ME2400 MIC PROJECT

FINAL REPORT

GROUP 7
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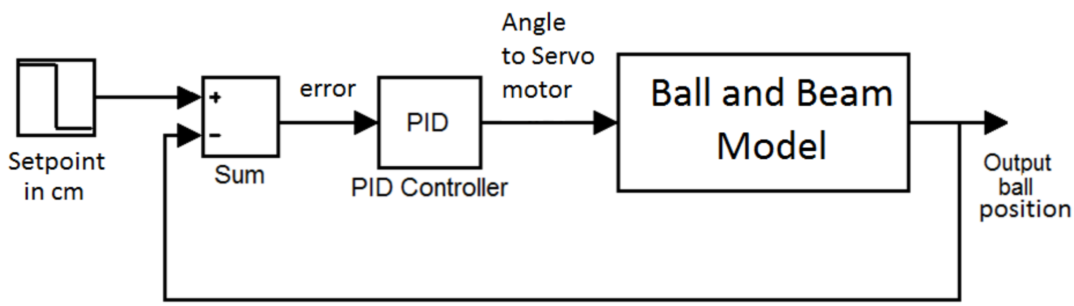
Abstract

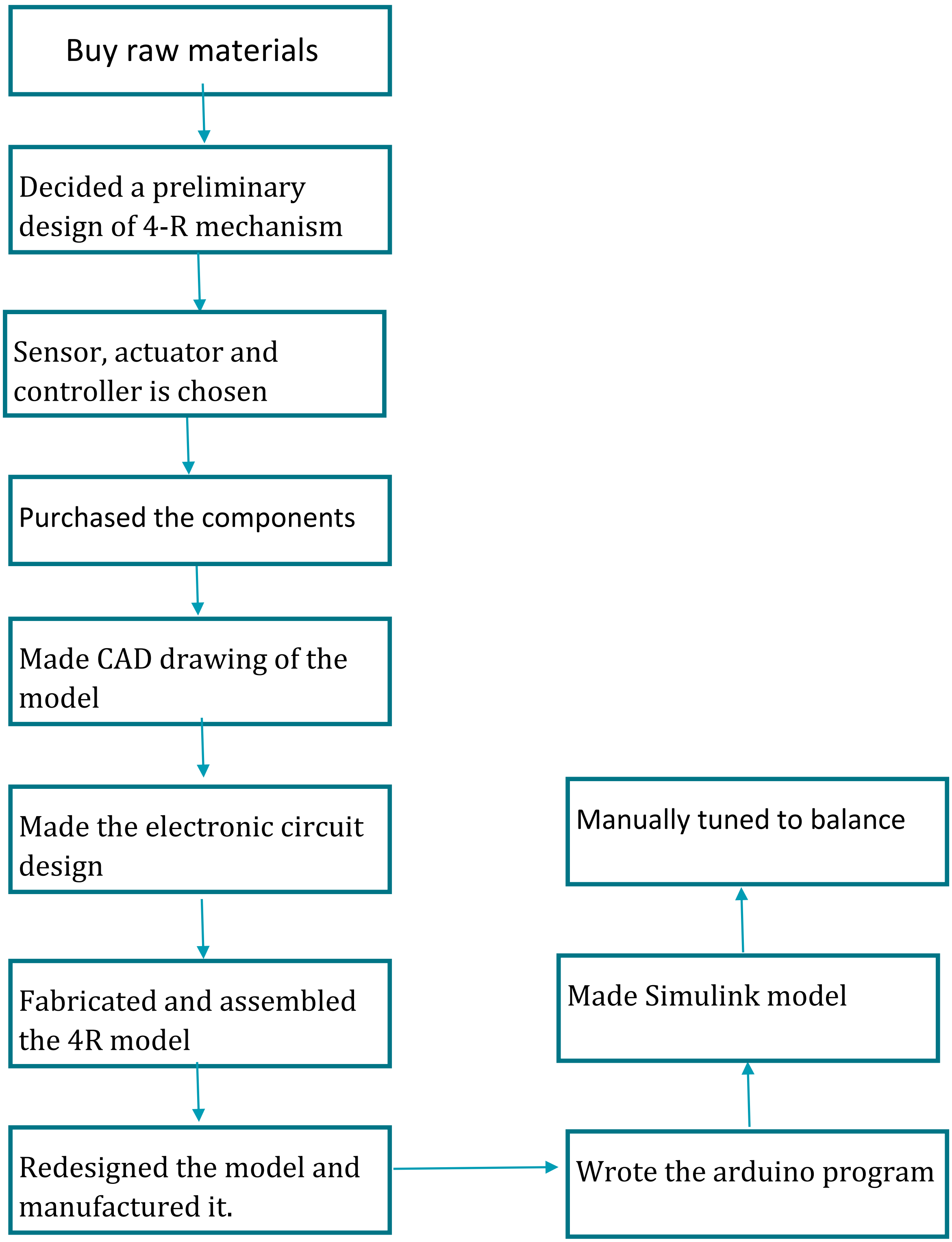
Our objective was to demonstrate a mechatronic system that can balance a ball along a linear grooved track by incorporating closed loop PID control. We first decided upon a preliminary design of 4-R mechanism according to required range of motion and constraints given to balance the ball. The ultrasonic ping sensor was chosen based on its compatibility with controller and other factors like ball material, range, accuracy etc. MG995 Servo motor was chosen as an actuator according to dynamics required to balance ball. A standard Arduino was used to control the see saw. The Arduino reads the sensor data, runs the PID control according to the code and controls the servo motor.



