SCARA Robot

Project made as an assignment for the summer semester of 2020.

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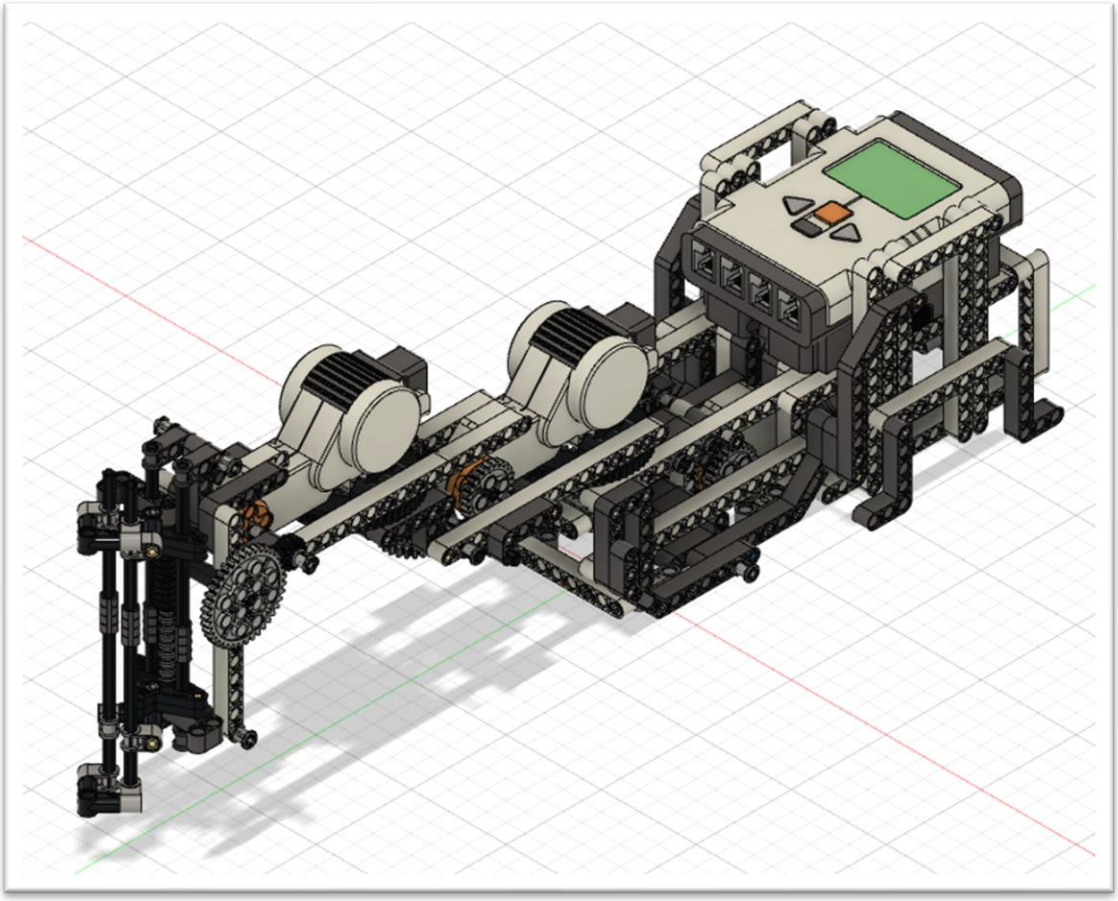
Link to the publication.



Introduction

This assignment came as the reaction to the AGH's inability of conducting courses as usual in the face of a global pandemic. Originally we were supposed to manually create a LEGO robot, program it, using micro controllers and present our inventions to both the group and course instructors.

Unfortunately the class assignment had to be overhauled and finally our task became to design a LEGO robot digitally, using Autodesk Fusion 360 software, and create the project's publication, which would undergo a scrupulous assessment from the course instructor.

Design idea

We were presented with a plethora of various robot types to choose from. While making the decision we kept in mind that the project we choose would have to be implemented from the ground up by ourselves so it would have to be something we would be able to both properly design and implement.

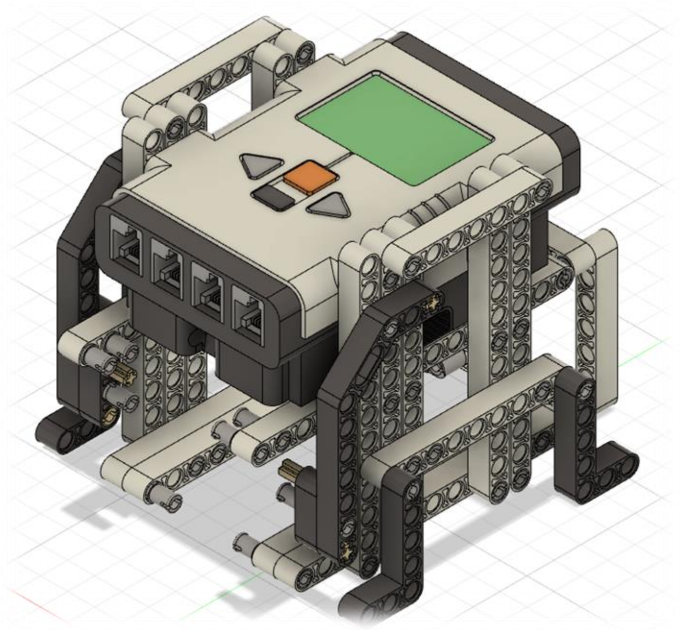
We chose to implement our own version of a SCARA robot (SCARA – acronym for Selective Compliance Assembly Robot Arm), which can simply be described as a mechanical arm, capable of complex motion in a three dimensional space. It is usually designed in a two-link parallel-axis joint layout. This type of a robot is widely used in assembly process of electronics and automotive equipment where precision is crucial.

We figured that while requiring innovativeness from our side this robot was something we were able to properly design by ourselves. We settled on a design that was both relatively simple but also quite reliable. We wanted to create a robot that would be able to reliably perform operations in a 3D space without any hassle that would be both modular and simple to assemble. After iterating over the design we decided to split the robot into four parts that would be assembled separately, before connecting them together. Subassemblies we settled on were named in the following manner:

- Base extension
- Base
- Link 1
- Link 2

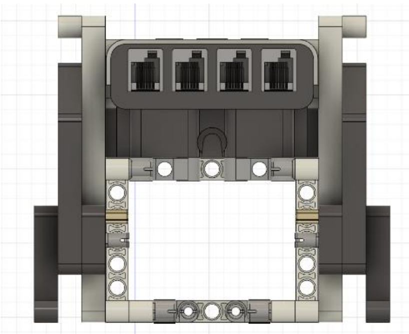
Every single module will be described in a separate paragraph.

