2R Robot Model Technical Report
Revision 1.0

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1. The 2R Robot

This technical report describes the development a model of a Revolute-Revolute (2R) type robot for use in classroom and laboratory exercises at Ecole Centrale Nantes (ECN) shown in Figure 1: 2R robot in the laboratory on 1 meter square table.. The robot will be used for experimental validation of:

1. Control strategies including joint control and computed torque control
2. Trajectory planning and generation
3. Forward and inverse kinematic computation algorithms
4. System identification

The robot is suitable to this purpose because of the high torque capacity of the motors relevant to its link Inertia. This allows the links to move at sufficient velocity to permit experimental observation of coupled dynamic effects often unobservable in more deliberately moving industrial robots. It has the additional benefit of moderate size and strength permitting direct student interaction.

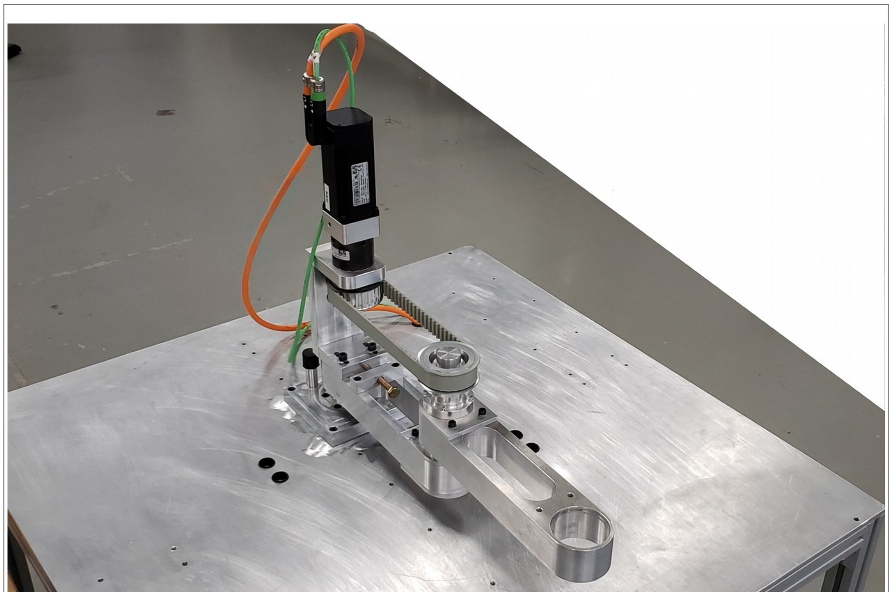


Figure 1: 2R robot in the laboratory on 1 meter square table.

1.1. Physical Parameters

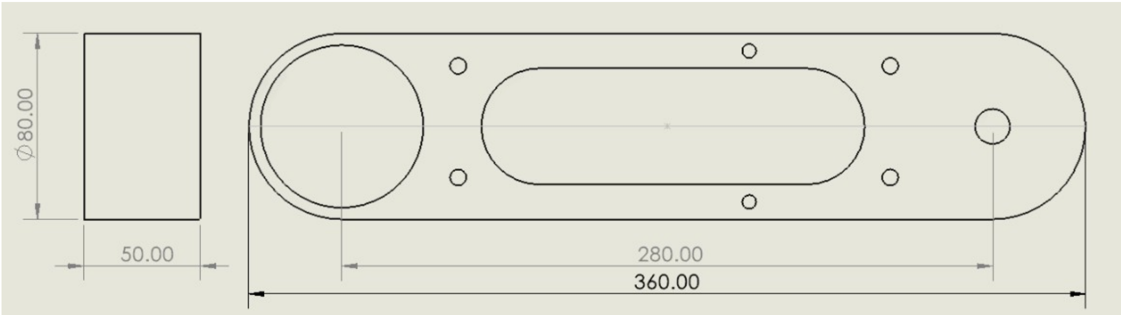


Figure 2: Key dimensions of arms in millimeters.

Dimensions were obtained through direct measurement and cross-referenced with existing Catia[1] models. As much of the robot structure was recycled from prior robotics projects, the Catia models were largely accurate with a few omissions and inaccuracies. Dimensioned drawings of some components are included in Appendix 3. The table below and Figure 2: Key dimensions of arms in millimeters. contains key parameters significant to the study of the robot kinematic and dynamics.

Axis-to-axis distance	280mm
Tip-to-tip length	360mm
Width	80mm
Depth	50mm

2. Modeling in SolidWorks

SolidWorks[2], a 3D solid modeling and simulation application available on the cloud computing platform at Roger Williams University was used to create a model. SolidWorks has the following abilities relevant to the modeling effort:

- Full 3D solid modeling
- Assignment of materials and computation of mass properties
- Simulation of motion under various physical conditions
- Tools available for generating universal robot description format (URDF) files

2.1. Procedure

1. Assemble the model from geometric shapes matching as closely as possible directly measurable dimensions and preexisting Catia models.
2. Insert SolidWorks library components or manufacturer supplied models[3], where available, in the installed locations.
3. Assign the material properties of aluminum to the apparently aluminum parts and the properties of steel to fasteners and apparently steel parts.
4. Assign manufacturer supplied component masses when available. See Appendix 2 for manufacturer supplied specifications on the motor and gear reducer.

[1]https://www.3ds.com/products-services/catia/products/
[2]https://www.3ds.com/products-services/solidworks/
[3]https://download.beckhoff.com/download/technical_drawings/drive_technology/step/ag3400/ag3400-npt015s-ma2-i-0a1-f2.zip

5. The resulting model shown in Figure 3: SolidWorks model duplicating robot. duplicates to the dynamic properties of the actual robot arm to the largest degree practicable.

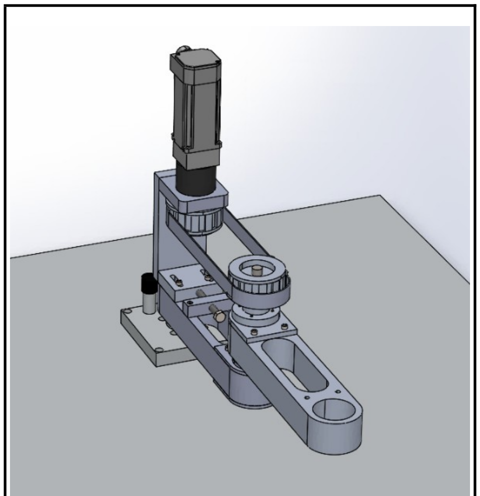


Figure 3: SolidWorks model duplicating robot.

2.2. Caveats and limitations

The robot was in working order and assembled from parts recycled from prior projects. It was neither practical nor worth potential risks to disassemble it. Without direct observation, model internals are the result of educated guesswork and approximation. The following are known limitations to model accuracy.

- All apparently aluminum parts are presumed to be Aluminum Alloy 1060. There is no information that this alloy was used, rather this is a commonly used alloy and that the density of aluminum is largely constant across alloys.[4]
- All fasteners were presumed to be AISI1020 steel. As above, there is no information that precisely this steel was used, rather this is a commonly used material for fasteners.
- It is presumed two bearings of type SKF 6002-2RSH/C3 support the joints. Although not visible, the Catia file referred to two parts by that part number. The models were not included in the Catia files but were available from the manufacturer’s website.
- The affixed stickers accurately reflect the motor and gear reducer used.
- Internals of the primary or “elbow” joint was constructed from Catia models, but these models did not perfectly align and/or fit together. This results in some material gaps in the model that are unlikely to be present in the actual robot. The central axle is presumed to be solid aluminum shaft.
- The belt is added as a passive rigid body in link 1 but would actually move with link 2.

2.3. Extracting Inertial Parameters

Individual solid components with material properties assigned have inertial properties computable by SolidWorks. This section presents the inertial properties of the main structural components both to demonstrate the procedure and for potential analytical use elsewhere. Note that the principal axes are shown in pink at the joint center of mass and that parameters are reported in the reference coordinate system shown on the top right of the link, as in Figure 4: SolidWorks model of arm component with principal axes displayed..

[4]The density of aluminium is about 2,710kg/m3. The density of the alloys of aluminium does not vary widely from this figure ranging between 2,640kg/m3 and 2,810kg/m3. https://www.thyssenkrupp-materials.co.uk/density-of-aluminium.html

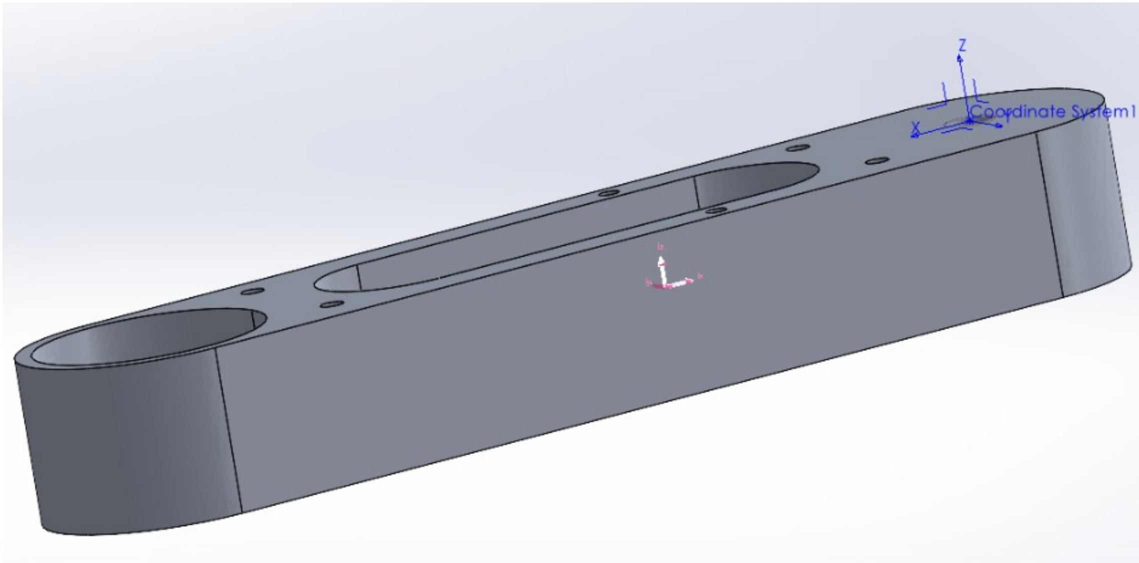


Figure 4: SolidWorks model of arm component with principal axes displayed.