We then purchased the raw materials and the components required. The CAD drawing of the mechanical model decided and the electronic circuit were designed. We then fabricated and assembled our model. The torque from the motor was not sufficient to lift the model and overcome friction between the links. We then redesigned our mechanical model and attached the beam directly to the servo motor. Our new mechanical model had: a base to attach the servo to, the track, the sensor bracket which was attached to the track and the ball. We then fabricated our new mechanical design, connected all the components to it and made the connections according to the circuit design.

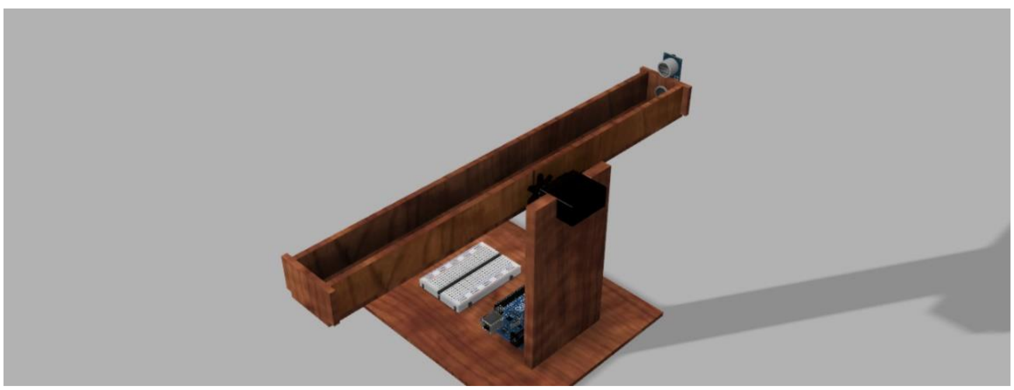
By now, our complete model was ready. We wrote the Arduino program and implemented a PID control. Our ping sensor was showing noise spikes; hence we conditioned the signal first. To tune the PID control, we used a Simulink model and also manually tuned it. The final Kp, Ki, Kd values obtained were 1.5, 0.01 and 0.75 respectively.

