Kosti-1 Manual

Features:

Kosti-1 is a 5 degree of freedom open-source robotic arm with a maximum payload of 500gm (including the end-effector) and a reach of approximately 55cm. The total part cost is around $700 in addition to machining and shipping costs.

The body of the arm requires both 3D-printed parts and aluminium parts that need to be machined and can't be omitted without significant design changes. All joints are driven by open-loop stepper motors, and 4 out of 5 of these joints have a timing belt and pulley drive for load reduction and/or power transmission. This manual includes schematics and examples for Arduino based control, but different methods of control can be employed.

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3D Printing the Parts:

Printer: All parts can fit inside a 220x220mm printer.

Filament: The design of the plastic parts assumes a shrinkage rate of no more than 2-3%, which is common for PLA, take that into consideration if you end up using another type of filament and consider printing a single piece first to check the fits before proceeding with the rest.

Printer settings: All parts were printed using 0.2mm layer, height and 20-25% infill and two outer shells; increasing the number of shells can add rigidity but would add to the weight. Make sure that you pick the print orientation that minimizes support material for each part.

CNC Machining:

There are 5 parts that need to be machined out of aluminium plate(s) using a CNC machine; the 3 maximum dimensions for each part are (**131** x **82** x **6**mm), (**131** x **148.17** x **6**mm), (**150.20** x **64** x **6**mm), (**112** x **110** x **8**mm) and (**93** x **60** x **4**mm), you can use these dimensions to select the stock plate.

Post Machining:

Shafts: An 8mm shaft needs to be cut into an 8x47mm one and an 8x110 one, and a 6mm shaft needs to be cut into a 6x95mm one and a 6x64mm one. A 0.5mm flat should be filed onto the 8x110mm and 6x95mm shafts for more secure joints, and optionally, the same can be done for the other two shafts.

Pulleys: The bore on two out of the six small pulleys needs to be increased in diameter from 6mm to 8mm to match the motor shafts, and ideally, a lathe would be used to do this, similar to what's done here. Other methods can be used with less precise results.

Threaded Rods: Four M3x75mm and four M3x55mm threaded rods need to be cut out of standards lengths ones.

M5 Screws: If narrow head M5 screws are not available, eight hex head ones can be filed to fit on the back of the face of the Nema24 and Nema23 motors.

'link3': Three M3 clearance holes need to be drilled into this part, see step NO. 36.

Platform: You are likely going to need to prepare some sort of platform, usually out of wood, to secure the base of the arm onto.

Tools:

The tools you need would depend, in some cases, on your preferred method of machining; you might want to cut the shafts with a hacksaw or a circular saw, you might have a mill for filing the flats or you might just use a file and a vise, and you might have a lathe for boring the pulleys or you might use a drill with a reamer bit. You will need a soldering iron, 1.5mm, 2mm and 2.5mm Allen keys, and some pliers.

Fits and Tolerances:

The CAD files included for aluminium parts have bearing and screw holes that simply match the nominal diameters of the ready parts, these can be edited to achieve the desired fit.

The bearing and screw-clearance holes on the 3D printed parts assume a shrinkage rate of 2-3%, if the fit on the test piece fails one way or the other, the .stl file can be slightly scaled up or down using the slicing application; make sure that use uniform scaling.

The screw holes on the printed parts match the diameter of the screw shafts and should shrink enough for the screws to self-tap into.

Belt Tensioning:

Base joint: The base is split into two fixed parts connected only by the belt; these two parts can be manually set apart and secured to the platform with a distance that ensures that the belt is properly tensioned.

Shoulder joint: The centre distance required for good tension between each two pulleys can be calculated using the provider's online tool, and the centre distance on the aluminium plate holding the two pulleys for the shoulder joint is 1% larger than the calculated one, which would result in good tension at installation without the need for a tensioner, assuming that the specified closed loop belt and pulleys are selected. In any case, a clearance hole for an M5 screw is present on the plate behind where the belt should be, and that hole can be used to add a tensioner similar the one included for the elbow joint and explained below.

Elbow joint: There's no easy way to predict the resulting centre distance on 3D printed parts, and proper tension can be hard to achieve, even when allowance is made for shrinkage, without some sort of adjustable tensioner; the tensioner for the elbow joint is simply two 5mm bore bearings with a thickness of 5mm held on an M5 screw and secured with nuts on both sides, the thickness of the bolt below the bearings can be filed down if they're too high and a spacer can be added if they're too low, and the tension can be adjusted by either 3D printing a small hollow cylinder that goes over the bearings or by using bearings with a larger outer diameter. See assembly step NO. 13.

Wrist Joint: The second link where the wrist joint belt is attached wasn't designed to hold a screw based tensioner, and I currently don't have access to the assembly to test another tensioner design, consequently, the recommended method for tensioning the upper most belt is cutting it and attaching the two ends with two

clamps (.stl included), a screw and a nut. The wrist joint should have more than the sufficient range of motion without the clamp reaching either pulley, but you're free to come up with other ways for tensioning this belt.

End Effector:

The end effector included is the open-source gripper from Anninrobotics.com; the assembly manual and bill of materials for the servo gripper are separately available at anninrobotics.com/downloads under 'Servo Gripper', but the printable files have been adjusted to fit onto the different hub and can be found with the rest of Kosti-1's files. Note that the same servo is included in both Kosti-1's BOM and the BOM for the gripper while you will only need one servo.

Bill of Materials:

NO.	PART NAME	QTY.	NOTE	LINK
	Belts & Pulleys			
1	80T Pulley, 3 mm Pitch, 8mm Bore	2		Link
2	20T Pulley, 3 mm Pitch, 6mm Bore	6		Link
3	184T, 3mm pitch, 9mm width Belt	1		Link
4	119T, 3mm pitch, 9mm width Belt	1		Link
5	118T, 3mm pitch, 9mm width Belt	1		Link
6	187T, 3mm pitch, 9mm width Belt	1		Link
	Motors			
7	Nema24 4.2A 4Nm	1		Link
8	Nema23 2.8A 1.26Nm	1		Link
9	Nema17 Geared	1		Link
10	Nema14 Geared	1		Link
11	Nema16	1		Link
	Electronics			
12	Servo	1		Link
13	arduino	1		Link
14	jumper wires	35		Link
15	bread board	1		Link
16	extension wires	8		Link
17	DM54T driver	2		Link
18	DM320T driver	3		Link
19	400W 24V power supply	1		Link
	Bearings			
20	35x62x9mm_bearing_16007	1		Link
21	50x80x10mm_bearing_16010	1		Link
22	40x52x7mm_bearing_6808-2RS	6		Link
23	20x27x4mm_bearing_6704ZZ	1		Link
24	5mm ID 5mm thick bearing	2		
	Fastners, Shafts & Hubs			
25	M3 x 0.5 x 10 Hex	6		Link
26	M3 x 0.5 x 35 Hex	9		
27	M3 x 0.5 x 12 Hex	6		
28	M3 x 0.5 x 8 Hex	8		
29	M3 x 0.5 x 25 Hex	14		
30	M3 x 0.5 x 5 Hex	12		
31	M3 x 0.5 x 40 Hex	12		

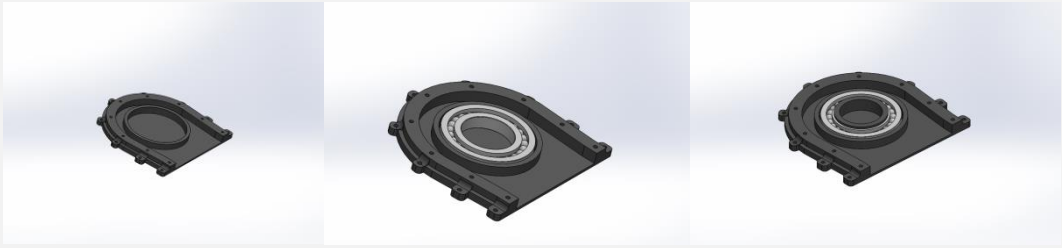
32	M3 x 0.5 x 30 Hex	19		
33	M3 x 0.5 x 20 Hex	8		
34	M3 x 0.5 x 16 Hex	4		
35	M3 x 0.5 x __ Hex	13 + 12		
36	Hex nut, M3 x 0.5	42 + 13 + 12		
37	M4 x 0.7 x 10	4		
38	M5 screw x 0.8 x 20	8		Link
39	M5 screw x 0.8 x 25	1		
40	M5 nut, M5 x 0.8	10		
41	Corner Bracket	4		Link
42	Threaded rod M3 x 0.5 x (75 + 55)	4		Link
43	M3 Insert	3		Link
44	Shaft 1, 2_8 x (47+110)	1		Link
45	Shaft 3, 4_6 x (95 +64)	1		Link
46	8mm hub	3		Link
47	6mm hub	3		Link
48	5mm hub	1		Link

*Some of these are affiliate links.

*You can source the same parts from any preferred distributer.

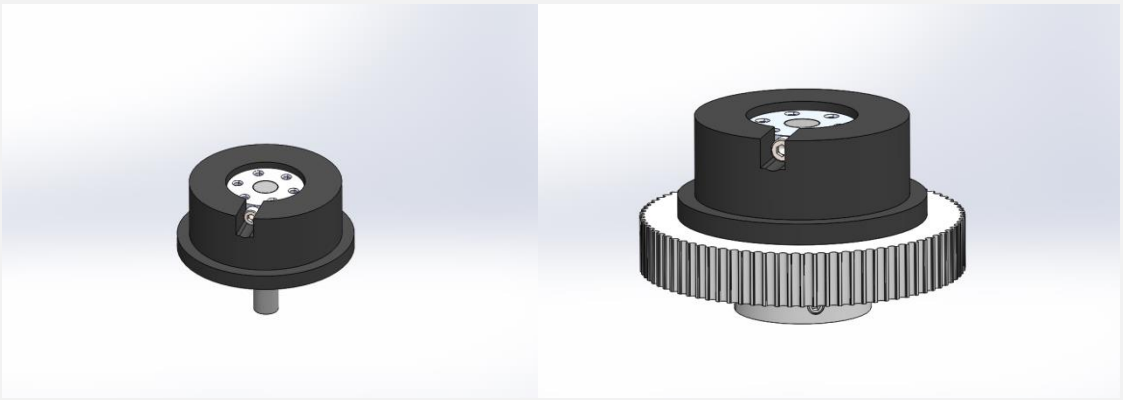
Assembly Guide:

*Some parts are supressed when they're not the focus of a given step.

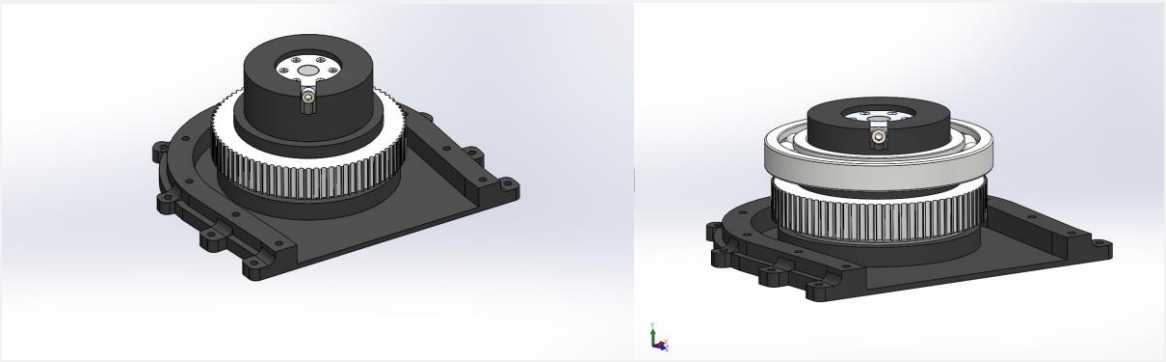


1. Insert the 35mm bore bearing into the piece making the bottom of the base and insert the 'plastic_hub' piece into the bearing; the bearing should have a slide fit.

