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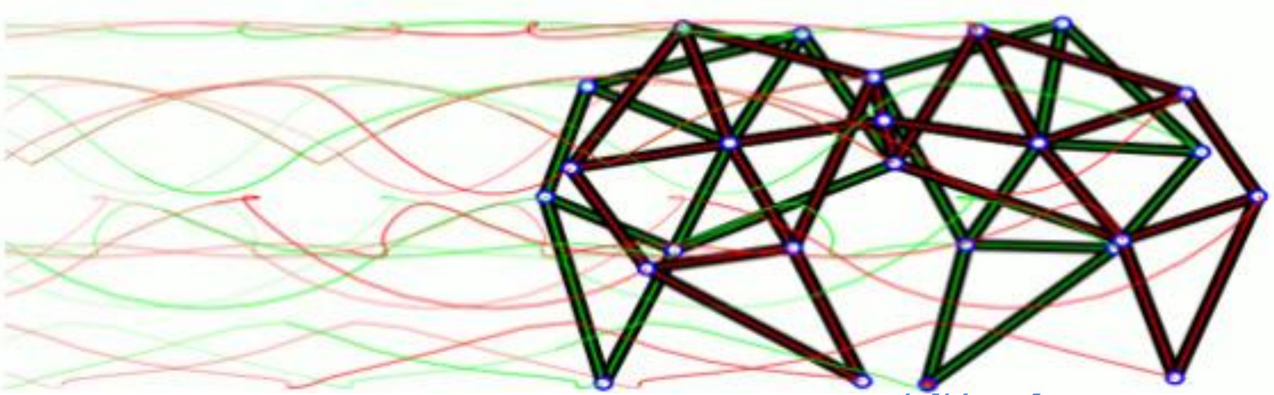
DESIGN, BUILD AND TEST AN ALL-TERRAIN VEHICLE USING THE THEO JANSEN PRINCIPLE FOR PROPULSION

Internship report – September 5th, 2022



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Abstract

This report aims to present the study of the principle of Theo Jansen and the adaptation to an all-terrain vehicle. The principle of propulsion developed by Theo Jansen is similar to the walking of an animal. This principle has the interesting particularity of being able to move a vehicle using only a single input rotation. This would allow in the future to be able to allow the movement of loads in extreme conditions with relatively little maintenance. The purpose of this internship subject is to study the feasibility of such a system and to see if a vehicle could respect the walking principle developed by Theo Jansen.

Several prototypes in reduced size will therefore be created and analyzed to adopt or not the different technical, technological, and conceptual solutions. Stability is at the heart of the project since it is a vehicle going on different types of more or less loose terrain. This is why stability and operation tests will be carried out to ensure the proper functioning of the prototype. We will then see that the choice of materials or the precision of design and sizing will greatly impact the proper functioning of the vehicle. Finally, a full-size design will be done to see if Theo Jansen's principle can be implemented in full-size.

Keywords

All-terrain vehicle

Reduced model

Stability and functional tests

Sizing

Principle of Theo Jansen

Résumé

Ce rapport a pour but de présenter l'étude du principe de Theo Jansen et l'adaptation à un véhicule tout terrain. Le principe de propulsion mis au point par Theo Jansen se rapproche de la marche d'un animal. Ce principe possède la particularité intéressante de pouvoir déplacer un véhicule utilisant uniquement une seule rotation en entrée. Cela permettrait dans le futur de pouvoir permettre le déplacement de charges dans des conditions extrême avec relativement peu de maintenance. Le but de ce sujet de stage est d'étudier la faisabilité d'un tel système et de voir si un véhicule pourrait respecter le principe de marche mis au point par Theo Jansen.

Plusieurs prototypes en modèle réduite vont donc être créés et analysés pour en adopter ou non les différentes solutions techniques, technologiques et conceptuelles. La stabilité est au cœur du projet puisqu'il s'agit d'un véhicule allant sur différents types de terrains plus ou moins meuble. C'est pourquoi des tests de stabilité et de fonctionnement vont être réalisés pour s'assurer du bon fonctionnement du prototype. Nous verrons alors que le choix des matériaux ou encore la précision de conception et de dimensionnement vont grandement impacter le bon fonctionnement du véhicule. Enfin, une conception à taille réelle sera effectuée afin de voir si le principe de Theo Jansen peut être mis en application en taille réelle.

Mots clés

Véhicule tout terrain

Modèle réduit

Tests de stabilité et de fonctionnement

Dimensionnement

Principe de Theo Jansen

Acknowledgments

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I finally want to thank my family and my friends who have given me moral support and great benevolence during the regular contact that I have been able to have with them.

Summary

Table of figures and tables

Glossary

AutoCAD: it is computer-aided design software. In this project, it was used for designing the different prototypes and making suitable files for the laser-cutting machine.

Crank: it is a mechanical piece that can transform a rotation into a rotation and a linear move. It is used in the prototype to link between the motor and each leg.

Fischertechnik: German brand of a construction toy. Rewarded and internationally known, Fischertechnik parts will be used for making the first shape of the system prototype.

LatisPro: it is a signal acquisition and processing software. In this project, it was used for analysing videos point by point at the bottom of each leg.

O-ring: also known as packing or toric joint, it is a mechanical gasket in a torus shape. This is used for the drive belt system.

Pivot links: it is a mechanical design that only permits one single rotation around its axe.

Polycarbonate plate: these plates made from acrylic were used in laser-cutting machines for making the legs and the frame of each prototype.

Strandbeests: this is a kinetic sculpture from the inventor, Theo Jansen.

* All words with an asterisk are defined in the glossary.

List of acronyms and abbreviations

3D -- *3 dimensions*
in. -- *internal*
out. -- *outside*
PVC -- *PolyVinyl Chloride*
RPM -- *Rotation Per Minute*

Introduction

The Arctic University of Norway is a university based in Norway and one’s northernmost universities in the world. This University is the largest research and educational institution in the north of Norway. The location of the University is relevant for the development of studies on the arctic environment, culture, and society of the region. Moreover, researchers work on a broad range of subjects and are recognized both nationally and internationally.

With the different types of terrain around Norway, an internship study was offered to me as part of my international mobility. It is research on an all-terrain vehicle using the Theo Jansen principle.

The mechanism to be used for the propulsion of the vehicle was designed by the sculptor Theo Jansen in 1991. Its principle will be useful to him in many dynamic sculptures: the Strandbeests* (beach beasts in Dutch). Theo Jansen thus presents the principle of walking in a much more simplified way since a single rotation is enough to reproduce walking. It is therefore the synchronization of the different legs that will allow the complete movement of the vehicle. [1][2]

The only actuator allowing the rotation of the legs is a simple rotary motor on which is mounted a central crank*. All the parts are thus connected by pivot links*, allowing only one degree of freedom. Only the angle of the crank* can give the position of the different parts.

To achieve near-perfect movement of the vehicle, it is necessary to know precisely the different lengths of the parts of the leg. For this, Theo Jansen used simulation software which made it possible to find the 13 lengths which will allow the leg to draw the almost perfect curve of the movement.

Starting from these 13 numbers, we had to design a reduced model of the final vehicle. Following this, a multitude of tests was brought out to validate or not the operation of the vehicle. A larger scale leg was created to see the performance on a bigger size model.

1. Prototype design

1.1 Pre-project research

It is relevant to discover the similar movement created by different technologies compared to Theo Jansen's one.

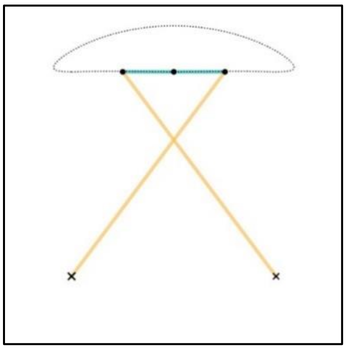


Figure 1: Tchebychev's horse

One of the oldest technologies is called the Tchebychev's horse (fig.1).

It is composed of 3 rods. The problem is that the creation of the straight line requires the perfect synchronization of two pivot links*, which is not the case with Jansen's mechanism.

