

DESIGN AND IMPLEMENTATION OF A PURELY ROTARY ROBOTIC MANIPULATOR WITH 5 DOF TO PICK UP AND PLACE OBJECTS FROM ONE PLACE TO ANOTHER THROUGH SMARTPHONE CONTROL

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ROBOTICS I
PROJECTS VI
7TH Semester
22/12/2021

OBJECTIVES

MAIN OBJECTIVE

- Design, simulate and implement a purely rotatory robot manipulator with 5 DoF which will be controlled wirelessly through a smartphone application.

SPECIFIC OBJECTIVES

- Develop a wireless control system that activates and moves the robot manipulator by means an application for smartphones made in MIT App Inventor
- Design the mechanism from scratch of a purely rotatory robot manipulator that has 5 degrees of freedom using Solidworks.
- Implement the robot manipulator designed that allows it to pick up an object from one place and leave it in another without causing any damage.



MOTIVATION

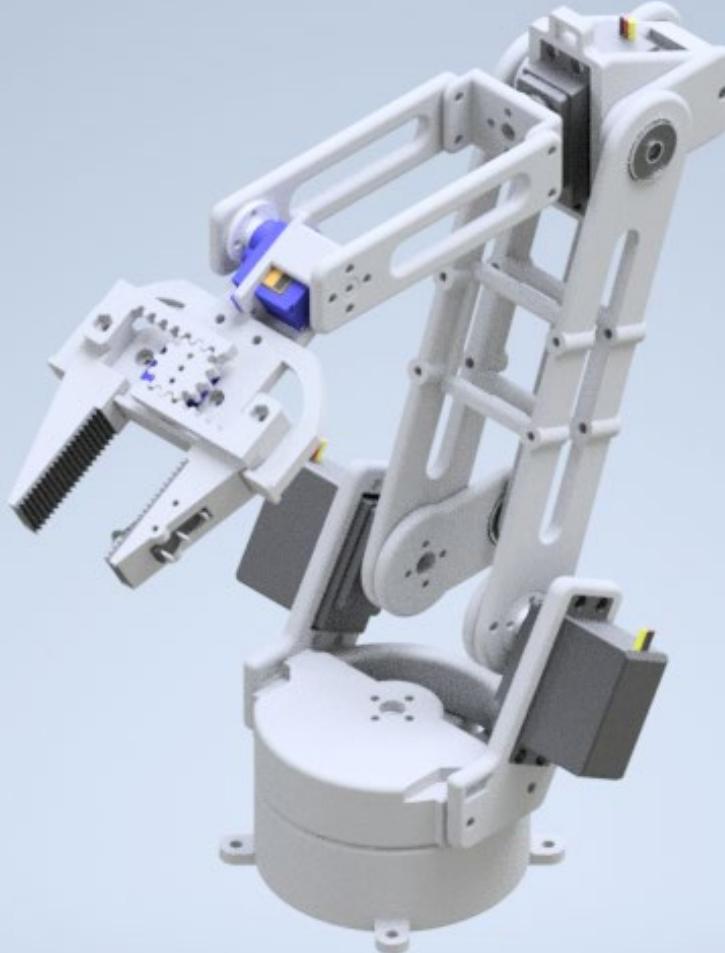
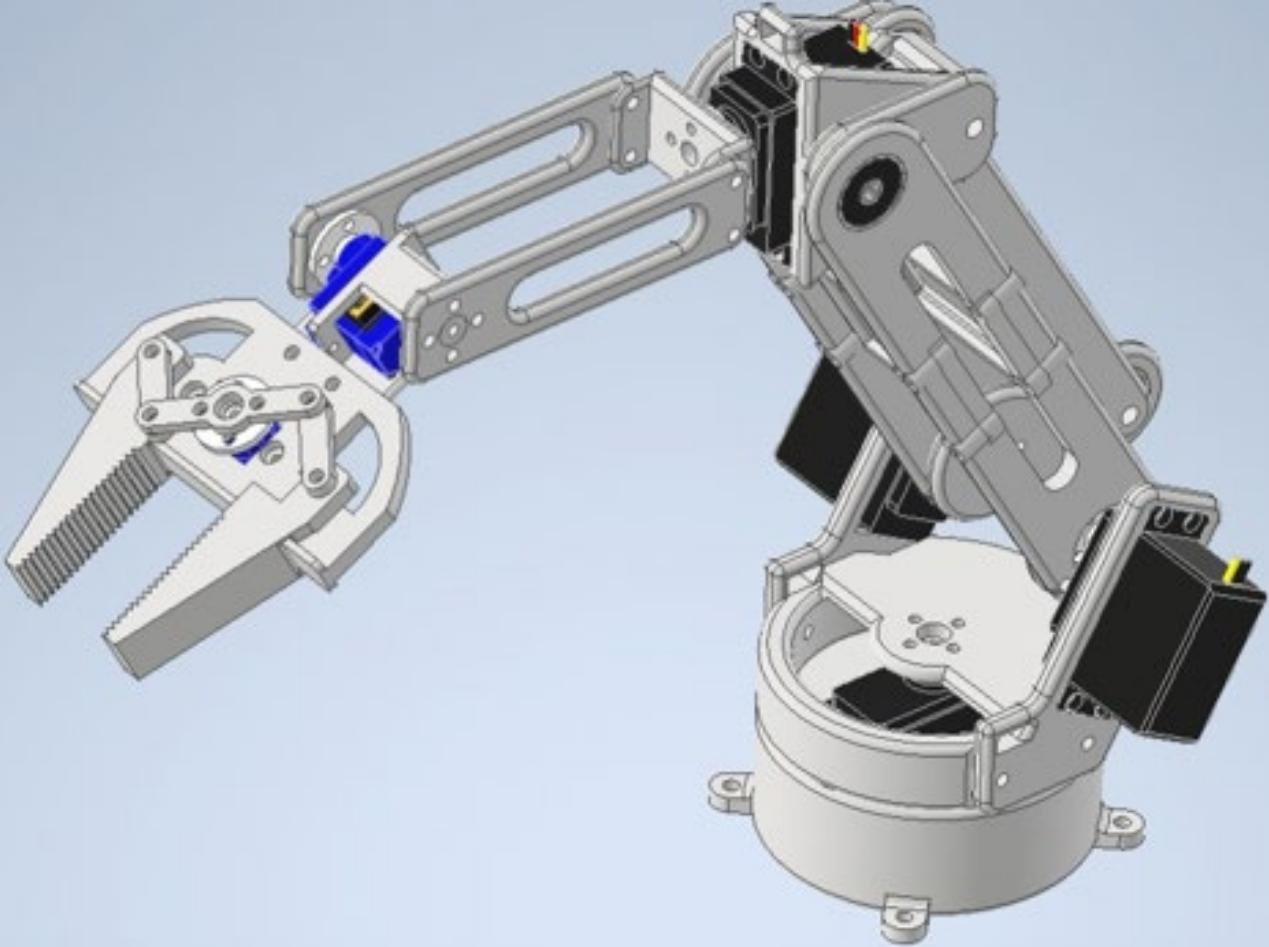
Mainly knowing how the robotic manipulators work, analyzing the complexity in making mechanisms for their correct operation and at the same time that each movement of the robot is useful, in addition to the correct electronic and control design so that the robot works optimally.



PROCESS

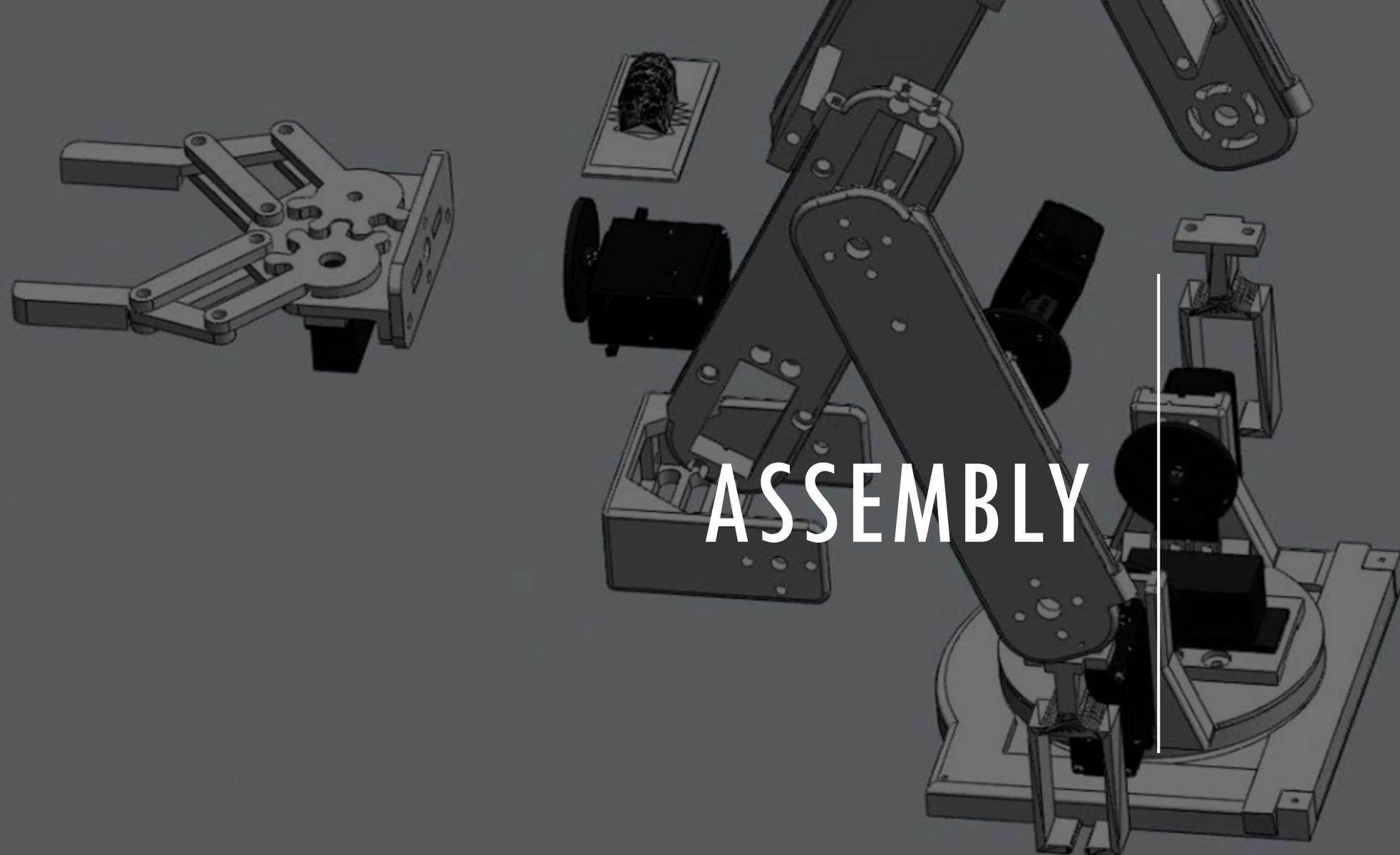
MECHANICAL DESIGN





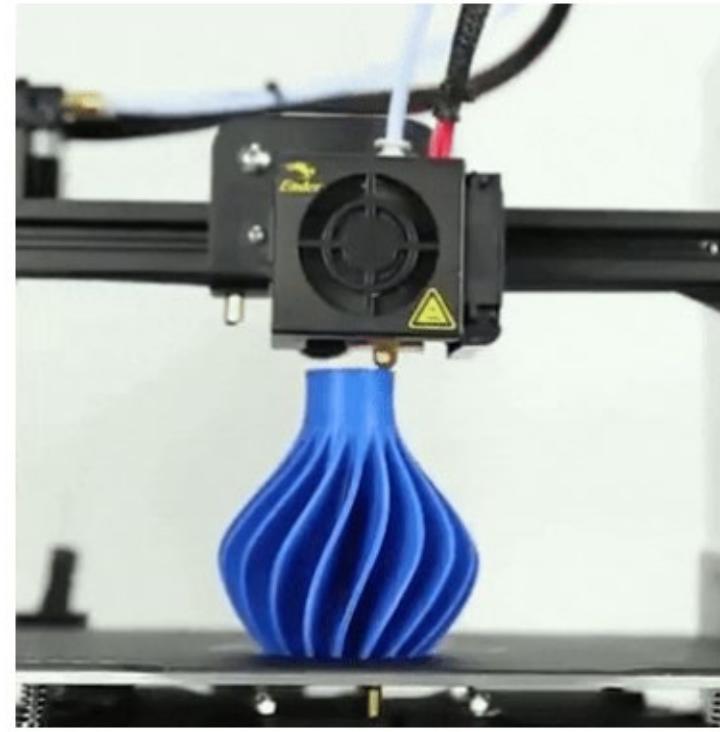
COMPLETED ALTERNATIVES:
VERSION #1 AND VERSION #2

