SYSTEM REPORT

GROUP Yamaha YK800XGP

Bolong Tan

Electrical and Computer Engineering | ELEC 391 | Apr 7, 2022

Abstract

A robot arm is developed. The robot arm consists of a base, two arms, two motors, two worm gears, two face-mount crossed-Roller bearings, two sensors, one pcb board and one Arduino board.

In this paper, section one discuss the mechanical design of robot arm in detail. Robot arm is evaluated from structural, covers, interfaces, components, stress& strain, cable routing perspective. One explosion graph is provided at the end of section one.

Section two discuss the SimulationX model in detail. SimulationX model simulate how robot works and used to test the whole design. The test result of several test cases are discussed.

Section three discuss the application of the robot arm. It is evaluated from the special features, efficacy and cost perspective.

Nomenclature

$	**Canadian dollar**
RCG	**requirement, constraint, goal**

MECHANICAL DESIGN

RCG

We established RCG(shown in table1) for our mechanical model based on the technical details of the product (**Yamaha YK800XGP**).

Table 1

Specification	Requirement	Constraint	Goal
Work space diameter	>=1.1m	-	Max
Design Height	>=700mm	-	Max
Payload	>=15KG	-	Max
Torque	>=50Nm	-	Max
Cost	<=1000 dollars	-	Min

Requirement:

1. Workspaceace diameter should be larger or equal to 1.1m
2. Design height should be higher than 700mm
3. The load that robot arm can carry should be heavier than 15kg
4. The torque that robot arm can produce 50 Nm
5. Cost should be less than 1000 dollars

Goal:

6. Workspaceace diameter should be maximized
7. Design height should be maximized
8. The load that robot arm can carry should be maximized
9. The torque that robot arm can produce should be maximized
10. Cost should be minimized

STRUCTURAL

1. Base support structure for shoulder joint

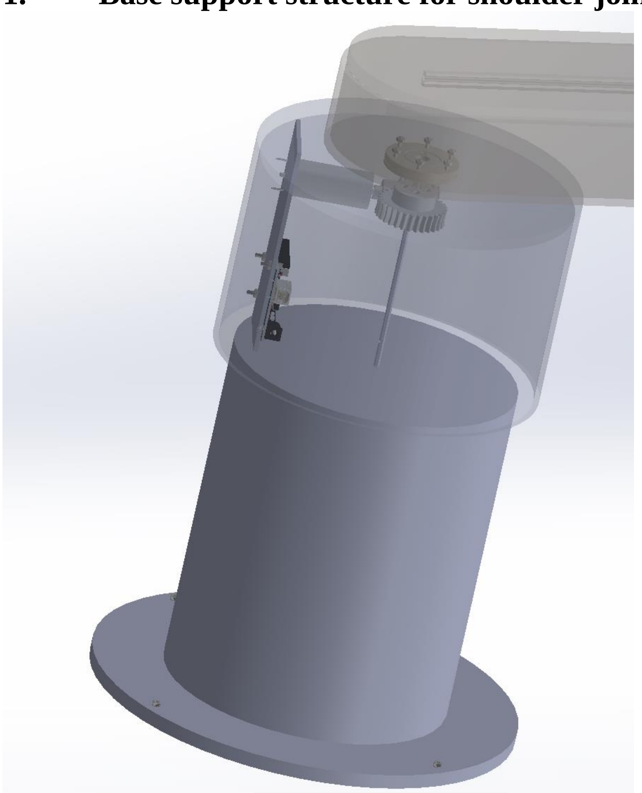
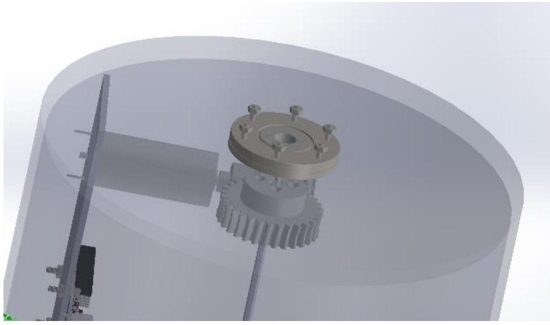


Figure 1 base shoulder

Figure1 shows the overall structure of the base shoulder joint.



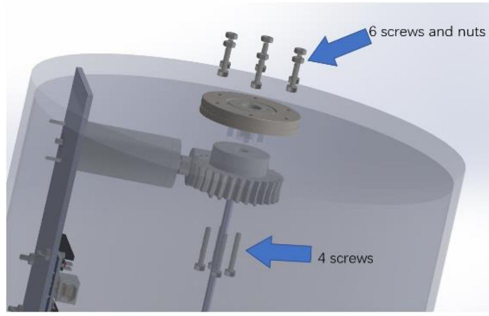


Figure 2 base shoulder

Figure 3

As shown in figure2 and figure3, one face-mount crossed-Roller bearing is used to connect the base and up-Arm. As shown in figure 3, six screws and nuts are used to connect the outer side of the face-mount crossed-Roller bearing and up-Arm. Four screws connect the inner side of the face-mount crossed-Roller bearing and base. The inner side of the face-mount crossed-Roller bearing stays still to the base.

As shown in Figure 3.1, four small holes and one bigger hole are created at the top of the base. Four small holes are used to let four screws go through. The bigger hole is used to let the shaft go through.

