A.Y. 2013/2014, Mechanical Engineering

CAD Lab

Alessandro Saccomani

Jinou Xu

Aldo Sestito

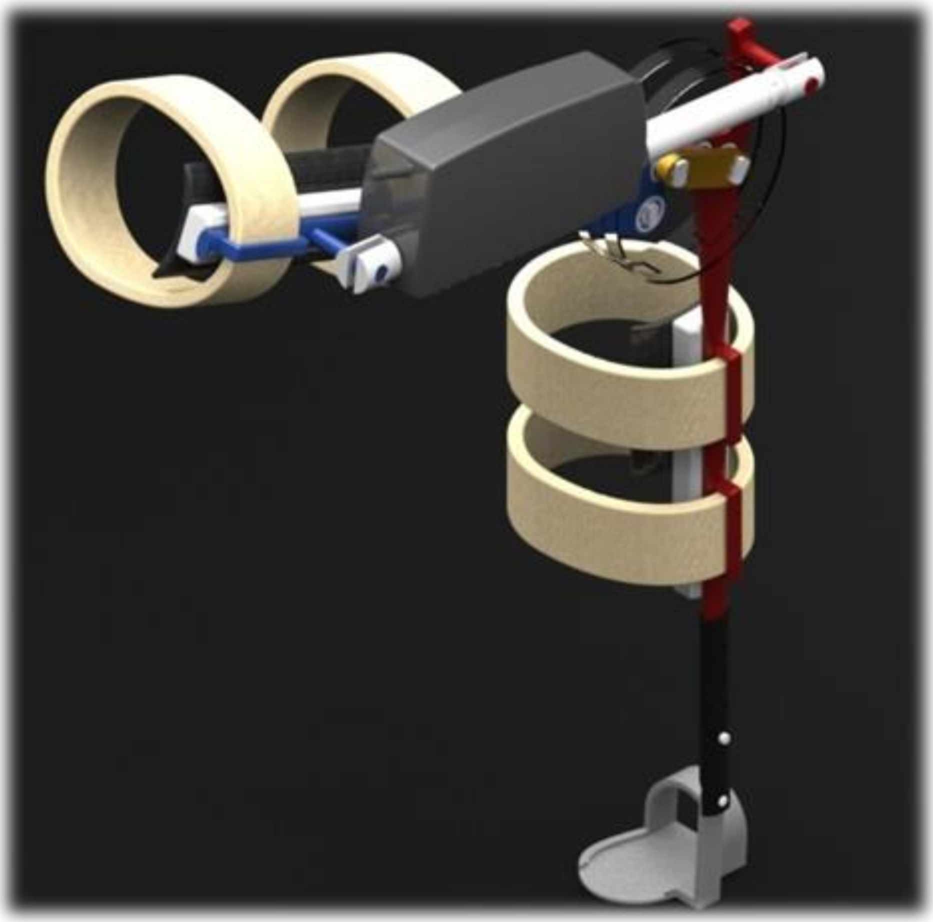
KNEE EXOSKELETON

"Your walk assistant"

Alessandro Saccomani
Jinou Xu
Aldo Sestito

Alessandro Saccomani
Jinou Xu
Aldo Sestito

1. Introduction



This project is based on a proposal suggested by the company Roadrunnerfoot, which was looking for a mechanism able to help people with disability. In particular, their aim was to create a prototype of an active knee brace, that could assist those people who suffer a partial or total impossibility of knee motion.

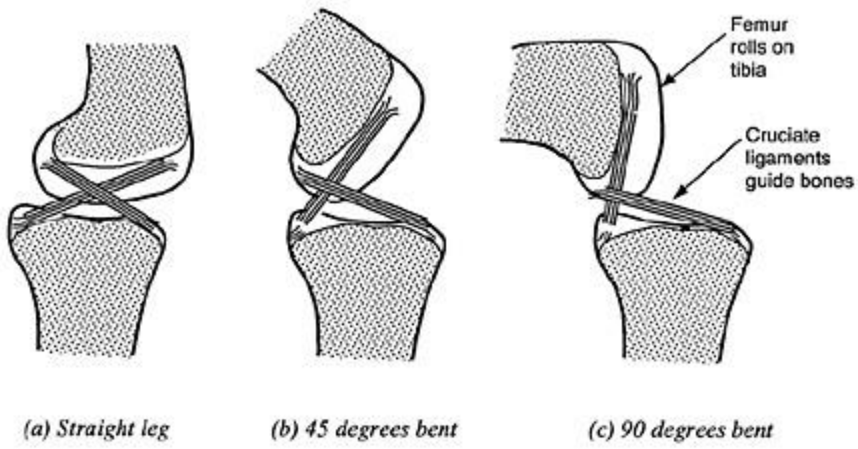
In the following pages we will describe in details how the system represented in the picture is made and works.

