TALLINN UNIVERSITY OF TECHNOLOGY

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Controlled Motion Simulation of an Exoskeleton Model

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Aim of the Work

The purpose of this work is to perform a motion study using several software tools, and to obtain a final simulation of the working conditions of the developed exoskeleton model. The simulation is based on previous knowledge of SolidWorks motion studies, accompanied with MATLAB Simulink modeling.

The first part of this report explains the developed SolidWorks model for upper body exoskeleton, in addition to procedure and results of the performed motion study; starting from motor placing, to exporting the model to MATLAB. The study is performed twice; initially without an added load, then with a load; to obtain more realistic results.

Afterwards, the model is exported to MATLAB, using Simscape Multibody, to obtain basic motion modules (blocks). A motor is chosen, based on research and comparison between parameters performed for similar exoskeletons. The motor parameters are added to Simulink blocks to obtain realistic simulation results. The results and procedures for simulation processes are explained in this report.

Tools

The design of exoskeleton was completed by using SolidWorks software of Dassault Systèmes. It is possible to simulate the motion of the exoskeleton with Motion Analysis tools in SolidWorks. MATLAB software of MathWorks was chosen to export the system model of the design for motion simulation. To be more specific, Simulink environment was used to work on the multidomain system. It is possible to export the 3D assembly as a Simscape Multibody model to Simulink with a plug-in for this task. Simscape Multibody, formerly known as SimMechanics, also makes it possible to add and adjust motors with the necessary specifications. All software tools used during the project was on the corresponding version of their last 2018 releases.

3D Design

The design that was done using Solidworks is inspired by already existing exoskeleton models such as AXON. In the presented model there are total of 4 rotational joints, and those are the joints that had the ability to move. They have motors to move them in rotational direction. As the model is an upper body exoskeleton, the 4 rotational joints are divided among the 2 arms equally, i.e. 2 for left arm and 2 for right arm. Simplifying into one arm model for explanation, there is a motor to make the motion of the elbow and one for the motion of the shoulder. The elbow and shoulder are able to make more than 1 degree of freedom movement, but the exoskeleton has mainly the function of lifting, so only 1 degree of freedom was needed for the motion of each joint.

There are some fixed sliding translational joints that are fixed and adjusted just for the length of the arm of the user, and they exist twice on each arm to be suitable for variety of users. Those translational joints are not taken into consideration in the analysis of the motion as they are supposedly fixed during operation, but they can be movable just during the time of the apparatus setup for a user.

The places for motors are already set but can be enhanced to be fitting with any chosen motor in aspect of dimensions. There might be a little modification in the design if needed, but the general design is fine.

The arms of the exoskeleton are mated to move parallel to each other in order to avoid miscalculation of minimal imperfections in the mating process. As a minimal imperfection would lead that the arms move totally in different paths, so it will not be as accurate as how it is supposed to be in real-life simulation. Therefore, the parallel mate feature was used to make the simulation as close to real-life as possible. The design of exoskeleton is shown in Figure 1.

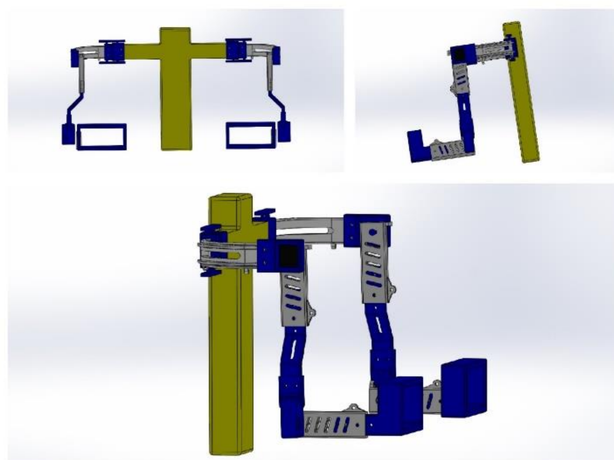

Figure 1: 3D Design of Exoskeleton

Some of the parts of the exoskeleton has empty spaces in the middle, that would be about reducing the total mass of the exoskeleton, which would make it possible to have smaller motor for the motion of the joints. The empty areas can be changed according to the stress analysis study that can be done on each part and apply maximum torque to study the bending moment.

Having the load being loaded on the exoskeleton would mainly make a change in the moment that is being subjected to each part, and that would also depend on each position the exoskeleton in moving through its motion path. That would be studied carefully through stress analysis on each part. Instead of making it dynamic stress analysis, it would be safer to apply maximum torque on each part by applying maximum load. This will endure during the process at the tip of the part, and to make the other tip of the part fixed as cantilever joint. Also the factor of safety will be taken into consideration which shall be at least 2 as it is a dynamic motion, according to the standard that was written by Robert L. Mott in his book Machine Elements in Mechanical Design [1]. Even though this standard is made for machine elements, it would be more safe for the operator to have a body that is designed to be as durable as machine elements, which are durable due to being expensive.

