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HAPTIC SYSTEM - Mechanical Design

Low-Cost Team

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1 Introduction

The aim of our work was to create a low-cost functional back drivable system with low friction and inertia. To respond to this project, we had to think about how to model a prototype that respects these criteria.

To do this, we first started to think about the sketch of the pantograph as described in the article [1] and then moved to 3D design. We thought about how we could adapt motor drive to our pantograph design and finally, we thought about the overall structure that our pantograph should have by incorporating a fitting base.

We will therefore study each part of the pathway to better understand how it works.

2 The pantograph

2.1 Arms

For the design of the pantograph, we took idea from the pantograph design shown in the article [1] as well as on the first models we created on Solidworks during the first initiation courses of the project.

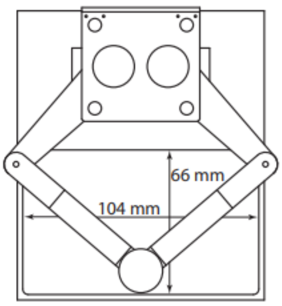


FIGURE 1 – Pantograph presented in the article [1].

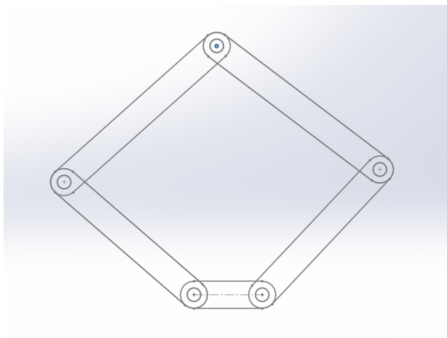
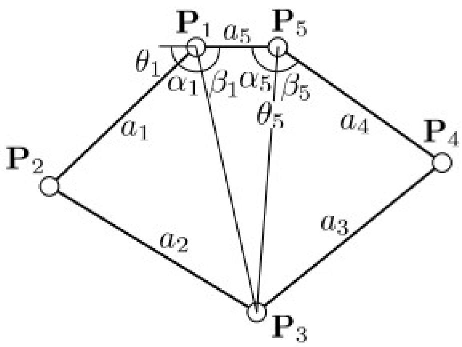


FIGURE 2 – First Pantograph sketch

We created arms of the size indicated in the article, as this is the basis on which all other groups started the project. This first prototype gave us a good understanding of how we needed to link the different parts of the pantograph in order to have the degrees of freedom we wanted.



$$a_{\mathrm{nom}} = [63\ 75\ 75\ 63\ 25]^\top .$$

FIGURE 3 – Size of the arms in the article 1

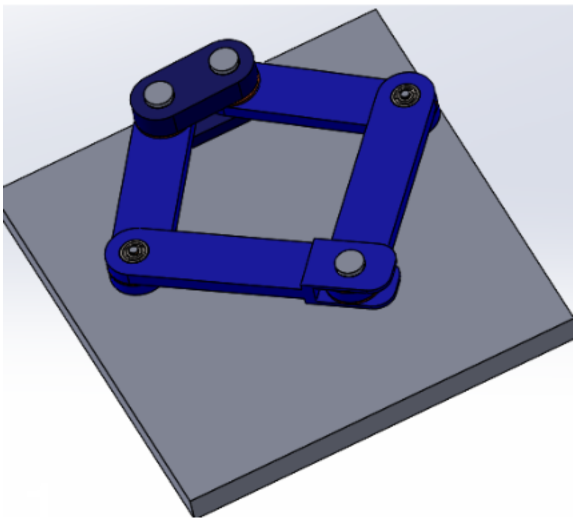


FIGURE 4 – First prototype of pantograph

After several iterative designs, We have realized this model :