Parameter	Value	
Mass	2.09468kg	
Volume	0.00078m^3	
Center of Mass		
X=0.10818m	Y=0.0m	Z=-0.025m
Moment of inertia taken at output coordinate system (kg * m^2)		
Ixx=0.00326	Ixy=0.0	Ixz=-0.00567
Iyx=0.0	Iyy=0.04760	Iyz=0.0
Izx=0.0	Izy=0.0	Izz=0.04736

Figure 5: Supporting Jaw dynamic parameters., shows a representative solid, a supporting jaw used to rigidly attach drive components to the arms. Reference coordinate system and principal inertia are display. All visible mechanical components were created as solids and assigned the apparent material properties. The supporting jaw shown is assigned the material properties of aluminum resulting in the mass and inertial properties shown.

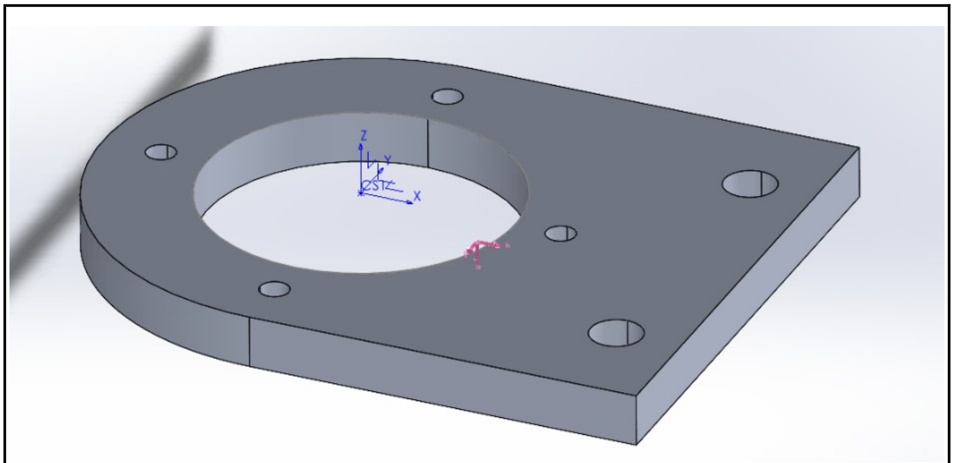


Figure 5: Supporting Jaw dynamic parameters.

Parameter	Value	
Mass	0.11533kg	
Volume	$0.000043m^3$	
Center of Mass		
X=0.018037m	Y=0.0m	Z=-.004m
Moment of inertia taken at output coordinate system ($kg * m^2$)		
Ixx=0.000072	Ixy=0.0	Ixz=-0.00567
Iyx=0.0	Iyy=0.000137	Iyz=0.0
Izx=-0.00567	Izy=0.0	Izz=0.000204

2.4. Combining Inertial Parameters

Individual components were combined into three composite bodies representing links 0,1 and 2 in the 2R assembly. For visual convenience link 0 is the table, primary rotation spindle and joint limit posts. Dynamic properties of link 0 are presented in Appendix A for completeness but these are stationary so have no affect on the simulation. As shown in Figure 6: Aggregate link bodies all bodies rotating about joint 1 are combined into link 1 shown in blue, all bodies rotating about joint 2 are combined into link 2 shown in orange.

The resulting composite bodies are shown in Figure 7: Link 1 inertial parameters. and Figure 8: Link 2 inertial parameters. and the associated parameter tables. These are considered the rigid structures of the links for the purposes of simulation, system identification and control.

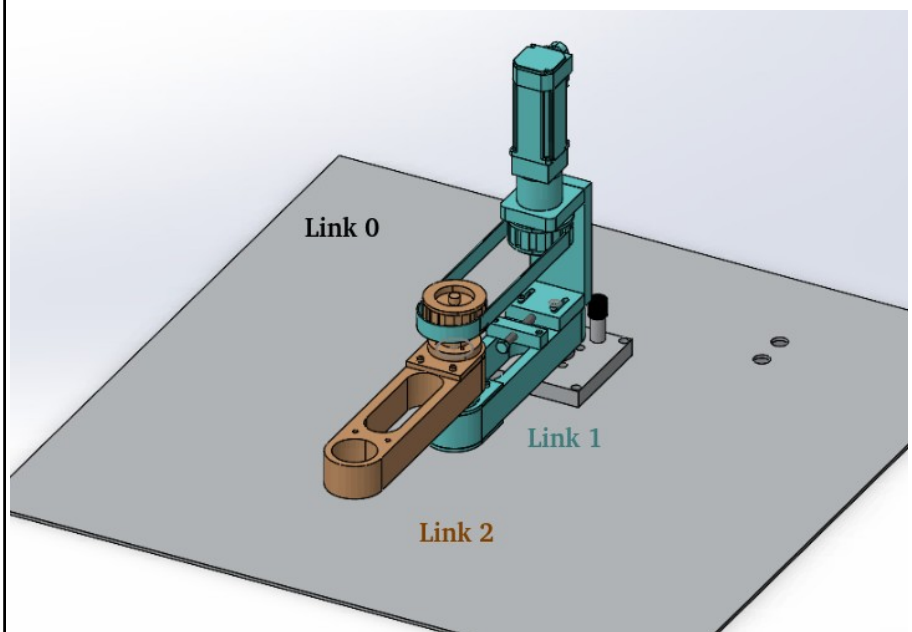


Figure 6: Aggregate link bodies

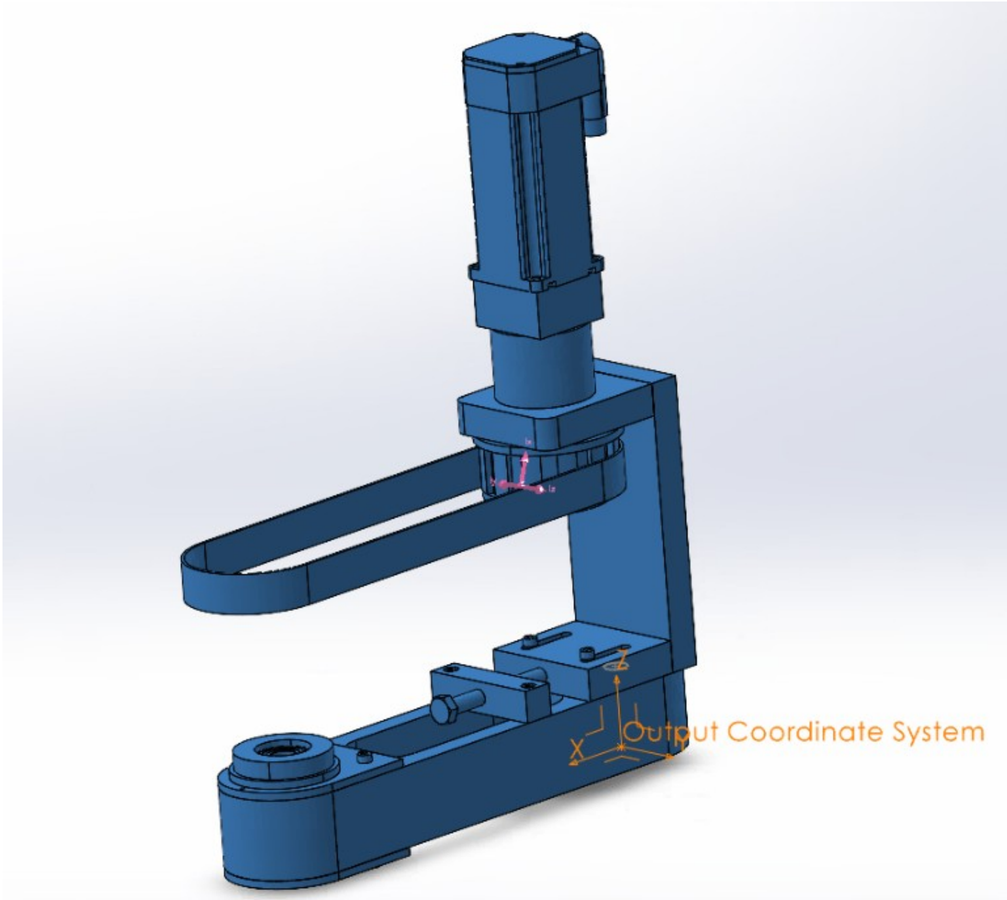


Figure 7: Link 1 inertial parameters.