Motion Study

Implementing the motion study on Solidworks would mainly do a simulation of the normal motion that will be done by the exoskeleton during operation. That means having 4 motors, 1 on left shoulder, 1 on right shoulder, 1 on left elbow, and 1 on right elbow.

The study aims just to make a 90 degrees motion for each joint. The simulation would be moving from the position in #1 to the final position of #2 in Figure 2. The final position doesn't have to be reached in real-life situation, but it is the maximum of what a motor might face. Making a simulation that reach to that level would help to make the motor sizing process to be as powerful as possible for securing the motor to have longer durability while handling masses.

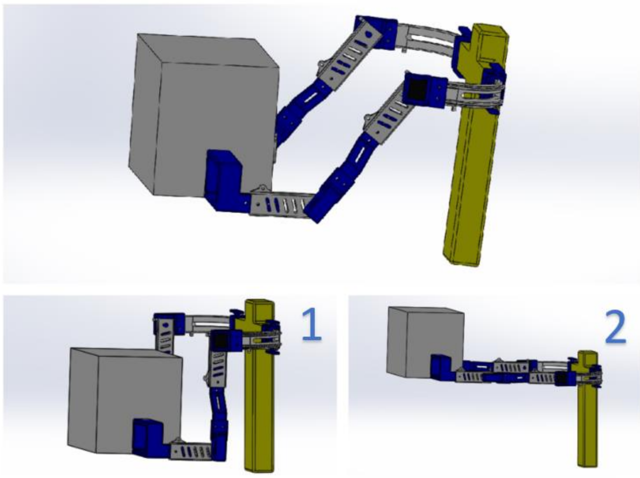

Figure 2: Design and Motion with Load

Mating feature in SolidWorks was important in this phase, as the mate to be done is the one that will be exported to MATLAB for calculation and further simulation to get the results with parameters to make the proper motor sizing. If mating was not done correctly, the arms will not move in synchronal manner, and will give a wrong Simulink model, which would affect the calculations done for the motion model.

Some problems have been encountered about mating the parts and the load. That's why the best solution was to mate the arms to be parallel to each other, so the motion profile would be the same. Moreover, the problem about mating the load with the ends of the arm had minimal imperfection. That is why the mating was not done on the same surfaces of each arm but was managed to be mated with each arm as well to make sure that each arm has the load and the mass applied to it, so the export to Simulink model would be as successful and accurate as possible to make it close to reality.

Multidomain Model

The exported XML file from the 3D model was imported through the MATLAB environment into the multidomain model. As a result, a data file and a Simulink model were created. The data file was necessary for the created blocks to work properly. It contained the information from the 3D model. Original Simulink file was perfectly capable of defining the parts of the design as a Simscape Multibody system. However, it was modified to be more understandable simply by organizing the blocks. To be more precise, joints were numbered as follows:

1. Left Shoulder
2. Right Shoulder
3. Left Elbow
4. Right Elbow

Inside the created Multibody system, it was started with the regular blocks which every worldly system starts, and then design blocks were created after the Transform block. Most importantly, joints were described with Revolute blocks and every Rigid block is a solid part in the design. The contents of the Rigid blocks are mostly very similar with each other as it can be seen Figure 3. Only difference between them is the number of ports. The relationships given in the previous tool were also featured in this system with Parallel, Prismatic and Planar blocks.

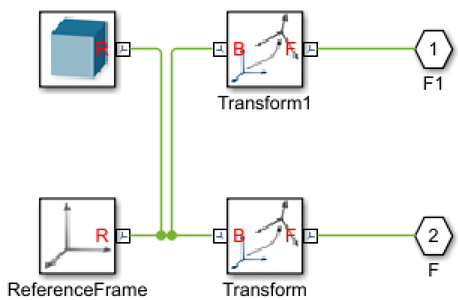

Figure 3: Rigid Block Example

The system is just a steady model with no motion given. It needed motors to simulate the motion since the previously created movements are not applicable in this tool. Motor blocks were created and added to joints. They give torque to the joint block and get the speed information as a feedback. Motor blocks can be seen in Figure 4.