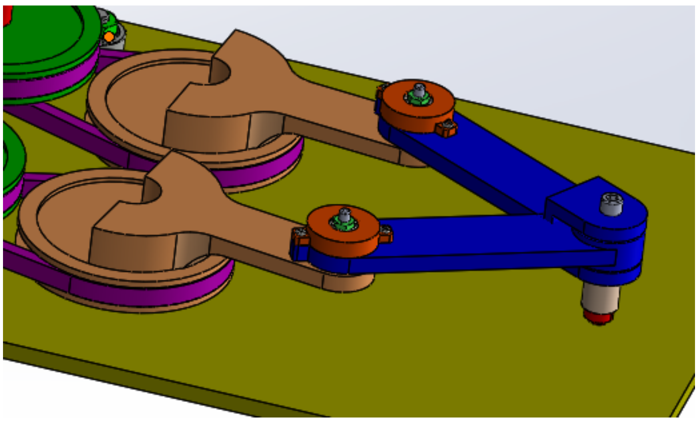


FIGURE 5 – Final prototype of pantograph

Due to the size of the large pulleys for the reduction system, the size of the base link (a5) was adjusted to 70mm to fit in our model, all other dimensions remain unchanged.

In order to realize the arm linkage, we used a ball bearing system which allowed us to have a pivot linkage between two arms.

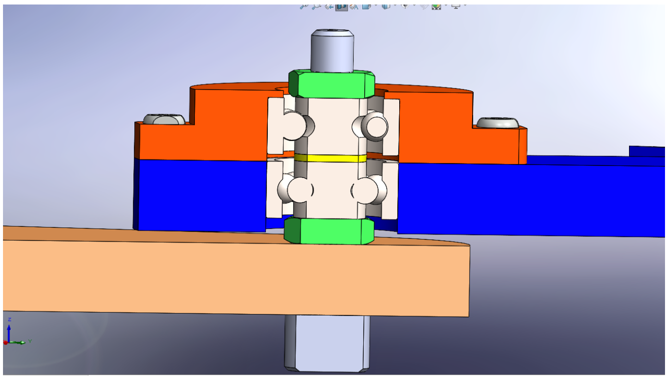


FIGURE 6 – Cut view of the arm linkage

As shown in Figure 5 above, we have a screw attached to the first arm on which we have added two nuts (in green) to secure it. In orange, we have attached a bracket to the arm (in blue) to create a support for the ball bearings. We also chose to add a small washer (in yellow) as an axial stop for the ball bearings.

2.2 Ball transfer unit

At the end of the pantograph it is important to add a support to prevent vertical deflection of the arms, which is why we use a ball transfer unit.

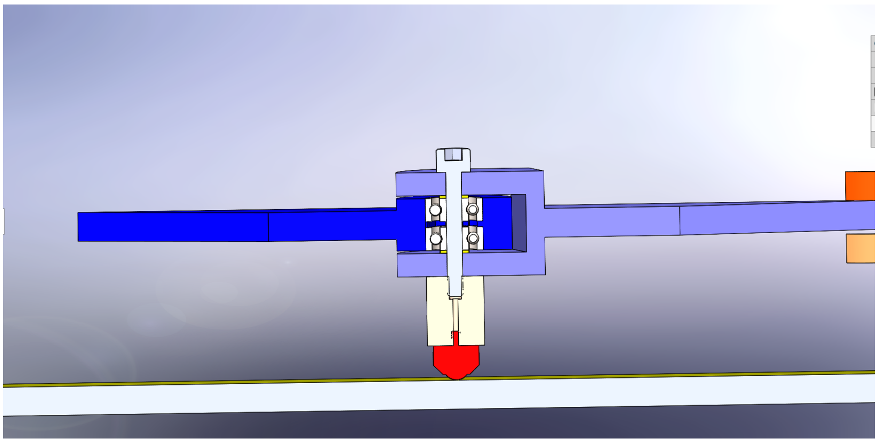


FIGURE 7 – Ball tranfer unit incorporated in the fork and eye system

We worked on different ball transfer units, but decided that this was a good solution as it allowed us to create a support with pantograph arms more easily while saving space.

In white on the Figure 6, we can see the support that we created to connect the ball transfer unit to the arms : this support is screwed with a screw that allows the pivot connection between the two arms, thanks to the upper hole which has a diameter equal to the screw diameter minus the pitch in order to properly fix the screw to the support. The bottom of the support is also screwed to the ball transfer unit with a central screw, which makes the pantograph compact.

3 The motor drive

3.1 System to create

The robotics team needed a reduction ratio of 10, and since we were the low-cost group, we couldn't buy a reducer. That's why they asked us to take care of the reduction part.