The Hoeckens mechanism (fig.2) can also be a good substitute for the Jansen mechanism. It is based on the use of two bars and a sliding link. The problem comes from the fact that the linear part is reversed when needed for the displacement of the complete system.

The system has to be in contact with the floor with only one single point. The leg has to make a line completely parallel to the floor.

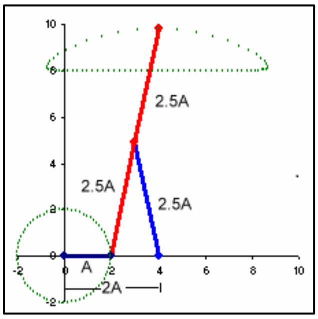


Figure 2: Hoeckens mechanism

The mechanism of Klann (fig.3) is very close to the mechanism of Theo Jansen since it uses two bars less than that of Jansen. It could be a great substitute for the Jansen mechanism.

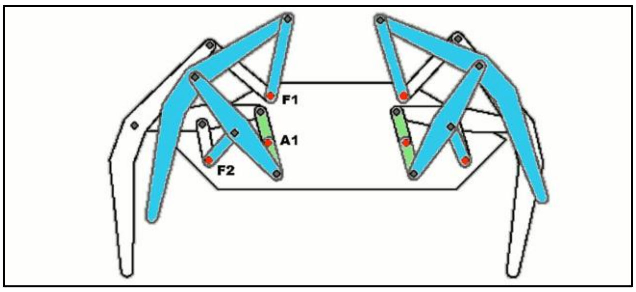


Figure 3: Klann's mechanism

But this kind of technology is very complicated to assemble and requires a very precise design and synchronization. Moreover, a rotation of the system could be more complicated than a Theo Jansen propulsion system.

All the technologies above are developed for one specific thing: to make the perfect curve. But the great asset of Theo Jansen technology is the simplicity and the great adaptability of a frame.

1.2 Research on Theo Jansen's principle

The mechanism is developed by Theo Jansen. He is a Dutch sculptor from the kinetic art movement. He creates works that can move with the wind. He, therefore, drew his inspiration from mechanisms, and engineering, but also aeronautics, robotics, and computer science. His sculptures are essentially made from PVC pipes and plastic bottles.

It is therefore interesting to understand how Jansen managed to obtain the ideal lengths of rods allowing his beach animals to move. The number of possible reports between 11 rods was immense.

According to Jansen, if we consider that each rod would have 10 different lengths, we would arrive at 10,000,000,000,000 possible curves which would take a computer about 100,000 years.

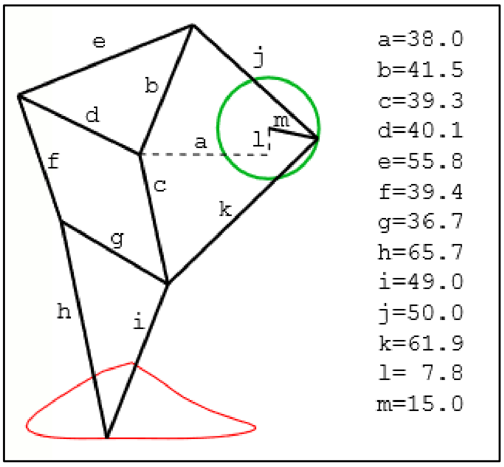


Figure 4: 13 lengths for the rods for a leg

This is why he preferred to opt for a faster but more precise method. It is therefore a question of entering the computer 1500 leg template with different rods of completely random lengths and observing the curves that are closest to the expected curve. Of these first 1500 curves, the computer retains only the 100 most satisfactory curves. The stems of these were copied and generated into 1500 new legs. The process is repeated until the ideal curve is obtained. There were still many generations that took several months, day and night, to be generated. [3]

In the end, 13 rods' lengths (fig.4) were generated and the curve was nearly that expected by Theo Jansen.

This project is mostly developed around the reduced model of the final vehicle. Multiple designs and technology are used to design the different prototypes of the vehicle. When the prototype can move by itself, the different tests could begin, especially balancing tests. When the balance of a prototype is satisfying, new tests will begin, regarding the different types of terrain and also power consumption. The last test will help us to design a larger-scale vehicle.

1.3 Project's objectives

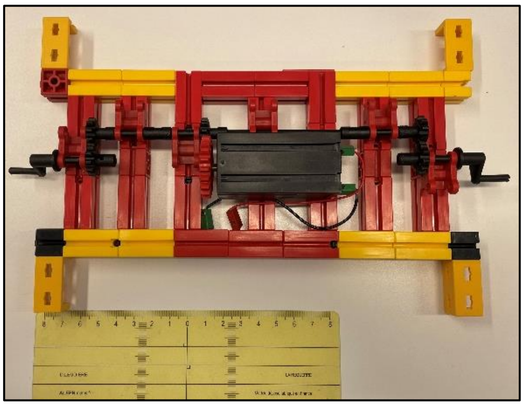
The objectives of the project are as follows:

- Design the different prototypes of the small-scale vehicle
- Do the different tests for balancing
- Reach the different problems for a working real-size model
- Testing a real-size prototype and comparing it with the theory

2. Small-scale prototypes

2.1 Prototype with Fischertechnik parts

The first prototype was made using Fischertechnik* parts (fig.5). This brand manufactures parts to build like the best-known brand namely LEGO. [4][5] The First step was to discover all the different existing parts and how to assemble them.



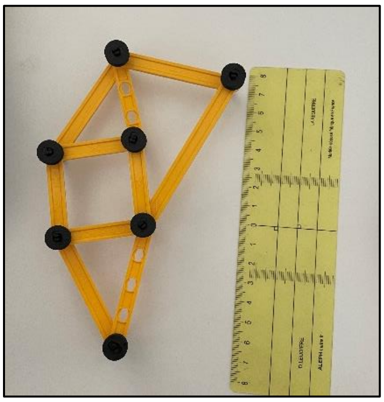


Figure 5: the frame and the leg of the vehicle

It was a 160mm high prototype. Only one motor was used to make legs in rotation. Axes and gear are used to transmit the rotation of the motor to the legs. This prototype worked and the curve of each leg was satisfying. One motor implied that the prototype could only go back and forth. It is not allowed to turn or rotate on itself.

Nevertheless, there are several problems with this solution. The parts were not enough rigid to support their weight and be able to move. The solution was only a simple idea of how can the frame be. That is why the next prototype is using polycarbonate plates* for the rods of each leg and the frame.

2.2 First polycarbonate prototype

The frame is based on Fischertechnik's prototype. By using a plan (appendix 1) in real size, the frame can be designed and adjusted to the motor drive and the different lengths of the legs.

It is necessary to know how we can build it and what type of material we can use. That is why Alexander Pankratov (one of the colleagues of Mr. Østrem) shows how laser-cutting technology works. It is the best option we can have because it is faster than 3D printing [6] and we can directly control the rigidity of the material by choosing the greatest depth of the plate.

The software used to design the vehicle to be cut by laser is AutoCAD* (appendix 2). This is the software used by Mr. Pankratov. So now, we need to transfer the idea from the plan to the software.

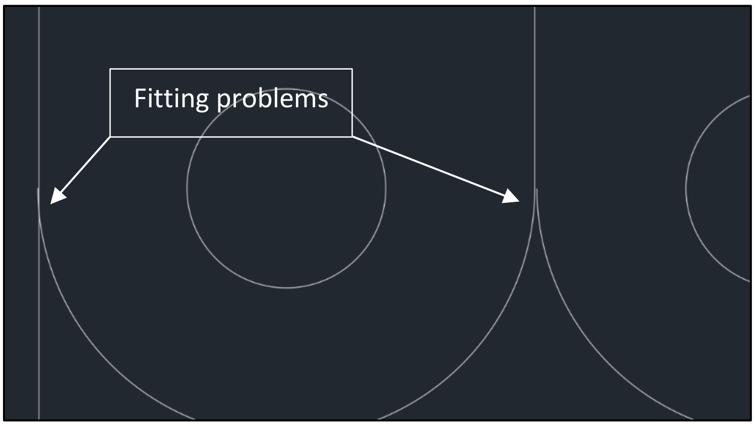


Figure 6: AutoCAD* problems

A lot of little problems were generated (fig.6), especially with a double pass of the laser head.