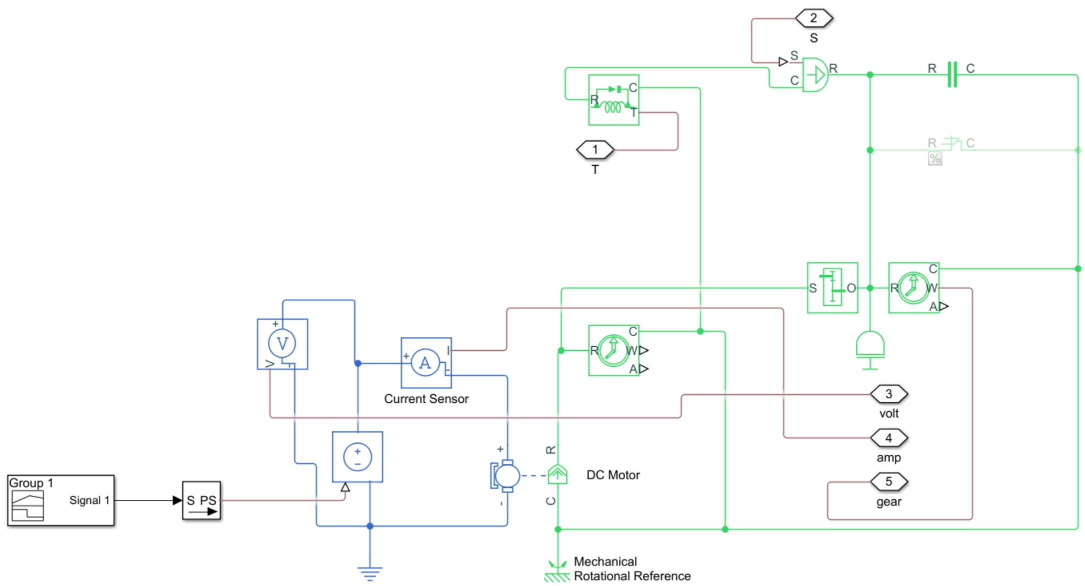

Figure 4: Motor Blocks

To be able to observe the voltage, current, and gear output a scope was added to all motors. The motor parameters and the plots are explained in below sections. The resulting system model can be seen in Figure 5 below.

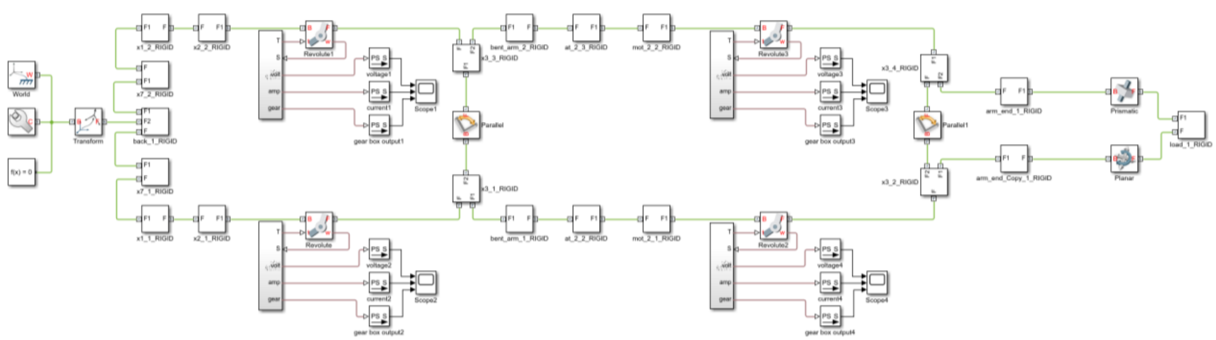

Figure 5: Complete Model

Motors & Parameters

When choosing motors for the exoskeleton, 3 different motor are compared from Maxon because it is an experienced company on producing exoskeleton motors. Most used motor type for upper-body exoskeletons are brushless DC motors. Therefore, 3 brushless DC motor models which are EC-i 40 [2], EC 60 flat [3] and EC 90 [4] flat are considered for this project. The important parameters that effects how much load a motor can lift are stall torque (which is the torque the motor can produce with zero rotation) and no-load speed. They are also the required parameters for multidomain model. The parameters of the motors are shown at Table 1. The motors have different parameters for 2 nominal voltage values, 18V and 48V. Only the maximum values are shown on the table.

Motor type	EC-i 40	EC 60 flat	EC 90 flat
Diameter	40 mm	60 mm	90 mm
Maximum Stall torque	4330 mNm	5010 mNm	7480 mNm
Maximum no-load speed	5000 rpm	4250 rpm	3190 rpm

Table 1: Motor Parameters

High torque is important for lifting heavy weights which EC 90 flat has the highest among the 3 motors. Also, speed of the motor has importance for keeping up with the fast movements of the human while using the exoskeleton. For this reason, EC-I 40 seems appropriate. Also, the dimensions of the motor have the most importance among the other parameters for this exoskeleton design. Therefore, the chosen motor is EC-I 40.

