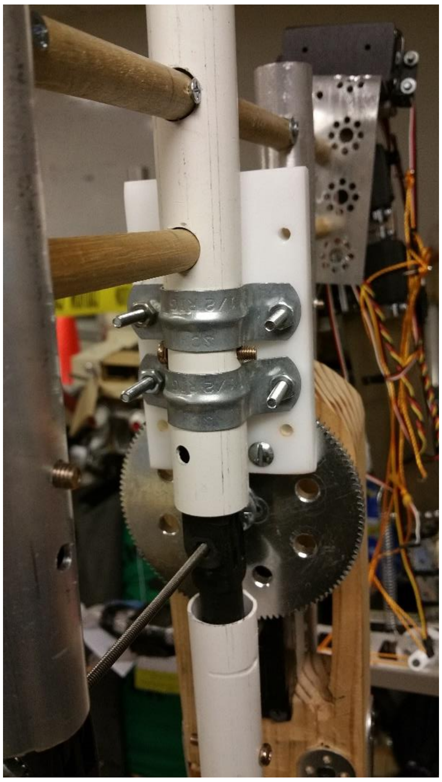

Figure 37 the plastic piece that holds the gear to the pipe

Figure 38 the plastic piece that holds the gear to the pipe

Figure 39 the support for the device

Figure 40 the long threaded rod at the center of the body

Figure 41 the long threaded rod at the center of the bending point

Figure 42 the device with the long threaded rods and the plastic piece

Attaching the arms

For holding the arms I used two wooden dowels that have pilot holes. I used two long dry screws to hold the arm. Figures# 43 and 44 shows where the two screws go and the wooden dowels.

Figure 43 the holes in the two wooden dowels

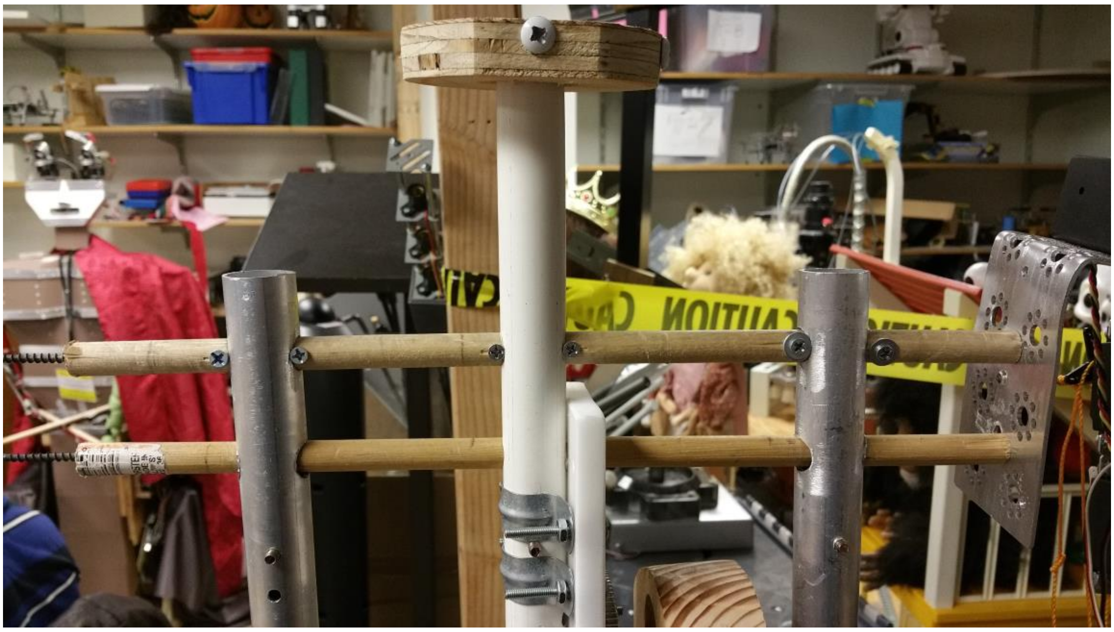

Figure 44 the two wooden dowels

The final place for the new Marie-Curie

Now, Marie-Curie body is more rigid. It is also able to bend forward and carry the whole load back to the straight back position. In addition, it can rotate 360. Although this does not sound like a human, it is a robot and it can do more what a normal human can do. Figure# 45 shows the final shape of the robot with the head and arms.