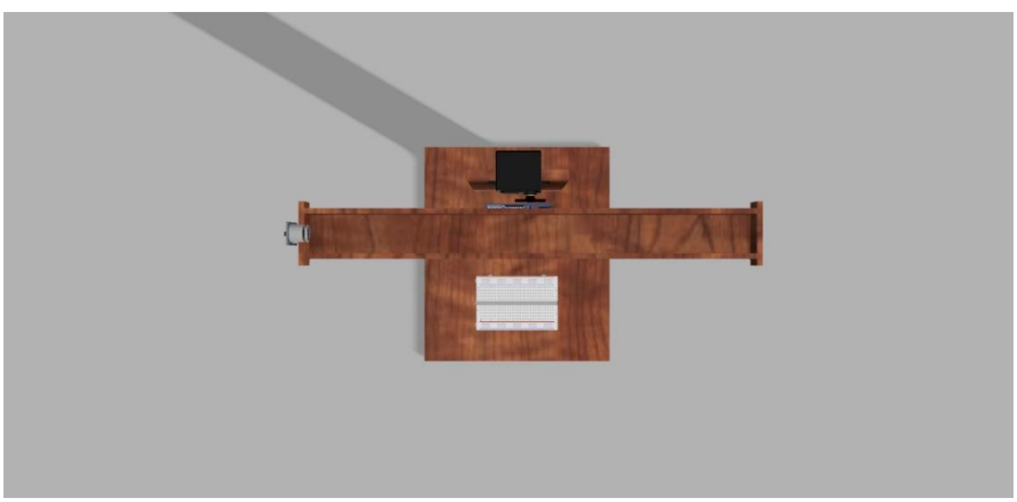
Flow chart of the project



CAD model design

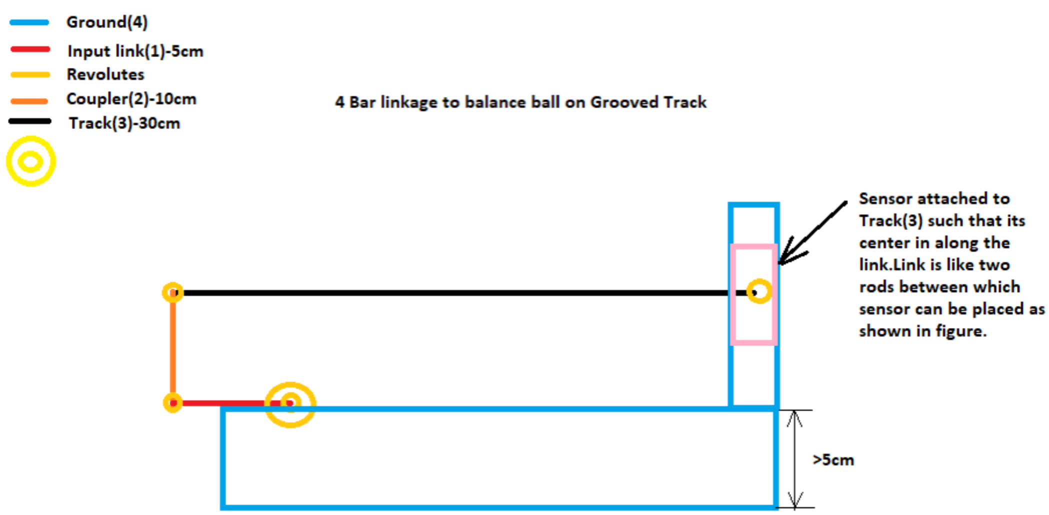
All the components have been manufactured by us. The material used was wood.





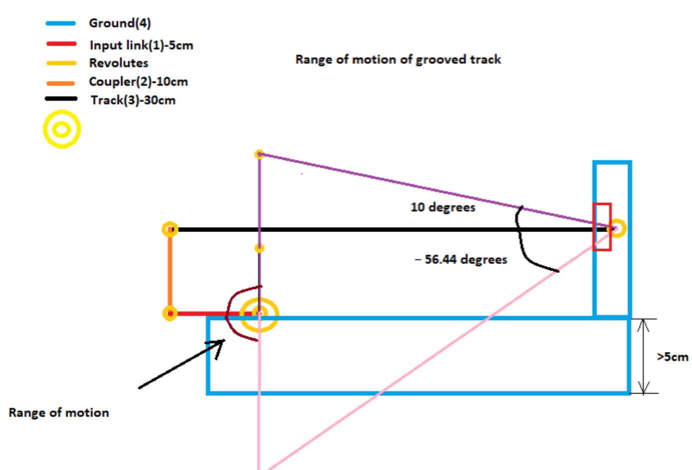
CAD model

Initially, we have designed and fabricated a 4-R model. Following is the schematic of the 4-bar mechanism used for balancing ball. Here sensor was placed in the groove such that center of the sensor coincided with the center of the ball. Above arrangement is done to reduce error by utilizing sensing angle of sensor to its fullest.



