Project Robot / manipulator design with 5 degrees of freedom

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Group:03

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1.State of art

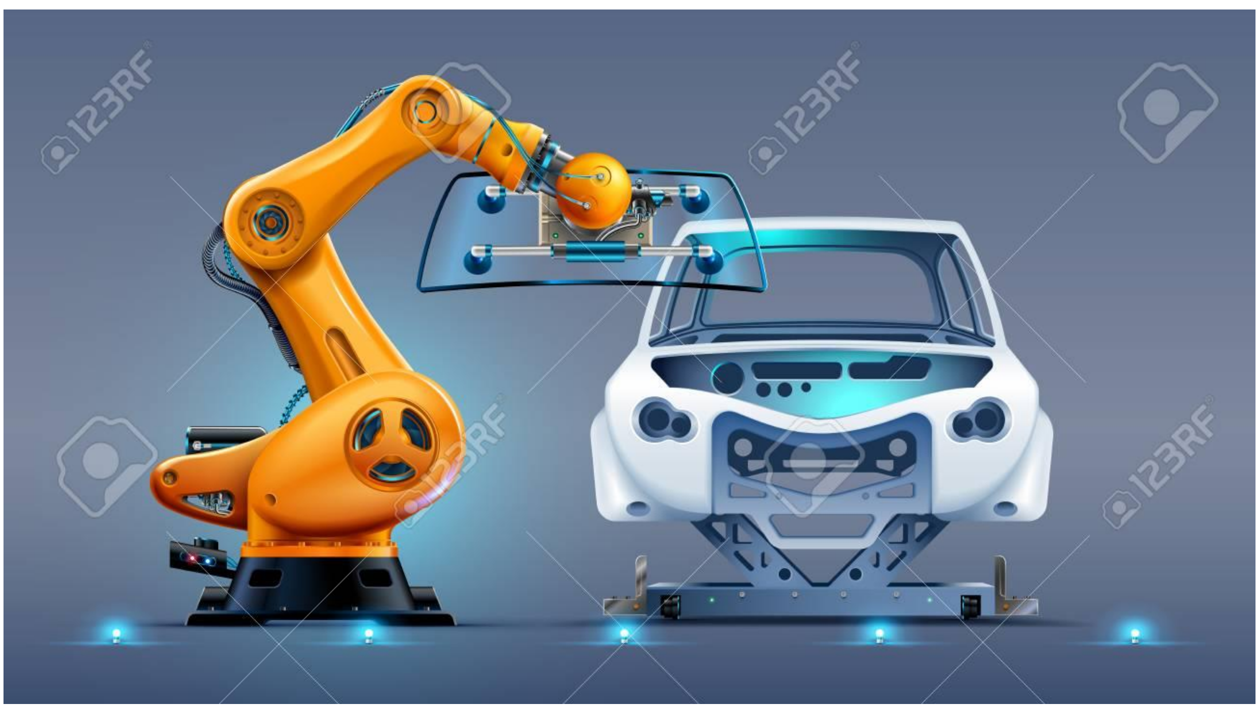
In this project I will construct robot arm (T050000)

One of the most common and typical 5DOF robotic arms in the factory today. This mechanism is flexible and can be combined with automation to quickly and easily complete work that requires 2-3 people to complete.

With the machines' ability to lift heavy objects, they are used in auto plants, manufacturing materials or freight.

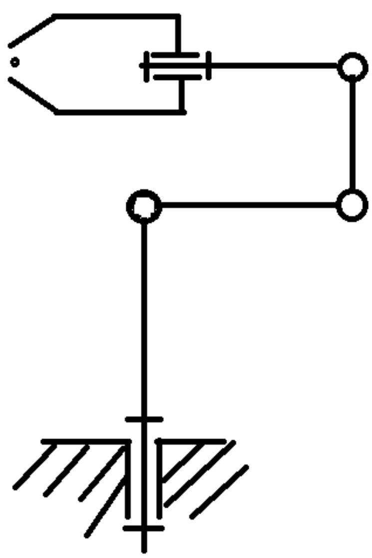
The construction of the robot can be adapted to be placed on a driving system based on linear guides and a high precision toothed bar drive. Thanks to this, the robot gains an additional axis of movement along which it can move with the load at almost any distance

I have tried to find some similar mechanism in the factories and laboratories:



2.Mechanism

Drawings of construction:



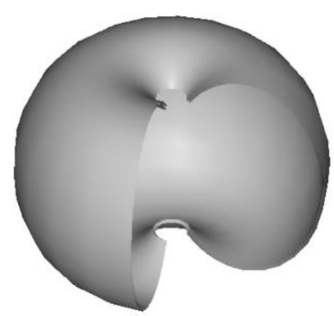
Degrees of freedom:

5 elements.

5 pair of class 1.

W= 6*5 - 5*5 = 5 degrees.

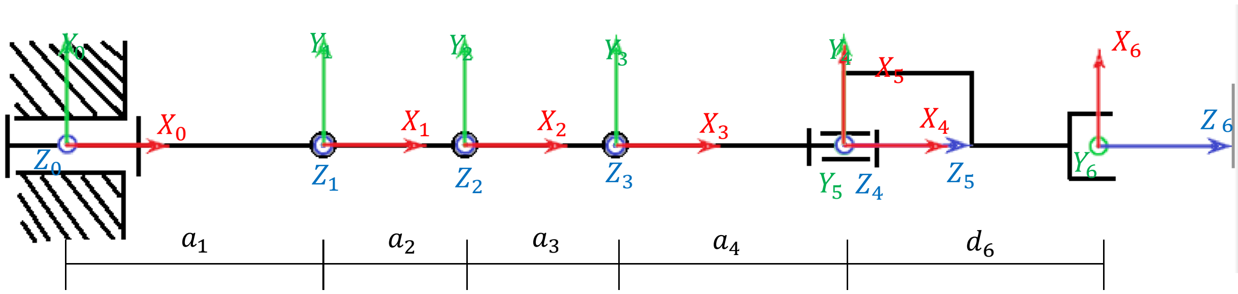
-Manipulators having three rotary joints are included in the group of anthropomorphic manipulators.



Work envelope

3.FOWARD KINEMATICS

3.1 Mechanism



3.2 Kinematic table

System	θ_i	d_i	a_i	α_i
1	0	0	a_1	$\alpha_{1,var}$
2	$\theta_{2,var}$	0	a_2	0
3	$\theta_{3,var}$	0	a_3	0
4	$\theta_{4,var}$	0	a_4	0
5	90	0	0	90
6	$\theta_{6,var}$	d_6	0	0

3.3 Obtained Results

```
A1 =

[1,            0,             0, a1]

[0, cos(alpha1), -sin(alpha1),  0]

[0, sin(alpha1),  cos(alpha1),  0]

[0,            0,             0,  1]


A2 =

[cos(theta2), -sin(theta2), 0, a2*cos(theta2)]

[sin(theta2),  cos(theta2), 0, a2*sin(theta2)]

[          0,             0, 1,              0]

[          0,             0, 0,              1]
```

```
A3 =
[cos(theta3), -sin(theta3), 0, a3*cos(theta3)]
[sin(theta3),  cos(theta3), 0, a3*sin(theta3)]
[          0,            0, 1,              0]
[          0,            0, 0,              1]

A4 =
[cos(theta4), -sin(theta4), 0, a3*cos(theta4)]
[sin(theta4),  cos(theta4), 0, a3*sin(theta4)]
[          0,            0, 1,              0]
[          0,            0, 0,              1]

A5 =
[0     0     1     0]
[1     0     0     0]
[0     1     0     0]
[0     0     0     1]

A6 =
[cos(theta6), -sin(theta6), 0,  0]
[sin(theta6),  cos(theta6), 0,  0]
[          0,            0, 1, d6]
[          0,            0, 0,  1]
```

```
T06 =

[-sin(theta2+theta3+theta4)*cos(theta6),
sin(theta2+theta3+theta4)*sin(theta6),
cos(theta2+theta3+theta4),
a1+a3*cos(theta2+theta3)+a2*cos(theta2)+a3*cos(theta2+theta3+theta4)+
d6*cos(theta2+theta3+theta4)]

[cos(theta2+theta3+theta4)*cos(alpha1)*cos(theta6)-sin(alpha1)*sin(theta6),
-sin(alpha1)*cos(theta6)-cos(theta2+theta3 +theta4)*cos(alpha1)*sin(theta6),
sin(theta2+theta3+theta4)*cos(alpha1),
cos(alpha1)*(a3*sin(theta2+theta3)+a2*sin(theta2)+a3*sin(theta2+theta3+theta
)+d6*sin(theta2+theta3+theta4))]

[cos(alpha1)*sin(theta6)+cos(theta2+theta3+theta4)*sin(alpha1)*cos(theta6),
cos(alpha1)*cos(theta6)-cos(theta2+theta3+theta4)*sin(alpha1)*sin(theta6),
sin(theta2+theta3+theta4)*sin(alpha1),
sin(alpha1)*(a3*sin(theta2+theta3)+a2*sin(theta2)+a3*sin(theta2+theta3+theta4
)+d6*sin(theta2+theta3+theta4))]

[0,
0,
0,
1]
```

4.Inverse Kinematic

For calculation of forward kinematic problem, I used a MAPLE software.

For my calculation I took equations from the T_{05} matrix to determine α_1 θ_2, θ_3 and θ_4 because this matrix reduce calculations and the A_6 matrix determines only the orientation of the end point (and moves the axis in z-axis but this change can be also given before rotation in A_6 or just after the A_5 matrix without any consequences).