Parameter	Value	Link 1 Parameters
Mass	7.084761kg	
Center of Mass		
X=0.066529m	Y=0.0m	Z=0.179392m
Moment of inertia taken at output coordinate system ($kg * m^2$)		
Ixx=0.147885	Ixy=0.0	Ixz=-0.033179
Iyx=0.0	Iyy=0.196455	Iyz=0.0
Izx=-0.033179	Izy=0.0	Izz=0.055095

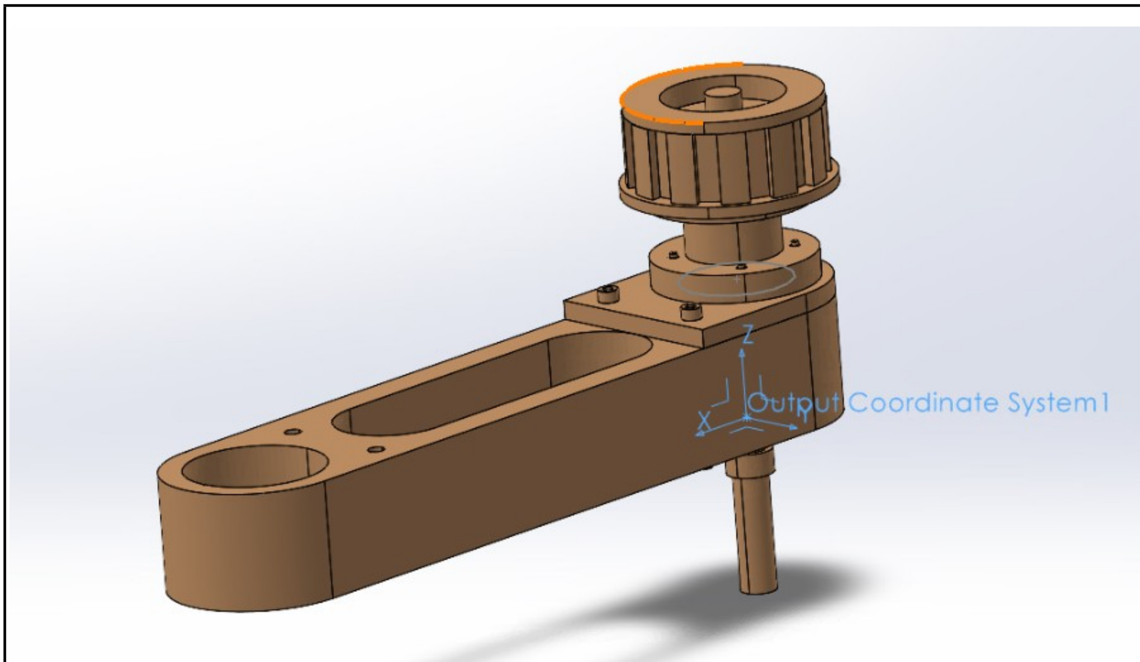


Figure 8: Link 2 inertial parameters.

Parameter	Value	
Mass	3.181291kg	
Center of Mass		
X=0.082451m	Y=0.0m	Z=0.045927m
Moment of inertia taken at output coordinate system (kg * m^2)		
Ixx=0.013725	Ixy=0.0	Ixz=0.006881
Iyx=0.0	Iyy=0.067471	Iyz=0.0
Izx=0.006881	Izy=0.0	Izz=0.057501

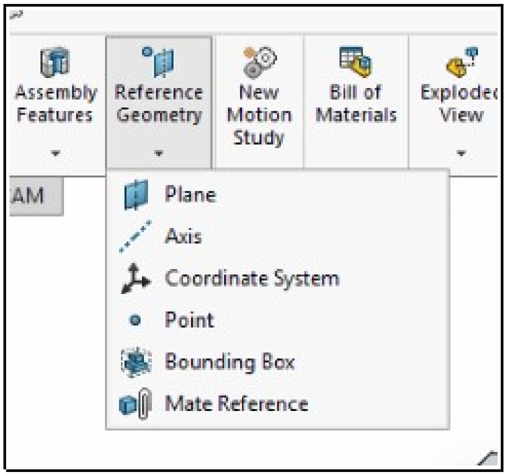
3. Preparing the model for Gazebo Simulation

The completed SolidWorks model was converted to URDF for simulation in Gazebo[5] or other robot simulation package. This process is greatly facilitated by a SolidWorks add-in sw_urdf_exporter[6]. This section details the (fairly complex) series of steps required for conversion.

1. Combine assemblies into a single part using SaveAs->SolidWorks Part. This process results in a single part as shown in Figure 6: Aggregate link bodies. The completed model consists of three links as shown in Figure 10: Three link model with assigned coordinate frames.
2. Create a new assembly with the three links and set Link 0 to fixed. Use one concentric mate and one coincident mate to define the joints. The completed model contains two joints, each defined as a concentric and coincident mate, for a total of four mates. Add mates to fix the arm in its zero angle position.

[5]https://gazebosim.org/home
[6]http://wiki.ros.org/sw_urdf_exporter contributed by Stephen Brawner

3. Use the **Reference Geometry menu**, shown here, to define origin points and axes for the joints. As these will be selected later in the process, it is recommended to create these before activating the exporter tool.



4. Install and execute the downloadable installer. On the RWU server it was necessary to re-install every day and re-start SolidWorks for the tool to be visible in the **Tool menu** as shown here.

5. Define the three links by selecting the link and providing the link name and joint name in the dialog window. Figure 9: Conversion to URDF using sw_urdf_exporter. shows this in-process. The dialog on the left allows selecting of links, the defining of link and joint names and the specification of child links. For this model link 0 is defined as base_link, link 1 is defined as a child of link 0 and link 2 is defined as a child of link 1. Select the "**Preview and export...**" button to go to the next panel.

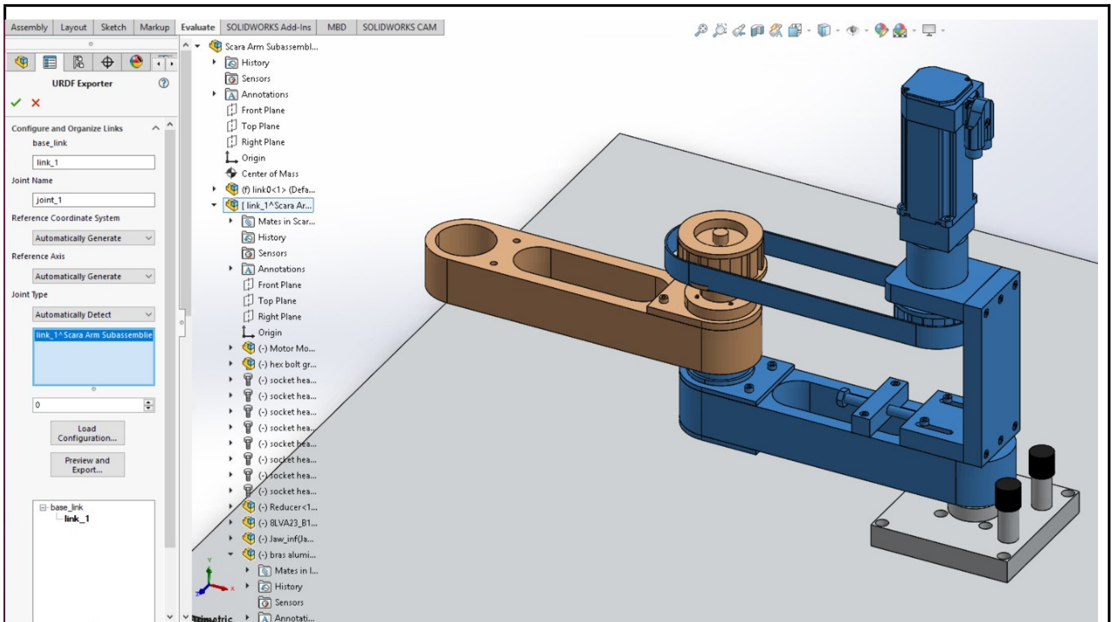


Figure 9: Conversion to URDF using sw_urdf_exporter.

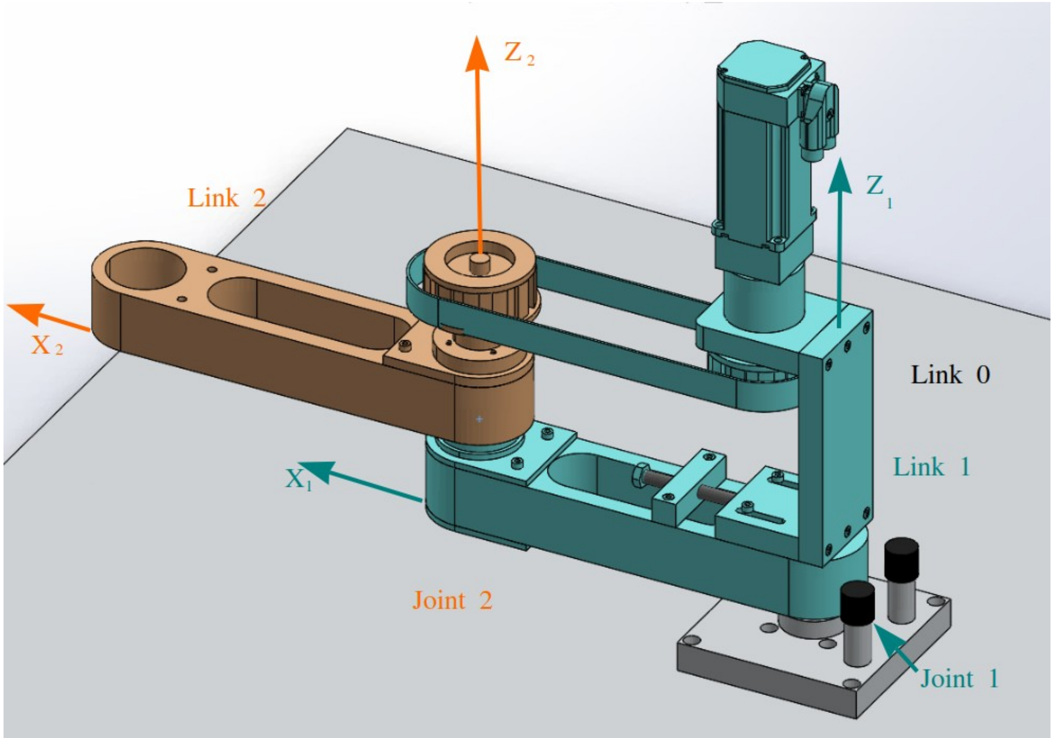


Figure 10: Three link model with assigned coordinate frames

6. In the joint creation dialog show in Error: Reference source not found, joint 1 is defined as revolute while the origin coordinate systems and axis are selected from pull-down menus of preexisting reference geometries. In defining the coordinates of Origin_joint_1 we employed the standard ROS practice of defining the Z-axis as the axis of the joint, positive towards the distal end of the robot and defining the X-axis as down the primary length of the link towards the distal end of the robot, resulting if the coordinate frames shown in Figure 10: Three link model with assigned coordinate frames. The origin shown in the panel will sucessfully populate the <origin> tag in the URDF file. Note that it is possible but not necessary to populate the joint limits and friction fields. As some manual manipulation of the resulting URDF file is necessary, these tags were manually added later. Select the **Next** button to access the next panel.