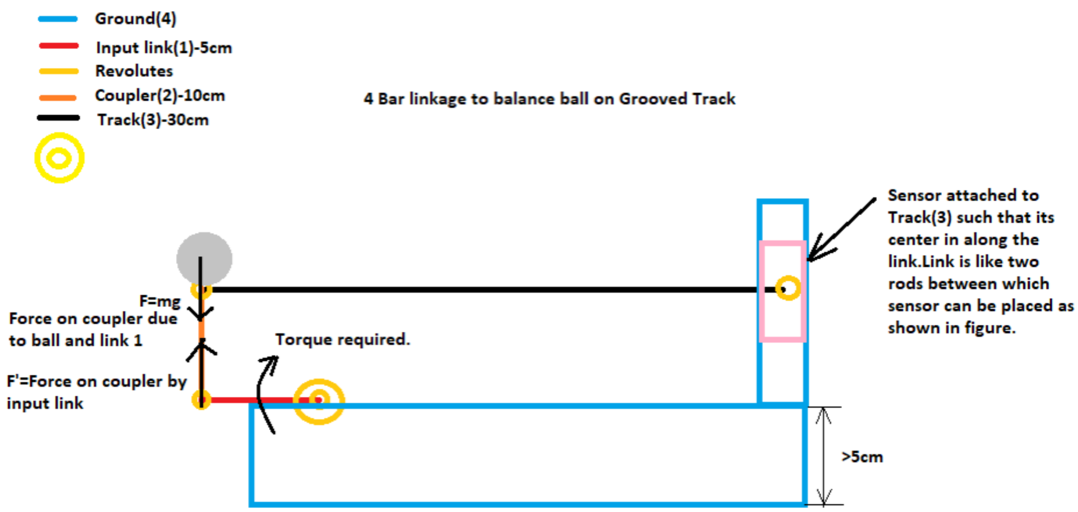
Schematic diagram of mechanism

Following is the range of motion of the linkage. Diagram shows two extremes positions of grooved track.10deg is just enough to accelerate ball from 0 to 1m/s in 0.6sec under gain 30_ component of acceleration. (Friction and impulses are neglected while calculation.)



Range of motion of mechanism

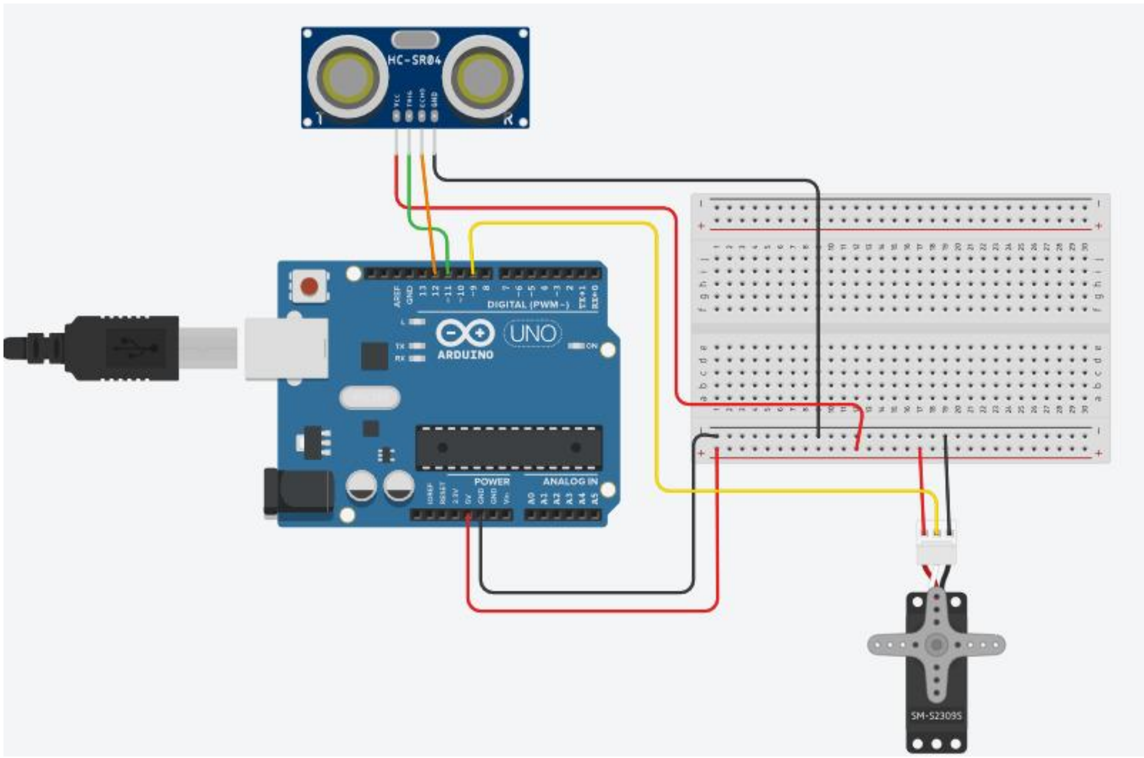
Following is the primitive dynamic analysis. The position shown in the diagram is the position where motor need to apply maximum torque. Hence torque at that position will be helpful in deciding motor. From torque equation required torque is 0.024525Nm (0.05(length of input link) x 0.05(mass of ball) x 9.81(value of g) =0.250kg-cm. (Links are assumed to be ideal. Other assumptions are made to simplify calculation.)