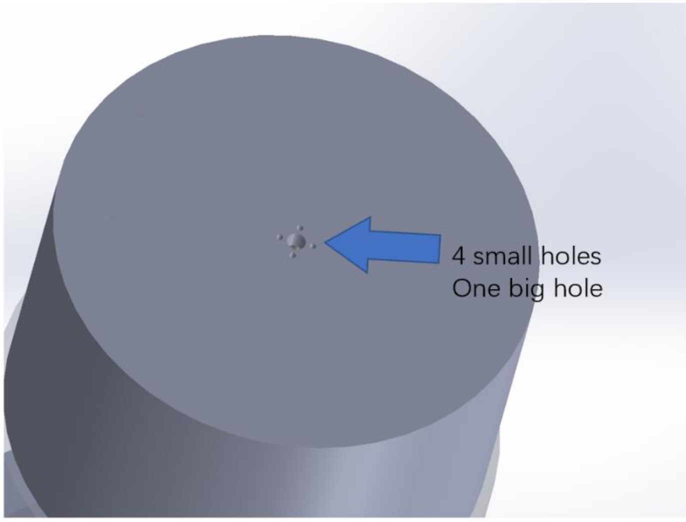


Figure 3.1

2. Up-Arm support structure for shoulder joint

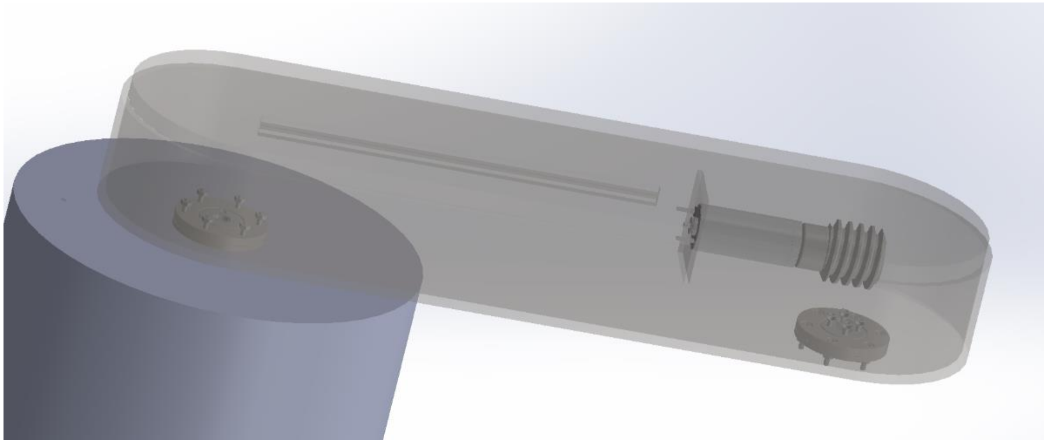


Figure 4

Figure4 shows the overall structure of the up-Arm shoulder joint.

Two face-mount crossed-Roller bearings are used. One face-mount crossed-Roller bearing is used to connect the base and up-Arm. Six screws and nuts connect the outer side of the face-mount crossed-Roller bearing and up-Arm. The outer side of the face-mount crossed-Roller bearing stays still to the Up-Arm. They both rotate at the same speed.

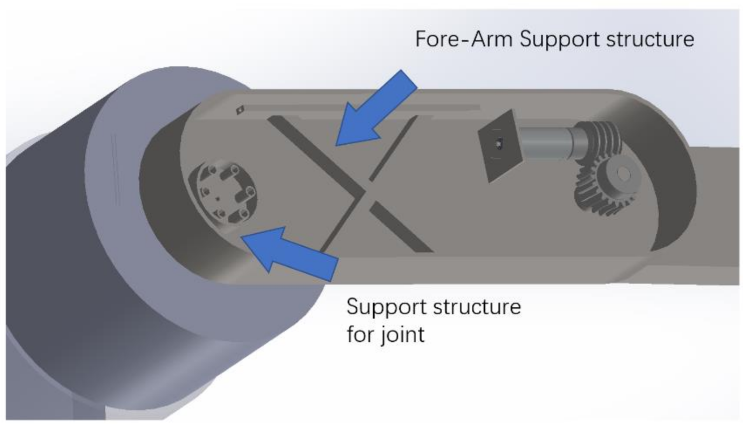


Figure 4.1

As shown in figure 4.1, the support structure is created to increase the structural strength. This support structure can let the shoulder joint withstand more load.

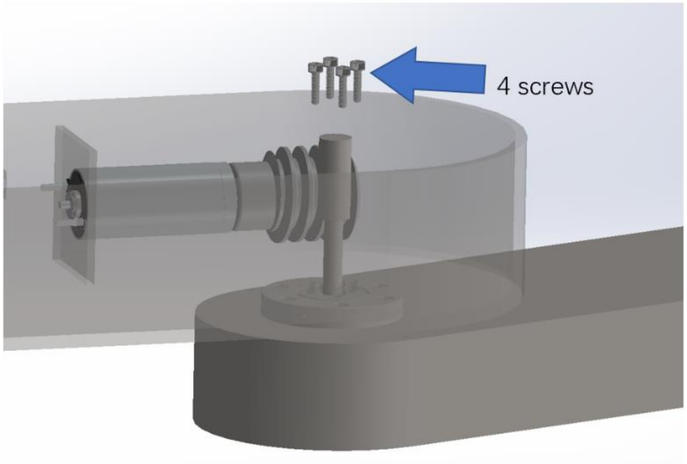


Figure 5

The other face-mount crossed-Roller bearing connects the Fore-Arm and up-Arm. As shown in figure 5, four screws connect the inner side of the face-mount crossed-Roller bearing and Up-Arm. The inner side of the face-mount crossed-Roller bearing stays still to the Up-Arm.

3. Fore-Arm support structure for shoulder joint

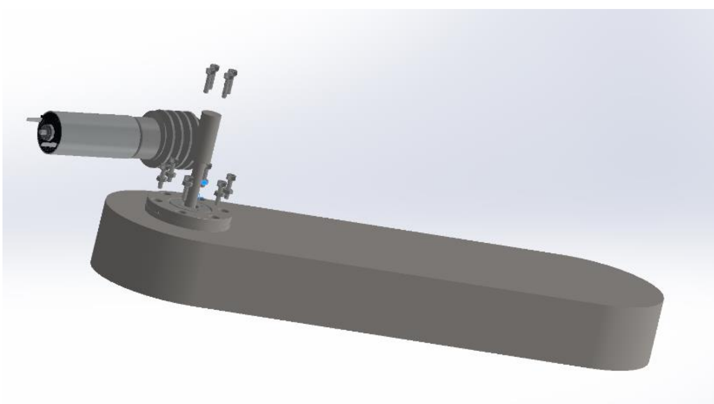


Figure 6

Figure 6 shows the overall structure of the Fore-Arm shoulder joint.

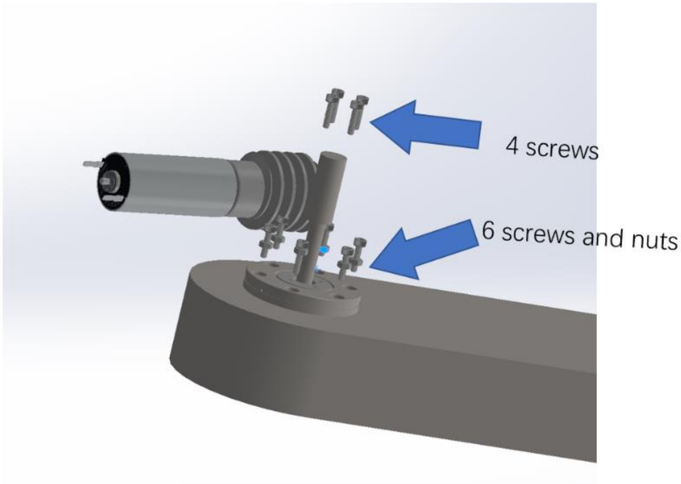


Figure 7

As shown in figure 7, six screws and six hex nuts are used to connect the outer side of the face-mount crossed-Roller bearing and Fore-Arm. The outer side of the face-mount crossed-Roller bearing stays still to the Up-Arm. They rotate at the same speed.

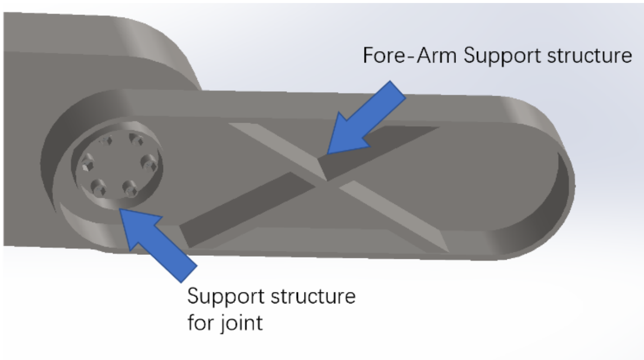


Figure 7.1

As shown in figure 7.1, the support structure is created to increase the structural strength. This support structure can let the shoulder joint withstand more load.