2. Insert the 8x47mm shaft into the 8mm aluminium hub, making sure that the end of the shaft is flat with the surface of the hub and secure the shaft to the hub using the M3x10mm socket head screw instead of the set screw. Install the remaining hub set screw normally.

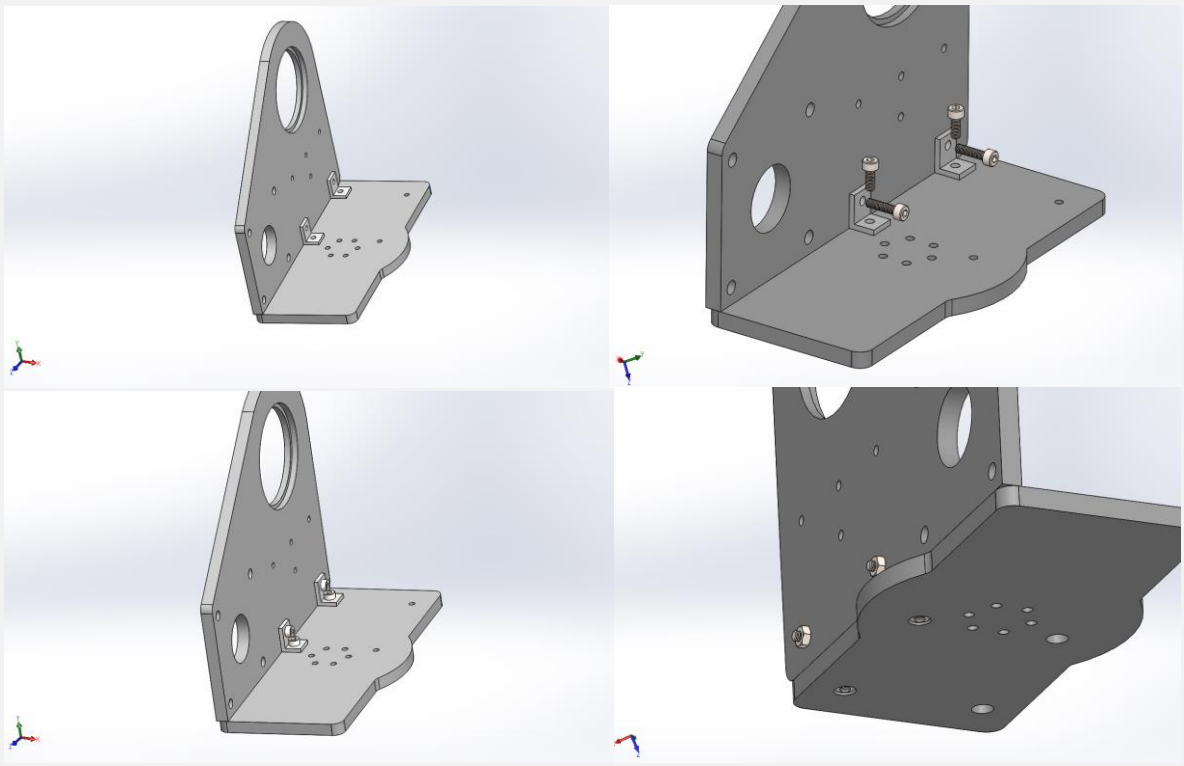


3. Place the shaft and aluminium hub inside the 'j1_hub' as shown and slide the remaining end of the shaft into the bottom of the large pulley and secure the shaft to the pulley using the two M4 set screws.

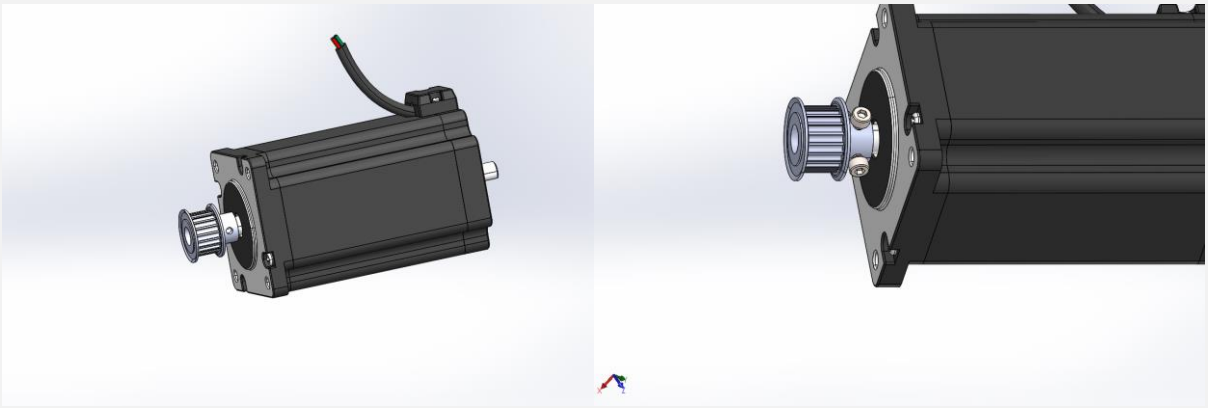


4. Place the protruding segment of the pulley inside the 'plastic_hub', place the 50mm bore bearing as shown and then wrap the closed 184 teeth belt around the pulley.

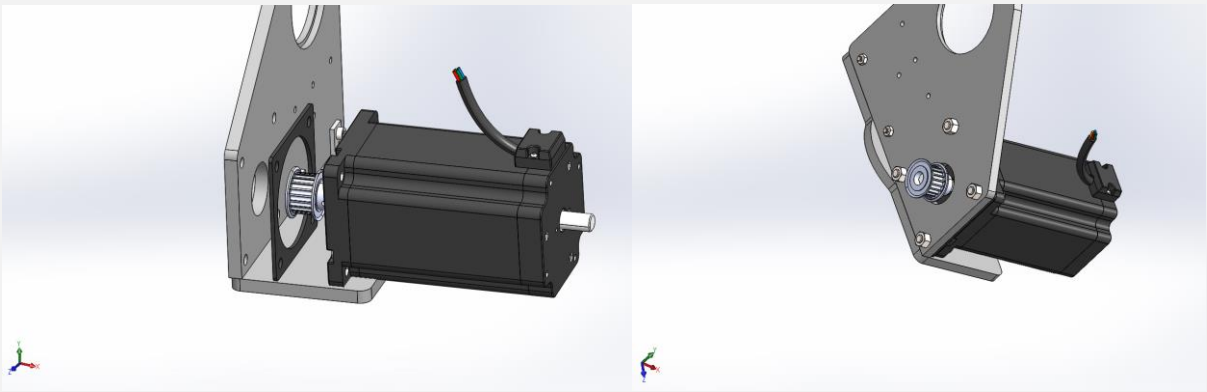
5. Complete the base by placing the two remaining plastic and aluminium pieces over the large bearing as shown and screwing everything using 9 M3x35mm socket head screws; the bearing should have a slide fit; note that the screws should self-tap into the bottom piece.



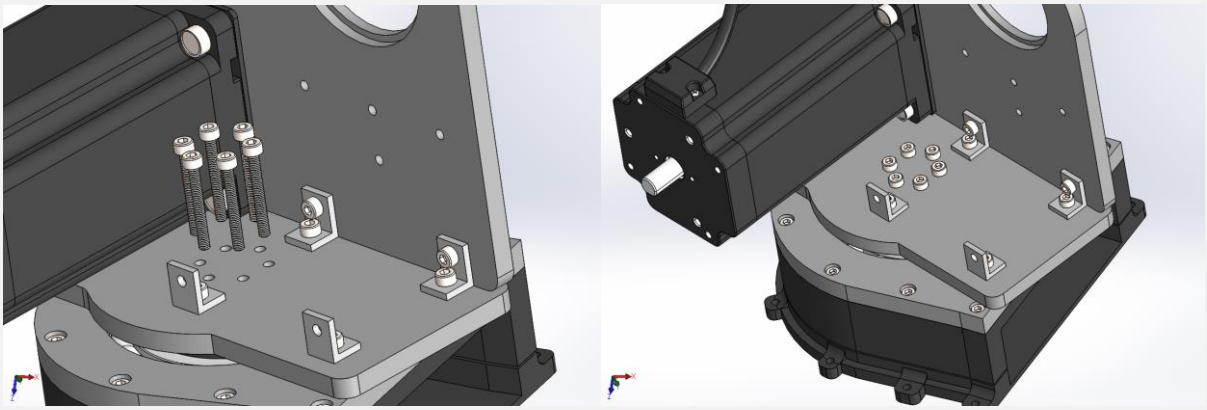
6. Secure the aluminium 'base_plate' and 'left-plate' using two corner brackets, two M3x12mm screws, two M3x8mm screws and 4 M3 nuts; note that the longer screws go into the side plate and that the longer side of the bracket should be the vertical one.



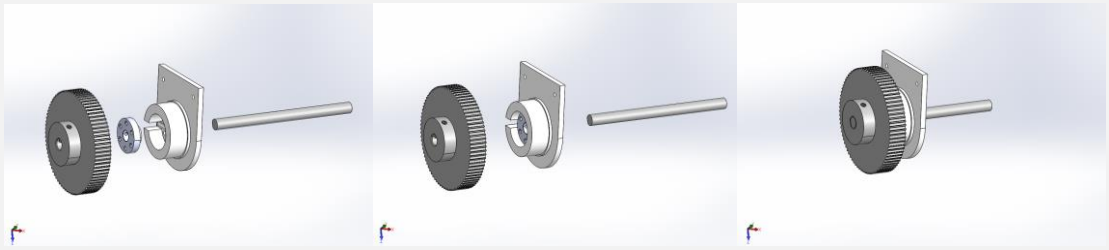
7. Secure the small 8mm bore onto the Nema24 motor using two 5mm screws, making sure that screws are pressing on the flat sides of the shaft and that the pulley is as close to the body of the motor as possible without the screws leaving the flat sides.