That is why the plan was rectified and controlled before being sent to the laser cutting machine.

After modelling and cutting, all the pieces can be assembled. The first problem was managing to fix the legs on the frame. So, the solution was to drill holes in the frame to fix the legs.

Once done, the second problem was to attach the legs to the motor via an eccentric (fig.7).

The laser-cut one was not suitable. It was therefore necessary to adjust a Fischertechnik* part to be able to fix the legs.

Figure 7: Fischertechnik* part adapted

Finally, the motors had to be fixed with two screws and a plate to be rigid to the frame (fig.8).

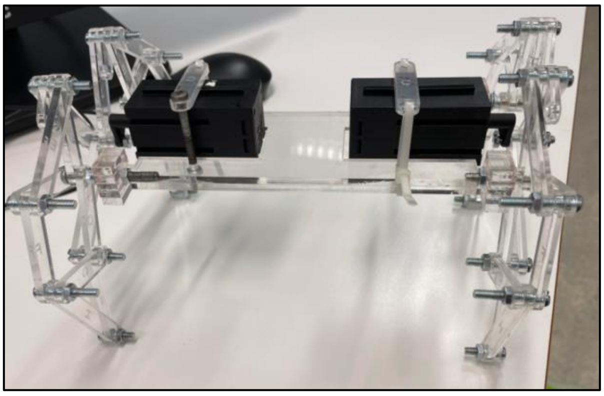


Figure 8: vehicle assembled

So, it seems that the center of gravity is a little too high which could destabilize the system. Moreover, the lack of synchronization of the two motors could also destabilize the entire vehicle.

2.2.1 Working test

The first step was to see if the rotation of the legs is correct or not. There was one side of the prototype that required more strength than the other.

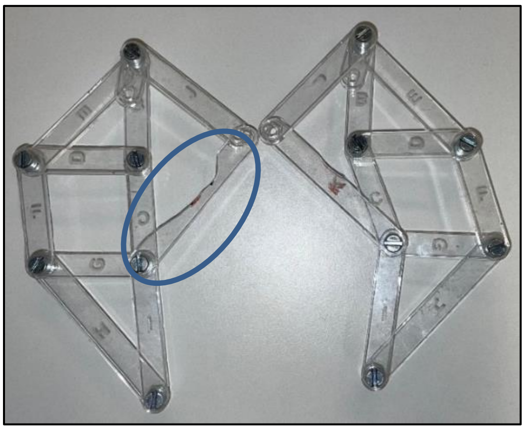


Figure 9: sanded rods

Moreover, the rods of one leg collided and stopped the rotation of the motor (while the second motor continued to operate normally). This could be due to a little different position of the fixation hole of one side compare to the other side. With this reduced scale model, a few millimeter difference could have a great impact, especially if we think about a real scale one.

To tackle this problem, we started to grind the rods (fig.9).

Unfortunately, the rotation was not the same as on the other side. That is why the prototype needs two supply voltages to control each motor separately.

2.2.2 Balance test

The test consists of powering the two motors and trying to synchronize them as well as possible. For this, two separate power supplies were used and then adjust the rotation speed of each of the motors. Indeed, as the adjustment, tightening or drilling is not identical on each of the 4 legs, one of the two motors may end up requiring less energy than the other.

Obviously, the movement is smooth and the vehicle moves well (only rotates) when only one of the two motors is running. The design must surely be redesigned to integrate a single motor (and thus perform linear displacement tests) to then be able to integrate a second motor (or other solution) allowing the vehicle to turn.

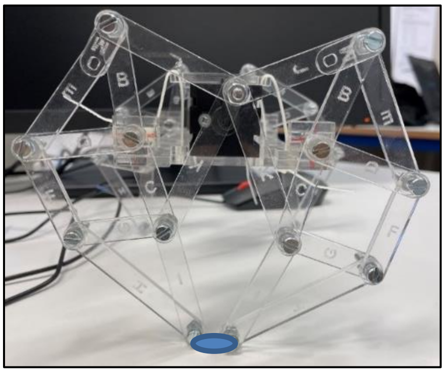


Figure 10: destabilization of the vehicle

Another problem is very relevant. At one moment of the rotation, the bottom of each leg is very close to each other and destabilizes the vehicle.

The blue circle (fig.10) represents the surface in contact with the floor. We can easily see that it is too small to support the frame. That is why the prototype was not correctly balanced and needs to be redesigned, especially to erase the problem with the bottom of the legs.

2.3 Second polycarbonate prototype

To tackle the problem of balance, four motors (one for each leg) could let the vehicle more stable. Nevertheless, the synchronization problem would render the vehicle unsuitable for the slightest movement. A system with a belt drive could be a great solution (fig.11) and avoid the utilization of four motors.

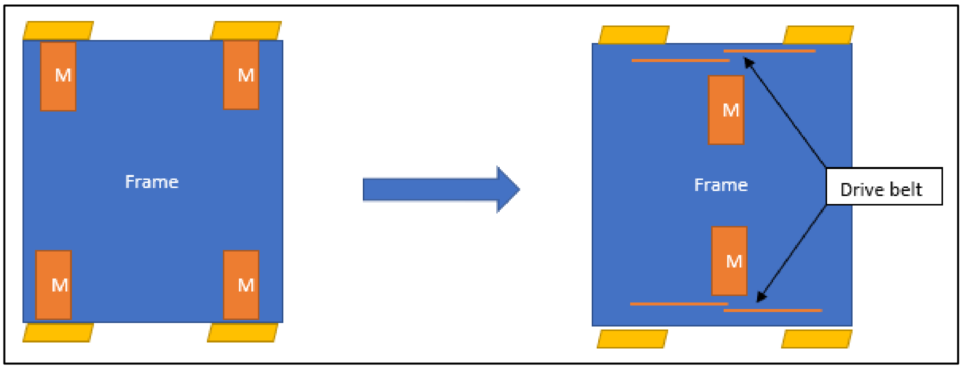


Figure 11: solution for the second prototype

Then, a new frame was designed on AutoCAD* (appendix 3) and sent to the laser-cutting machine to be cut from acrylic to assemble the entire prototype (fig.12).

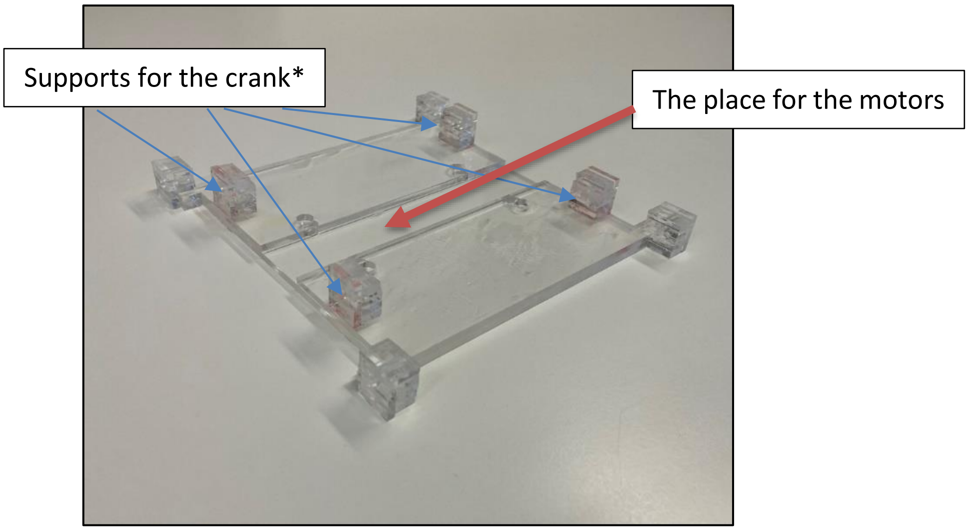


Figure 12: frame assembled

Figure 13: solution for the crank* and belt drive

But some problems appear because of this disposition. With the first prototype, only one crank* for two legs was necessary.