COVERS

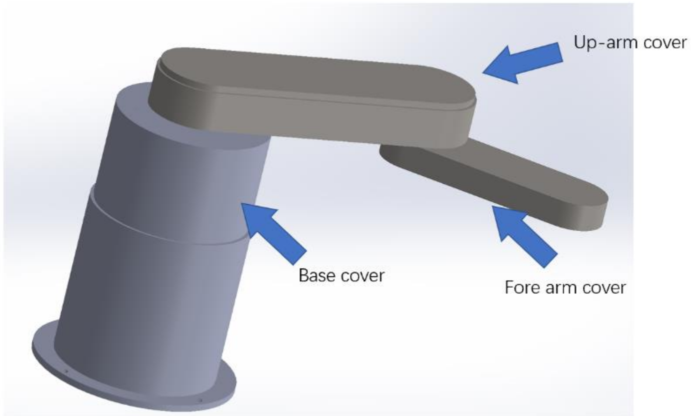


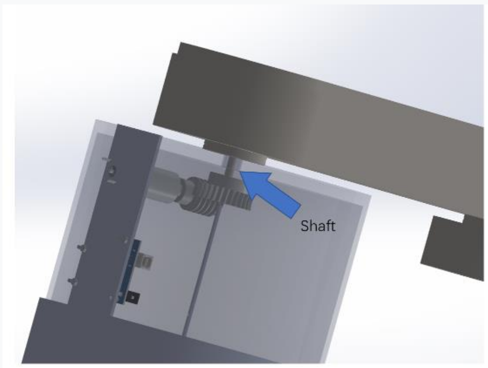
Figure 8

Figure 8 shows the overall covers structure of the design.

As shown in figure8, the base cover is a cylindrical structure that is easy to be manufactured, and that would reduce the manufacturing cost. The upper arm cover and forearm cover have a similar structure. The upper arm cover and forearm cover are made as easy to manufacture as possible. Our team intends to lower the manufacturing cost. Cast Alloy steel is chosen to build the base, up-Arm cover and forearm cover. The reason why Cast Alloy steel is chosen is that Cast steel has the metallurgy manufacturing flexibility and strongest variability. This allows for complex shapes and hollow cross-section parts.

INTERFACES

Shaft connections



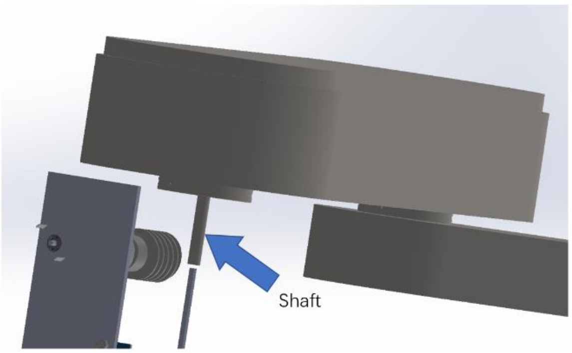


Figure 9 Figure 10

As shown in figure 9 and figure 10, the shaft connected to the worm gear is part of the Up-Arm. The shaft diameter is the same as the worm gear’s shaft diameter. The shaft rotates at the same speed as up-Arm. The motor rotates the worm gear. The worm gear then rotates the shaft and the shaft rotates the up-arm.

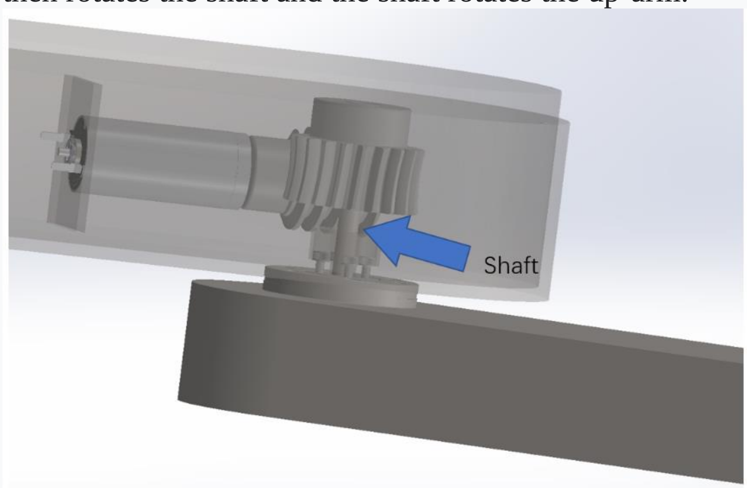


Figure 11

As shown in figure 11, a shaft connected to the worm gear is part of the fore-Arm. The shaft diameter is the same as the worm gear’s shaft diameter. The shaft rotates at the same speed as the fore-Arm. The motor rotates the worm gear. The worm gear then rotates the shaft, and the shaft rotates the forearm.

Base mount

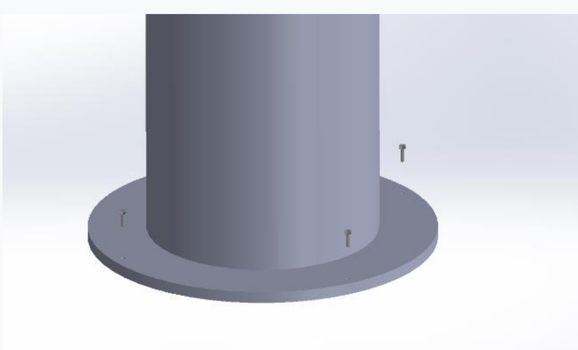


Figure 12

As shown in figure12, the base can be mounted to the ground and the table using four screws.

PCB and Arduino mount

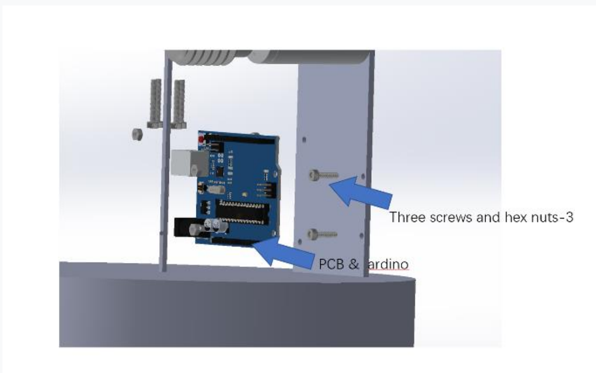


Figure 13

As shown in figure 13, the PCB board and Arduino are mounted to the base using three screws and three hex nuts.