Thus, our first idea was to use two grooved pulleys, a small one with a certain number of grooves and another one with 10 times the same number. We wanted to use groove pulleys in other to have a good traction and ensure a better transmission, but when we dimensioned our pulleys in SolidWorks we realized that having a 10 times larger pulley was not possible for the size of our assembly. That's why we decided to make several stages of reduction called compound belt drives. Each stage had a reduction ratio of 3, thus by superimposing the stages, the ratios were multiplied and we found the final ratio of 9 which is close to what we wanted.

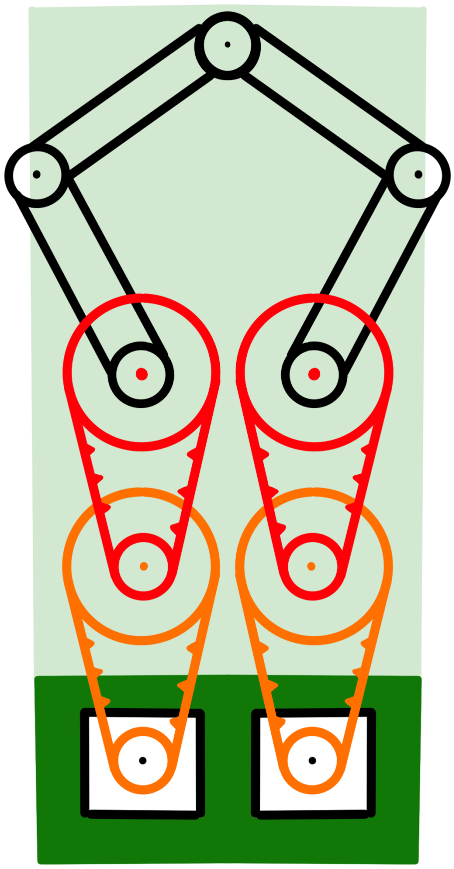


FIGURE 8 – First sketch of reduction system

Based on the concept of compound belt drive, we then modeled and printed all our parts in 3D to check that the plastic parts could work for our design and thus no need to buy anything (always to respect the low-cost constraint)

Thanks to the prints we made we could conclude that the plastic was enough solid and the

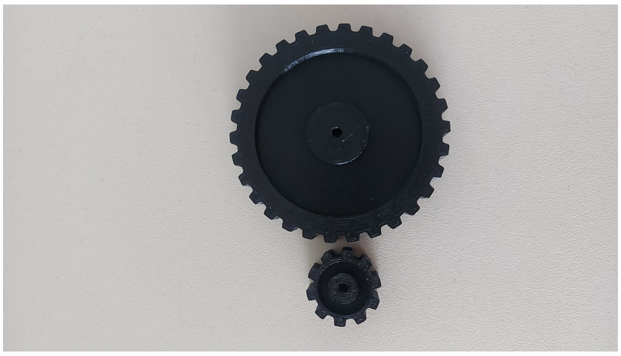


Figure 9 – 3D-printed pulley

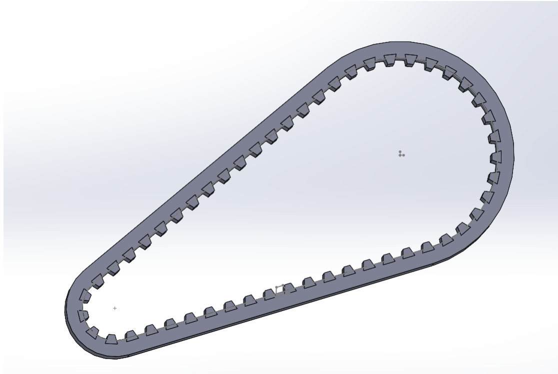


Figure 10 – Model of the belt on SolidWorks

belt enough elastic so we decided that we will not buy either belt or pulleys.

However, following our second presentation, our attention was drawn to the fact that in order to have a smooth transmission which is needed for an haptic pantograph, we could not have grooved pulley because the discrete movement of the belt along the pulley will result in a non-smooth transmission.

That's why we switched to smooth pulleys and belts for our latest version.