ASSEMBLY



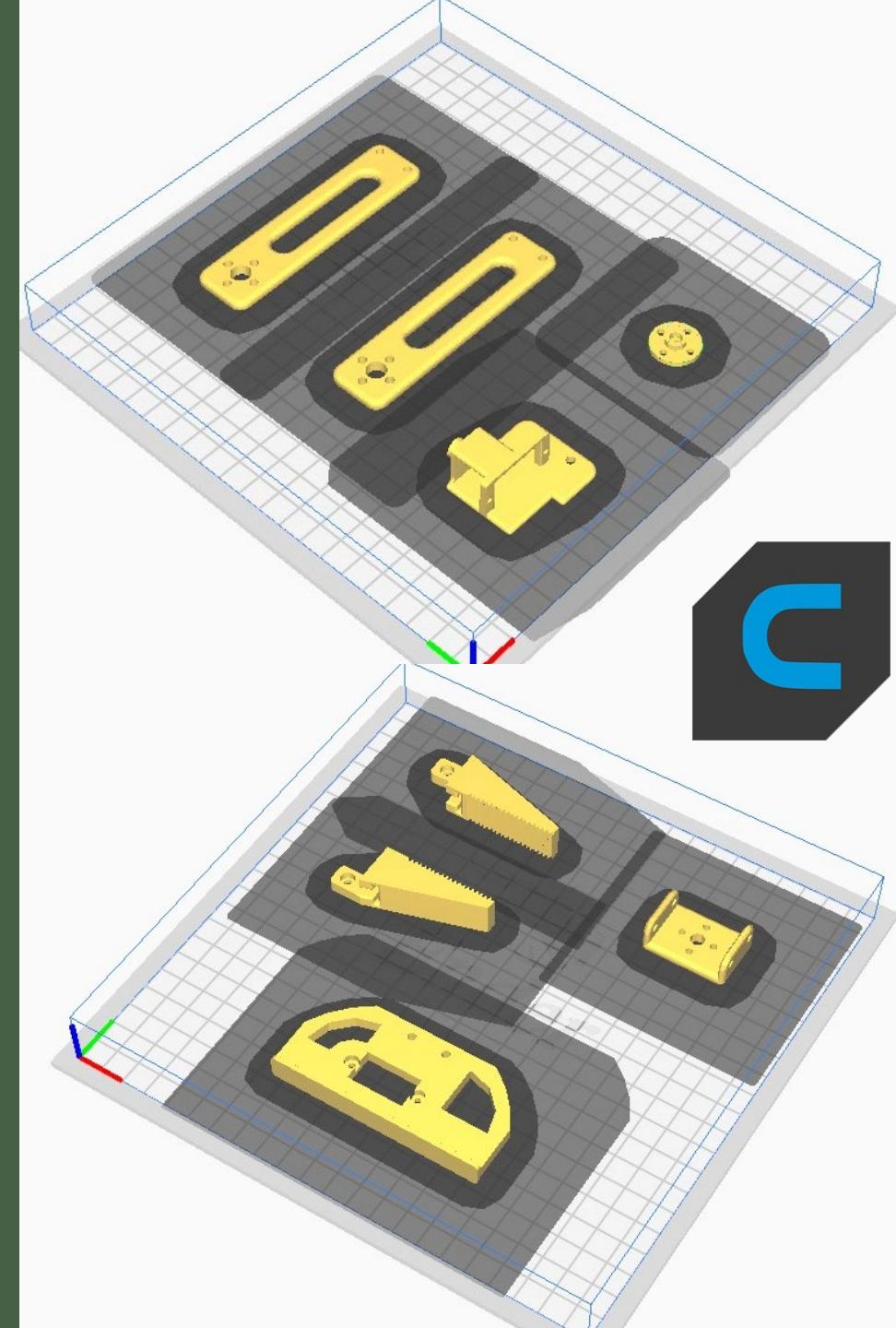
MANUFACTURING

- ❖ Process: 3D Printing
 - ❖ Ender 3V2
 - ❖ Ender 3
 - ❖ Prusa MK2
- ❖ Material: PLA
 - ❖ Colors: white and gold
 - ❖ Brand: Creality
 - ❖ Series: CR
 - ❖ Print Temperature: 195-220°C
 - ❖ Bed Temperature: 60°C

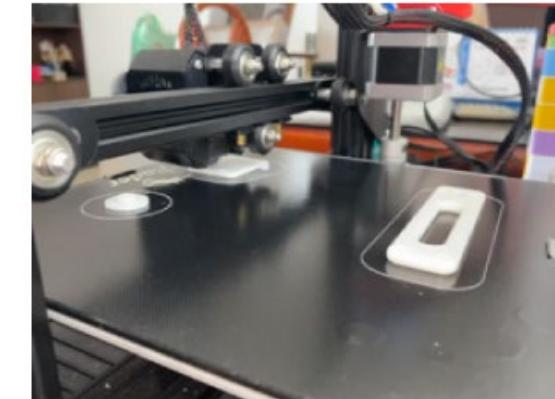
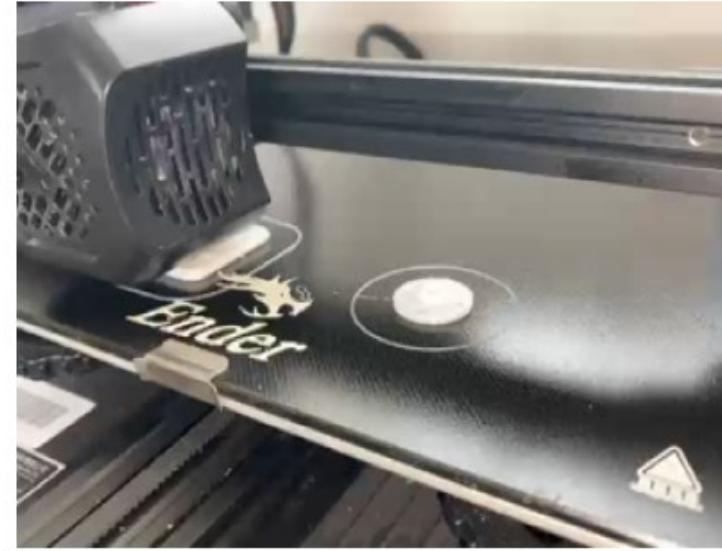


PREPARING THE PARTS TO PRINT

- ❖ Transformation to .STL format
- ❖ Slicing Software: ULTIMAKER CURA
- ❖ Slicing Parameters:
 - ❖ Infill: 20%
 - ❖ Layer height: 0.2
 - ❖ Horizontal expansion: -0.1
 - ❖ Walls: 3
 - ❖ Printing Temperature: 205°C
 - ❖ Build Plate Temperature: 60°C

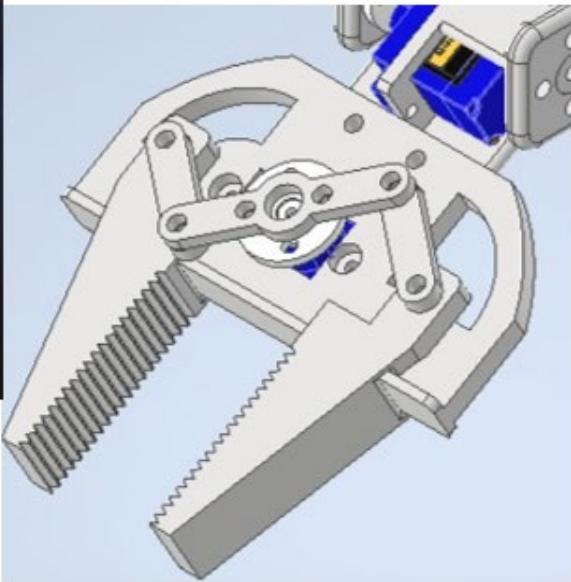
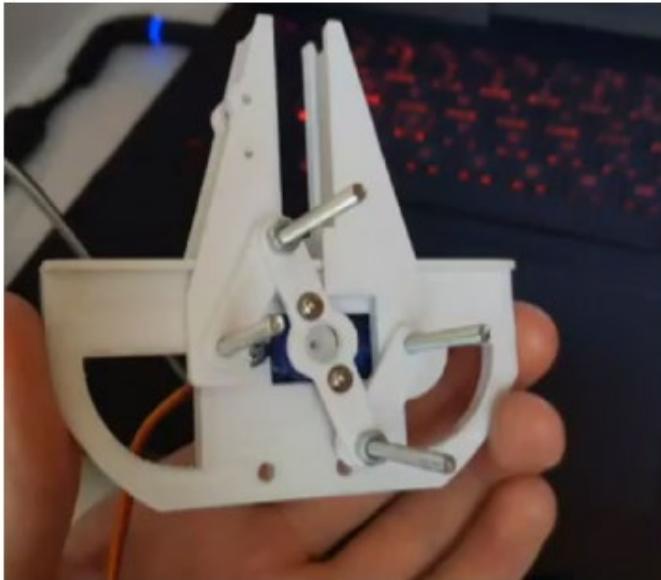