Now the prototype needs four cranks*, with a special thing to transfer the rotation by the drive belt.

The solution consists of taking Fischertechnik* parts as the first prototype (taking an eccentric and drilling on it) and letting passing throw two screws, one for the leg fixation, and the other one for the frame fixation with a pulley to transfer the rotation from the motor to each leg. Moreover, another pulley is useful in the axe of the motor to transmit the rotation to the drive belt (fig.13).

After solving the problem, the prototype can be tested to see its performance.

2.3.1 Rotation test

By testing all the four supports for the cranks* (appendix 4), we can see that the rotation is very good and very similar between all the legs (which was not with the first prototype).

Each hole for each fixation leg was made by using a pattern to make every hole similar. That permit a better rotation and a better similarity for each leg.

The conclusion of this test is the good rotation of each leg and a great start for the next test.

2.3.2 Working test

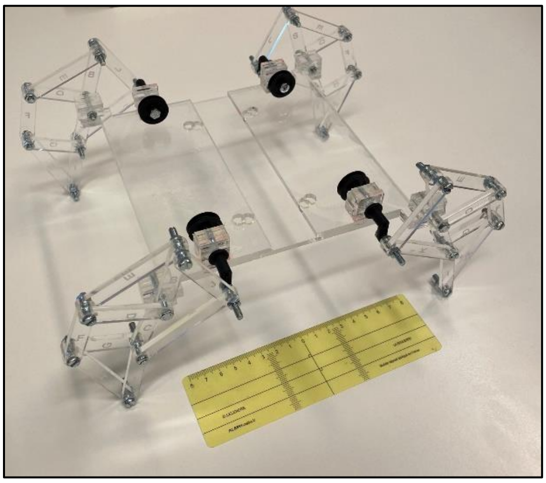


Figure 14: frame with four legs

First, the vehicle was fully assembled with its four legs (fig.14).

It is necessary now to know how to fix the two motors and find the drive belt adapted to the vehicle.

Unfortunately, this design for the crank* requires the adjustment of the driving pulley with the receiving pulley.

With the motor's larger, this adjustment can't be possible by each of the motors. That is why the crank* must be redesigned.

After putting the pulley in front of the leg support on the frame, both of the motors fit on the frame (appendix 5).

Testing each leg with a drive belt system is relevant to see the similarity. For that, three kinds of drive belts were used to know which one is better and which one has a better friction coefficient. We used 2 rubber bands and one O-ring*.

After trying all of the solutions, one rubber band broke, the other one had a bad friction coefficient and the O-ring* is too small. Nevertheless, the O-ring* solution is the greatest because it has a better friction coefficient (once stretched) than the rubber band (which is not enough rigid). In conclusion, only the O-ring* can move the leg.

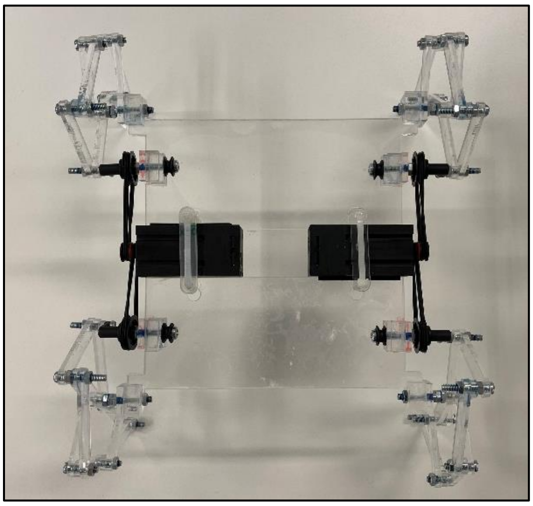


Figure 15: prototype with suitable belt-drive

After more research to find a suitable drive-belt, a 46 mm inner diameter O-ring* is a great choice (and has better elasticity than the first O-ring*).

That permits the prototype to be functional (fig.15). By making a little test in which the prototype was not posed on the floor, motors could be better synchronized and both sides are very similar in comparison to the first prototype.

It is a great hope of a working prototype and a good beginning for the further test, especially the balance one.

2.3.3 Balance test

The first balance tests could begin. After little modification of the crank* (to avoid some symmetrical problems), the balance test with unsynchronised motors was successful. The prototype didn't flip upside down at all.

Moreover, the drive belt is a great solution and each pair of legs is nearly synchronized.

To go further, another test with non-synchronized legs is used to know if the prototype has a great balance in difficult conditions. This test was successful and the prototype is greatly balanced. We can begin to make the following tests:

- make only one motor in rotation to see if the prototype can turn
- make the two motors in rotation but in reverse to see if the prototype can turn on itself
- try different kinds of terrain to see if there are some difficulties in the special grip

The first one is to see if the prototype can turn or not.

2.3.4 Rotation tests

These new tests will be used to see if we can control the prototype in any direction. For that, one motor will be in rotation and the other one will be stopped. This is to see if the prototype could turn or not. By carrying out this test, we see that the prototype begins to turn Unfortunately, it has no grip on the laboratory floor.

The robot begins to slip which does not allow it to turn properly. The problem has to be tackled.

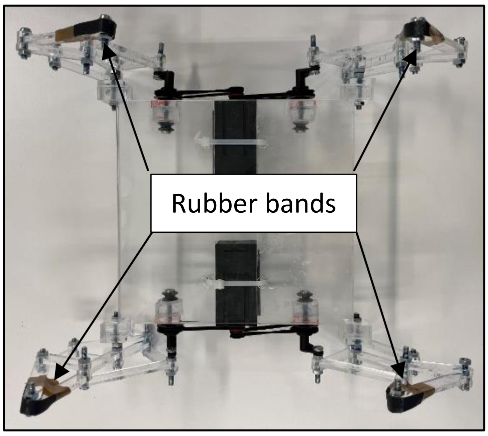


Figure 16: second prototype with upgrade grip

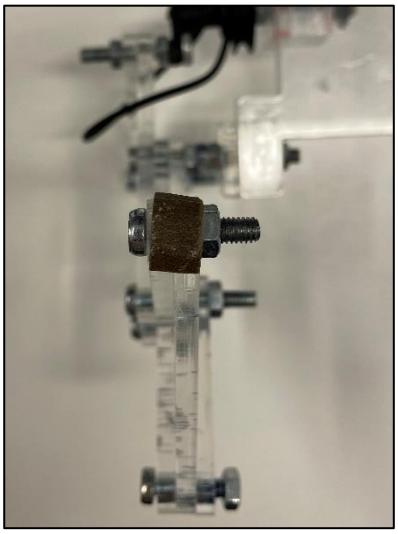
The first solution is to put a rubber band on the bottom of each leg to improve the grip (fig.16).

The result is quite good but the turn is not very satisfying.

The prototype is quite slow and some rotations keep slipping due to the dust on the floor.

The next test will therefore be to polish the end of the legs with sandpaper to increase the friction and therefore the adhesion of the prototype.

With this little polishing, the prototype can turn better. The next step is to see if it can turn on itself by powering the two motors in reverse from each other. But the polishing is not enough to let the prototype turn on itself.



To solve this new problem, the sandpaper will be glued directly to the bottom of each leg (fig.17).

So, the turning and rotation test can be repeated to see if the grip problem has been solved. The turning test (when only one motor is driven) is successful.

Now the rotation of the prototype can be led to see if it is a success too. It is nearly a success but the prototype keeps slipping.

Figure 17: leg with sandpaper

It seems for the prototype doesn't respect the right curve of Theo Jansen. The legs just go back and forth on the ground but don't go up. That is a great issue because this non-correct curve can damage the grip. In conclusion, the prototype works but doesn't properly.

2.3.5 Suitable curve test

By recording a video of a leg, we can analyse if this leg respects the Theo Jansen curve. For that, the LatisPro* software was chosen.[7] So, the video analysis could be made after converting, importing, and tracking points by points at the bottom of the leg (appendix 6).