Primitive Dynamic analysis of motion.

We rejected this model after manufacturing as the torque of the motor was not able to overcome the friction between the links. We designed another model (shown in the cad drawings) with the motor directly fixed to the beam. The dimensions of the track are-
Length=40cm
Width=4 cm
Height=5 cm
This motor’s torque would be sufficient for this model by qualitative analysis and comparison with the previous model.

Electronic circuit design



Circuit design

We are going to buy following electronic components:

1. Arduino Uno
2. Ultrasonic Module HC-SR04
3. Servo motor tower sg-90
4. Jumper wires

We are using Arduino Uno as project statement requires it. Besides it, it is cheap (Around 500 Rs.) and widely used microcontroller.
We are using Ultrasonic Module HC-SR04 because of its range, price (Around 100Rs.), material independency etc. as mentioned above in Sensor Section.
We are using Servo motor tower sg-90 as it can produce torque up to 2.5 kg-cm>0.25kg-cm (required torque). Also, it is cheap (Around 200Rs.)
Jumper wires to connect different components with Arduino.
For details of why we have chosen specific component see Sensors and actuator (correcting elements) section.

Arduino Uno

CHOICE OF SENSOR

As to balance ball we need to know the position of the ball. Following was the possible list of sensors that might be used:

Proximity sensors-

Inductive
Capacitive
Optical
Ultrasonic

Touch screen sensor-

Capacitive
Resistive

First, we thought of choosing touchscreen sensors, in which we have chosen resistive as it is cheaper than capacitive and detection of ball can be done by required accuracy. The cheapest of resistive touchscreen is 4 wire resistive touch screen which is used to detect x, y coordinate of ball (due to change in resistance) using two pairs each. To further reduce cost and due to unavailability of resistive touchscreen with length >>> than width we searched for 2 wire resistive touchscreen as we required only x coordinate of ball but such resistive touchscreens doesn't exist. Also attempt has been made to procure

4 wire resistive touchscreen of required dimensions but cost of it exceeds the required limit. (After adding cost of all components). So, we move toward proximity sensors. We rejected inductive and capacitive sensors due to its low range and material dependency (i.e. Material of ball.). We have rejected Optical sensor

primarily because of its dependence on structure of object to be detected. Also, it will depend on material of object too. So finally, we have chosen ultrasonic sensor (details of which mentioned in next paragraph.). Though accuracy and response speed is more in optical sensor its detecting range is too low (10 cm only.)