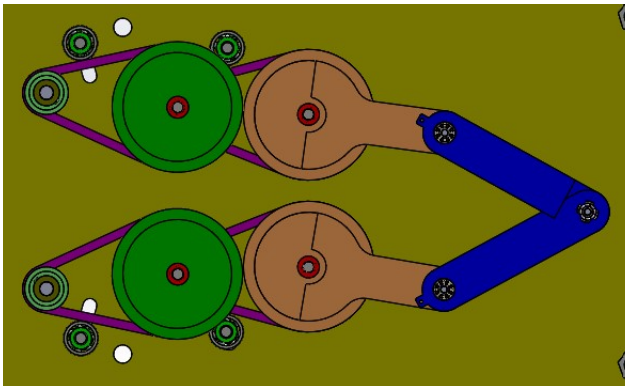


Figure 11 – Top view of reduction system

Figure 12 – Model of the smooth belt on SolidWorks

In order to use this type of pulley connected to the pantograph arms, we had to increase the initial size between the two pantograph arms, which will eventually require changing the size of all pantograph arms.

3.2 Small pulley for the motor

To connect the motor to the reduction system, we have created a pulley that attaches to the motor shaft using a screw.

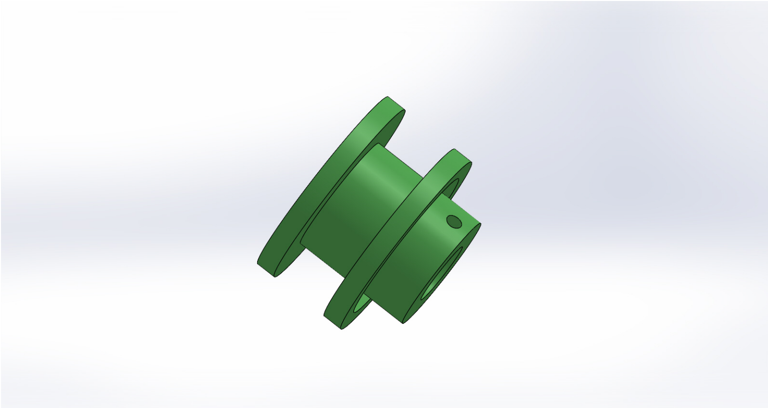


FIGURE 13 – Small pulley motor

3.3 Combined pulley

Then, to create our reduction stages, we started by creating two pulleys on the same axis : a large pulley to make the first reduction stage and a small one to make the second. After thinking about the model, we realized that these two pulleys could be combined. This is why we have created the following part which makes it possible to create a single part for the two stages of reduction.

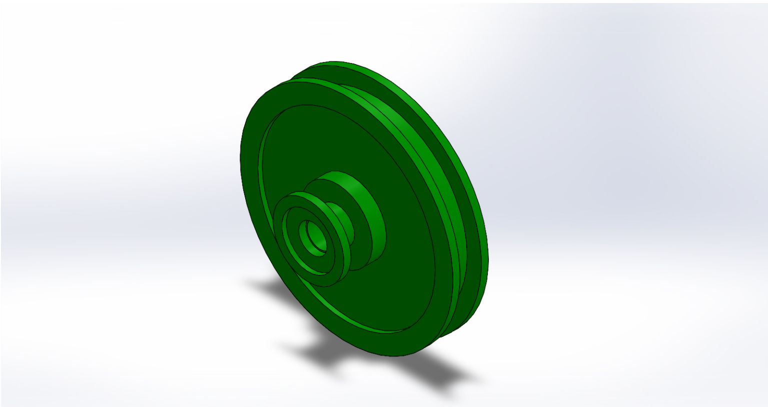


FIGURE 14 – Combined pulley

For this part to be in good pivot connection with the screw fixed to the base, we have also added a ball bearing system. Inside the part, we have created internal support for the ball bearings which allowed us to fix them well inside.

3.4 Pulley combined to the pantograph's arm

Finally for the last pulley of the reduction system, we had to create a pulley that is directly linked to the first arm of the pantograph. Once we realized that these two parts had to be united, we decided to combine them in order to best respect the compactness criterion of the project while keeping all the constraints they respectively had.