Alessandro Saccomani
Jinou Xu
Aldo Sestito

2. General problem

We focused on the real behavior of the knee movement in order to achieve a system which was able to follow the motion of the knee without forcing the ligaments with a not natural kinematic.

In fact, after some researches, we found that the knee doesn't just rotate around a fixed point as it's easy to imagine watching it from the outside, but behaves as a 4 bar linkage, which of course is much more complex. That was the first problem we faced once we decide to model the knee according to this theory, but not the only one because it was also rather complex to decide which was the best way to induct the motion of this 4 bar system, considering that in a 2D scheme it's just a one degree of freedom system like this:



We didn't want only to respect as more as possible this physiological constrain, but we also wanted to satisfy some other extra aims:

-Lightness of the whole system ;

-Comfortable wearing ;

-Safety design;

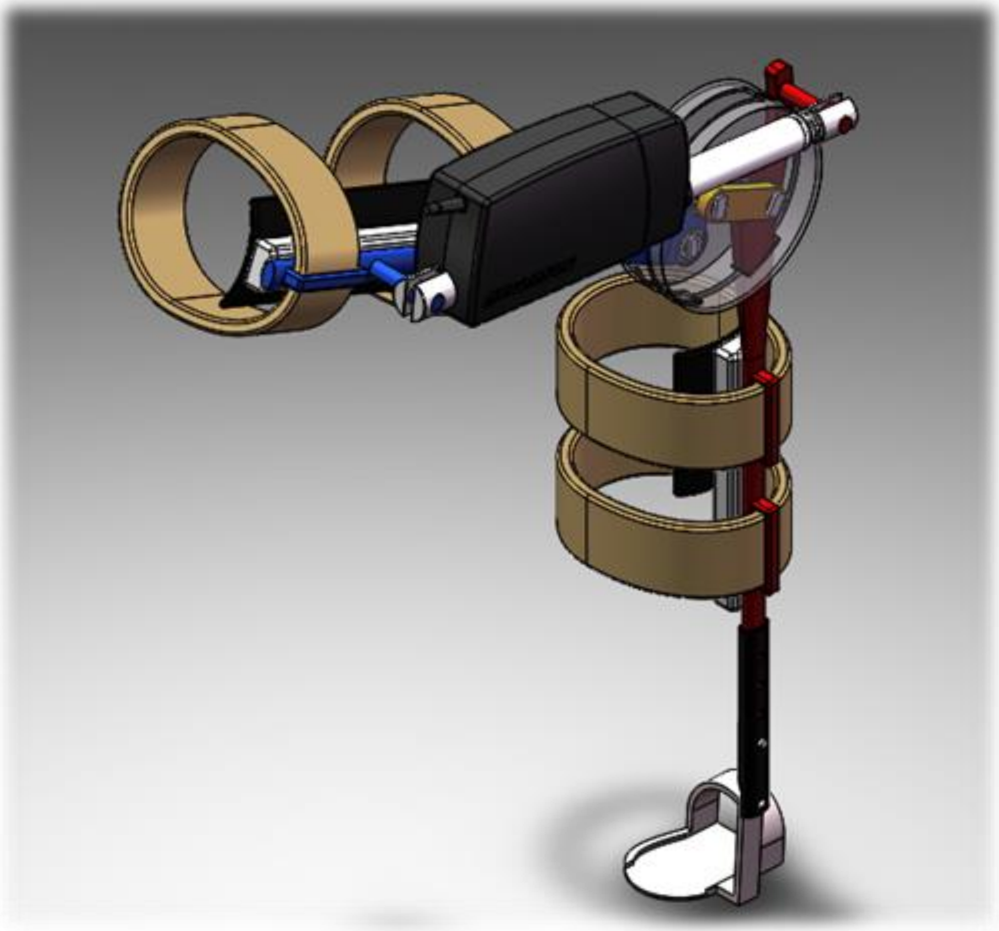
-Innovative solution;

-Adaptability;

In order to achieve this results, we have done some design choices we'll describe later.