Item	Optical (reflective model) *	Ultrasonic
Detectable target	Detection is affected by target materials/colors	Detection is unaffected by target materials/colors
Detecting distance	1000 mm ***3.94"*** max.	10 m ***32.8'*** max.
Accuracy	High	Low
Response speed	Fast	Slow
Dust/water	Affected	Unaffected
Measuring range	Small	Large

Comparison between ultrasonic sensor and optical sensor

After going through different ultrasonic sensors, we come upon Ultrasonic Ranging Module-HC-SR04 with following parameter

Working Voltage	**DC 5 V**
Working Current	**15mA**
Working Frequency	**40Hz**
Max Range	**4m**
Min Range	**2cm**
MeasuringAngle	**15 degree**
Trigger Input Signal	**10uS TTL pulse**
Echo Output Signal	**Input TTL lever signal and the range in proportion**
Dimension	**45*20*15mm**

Electric Parameters of Ultrasonic Module-HC-SR04

The accuracy of module is 3mm which is decent according to required application. Range:2cm-4cm (Can be used for 30cm track). It is compatible with Arduino Uno too. (Microcontroller which we are going to use.)

Ultrasonic module-HC-SR04

CORRECTION ELEMENTS

As servomotor uses position feedback to control its motion and final position, we are using it. After extensible search we have chosen Tower pro MG995 Metal Gear Servo Motor (180º Rotation) motor with following parameters:

1. Weight: 55 gm
2. Operating voltage: 4.8V~ 7.2V
3. Servo Plug: JR
4. Stall torque @4.8V: 10 kg-cm
5. Stall torque @6.6V: 12 kg-cm

Since this torque is greater than the torque required by our model, we have chosen this servo motor.

Tower pro MG995

Fabrication of the CAD model and assembly of sensor, actuator and controller

We began the manufacturing process by cutting our thin plywood into 2 pieces of length 40cm to make the tracks for the ball.

Three thicker pieces of wood were used to join the two tracks.

We connected this track to a wooden base using another piece of wood with the motor serving as a link between the track and the connection to the base. The motor was attached keeping in mind the reference point of the motor.

A combination of superglue and hot glue was used to make all the connections other than that of the arrangement to the base. For this connection we used nails for further sturdiness.

Next, we attached a piece of plywood with a hole drilled in it(to fit the ultrasonic sensor) to one side of the track. A similar piece of plywood was then attached to the opposite end with no hole.

The head of the ultrasonic sensor was then fitted into the drilled hole and reinforced with superglue. Great care was taken to attach the ultrasonic sensor perfectly parallel to the tracks.

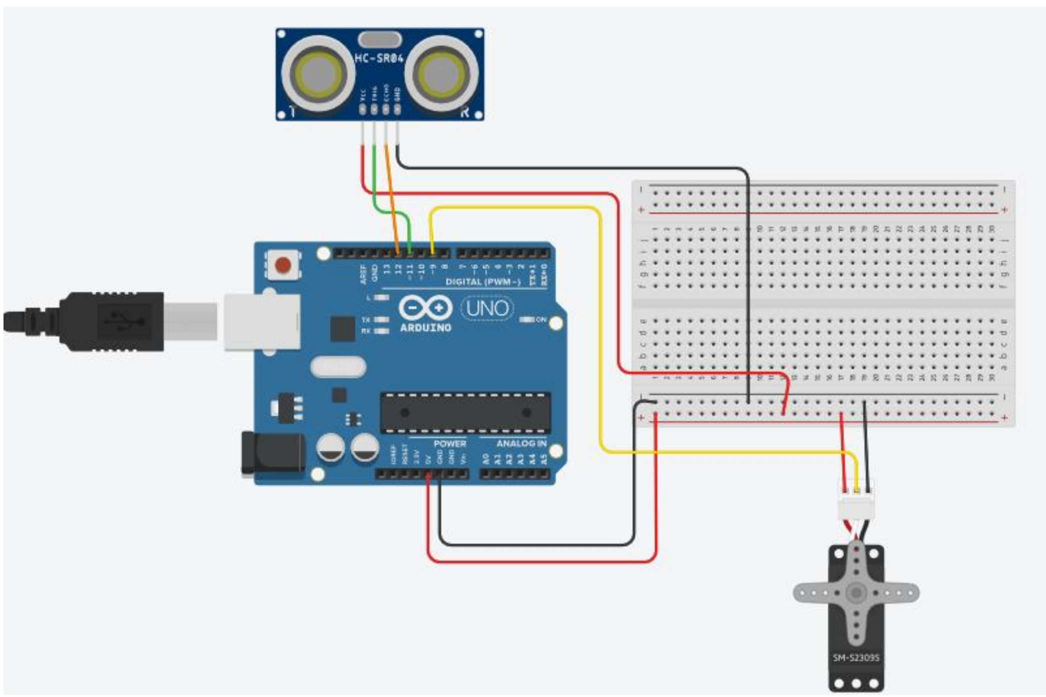
We then used chart paper to make a curved base between the tracks. This was done to allow the ultrasonic sensor to sense only the ball and not the rungs connecting the two tracks.