PRINTING THE PARTS

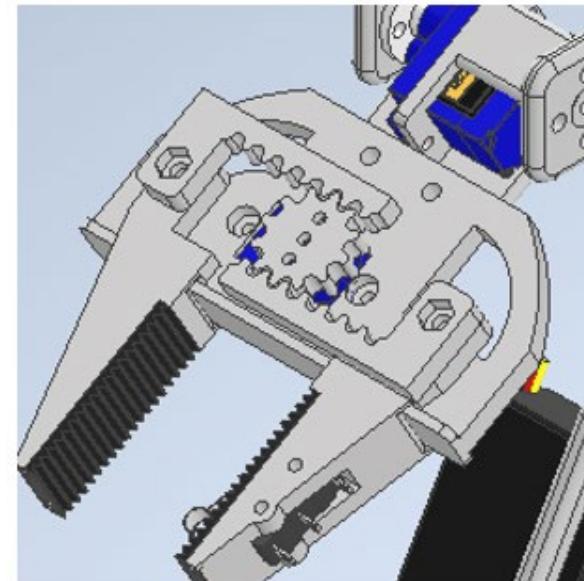


REDESIGN OF THE GRIPPER

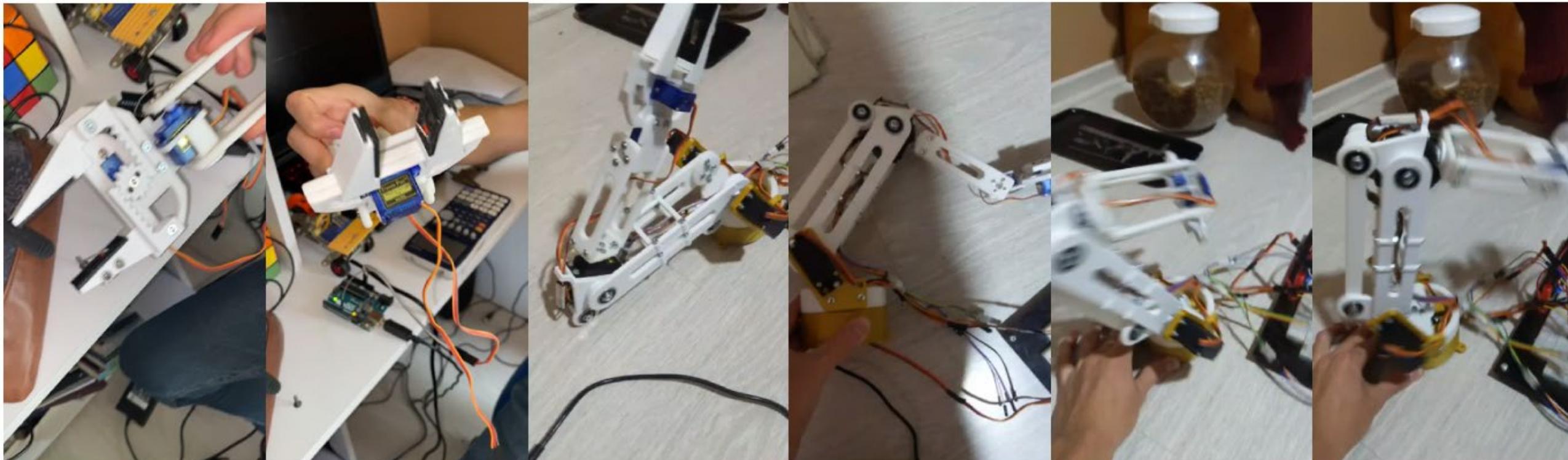
GRIPPER VERSION #1



GRIPPER VERSION #2



FUNCTIONALITY TESTS



GRIPPER

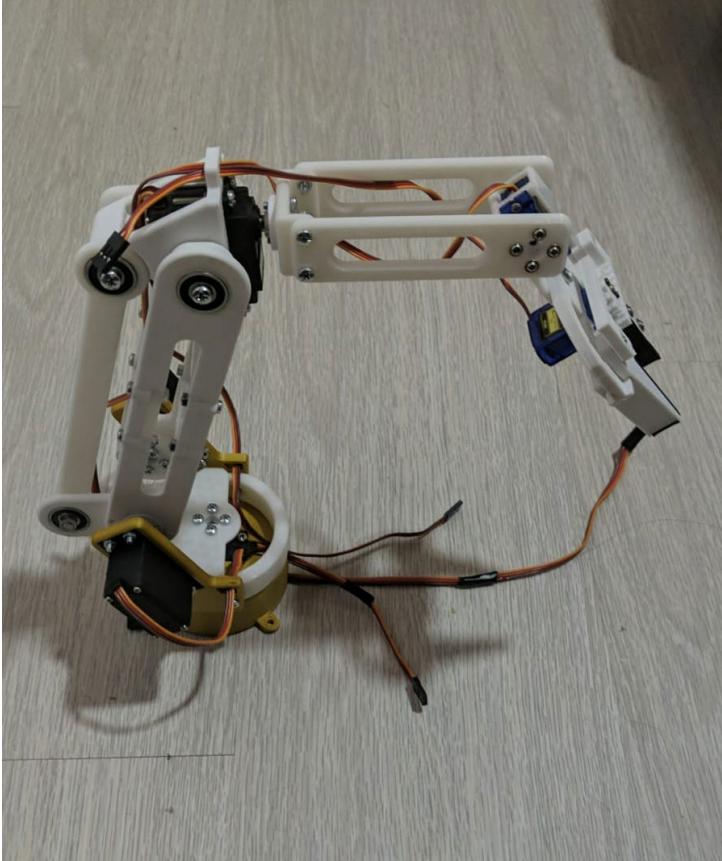
WRIST

FOREARM

ELBOW

ARM

BASE



ASSEMBLING THE PRINTED PARTS WITH THE MECHANICAL COMPONENTS

MECHANICAL COMPONENTS:

- ❖ Bolts
- ❖ Nuts
- ❖ Bearings ($d=20\text{mm}$)

ELECTRICAL COMPONENTS:

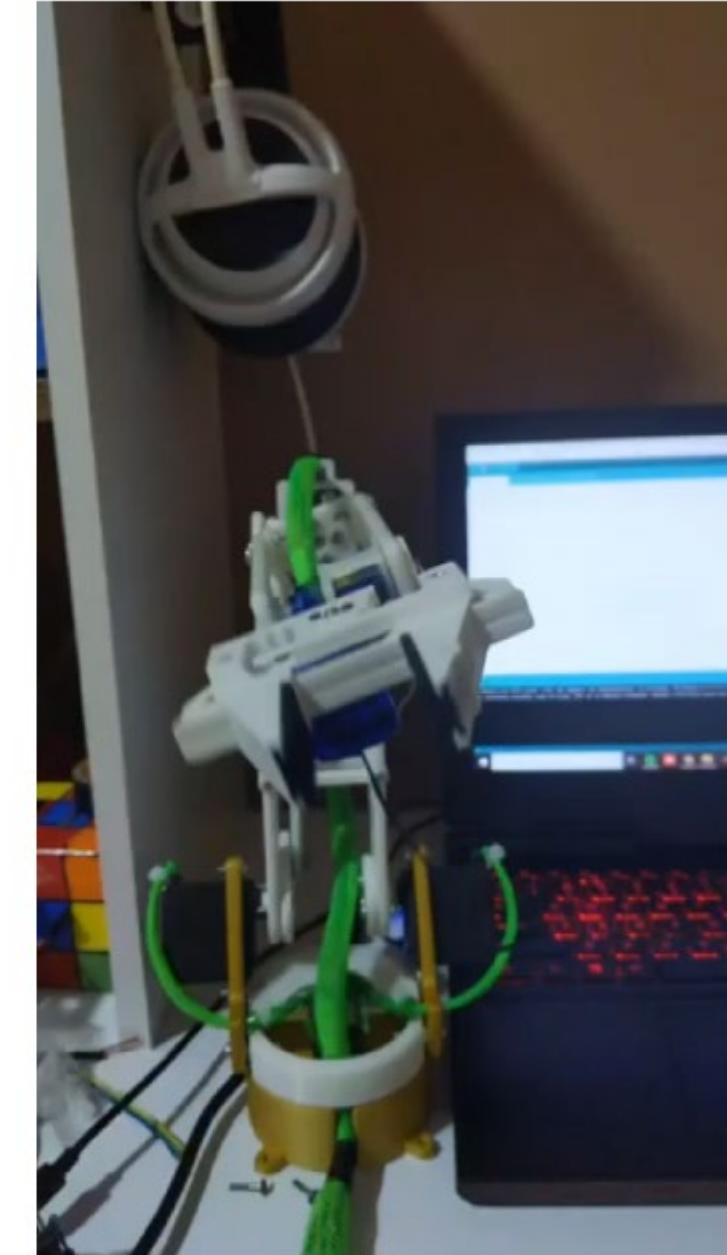
- ❖ Servomotors (MG996R and SG90)
- ❖ Limit switch

EXTRAS:

To move freely without causing tangles or disconnections

- ❖ Cable ties
- ❖ Tapes
- ❖ Mesh covers

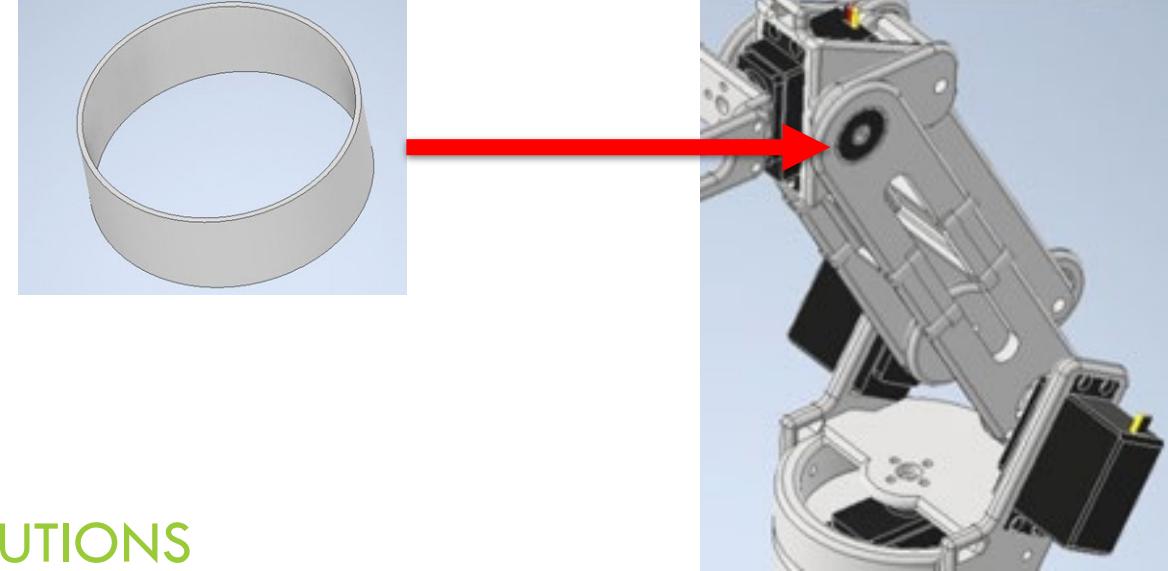
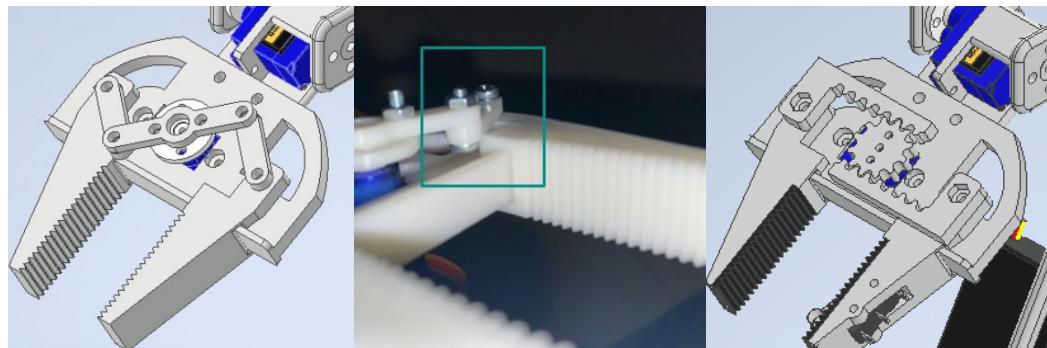
FINAL TEST AND SPEED REGULATION



PROBLEMS

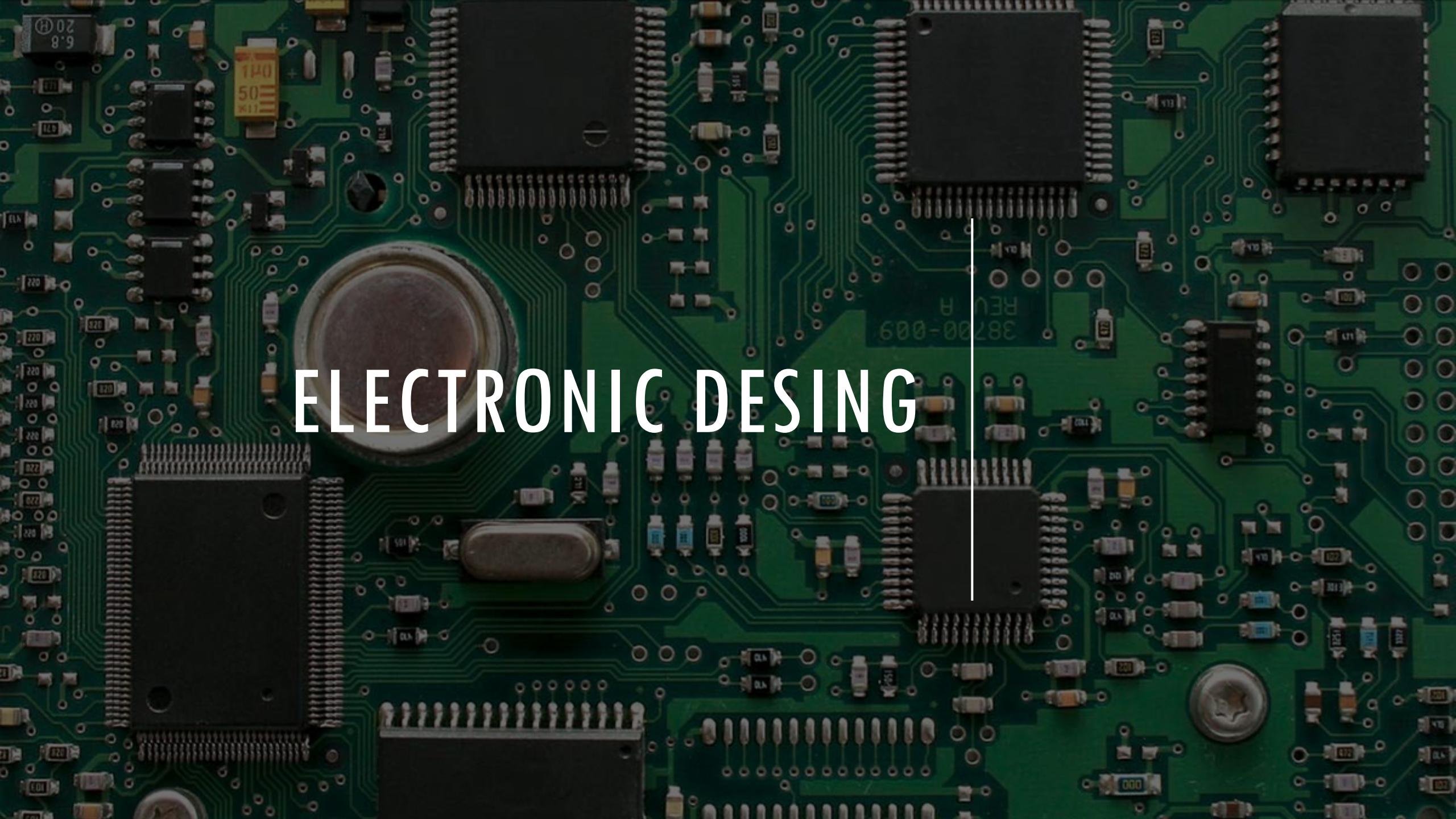
COMPLICATIONS

- ❖ Unconsidered tolerances
- ❖ Gripper: Bolts and nuts crashing with the parts
- ❖ Not fitting bearings