Alessandro Saccomani
Jinou Xu
Aldo Sestito

3. Our solution



This is a general view of what we have done.

The exoskeleton is composed by two main supports (lower one and upper one), which are fixed on the leg by means of velcro closures that tighten themselves over a soft rubber part (the black partial circular offset). The two supports are linked together with a four-bars system, that provides a path which follows the knee motion. The four-bars mechanism is protected inside a transparent box for safety reasons.

The power is provided by a linear actuator (which works like the mechanism of the crane) that converts a linear motion into a roto-translational one.

On the lower part there is a system which allows the customer to change the length of the support to better suit to the leg. The pedal was added with a rotational joint to allow the ankle to rotate, since we have verified on internet that the ankle just rotates around a joint. It's also useful to discharge the forces to the ground.

Between the leg and the exoskeleton there is the already cited soft part which provides comfort and avoid dry friction between the parts that has to be connected.

Alessandro Saccomani
Jinou Xu
Aldo Sestito

4. Four-bar System

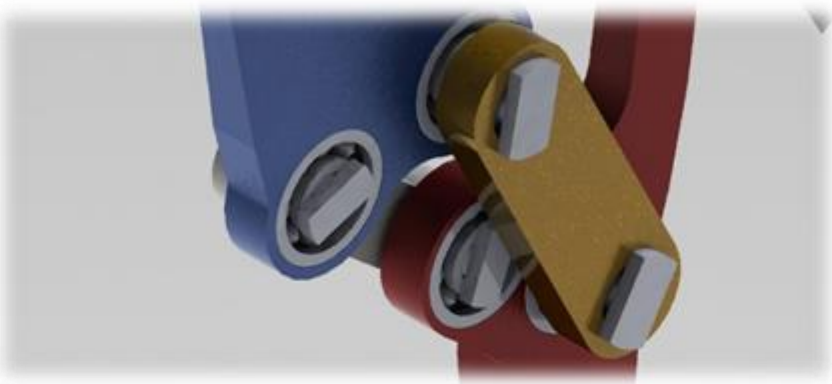
Now we have to justify properly our choices.

The idea of the four-bar system was taken from a thesis on the mechanism simulating the knee motion (The link is one the website).

As we can see, that study was focused on the inner knee substation, but we thought that it was possible to apply such a mechanism also on an external support for people who still have legs, but aren't able to move it. In fact, we observed that many companies dealing with this problem never use the 4 bars system.

By a mechanical point of view, the 4 bar system is not complicated, but it was really difficult to understand the dimensions that should be used in order to not stress too much the knee. It's important to understand that into a real knee, the yellow and the grey bars (represented in the next page) have no constant lengths, but can elongates depending on the position of the leg. So it's an approximation. But we found some useful information on some books that provides us some values of dimensions of similar mechanisms that can be accepted (and of course that are already in use).

The result is the following:

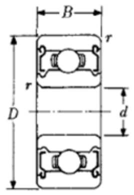


Alessandro Saccomani
Jinou Xu
Aldo Sestito

As it's easy to see, we use 4 bearings into the 4 rotational joints. The mechanical properties of those part can be checked on this table (it's the number 608):