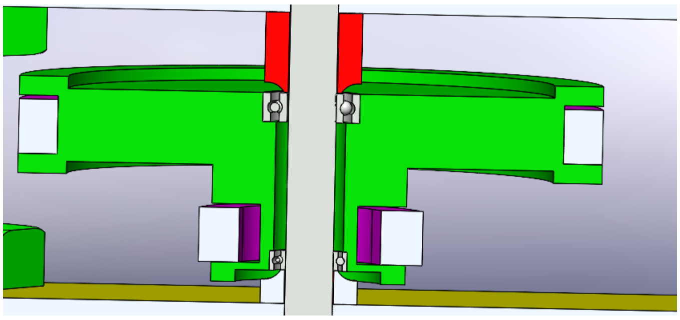


FIGURE 15 – Cut of the combined pulley 1

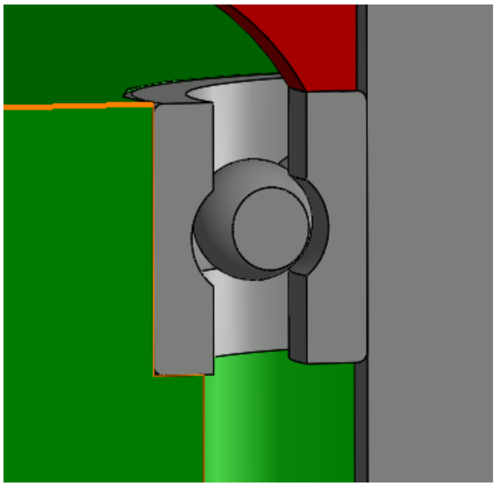


FIGURE 16 – Cut of the combined pulley 2

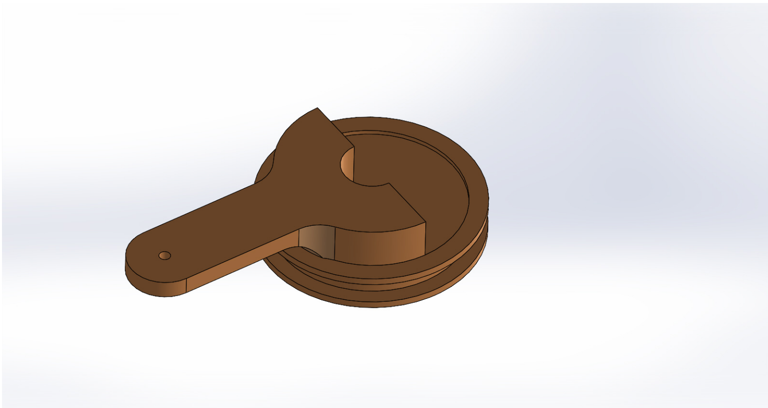


FIGURE 17 – Pulley combined to the pantograph's arm

In order to create the necessary pivot connection with the axle fixed to the base, we also used ball bearings integrated in the pulley and fixed with washers.

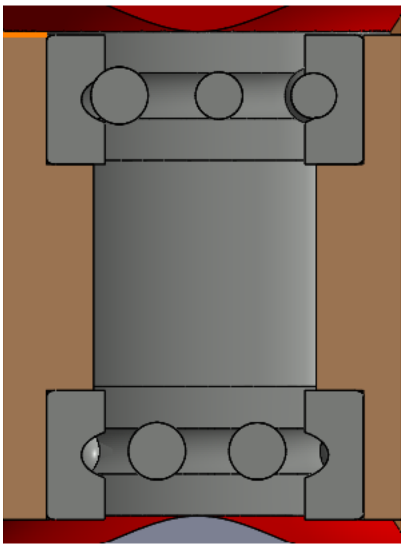


FIGURE 18 – Cut of the pulley combined to the pantograph's arm

3.5 Tensioner system

In order to keep the belt under constant tension, we have created a part called "tensioner roller" which compensates for variations in belt tension and allows efficient and reliable power transfer between the pulleys.

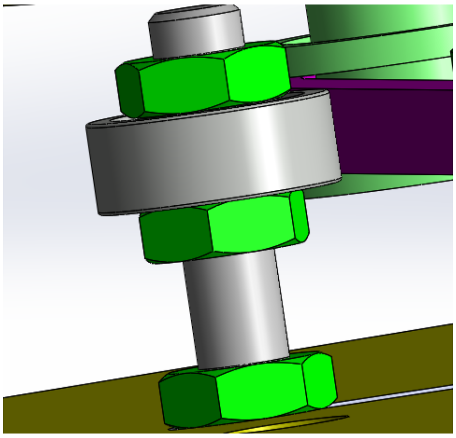


FIGURE 19 – Tensioner roller system

This part is composed of a ball bearing that presses on the belt and is held in place by nuts. In order for this effort to be adjustable, we have made our part with a kind of trench to accommodate the screw at different positions in relation to the belt.