4.1 MAPLE CODE AND POSSIBLE SOLUTIONS FOR GIVEN POSITON

$equ\_1 := a1 + a3 * \cos(theta2 + theta3) + a2 * \cos(theta2) + a3 * \cos(theta2 + theta3 + theta4) + d6 * \cos(theta2 + theta3 + theta4) = x;$

$$equ\_1 := a1 + a3\cos(\theta2 + \theta3) + a2\cos(\theta2) + a3\cos(\theta2 + \theta3 + \theta4) + d6\cos(\theta2 + \theta3 + \theta4) = x$$

$equ\_2 := \cos(alpha1) * (a3 * \sin(theta2+theta3) + a2 * \sin(theta2) + a3 * \sin(theta2+theta3+theta4) + d6 * \sin(theta2+theta3+theta4)) = y;$

$$equ\_2 := \cos(\alpha1)\ (a3\sin(\theta2+\theta3) + a2\sin(\theta2) + a3\sin(\theta2+\theta3+\theta4) + d6\sin(\theta2+\theta3+\theta4)) = y$$

$equ\_3 := \sin(alpha1) * (a3 * \sin(theta2+theta3) + a2 * \sin(theta2) + a3 * \sin(theta2+theta3+theta4) + d6 * \sin(theta2+theta3+theta4)) = z;$

$$equ\_3 := \sin(\alpha1)\ (a3\sin(\theta2+\theta3) + a2\sin(\theta2) + a3\sin(\theta2+\theta3+\theta4) + d6\sin(\theta2+\theta3+\theta4)) = z$$

$a1 := 1; a2 := 1; a3 := 3; a4 := 2; d6 := 2;$

$x := 2; y := 4; z := 0;$

$$x := 2$$
$$y := 4$$
$$z := 0$$

$evalf[3](solve(\{equ\_1, equ\_2, equ\_3\}, \{alpha1, theta2, theta3, theta4\}));$

Software solves equations and shows all solutions (a lot of). I show some solutions:

$\{\alpha_1 = 0., \theta_2 = 0., \theta_3 = 0., \theta_4 = 2.21\}$, $\{\alpha_1 = 0., \theta_2 = 1.57, \theta_3 = 1.57, \theta_4 = -2.50\}$,

$\{\alpha_1 = 3.14., \theta_2 = 2.65, \theta_3 = 0., \theta_4 = -2.21\}$, $\{\alpha_1 = 0., \theta_2 = 3.14, \theta_3 = 2.83, \theta_4 = 2.06\}$,

$\{\alpha_1 = 3.14, \theta_2 = 3.14, \theta_3 = 0.614, \theta_4 = 2.05\}$, $\{\alpha_1 = 0., \theta_2 = -1.57, \theta_3 = 1.71, \theta_4 = = 1.84\}$

To make sure all solutions and code are right. I try calculating again with MATLAB:

```
clear all
alpha1 = 0., theta2 = 0., theta3 = 0., theta4 = 2.21;
a1=1; a2=1;a3=3;a4=2;d6=2;
x=a1+a3*cos(theta2+theta3)+a2*cos(theta2)+a3*cos(theta2+theta3+theta4)+d6*cos(theta2+theta3+theta4)
y=cos(alpha1)*(a3*sin(theta2+theta3)+a2*sin(theta2)+a3*sin(theta2+theta3+theta4)+d6*sin(theta2+theta3+theta4))
z=sin(alpha1)*(a3*sin(theta2+theta3)+a2*sin(theta2)+a3*sin(theta2+theta3+theta4)+d6*sin(theta2+theta3+theta4))
```

```
x =            x =            x =

    2.0172         2.0057         1.9974

y =            y =            y =

    4.0129         3.9924         4.0178

z =            z =            z =

     0              0         -4.9204e-16
```

As we can see that the results are good.

4.2 THE SOLUTION FOR θ_6

ω = θ_6 + α_1

θ_6= ω - α_1

ω – desired orientation of wheel in z-axis

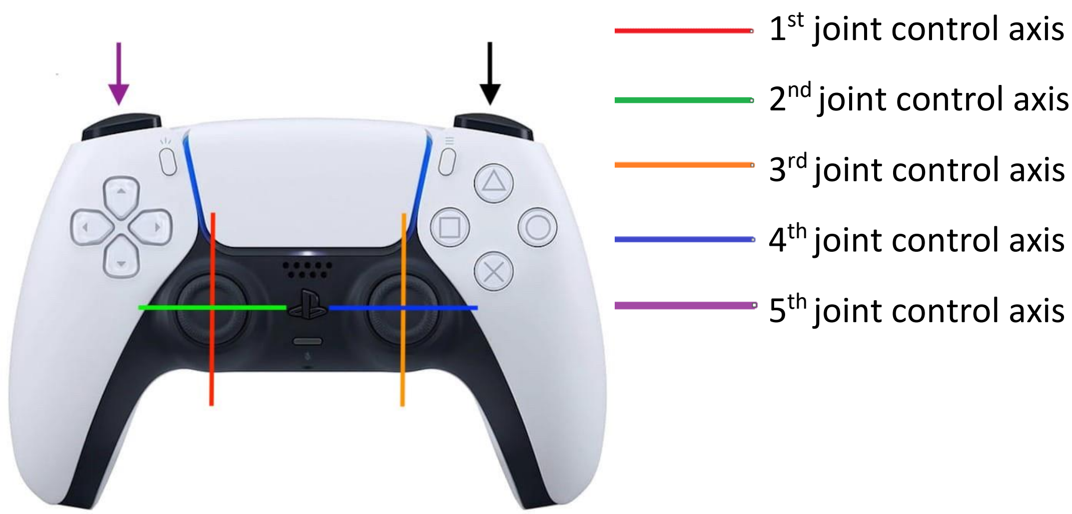
From results we should remove ones with imaginary parts. As we can see the arm sometimes is able to obtain more than one result.

5.Simple control

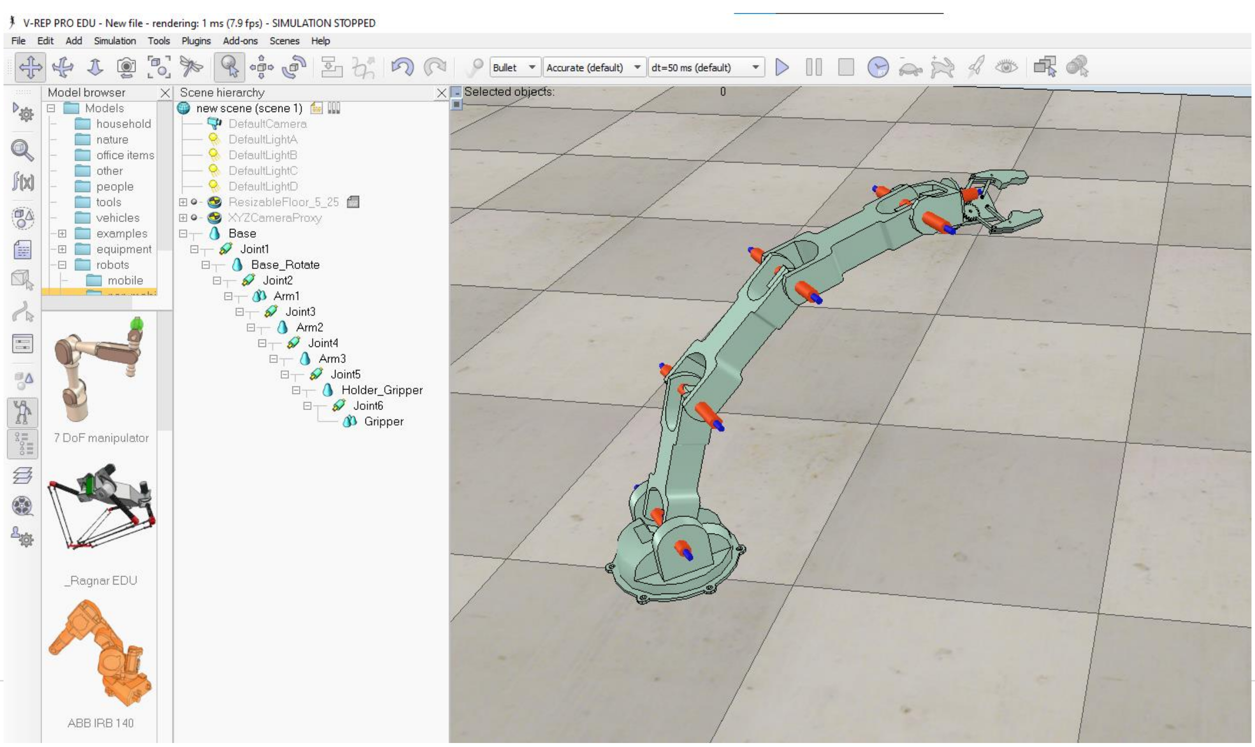
5.1 ROS and V-REP

In laboratory classes I have also made a simple control in ROS and V-REP program.

I control the arm via Sony PS5 Pad Controller.



To control the simulation in V-REP I had to create a node thanks which it would be possible. The code of the node is included in Appendix 2.