Base extension

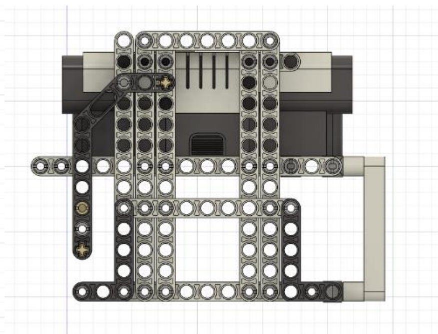


Base extension that holds the power supply

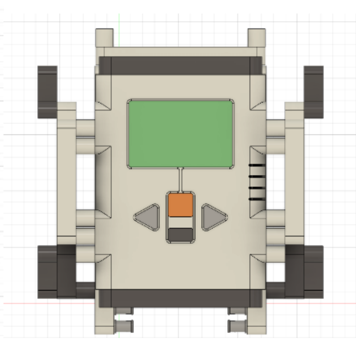
The bulkiest and heaviest part of the robot's base. It's sole role is to hold the robot's power supply and act as a counter weight that stabilizes operations and prevents the robot from tilting forward while operating its arm. It was designed as a rigid cage that holds the LEGO power supply safely and prevents it from moving in any direction. It connects to the other part of the base via several pins that ensure that the connection is stable and both parts create a rigid base for the entire robot.



View from the right

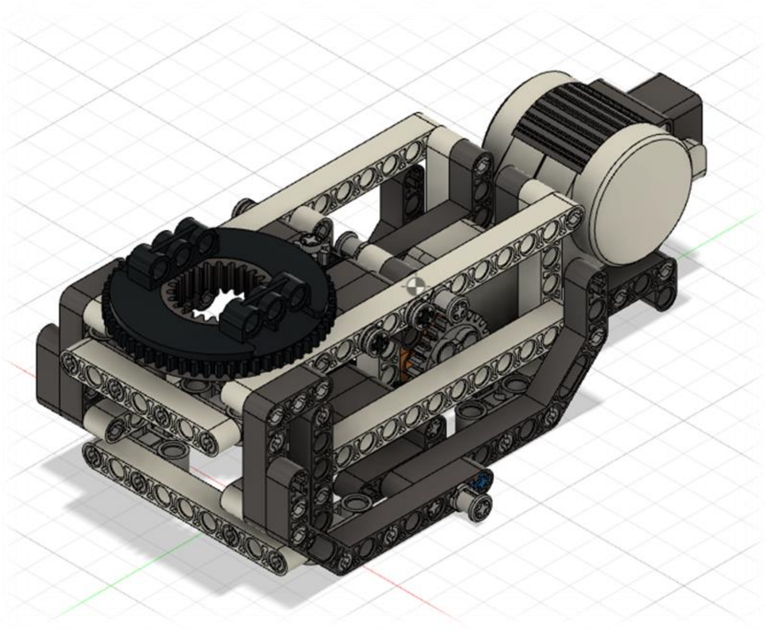


Front view



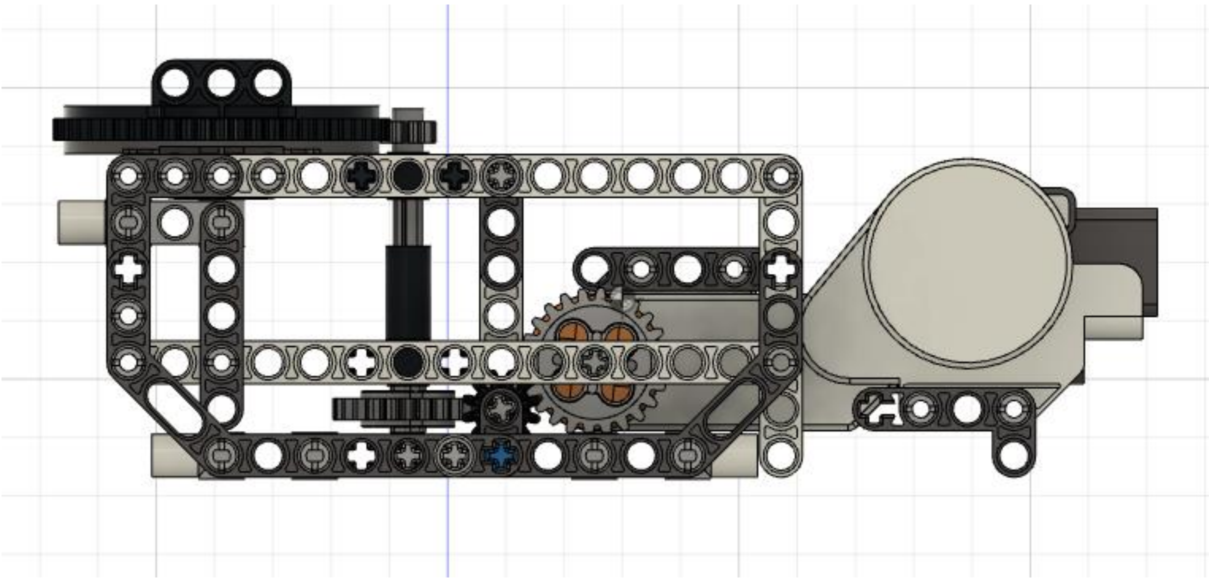
View from the top

Base



The arm's actual base

This part serves as SCARA arm's actual base. It connects to the base extension via pins mentioned earlier and houses an engine, connected to a rotating platform that houses robot's arm. Similarly to the previous part it was designed as a rigid cage, able to withstand any forces acting on it during the robot's operation. The arm is mounted on the rotating platform, that in turn is connected to an engine powered by the battery.