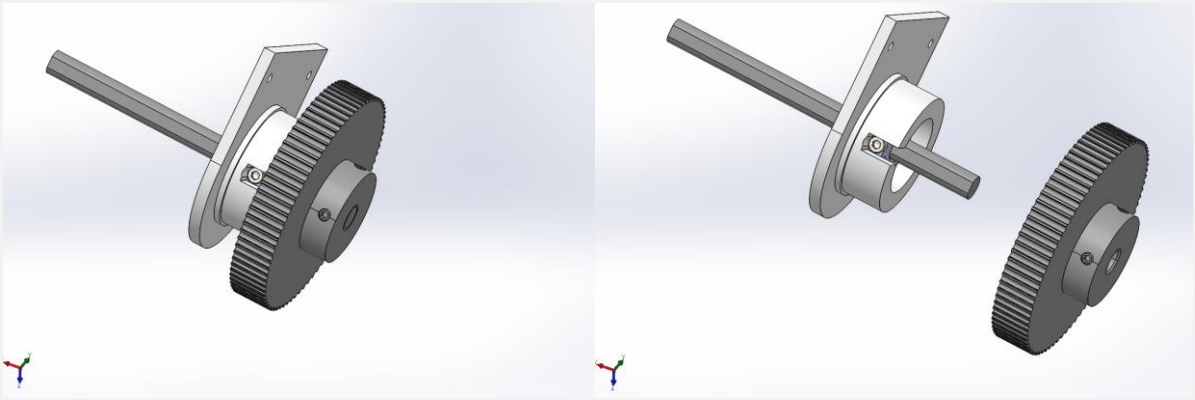
8. Secure the Nema24 motor to the side plate, through the spacer, using 4 M5x20mm screws and 4 M5 nuts.



9. Secure the plates and the motor to the base using 6 M3x25mm screws; the screws should go through the threaded 8mm hub below and self-tap into the plastic, so make sure that the 6 holes on the hub and plate are properly aligned.

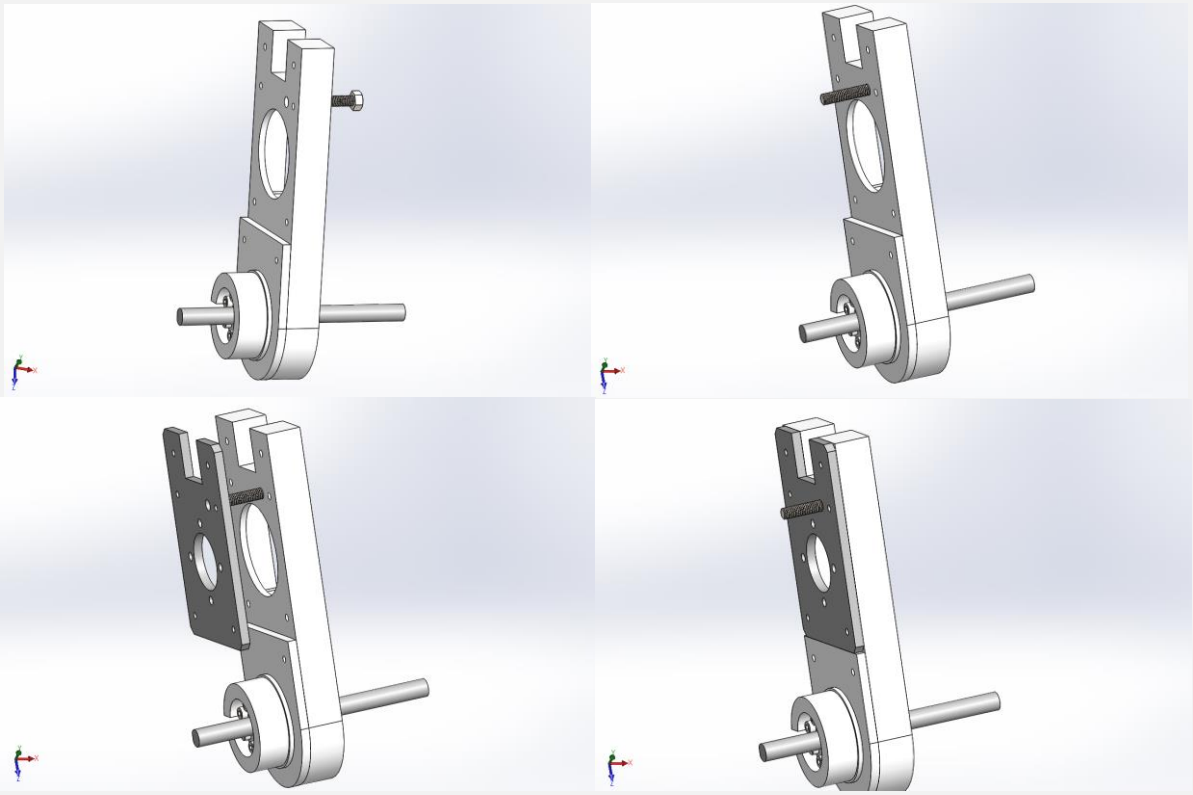


10. Insert the 8mm aluminium hub into 'j2_hub1' as shown, with the set screw holes facing the removed part of the plastic cylinder, and slide the 8x110mm shaft through a large pulley that's held flat against 'j2_hub1', making sure that the end of the shaft is flat with the surface of the pulley. The pulley shouldn't be secured yet and is only needed to mark the shaft distance.

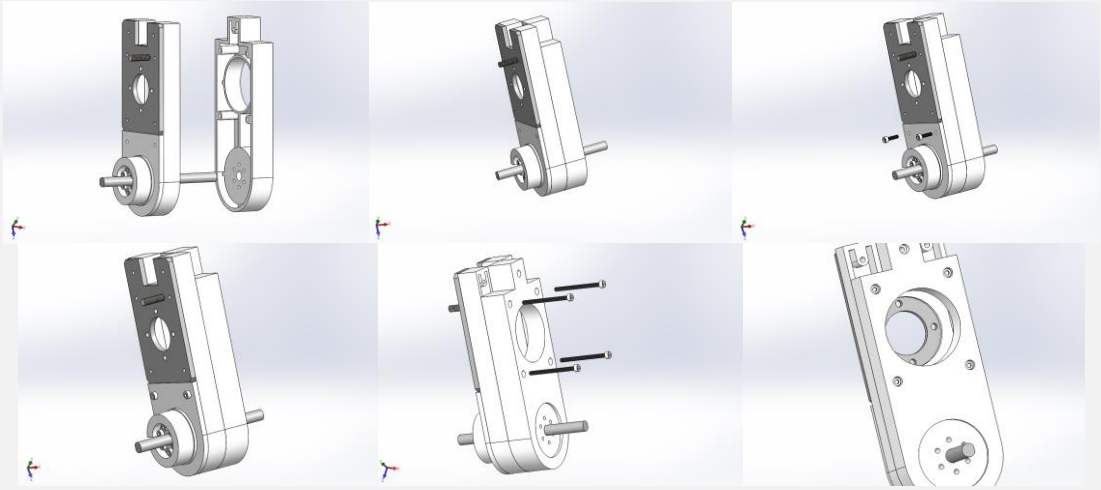


11. Secure the shaft to the hub using an M3x10mm screw and remove the pulley.

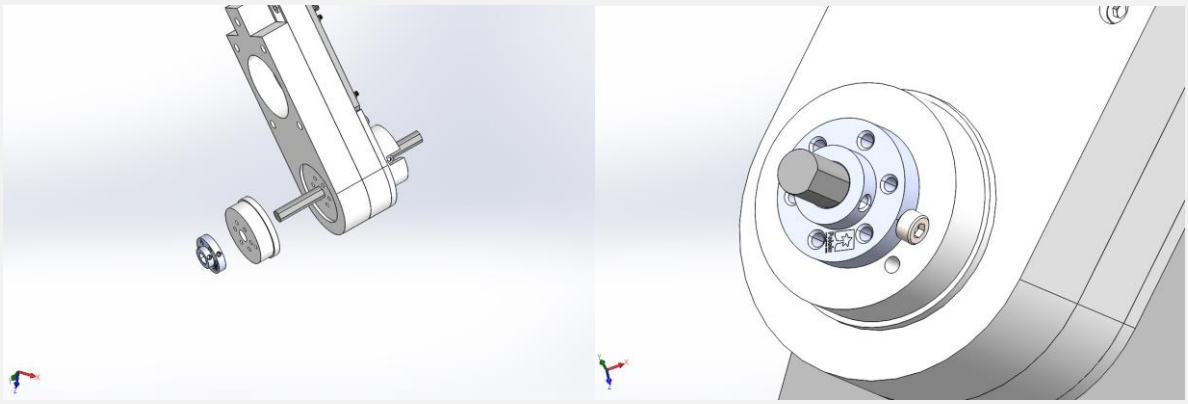
12. Install the 'j2_hub' and the shaft to 'lower_arm_left_1' using 6 M3x25mm screws that should go through the aluminium hub and self-tap into the arm.



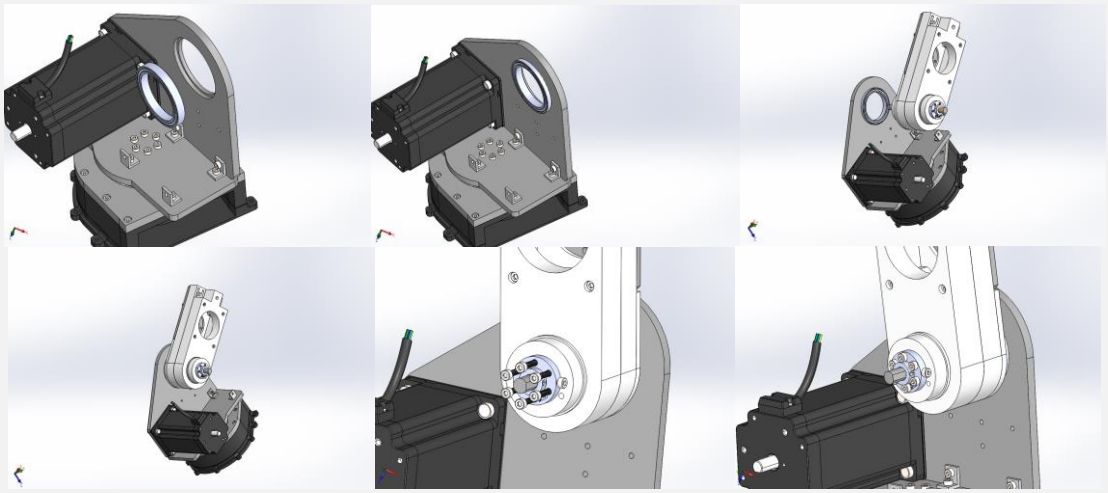
13. Insert the M5x25mm screw needed for tensioning the belt through the hole shown on the arm and through the aluminium 'j3_plate' and secure it using an M5 nut. Two small bearings can be installed on the M5 screw to tension the belt and another M5 nut can be used on top to secure the bearings.