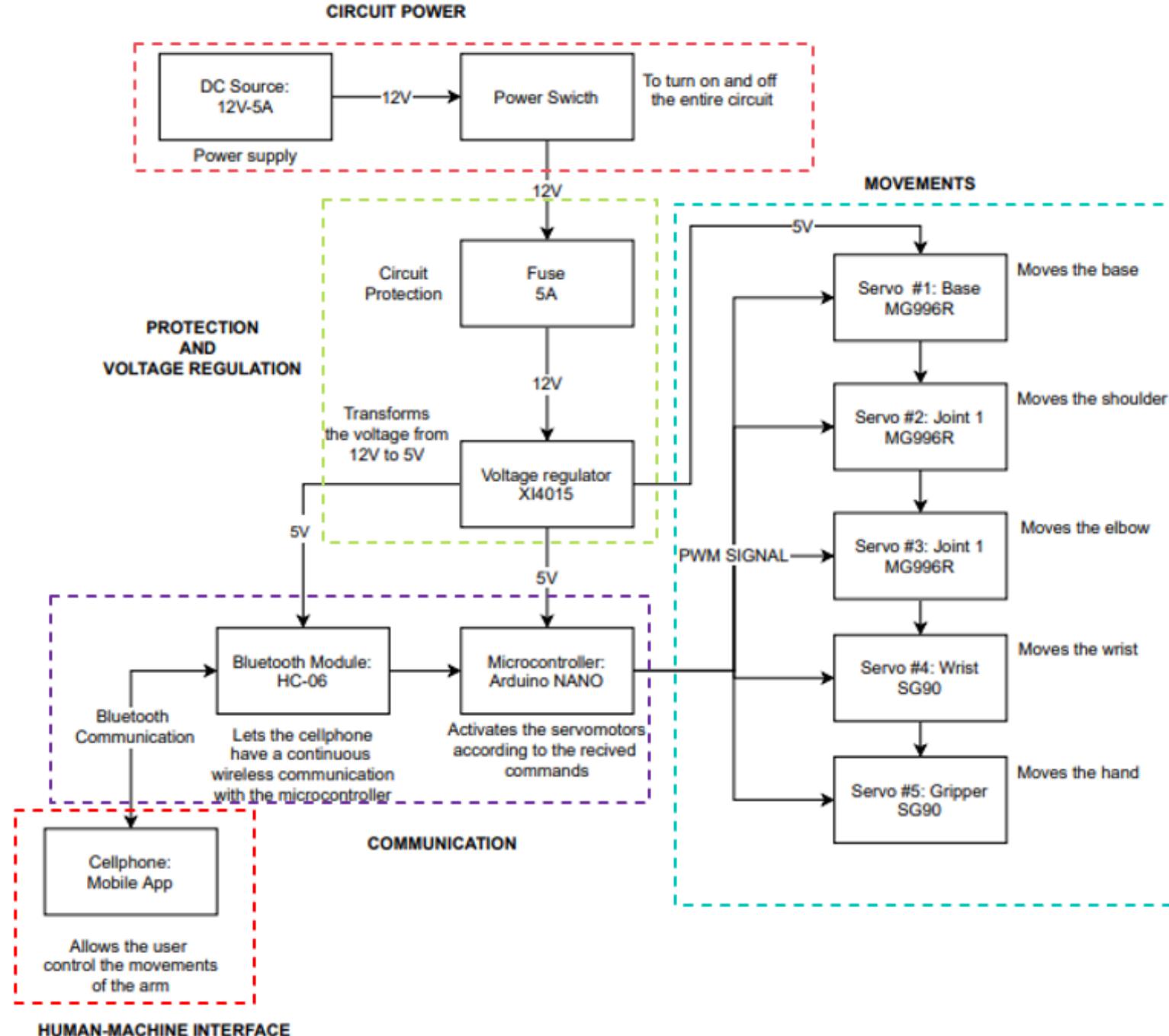
SOLUTIONS

- ❖ CURA parameters: Horizontal Expansion =-0.1mm
- ❖ Changing the gripper mechanism.
- ❖ Printing a ring with the size of the necessary space to make the bearings fit.

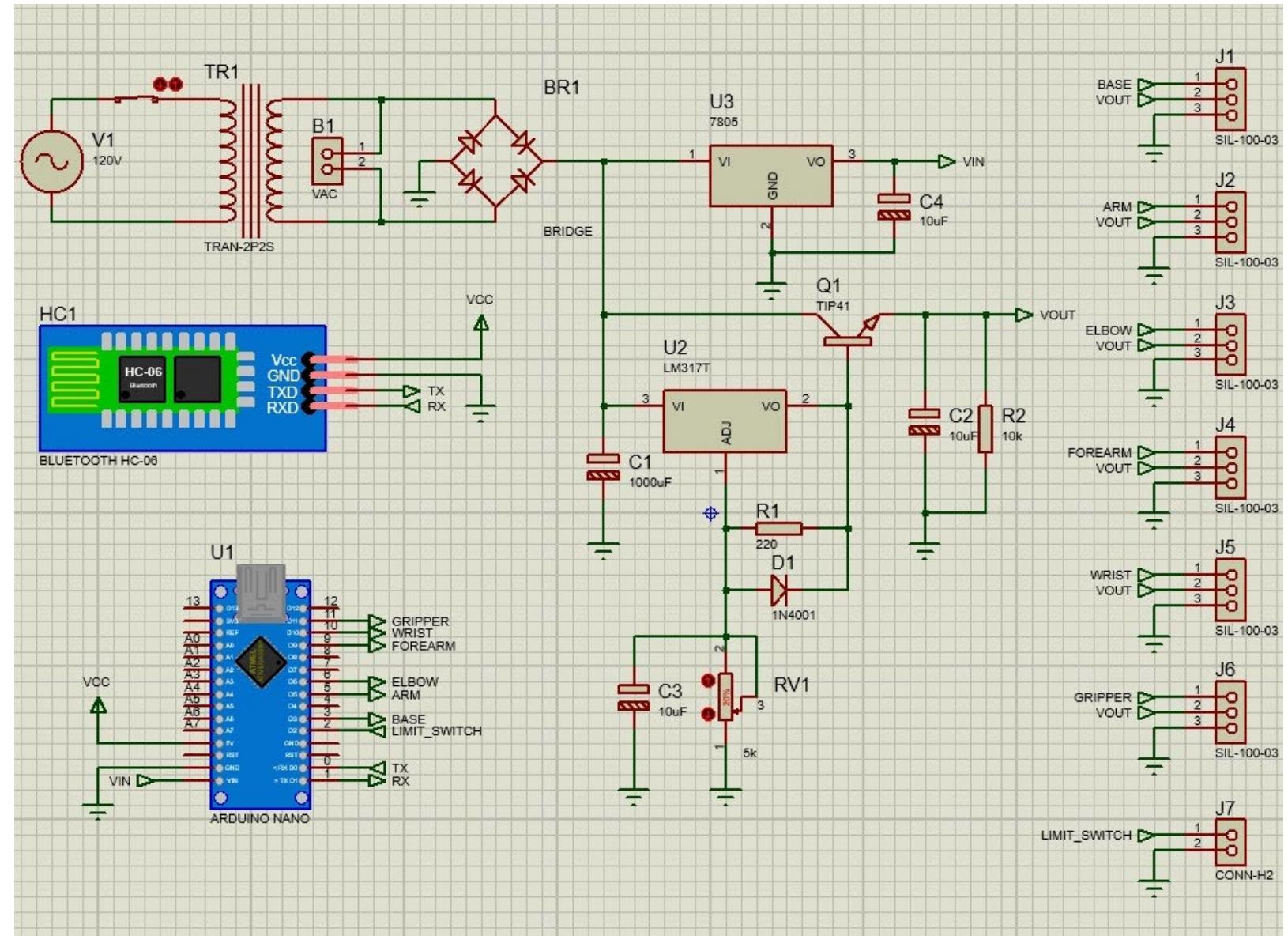


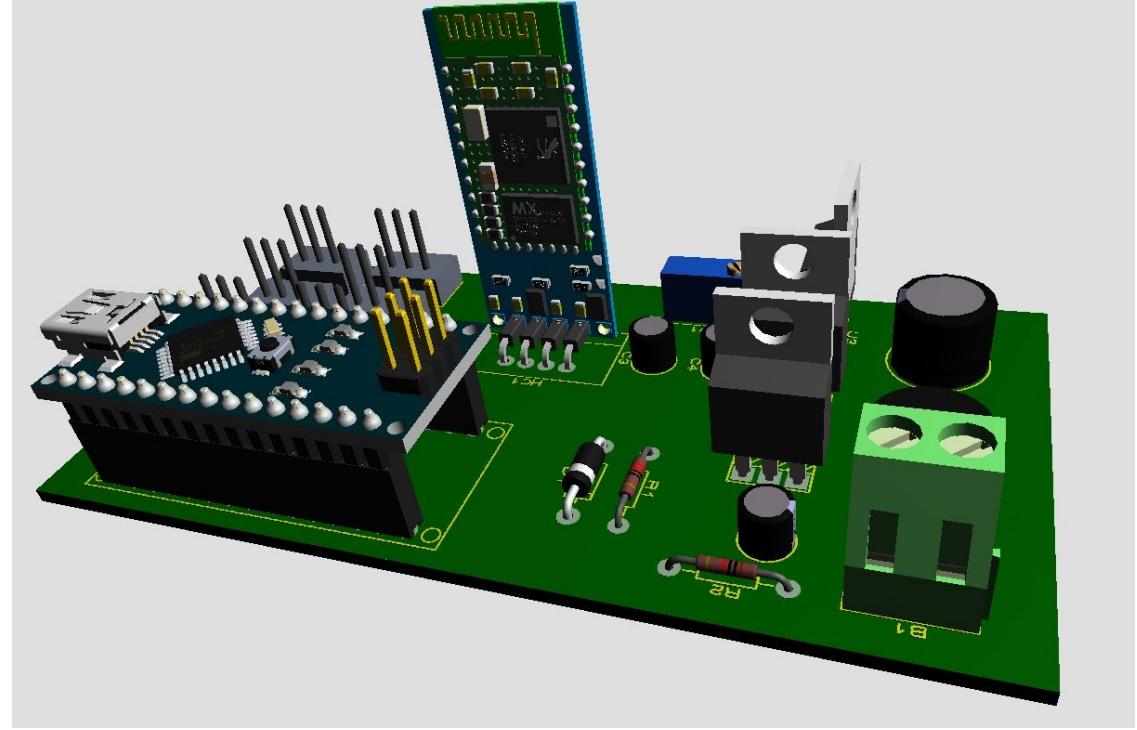
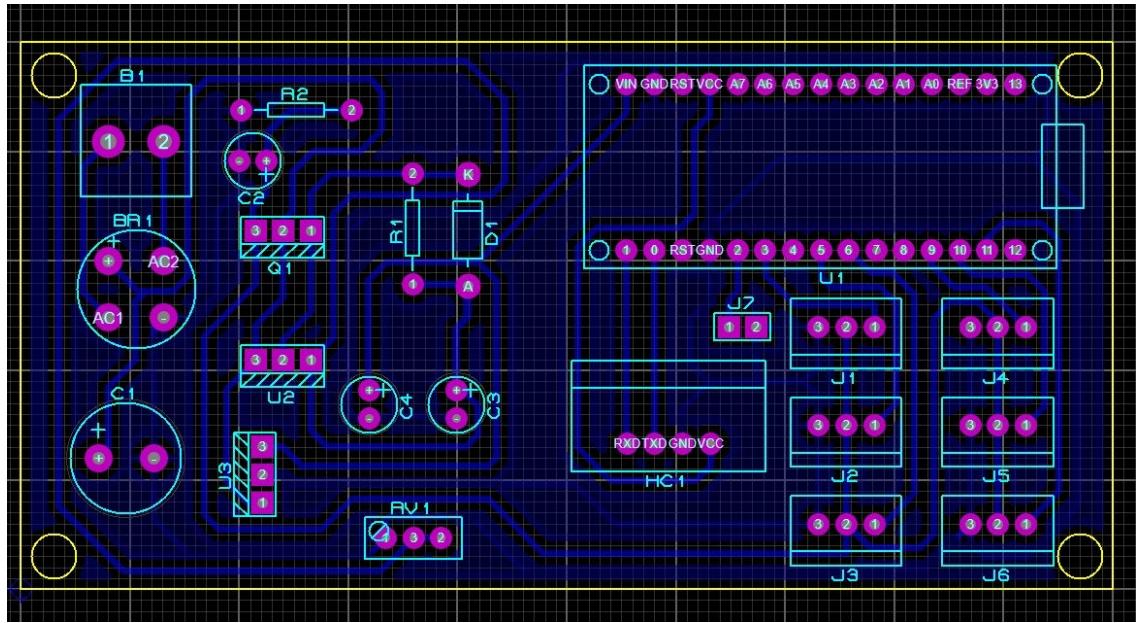
ELECTRONIC DESING