NTN SERIES 600

Units: INCHES
Millimeters



Double Shielded
ZZ

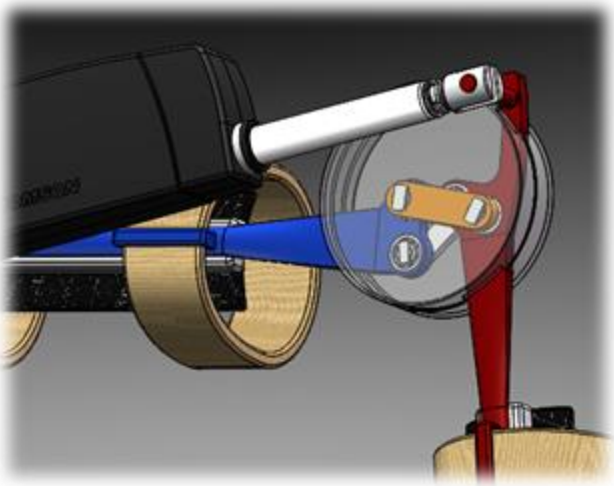
SINGLE ROW RADIAL BALL BEARINGS

Bearing No.	Bore	O.D.	Width	Fillet Radius	Basic Load Ratings (lbs)		Weight (lbs)	Limiting Speed		
	d	D	B	r	Dynamic C	Static C_o		Grease	Oil	LLU
605	.1969 5	.5512 14	.1969 5	.008 .2	299	114	.008	39,000	46,000	—
606	.2362 6	.6693 17	.2362 6	.012 .3	495	195	.013	35,000	42,000	—
607	.2756 7	.7480 19	.2362 6	.012 .3	505	205	.018	34,000	40,000	28,000
608	.3150 8	.8661 22	.2756 7	.012 .3	750	315	.026	32,000	37,000	23,000
609	.3543 9	.9449 24	.2756 7	.012 .3	765	325	.031	31,000	36,000	22,000
623	.1181 3	.3937 10	.1575 4	.006 .15	144	50	.004	50,000	58,000	—
624	.1575 4	.5118 13	.1969 5	.008 .2	295	110	.007	42,000	49,000	—
625	.1969 5	.6299 16	.1969 5	.012 .3	395	153	.011	37,000	44,000	—
626	.2362 6	.7480 19	.2362 6	.012 .3	525	199	.018	34,000	40,000	30,000
627	.2756 7	.8661 22	.2756 7	.012 .3	750	315	.029	32,000	37,000	23,000
628	.3150 8	.9449 24	.3150 8	.012 .6	900	355	.037	31,000	36,000	24,000
629	.3543 9	1.0236 26	.3150 8	.024 .6	1,030	440	.044	30,000	35,000	21,000
634	.1575	.6299	.1969	.012	395	153	.011	37,000	44,000	—

Over these values, we have built the bars and their holes adapt to these dimensions.

Alessandro Saccomani
Jinou Xu
Aldo Sestito

5. Motor implementation




A following design feature that was difficult to deal with was to find some motor that was able to generate a large force without being too heavy and big (and so hard to support). Strictly related to that, it was the problem of selecting the best kind of motion to apply: rotation or translation, since we had to convert it into the roto-translation of the knee.

Our main inspiration was the mechanism of the crane, with a linear actuator that, attached to the upper bar, was able to induct a linear motion to the lower bar that converts it to the motion we were looking for.

The linear actuator is fixed on the two supports with a rotational joint, thanks to the welded small cylinder which as a change in radius that locks the holed part of the piston.

The mechanism works exactly like the crane. The only difference is that the crane just activate a rotation, while in our case the actuator provides the degree of freedom that allow the motion of the four bar system.

The tool we have chosen is this one, with all the specifics reported in the tab in the next page:

Alessandro Saccomani
Jinou Xu
Aldo Sestito

Performance Specifications	W1202	W2402
Input Voltages (VDC)	12	24
Maximum Stroke Length: mm (in)	500 (19.0)	
Max Dynamic Load: N (lbf)	2000 (450)	
Max Static Load: N (lbf)	2000 (450)	
Maximum Rated Current Draw (A)	4.5	2.2
Maximum Stall Current Draw (A)	14	8.0
Max No-Load Speed: mm/s (in/s)	5.8 (.23)	
Max Full-Load Speed: mm/s (in/s)	4.0 (.16)	
Maximum Duty Cycle	10%	
Operating Temperature: °C (F)	-25 (-13) to +40 (105)	
Sound Level (dBa)	< 45	
Average Life (cycles)	10,000	
Lead Screw Type	Acme	

It completely satisfy our constraints of lightness, costs and forces we need it to be able to exchange.