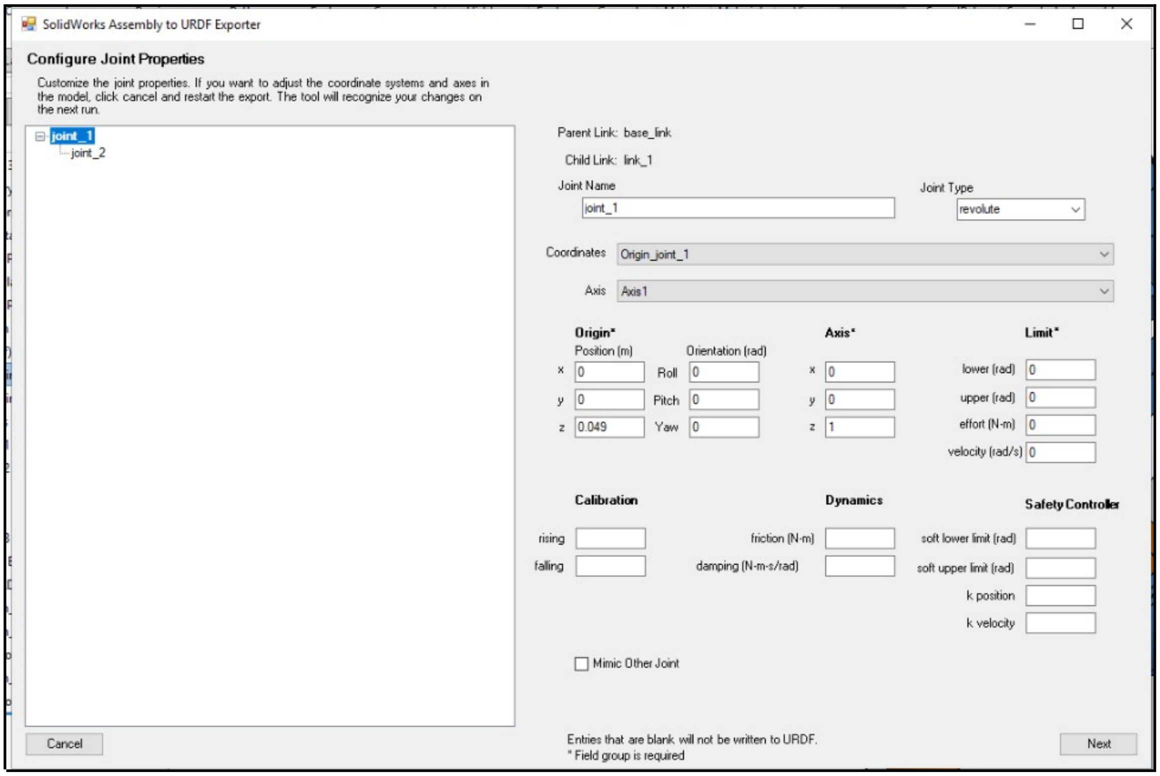


Figure 11: Configure Joint Properties dialog.

7. The link definition panel shown in Figure 12: Configure link Properties dialog displays the populated inertial parameters. However, these parameters are not successfully transcribed to the URDF in our experience. It was therefore necessary to manually extract the inertia parameters by a process described in a subsequent step. It is only necessary to select the **Export URDF and Meshes** button, provide a save name and then exit the dialog.
8. The exporter creates a folder of the specified name and creates sub-folders *config, launch, meshes, textures* and *urdf,* plus file at the root level to comprise a package suitable for transfer to a ROS workspace. In this implementation we created a zip file, downloaded and then extracted the zip file into the *src* directory of a catkin workspace. Executing catkin_make in the workspace added the package to the path with no errors. Note that the root filename is hard-coded into the URDF and package files, so we found it best to use the simple name “scara_sw” and did not attempt to rename the file.

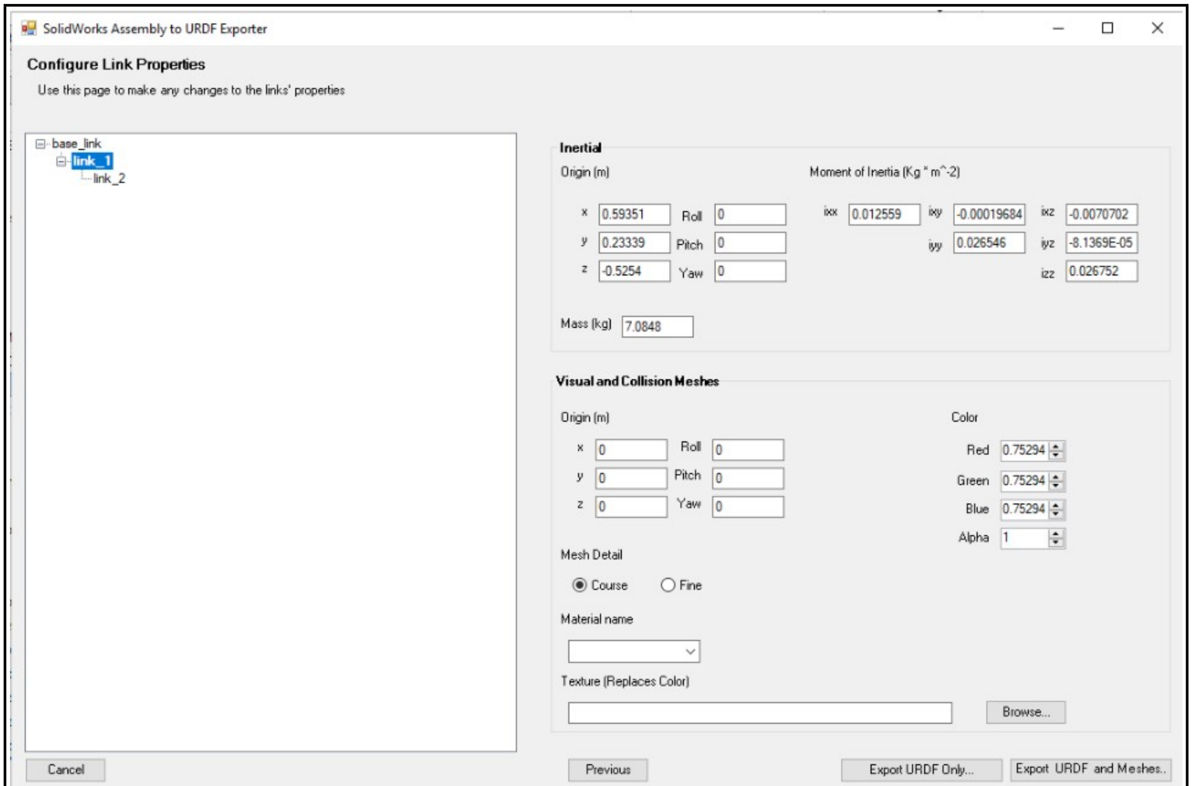


Figure 12: Configure link Properties dialog

4. The Gazebo Simulation

The exported package works immediately in a ROS workspace. The launch folder contains two launch scripts *gazebo.launch* and *display.launch* each works as installed with the former launching a gazebo simulation and the latter an Rviz window. Although the gazebo window opens and displays an accurate image of a robot (initially gray) as in Figure 16: Gazebo simulation based on SolidWorks model, the simulation does not work. This section details manual alterations required to complete the conversion.

1. The base is not fixed to the world, and thus any external forces will cause whole body motion of the entire assembly in the direction of the applied force. This snippet is added near the top of the URDF file to attach base_link to the world. Note that these tags also permit rotating the robot into the vertical plane and moving the robot above the world floor. We observed instability in the simulation when the robot contacts the floor due to built-in collision detection.

```
<!-- Used for fixing robot to Gazebo 'base_link' -->
<link name="world"/>
<joint name="world_joint" type="fixed">
      <origin xyz="0 0 1.0" rpy="1.57079632679 -1.57079632679 0"/>
  <parent link="world"/>
  <child link="base_link"/>
</joint>
```

2. Colors selected in SolidWorks are successfully shown in Rviz but are not correctly transferred to gazebo. To return color to the robot, the following special tags are added near the top of the URDF file. See the tutorial[7] for available colors.

[7]http://wiki.ros.org/simulator_gazebo/Tutorials/ListOfMaterials

```xml
<!-- Note that material tags supplied by SolidWorks are used in rviz but ignored by Gazebo -->
<gazebo reference="link_1">
  <material>Gazebo/Turquoise</material>
</gazebo>
<gazebo reference="link_2">
  <material>Gazebo/Orange</material>
</gazebo>
```

3. The following tags are manually added for ros control of gazebo. Note that joint tag permits the specification of a gear reduction and this has been filled in consistent with gear reducer present, but there is no implementation of this tag at the time of this writing. In other words simulation behavior is unchanged by the contents of the mechanicalReduction tag. The corresponding tag for joint 2 was also added.

```xml
<gazebo>
  <plugin name="gazebo_ros_control" filename="libgazebo_ros_control.so"/>
</gazebo>
```

```xml
<!-- Required for ROS control -->

 <transmission name="joint_1_transmission">
   <type>transmission_interface/SimpleTransmission</type>
   <joint name="joint_1">
     <hardwareInterface>hardware_interface/EffortJointInterface</hardwareInterface>
     <mechanicalReduction>15</mechanicalReduction>
   </joint>
   <actuator name="joint_1_actuator"/>
 </transmission>
```

4. Joint limits and friction parameters generate the following tags in the joint sections of the URDF file. Effort and velocity limits are reasonable guesses. The values shown were chosen to implement the hardware limits on the joints. Joint 1 is limited by the (black tipped) mechanical stoppers shown in Figure 3: SolidWorks model duplicating robot. while joint 2 is limited by self-collision with the motor support bracket. Nominal friction values will dampen arm free-fall so the robot to come to rest in the neighborhood of 15 seconds rather than swinging indefinitely.

```xml
<limit
  lower="-3.211405854"
  upper="0.0698132"
  effort="100"
  velocity="10" />
<dynamics
  damping="0"
  friction="0.01" />
```