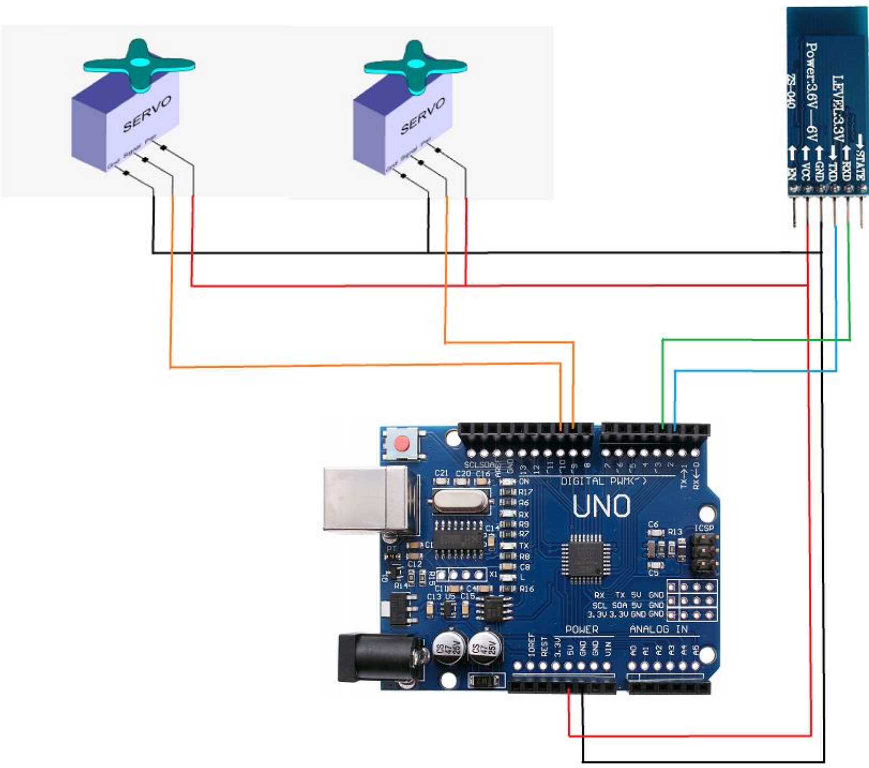


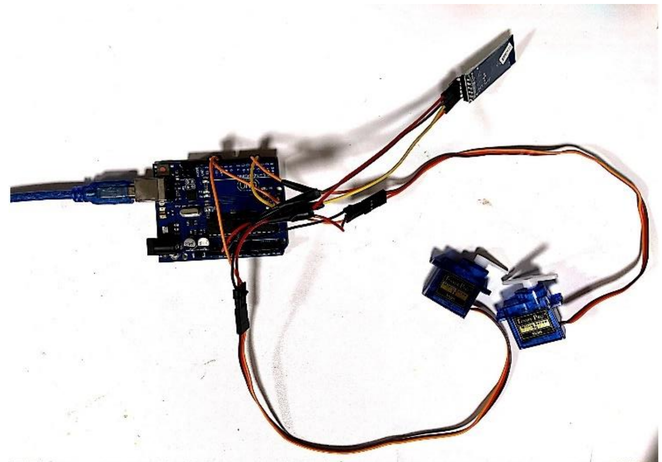
5.2 Arduino with Servos

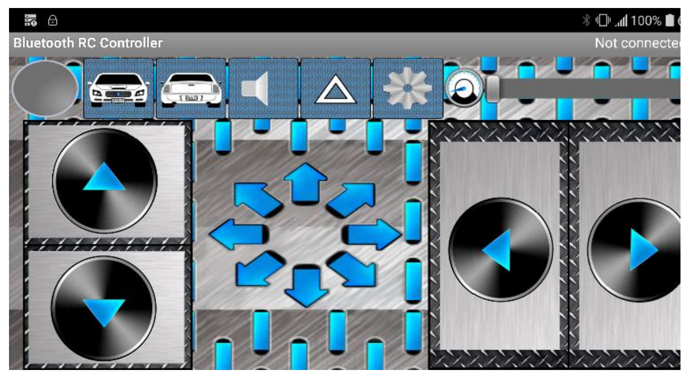
To control Robot. I use Arduino UNO R3, Module Bluetooth HC-05 with Servos.

Connect Module Bluetooth with phone via app Bluetooth RC Controller.

Scheme





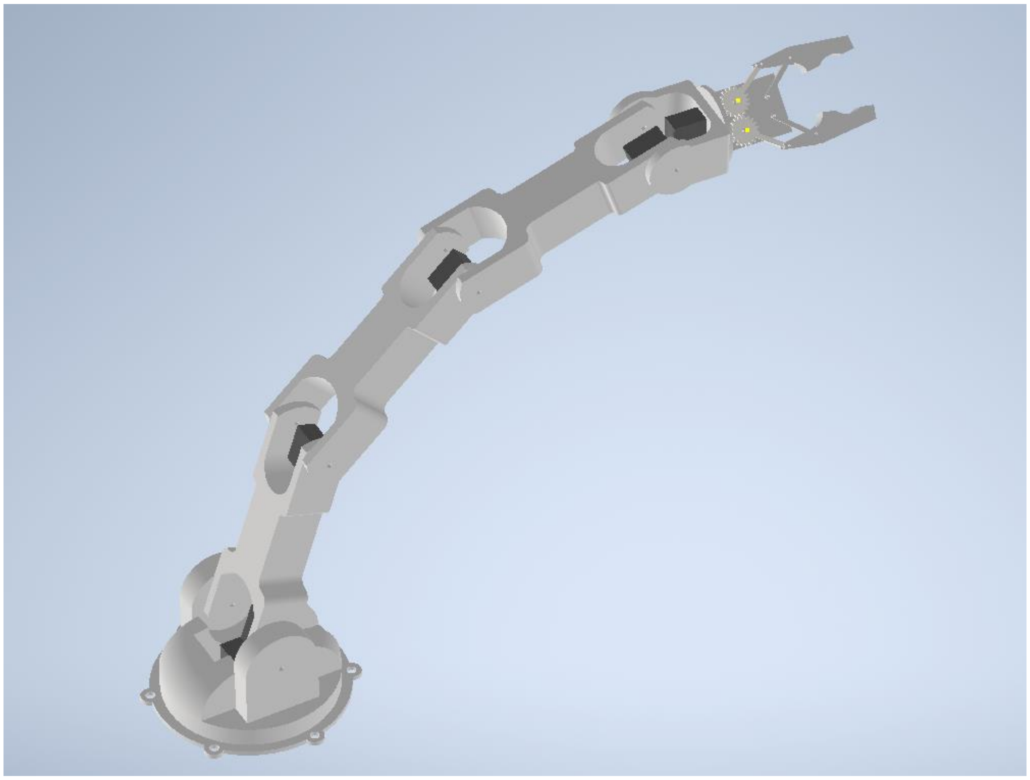


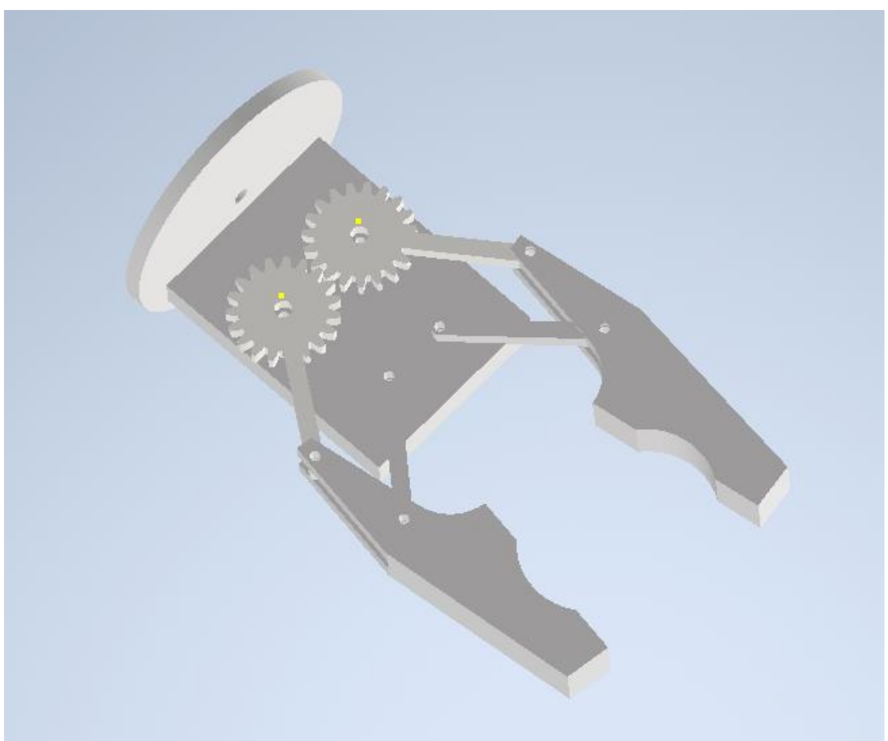
With this base we can connect to many servos to control. Due to the limited port of the Arduino, the Arduino can control up to 6 servos at the same time.

This is very convenient because it is remote control via Bluetooth

The code for Arduino in Appendix 3.