4 The base

Since we were the Low-cost team, we had to make sure to create a compact support while spending as little money as possible, that's why in the end, we created a support composed of only two plates.

4.1 Plates

In each of the plates, we drilled the necessary holes for the various screws and threaded shafts.

For the inferior plate, we have created a hole for the tensioner system.

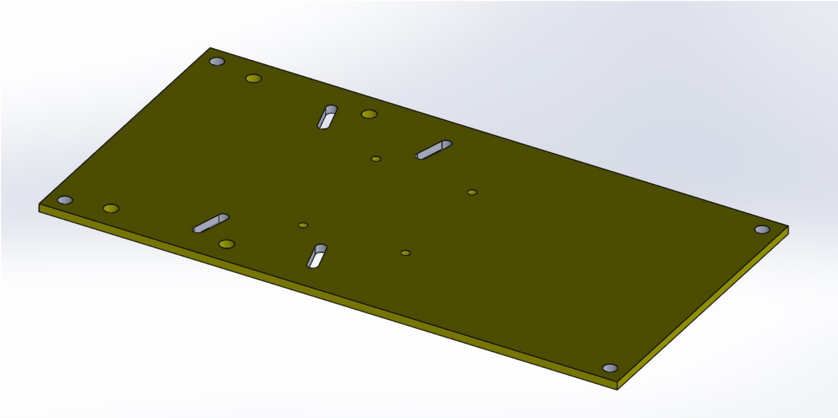


FIGURE 20 – Inferior Plate

For the superior plate, we have also created a hole for the motor.

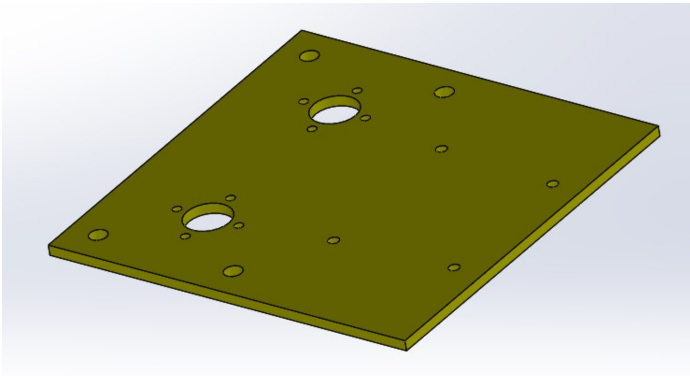


FIGURE 21 – Superior Plate

4.2 Shafts

In order to create pivot links between the different parts, we had to use a fixed axis which served as a support for the link. For this, we have proceeded in gods different ways.

For the reducer part, we chose to work with a fixed shaft with the support in order to create a pivot connection between the shaft and the pulleys. This shaft is fixed to the supports using nuts on the lower threaded part of the shaft which allows it to remain firmly fixed during the movement of the pulleys around it.

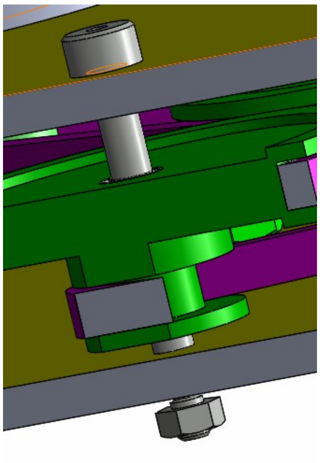


FIGURE 22 – Shaft for pulleys

Then for the shafts used between the two plates, we chose to use threaded shafts in order to be able to adjust the distance between the plates during assembly in real life. For these shafts, we have chosen a larger size than the other shafts since these are the support shafts for the entire base.