Figure 45 the final shape of the robot with head, arms, and leg

The final weight of the body is 3.55. That include the skeleton, the base, and the Monster Torque. Figure# 46 shows what is included in the total weight of the body.

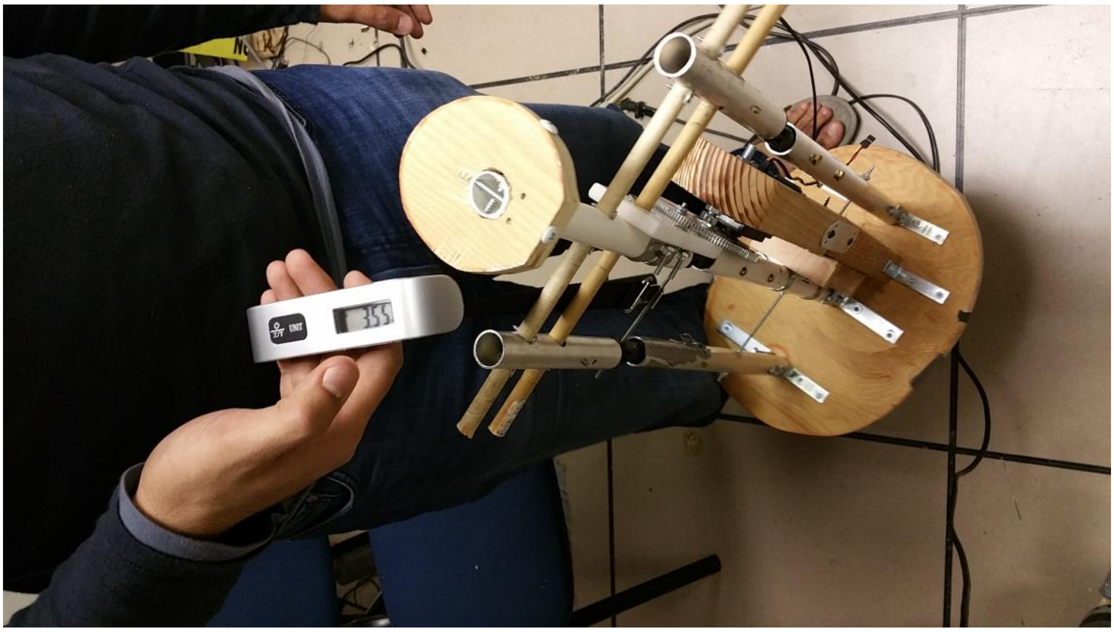

Figure 46 body weight

Controlling the bending and the rotation motion using Pololu

The Pololu Maestro Control Center has more tools than what I need to control the two servos. It has a sequence of commands that can be sorted to control the servo. Figure# 47 shows the sequence of commands used in the demo.