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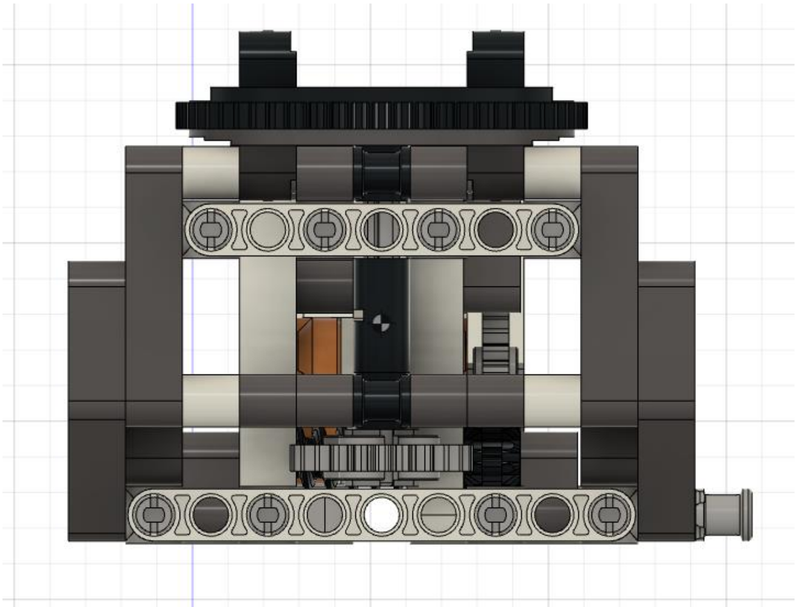
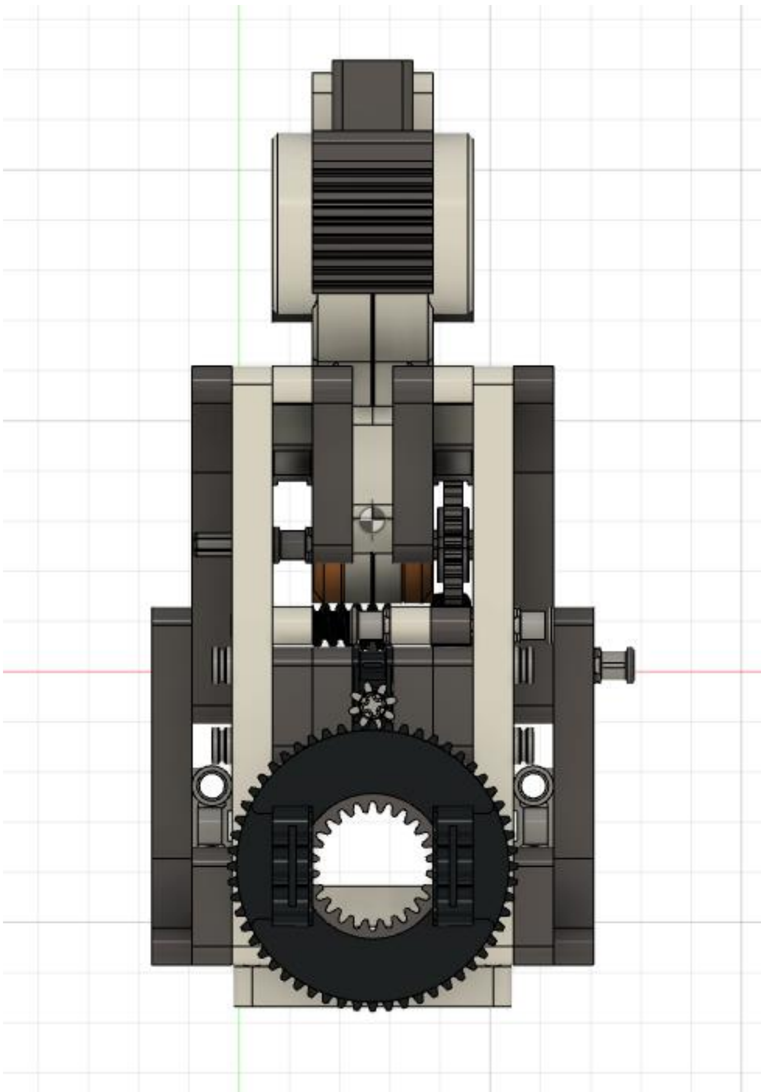
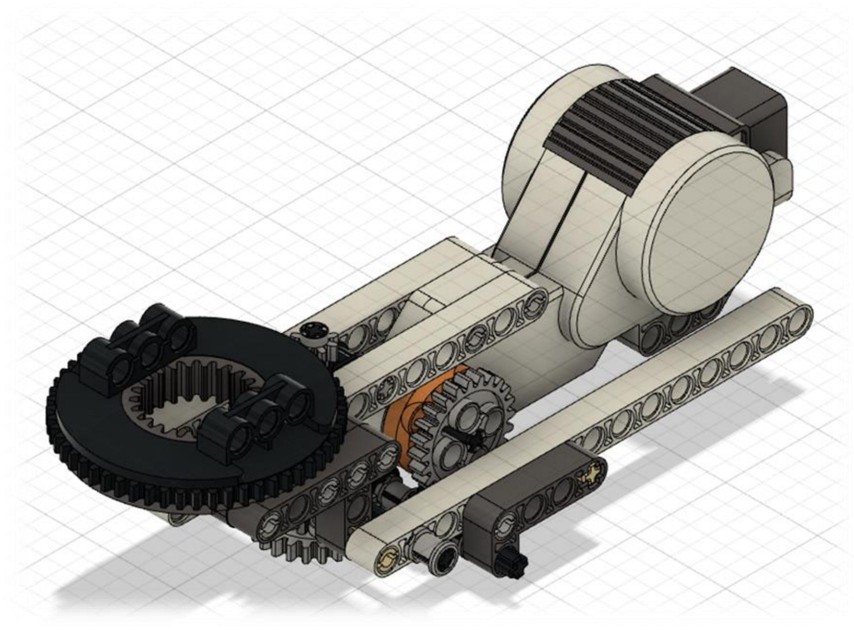


Front view



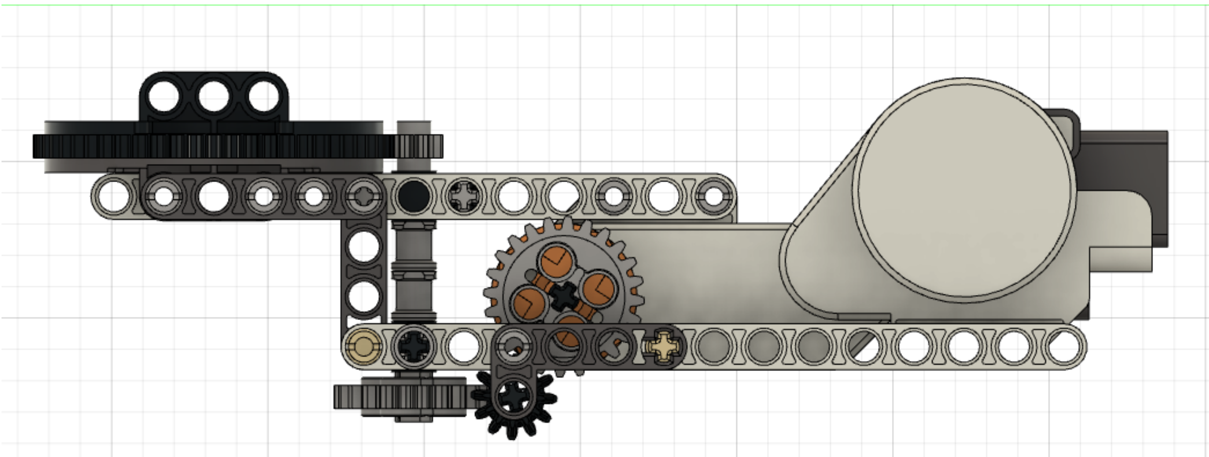
View from the top

Link 1



Arm's first link

This part is the first link of the robot's arm. It is connected to the base via the rotary platform. It itself also houses a rotating platform that connects to the other link. This double rotating design allows us to operate at any distance, within the arm's reach, in a very straightforward manner. As previous modules we designed it in such a way so that it can withstand any forces acting on it during the robot's operation.