By transferring the points to every vector, we can easily see the curve:

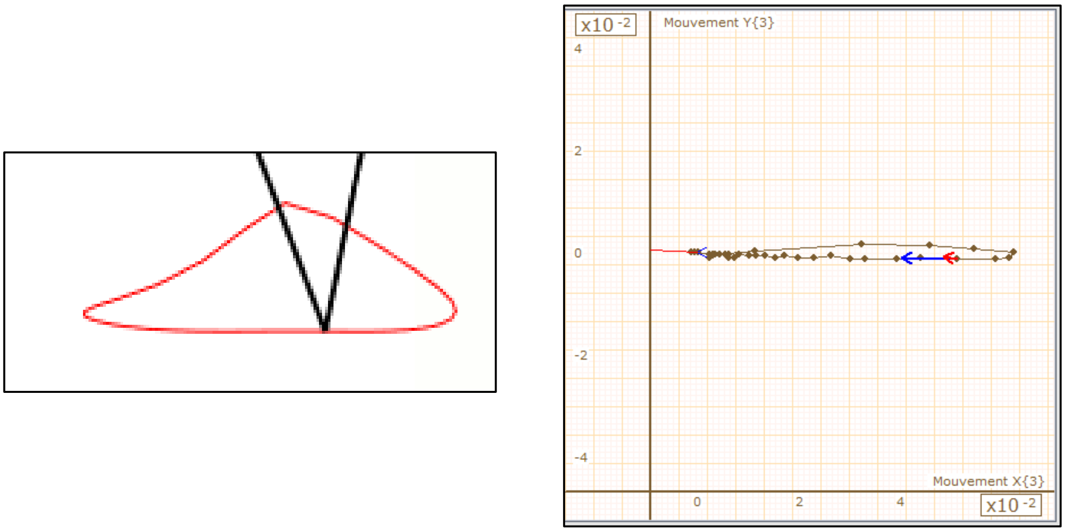


Figure 18: theory curve (left) and experimental curve (right)

By comparing the theory with the experience (fig.18), we can see a great difference. Each leg is just back and forth and is nearly constantly touching the floor.

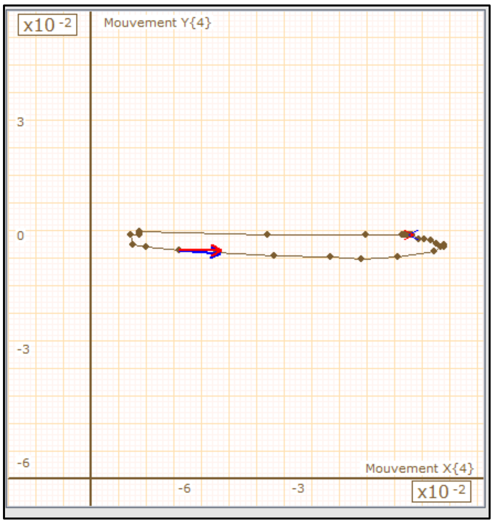


Figure 19: experimental curve

By checking on another leg (fig.19), we can see a little amelioration but it is still far from the original curve from Theo Jansen's principle.

It seems that the problem comes from the fact that the fixing screws of the legs are not tightened to the maximum (to reduce friction between the parts) which generates slack between the different parts.

Each leg needs to have something between the different parts to reduce this friction. That is a problem with this small-scale model because it is nearly impossible to put some bearings or other solutions to reduce the friction. That is why we have to try a full-scale model to see if the problem is recurrent or not.

Also, the crank* made from Fischertechnik* parts may cause the problem. The crank's length is not the exact one from Theo Jansen's theory.

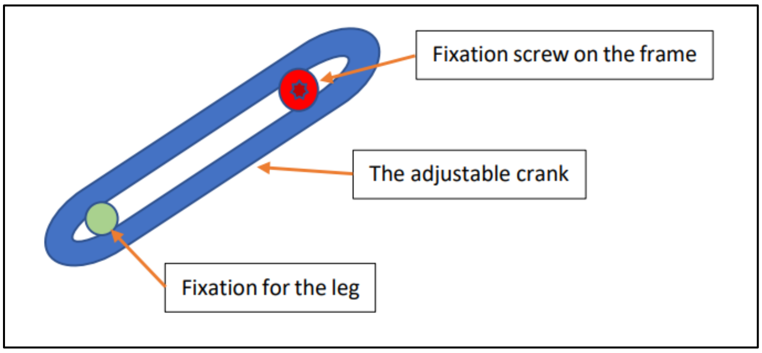


Figure 20: adjustable crank* design

That is why modifying this part could improve the rotation. Moreover, to improve the upper leg rotation, we could enlarge the crank*.

That is why making an adjustable crank* (fig.20) could be a great solution to find the perfect length for this last.

To see if the problem comes from the reduced-scale prototype or not, we need to make a larger-scale prototype.

3. Larger scale prototype

3.1 Manufacture of the prototype

First of all, since the problem seems to come from the legs and not from the frame, it is relevant to do some tests on the legs of the real size. Moreover, we can also make the adjustable crank* to see how the distance manages the curve.

For making a larger scale model, all length has to be multiplied by 5 from the actual length rods. It is nearly a meter in height which is a great length for the system.

This is a table of recapitulation of the different rods' lengths:

Name of the rod	Reduce scale model	Full-scale model
A	38.0 mm	190 mm
B	41.5 mm	207.5 mm
C	39.3 mm	196.5 mm
D	40.1 mm	200.5 mm
E	55.8 mm	279 mm
F	39.4 mm	197 mm
G	36.7 mm	183.5 mm
H	65.7 mm	328.5 mm
I	49.0 mm	245 mm
J	50.0 mm	250 mm
K	61.9 mm	309.5 mm
L	7.8 mm	39 mm
M	15.0 mm	75 mm

Table 1: the dimension of the reduced and full-scale prototype

These new dimensions will be used to make another assembly on AutoCAD* software.

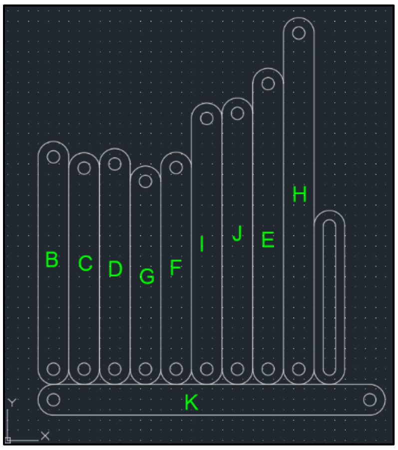


Figure 21: AutoCAD* capture

Because the leg in real size will be used only to see which dimension of the eccentric could be the better one, cutting in metal is not necessary.

That it the laser cutting machine is adequate to create the leg in polycarbonate* (fig.21).

After the laser cutting machine, the larger size leg could be assembled by using M12 screws (fig.22). This hole diameter was chosen to easily put bearings ball to decrease the friction between each rod.

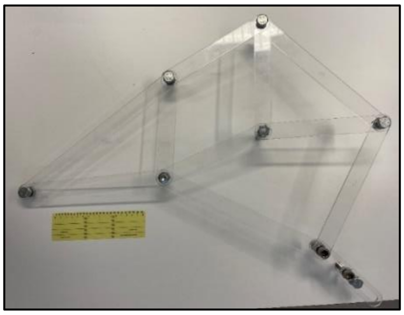


Figure 22: leg in a larger size

To see if problems were solved with a bigger leg, we make the same tests as we made on the reduced scale prototype.

3.2 Suitable curve test with original dimension

The first test is with the exact dimension of Theo Jansen's theory. By making a video and analysing it on LatisPro* software, we can see that the leg has the correct curve compared to the theory (fig.23).