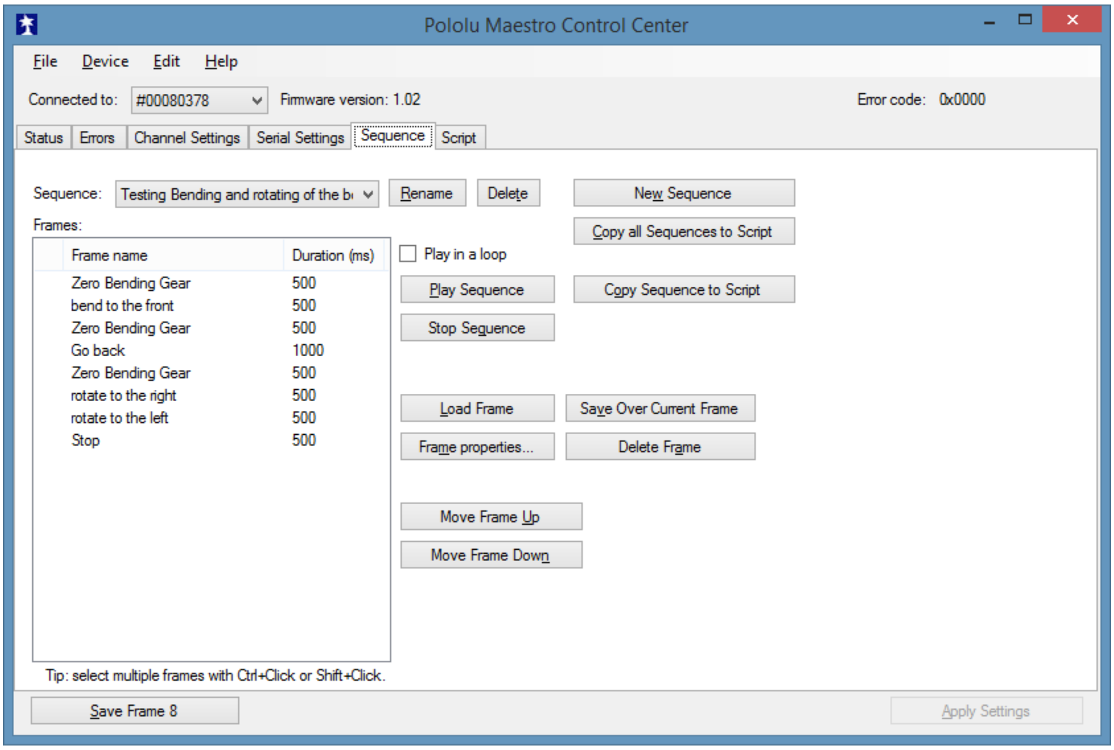

Figure 47 the Pololu Maestro Control Center

Additional touch to the robot

Since this body is going to be used for many years later, I have cut the back of the body. This will provide an easy access to the components inside the body. In addition, there is enough room for all the other components needed to control the robot. Figure# 48 shows the back of the robot.

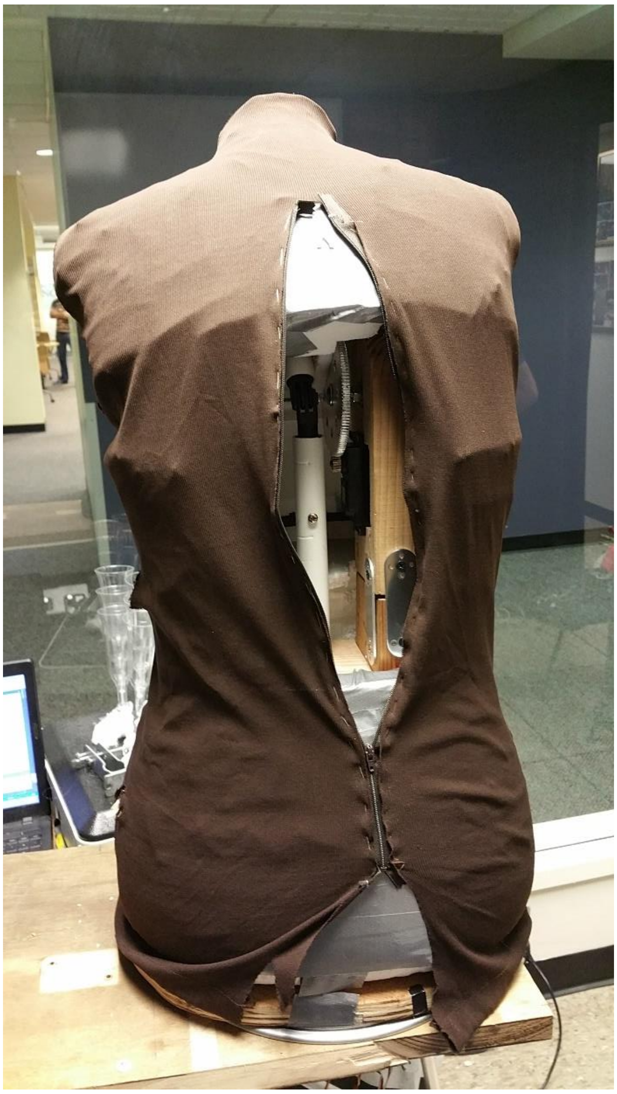

Figure 48 the back of the robot

Cost

Item name	Price
Duct tape	7.42
Zipper	2.49
Horn gear + gear	35.93
Long screws with nuts	1.3
Lazy Susan	15.52
Servo brackets + C brackets	65.17
Power supply	14.99
Servo Extensions	6.95
Horn gear	22.94
Drill bits forstner	16.97
Total	189.68

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