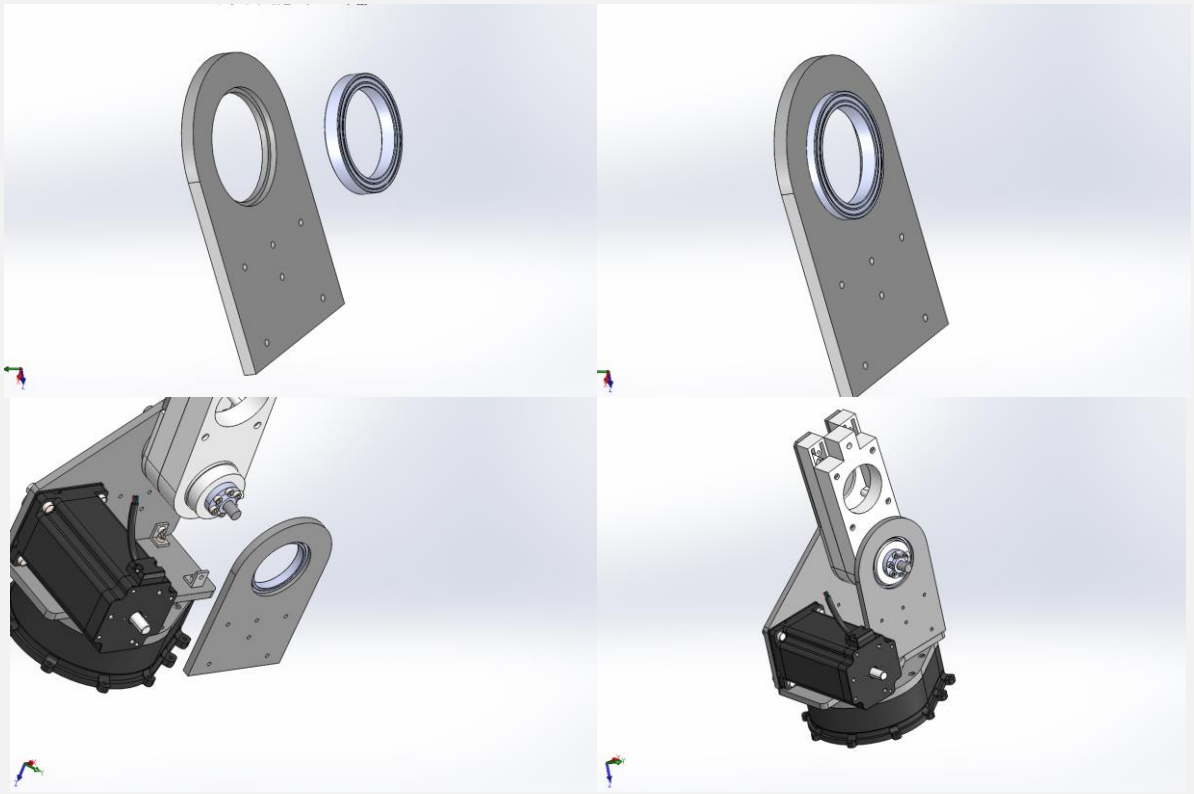
14. Attach 'lower_arm_right_1', secure 'j2_hub' using two M3x12mm screws and secure 'lower_arm_right_1' using 4 M3x40mm screws and 4 M3 Nuts.



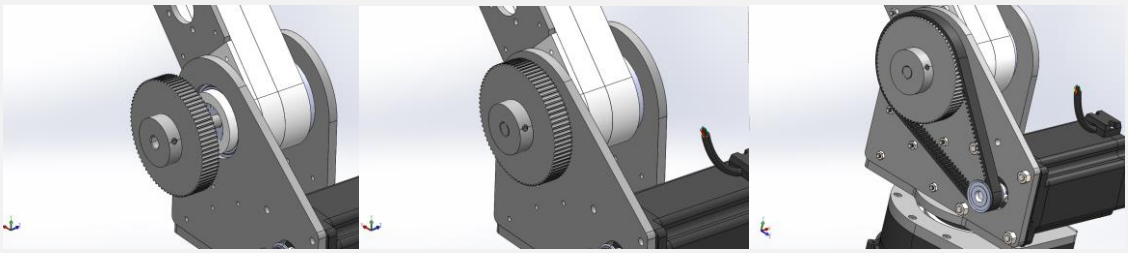
15. Attach 'j2_hub2' and the 8mm aluminium hub to the shaft, making sure that all holes are aligned and that set screw holes are over the flat side of the shaft, and secure the aluminium hub to the shaft using an M3x10mm screw.



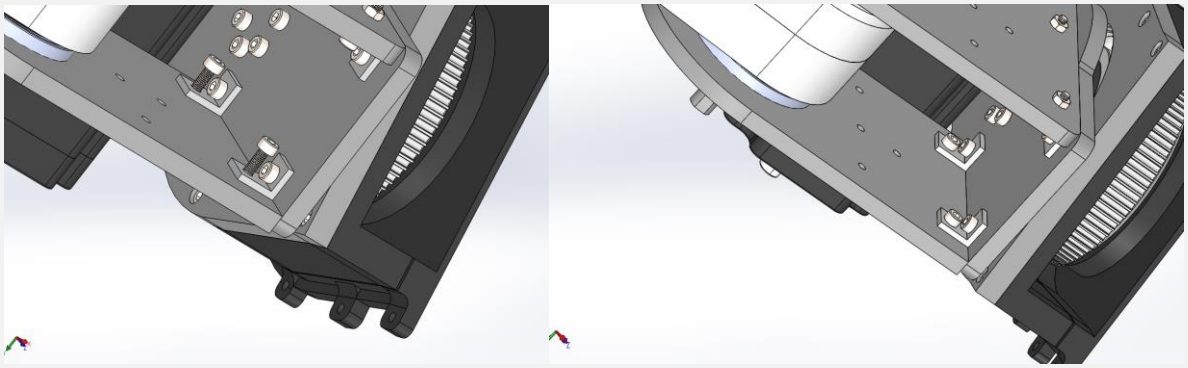
16. Slide the 40mm bore bearing into the designated place on the side plate, attach the assembled part of the arm as shown and secure the right aluminium hub using 6 M3x30mm screws.



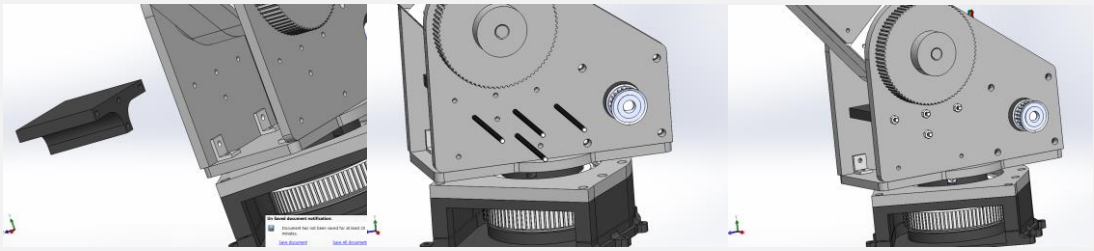
17. Slide a 40mm bore bearing into the other side plate and attach both to the other side of the arm without screwing anything yet.



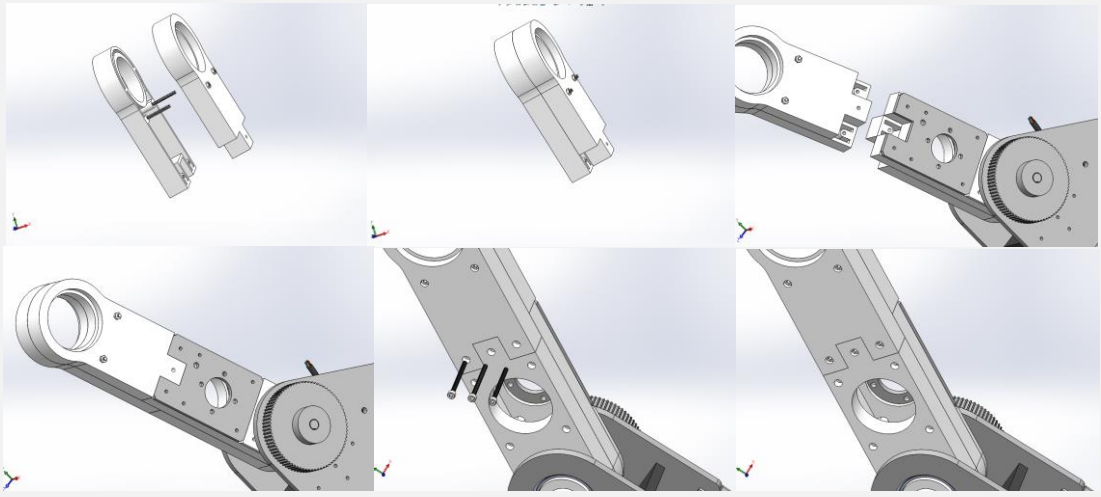
18. Attach the large pulley to the other side and install the 119 teeth belt, moving things around as needed to avoid straining the belt.



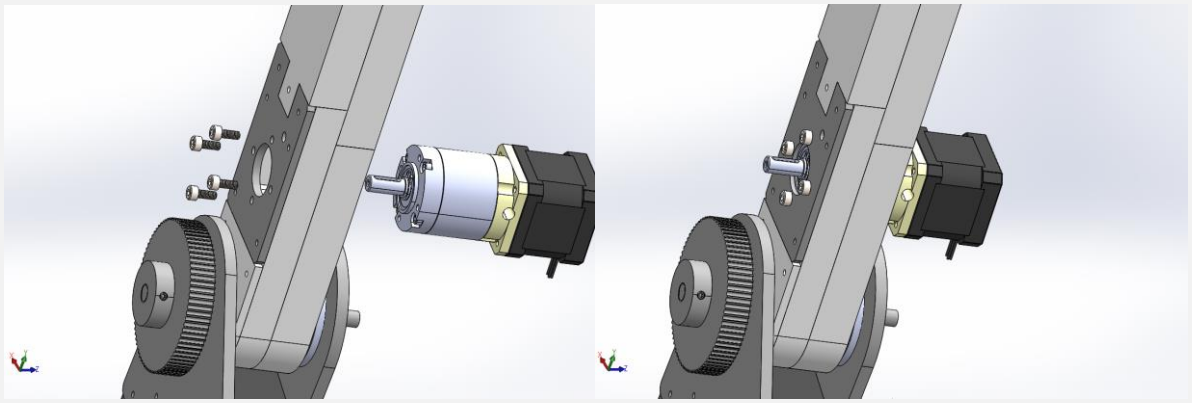
19. Secure the unsecured right plate using two brackets, two M3x12mm screws on the side, two M3x8mm screws on the bottom and 4 M3 nuts, similar to the left plate.



20. Slide the 'support' between the two plates and hold everything together using 4 M3x65mm threaded rods and 8 M3 nuts.

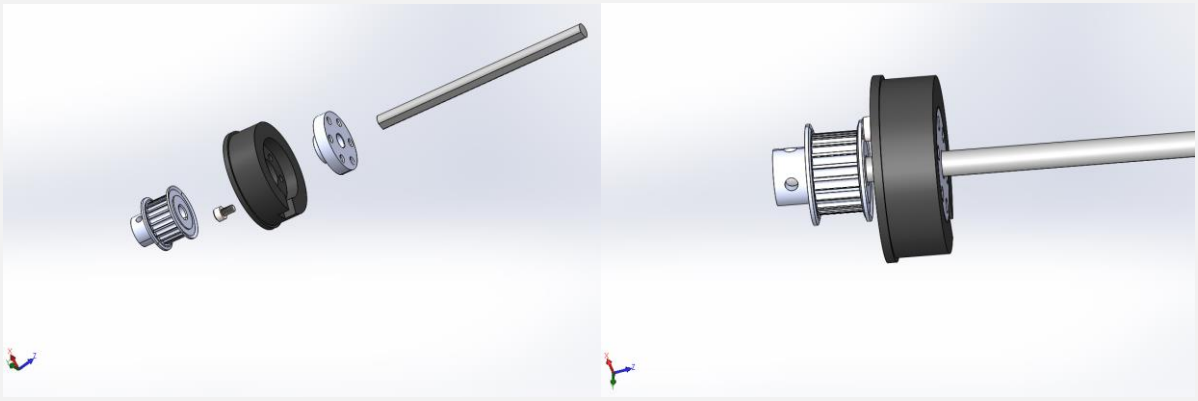


21. Attach 'lower_arm_right_2' and 'lower_arm_left_2' together using 2 M3x40mm screws and two nuts as shown, attach the result to the assembled half of the arm and secure these two halves using 3 M3x40mm screws and 3 nuts.