INICIAL SCHEME

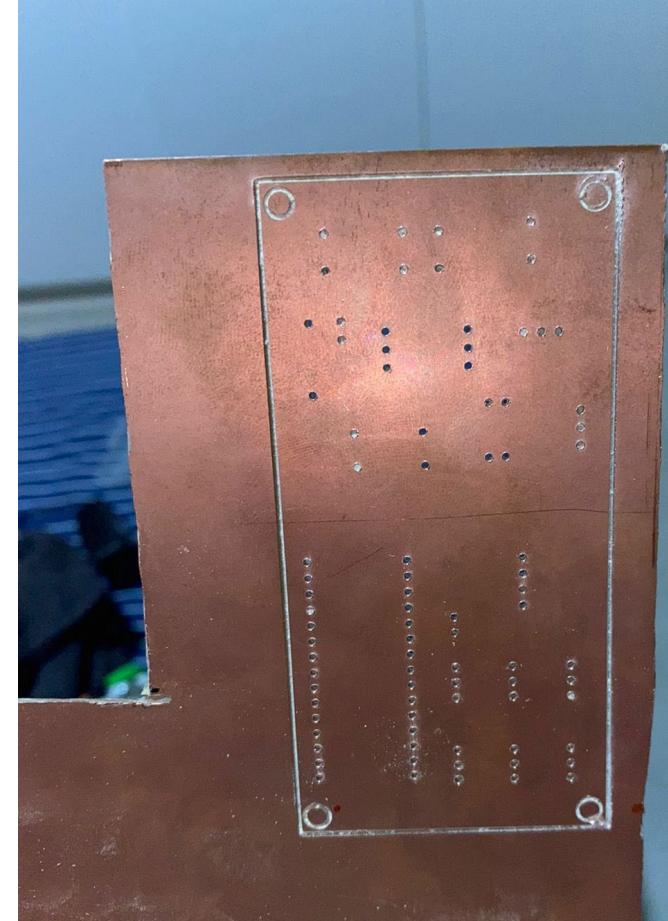
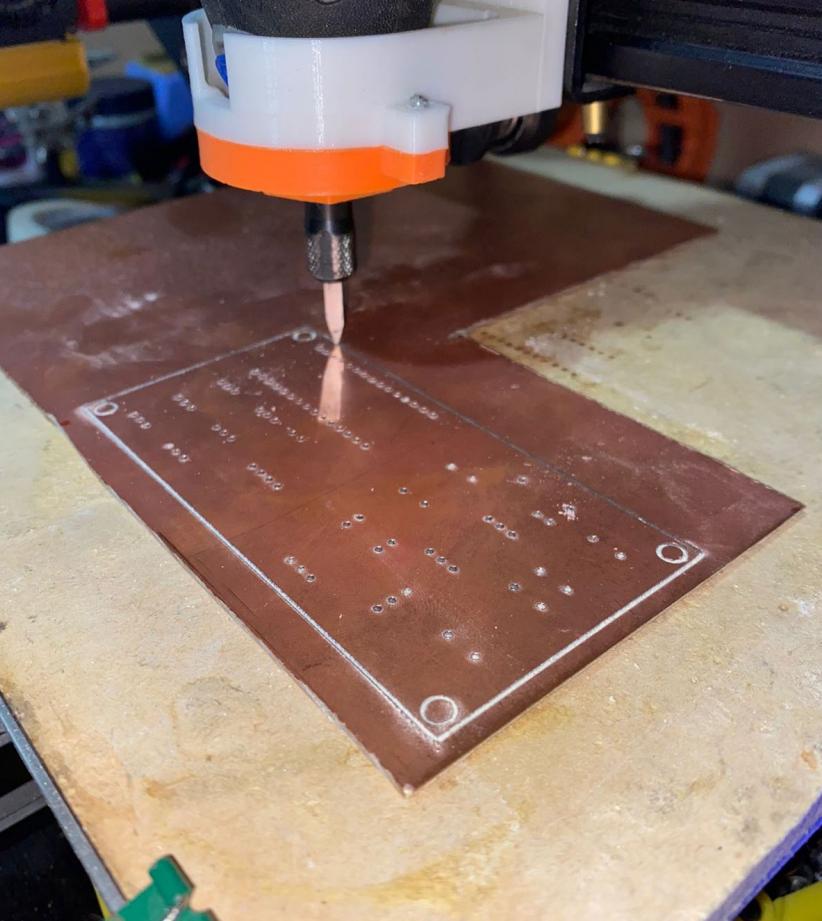
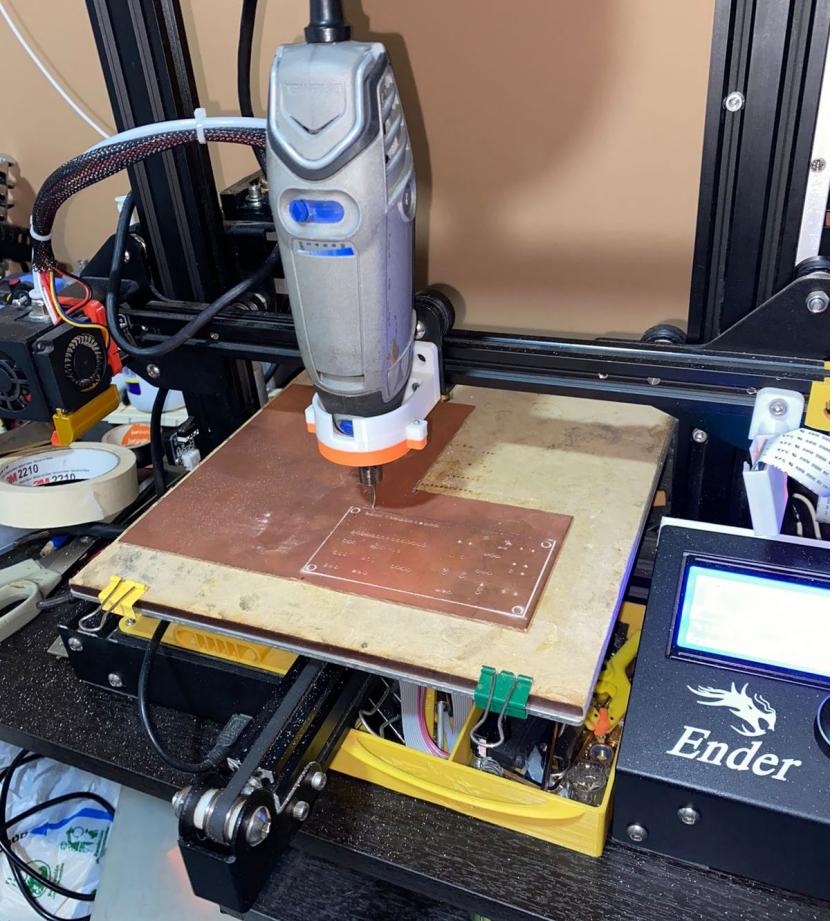


ACTUAL PROTEUS IMPLEMENTATION





PCB DESIGN



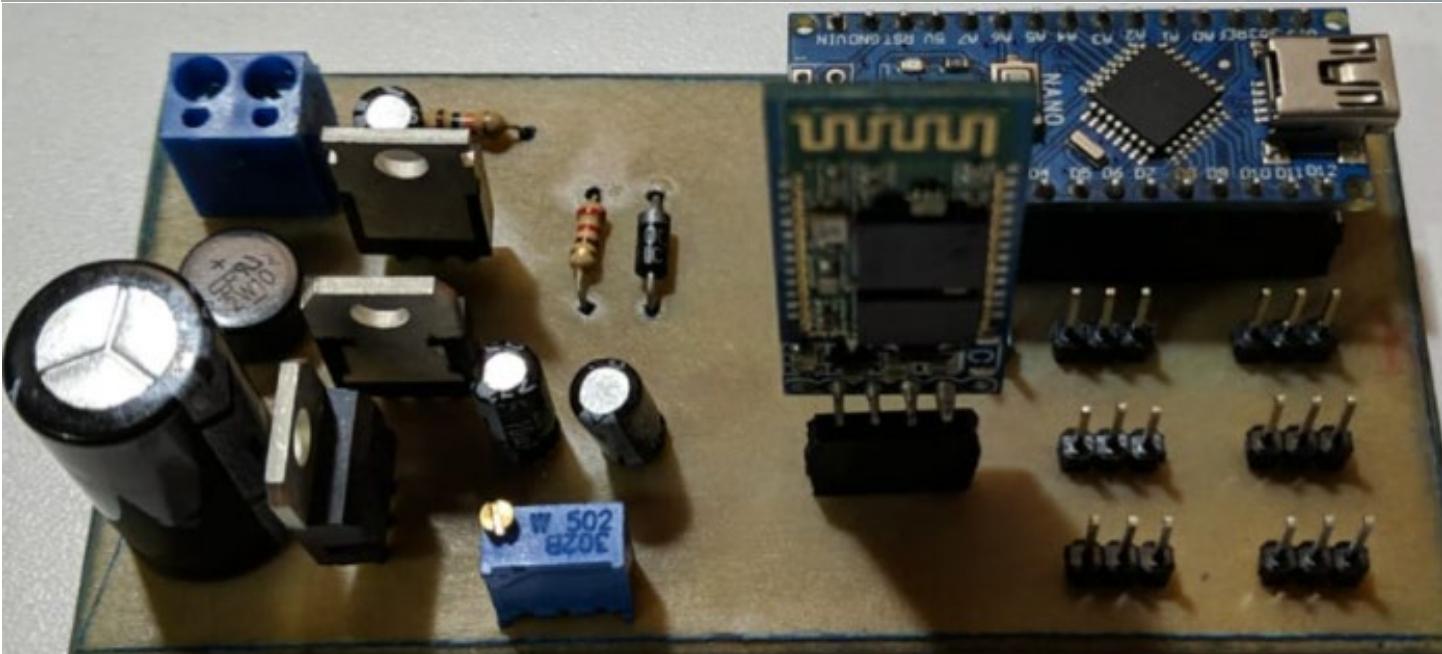
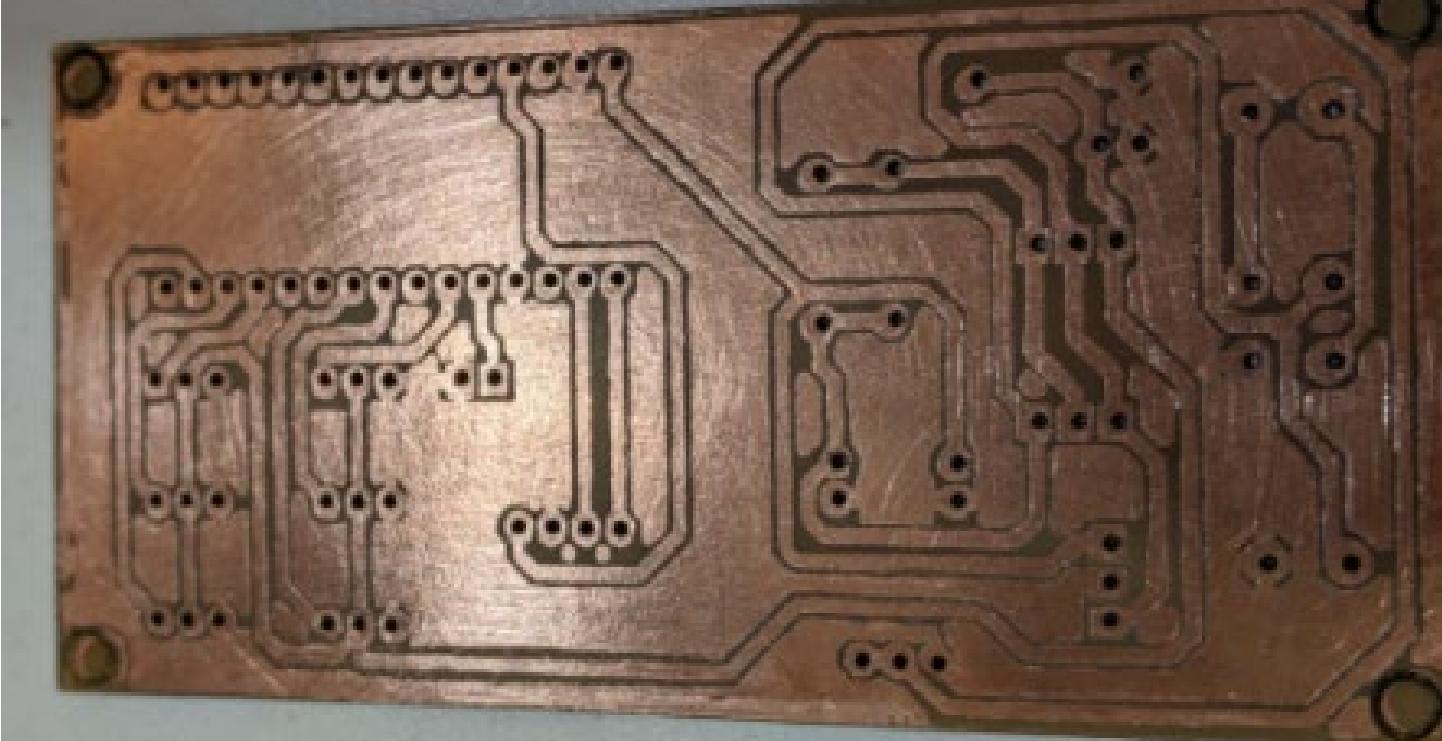
PCB MANUFACTURING