Simulation Results

After entering the parameters of EC-I 40 motor for 18V nominal voltage the first simulation is started and the model moved as expected. The movement of the model can be seen at Figure 6. At first no input is given to the motors so arms of the exoskeleton started go downwards slowly because of the box attached to its hands. After that input voltage is given to all 4 motors, the arms started moving until they are horizontal. For comparison purposes, for the left elbow and right elbow motors the input voltage starts from 0 and gradually increases until the end of the simulation time. For other two motors the input is given instantly. As a result of the first simulation, the output scopes of the motors at each joint can be seen at Figures 8, 9, 10 and 11. The joint numbers 1, 2, 3 and 4 correspond to left shoulder, right shoulder, left elbow and right elbow respectively.

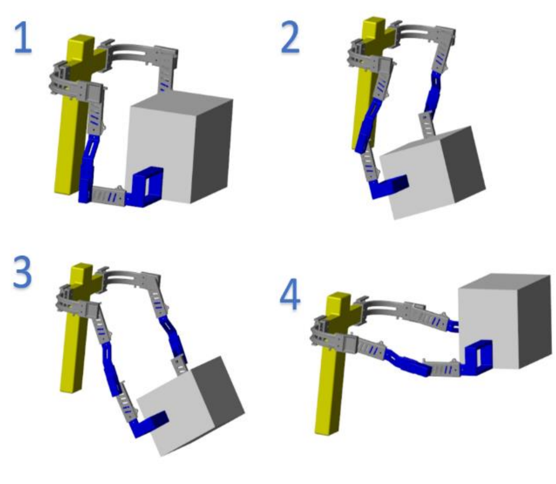

Figure 6: Simulation Motion with 18V parameters

At the beginning of the simulation there is in-rush current for each motor. This in-rush current can be harmful to the motor at high levels. However, in this case it does not exceeds the safe limits. Also, for the physical implementation there will be a microcontroller for the motors and there are microcontrollers that eliminates the in-rush current. After the in-rush current, as the input voltage (yellow line) increases the current (blue line) also increases until the end of the simulation motion.

For the second simulation the parameters for 48V nominal voltage are entered. After the end of the simulation, it is observed that with the same input given the arms are moved more than needed. Therefore, input voltage level is lowered, and the expected result achieved as seen in Figure 7. The output scopes of the motors at each joint can be seen at figures 12, 13, 14 and 15. Again the in-rush current and the other current changes are observed as expected. All in all, the simulations were smooth with the chosen EC-i 40 brushless DC motor.