6.Model





7.APPENDIX

7.1 MATLAB CODE

```
clear all
close all
clc
syms a1 a2 a3 a4 ;
syms d6;
syms alpha1 theta2 theta3 theta4 theta6;
%system 1
Tranx_a1=[1 0 0 a1;0 1 0 0;0 0 1 0;0 0 0 1];
Rotx_alpha1=[1 0 0 0;0 cos(alpha1) -sin(alpha1) 0; 0 sin(alpha1) cos(alpha1)
0;0 0 0 1];


%system 2
Rotz_theta2=[cos(theta2) -sin(theta2) 0 0;sin(theta2) cos(theta2) 0 0;0 0 1
0; 0 0 0 1];
Tranx_a2=[1 0 0 a2;0 1 0 0;0 0 1 0;0 0 0 1];


%system 3
Rotz_theta3=[cos(theta3) -sin(theta3) 0 0;sin(theta3) cos(theta3) 0 0;0 0 1
0; 0 0 0 1];
Tranx_a3=[1 0 0 a3;0 1 0 0;0 0 1 0;0 0 0 1];


%system 4
Rotz_theta4=[cos(theta4) -sin(theta4) 0 0;sin(theta4) cos(theta4) 0 0;0 0 1
0; 0 0 0 1];
Tranx_a4=[1 0 0 a3;0 1 0 0;0 0 1 0;0 0 0 1];


%system 5
Rotz_90=[0 -1 0 0;1 0 0 0;0 0 1 0;0 0 0 1];
Rotx_90=[1 0 0 0;0 0 -1 0;0 1 0 0;0 0 0 1];


%system 6
Rotz_theta6=[cos(theta6) -sin(theta6) 0 0;sin(theta6) cos(theta6) 0 0;0 0 1
0; 0 0 0 1];
Tranz_d6=[1 0 0 0;0 1 0 0;0 0 1 d6;0 0 0 1];

%Danavit-Hartenberg Notations
A1=Tranx_a1*Rotx_alpha1;    A1=simplify(A1)
A2=Rotz_theta2*Tranx_a2;    A2=simplify(A2)
A3=Rotz_theta3*Tranx_a3;    A3=simplify(A3)
A4=Rotz_theta4*Tranx_a4;    A4=simplify(A4)
A5=Rotz_90*Rotx_90         %A5=simplify(A5)
A6=Rotz_theta6*Tranz_d6;    A6=simplify(A6)

%Forward kinematic for each joint
```

```
T01=A1;
T02=T01*A2;
T03=T02*A3;
T04=T03*A4;
T05=T04*A5;
T06=T05*A6;
T06=simplify(T06)
```

7.2 ROSNODE CODE

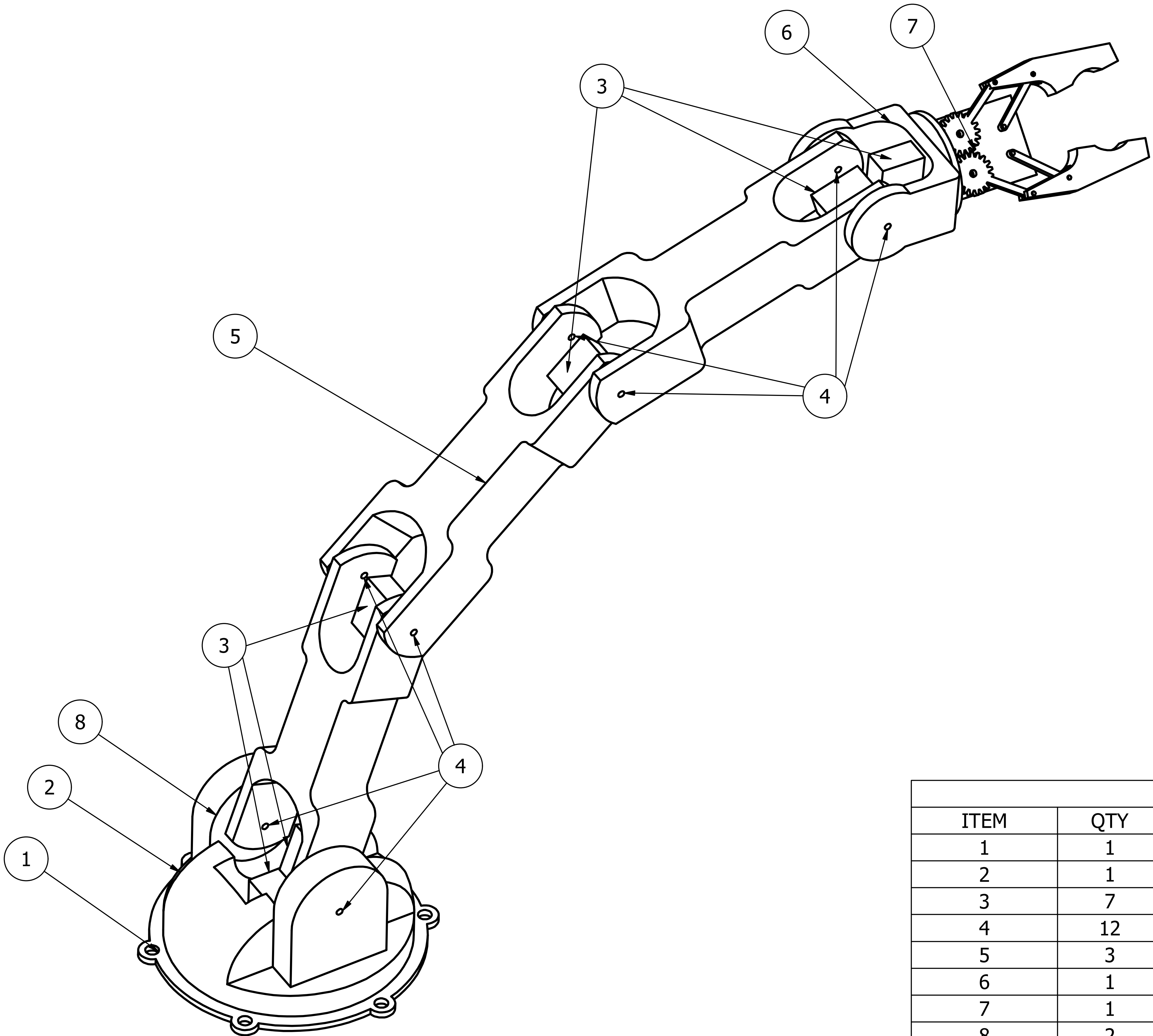
```
#include <ros/ros.h>

#include <std_msgs/Float64.h>

#include <sensor_msgs/Joy.h>


 ros::Publisher servo1_pub;

 ros::Publisher servo2_pub;

 ros::Publisher servo3_pub;

 ros::Publisher servo4_pub;

 ros::Publisher servo5_pub;


void joyCallback(const sensor_msgs::Joy::ConstPtr & joy) {

 double first_joint =joy->axes[0]

 double second_joint = joy->axes[1];

 double third_joint = joy->axes[2];

 double fourth_joint = joy->axes[3];

 double fifth_joint = joy->axes[4];


 std_msgs::Float64 servo1;

 std_msgs::Float64 servo2;

 std_msgs::Float64 servo3;

 std_msgs::Float64 servo4;

 std_msgs::Float64 servo5;


 servo1.data=first_joint;
```

```
  servo2.data=second_joint;
  servo3.data=third_joint;
  servo4.data=fourth_joint;
  servo5.data=fifth_joint;

  servo1_pub.publish(servo1);
  servo2_pub.publish(servo2);
  servo3_pub.publish(servo3);
  servo4_pub.publish(servo4);
  servo5_pub.publish(servo5);
}
int main (int argc, char **argv) {
  ros::init(argc,argv,"joy_controller_node");
  ros::NodeHandle nh_("~");

  std::string servo1_name;
  std::string servo2_name;
  std::string servo3_name;
  std::string servo4_name;
  std::string servo5_name;

  std::string servo1_string;
  std::string servo2_string;
  std::string servo3_string;
  std::string servo4_string;
  std::string servo5_string;

  nh_.param<std::string>("first_motor_name",servo1_name,"RobotArm_servo1");
  nh_.param<std::string>("second_motor_name",servo2_name,"RobotArm_servo2");
  nh_.param<std::string>("third_motor_name",servo3_name,"RobotArm_servo3");
```

```
  nh_.param<std::string>("fourth_motor_name",servo4_name,"RobotArm_servo4");
  nh_.param<std::string>("fifth_motor_name",servo5_name,"RobotArm_servo5");

  servo1_string.append("/vrep/")
  servo1_string.append(servo1_name);
  servo2_string.append("/vrep/")
  servo2_string.append(servo2_name);
  servo3_string.append("/vrep/")
  servo3_string.append(servo3_name);
  servo4_string.append("/vrep/")
  servo4_string.append(servo4_name);
  servo5_string.append("/vrep/")
  servo5_string.append(servo5_name);

  ros::Subscriber joy_sub;
  joy_sub = nh_.subscribe<sensor_msgs::Joy>("joy",1,joyCallback);

  servo1_pub = nh_.advertise<std_msgs::Float64>(servo1_string,1);
  servo2_pub = nh_.advertise<std_msgs::Float64>(servo2_string,1);
  servo3_pub = nh_.advertise<std_msgs::Float64>(servo3_string,1);
  servo4_pub = nh_.advertise<std_msgs::Float64>(servo4_string,1);
  servo5_pub = nh_.advertise<std_msgs::Float64>(servo5_string,1);

  ros::Rate loop_rate(5);
  while (ros::ok()){
   ros::spinOnce();
   loop_rate.sleep();
  }
}
```