CNC

PCB MANUFACTURING

Ironing Method

Soldering



SOFTWARE DESIGN

```
1<?php language_attributes(); ?>
2
3    <?php bloginfo( 'charset' ); ?>
4
5    <meta name="viewport" content="width=device-width" />
6
7    <?php wp_title( '|', true, 'right' ); ?>
8
9    <?php wp_head(); ?>
10
11    <?php get_header(); ?>
12
13    <?php get_sidebar(); ?>
14
15    <?php get_content(); ?>
16
17    <?php get_footer(); ?>
18
19    <?php wp_footer(); ?>
20
21    <?php do_action( 'wp_footer' ); ?>
22
23
24    <?php wp_get_archives( 'list' ); ?>
25
26
27    <?php wp_get_archives( 'list', 1, 1 ); ?>
28
29
30    <?php wp_get_archives( 'list', 1, 1 ); ?>
31
32
33    <?php wp_get_archives( 'list', 1, 1 ); ?>
```



APP INVENT

SOFTWARE:
MIT APP INVENTOR

MIT APP INVENTOR DESIGN

ACCES LINK:

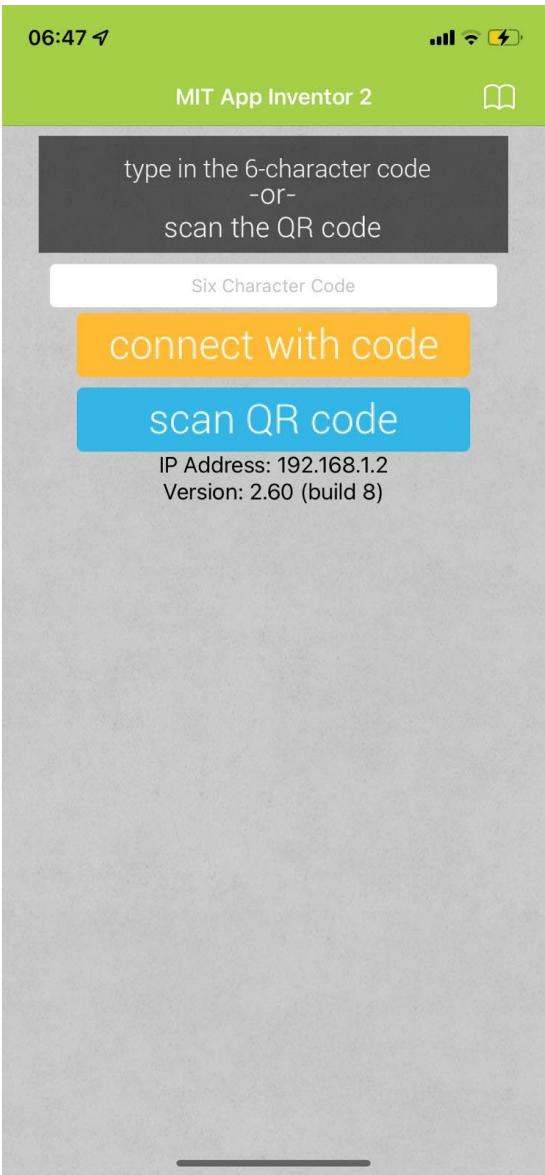
<https://gallery.appinventor.mit.edu/?galleryid=0a2205fc-54dc-416d-8233-d65bdfcbcf2e>

The screenshot shows the MIT App Inventor interface with the project titled "Robotic Arm 5DOF_1". The central area displays a smartphone screen with the app's user interface. The UI includes a title bar "Projects VI | Robotics I" and "5R ROBOTIC MANIPULATOR CONTROL". Below this are two large buttons: "CONNECT" (blue) and "DISCONNECT" (pink). A section labeled "STATUS:" shows a 3D model of a robotic arm with labels W, F, G, and B. Below this is a section titled "SELECT A MODE:" with two buttons: "FORWARD KINEMATICS" (green) and "INVERSE KINEMATICS" (pink).

The left sidebar contains a "Palette" with various UI components like Button, CheckBox, DatePicker, Image, Label, etc. The right side has panels for "Components" (listing Screen1, Label1, HorizontalArranger, etc.) and "Properties" (Screen1 properties like AccentColor, AlignHorizontal, AlignVertical, AppName, BackgroundColor, etc.).

On the right, there is a preview of the robotic arm and a brief description: "Control of the forward and inverse kinematics of a 5DOF robotic manipulator." It also lists the credit: Juan Esteban Chiriboga, Melissa Arias, Jean Collaguazo, and Ricardo Yépez.

At the bottom, there are links to "Load App Into MIT App Inventor", "Other projects by same author", "Report Project", and the permanent link: <https://gallery.appinventor.mit.edu/?galleryid=0a2205fc-54dc-416d-8233-d65bdfcbcf2e>.



PHONE CONNECTION

APPLICATION EVOLUTION

Three screenshots illustrating the evolution of a robotic manipulator control application:

Screenshot 1: Basic Control Interface (12:07)

Projects VI | Robotics I

SR ROBOTIC MANIPULATOR

- CONNECT** (Green) / **DISCONNECT** (Red) button.
- Control sliders for: **GRIFFER**, **WRIST**, **ELBOW ROTATION**, **ELBOW**, **SHOULDER**, **BASE**, and **SPEED**.
- STATUS: Disconnected** message.
- Image of the physical robotic arm with joints labeled **W**, **F**, **E**, **G**, **B**, **S**.

Screenshot 2: Advanced Control and Visualization (12:24)

Projects VI | Robotics I

SR ROBOTIC MANIPULATOR

- CONNECT** (Green) / **DISCONNECT** (Red) button.
- Control sliders for: **GRIFFER**, **WRIST**, **ELBOW ROTATION**, **ELBOW**, **SHOULDER**, **BASE**, and **SPEED**.
- STATUS: Disconnected** message.
- Image of the physical robotic arm with joints labeled **W**, **F**, **E**, **G**, **B**, **S**.
- MANUAL MODE** and **AUTOMATIC MODE** buttons.
- END EFFECTOR POSITION: [cm]** input fields for **X axis**, **Y axis**, and **Z axis**.
- OK** button.
- UIDE** logo.

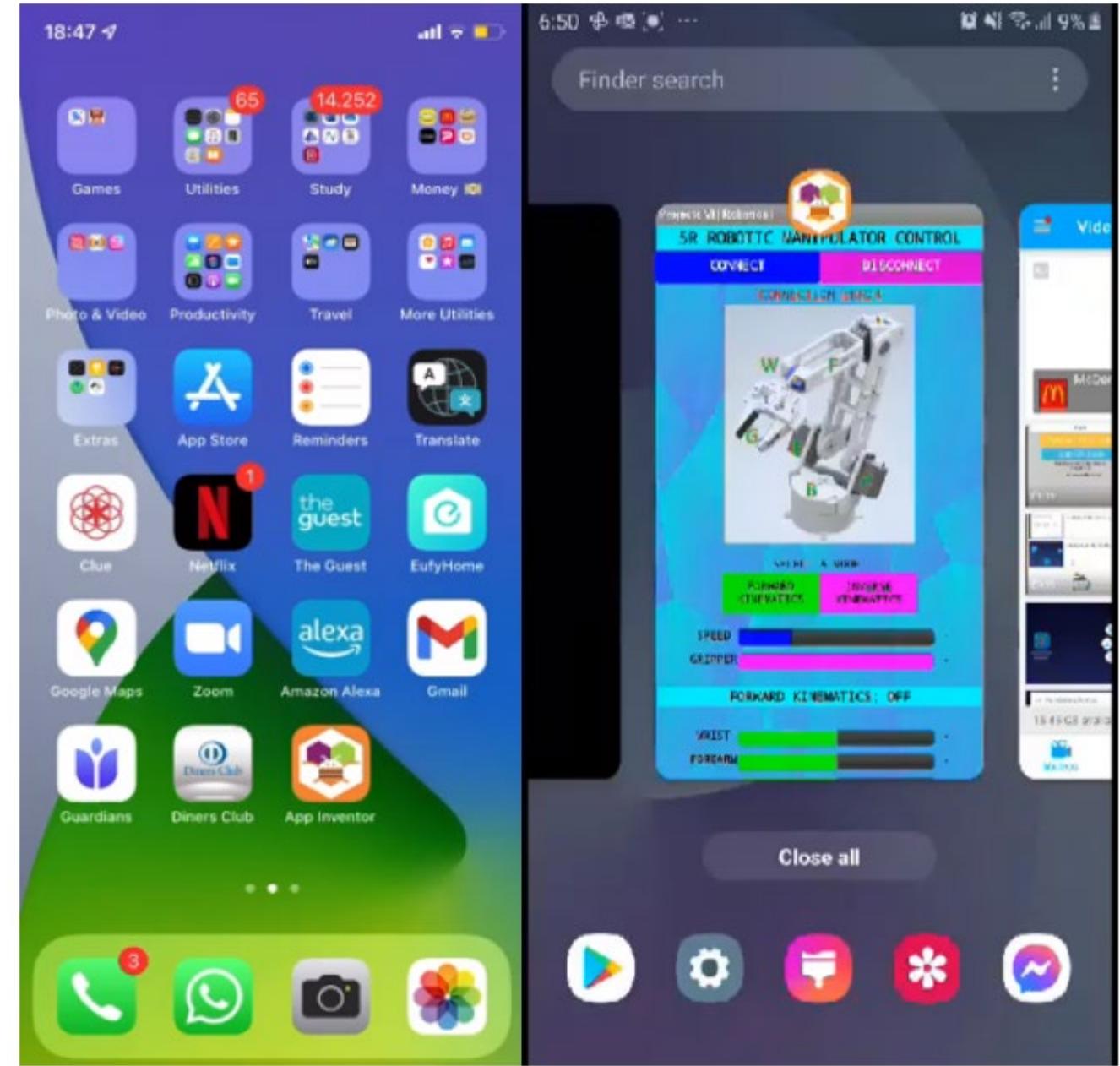
Screenshot 3: Full Kinematics and Visualization (16:38)