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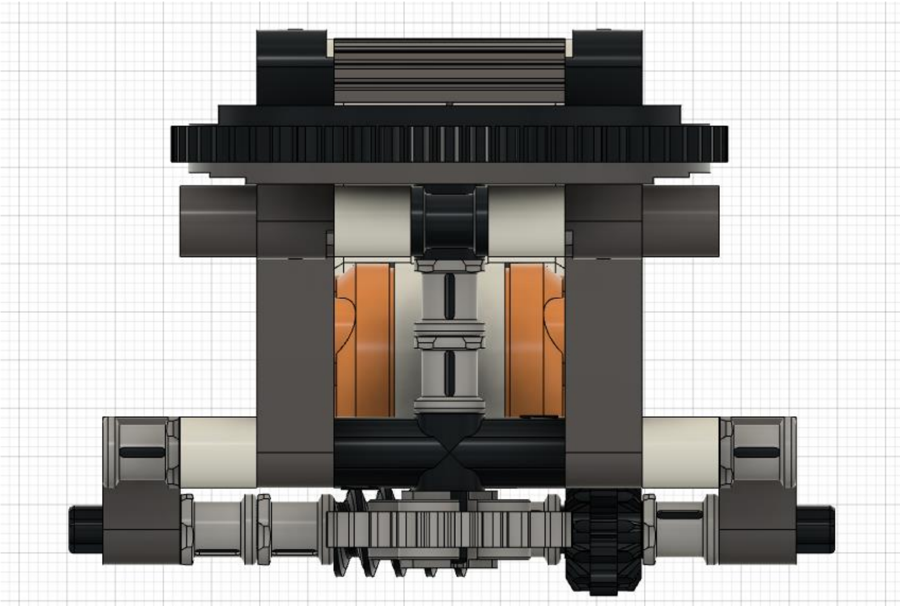
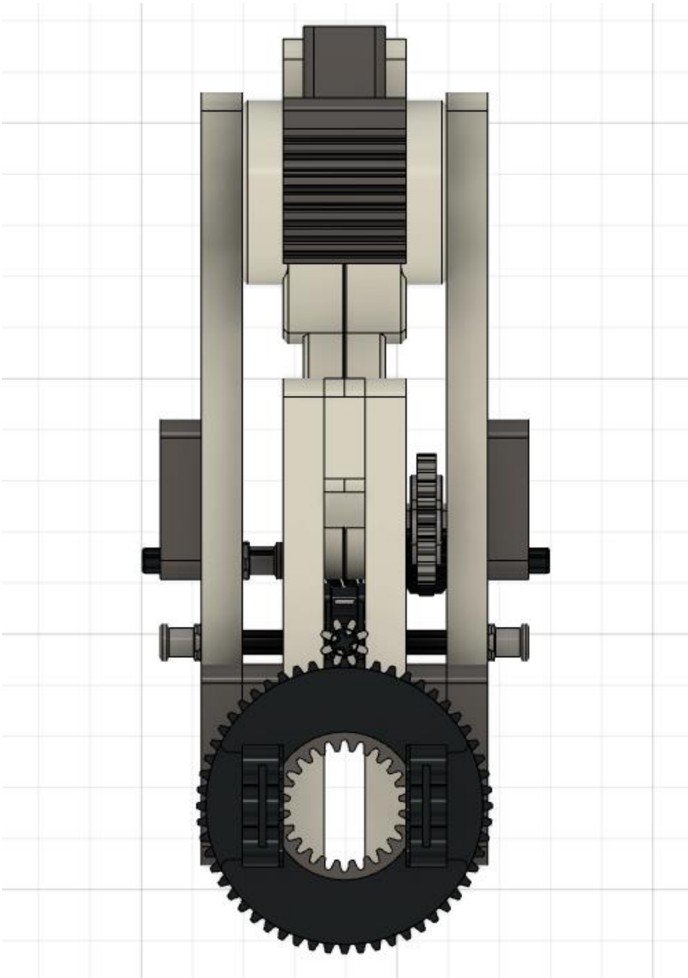
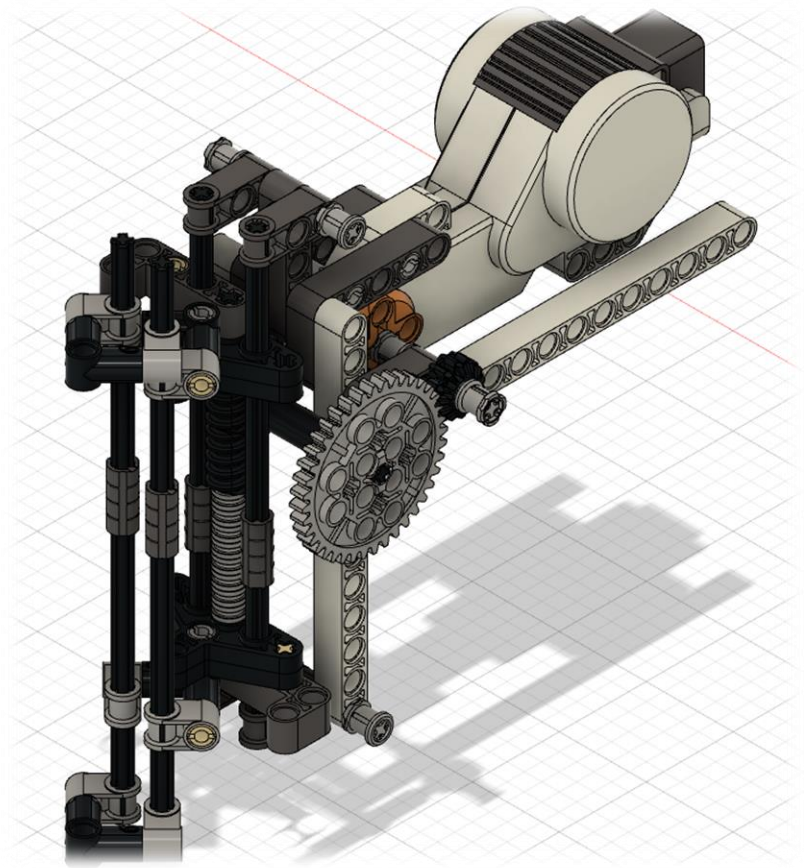