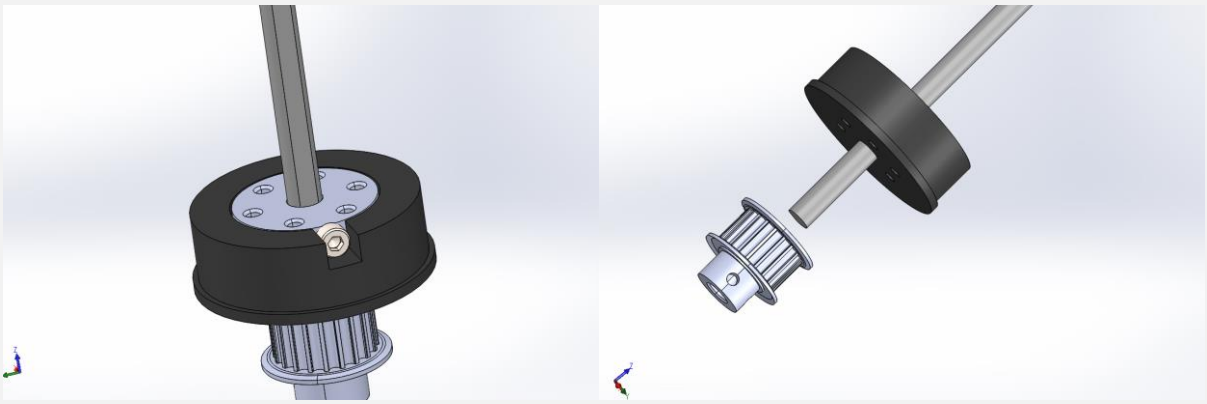


22. Install the geared Nema17 motor, with the motor wires pointing down using 4 M4x10mm screws.

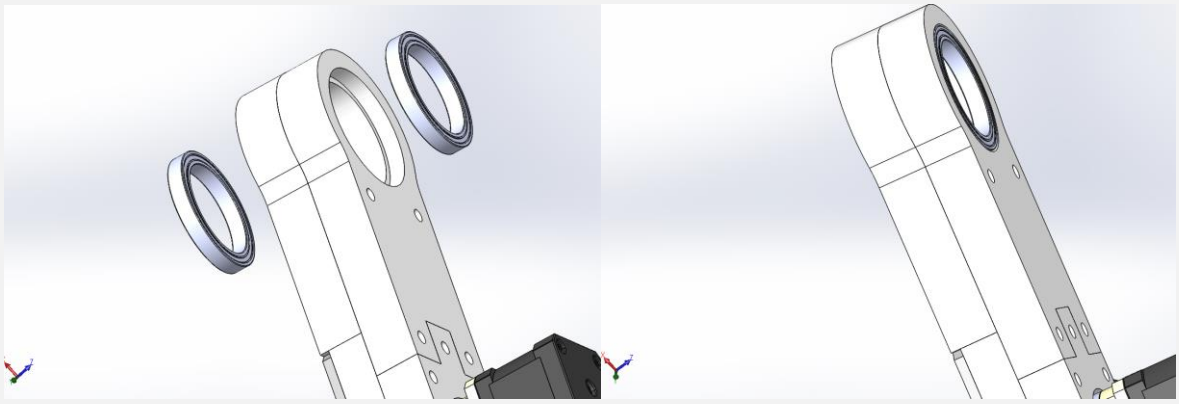
23. Attach the 'J3_hub2', 'upper_arm_left_1' and the 6mm aluminium hub using 3 M3x30mm screws inserted on every second hole as shown; make sure that set screw holes on the aluminium hub are facing the lower end of the arm. Note that parts 'j3_hub' and 'j4_hub2' are identical.



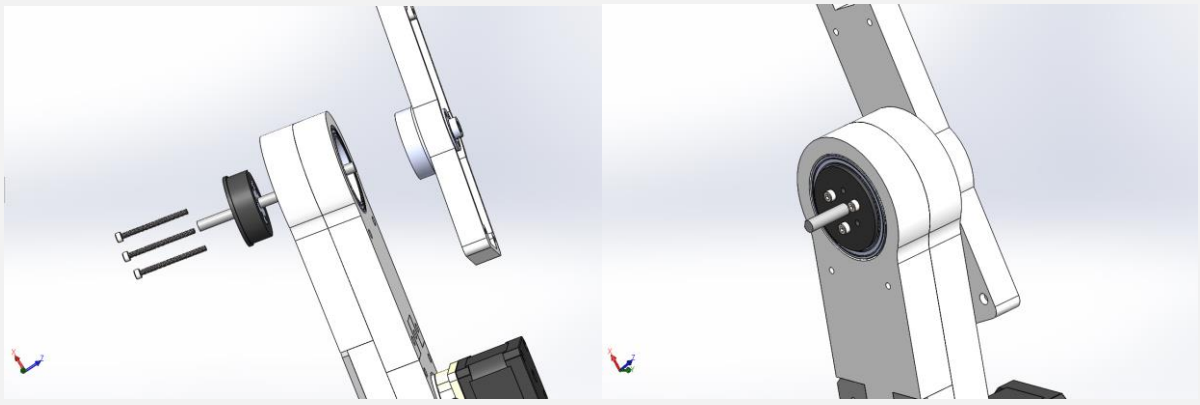
24. Insert the 6mm aluminium hub into 'J3_hub1', making sure that all holes are aligned, and slide the 6x95mm shaft through the hub followed by an M3x5mm screw and a small pulley to mark the shaft distance.



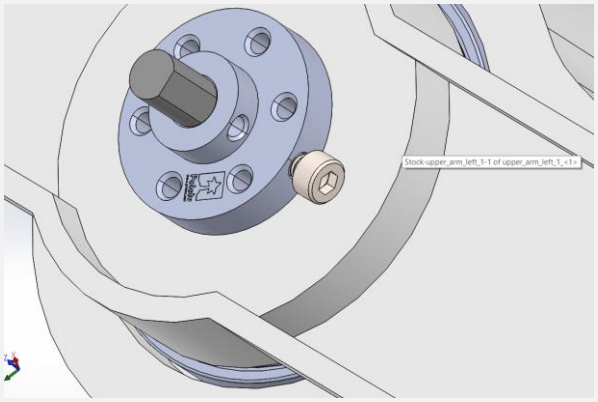
25. With one end of the shaft flat with the surface of the pulley, secure the shaft to the aluminium hub using an M3x12mm screw against the flat of the shaft and remove the pulley and the M3x5mm screw.



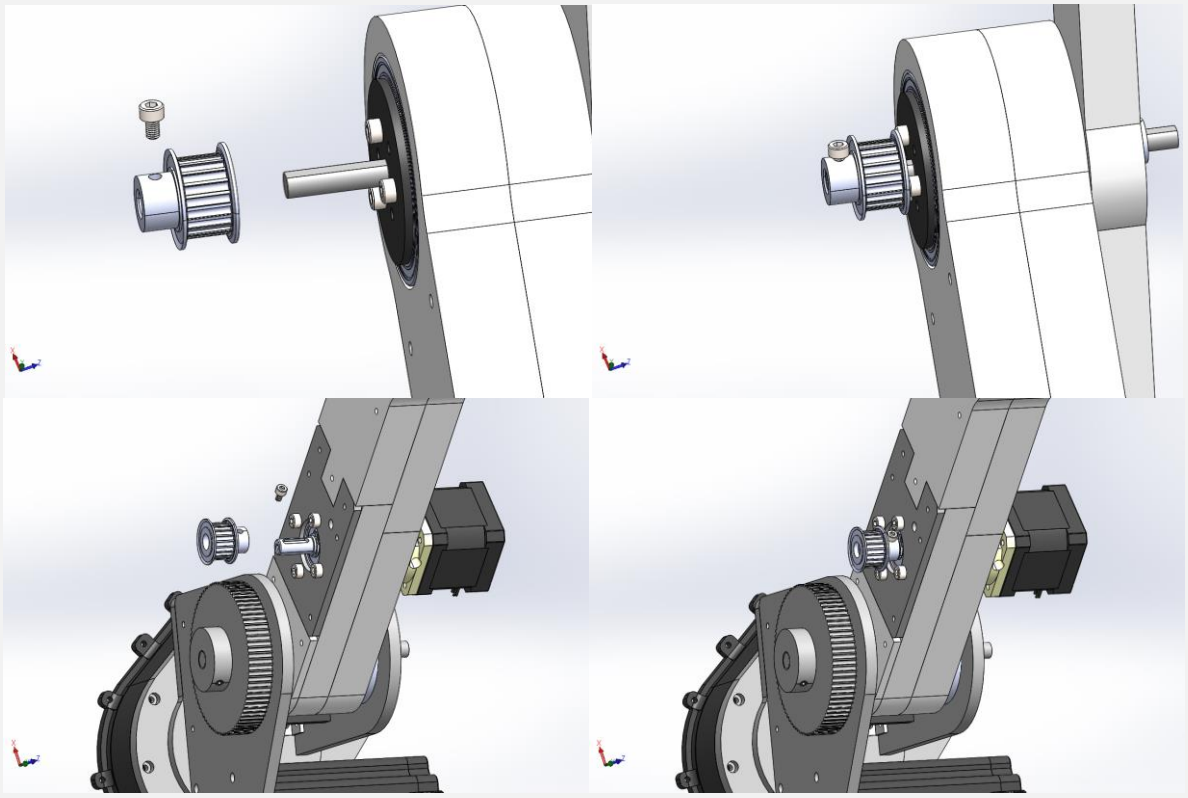
26. Insert two 40mm bore bearings into the upper end of the assembled arm.



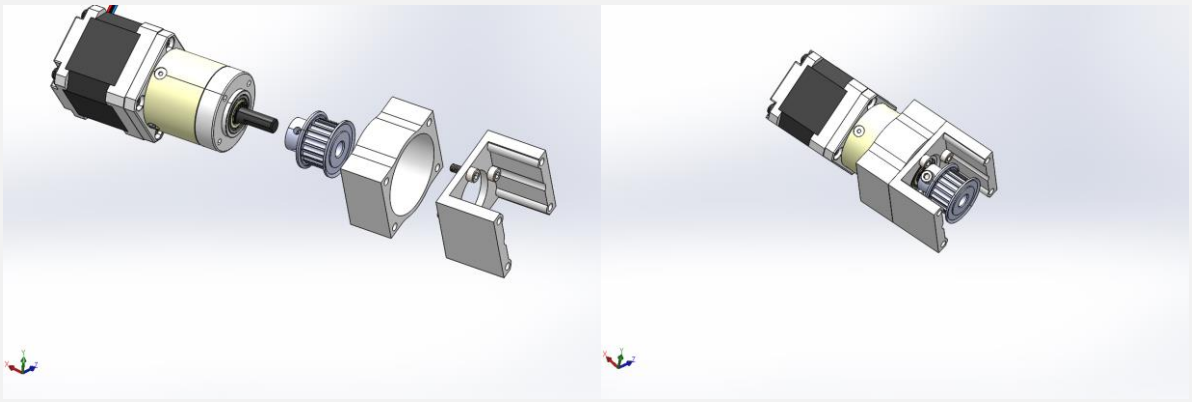
27. Attach 'J3_hub1' and 'J3_hub2' together, through the bearings, using 3 M3x40mm screws, making sure that the 3 screws on the left side aren't aligned with those on the right side, and that the flat side of the shaft is aligned with set screw holes on the right hub.