The distance between the tracks was carefully set such that the ball did not touch the chart paper. It simply remains suspended between the two tracks. The ball we used is a practice golf ball which weighs exactly 50gm.

Finally, the Arduino was placed on the base and connections were made using male-male, male-female and female-female wires to connect the Arduino to the motor, sensor and the power source(laptop).

We put in a lot of thought to make the best possible mechanical model. This greatly simplified the tuning process.

Ardiuno program



Circuit design

Explain connection diagram of sensors and actuators to Arduino.

Vout and GND of Arduino are connected to the breadboard through which Vcc and ground of motor and ultrasonic sensor are connected. Input wire of servo motor is connected to input pin 9 of the Arduino. Trig and Echo pin of ultrasonic sensor are connected to input pin 11 and 12 respectively.

• Explain signal conditioning if any.

We have used low pass filter so that if by mistake ultrasonic sensor detect more than 40cm (track length) it will return 40 cm value.

We have also used exponential filter so that after setting at the setpoint groove doesn't oscillate due to small noise detected by ultrasonic sensor.

• Controller design – what type of control, how did you tune, final parameter

values.

Controller is Arduino.

Kp=1.5

Ki=0.01

Kd=0.75

• Provide Arduino program algorithm and flow chart.

Give initial value of setpoint and output limits for oscillation of the track. Provide PID constants.

Ultrasonic sensor detects the distance.

Distance will get filtered by low pass filter and exponential filter.

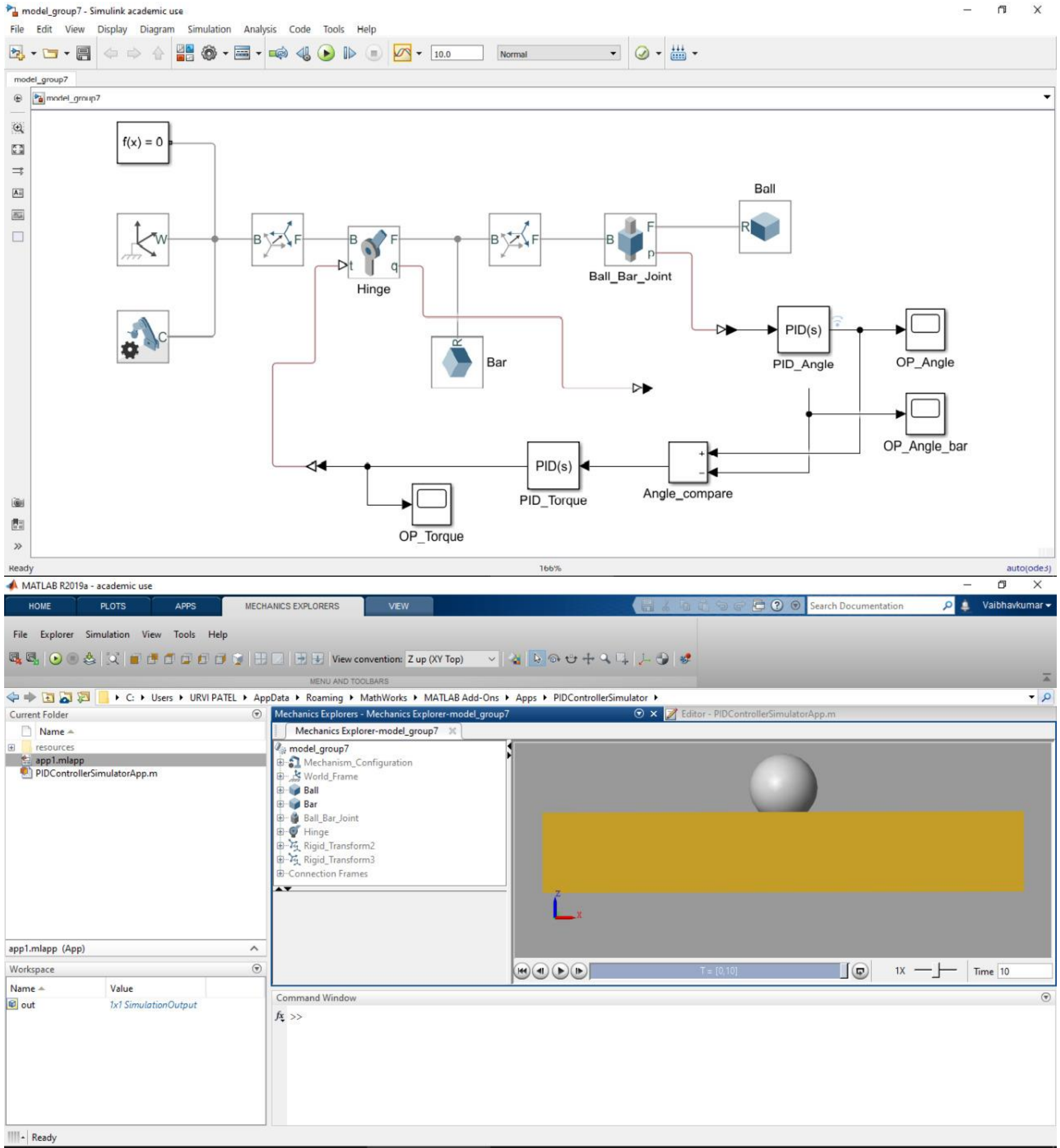
Now according to PID constants output will be provided by servo motor