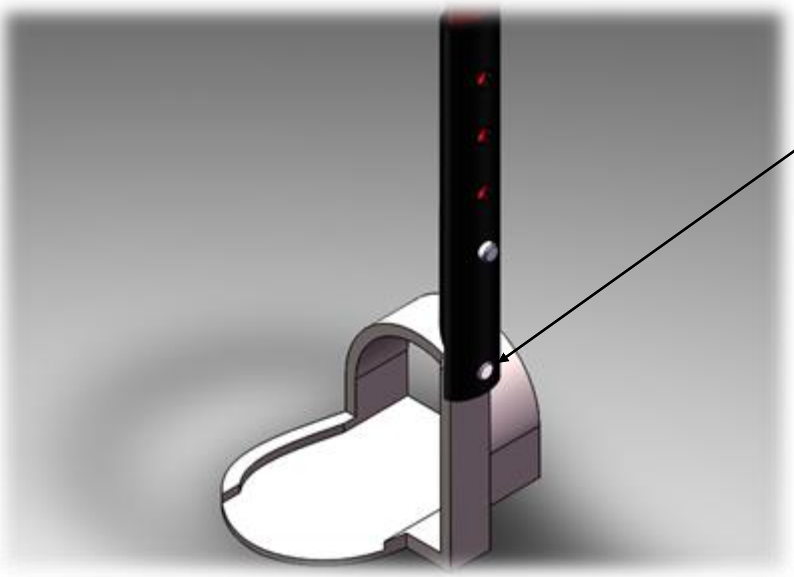
Of course, the huge expense of energy required by the system requests a sort of very powerful battery that many other companies working on similar things usually put just into a bag that the man brings on his back. For further information on the company that produce this stuff, we report the webpage:

http://www.thomsonlinear.com/website/com/eng/products/actuators/whispertrak.php#OH

Alessandro Saccomani
Jinou Xu
Aldo Sestito

6. Other features

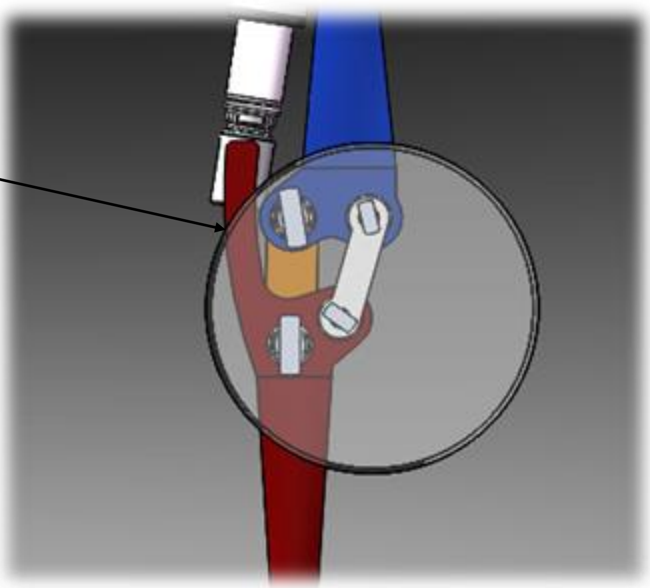
ADJUSTABLE LENGTH



In order to adapt the device to different people, we thought to model this simple mechanism that allows people to change the length of the lower bar.