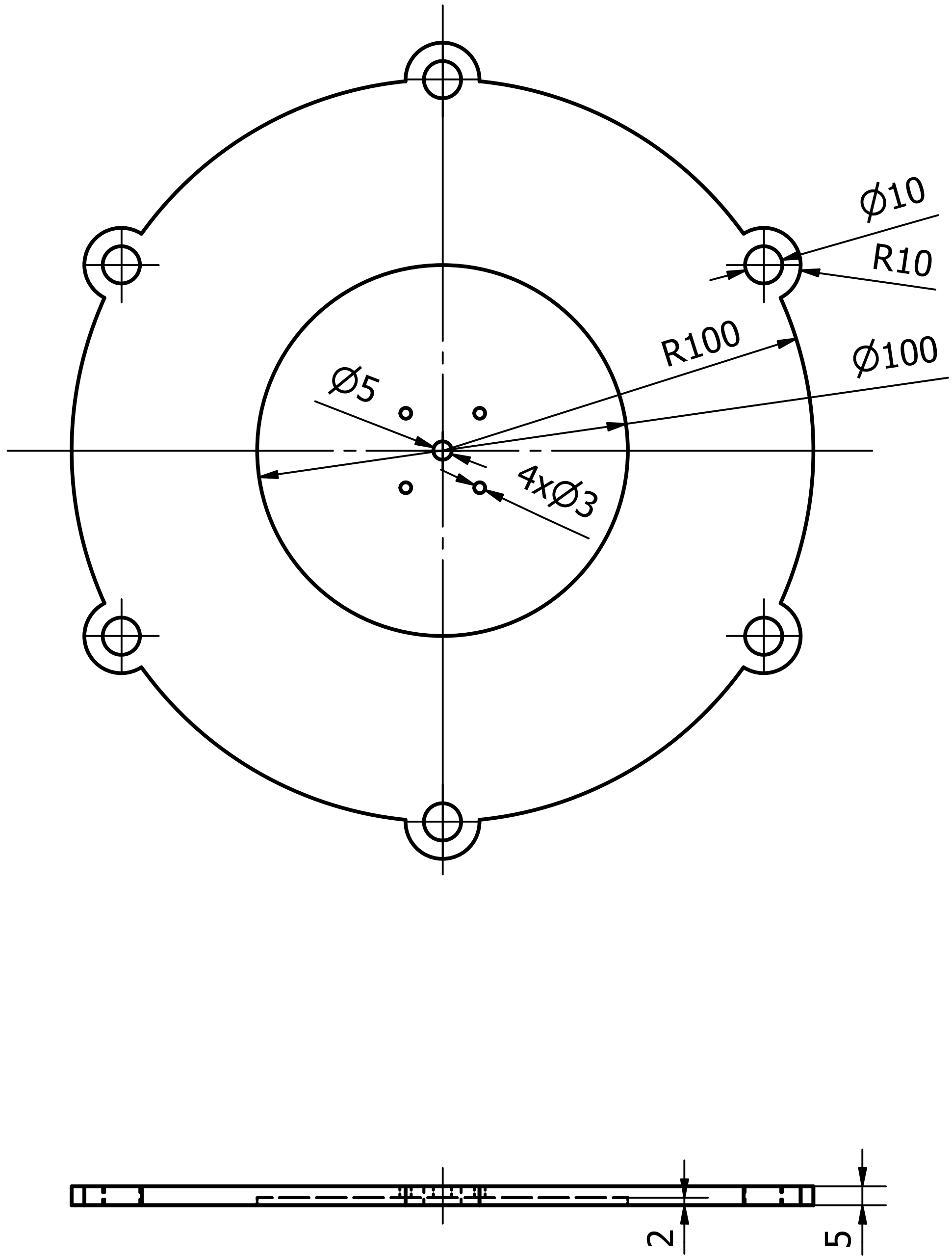
7.3 ARDUINO CODE

```
#include <SoftwareSerial.h>
#include <Servo.h>
SoftwareSerial HC05(2,3);
char tem;
Servo myservo1;
int servoPin1=9;
int angle1=0;
Servo myservo2;
int servoPin2=10;
int angle2=0;
void setup (){
 Serial.begin (115200) ;
 HC05.begin (9600) ;
 myservo1.attach(servoPin1);
 myservo2.attach(servoPin2);
}
void loop() {
 if (HC05.available ()) {
  tem= HC05.read () ;
 }
switch (tem) {
 case 'F':
 {
 angle1=angle1+1;
 break;
 }
 case 'B':
 {
 angle1=angle1-1;
 break;
 }
 case 'L':
 {
 angle2=angle2+1;
 break;
 }
 case 'R':
 {
 angle2=angle2-1;
 break;
 }
 }
  Serial.println (tem) ;
  myservo1.write(angle1);
  delay(5);
  myservo2.write(angle2);
  delay(5);
}
```

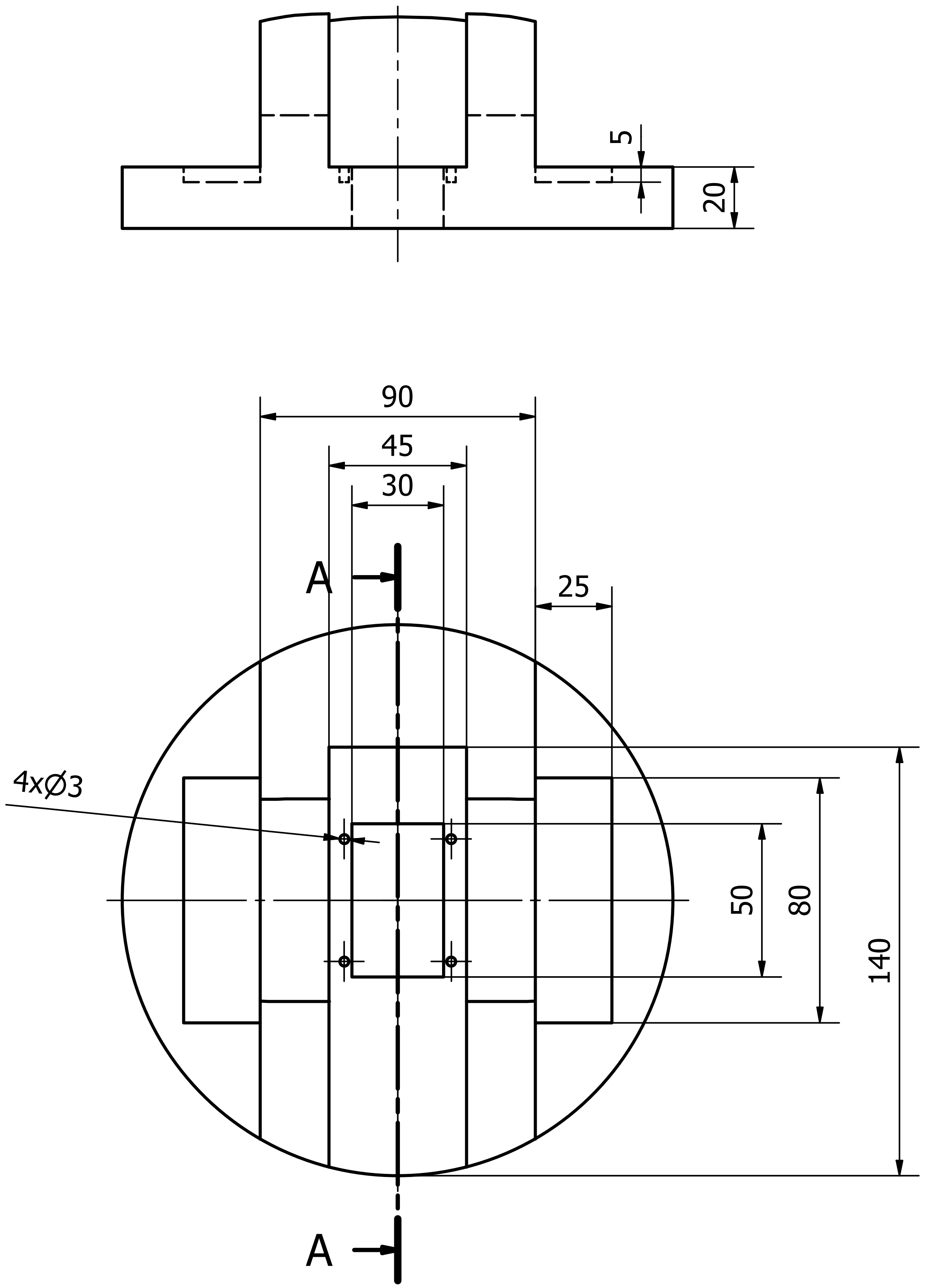


PARTS LIST			
ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	Base	
2	1	Baserotate	
3	7	Servo	
4	12	Scew M5x20	
5	3	ArmPart	
6	1	Holder Gripper	
7	1	Gripper	
8	2	Rotate Connection	

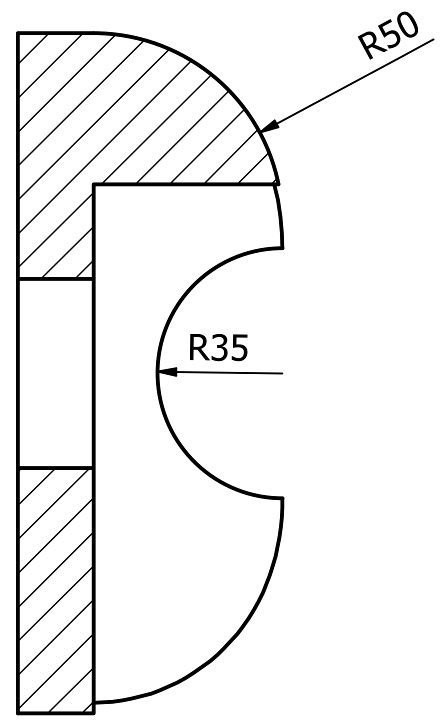
Konstruował	N.Hop			AGH	Wydział	IMiR
Sprawdził						
Podziałka 1/ 3	Nazwa Arm Robot			Materiał -	Masa -	Nr. rysunku