Projects VI | Robotics I

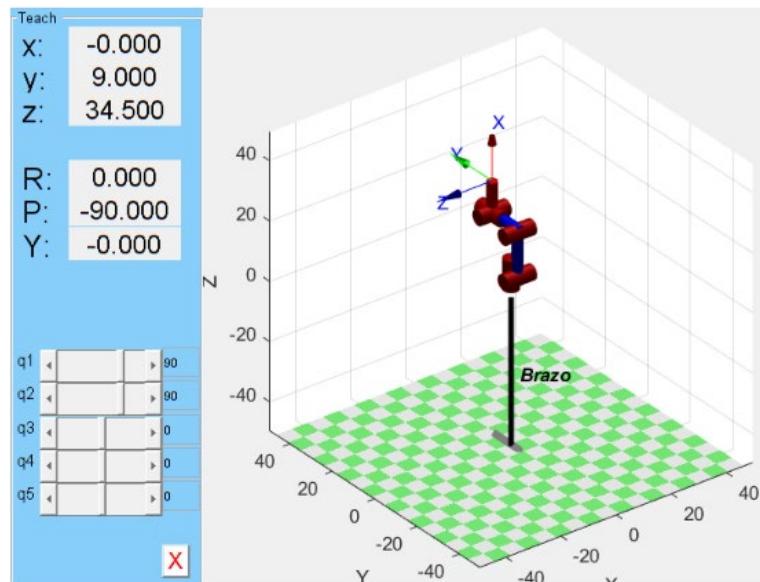
SR ROBOTIC MANIPULATOR CONTROL

- CONNECT** (Blue) / **DISCONNECT** (Pink) button.
- STATUS: Disconnected** message.
- Image of the physical robotic arm with joints labeled **W**, **F**, **E**, **G**, **B**, **A**.
- SELECT A MODE:** **FORWARD KINEMATICS** (Green) / **INVERSE KINEMATICS** (Pink).
- SPEED** slider.
- GRIFFER** slider.
- FORWARD KINEMATICS: OFF** message.
- Control sliders for: **WRIST** and **FOREARM**.
- FORWARD KINEMATICS: OFF** message.
- END EFFECTOR POSITION WITH RESPECT TO THE BASE [cm]** input fields for **X**, **Y**, and **Z**.
- ENTER THE END EFFECTOR POSITION WITH RESPECT TO THE BASE (X,Y,Z) [cm]** input fields for **X axis**, **Y axis**, and **Z axis**.
- OK** button.
- Wrist:** **Forearm:** **Elbow:** **Arm:** **Base:** input fields.
- UIDE** logo.

APP FUNCTIONALITY



DENAVIT-HARTENBERG PARAMETERS



```
L(1)=Link([0 8 0 0],'modified');
L(2)=Link([0 0 -3 pi/2],'modified');
L(3)=Link([0 0 15 0],'modified');
L(4)=Link([0 12 1 pi/2],'modified');
L(5)=Link([0 0 0 pi/2],'modified');
robot=SerialLink(L,'name','Brazo')
```

```
robot =
Brazo:: 5 axis, RRRR, modDH, slowRNE
+-----+-----+-----+-----+
| j | theta | d | a | alpha | offset |
+-----+-----+-----+-----+
| 1 | q1 | 8 | 0 | 0 | 0 |
| 2 | q2 | 0 | -3 | 1.5708 | 0 |
| 3 | q3 | 0 | 15 | 0 | 0 |
| 4 | q4 | 12 | 1 | 1.5708 | 0 |
| 5 | q5 | 0 | 0 | 1.5708 | 0 |
+-----+-----+-----+-----+
```

Denavit-Hartenberg table

$$a_{i-1} \ a_{i-1} \ d_i \ \phi_i$$

disp(dh)

$$\begin{pmatrix} 0 & 0 & L_0 & q_1 \\ \frac{\pi}{2} & -L_1 & 0 & q_2 \\ 0 & L_2 & 0 & q_3 - \frac{\pi}{2} \\ \frac{\pi}{2} & L_3 & L_4 & q_4 - \frac{\pi}{2} \\ \frac{\pi}{2} & 0 & 0 & q_5 \end{pmatrix}$$

Jacobian

```
q=[q1 q2 q3 q4 q5];
p=fkinematics(1:3,end);
for i=1:3
    for j=1:5
        Jtool(i,j)=simplify(diff(p(i),q{j}));
    end
end
disp(Jtool)
```

$$\begin{pmatrix} 3 \sin(q_1) - 15 \cos(q_2) \sin(q_1) - 12 \sin(q_1) \sin(q_2) \sin(q_3) - 9 \cos(q_1) \cos(q_4) \cos(q_5) + 12 \cos(q_2) \cos(q_3) \sin(q_1) - \cos(q_2) \sin(q_1) \sin(q_3) - \cos(q_3) \sin(q_1) \sin(q_2) + 9 \cos(q_2) \cos(q_3) \sin(q_1) \sin(q_5) - 9 \cos(q_2) \cos(q_3) \sin(q_2) \sin(q_5) \\ 15 \cos(q_1) \cos(q_2) - 3 \cos(q_1) - 12 \cos(q_1) \cos(q_2) \cos(q_3) + \cos(q_1) \cos(q_2) \sin(q_3) + \cos(q_1) \cos(q_3) \sin(q_2) - 9 \cos(q_4) \cos(q_5) \sin(q_1) + 12 \cos(q_1) \sin(q_2) \sin(q_3) - 9 \cos(q_1) \cos(q_2) \cos(q_3) \sin(q_5) + 0 \end{pmatrix}$$

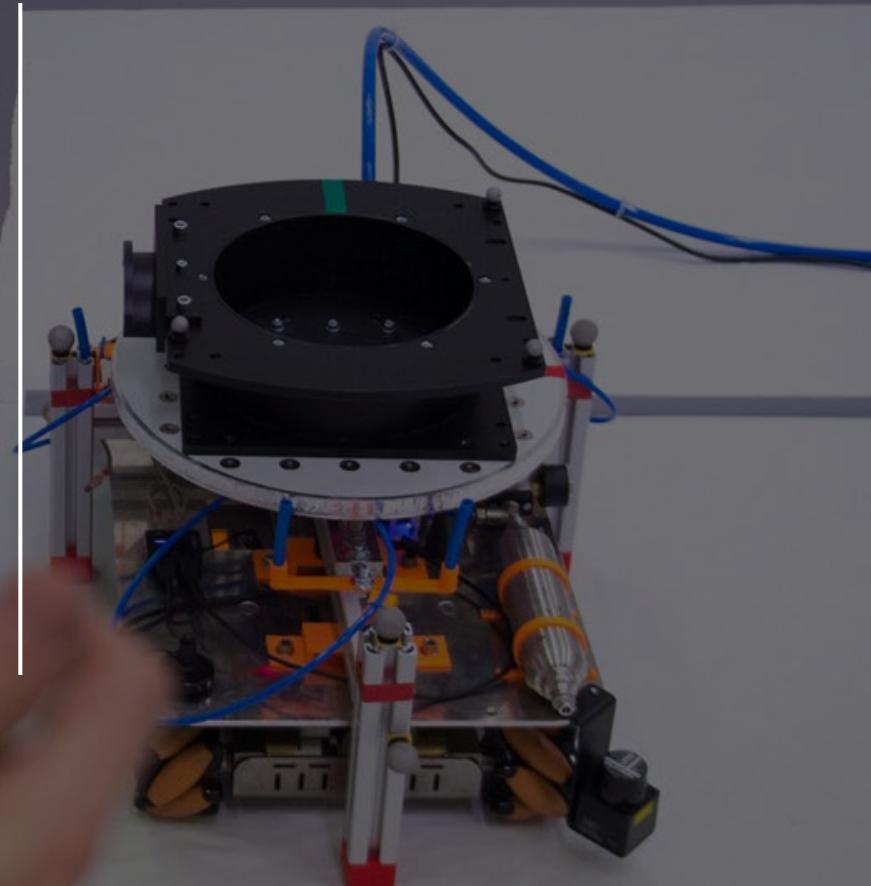
```
RrelT=tr2rt(fkinematics)';
J=simplify(RrelT*Jtool);
disp(simplify(J))
```

$$\begin{pmatrix} -\cos(q_4) \cos(q_5) (12.0416 \cos(q_2 + q_3 + 0.0831) - 15 \cos(q_2) + 3) \\ -\cos(q_4) (15 \cos(q_2) \sin(q_5) - 9 \cos(q_2) \cos(q_3) - 3 \sin(q_5) + 9 \sin(q_2) \sin(q_3) + 12 \sin(q_2) \sin(q_5) - 12 \cos(q_2) \cos(q_3) \sin(q_5) + \cos(q_2) \sin(q_3) \sin(q_5) + \cos(q_2) \sin(q_4) \sin(q_5) - 3 \sin(q_4) + 12 \sin(q_2) \sin(q_3) \sin(q_4) - 12 \cos(q_2) \cos(q_3) \sin(q_4) + 9 \cos(q_2) \cos(q_5) \sin(q_3) + 9 \cos(q_3) \cos(q_5) \sin(q_2) + \cos(q_2) \sin(q_3) \sin(q_4) + \cos(q_3) \sin(q_2) \sin(q_4) - 9 \cos(q_2) \cos(q_3) \sin(q_5) \\ 0 \end{pmatrix}$$