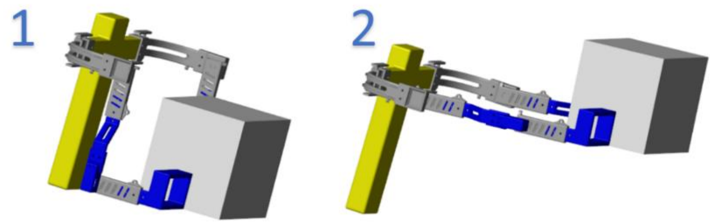

Figure 7: Simulation motion with 48v parameters

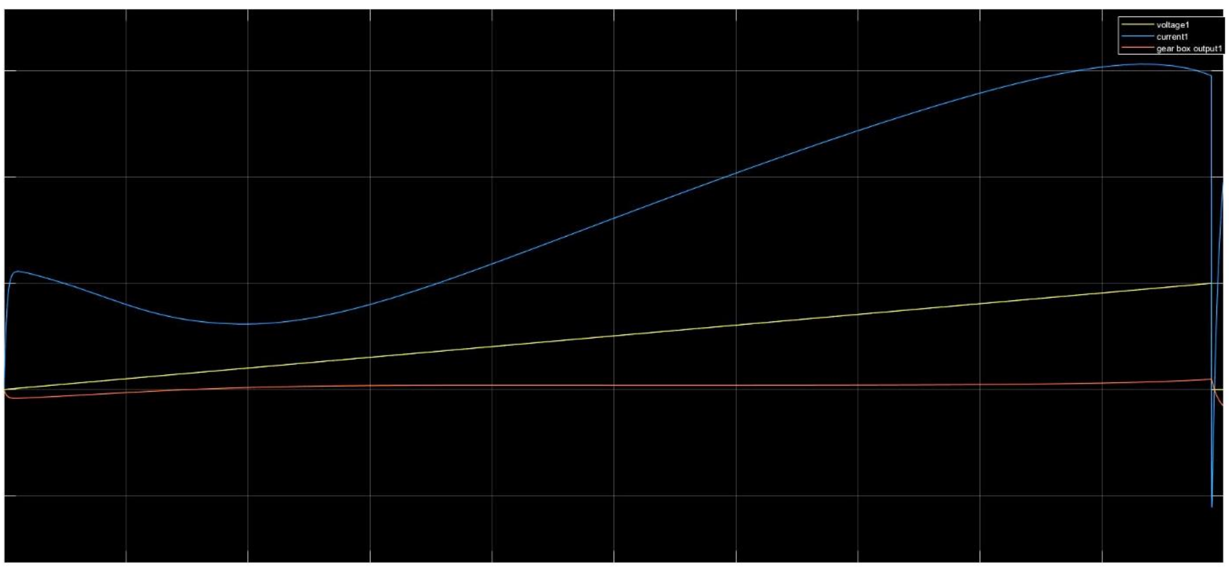

Figure 8: Joint 1 scope with 18v parameters

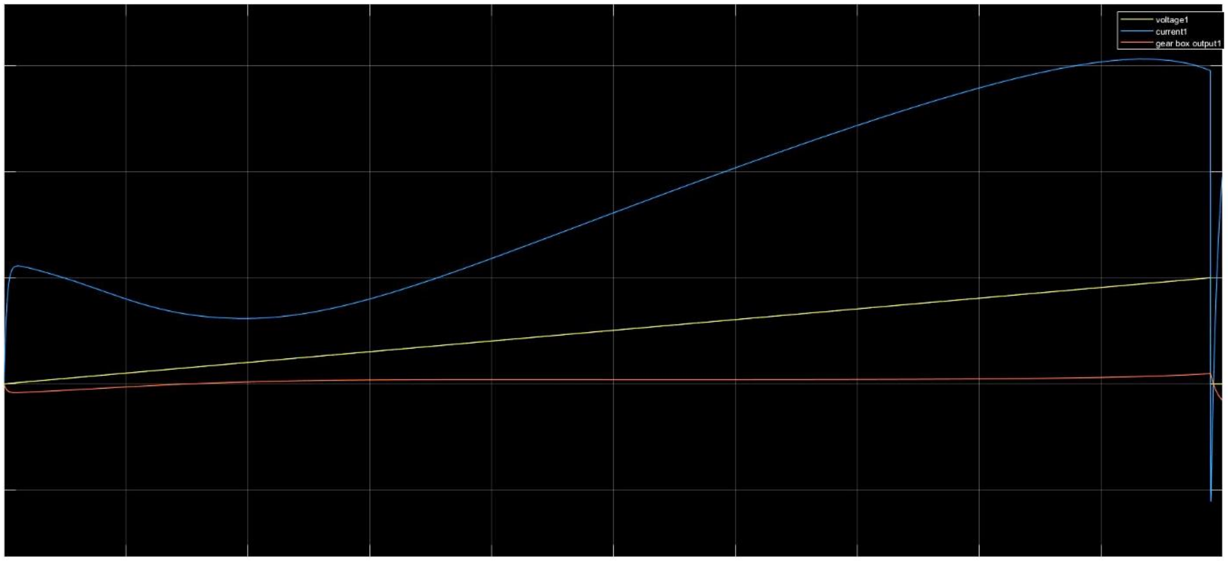

Figure 9: Joint 2 scope with 18v parameters

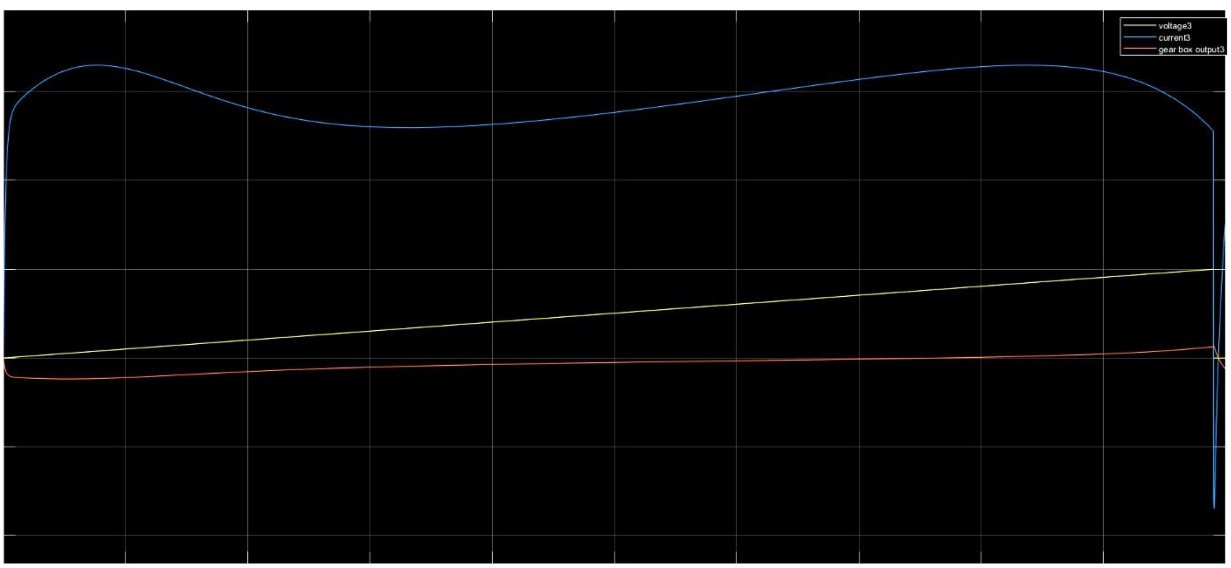

Figure 10: Joint 3 scope with 18v parameters

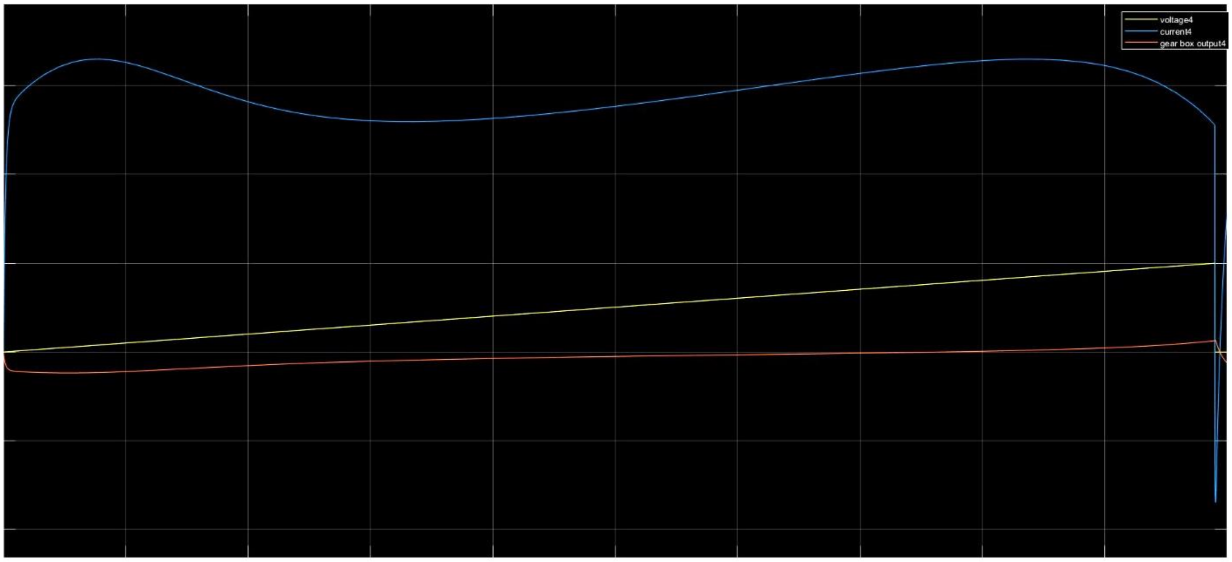

Figure 11: Joint 4 scope with 18v parameters

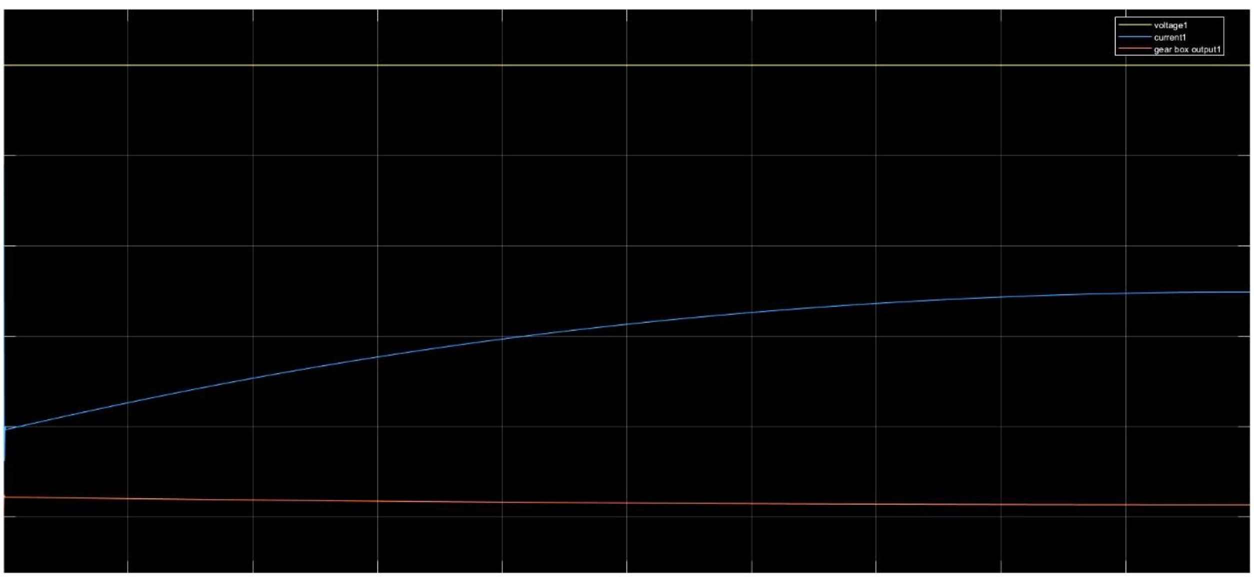

Figure 12: Joint 1 scope with 48V parameters

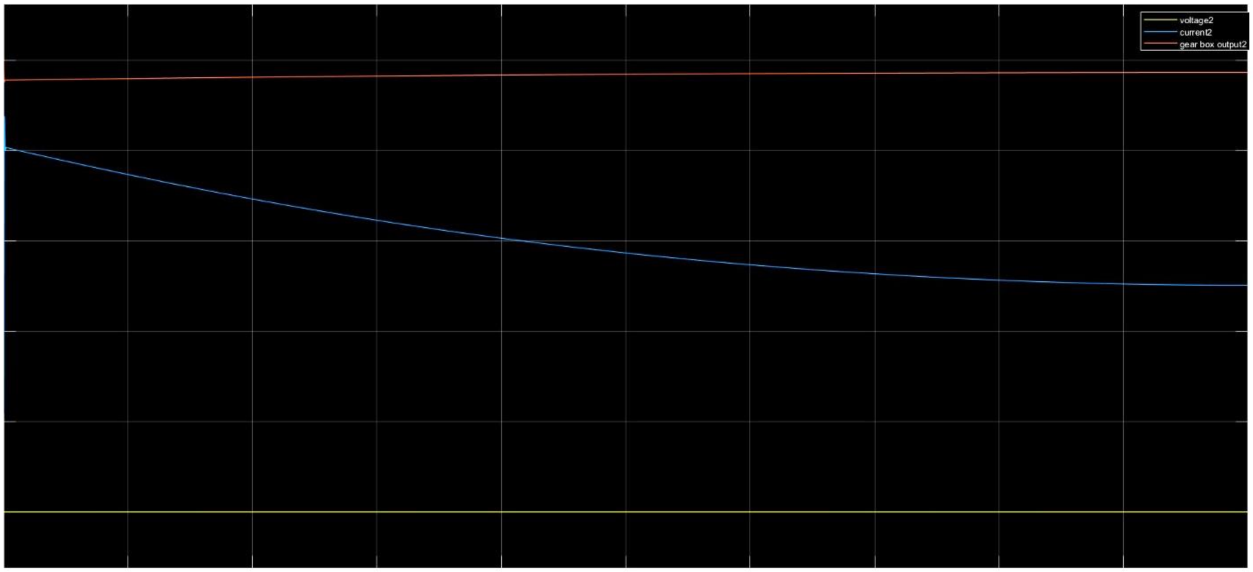

Figure 13: Joint 2 scope with 48V parameters