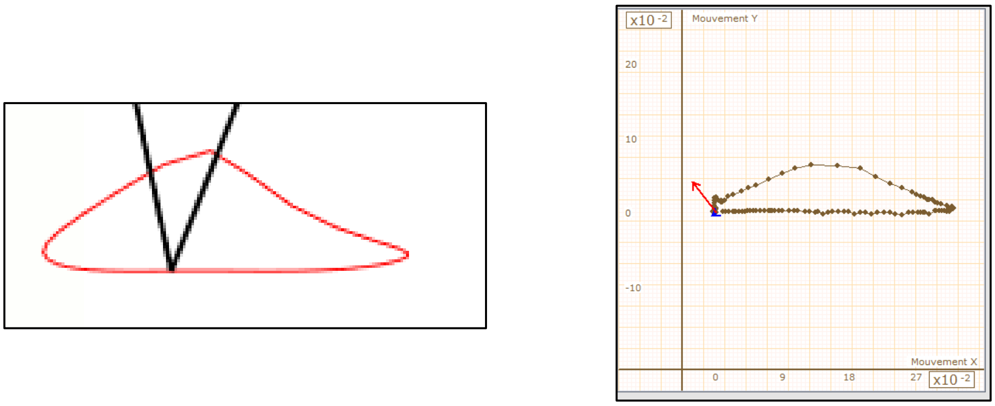


Figure 23: right curve (left) compares to the experimental one (right)

In conclusion for this first test, the real size leg is closer to the theory compared to the reduced scale model one. Moreover, screws can be tighter and friction is not a huge problem anymore.

Even if the results were satisfying, an improvement can be led if we can adjust the length of the crank* and therefore see how this adjustment can affect the performance

3.3 Suitable curve test with adjustable crank

The test is driven by an 80mm crank*. A comparison can be made with the original size (fig.24). By moving the attach point of the crank*, the curving performance of the bottom of the leg can be improved.

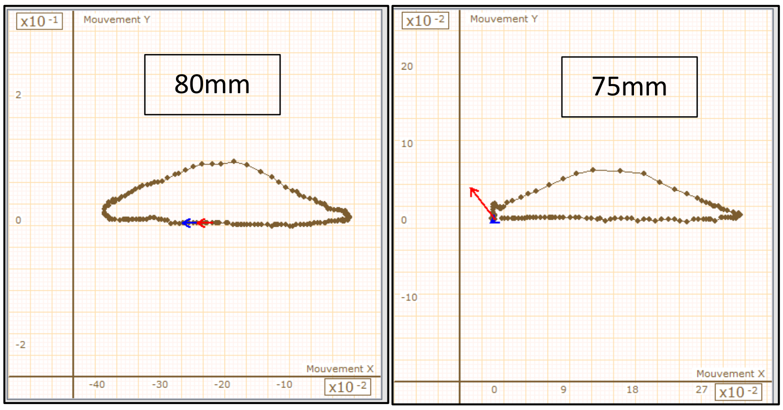


Figure 24: comparing different crank* dimensions

We can see with the 80mm crank* that the bottom of the curve is not completely flat compared to the 75mm. But we can also see that the leg goes higher for the 80mm one. So, it is interesting to consider the benefits of a longer crank*.

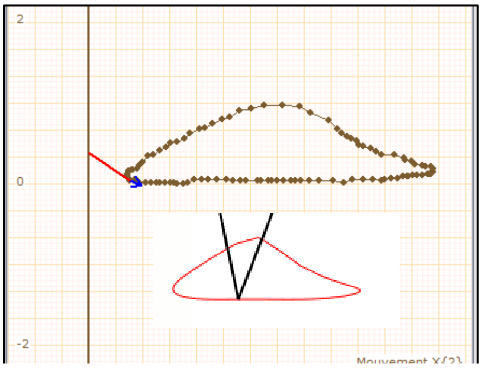


Figure 25: the curve with 85mm crank*

With an 85mm crank*, the curve is closer to the theory (fig.25).

An 85mm crank* is a great choice to be closer to the theory.

The last test is with a shorter crank*, with for example a 65mm crank*. By analysing with LatisPro*, the curve is no closer to the theory. Moreover, the bottom of the curve is not flat and that will be problematic for the walk of the prototype.

In conclusion, the better crank* is 85mm in length, even if the theory uses a 75mm crank*.

3.4 Technological choices

To go further and have a better curve, we can continue to reduce the friction between tight screws and the rods of each leg.

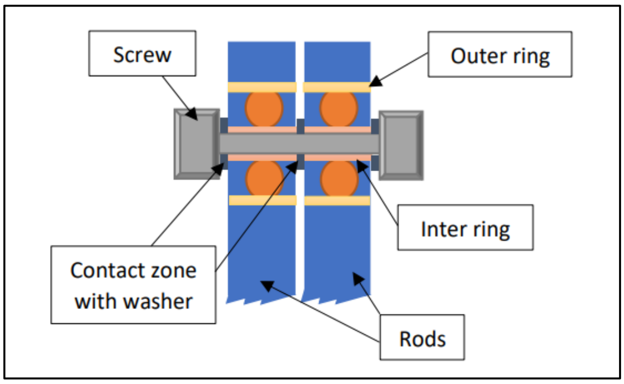


Figure 26: solution to reduce friction between rods

That is why the utilisation of bearings ball could be a great solution.

The inner ring of each bearing will be in contact and let the rods of the legs be completely functional even if the screws will be very tight (fig.26).

By making some research, several bearings balls could fit in the configuration below (tab.2).

The larger of each rod is 4mm, and the diameter of each hole is 12mm. That is why bearings balls with 12mm of outer diameter and 4mm large are a great choice. Now one decisive factor is the static load and dynamic load. Moreover, an inside diameter of 6mm would provide sufficient clamping force compared to a diameter of 4mm which might not be sufficient.

in. diameter	out. diameter	width
8mm	12mm	3,5mm
4mm	12mm	4mm
6mm	12mm	4mm
8mm	12mm	3,5mm
4mm	12mm	4mm

Table 2: bearings ball dimension

power	RPM	voltage	torque	axe diameter
37 W	22	24 V DC	15 Nm	12 mm
37 W	35	24 V DC	5,2 Nm	9 mm
37 W	8	24 V DC	15 Nm	12 mm
20 W	40	12 V DC	5 Nm	9 mm
40 W	25	12 V DC	80 Nm	14mm
41,3 W	67	12 V DC	2 Nm	8 mm
27 W	14	24 V DC	5 Nm	8 mm
80 W	23	24 V DC	20 Nm	19mm
41,7 W	27	12 V DC	2,5 Nm	8 mm

Table 3: motors characteristics

Finally, some research was made about the motor gear which will be used to move the real-size prototype (tab.3). We are focused on 12 or 24 V because the prototype will be used with some battery pack.

The decisive factors are the RPM, Power and torque. To be great, the prototype must work at less than 60 RPM. A controller could also be used to adjust the speed rotation of the motor.

4. Conclusion

An all-terrain vehicle using the Theo Jansen principle for propulsion is a relevant project for an alternative means of travel in this special climate. This vehicle could help people in backside areas because of its low maintenance and a rather simple assembly. Moreover, this kind of vehicle could be an attraction for visitors to discover the diversity of the university's projects.

With the different prototypes, the choice of materials is the first key to making a working vehicle. Polycarbonate plates* for a reduced scale prototype are suitable but for the bigger size, another material or a bigger thickness of the acrylic plates is necessary. This necessity is explained by the onboarding of the motion system such as the motors, batteries pack, or controller.

Even though, the different tests on reduced and large scale were able to highlight the possibility of making a suitable and fully working vehicle by using the Theo Jansen principle.

Nevertheless, this vehicle should reduce the friction between each rod from each leg by using suitable bearing balls, should also choose a suitable motor with enough torque to move correctly the system, and furthermore design where the battery pack could be and how to command the vehicle movement.

It could be very interesting after these many steps to manage to automate the vehicle with many onboard sensors that would allow the system to evolve naturally throughout the university and even more so in the wild regions of Norway.

5. Personal review

The opportunity to do an internship abroad allowed me to develop, both intellectually and humanly speaking. Indeed, I have developed a rigorous working method to achieve the desired results, but I have also learned to open up to others. Finding myself as a foreigner who did not speak the language of the country made me realize the indulgence that some people showed (more details in appendix 7).