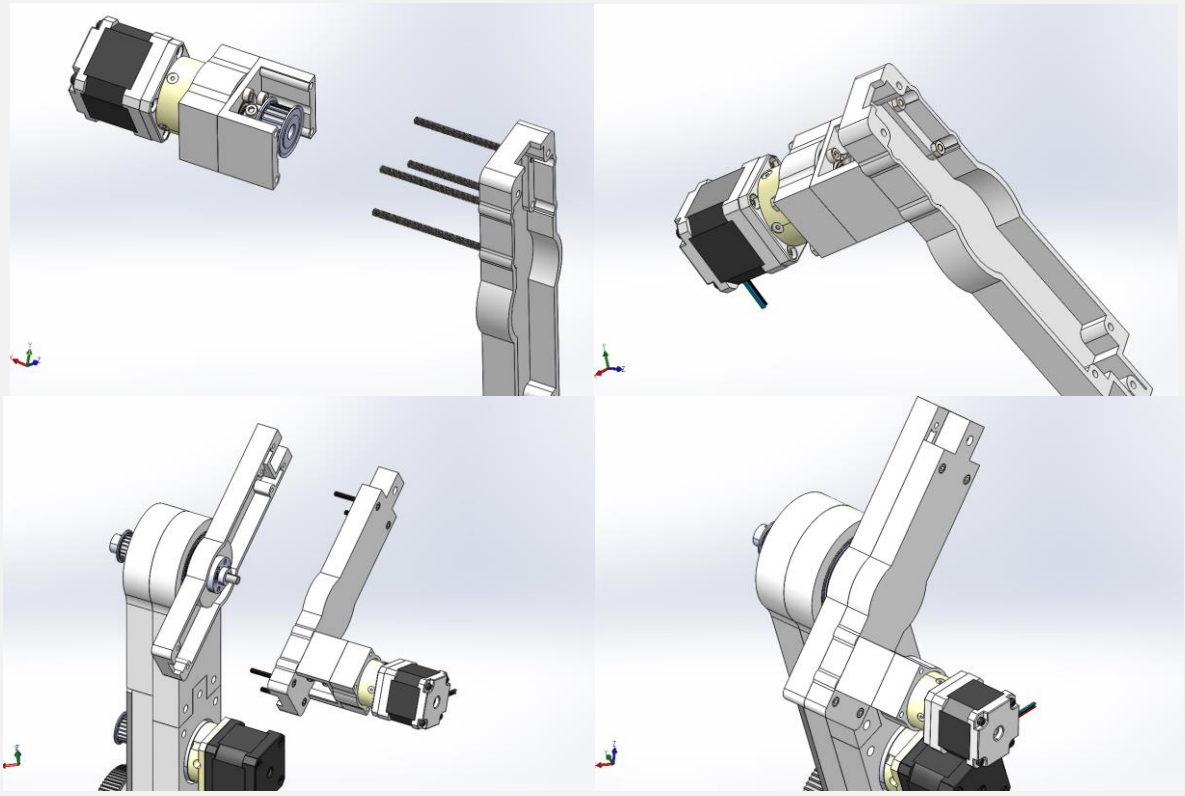
28. Secure the shaft to the right hub using an M3x12mm screw.



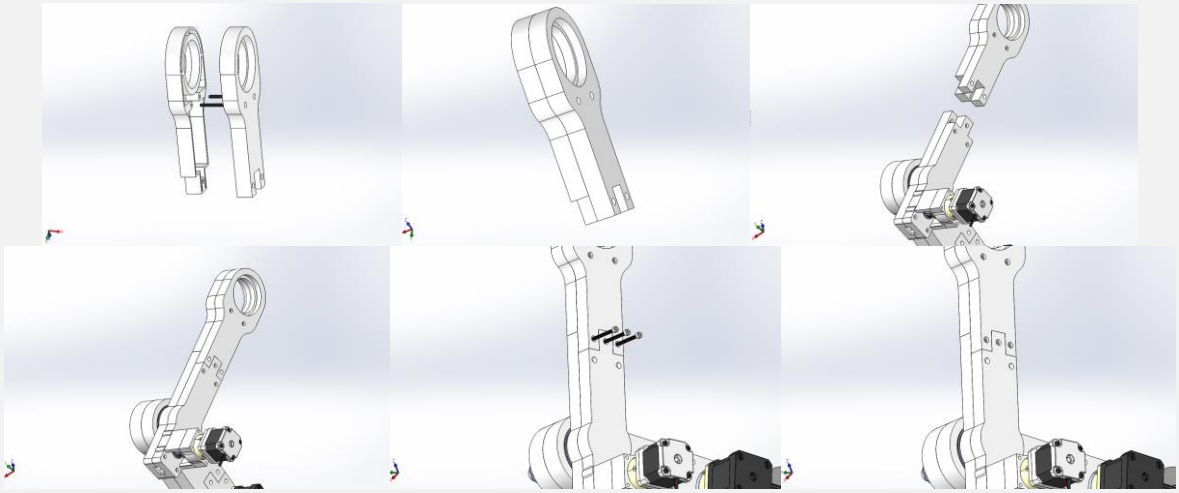
29. Secure a small 8mm bore pulley to the motor shaft using one M3x5mm screw through the motor shaft's key hole, making sure that the pulley is as close as possible to the motor's body, and secure a small 6mm bore pulley to the upper shaft using two M3x5mm screws, with one of the two screws against the flat side of the shaft. *Take note of the direction with which each pulley was installed below and wrap the 118 teeth belt around both pulleys before simultaneously installing them onto their respective shafts.



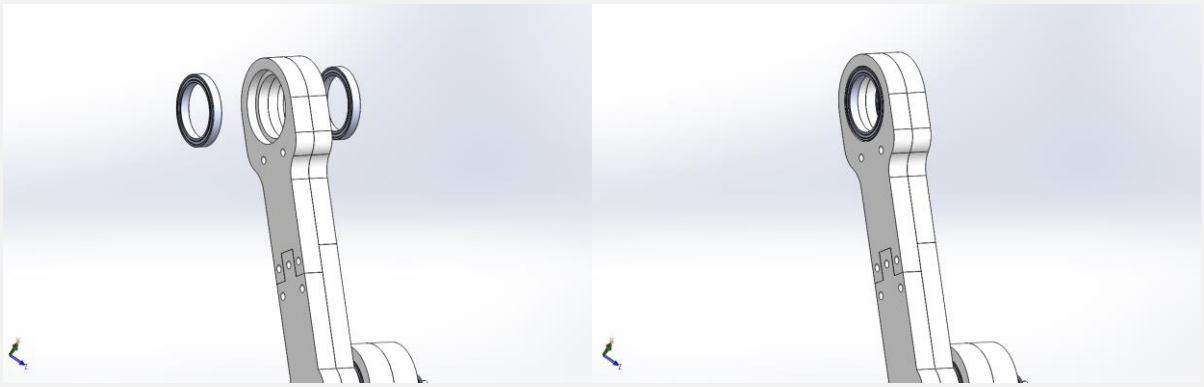
30. Slide 'J4_mount2' through the geared Nema14 motor, attach 'j4_mount' to the motor using 4 M3x8mm screws and secure a small 6mm bore pulley to the motor using one M3x5mm screw against the flat of the shaft, making sure that the pulley is as close to the body of the motor as possible.



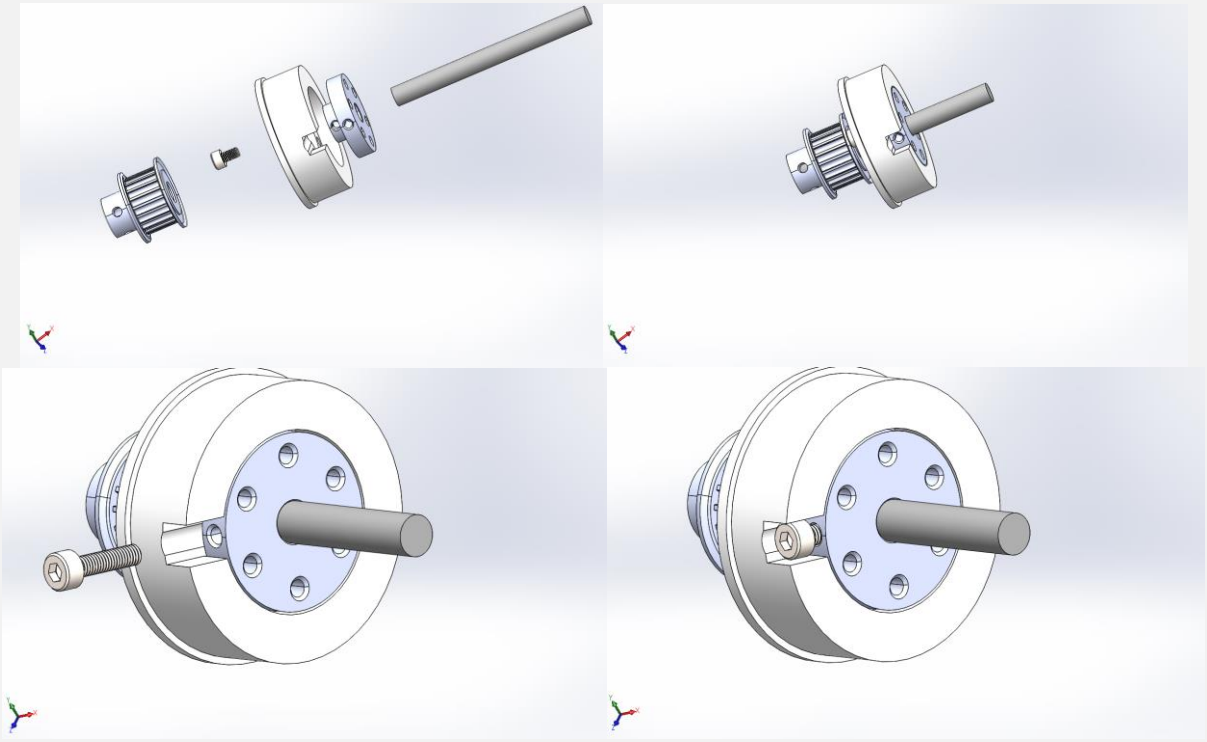
31. Attach the motor to 'upper_arm_right_1' using 4 M3x55mm threaded rods and 8 nuts after wrapping the 187 teeth belt around the pulley and attach 'upper_arm_right_1' to 'upper_arm_left_1' using 4 M3 nuts, two M3x30mm screws at the top side and two M3x25mm screws at the bottom side.