Base and up-arm mount

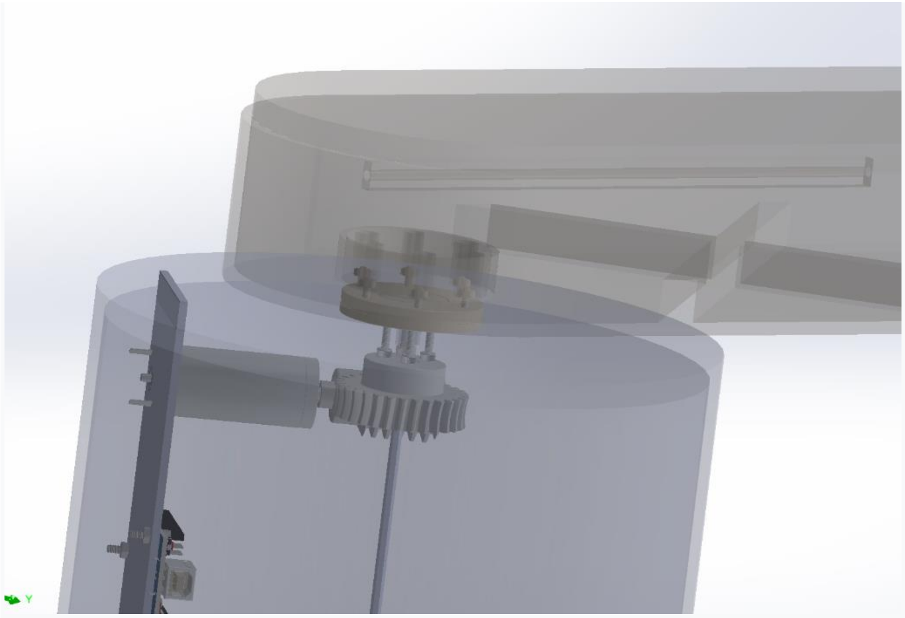


Figure 14

As shown in figure14, a face-mount crossed-Roller bearing is used to connect the base and up-Arm. Six screws and six hex nuts connect the outer side of the face-mount crossed-Roller bearing and up-Arm. The outer side of the face-mount crossed-Roller bearing stays still to the Up-Arm. They both rotate at the same speed. Four screws connect the inner side of the face-mount crossed-Roller bearing and base. As shown in Figure14.1, four small holes and one bigger hole are created at the top of the base. Four small holes are used to let four screws go through. The bigger hole is used to let the shaft go through. The inner side of the face-mount crossed-Roller bearing stays still to the base.

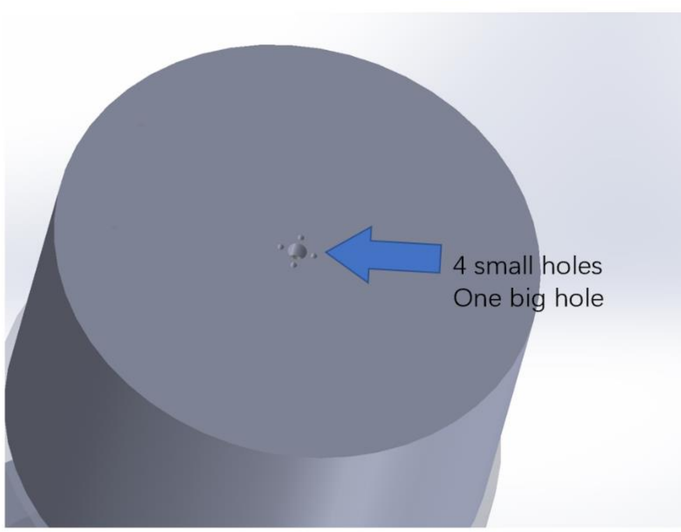
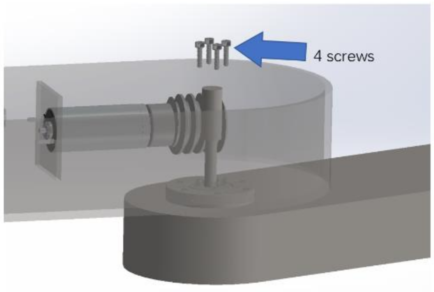


Figure 14.1

Forearm and up-arm mount



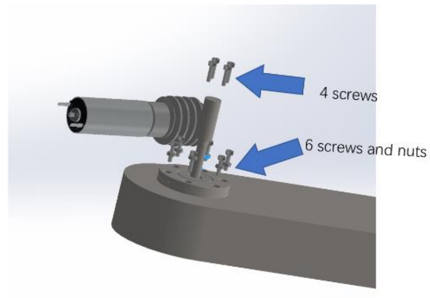


Figure 14.2 Figure 14.3

A face-mount crossed-Roller bearing is used to connect the Fore-Arm and up-Arm. As shown in Figures 14.2 and 14.3, four screws are used to connect the inner side of the face-mount crossed-Roller bearing and Up-Arm. The inner side of the face-mount crossed-Roller bearing stays still to the Up-Arm. Six screws and six hex nuts connect the outer side of the face-mount crossed-Roller bearing and Fore-Arm. The outer side of the face-mount crossed-Roller bearing stays still to the Up-Arm. They rotate at the same speed.

COMPONENTS

We integrated all the necessary electronics and mechanical parts in our CAD model, including:
Screw: 91290A123_Black-Oxide Alloy Steel Socket Head Screw
Nuts: 90592A085_Steel Hex Nut
Motor: DCX26L EB KL 24V
motor selection:

The design aims to pick up a 15 kg load.(two arms combined length is 600mm)

So using the formula J=m*r^2

Load Inertia is: Jload = 15kg*0.6m^2 = 5.4 Nm

Using Solidworks mass property function we get arm inertia is:

Jarm = 0.42136

So the interia that joint 1 can feel is:

Jall = Jarm + Jload = 5.821 Nm

According to our design goal, we want our robot arm's angular acceleration(a) to be 0.25 rad/s^2.

Using formula: torque = Jall* a = 1.4525 Nm

For joint1, we choose to use a worm gear and the gear ratio is 30.

Torque from motor = torque/30 = 0.0485Nm

In this way, we need a motor which can provide 0.0485Nm torque.

So, we choose the DCX26L EB KL 24V motor for joint 1.

DCX26L EB KL 24V motor can provide us 52.30 mNm torque which is higher than the requirement.

Worm gear: 57545K639_Steel Worm & 57545K779_Metal Worm Gear. The gear ratio is 30.
We chose this model of gear primarily based on the consideration of the Torque requirements and Price.
The steel worm is connected to the motor through a shaft.
The Metal Worm Gear is connected to the up-Arm through a shaft.

Worm gear: 57545K644_Steel Worm & 57545K819_Metal Worm Gear.
The gear ratio is 20.
We chose this gear model primarily based on the consideration of the Torque requirements and Price.
The steel worm is connected to the motor through a shaft.
The Metal Worm Gear is connected to the fore-Arm through a shaft.