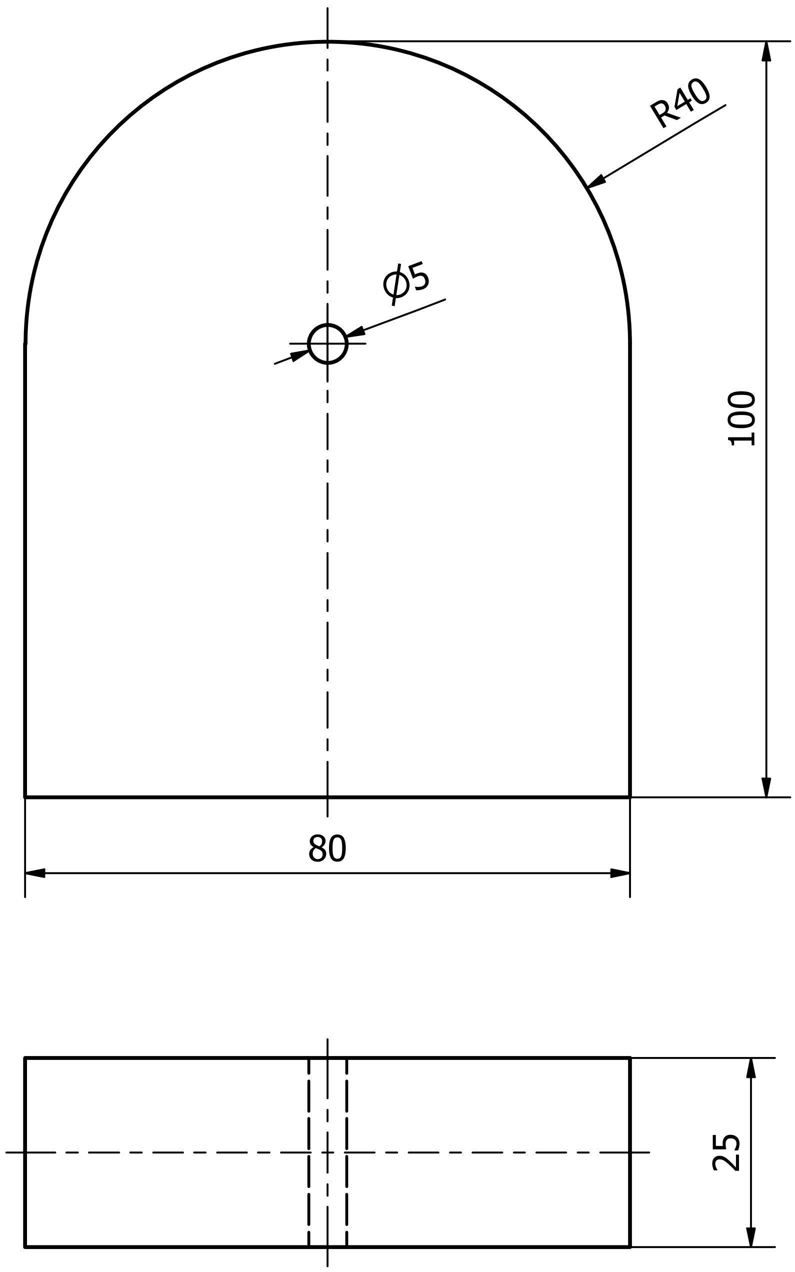
Konstruował	N.Hop			AGH	Wydział IMiR	
Sprawdził						
Podziałka 1 : 2	Nazwa Base			Materiał	Masa	Nr. rysunku 01



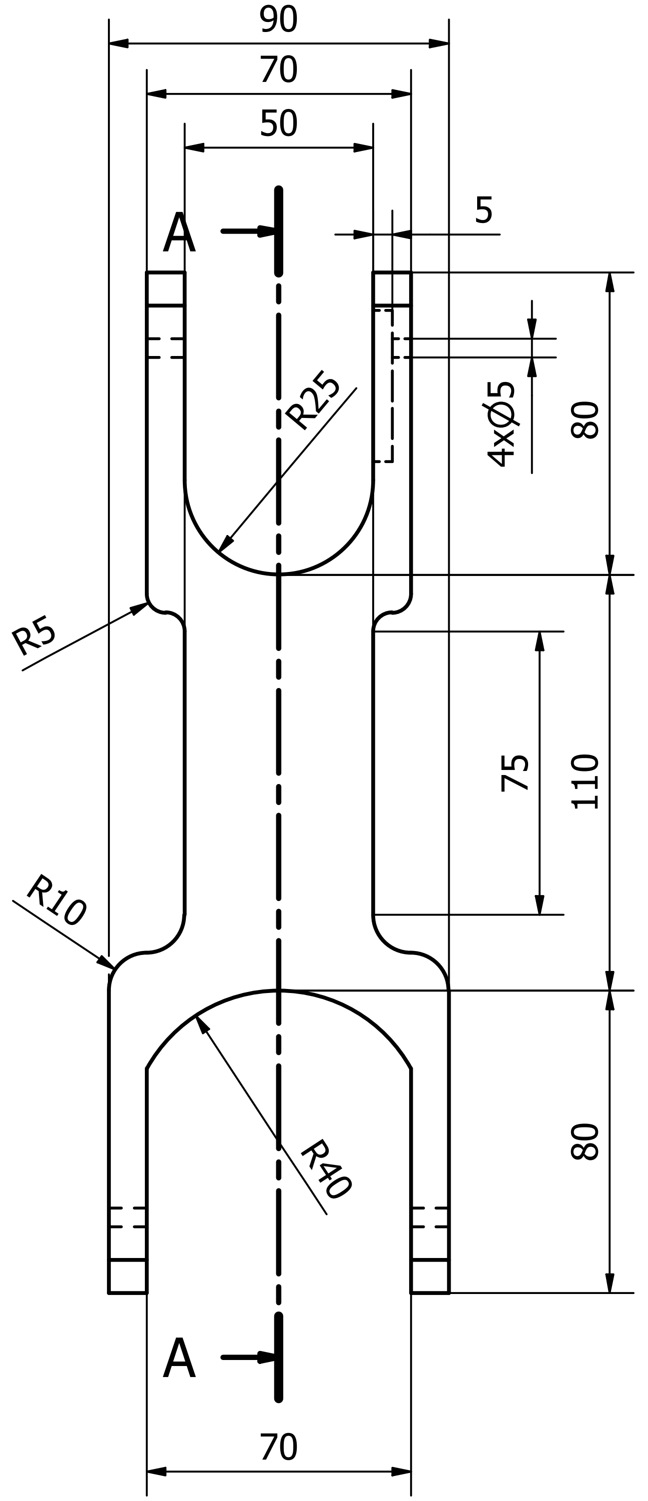
A-A (1 : 2)

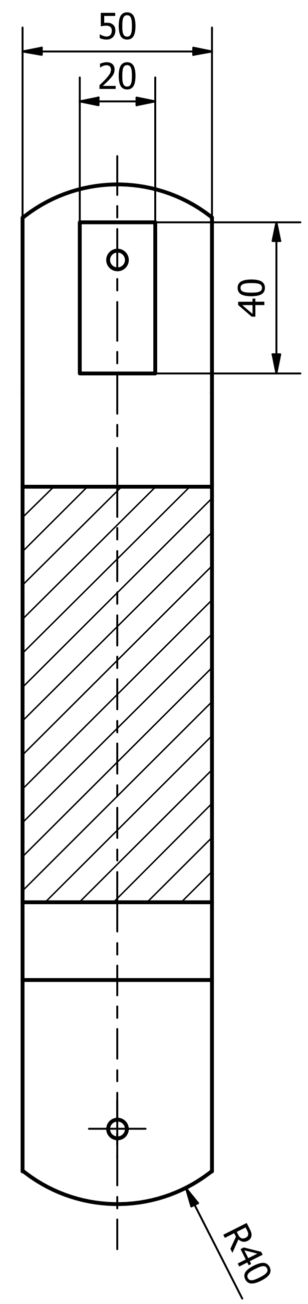


Konstruował	N.Hop			AGH	Wydział IMiR	
Sprawdził						
Podziałka 1 : 2	Nazwa Base			Materiał -	Masa -	Nr. rysunku 02