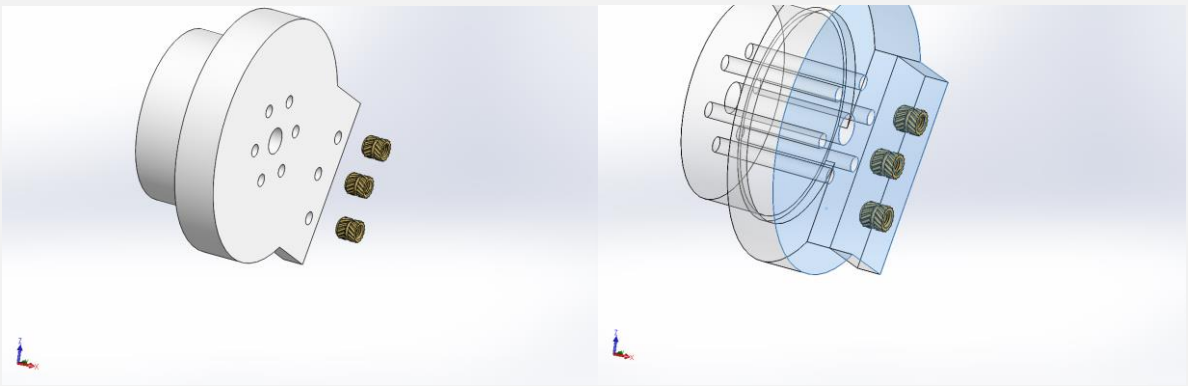
32. Attach ‘upper_arm_right_2’ to ‘upper_arm_left_2’ using two M3x30mm screws and two M3 nuts and attach this half to the rest of the arm using 3 M3x30mm screws and 3 M3 nuts.



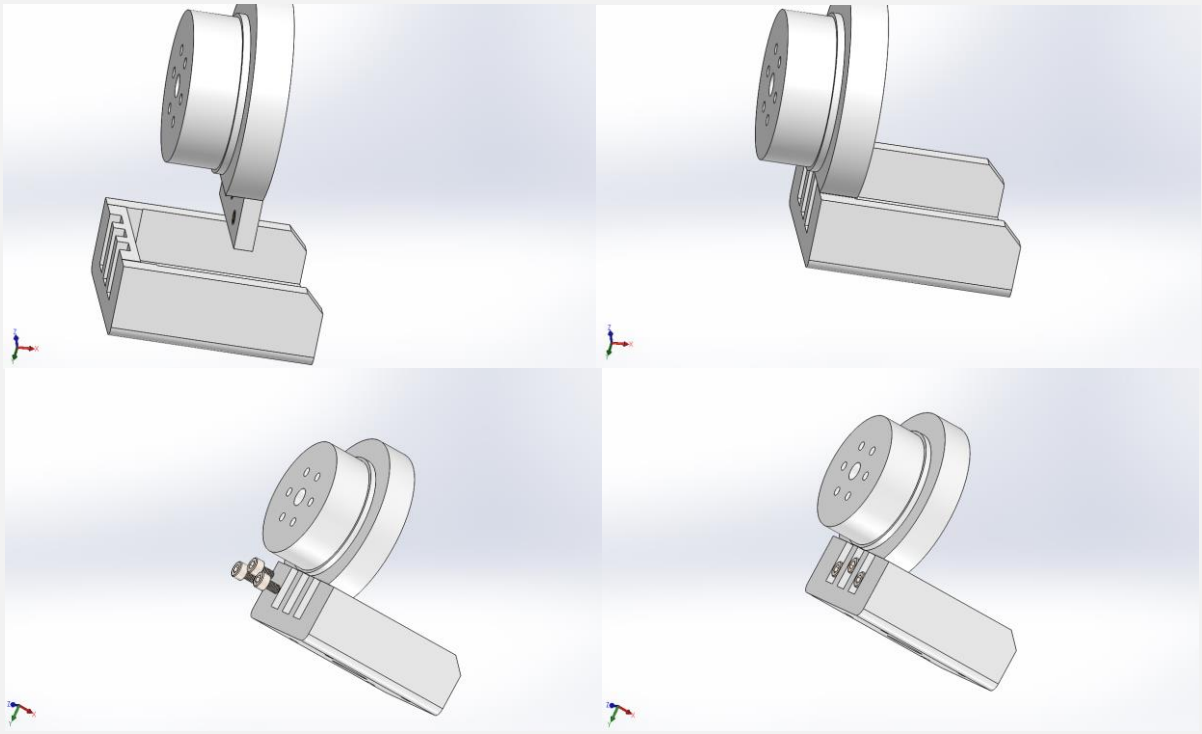
33. Slide two 40mm bore bearings into their designated holes on the end of the assembled arm.



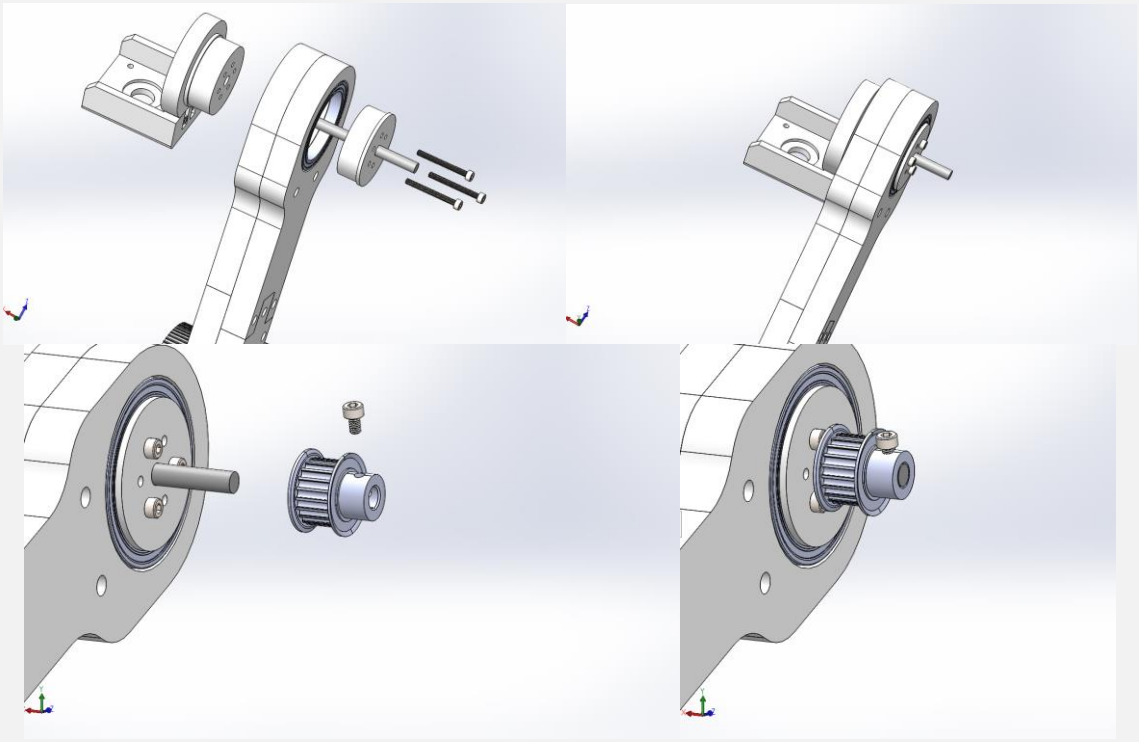
34. Insert the 6mm aluminium hub into 'J4_hub2', making sure that all holes are aligned, and slide the 6x64mm shaft through the hub followed by an M3x5mm screw and a small pulley to mark the shaft distance. With one end of the shaft flat with the surface of the pulley, secure the shaft to the aluminium hub using an M3x12mm screw and remove the pulley and the M3x5mm screw.



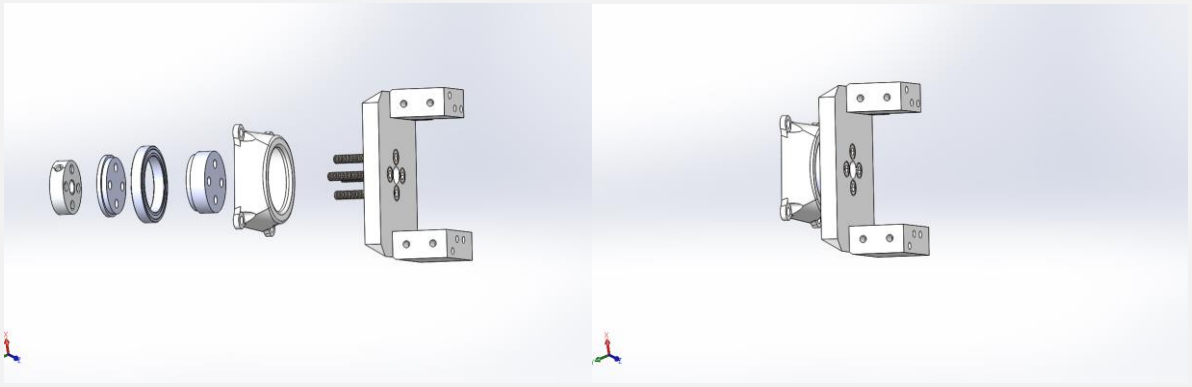
35. Install 3 threaded M3x4-5mm inserts into 'j4_hub1'



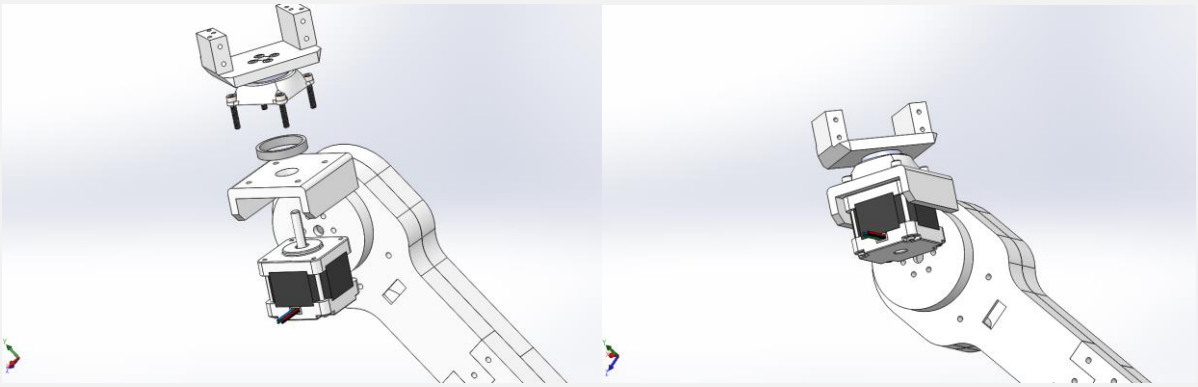
36. Align ‘j4_hub1’ and ‘link3’ as shown to mark the 3mm diameter holes that need to be drilled into ‘link3’ and attach ‘j4_hub1’ to ‘link3’ using 3 M3x12mm screws that go into the threaded inserts.



