Laboration: Force control of The Classroom Exo

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1 Lab Introduction

Summary

In this chapter you will find the necessary documentation to setup your Classroom Exo, and try out the Force options. We have prepared some Lab exercises, to help you learn more about the force control options!

An exoskeleton is a wearable mechanical structure that enhances or restores the physical abilities of the wearer by providing external support or amplification of movements [6]. As the field of robotics grows leaps and bounds with every passing day as the world of STEM aims to integrate technology with humans to aid and support or enhance activities of daily living. Education leveraging these technologies has however been lacking. This lab is intended for use at a university level and is a derivative of a project aimed at converting an open-source exoskeleton into educational material [6]. The Classroom Exo, the product that we will be using through the course of this lab, is a student-friendly optimized version of the EduExo Pro - An Advanced Robotic Exoskeleton Kit developed by Auxivo AG.

1.1 Risk section

The Classroom Exo is not categorized as a medical device. Instead, its primary focus is educational. It is designed to provide hands-on experience with various control systems. There are some risks associated with the use of the Classroom Exo. Listed below are the potential risks, what has been done to prevent them, and the possible causes of these risks.

- **Muscle fatigue:** Muscle fatigue can occur during prolonged use, as the Classroom Exo is somewhat heavy. To minimize this risk, an ergonomic design and proper usage guidelines have been implemented.
- **Injury risk:** The risk of injury is very low, but it still exists. The primary cause is misalignment between the Classroom Exo's mechanical joints and the user's shoulder and elbow joints. This risk has been minimized through proper calibration, an emergency stop feature, and clear instructions for how to put on the Classroom Exo.

1.2 Learning objectives

The goal of this lab is to provide hands-on experience with the Classroom Exo as a practical example of applying engineering principles within the biomedical field. Throughout the lab, you will explore how force sensors can be used to control an exoskeleton. By experimenting with different thresholding levels you will consider the practical applications of force-controlled exoskeletons, understanding how and why they are used in different scenarios. By the end of this lab you should be able to:

- Implement force control on an exoskeleton and adjust threshold settings.
- Explain how threshold settings influence exoskeleton movement, and analyze its impact on performance and safety.

- Evaluate the practical applications for this control method in terms of use case and user safety.

1.3 Prerequisite knowledge

There is no specific prerequisite knowledge required for this lab. Any student group interested in product design, user safety, or gaining insight into biomedical engineering principles can benefit from this lab. However, due to the complexity of the system, the use of MATLAB, and potential troubleshooting, this lab may be most suitable for engineering students.

1.4 Materials and methods

For this lab, you will need a Bluetooth-enabled computer and MATLAB 2023b (although newer versions should also work). We will be interfacing with the exoskeletons using the "Updated BT-GUI" MATLAB application. Additionally, you will need one exoskeleton and a 2.5 and 3,0 Allen Key to adjust the arm length of the exoskeleton to fit the anatomy of the student who will be wearing the exoskeleton.

1.5 To do at home before the lab

To make the most of the limited time you will have with the exoskeletons, you must come to the lab session well-prepared. Unforeseen issues or complications with the setup of the exoskeletons may arise, so proper preparation will ensure you have as much hands-on time as possible with the exoskeleton. Therefore before the lab asks you to:

1. Download MATLAB 2023b.
2. Download the "Updated BT-GUI_10-24" folder from the GitHub link: https://github.com/fabianjust/classroom-exo
3. Download and install the following MATLAB packages:
   - Control System Toolbox (version 23.2)
   - Instrument Control Toolbox (version 23.2)
   - Robotics System Toolbox (version 23.2)
   - Sensor Fusion and Tracking Toolbox (version 23.2)
   - Signal Processing Toolbox (version 23.2)
   - Symbolic Math Toolbox (version 23.2)
4. Read the lab PM thoroughly.

2 Introduction to the Exoskeleton

Exoskeletons are increasingly being incorporated into rehabilitative settings, such as walking assists for people who have undergone spinal cord injuries, strokes, etc., in physiotherapy, and occupational therapy [4]. Although aimed to be used in educational settings only, the Classroom Exo is an exoskeleton connected to the upper part of the body, over the shoulder, and the upper and lower arm, with a spring support to help lift the arm Figure 1. Programmed on Arduino, it has three control systems - proportional–integral—derivative controller (PID Controller), Electromyography signals from the muscles, and a force sensor on the wrist, the software of which is accessible as open-source, with a classroom-friendly graphical interface implemented on MATLAB.