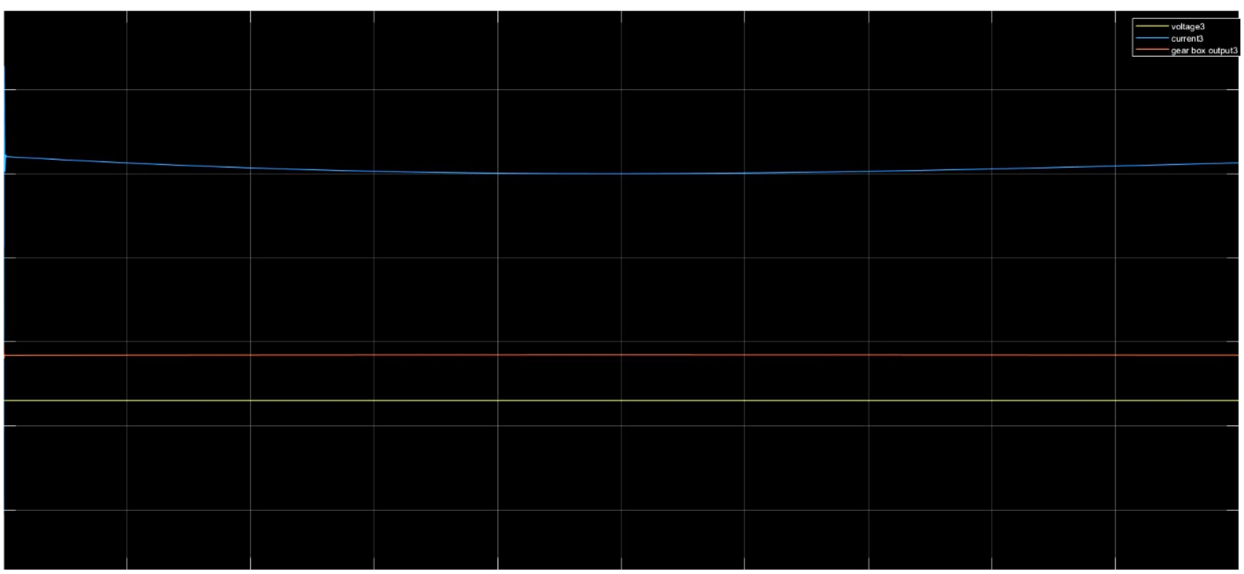

Figure 14: Joint 3 scope with 48V parameters

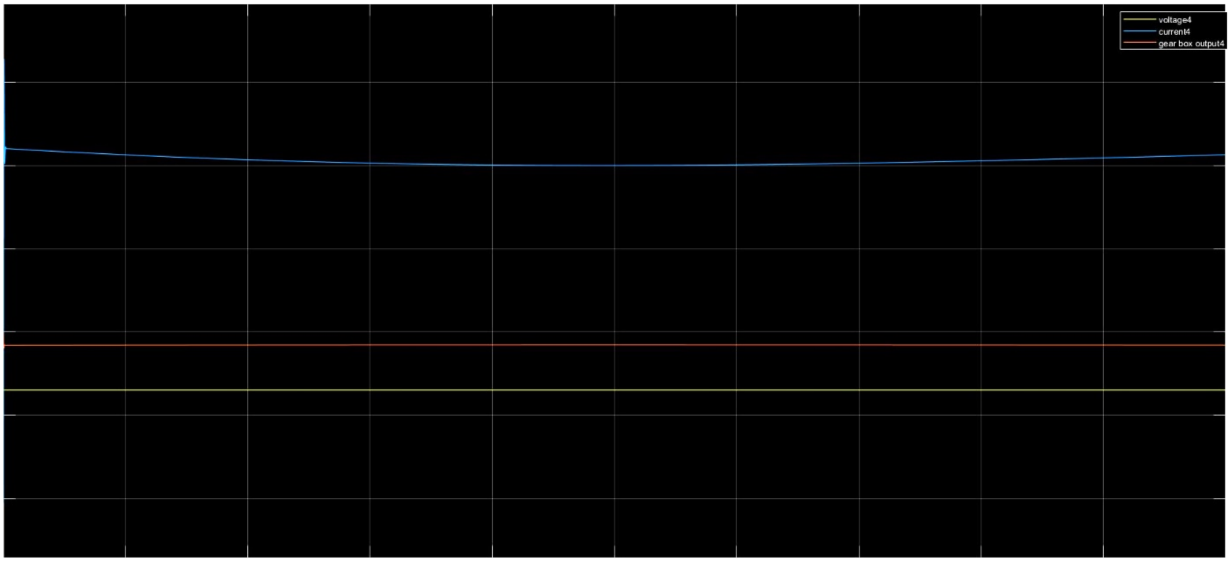

Figure 15: Joint 4 scope with 48V parameters

Conclusion

The aim of this task was to perform a simulation of the exoskeleton movement using features from Solidworks and MATLAB. In Solidworks, it was concluded that the best motion to assess and test the model is performing a 90 degrees motion for each joint, whose results were demonstrated above. Afterwards, the model was exported to MATLAB's Simulink environment to test proposed real motor performance in a loaded operation. This purpose has been successfully fulfilled.

Simulation results show in-rush current at the beginning of the simulation for each motor. This in-rush current can be harmful to the motor at high levels. However, in this case it does not exceeds the safe limits. Moreover, during physical implementation, a microcontroller will be used, which eliminates in-rush currents.

This study provided insightful results, and potential errors, to be considered during later phases of prototyping and implementations. Along with regulations and guidelines obtained from engineering standards governing exoskeletons and exosuits, this forms a very good starting point for further research and implementation.

References

[1] R. L. Mott, Machine Elements in Mechanical Design, 2004.

[2] EC-i 40 motor datasheet, [Online]. Available: https://www.maxonmotor.com/medias/sys_master/root/8830903517214/2018EN-250.pdf

[3] EC 60 flat motor datasheet, [Online]. Available: https://www.maxonmotor.com/medias/sys_master/root/8831018893342/2018EN-270.pdf

[4] EC 90 flat motor datasheet, [Online]. Available: https://www.maxonmotor.com/medias/sys_master/root/8825435389982/17-EN-271.pdf