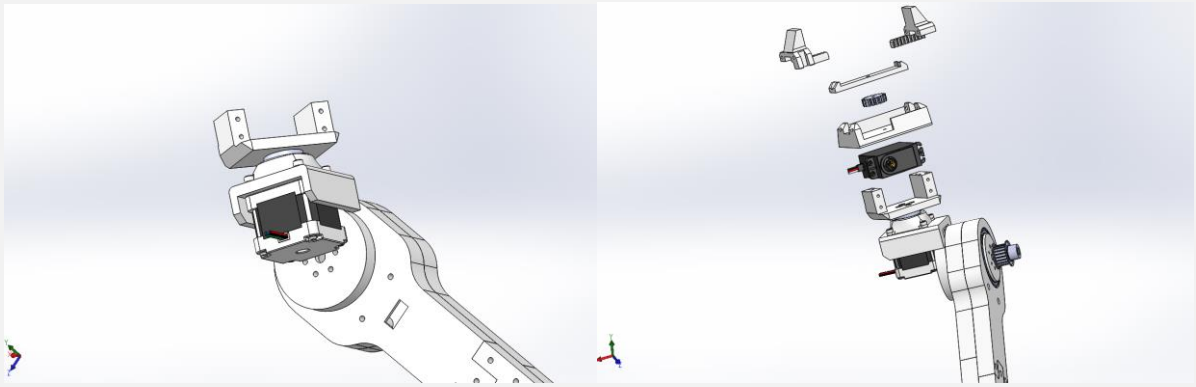
37. Attach ‘j4_hub1’ and ‘j4_hub2’ using 3 M3x30mm screws and secure a small 6mm bore pulley to the shaft using 1-2 M3x5mm screws, with the 187 teeth belt wrapped around the pulley.



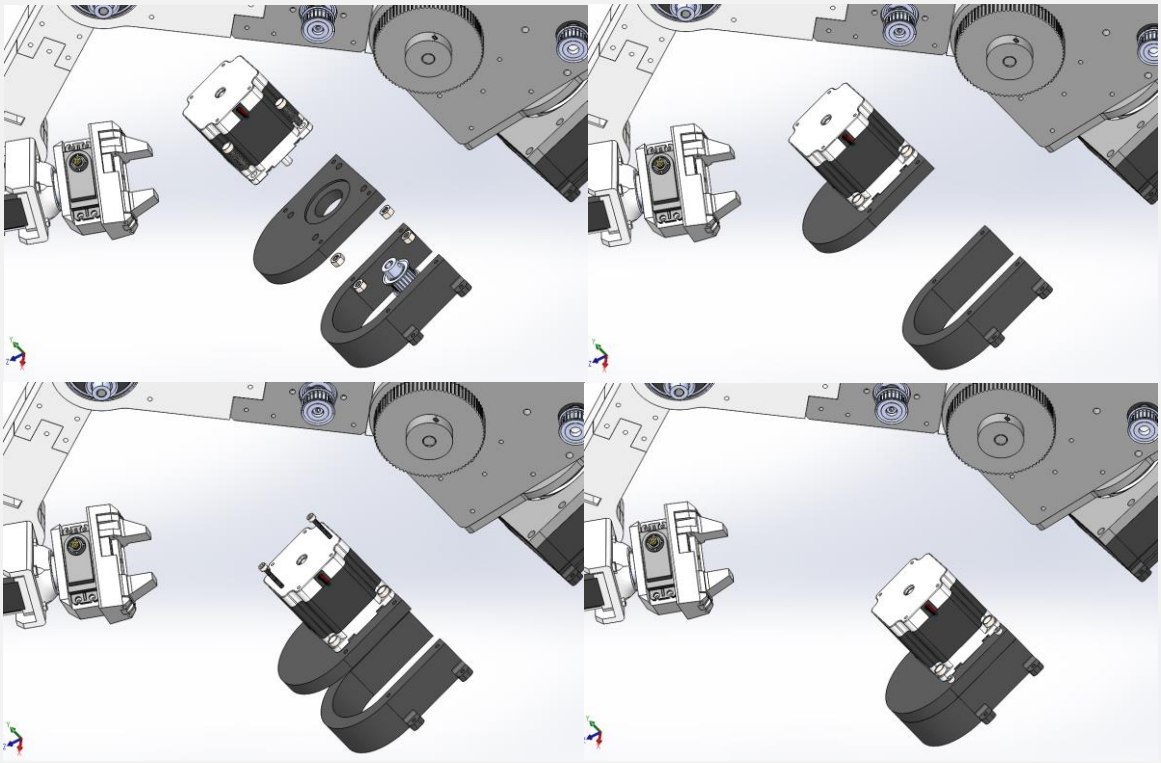
38. Attach the base of the end effector to the aluminium 5mm hub and two plastic hubs through the bearing housing and bearing as shown using 4 M3x20mm screws. The housing holds the outer ring of the bearing and the remaining 4 pieces should be secured to the inner ring.



39. With the cylindrical piece called 'bearing_housing2' at the bottom, secure the rest of the housing and the bearing using 4 M3x16mm screws as shown.



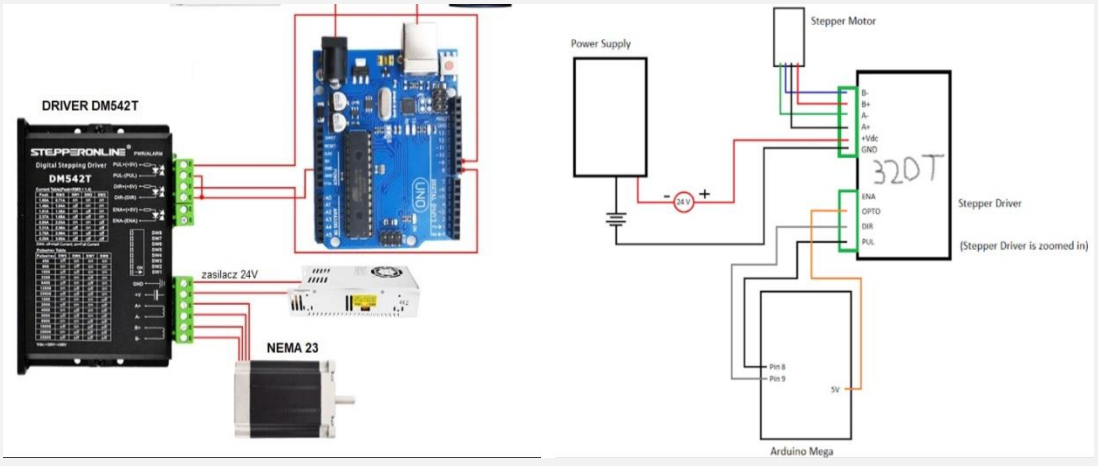
40. Read the gripper's original manual at anninrobotics.com/downloads for its remaining assembly instructions.



41. Secure a small 6mm bore pulley to the Nema23 motor with one M3x5mm screw against the flat of the shaft and with the pulley as close as possible to the body of the motor without the screw leaving the flat. Attach the motor to 'J1_1' using 4 M5x20mm screws and 4 M5 nuts and secure 'j1_1' to 'j1_2' using 4 M3x20mm screws.

Stepper Motor Wiring:

The Nema16, Nema14 and Nema17 motors use the DM32T drivers, and the Nema23 and Nema24 motors use the DM542T; the wiring for each is as follows:

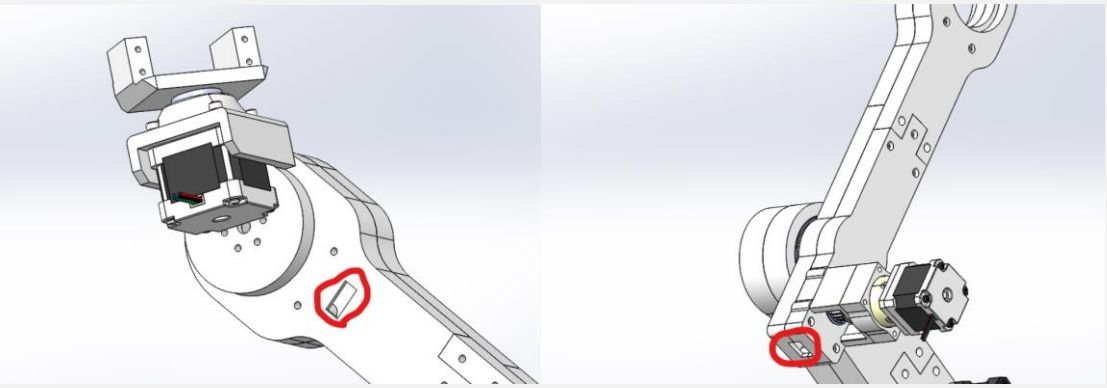


For the DM542T, two signal wires are connected to the Arduino for 'pull' and 'direction', two are connected to the Arduino's ground, two to the DC power supply's positive and negative and four are connected to the motor.

The order of the motor wires can be found on each motor's manual, and the driver can be adjusted using the switches on its side to limit power draw, to turn on 5V signal mode and to adjust the step settings; quarter steps

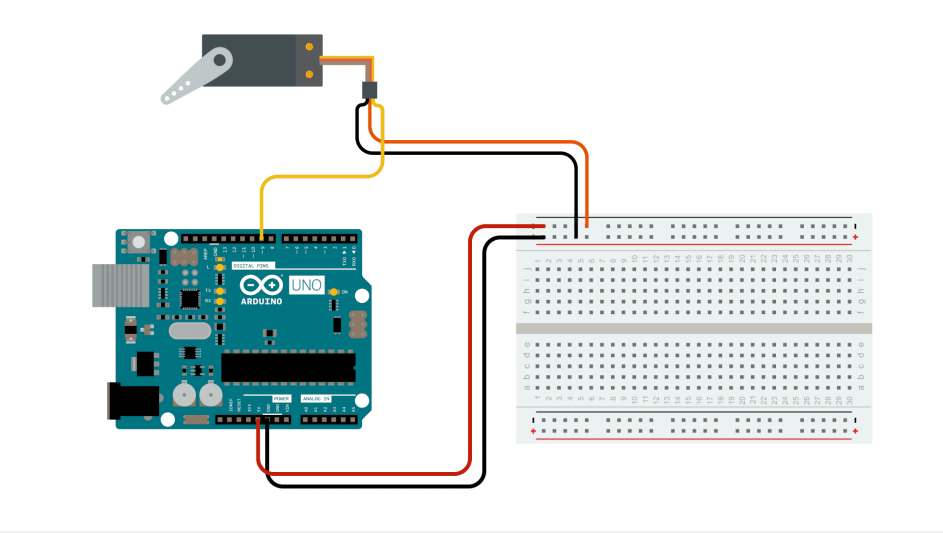
are recommended for the Nema24 motor, which is equal to 800 steps/revolution for 1.8° per full step motors, and 1600 steps/revolution are recommended for the Nema23. The DM32T driver doesn't have a full step option, and can only support 400 steps/revolution settings. Note that gear/belt reductions and step fractions need to be taken into account while coding.

Most motors wires, including the servo's, would need to be extended so they can comfortably reach the drivers in a spot clear from the arm, but wires that are too long can cause interference.



The second link has two holes for passing the wires for the gripper and j5 motor.

Servo Motor Wiring:



The servo has one wire for the signal and two for power; you should preferably power your servo from an external 5V source with more power, but remember that the Arduino, the external power source and the servo should still share a common ground.

Two example sketches can be found in the 'example code' folder.