The shifted work schedules compared to my country of origin taught me to adapt to the ways of life of the Norwegians. In addition, resources being limited, I had to be ingenious to be able to carry out this project. Currently, my skills in management, research, organization and the development of alternative solutions have been greatly developed.

Some frustrations arise from this internship, in particular not having succeeded in making a fully functional prototype, but also not have been able to open up to others earlier in the internship.

The first part of the project was the longest, especially in the prototype design since no proposal had been issued before, but it allowed me to see what my capacities were in terms of design, creation but also optimization. I took a lot of pleasure in the realization of this one and I was able to discover mechatronics, a specialty that I liked.

I also learned the use of new computer-aided design software such as AutoCAD*. In addition, a new analysis tool (LatisPro*) also allowed me to carry out my various tests.

Finally, I have grown from this internship since many situations, whether within the project but also in everyday life, have taught me to think differently and opt for solutions that until then would have been impossible for me to have.

Table of contents

References

Bibliography

[1]. Anonyme, "Wang et Hou - 2018 - Analysis and Applications of Theo Jansen's Linkage.pdf", *Theo Jansen's Linkage Mechanism on Kinetic Architecture* [online], [consulted on 10/04/2022]. URL:http://papers.cumincad.org/data/works/att/caadria2018_140.pdf.

[2]. CAROLINA HERNANDEZ A., GOMEZ C., CRESPO J.,BARBER R., "A HOME MADE ROBOTIC PLATFORM BASED ON THEO JANSEN MECHANISM FOR TEACHING ROBOTICS", University of Carlos III, [online], 2016, [consulted on 12/04/2022], URL: https://www.researchgate.net/publication/303702599_A_Home-Made_Robotic_Platform_based_on_Theo_Jansen_Mechanism_for_Teaching_Robotics.

Webography

[3]. Strandbeest,"Home - Strandbeest ", [official website], Consulted on 12/04/2022 URL : https://www.strandbeest.com/.

[4]. Klingel8, "Fischertechnik* Strandbeest* V1.1", [video]. Consulted on 18/04/2022. URL: https://www.youtube.com/watch?v=oHjy8-faLuk.

[5]. Klingel8, "Fischertechnik* Strandbeest* 3.0", [video]. Consulted on 18/04/2022. URL: https://www.youtube.com/watch?v=9oy6ta2p9pY.

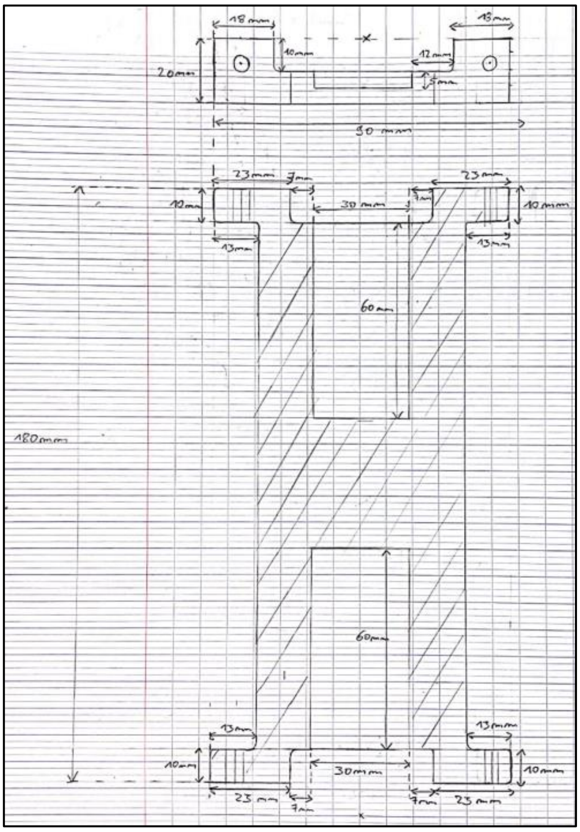
[6]. Thingiverse.com, "Sphero Landstrider #make5000 by PowerChainPro", [wiki]. Consulted on 15/04/2022. URL: https://www.thingiverse.com/thing:428931.

[7]. Nicolas Braneyre, "Comment utiliser Latis Pro* comme logiciel de pointage", [video]. Consulted on 23/06/2022. URL : https://www.youtube.com/watch?v=Buibo1QN03Q.

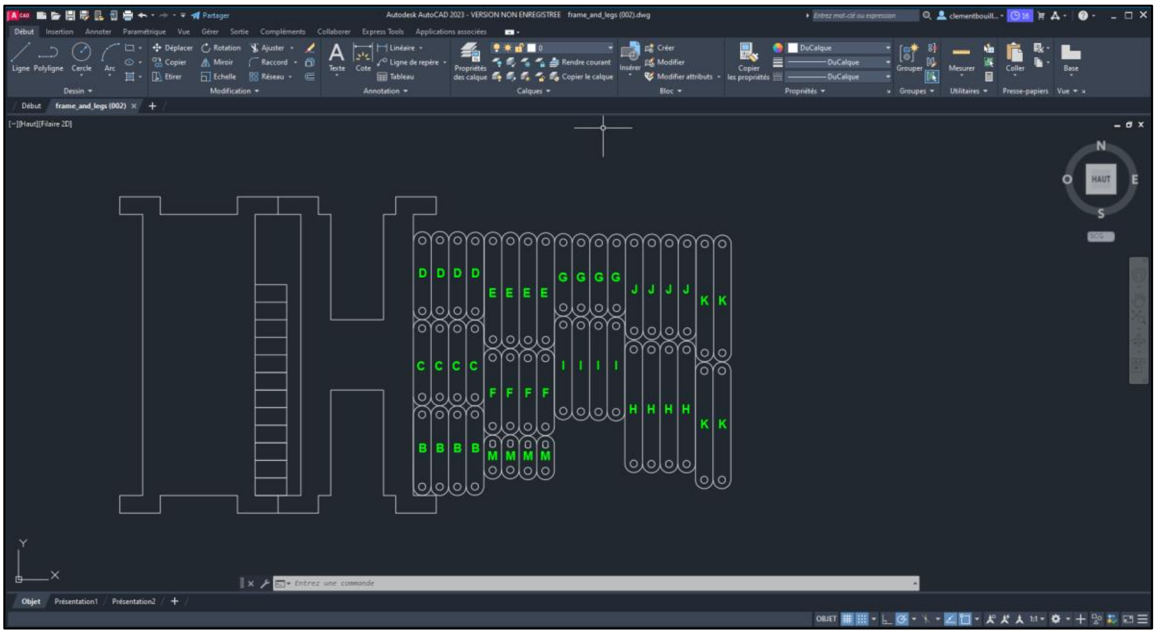
Table of appendixes

Appendixes

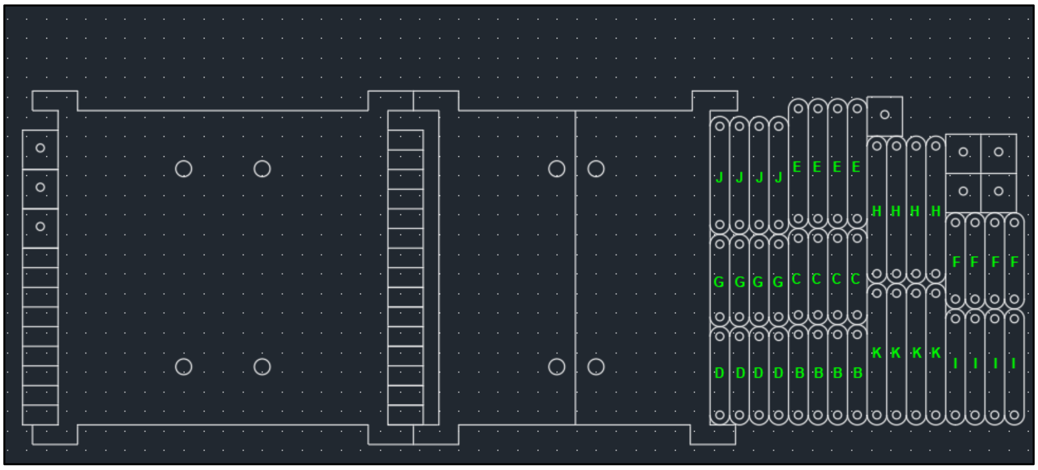
Appendix 1: Plan of the first prototype frame