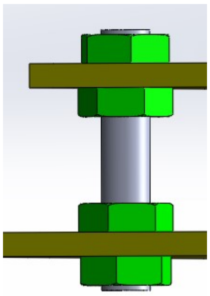


FIGURE 23 – threaded shaft for the base

4.3 Spacers

The spacer is an axial stop. In this case, it will prevent the base to go down and the pulley to go up.
The special form of this spacer is to make sure that the end of the spacer is only touching the inner ring of the ball bearing and not both the inner and the outer one to do not block the rotation.
Using spacer is really important to increase the solidity of the linkage

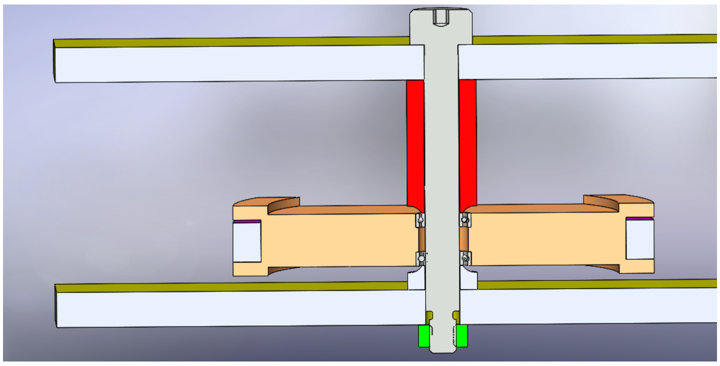


Figure 24 – Cut view showing spacer in red

4.4 Washers

Inside the linkage between two ball bearings, we have added washers that prevent the contact of the two bearings, and therefore the friction between them to be sure that the rotation will be done correctly.
We can see it in yellow in the following figure :

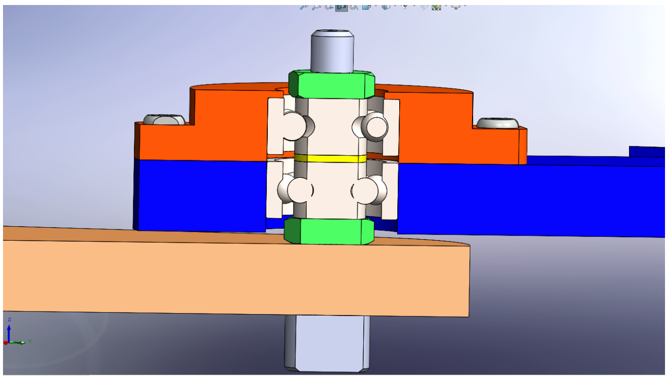


Figure 25 – Cut view showing washer in yellow

The washer is fixed with the screw and the inner ring of the ball bearing. It's also quite solid because its role is to serve as axial stop between the two ball bearings and avoid any contacts

4.5 Feet

Once we added all the screws and nuts back to our bottom base, we realized that our model couldn't be fixed. We have therefore added feet to the four ends of our model in order to give it more stability and to be able to be fixed during the movements of the arms.

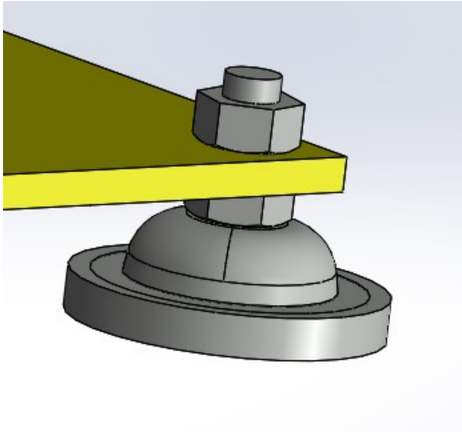


Figure 26 – Feet of the base

5 The final model

At the end of this project, we, therefore, succeeded in obtaining a final model that could be mechanically produced.

We paid careful attention to all the contacts in the various linkages by placing washers. We tried to be as compact as possible in the design by combining pulleys or pulleys and arm (we can do it because we will print those parts).

All parts used in this latest assembly are either referenced on Misumi's website, 3D printed, or laser cut.

Therefore with a little more preparation with the other group of the low-cost project, we would possibly be able to assemble in real life every part of this pantograph following our Solidworks model and this bill of material.