Front view



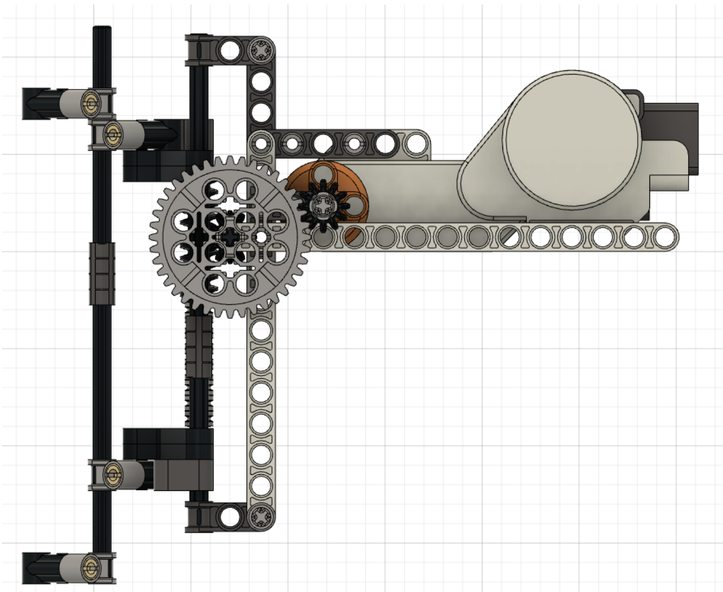
View from the top

Link 2

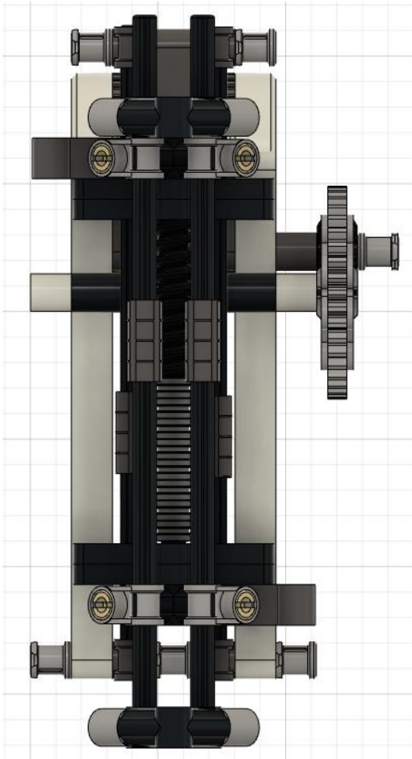


Arm's second link

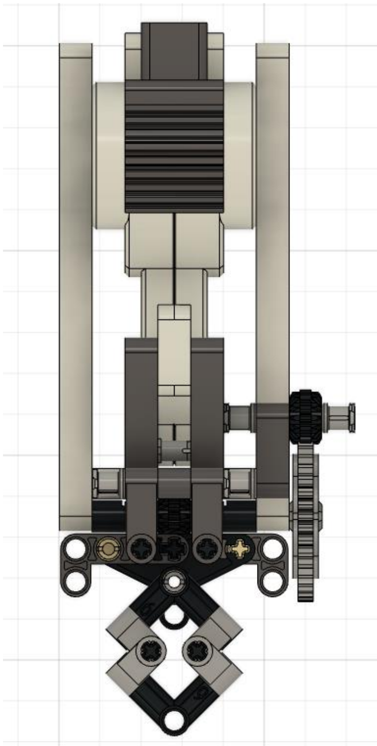
This is the final module designed by us. It connects to the first link and houses a pen, that can move in a vertical direction, hold tools and perform actions based on a task. As it is the outermost part of the robot it is the most sensitive to the influence of both outside forces and forces acting on the robot while performing it's task. We did our best to make this part as rigid and resistant to foreign influences as possible.



View from the right



Front view



View from the top

Design summary

As it can be seen from both images and descriptions above the design we settled on is both simple in implementation and reliable during the operation. In order to make our robot as error-proof as possible we decided to use as few moving parts as possible and not include any unnecessary parts. The device we created in the end is rigid throughout most of its construction and simple were it could be unnecessarily complex. An example of the robot's operation can be found under the following link.

Analysing the robot

We performed three different types of analysis on our device: FEM analysis, kinetic analysis and thermal analysis. Results of these analyses are contained in a compressed directory, attached to the publication. Below is the discussion of the results of FEM analysis.

Kinetic analysis

For the purposes of kinetic analysis we designed several models in the SAM program and attached them to the rest of our files.

We also calculated things such as degrees of freedom, speeds of motors and output speed of links, and also our robot's ranges of motion.

Degrees of freedom

We decided to calculate degrees of freedom with regards to the pen element as it's position depends on its vertical motion and rotational motion of robot's both links. Thus we arrived at the conclusion that since its position has to be explained by three independent variables then it has to have three degrees of freedom.

Speeds

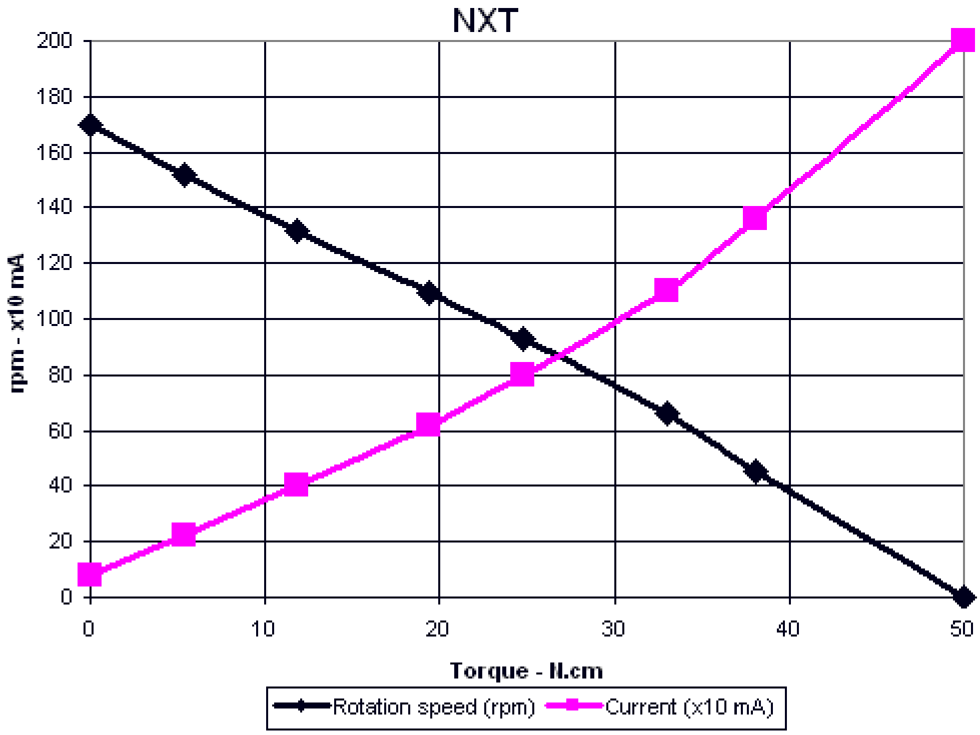
Motors we used to allow our robot's motion were LEGO 53787, Electric Motor – NXT. It is a rotational DC motor with 1° resolution and power by a 9V electric current, its characteristics are displayed below.

LEGO NXT motor

Mass	80 [g]
Rotation speed	117 [rpm]
No-load current	60 [mA]
Stalled torque	50 [Ncm]
Stalled current	2 [A]
Torque	16.7 [Ncm]
Current	0.55 [A]
Mechanical Power	2.03 [W]
Electrical Power	4.95 [W]
Efficiency	91%

All the above data was created assuming 9 Volt current supplying power to the engine.

Below is rotation speed vs torque and current consumed vs torque characteristic for NXT motor.



Vertical velocity of the pen holder

The pen holder will move with a constant vertical velocity.

$$v_{vertical} = \frac{\omega_{NXT} \times 6.85\,[mm]}{3.33}$$

Where,

$$\omega_{NXT} = 117RPM = 12.3\left[\frac{rad}{s}\right]$$

Finally,

$$v_{vertical} = \frac{12.3 \times 6.85}{3.33} = 25.3\left[\frac{mm}{s}\right]$$

Rotational speed of links

The gearbox we constructed allows the motor to pass $\frac{1}{28}$ of its rotational speed to rotating platforms, thus, since we use the same motors throughout the entire construction, the speed at which each of these platforms rotate is the following.