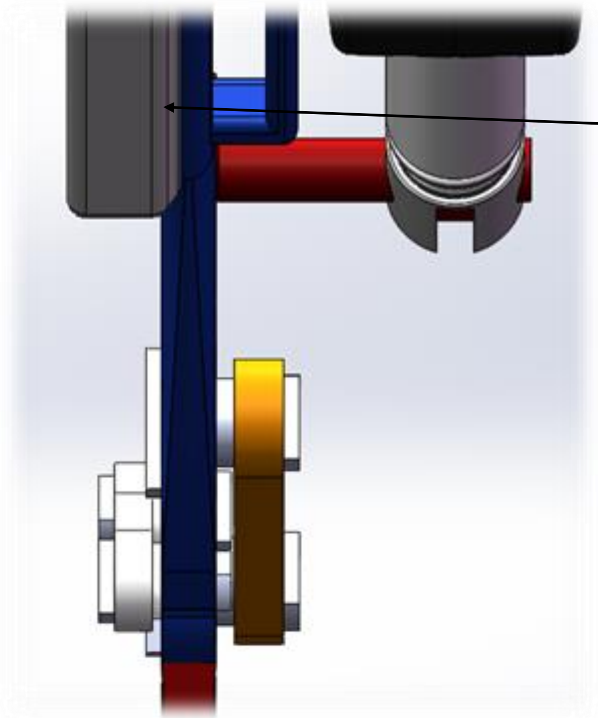
SELF LOCKING ANGLE

The maximum and the minimum angles of rotation are just fixed when the run is over. It's important also because the length of the piston is limited.



Alessandro Saccomani
Jinou Xu
Aldo Sestito

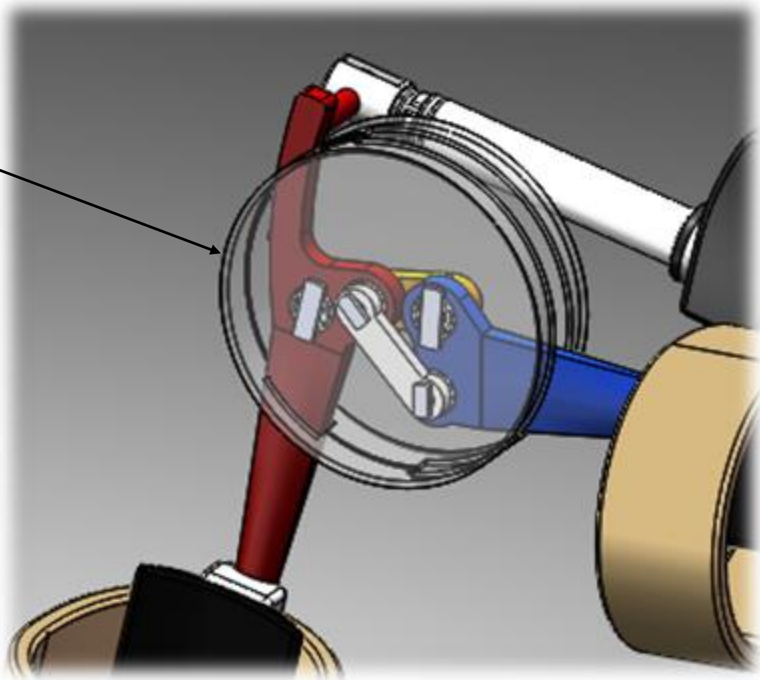
PROTECTING LAYER



Between the bars and the leg, we just added a layer that divides the mechanism and the anatomical parts. Moreover, a soft part after the layer is inserted to gain comfort.

PROTECTING BOX

It's simply a stuff used to contain the 4 bars system. By a practical point of view, it's useful to avoid that the mechanism pinches someone or something.