Ball balances on the groove.

Simulink model

• Provide Control system block diagram and transfer function model;

MATLAB Simulink model description



Integration of Simulink model and original model

Kp, Ki, Kd values from Simulink model are 1.3,0.04 and 0.5 respectively which is reasonably close to PID constants of original model. (Kp=1.5, Ki=0.01, Kd=0.75)

Any additional works done for BONUS marks.

• The larger the groove track length more the bonus marks.

Our groove length is 40cm which is larger than 15cm constraint provided in the template.

• Ability to hold the ball at any desired location along the groove track.

Yes, by changing set point we are able to do that.

• Control the ball position with your smartphone.

We have tried attaching Bluetooth module through which setpoint values can be sent to the model, but we don't have an appropriate Arduino/IOS app to do that.

Challenges faced and how did you overcome it as a team

• Approximate time spent in the overall project and specify the section (design, fabrication, Arduino, Simulink, etc.) which took the maximum time.

- We have done this project in the period of 2 months.

Design	2-3 days
Buying the material & fabrication according to design	5 days
Arduino	2 days
Simulink	2-3 days

• Lessons learnt from the project.

- We learnt about the practical application of the theory and coursework taught in class
- Working in a team of 4 was a great experience, got know each other very well.
- Explored different software such as Simulink and Arduino which wasn't even taught in class.
- Helped us to improve decision making abilities.

• List the challenges faced and how did you overcome it as a team.

- ➢ The motor we firstly got was a velocity control motor, which couldn't be visually differentiated over the angle control one.
  - We spent over 5 hours playing with that motor which wasn't working how it was supposed to be. Then we did research about the different types of motors and what all differences are there. Then we got to know about that the motor we had was one with velocity control. Then we went to shop and got it replaced with the correct one.
- ➢ The 4R mechanism which we made earlier, after fabrication we found out that the material which we used (hard cardboard) wasn't able to hold the structure properly. Also, the revolute joints weren't properly rotating.
  - To overcome this situation, we talked with other groups and got to know how they have done their models. The analysis for the 4R mechanism was far more complicated that the analysis of the new model that we have made. So to make the new model, we worked on the new design where the motor is attached at the centre of track and fabricated the whole project in single day.

• Total cost of all components in a tabular column (attach soft copies of bills, if any); all components must be new and unused.

ITEM	PRICE
Arduino Board	500 Rs
Plywood	100 Rs
Ultrasonic Sensor	100 Rs
Breadboard	100 Rs
Jumper wires	50 Rs
Servo Motor	400 Rs
Ball (Golf ball)	70 Rs
Miscellaneous	40 Rs
Total	1360 Rs