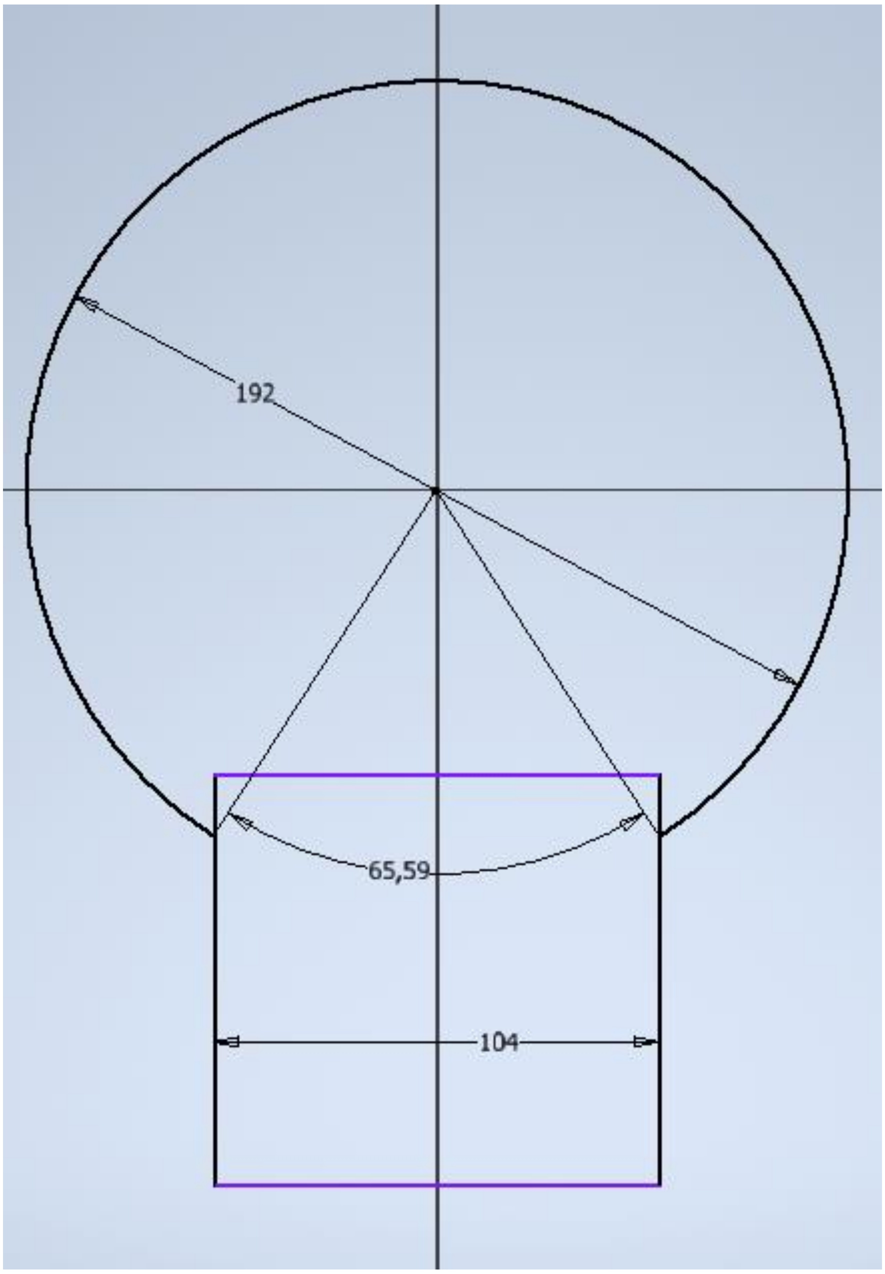
$$\omega_{platform} = \frac{\omega_{NXT}}{28} = 0.44\left[\frac{rad}{s}\right]$$

Ranges of motion

Ranges of rotational motion of both links can be displayed as a circle, 192 millimetres in diameter (The length of a link from its housing to another link's housing is about 96 millimetres). Since each link's movement I equally important to the robot's operation we will calculate ranges of motion separately for each of them.

Link 1 range of motion

Link 1 can rotate freely in a circle, constrained only by the presence of the base. We took the width of the base at its thickest point and fit in on the circle, thus calculating the angle at which it can freely rotate.

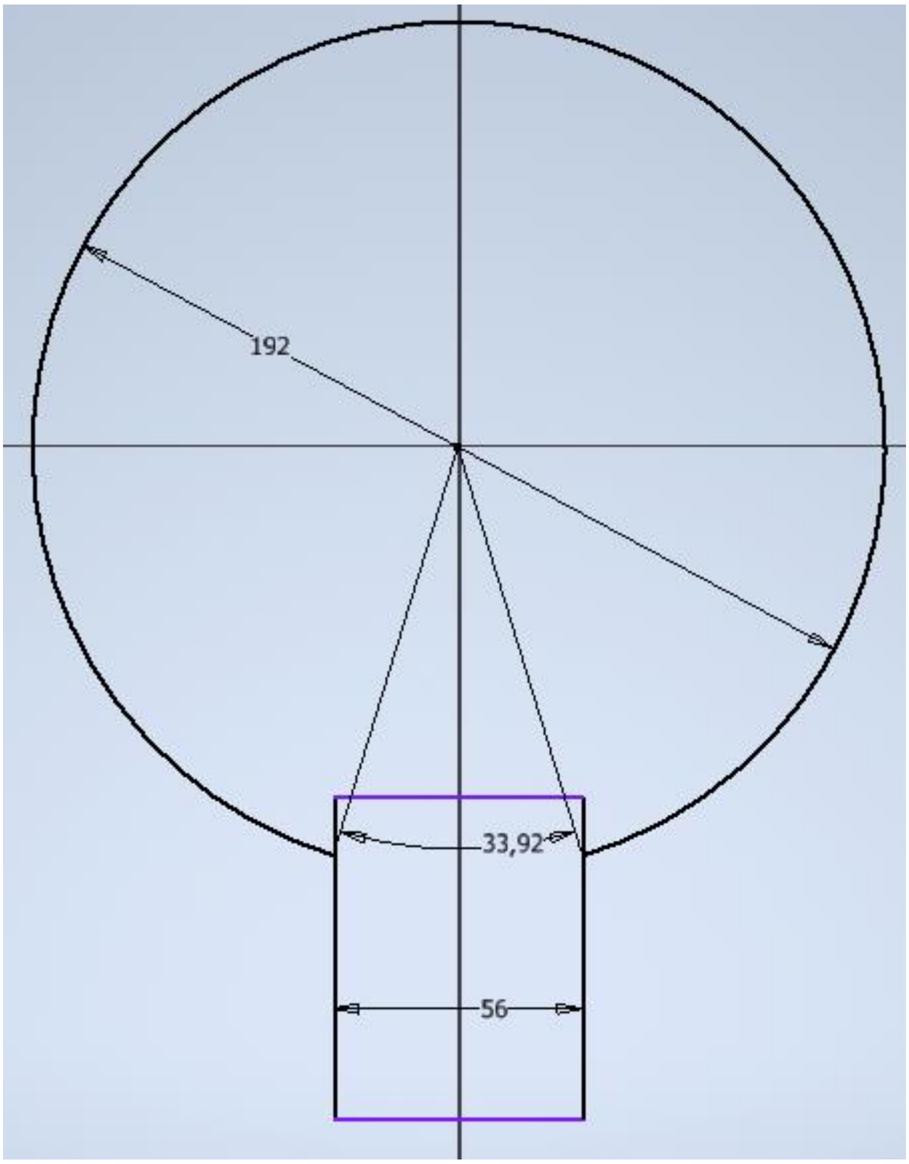


Example sketch for calculating the range of motion

As we see if we subtract the arc unavailable for the purposes of movement then we can arrive at the angle of 290° guaranteed unconstrained movement. As a note we chose to subtract 70 degrees to have an absolute guarantee that our calculations are correct.