Alessandro Saccomani
Jinou Xu
Aldo Sestito

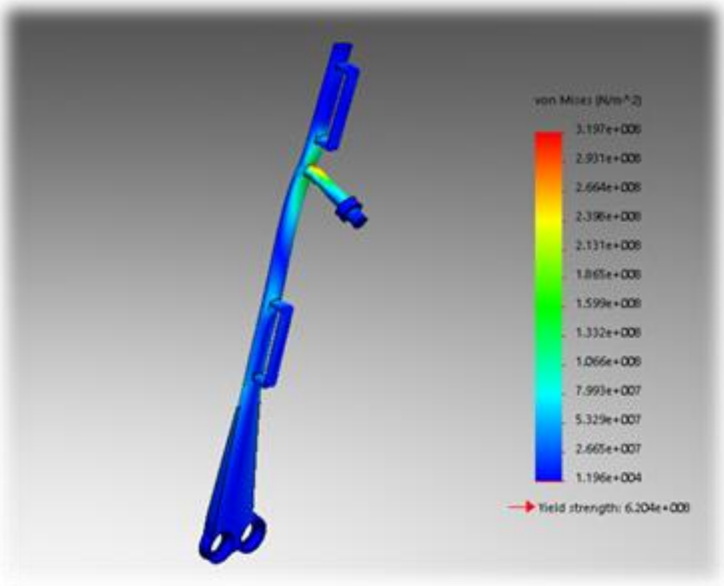
7. FEM analysis

Now it's rather important to see the effects of the force generated on the whole system by the actuator making a proper FEM analysis and see if the values of the stress, strain and displacement are acceptable. We suppose an exchanged force of 500 Newton (more than 50 kilos for each leg, that is a correct value if we consider a person that doesn't exceed the 90 kg of weight) that discharges on the bars. In particular it's applied exactly where the actuator is mounted. It was also important to use a material which was not too heavy and expensive. We were lucky because we realized, after a very first FEM analysis, that the common alloy steel was suitable for our intent. Moreover, the total weight of the system does not exceed 4.5 kg (for each leg), so our aim of lightness is satisfied. To perform the analysis, of course we need to impose the constrains, that are slider constrains and rotational ones. We also added the presence of gravity.

Below the graphs of the analysis made with the software SolidWorks are reported.

NB: the mesh is automatically done by the software.

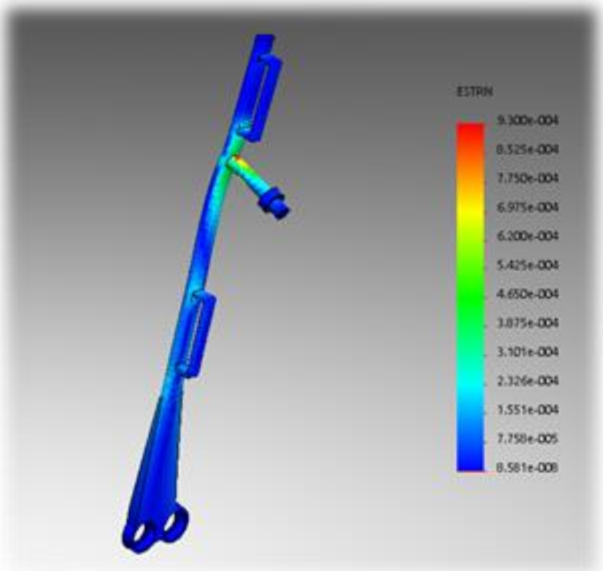
UPPER BAR

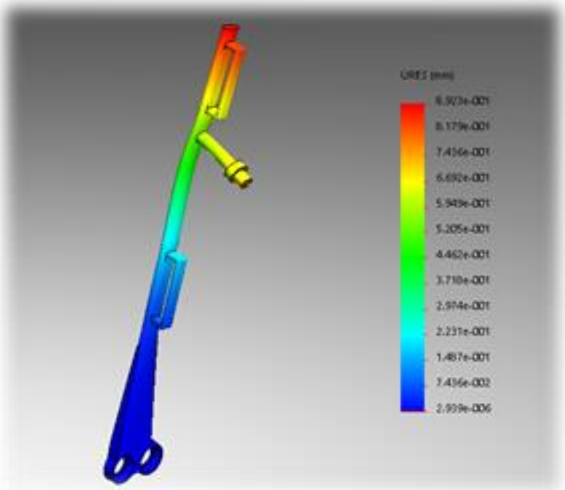


The maximum stress on the upper bar in much lower than the Yield strength of the selected material, so we don't have to worry for problem regarding the elasticity of the tool.

Alessandro Saccomani
Jinou Xu
Aldo Sestito

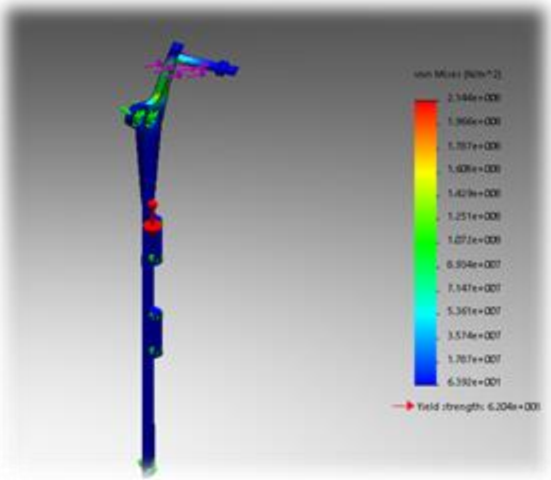
Also the values of the strain are acceptable…