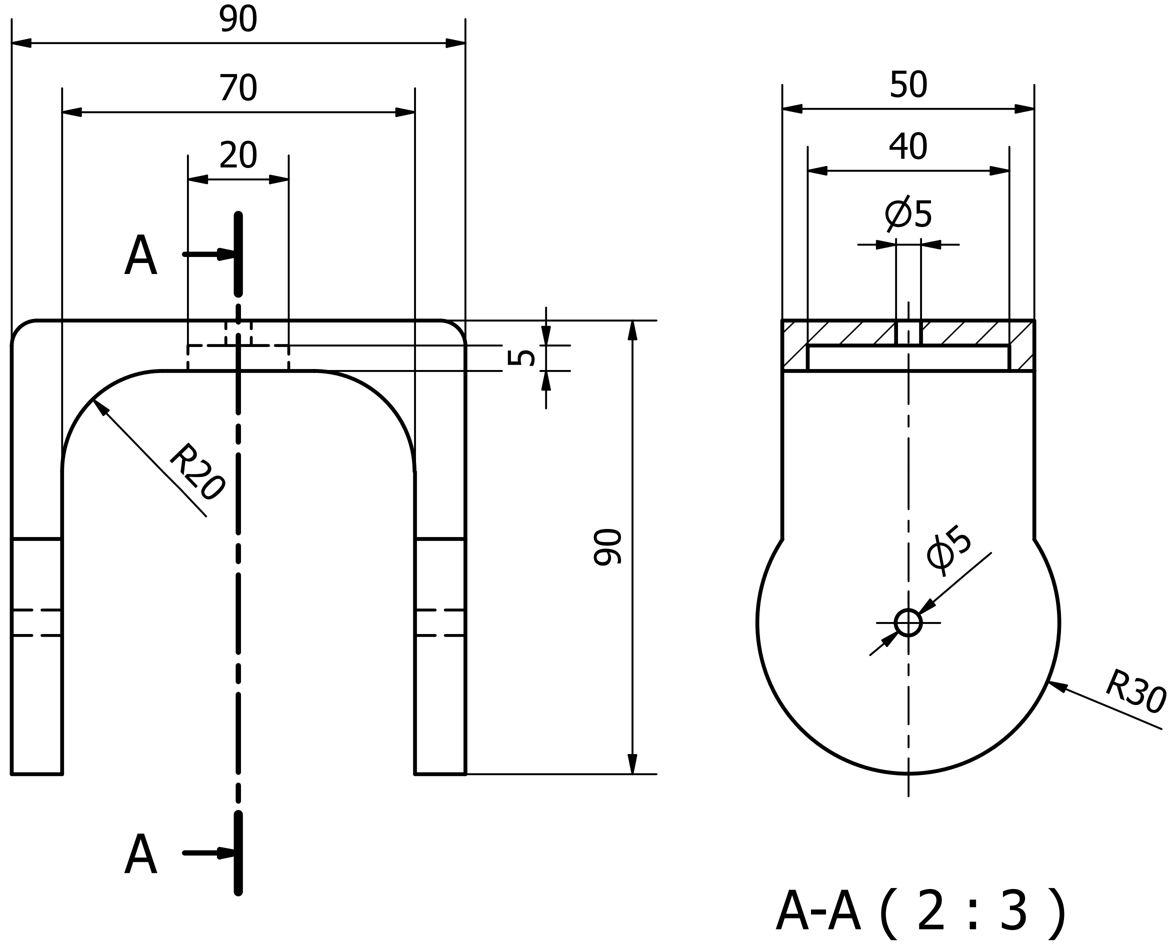
Konstruował	N.Hop			AGH	Wydział IMiR	
Sprawdził						
Podziałka 1 : 1	Nazwa Foot			Materiał	Masa	Nr. rysunku 03



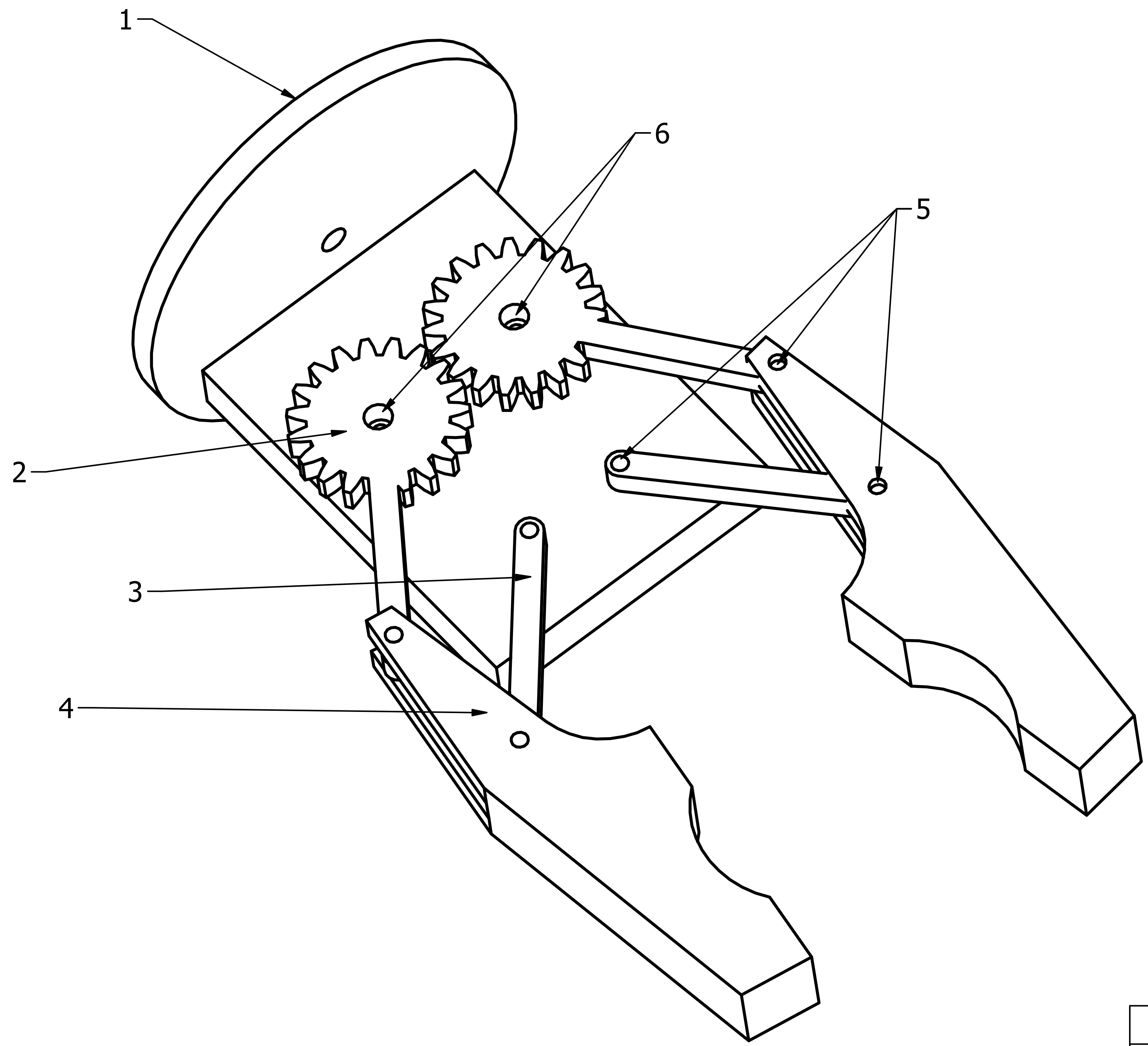


A-A (1 : 2)

Konstruował	N.Hop			AGH	Wydział	IMiR
Sprawdził						
Podziałka 1 : 2	Nazwa Arm part			Materiał -	Masa -	Nr. rysunku 04

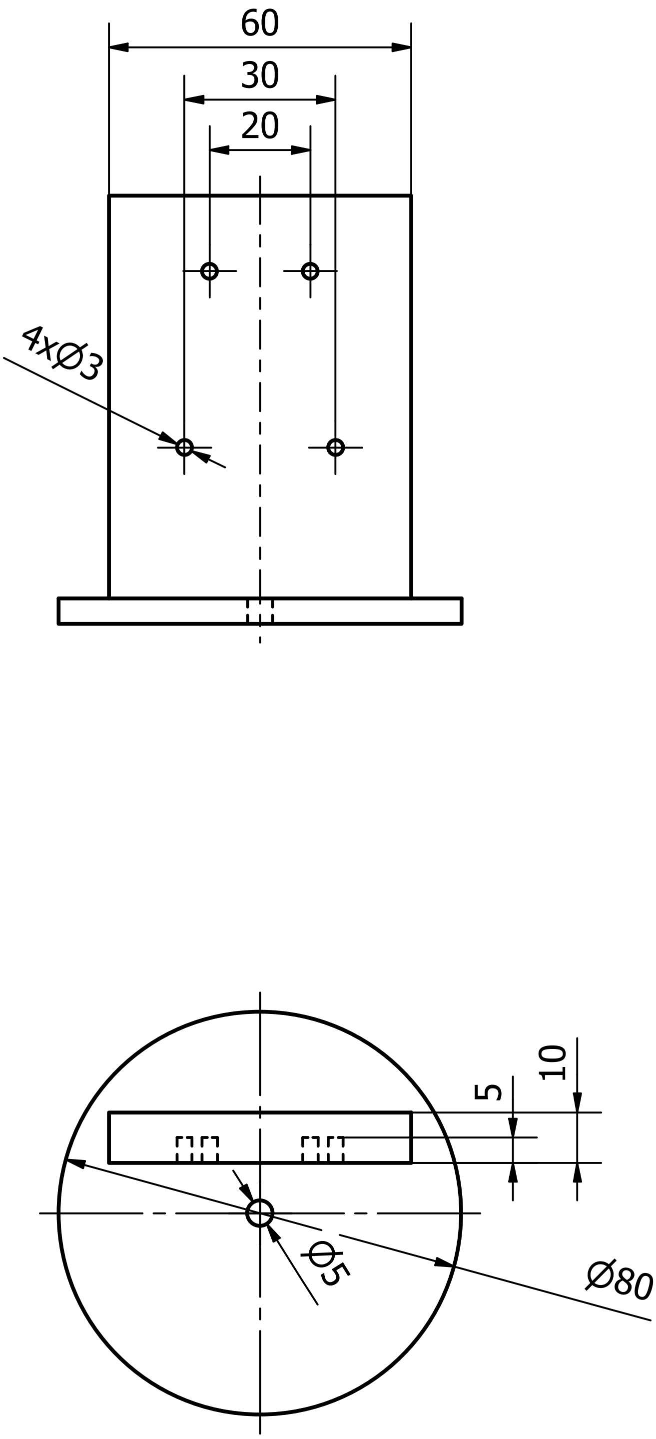


Konstruował	N.Hop			AGH	Wydział IMiR	
Sprawdził						
Podziałka 2 : 3	Nazwa Connect gripper			Materiał	Masa	Nr. rysunku 05