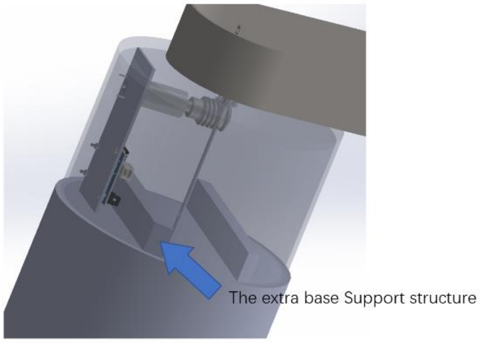
Arduino and customized PCB circuit: Arduino UNO
PCBs and Arduino are mounted on the upper shelf of the Base.

Face-mount crossed-Roller bearing:2010N11_Face-Mount Crossed-Roller Bearing
We chose this gear model primarily based on the consideration of the magnitude of pressure that the base would feel and the Price.

STRESS AND STRAIN

Solidworks built-in SimulationXpress function is used to exam the amount of force each part is able to bear. The test result shows that all part could able to withstand around 234KG of the load. However, the face mount bearing used to connect the two arms would experience a maximum of 200KG of load. So, the **Face-mount crossed-Roller bearing** could be weakest part in our design.

BASE GEOMETRY



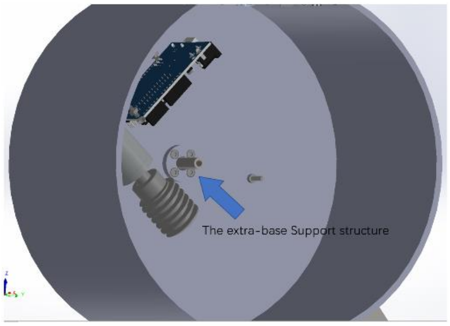


Figure 4 Figure 4.0

As shown in figure4, **the extra base support structure** aims to increase the structural strength of the base. **The extra base support structure** connects the base cover and base. This support structure can let the base withstand more load. The **extra base support structure** shown in figure 4.0 aims to increase the structural strength of the base cover. It is helpful to stabilize the screws which connect the base cover and face mount bearing together.

ARMS GEOMETRY

Up Arm

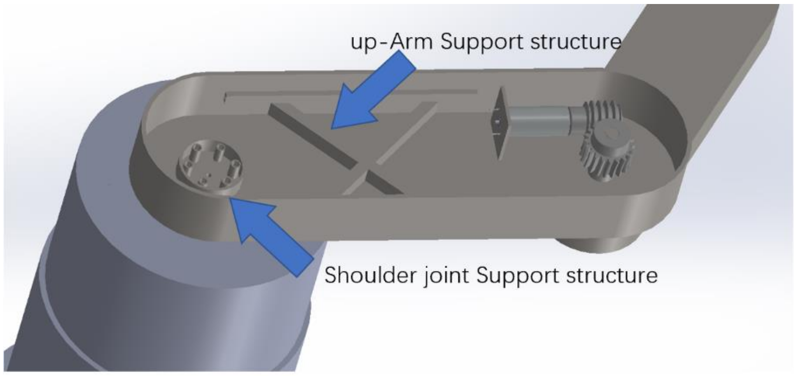


Figure 4.1

As shown in figure4.1, **the support structure for the joint** is created to increase the structural strength of the shoulder joint. This support structure can let the shoulder joint withstand more load. The “X-shape” up-arm support structure shown in figure 4.1 aims to increase the structural strength of the up arm.

Fore Arm

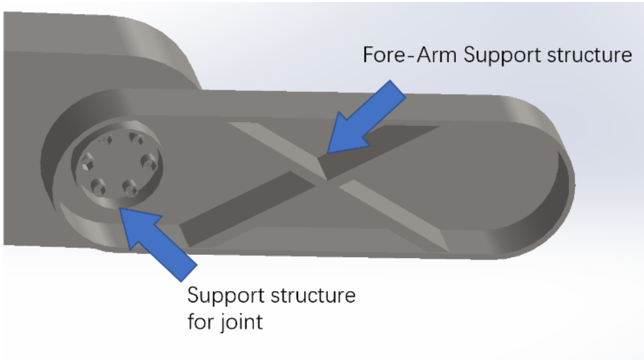
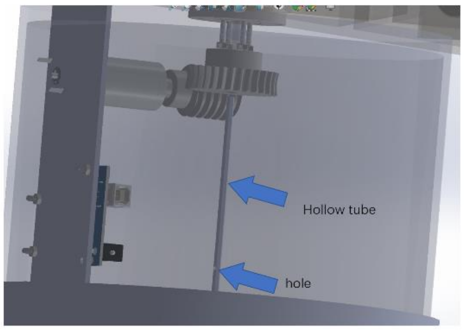


Figure 4.2

As shown in figure4.2, **the support structure for the joint** is created to increase the structural strength of the shoulder joint. This support structure can let the shoulder joint withstand more load. The “X-shape” fore-arm support structure shown in figure 4.2 aims to increase the structural strength of the up arm.

CABLE ROUTING



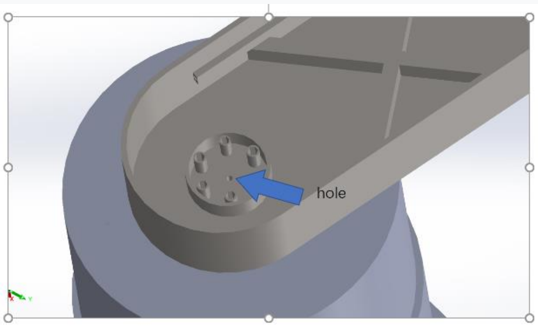


Figure 15 Figure 16

As shown in figure 15, the tube is hollow and there are two holes in the tube. The cable can go through the hole and the hollow tube in figure15 to reach the hole shown in figure16 which is located on the up arm. The hollow tube is located at the center of the base. In this way, when the up arm rotates, the cable would not to be stretched to cause some damage.

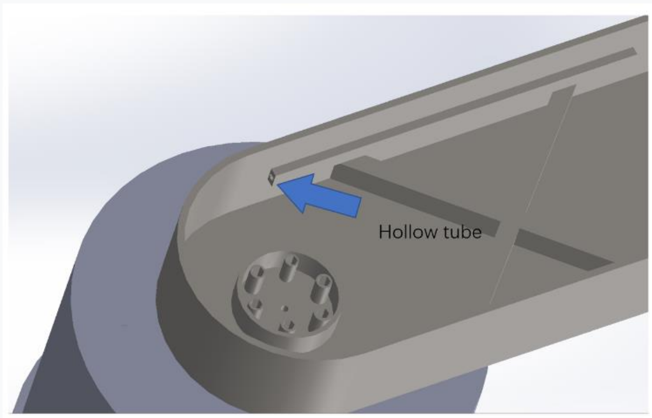


Figure 17

After the cable goes through the hole shown in figure 6, the cable will go through the hollow tube shown in figure 17.