Link 2 range of motion

When it comes to link to we carried out our calculations in the same way, the only difference being that the angle unavailable to us is going to be smaller. This is due to the fact that this time we are constrained buy link 1 not the base.



Example sketch for calculating the range of motion

As previously we'll take the unavailable angle, round it up and subtract from the whole circle. The result is 320° of free movement for the second link.

All in all, although constrained, both links' movement guarantees enough freedom of movement for most tasks required.

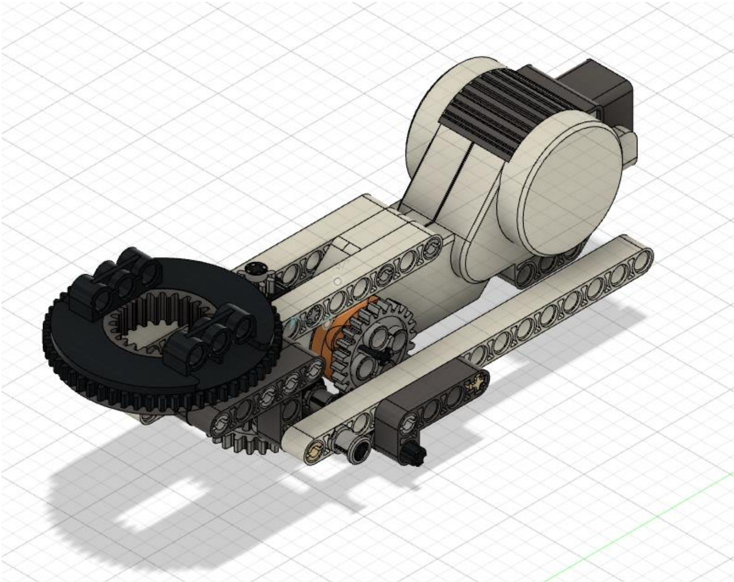
FEM analysis

Introduction

FEM (Finite Element Method) is one of the most widely used methods of solving problems both in engineering and mathematical models. Typical fields of application of this method that also proved relevant to us were structural analysis and heat transfer. FEM method can be summarized as a method of solving partial differential equations of a mechanical system subdivided into smaller, simpler parts called 'finite parts'.

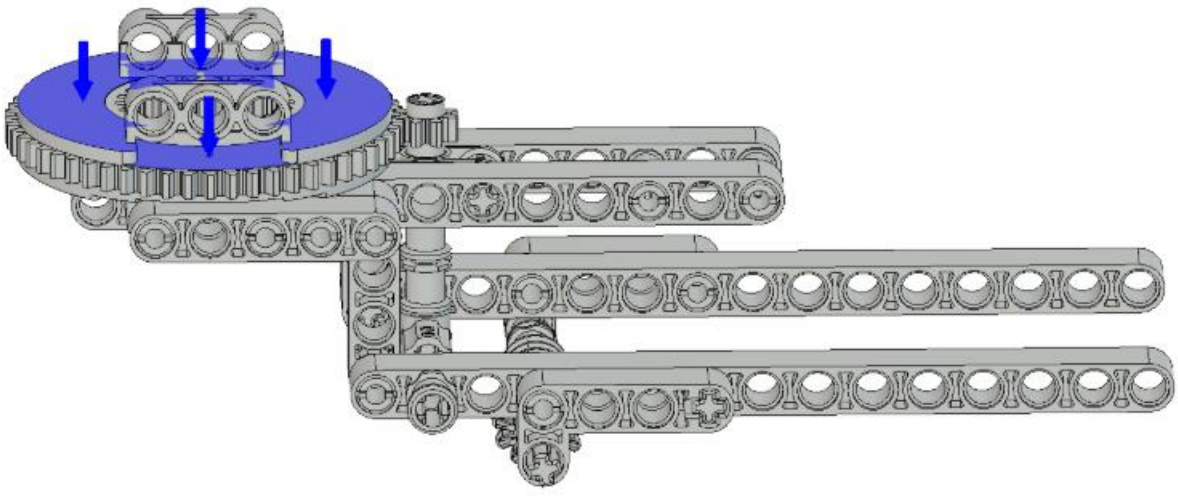
We chose to conduct an element-wise FEM analysis, analysing each part separately. Since we can easily divide the robot into constituent components for which this analysis is relevant (Links in the arm) this proved to be the best approach.

Link 1 analysis



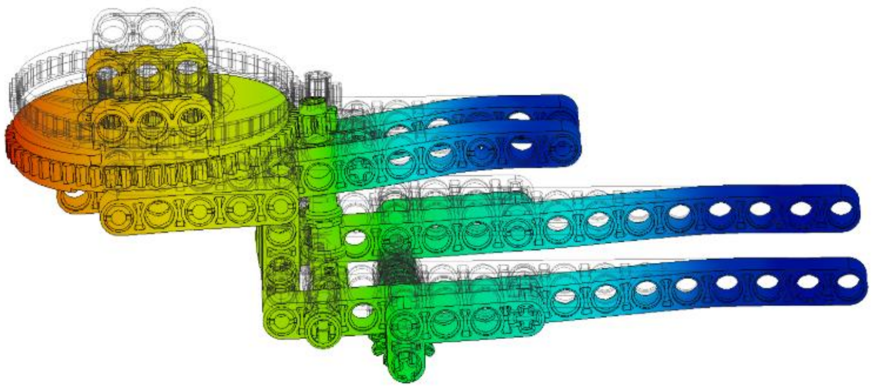
Link 1

During this analysis we a constant applied force at the top of the rotary platform where the second link is supposed to be mounted, we did it in this way in order to simulate a scenario where this link is under a load due to some intensive operation by the second link, the direction of the force is displayed on the illustration below. Pictures used for this analysis notably exclude the motor, that is supposed to be mounted to this link as it can be assumed as a rigid connection to the base. The force considered was 3.38 Newtons.



Forces applied

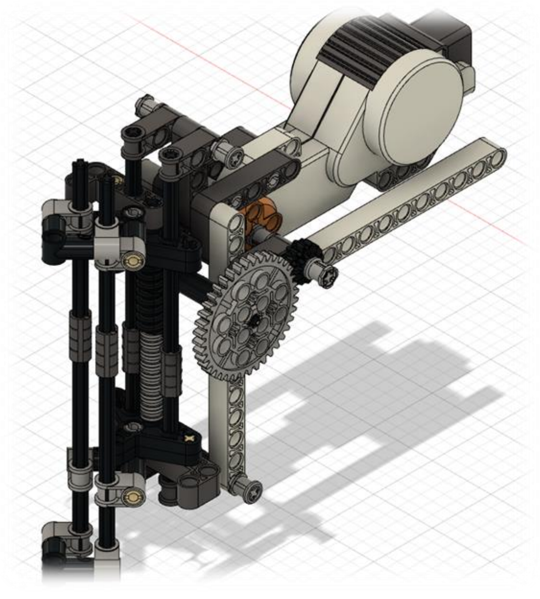
Deformation of this part under the load is shown in the picture below.