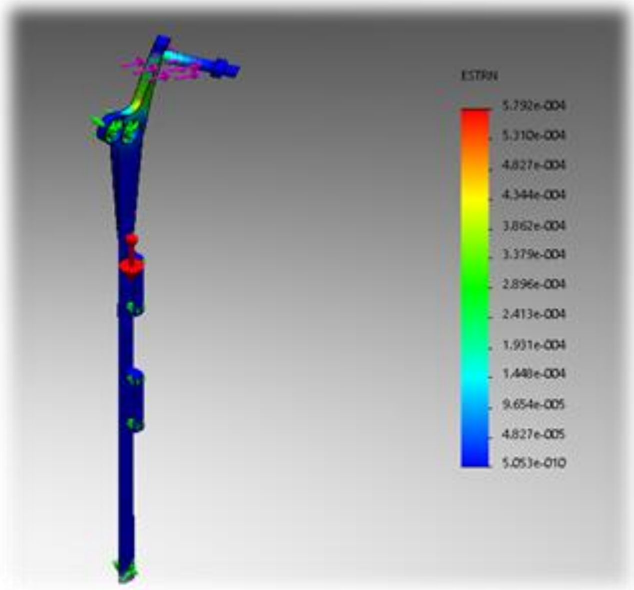
…and the maximum displacement is in the order of the tenth of millimeter, which is of course acceptable for a system of that kind (exactly 0.9 mm).

LOWER BAR

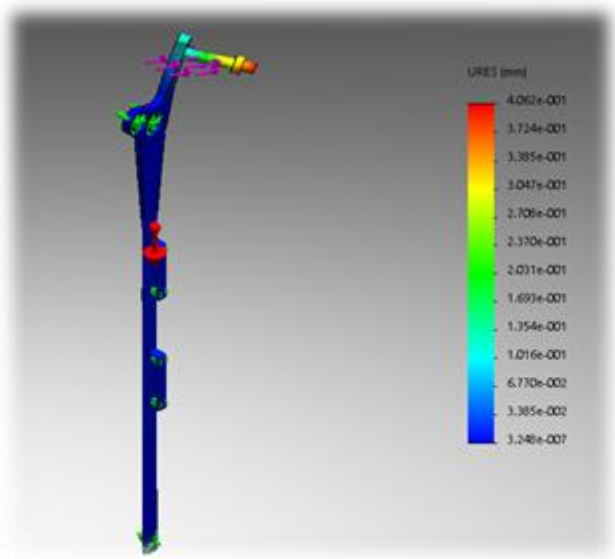


Similar reasoning can be done for the stress of the lower support, getting the same result as before: to not overcome the yield strength.

Alessandro Saccomani
Jinou Xu
Aldo Sestito



No problems at all were found in the analysis of the strain and of the displacements (max value of 0.4 mm) also for the lower part.



We can conclude that, from the structural point of view, we have no particular problems with our system.

8. Exploded view

Num. articolo	Num. parte	Quantità
1	Lower Knee Support	1
2	Upper Knee Support	1
3	Short Bar	1
4	Long Bar	1
5	Radial Ball Bearing	4
6	PinBolt	2
7	HoledPin	2
8	Pin	2
9	Pin Bolt Cover Small	4
10	Pin Bolt Cover Large	2
11	Pin Bolt Cover STD	2
12	Washer	2
13	Foot Base	1
14	Foot Pin	1
15	Front Adapter Actuator	1
16	Housing Actuator	1
17	Inner Tube Actuator	1
18	Outer Tube Actuator	1
19	Rear Adapter Actuator	1
20	Hard Material Lower	1
21	HardMaterial Upper	1
22	Protecting Box 1	1
23	Protecting Box 2	1
24	Adjustable Part	1
25	Locking	1
26	Carbon Fiber Support Upper	1
27	Carbon Fiber Support Lower	1
28	Velcro Closure	4