5. The inertial parameters are essential for simulation fidelity. If correctly implemented, the Gazebo model and the SolidWorks model will exhibit identical behavior when the robot is released from rest in the presence of gravity and freely swings. Initially this was not the case, although both models exhibited reasonable looking free-fall behavior, they did not swing at exactly the same amplitude and frequency. Close investigation revealed that the exporter did not select the correct parameters for exportation to the inertia tag, and therefore it is necessary to populate these tags using this procedure.
   1. Use the reference coordinate system previously created to define the link coordinate frames. In the dialog shown in Figure 15: Inertia parameters reported in the output frame, link 1 is selected and Output Coordinate System1 is selected in the "Report coordinate values relative to" box. Transcribe the **Center of Mass: (meters)** values to the <origin> tag, in this example the values shown for center of mass created the origin tag shown.
   2. Transcribe the values in **Taken at the center of mass and aligned with the output coordinate system (using positive tensor notation):** to the inertia parameters in the <inertia tag. The values in Figure 15: Inertia parameters reported in the output frame produced the inertia tag shown below.
   3. Verify that the inertias in Gazebo accurately reproduce the SolidWorks inertias by displaying center of mass and inertia in the Gazebo window. The pink coordinate

axes in Figure 13: Link 2 center of gravity and principal inertia must be duplicated by the pink outline boxes in Figure 16: Gazebo simulation based on SolidWorks model.

```
<inertial>
  <origin
    xyz="0.066529 0.00 0.179392"
    rpy="0 0 0" />
  <mass
    value="7.084761" />
  <inertia
    ixx="0.147885"
    ixy="0.0000"
    ixz="-0.033179"
    iyy="0.196455"
    iyz="0.0000"
    izz="0.055095" />
</inertial>
```

4. Test simulation fidelity by comparing motion study results to Gazebo results. Motion study results for joint angles vs. time were exported as CSV. Likewise model parameters-joint_position_axis 1&2 are plotted in Gazebo and exported as CSV. Graphs are then superimposed and show negligible deviation over time within numeric precision, representative figure shown in Figure 17: Free fall trajectories of SolidWorks motion study and Gazebo simulation.

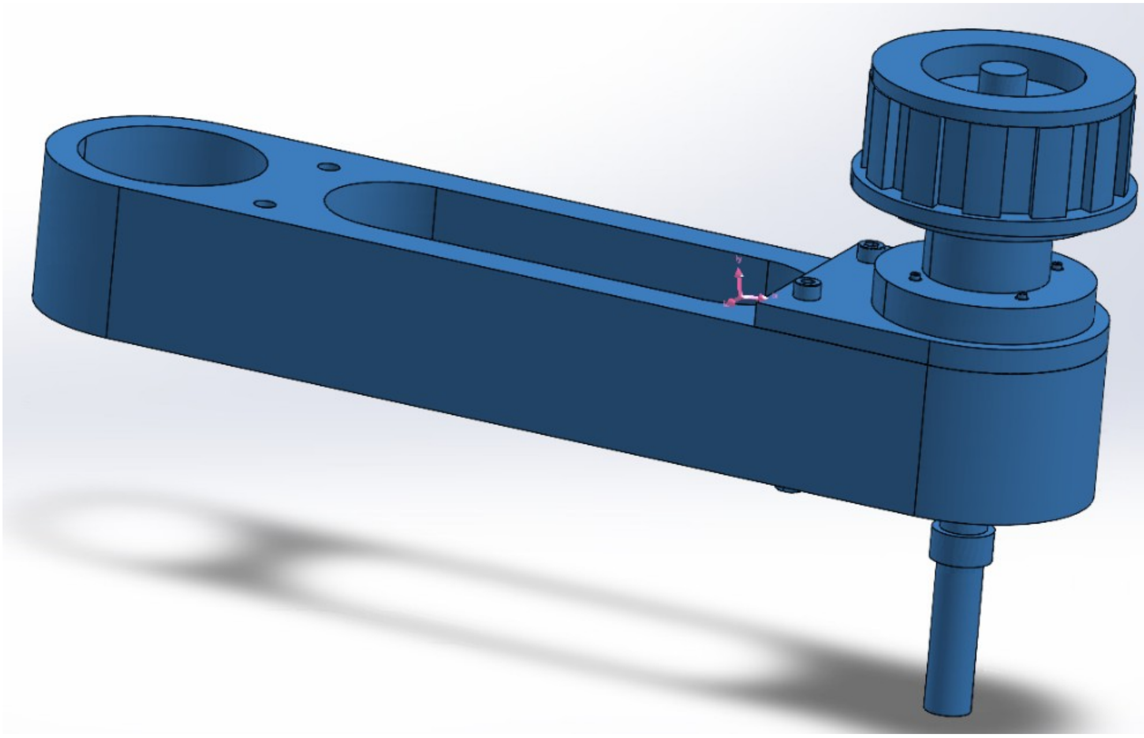


Figure 13: Link 2 center of gravity and principal inertia

5. Closed loop control of the Gazebo simulation

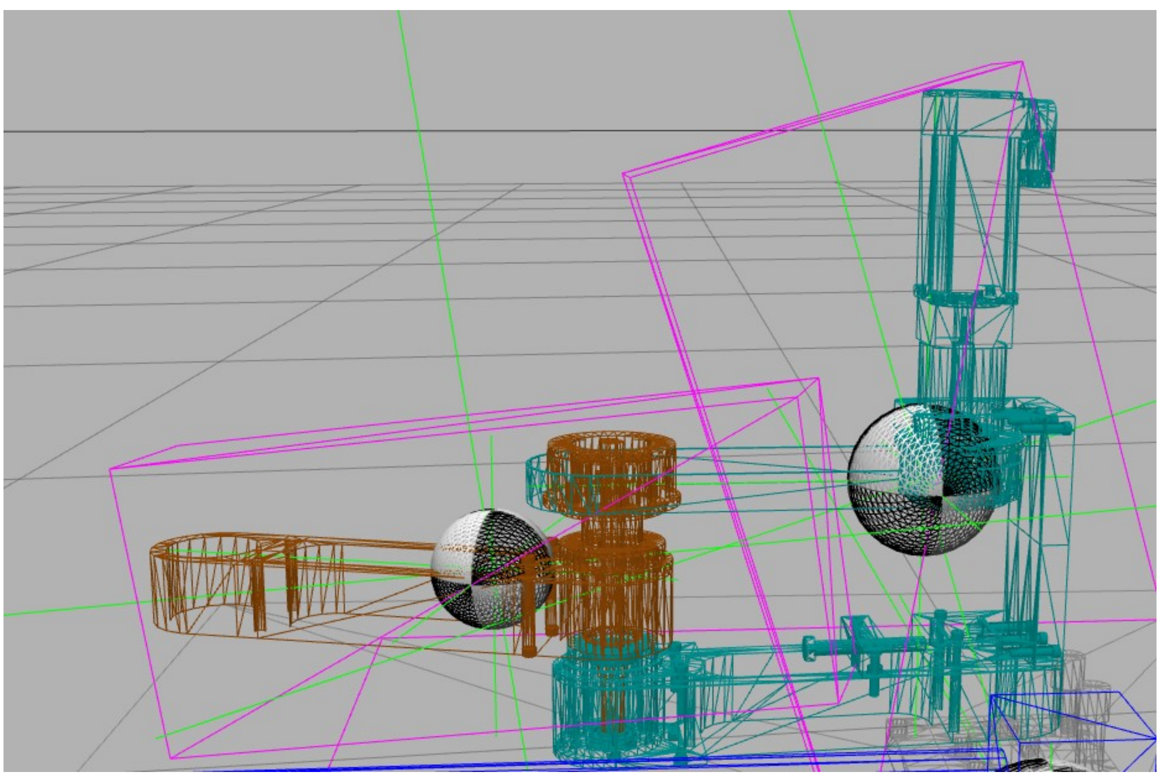


Figure 14: Link inertia and center of gravity verified in Gazebo

Tags inserted into the URDF permit two forms of closed loop control of the Gazebo simulation. The first, joint position control via a built-in PID control scheme, is useful for validating that the simulation is working and for comparison to other control methods. Only a few steps are required to implement this control scheme.

1. Add tags to the launch file to activate the control scheme. These spawn a node for the built-in joint position control with the parameters contained in arm_control.yaml file shown below. Note that the names joint_1 and joint_2 must agree with the joint name tag in the URDF file.

```
# Publish all joint states -----------------------------------
joint_state_controller:
    type: joint_state_controller/JointStateController
    publish_rate: 2500

# Position Controllers ---------------------------------------
joint1_position_controller:
    type: effort_controllers/JointPositionController
    joint: joint_1
    pid: {p: 200.0, i: 0.01, d: 10.0, antiwindup: true, i_clamp_min: -40.0, i_clamp_max: 40.}

joint2_position_controller:
    type: effort_controllers/JointPositionController
    joint: joint_2
    pid: {p: 200.0, i: 0.01, d: 10.0, antiwindup: true, i_clamp_min: -40.0, i_clamp_max: 40.}

joint1_effort_controller:
    type: effort_controllers/JointEffortController
    joint: joint_1

joint2_effort_controller:
    type: effort_controllers/JointEffortController
    joint: joint_2
```

2. The controller will be active as soon as the simulation starts. To modify the setpoint publish to the command topic, in the figure below rqt was convenient for publishing sinusoidal commands.

/joint1_position_controller/command	std_msgs/Float64	1.00	
data	float64		-1.57+sin(i/1)
/joint2_position_controller/command	std_msgs/Float64	1.00	
data	float64		cos(i/0.9)

3. Computed torque or other control schemes are not discussed in this report, but some modifications to the above are necessary for their implementation. In the launch file change the argument “control” from “position” to “effort” as described by the comment. Any node may then publish to the topics below to apply torque to the joints.