ASSEMBLY

EXPLOSION VIEW OVERVIEW

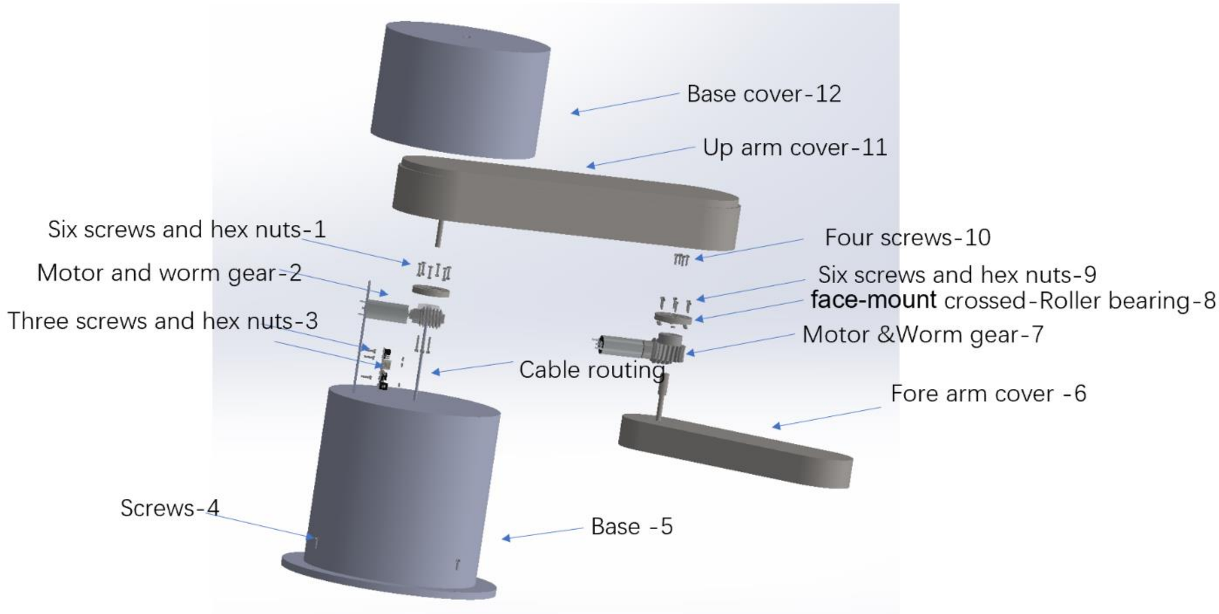


Figure 9 Explosion graph

Figure 9 shows the Explosion graph. All the components used in the design are labeled with a name and numerical number.

Components in Figure9:

Six screws and hex nuts-1:

Screw: 91290A123_Black-Oxide Alloy Steel Socket Head Screw

Nuts: 90592A085_Steel Hex Nut

Motor and worm gear-2:

Motor: DCX26L EB KL 24V

We choose this model of the DC motor primarily based on the consideration of the Torque requirements and Price.

Worm gear: 57545K639_Steel Worm & 57545K779_Metal Worm Gear

The gear ratio is 30.

Three screws and hex nuts-3:

Screw: 91290A123_Black-Oxide Alloy Steel Socket Head Screw

Nuts : 90592A085_Steel Hex Nut

Screws-4:

Screw: 91290A123_Black-Oxide Alloy Steel Socket Head Screw

Base -5:

Base is mounted to the ground using 4 screws (91290A123_Black-Oxide Alloy Steel Socket Head Screw**).**

Forearm cover -6:

Forearm cover was created using Solidwork.

Motor &Worm gear-7:

Motor: DCX26L EB KL 24V

We choose this model of the DC motor primarily based on the consideration of the Torque requirements and Price.

Worm gear: 57545K644_Steel Worm & 57545K819_Metal Worm Gear

The gear ratio is 20.

Face-mount crossed-Roller bearing-8:

face-mount crossed-Roller bearing:2010N11_Face-Mount Crossed-Roller Bearing

Six screws and hex nuts-9:

Screw: 91290A123_Black-Oxide Alloy Steel Socket Head Screw

Nuts : 90592A085_Steel Hex Nut

Four screws-10:

Screws: 91290A123_Black-Oxide Alloy Steel Socket Head Screw

Up arm cover-11:

Up arm cover: Up arm cover was created using Solidwork.

Base cover-12:

Base cover: The base cover was created using Solidwork.

SIMULATIONX DESIGN

RCG

For the SCARA arms, we have two main concerns. First, it should be accurate so that it can be used in an assembly line. Next, it should be fast to be competitive in the market.
Requirement:
- Must be able to settle within 1.5 seconds

Constraint:
- Must not have an overshoot larger than 20%

Goal:
- Minimize settle time
- Minimize overshoot
- Minimize steady-state error

Diagram

The diagram view of the simulation x model is shown in the figure10 below. The torques go through the gearboxes and rotate the joints.