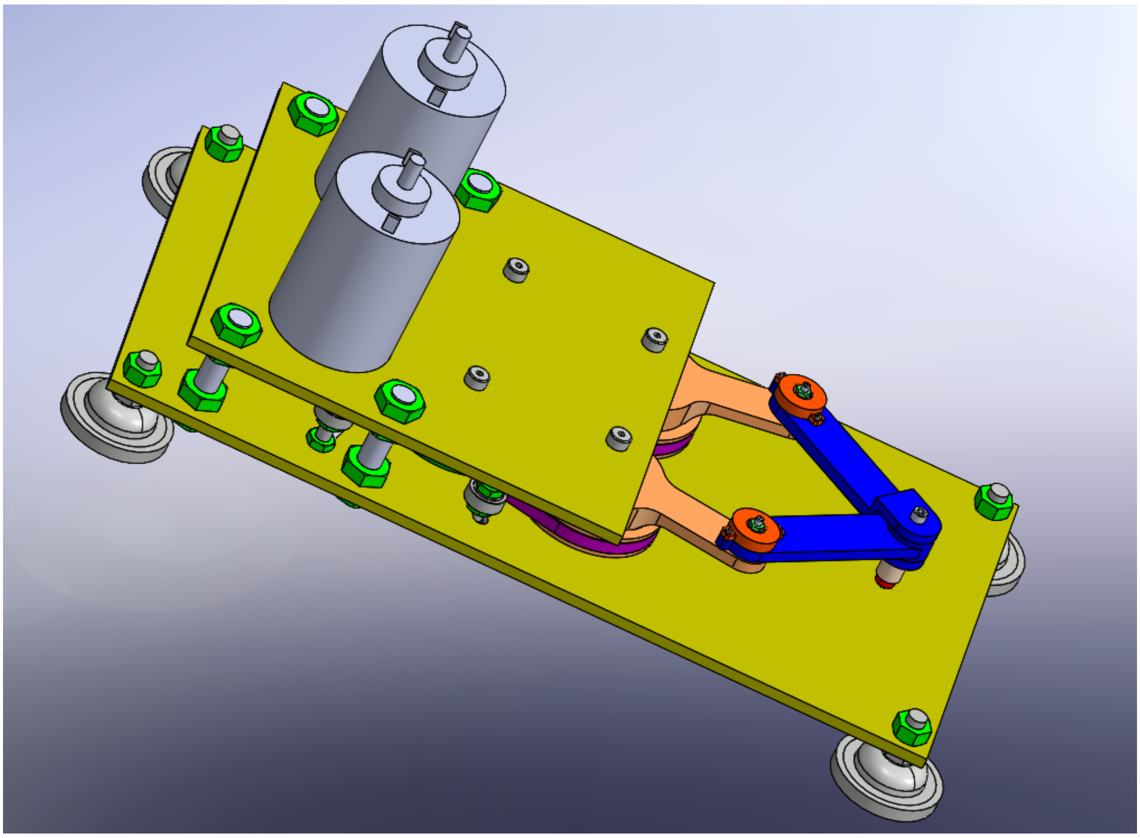


FIGURE 27 – Final Assembly

6 Bill of Material

We have summarised everything in this world document table : here

7 Conclusion

At the end of the project, We have achieved a low-cost design of a backdrivable low inertia and low friction haptic pantograph system. During the project, we carried out different mechanical feasibility analyses through the studies of engineering principles and paid attention to detail in order to ensure that the constraint of low inertia and low friction were respected and to ensure that the solution is mechanically realizable. The careful selection of materials and the design of a compact architecture allowed us to come up with a low-cost solution.

In order to prototype this CAD design in the future, we have provided all the CAD design in .stl for the 3D printed parts, .dxf for the laser cutting parts as well as the solidworks parts and assembly in a folder named [Pantograph CAD design 2023], The Assembly file is titled "Final Assembly" in the folder "Pantograph assembly + parts". A comprehensive bill of materials and links to buy parts that can not be printed can be found on the Excel sheet : here

8 References

[1] The Pantograph Mk-II : A Haptic Instrument, by G. Campion, Q. Wang, and V. Hayward, Proc. IROS 2005, IEEE/RSJ Int. Conf. Intelligent Robots and Systems, pp. 723-728