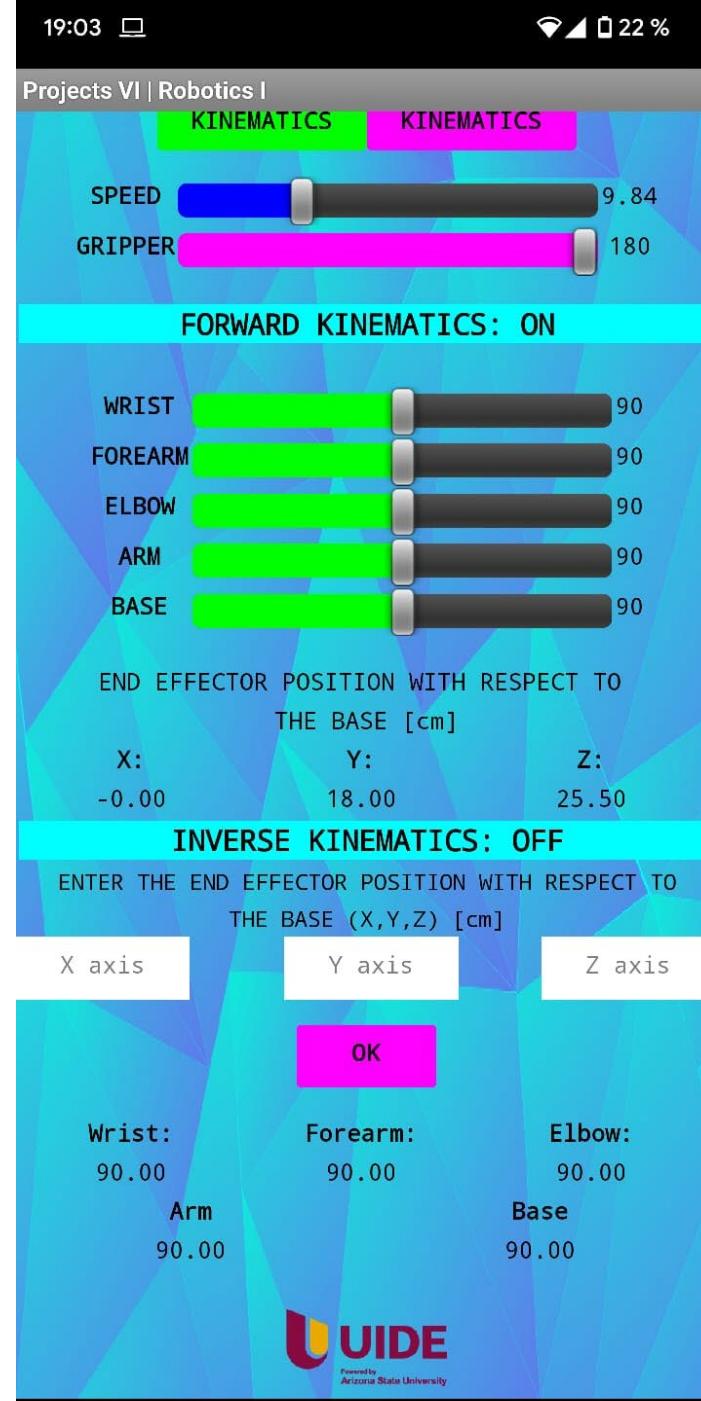
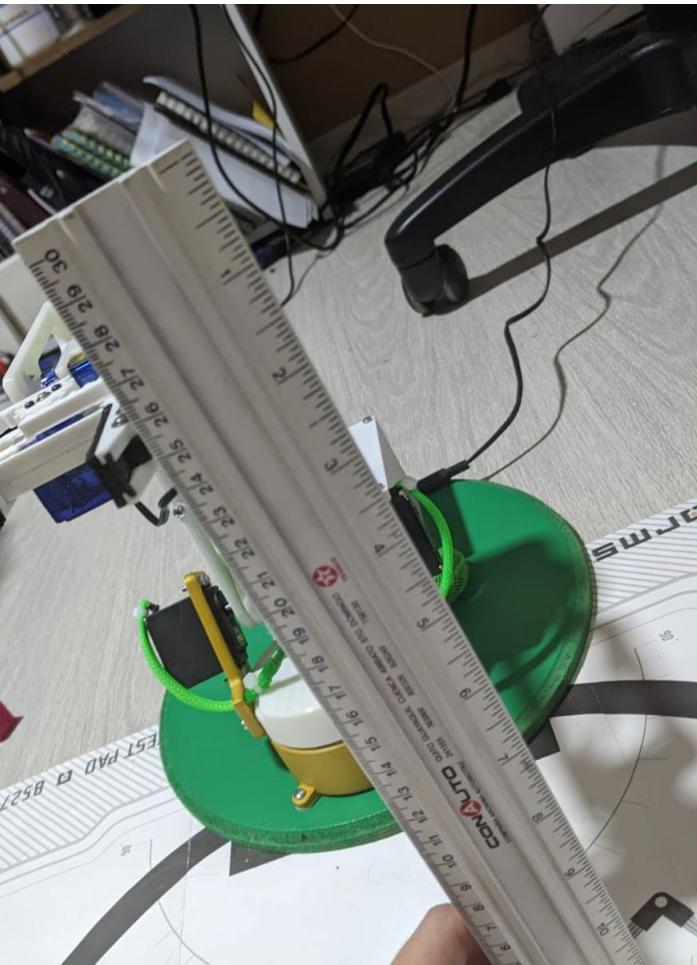
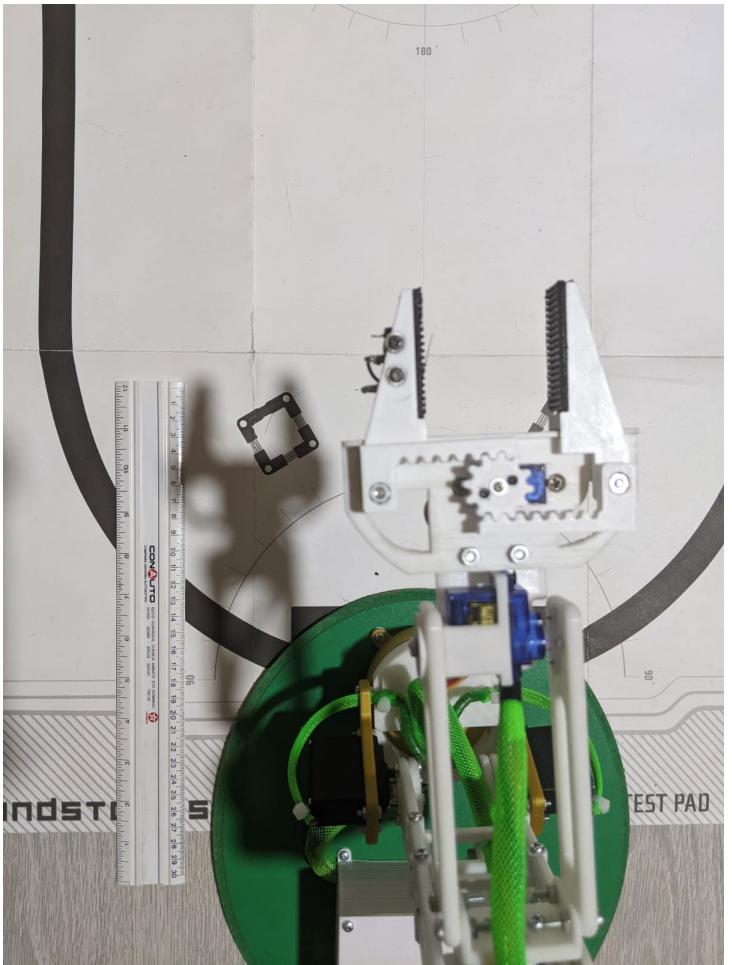
JACOBIAN



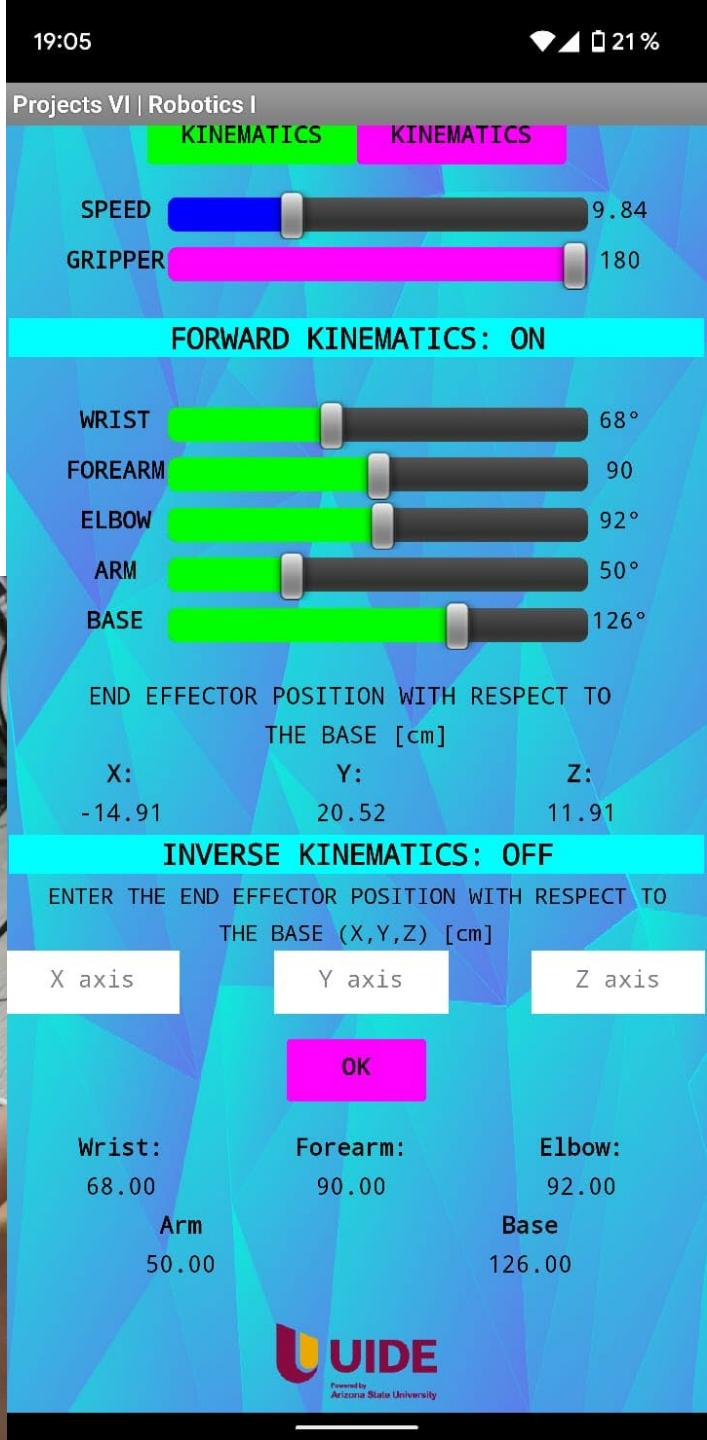
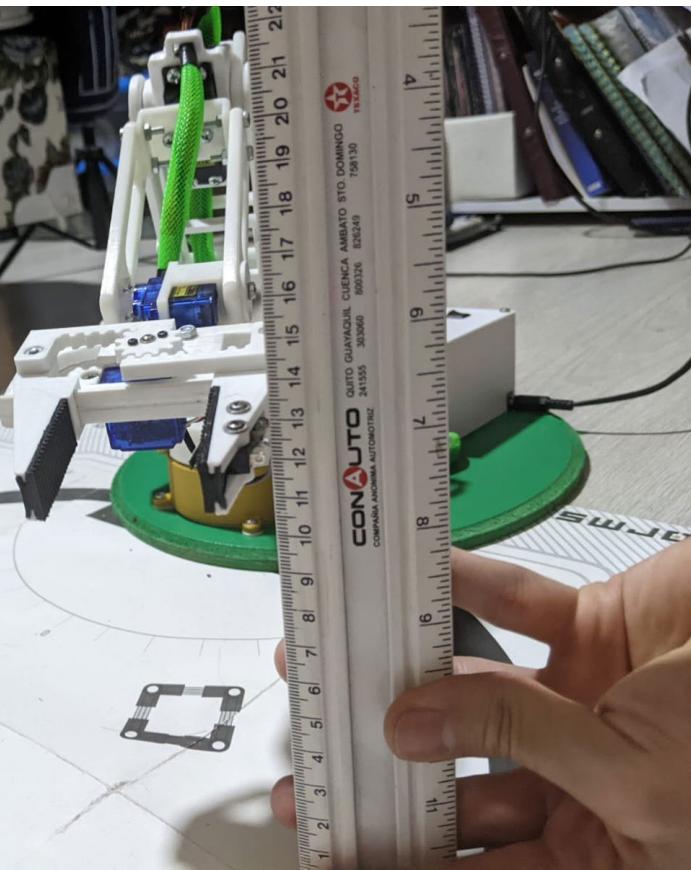
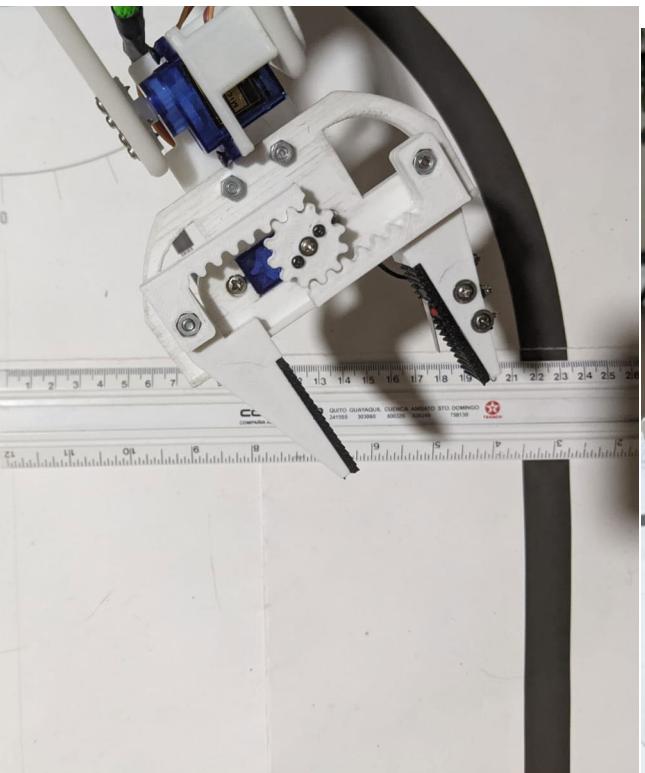
TESTS AND RESULTS



TEST #1



TEST #2



THANK YOU FOR
YOUR ATTENTION