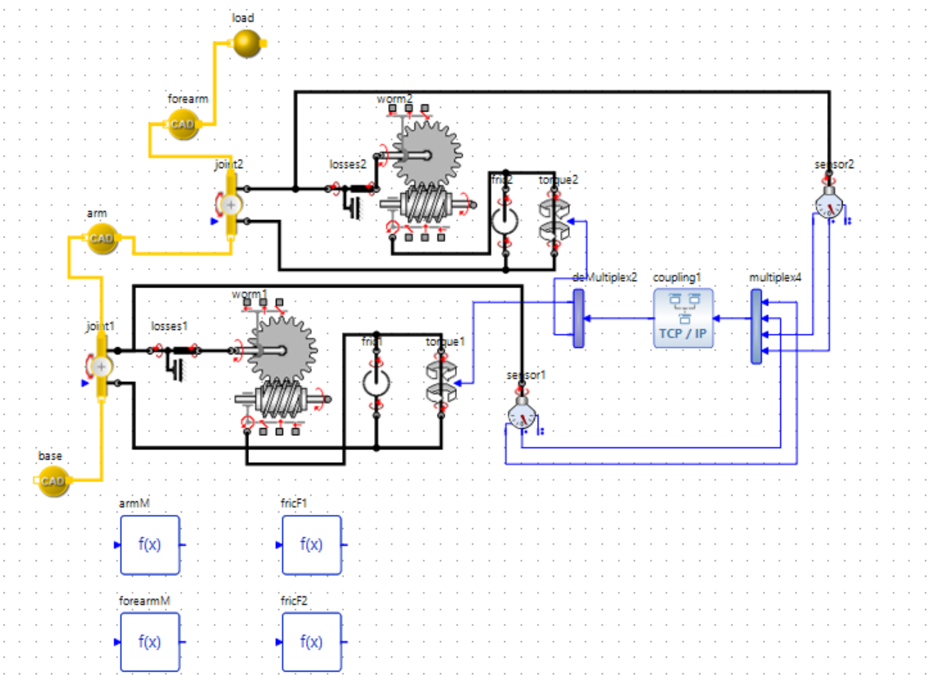


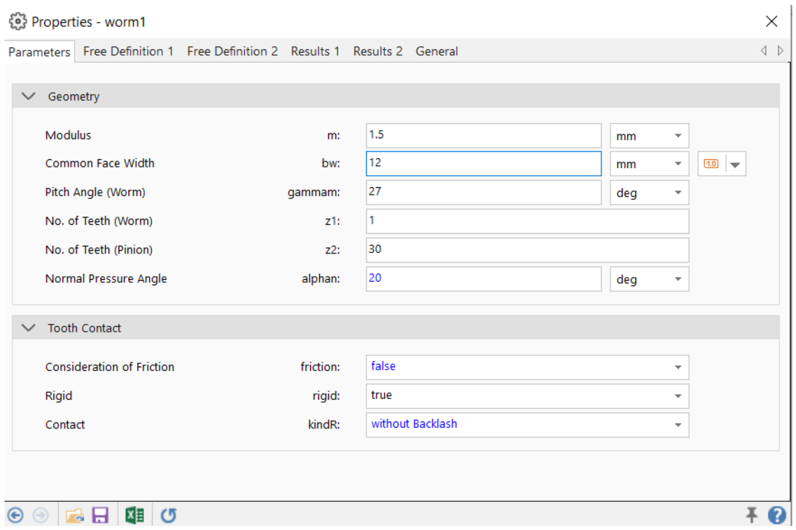
Figure 10

Here, the friction before the gear is the friction of the motor. The friction is 2.1828e-6 Nms/rad (from the motor datasheet).

Worm gears transform the torque along the x-axis to the z-axis and increase the torque to drive the arms.

We used the worm gear model available in Simulation X to simulate the worm and gear system of our design. The figure shows the parameters of worm gear 1 for the shoulder joint1 (30:1). The Pitch angle is inferred to be around 27 degrees because it should be near the normal

pressure angle.



The arm (up-arm), forearm and base are imported as STL files. The inertia and mass are evaluated using SolidWorks. The robot arms are evaluated with motors, gears and bearings installed, so the respective inertia is accounted for.

The joints allow the arms to rotate. We decided to model the joints as ideal no-loss joints because bearings are used to reduce the dynamic friction, and the static friction is given in the Simulink model. More about the bearings are discussed below. Joint 1 drives the up-arm around the base, and joint 2 makes the forearm rotate around the up-arm.

At the end of the forearm, a 1kg load is attached to simulate the working condition of the arm.

The sensors observe the angle and angular velocity of the arms and send them back to the Simulink Co-simulation coupling through the multiplexer. The coupling also gets the torque output of the Simulink model and sends them to the torque block as the torque the system is experiencing.

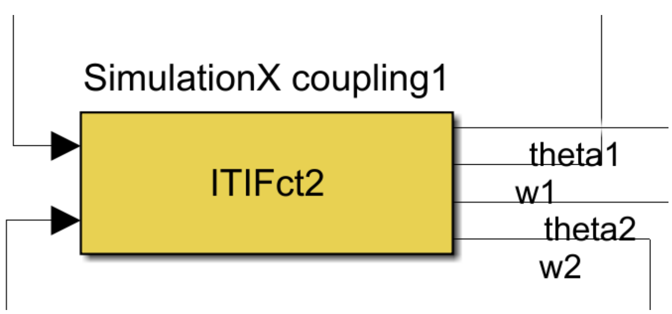


Figure 10.1

As shown in the figure10.1, Simulink receives the output from SimulationX and use these signal to update the model.

ADJUSTABILITY

Some of the parameters are extracted and put into constant returning functions. For example, as shown in the figure10.2 below, the frictions of two joints and the mass of the two arms are factored out and out into functions.

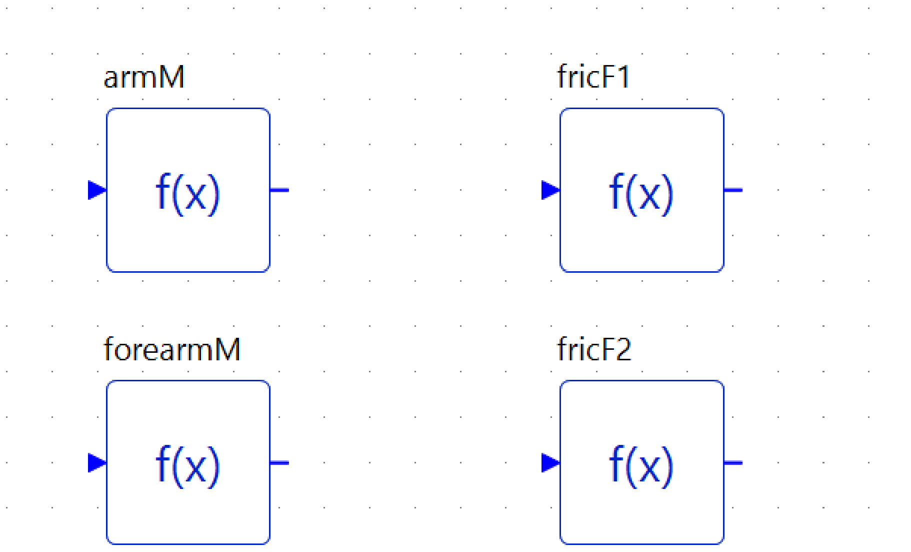


Figure 10.2

This approach allows us to quickly test out the design and adjust the parameters of each component in the system.

RESULTS

Give the up arm a step function input of 2 rad, and the forearm a step function input of 1 rad, the resulted angle of co-simulation is shown as figure 10.3 :

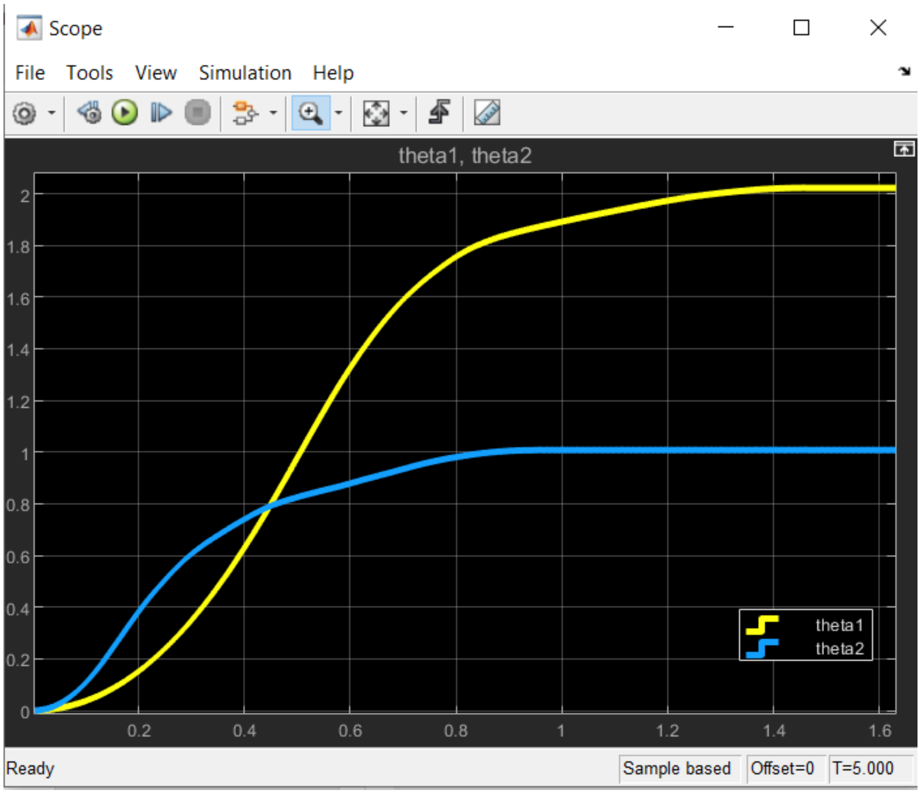


Figure 10.3

The figure shows that the arms settle within 1.5 seconds, which satisfies our goal of settling within 1.5 seconds.