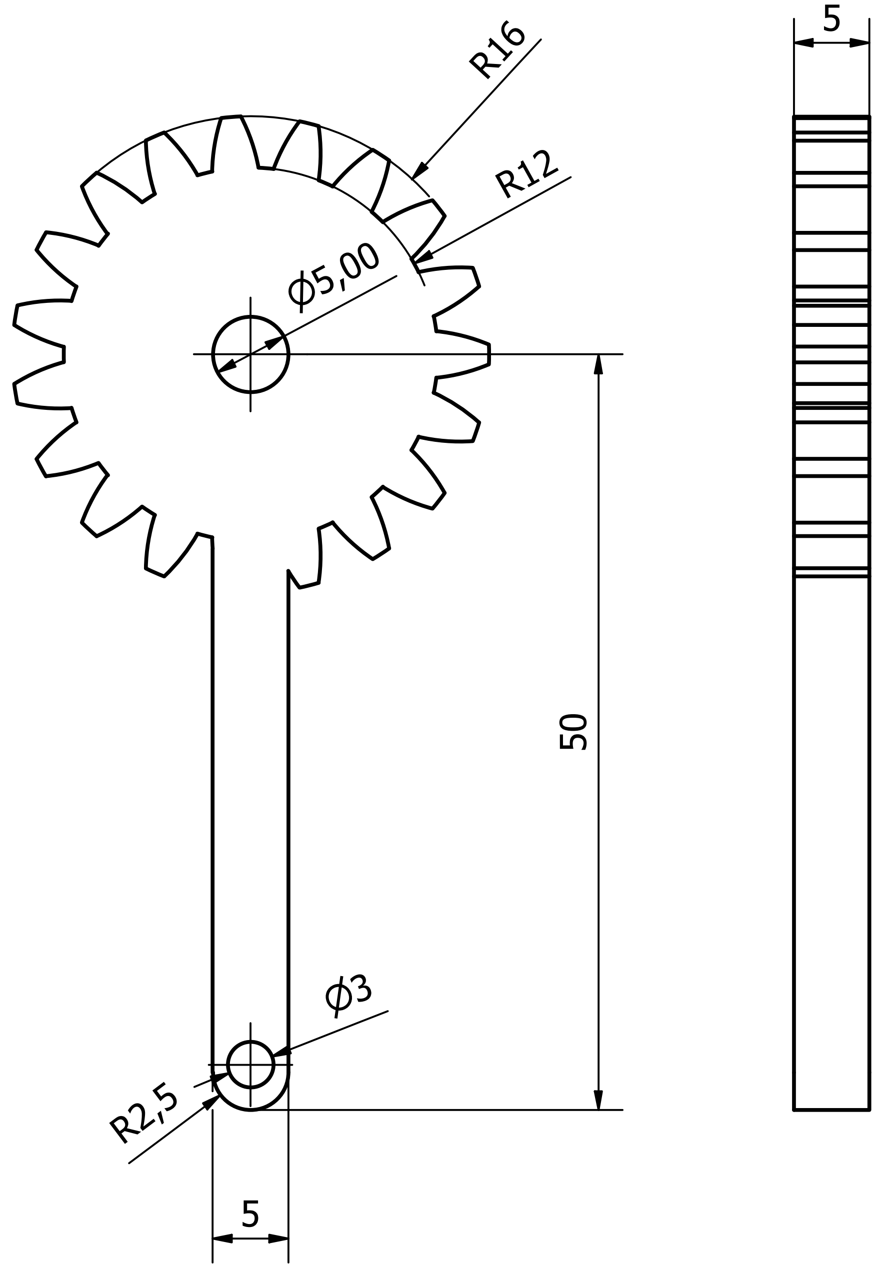
PARTS LIST			
ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	Base	
2	2	Gear bar	
3	2	Bar	
4	2	Holder	
5	6	Scew M3x20	
6	2	Scew M5x20	

Konstruował	N.Hop			AGH	Wydział	IMiR
Sprawdził						
Podziałka 1 : 1	Nazwa Gripper			Materiał -	Masa -	Nr. rysunku 10

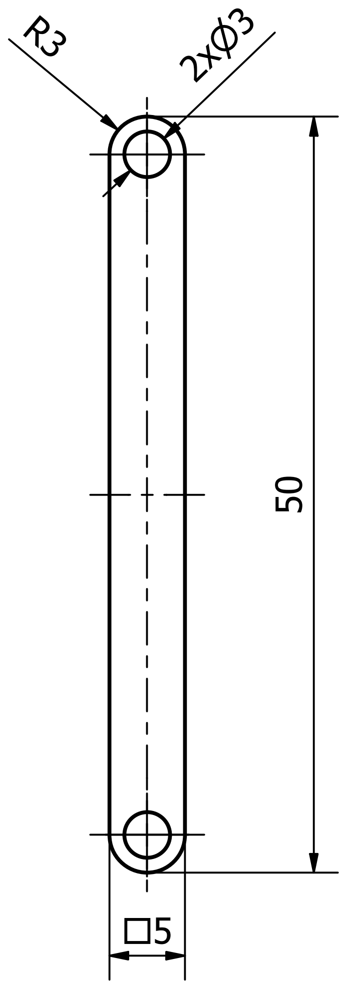


Konstruował	N.Hop			AGH	Wydział IMiR
Sprawdził					

Podziałka 2 : 3	Nazwa Base gripper	Materiał	Masa	Nr. rysunku 06

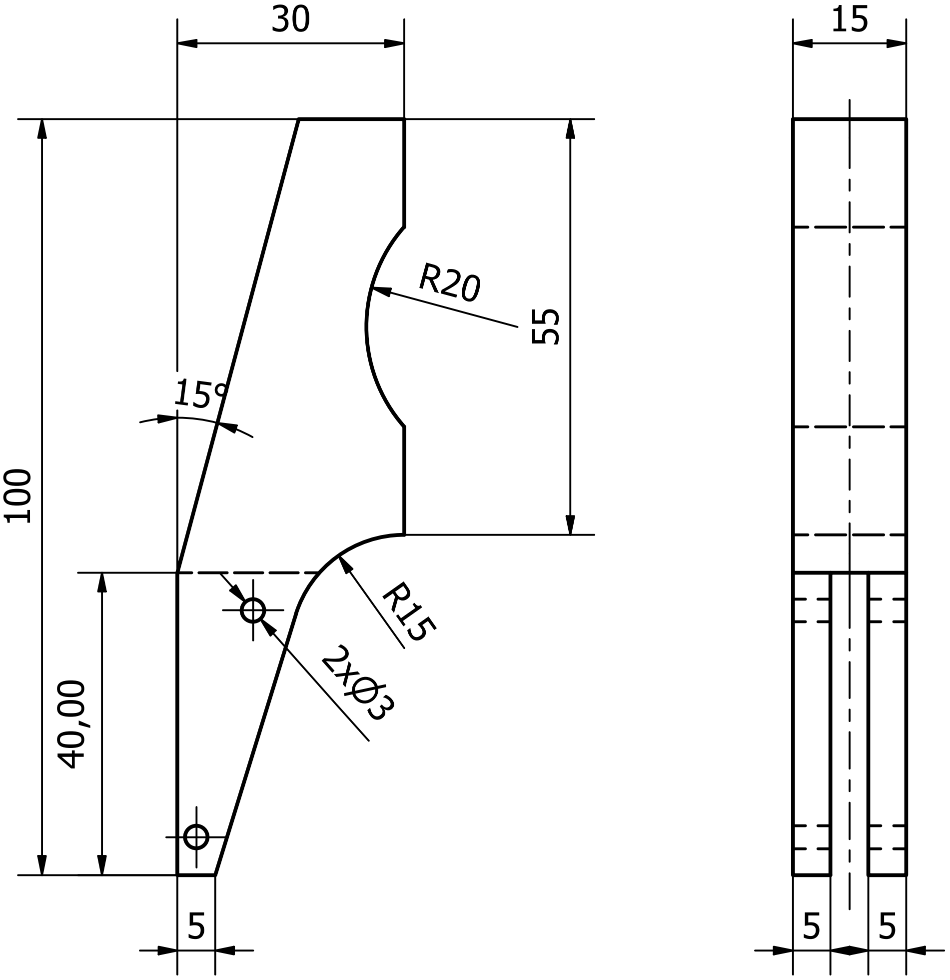


Konstruował	N.Hop			AGH	Wydział IMiR	
Sprawdził						
Podziałka 2 : 1	Nazwa Gear Bar			Materiał	Masa	Nr. rysunku 07



Konstruował	N.Hop			AGH	Wydział IMiR
Sprawdził					

Podziałka	Nazwa	Materiał	Masa	Nr. rysunku
2 : 1	Bar Gripper			08



Konstruował	N.Hop			AGH	Wydział IMiR	
Sprawdził						
Podziałka 1 : 1	Nazwa Holder			Materiał	Masa	Nr. rysunku 09