Deformation

The results of FEM analysis are the following. There was some deformation sustained by the part. Luckily, its extent can be regarded as minimal as the most deformed areas suffered from about 0.0695 millimetre deflection. The safety factor we achieved was high, between 14 and 15 throughout the whole part, which allows us to rest assured that the construction is stable enough for our purposes. For more information please refer to the generated HTML file.

Link 2 analysis

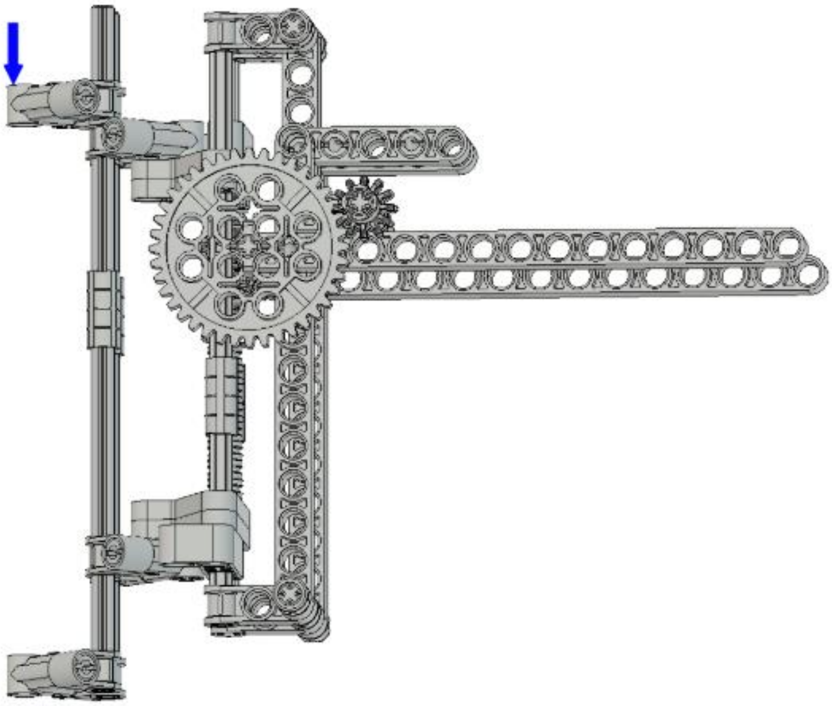


Link 2

As visible this is quite a complicated part, that when under stress might possibly deform or lose its ability to perform its function properly. Important properties to consider are:

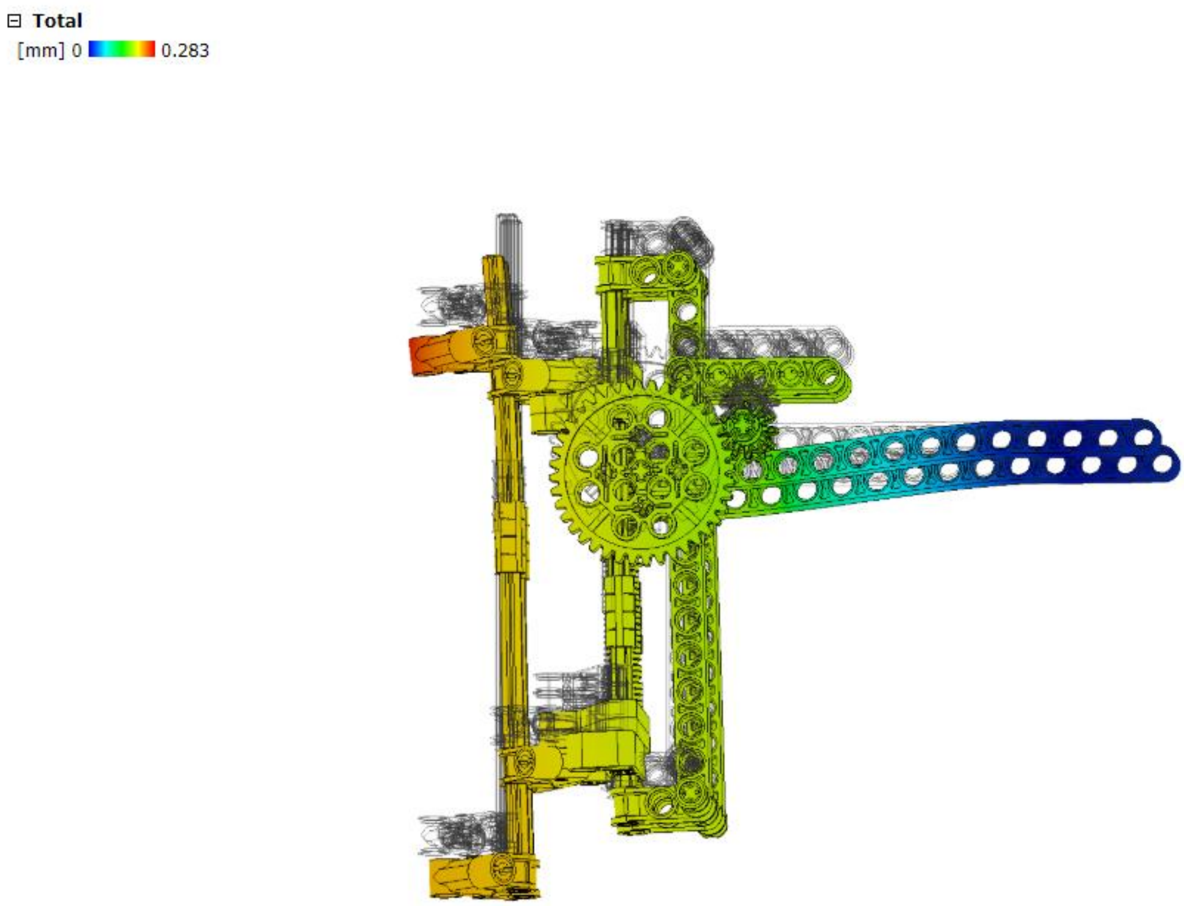
- Load carried by the pen element considered was 2 Newtons high.
- The element moves in a polar axis.
- Forces acting on it are constant

Image of this part under a constant load during a simulation is displayed below. Again we omit mounting to the first link and this link's motor. The place where the connection is supposed to be is treated as a rigid connection anyway.



Forces applied

Deformation of this part due to this constant load is displayed below.



Deformation

The results show that this part can be severely damaged. Although the connection wasn't deformed in any way, which shows us that this part wouldn't break away from the first link, the rest of the link wasn't that lucky. This is a very complex and delicate part and it reacted to the stress like one. The pen suffered the worst fate out of all the elements, at the most severe point reaching up to 0.283 millimetres of deformation, which for a robot that boasts precision is quite much. These results confirm the fact that this part wasn't designed to sustain any heavy load and we shouldn't treat it like it could in any way. The HTML file, featuring more details is naturally attached to project files.

Conclusions

Designing a SCARA robot from the ground up using LEGO parts indeed proved a significant challenge. We are quite happy with the results, since we obtained a simple and reliable robot, exactly as we intended. Naturally, we are aware of the fact that our design is nowhere near as sophisticated and versatile as industry-rate solutions, we are far from those. Nevertheless, the robot works as intended (as can be seen in an animation attached to the publication) and it is able to serve its intended purpose.