Next, we test the output of inverse/direct kinematics, the arm goes to (0.6,0), (0,0.5), (-0.5,0.2) and back.

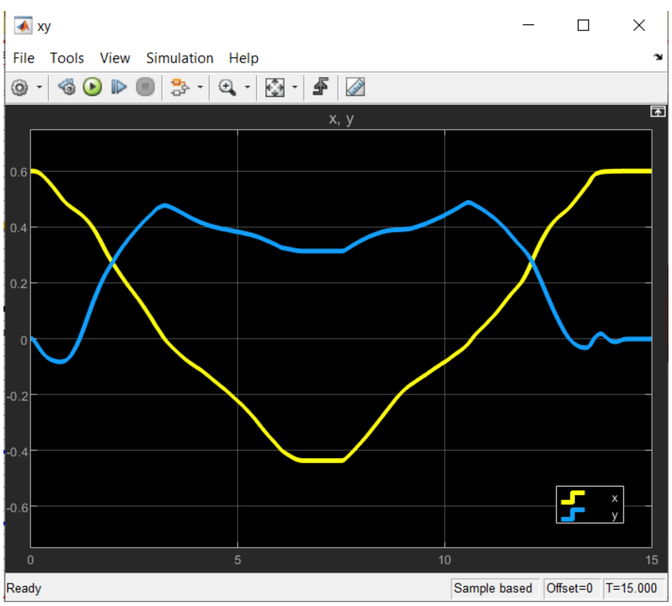


Figure 10.4

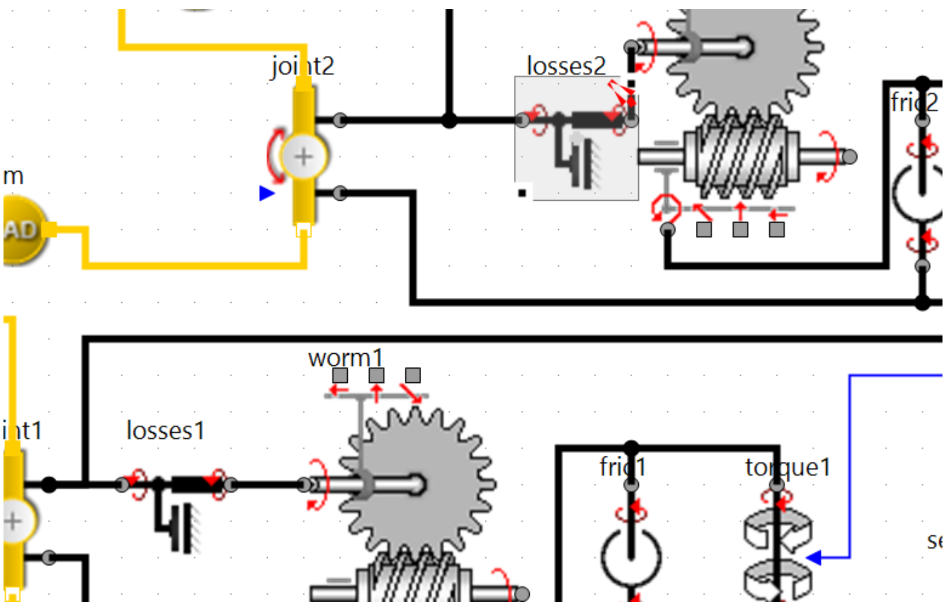
As shown in figure 10.4. The yellow represent the X location of arm, and blue line represent the Y location of arm. The arm moves relatively fast and smooth, but as shown in the middle of the graph, the accuracy is lowered as the arms are in constant movement. We evaluate our RCG and decided that given enough time, the arm will reach the point, so it is more important to have faster arms.

Saturation and non-linearity avoided

In Simulink model, a saturation block is used to prevent the voltage from being too high which could break the motor. The saturation block adds Non-Linearities to the control system. In order to avoid non-linearity, the step 9 and 10 in 10 step calculations are used.

SENSITIVITY

To account for bearing wear, the rotational losses block is added to the two joints. The efficiency is chosen to be 80%. The wore bearing would have an increased friction due to wearing out, so the torque transported would be less. Thus, the rotational loss is added to the diagram.



APPLICATION

RCG

We established RCG for our mechanical model based on the technical details of the product (**Yamaha YK800XGP**) as follow:

Requirement:
- Must be able to grab >=15kg object
- The settling time must be <= 1.5s
- cost must be <= 1000 dollars

Constraint:
- Must not have an overshoot larger than 20%

Goal:
- Minimize settling time
- Minimize overall cost
- Maximize the weight of the load it can carry

SPECIAL FEATURES

Our robot arm is designed to work in a flow shop. It is mounted on the table and used to move some objects from one place to another place. That requires our robot arm have a large workspace diameter. In this way, we designed our robot arm length to be 600mm, and workspace diameter is 1.2m.

One workshop could need multiple robot arms. To lower the cost, the base cover, the upper arm cover and the forearm cover are made easy to manufacture, so different components can be manufactured using the similar mold.

EFFICACY

Our robot arm design satisfies all the RCGs based on the Simulationx test result and cost calculation below. We test our SimulaitonX model, carrying a 15kg object. The test result shows that our robot arms can reach the desired location within 1.5s. From the calculation, the overall cost is 980 dollars, which satisfies the requirement.

COST

According to our RCG, we want to minimize the cost.

When we choose the component used to build the robot arm, our team always chooses the cheapest option except for the motor. Two motors cost 462 dollars in all. In the robot arm, 27 screws and 15 hex nuts are used, which cost 191 dollars in total. Two face-mount crossed-Roller bearings cost 36 dollars. Two worm gears cost 80 dollars. Two sensors cost 80 dollars. One Arduino and one PCB cost 60 dollars. For the base cover and arm cover material, Alloy steel is chosen. The total cost of the design is around 980 dollars.

Trades off

We keep our robot arm shape as simple as possible to minimize the manufacturing cost. When we choose the component used to build the robot arm, our team always chooses the cheapest option except for the motor. If we can ignore the price of components used in our design, we can further improve the performance of our design. For example, we can choose better ball bearings and screws to make the arm carry a heavier load.

Appendix

$J = m*r^2$

$Torque = J*a$