/joint1_effort_controller/command	std_msgs/Float64	0.50	
data	float64		20
/joint2_effort_controller/command	std_msgs/Float64	1.00	
data	float64		-5

4. It will typically also be necessary to access the joint states. Joint state messages are available on the /joint_states topic shown, where the name will be “joint_1” or “joint_2”. Caution that joint state message contain joint information in alphabetical order, so array indexing works only because “joint_1” proceeds “joint_2” alphabetically.

/joint_states	sensor_...	not monitored
header	std_msg...	
name	string[]	
position	float64[]	
velocity	float64[]	
effort	float64[]	

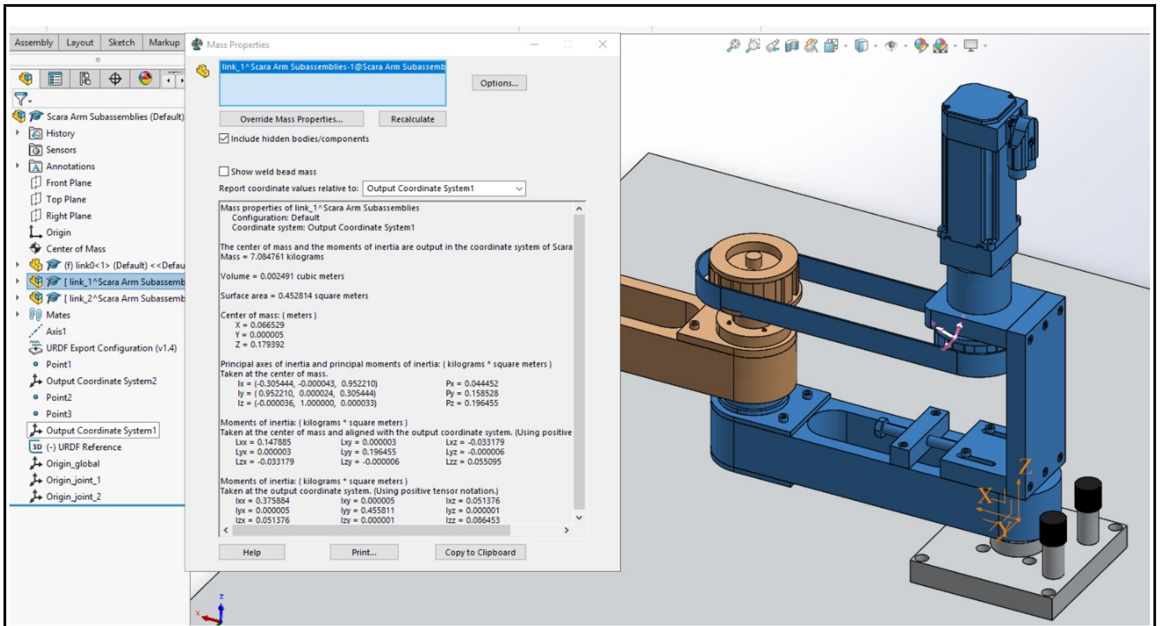


Figure 15: Inertia parameters reported in the output frame

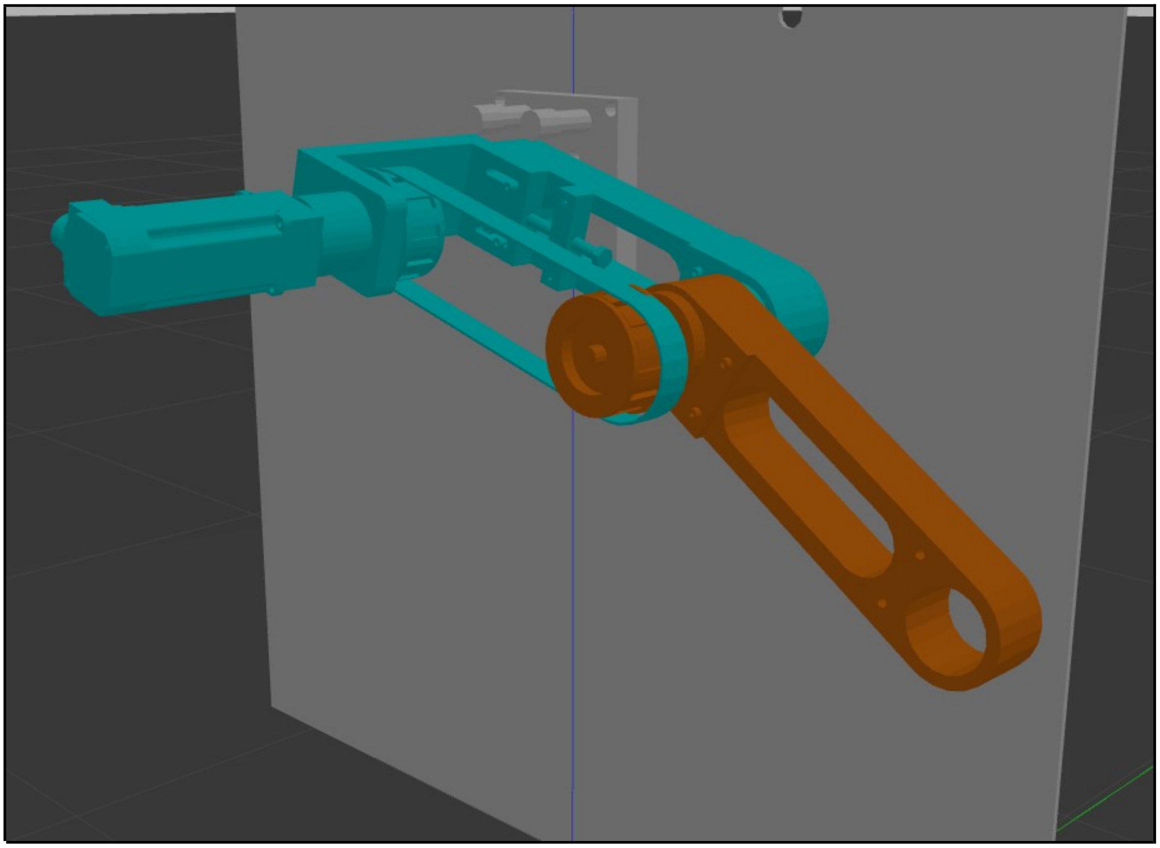


Figure 16: Gazebo simulation based on SolidWorks model

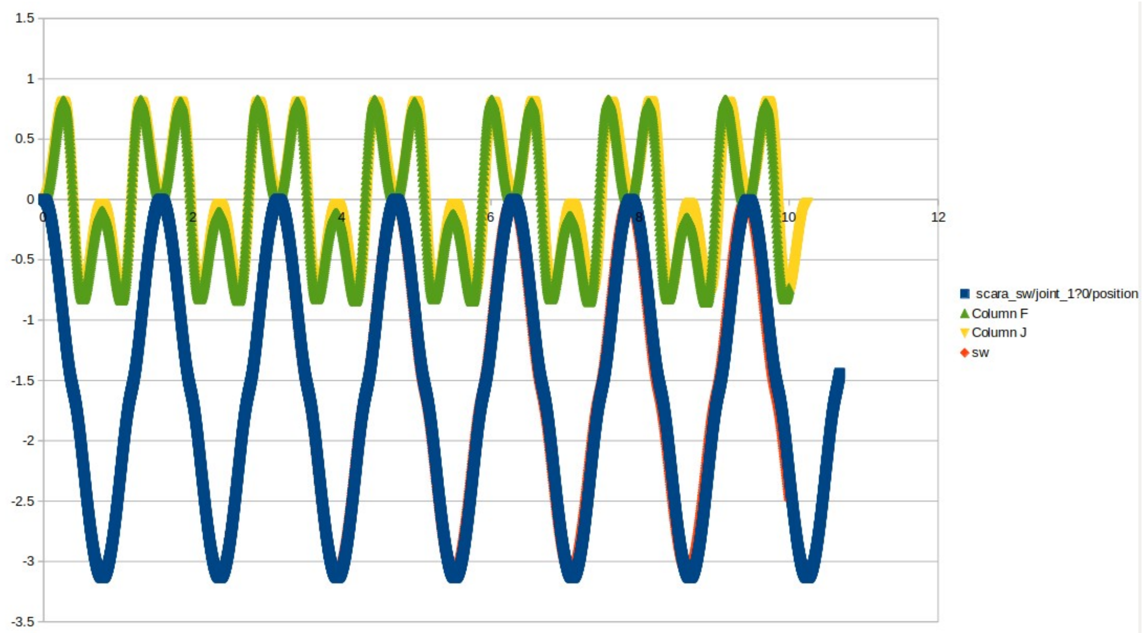


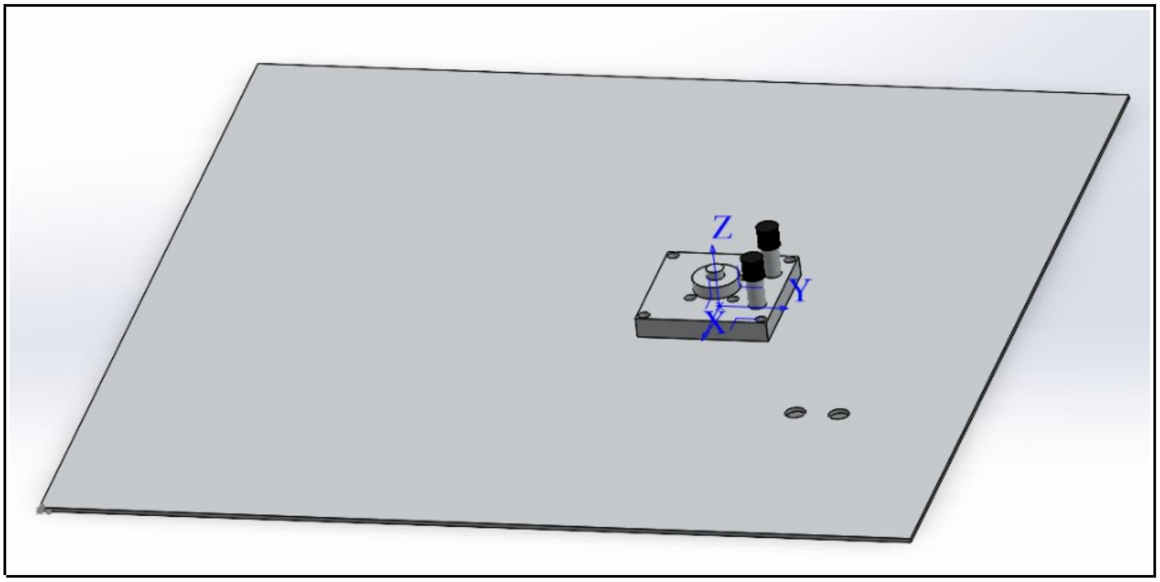
Figure 17: Free fall trajectories of SolidWorks motion study and Gazebo simulation