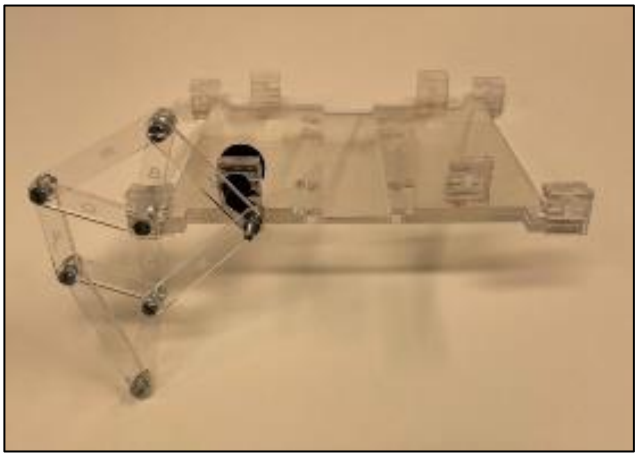
Appendix 2: Capture of the design of the first prototype on AutoCAD* software



Appendix 3: Capture of the design of the second prototype on AutoCAD* software

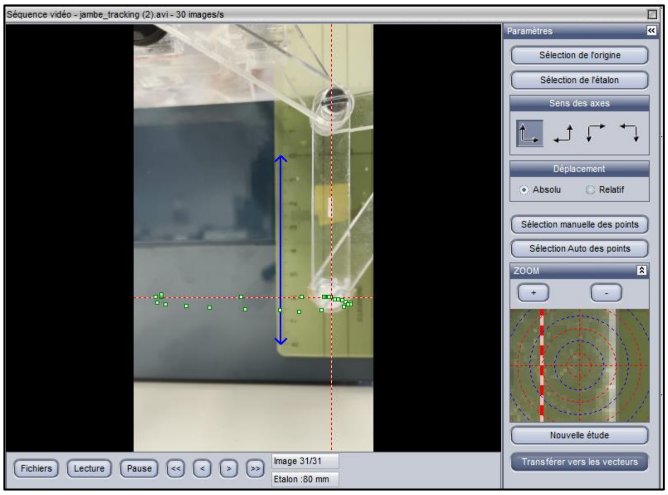


Appendix 4: Second prototype frame with one leg



Appendix 5: Second prototype with redesign crank*

Appendix 6: Capture of video analysis from LatisPro* software



Appendix 7: Cultural openness

The first thing that was most enjoyable and that allowed us to rediscover a new culture was the work atmosphere which was tight and focused on well-being throughout this internship. Indeed, the working rooms, the laboratories and even the common areas are well equipped, with offices, and seats that have been chosen to be as comfortable as possible during our work. In addition, music rooms, restrooms or table tennis tables are available for everyone to recharge during breaks.

The people met were very respectful and especially benevolent and open-minded. We felt no judgment on any of our actions or thoughts. Also, everyone is very thorough in every task they have to perform. Buses are always on time; safety is paramount and the terms are very strict. Compliance with the rules is also very important. For example, at each pedestrian crossing, motorists stopped and left a safety margin of approximately 50m. The call button on the pedestrian light works much better than in France (a few seconds were enough for the light to go green). Access to laboratories for example is subject to MCQ and practice tests. The people met come from all walks of life and cultural openness here is impregnating. We can meet a lot of international students and students participating in an exchange between two universities. This diversity is also found in the natural bilingual of each inhabitant who could speak both Norwegian and English. This mix makes you want to learn new cultures and languages.

Finally, the inclement weather, the considerable thickness of the ice as well as the cold of the regions are the most shocking things upon our arrival. Temperatures ranged from -5°C in April to 12°C in July. We experienced a heat wave where the temperature remained around 26°C for more than a week. So, the continuous day was a huge shock especially when we went to sleep since this arctic day made us lose all consciousness of the hour. Nevertheless, it was an advantage when you went hiking or discovering new landscapes. We no longer cared what time we had to go home.

The cost of living was something that had an impact on our training course since the least food or going out with friends was relatively expensive. However, we have noticed that the quality of life and the quality of the products are impeccable.

The landscapes are of course breathtaking, and discovering this region of the world was a real pleasure. Whether in terms of landscapes, like the encounter with others, this course was extremely enriching in every way. The monumental pressure we had in France where our well-being was somewhat put aside was caught up in those 4 months when our well-being was just as important as our work. Four sports sessions per week managed to find their place throughout this internship.

Appendix 8: Checklist

Couverture	✓	logos, titre, prénoms/noms des étudiants, noms des tuteurs, mention « rapport de stage » ou « rapport de projet », année, département ; nom de l'école en entier (Polytech Clermont)
Résumé en francais et en anglais, mots clés	✓	Résumé + mots clés Abstract / keywords
Remerciements	✓	ordre (en gras ce qui est obligatoire) : **tuteur entreprise**, personnels entreprise, **tuteur école**, enseignants école, autres « Mr. » = Mister ; Monsieur = « M. » Attention à l'accord des participes passés
Sommaire	✓	2 niveaux de titres
Table des figures et des tableaux	✓	toutes les figures et tous les tableaux sont répertoriés classement dans l'ordre d'apparition des figures et tableaux « Figure 1 : Titre, numéro de page »
Glossaire	✓	les mots du domaine présentés en ordre **alphabétique** en fin de lexique : une mention indiquant que « tous les mots suivis d'un astérisque sont définis dans le lexique » dans le texte : un astérisque à chaque mot défini dans le lexique
Table des abréviations	✓	obligatoire s'il y a utilisation d'abréviations ordre alphabétique
Introduction	✓	Accroche, sujet, problématique, entreprise, enjeux, méthode de travail, annonce du plan
Conclusion	✓	rappel de la problématique, rappel synthétique des résultats, distance critique par rapport à ces résultats, ouverture vers un autre sujet ou une autre problématique
Bilan (personnal review)	✓	prise de recul, analyse des compétences acquises
Bibliographie sitographie		Application des consignes ATTENTION à bien citer dans le texte **toutes** les références
Table des matières	✓	tous les niveaux de titres
Figures	✓	Elles sont TOUTES : numérotées, titrées, référencées dans le texte, sourcées
Annexes	✓	table des annexes (« Annexe 1 : TITRE, page ») les annexes sont numérotées et classées en ordre d'apparition dans le texte, elles sont toutes appelées dans le texte, paginées en chiffres romains, à partir de 1
Fiche du tuteur	✓	Présence de la fiche de validation du stage par le tuteur.
Différences culturelles	✓	Présence d'une partie sur les différences culturelles

Appendix 9: Reading certificate

UNIVERSITE CLERMONT-AUVERGNE
POLYTECH CLERMONT

Année universitaire / Academic year: 2021/2022

UNIVERSITÉ Clermont Auvergne

POLYTECH® CLERMONT

Attestation de lecture de rapport de stage
Internship report reading certificate

Je soussigné(e), M./Mme
I, the undersigned, Mr

Trond Østrem
....

(tuteur d'entreprise), atteste avoir lu et autorise l'envoi au jury le rapport de stage intitulé
(intern's supervisor in the Company) attest to having read and authorizes the sending to the jury of the internship report entitled

DESIGN, BUILD AND TEST AN ALL-TERRAIN VEHICLE USING THE THEO JANSEN PRINCIPLE FOR PROPULSION
....

de l'élève M./Mme
of the student Mr

Clement Bouillot
....

date
date
25 August 2022

Signature du tuteur
Company supervisor's signature

Trond Østrem