Summary

The 2R robot described in this report is a laboratory resource permitting advanced study in robotics for upper level and masters students at Ecole Centrale Nantes. While laboratory experiences always have some benefit, in-depth study is promoted by comparison of experimental results with theoretical expectations. It is anticipated that students developing novel control algorithms will test these in simulation in advance of implementation on the real robot. The model developed in this report permits theoretical examination of advanced robotic concepts such as system identification, computed torque control, visual tracking.

Appendices

1. Inertial Parameters of Link 0



Parameter	Value	
Mass	15.136597kg	
Center of Mass		
X=-0.000170m	Y=-0.1379088m	Z=0.000419m
Moment of inertia taken at output coordinate system (kg * m^2)		
Ixx=1.156125	Ixy=0.0	Ixz=0.0
Iyx=0.0	Iyy=1.128704	Iyz=0.0
Izx=0.0	Izy=0.0	Izz=2.291404

2. Motor Parameters

Fiche signalétique
pour le robot Scara (Centrale Nantes)

Caractéristiques moteur

	BECKHOFF	Limitation/ Remarque
Nomenclature	8LVA23.B1030D200-0	
Vitesse nominale (tr/min)	3000 (314 rad/s)	
Vitesse max (tr/min)	6000 (691 rad/s)	
Torque nominal (Nm) (Kt*Intensité)	1.3	
Torque max (Nm)	4	
Inertie moteur (Jrotor+JBrake) (kgm^2)	(26+12) e^{-6} = 38e^{-6}	
Intensité nominale (A)	5.8	
Intensité max (A)	20.7	
Ke (Vrms/rad/s)	(13.61*60)/(1000*2*pi)=0,12996	
Kt (Nm/A)	0.23	(Kt!=Ke)
R (Ohm)	0.83	

Caractéristiques codeur moteur

	BECKHOFF
Nomenclature	Heidenhain EBI 1135
Technologie	EndDat 2.2
Résolution par révolution (pts/tr)	2^{18}= 262144
Révolutions (multi-tours) (bit)	2^{16}= 65536 (32768/-32767 pour B&R)
Résolution Variateur (pts/tr)	2^{18}

Caractéristiques réducteur

	BECKHOFF	Limitations
Nomenclature	8GP40-060-015S2V2	
Nbr d'étage	2	
Vitesse nominale (tr/min)	4500 (471 rad/s)	
Vitesse max (tr/min)	13000	
Inertie (Jred) (kgm^2)	7.7e^{-6}	
Rapport	15	
Rendement (%)	94	
Torque sortie nominal (Nm)	44	
Torque en entrée (Nm)	44/(15*0.94)= 3.12	

Attachments: Motor Datasheet, Gear Reducer Datasheet

2.5 General motor data

General information	Cooling type A
CE certification	Yes
C-UR-US listed	Yes
UL file number	PRHZ2.E235396

Electrical characteristics	
DC bus voltage on the ACOPOSmicro	80VDC 1)
Conventional connection type (power connection / encoder connection)	ytec circular connector from Intercontec
Connection type - Single-cable solution (hybrid)	htec circular connector from Intercontec

Thermal characteristics	
Insulation class in accordance with EN 60034-1	F
Methods of cooling in accordance with EN 60034-6 (IC code)	Self-cooling, no separate surface cooling (IC4A0A0)
Thermal motor protection in accordance with EN 60034-11	Size 1: No, size 2 and 3: KTY 83-110 Maximum winding temperature 155°C (limited by the thermal motor protection in the ACOPOSmicro drive system to 110°C with EnDat feedback and 130°C with resolver feedback)

Mechanical characteristics	
Roller bearing, dynamic load ratings and nominal service life	Based on DIN ISO 281
Shaft end in accordance with DIN 748	Form E
Oil seal in accordance with DIN 3760	Form A
Key and keyway in accordance with DIN 6885-1	Form A keys, form N1 keyway
Balancing the shaft in accordance with ISO 1940/1, G6.3	Half-key arrangement
Mounting flange	IEC 72-1
Smooth rotation of shaft end, coaxial properties and mounting flange plane in accordance with DIN 42955	Tolerance R
Coating Color	Water-based coating RAL 9005 flat

Operating conditions	
Rating class, operating mode in accordance with EN 60034-1	S1 - Continuous operation
Ambient temperature during operation	-15°C to +40°C
Maximum ambient temperature during operation	+50°C 2)
Relative humidity during operation	5 to 95%, non-condensing
Reduction of the nominal current and stall current at temperatures above 40°C	5% per 5°C
Reduction of the nominal current and stall current at installation elevations starting at 1000 m above sea level	10% per 1000 m
Maximum installation elevation	2000 m 3)
Max. flange temperature	65°C
EN 60034-5 protection (IP code) With optional oil seal	IP54 4) IP65 4) 5)
Construction and mounting arrangement type in accordance with EN 60034-7 (IM code)	Horizontal (IM3001) Vertical, motor hangs on the machine (IM3011) Vertical, motor stands on the machine (IM3031)

Storage and transport conditions	
Storage temperature	-20 to +60°C
Relative humidity during storage	Max. 90%, non-condensing
Transport temperature	-20 to +60°C
Relative humidity during transport	Max. 90%, non-condensing

2.10 8LVA2 - Technical data

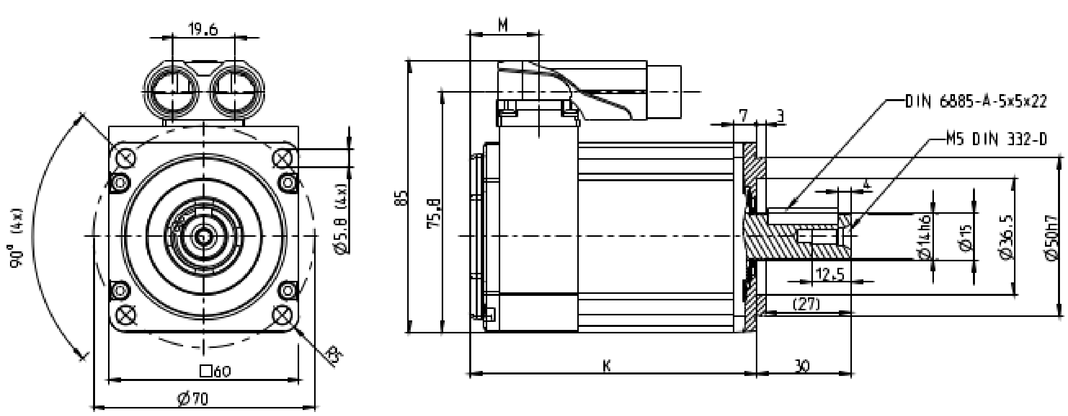
Size 2

Model number	8LVA22.ee015ffgg-0	8LVA22.ee030ffgg-0	8LVA23.eeA95ffgg-0	8LVA23.ee015ffgg-0	8LVA23.ee030ffgg-0
Motor					
Nominal speed n_N [rpm]	1500	3000	950	1500	3000
Number of pole pairs			4		
Nominal torque M_n [Nm]	0.67	0.65	1.33		1.3
Nominal power P_N [W]	105	204	132	209	408
Nominal current I_N [A]	1.61	2.9	2.02	3.2	5.8
Stall torque M_0 [Nm]	0.68			1.35	
Stall current I_0 [A]	1.64	3	2.05	3.25	6
Maximum torque M_{max} [Nm]	2			4	
Maximum current I_{max} [A]	5.6	10.3	7.8	11.2	20.7
Maximum speed n_{max} [rpm]			6600		
Torque constant K_T [Nm/A]	0.42	0.23	0.66	0.42	0.23
Voltage constant K_E [V/1000 rpm]	25.13	13.61	39.79	25.13	13.61
Stator resistance R_{2ph} [Ω]	6.02	2	6.36	2.6	0.83
Stator inductance L_{2ph} [mH]	12.2	4.1	15.3	6.3	2
Electrical time constant t_{el} [ms]	2	2.1		2.4	
Thermal time constant t_{therm} [min]	35			38	
Moment of inertia J [kgcm²]	0.14			0.26	
Mass without brake m [kg]	1.05			1.45	
Holding brake					
Holding torque of the brake M_{Br} [Nm]			2.2		
Brake mass [kg]	0.29			0.25	
Moment of inertia for the brake J_{Br} [kgcm²]			0.12		
Recommendations					
ACOPOS 8Vxxxx.xx...	1010.50	1016.50	1010.50	1016.50	1090
ACOPOS P3 8EI...	2X2M		4X5M		8X8M
ACOPOSmicro 80VD100Px.xxxx-01			C0XX		
Cross section for B&R motor cables [mm²]			0.75		
Connector size			1.0		

Servo drive: The recommended servo drive / inverter module is designed for 1.1x the stall current. If more than double the amount is needed during the acceleration phase, the next larger servo drive should be selected. This recommendation is only a guideline; detailed inspection of the corresponding speed/torque characteristic curve can result in deviations of the servo drive size (larger or smaller).
ACOPOS missing information: The DC bus voltage must be reduced in order to operate this device with an ACOPOS drive (max. 325 VDC).
ACOPOSmulti: Operating this device with ACOPOSmulti inverter module is not possible due to the high DC bus voltage when powered from the mains.

NOTE cable: The suitable cables can be found in the catalog (Book 1) chapter ACOPOSmicro servo drive.

2.10.1 8LVA2x - Dimensions



Double angular built-in connector

8GP40-060 standard

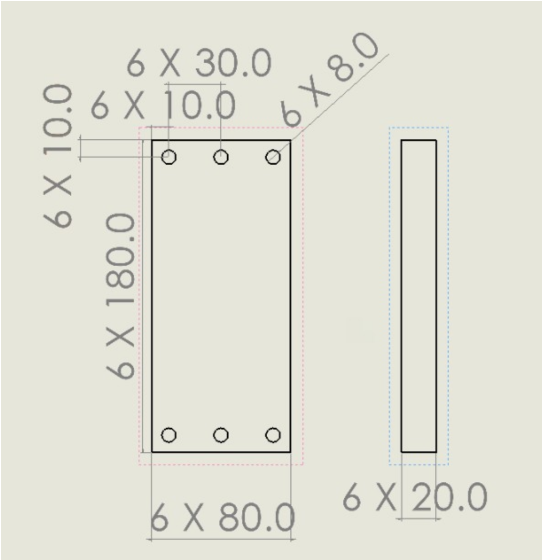
Technical data

	8GP40-060hh003klmm	8GP40-060hh004klmm	8GP40-060hh005klmm	8GP40-060hh008klmm	8GP40-060hh010klmm	8GP40-060hh009klmm	8GP40-060hh012klmm	8GP40-060hh015klmm	8GP40-060hh016klmm	8GP40-060hh020klmm	8GP40-060hh025klmm	8GP40-060hh032klmm	8GP40-060hh040klmm	8GP40-060hh064klmm	8GP40-060hh100klmm
Gearbox															
Number of gear stages	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2
Gear ratio i	3	4	5	8	10	9	12	15	16	20	25	32	40	64	100
Nominal output torque T_{2N} [Nm]	28	38	40	18	15	44	44	44	44	44	40	44	40	18	15
Max. output torque T_{2max} [Nm]	45	61	64	29	24	70	70	70	70	70	64	70	64	29	24
E-stop torque T_{2Stop} [Nm]	66	88	80	80	80	88	88	88	88	88	80	88	80	80	80
Idle torque [Nm] at 20°C and 3000 rpm	0.15	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Max. average drive speed $n_{1N50\%}$ [rpm] at 50% T_{2N} and S1								4500							
Max. average drive speed $n_{1N100\%}$ [rpm] at 100% T_{2N} and S1								4500							
Max. drive speed n_{1max} [rpm]								13000							
Max. backlash J_t [arcmin]	10	10	10	10	10	12	12	12	12	12	12	12	12	12	12
Reduced backlash J_t [arcmin] less than								0							
Torsional rigidity C_{t21} [Nm/arcmin]	2.3	2.3	2.3	2.3	2.3	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Tilting rigidity C_{2K} [Nm/arcmin]								0							
Max. breakdown torque M_{2Kmax} [Nm]								0							
Max. radial force Fr_{max} [N] for 30,000 h								340							
Max. radial force Fr_{max} [N] for 20,000 h								400							
Max. axial force Fa_{max} [N] for 30,000 h								450							
Max. axial force Fa_{max} [N] for 20,000 h								500							
Operating noise L_{PA} [dB(A)]								58							
Efficiency at full load η [%]	96	96	96	96	96	94	94	94	94	94	94	94	94	94	94
Min. operating temperature $B_{Tempmin}$ [°C]								-25							
Max. operating temperature $B_{Tempmax}$ [°C]								90							
Mounting orientation								Any							
Protection								IP54							
Weight m [kg]	0.9	0.9	0.9	0.9	0.9	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
Moment of inertia J_1 [kgcm²]	0.135	0.093	0.078	0.065	0.064	0.131	0.127	0.077	0.088	0.075	0.075	0.064	0.064	0.064	0.064

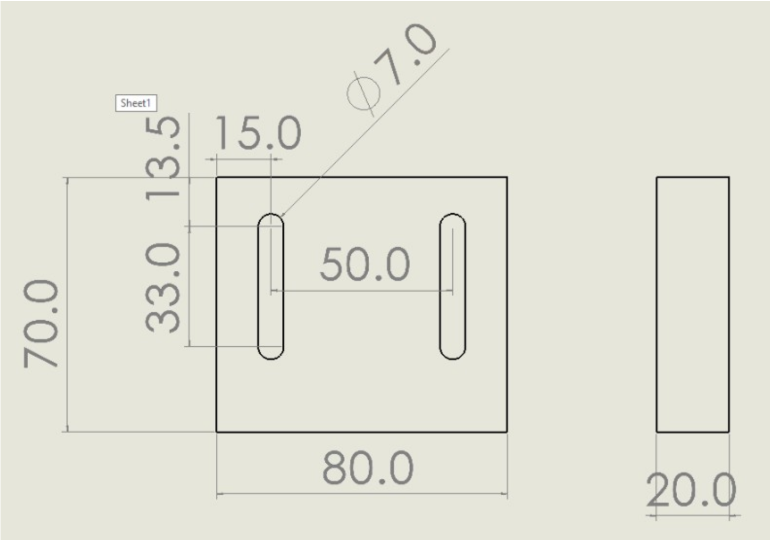
NOTE – Output torque / Max. output torque: This refers to an output shaft speed of n_2 = 100 rpm and application factor K_A = 1 as well as S1 operating mode for electrical machines and T = 30°C, depending on the diameter of the motor shaft. The maximum output torque is only permissible for 30,000 revolutions!
NOTE – E-stop torque: Approved for 1000x
NOTE – Axial / radial force: With reference to the middle of the output shaft; the entries refer to an output shaft speed of n_2 = 100 rpm and application factor K_A = 1 as well as S1 operating mode for electrical machines and T = 30°C
NOTE – Running noise: Noise level at a distance of 1 m; at an output speed of n_1 = 3000 rpm without a load; i = 5
NOTE – Operating temperature: With reference to the middle of the housing surface
NOTE – Weight: Planetary gearbox including universal flange (specific weight upon request)

3. Dimensioned Drawings of main components

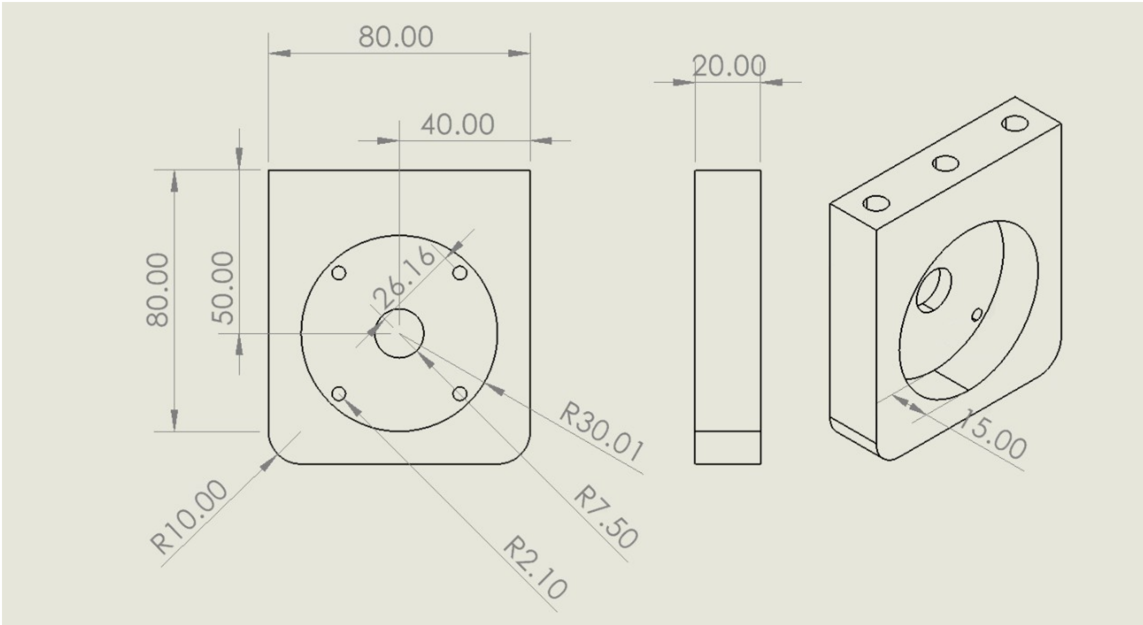
3.1. Motor Mount Riser



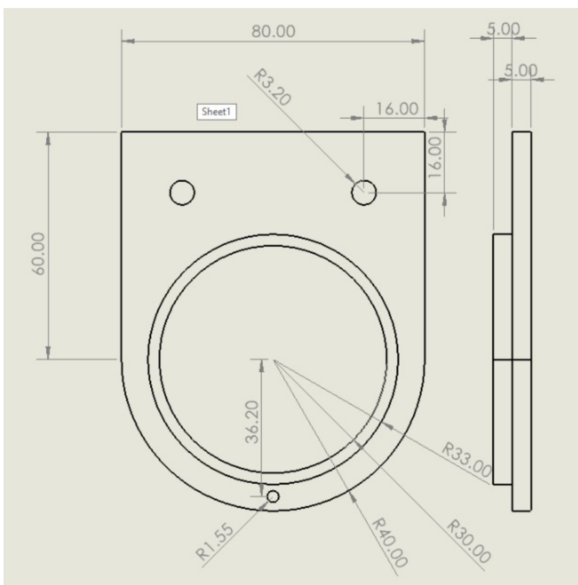
3.2. Motor Mount Base



3.3. Motor Mount Top



3.4. Clamping Jaw



3.5. Pulley