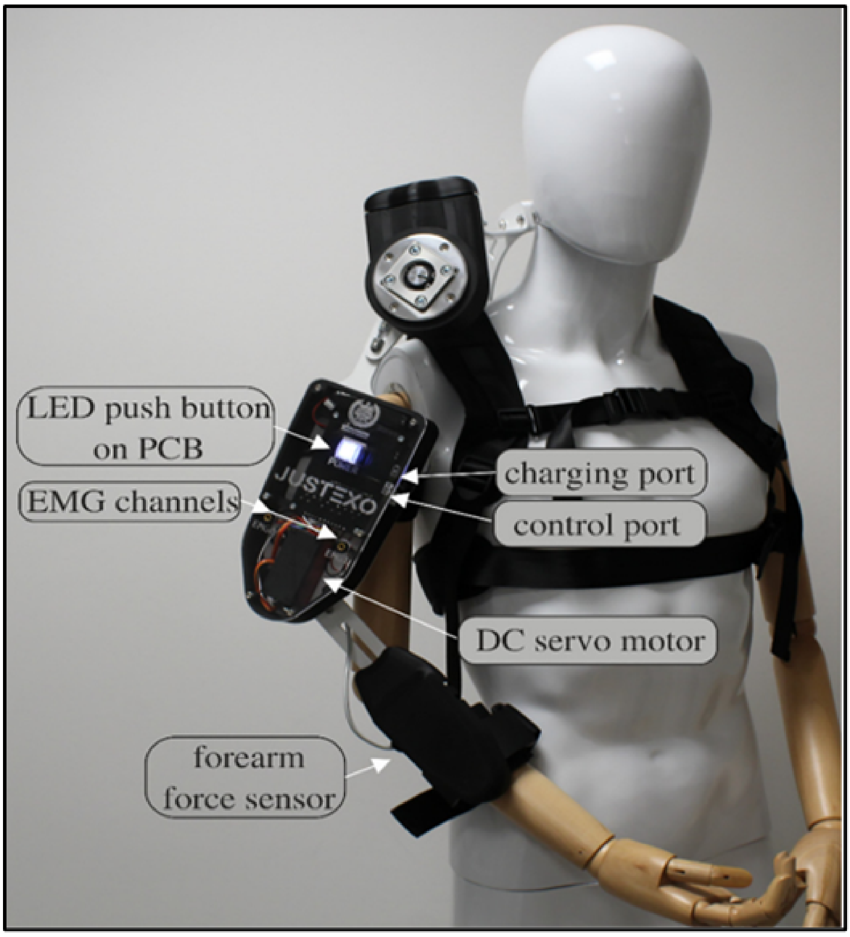

Figure 1: *The Classroom Exo and its adaptations from EduExo Pro*

2.1 Setting up the Classroom Exo

While putting on the exoskeleton it is helpful if one person holds it up and another tightens the straps.

1. Put on the vest and fasten the buckles.
2. Make sure that the shoulder part of the exoskeleton is aligned with your shoulder, which can be seen in Figure 2. And then tighten the chest and waist straps.

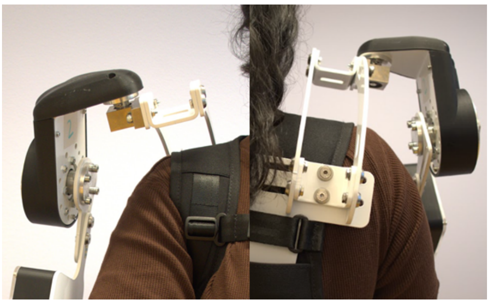

Figure 2: *Shoulder joint aligned (left) and misaligned (right).*

3. Tighten the straps around the elbow and the wrist and check alignment with the elbow joint according to Figure 3.

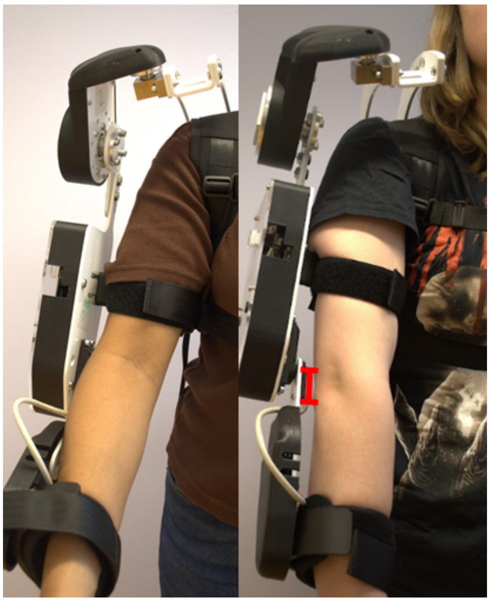

Figure 3: *Correct alignment of elbow joint (left) and incorrect alignment (right), misalignment marked in red.*

4. If the Classroom Exo has the correct joint alignment as seen in figure 4 and 3, proceed to section 2.1.2. If not, proceed with section 2.1.1 "Adjusting the exoskeleton".

2.1.1 Adjusting the exoskeleton

To be able to adjust the arm length of the Classroom Exo, a 2.5 and 3.0 Allen Key is needed.

1. Under the shoulder joint on the back of the exoskeleton you can find two bolts for which the 3.0 Allen Key fits, the bolts are marked in Figure 4. Loosen these, align shoulder joints according to Figure 2 and tighten the bolts.

Figure 4: *Bolts for adjusting shoulder breadth in red.*

2. To align the elbow, loosen the bolts on the inside of the shoulder joint illustrated in Figure 5. Use the 3.0 Allen key to do this. Slide the arm such that the elbow joint of the exoskeleton and the user is aligned such as in Figure 3. Tighten the bolts.

Figure 5: *Bolts to adjust upper arm length for elbow alignment marked in red.*

3. To adjust the position of the wrist cuff, loosen the bolt on the lower part on the arm of the exoskeleton marked in Figure 6, using the 2.5 Allen key. Adjust length and tighten the bolts.

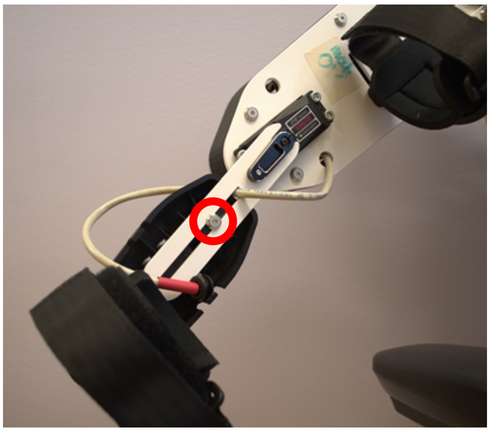

Figure 6: *Bolts to adjust lower arm length for positioning of wrist cuff marked in red.*

2.1.2 Connecting to the device and starting the GUI

1. Turn on the exoskeleton by pushing the "LED push button on PCB" as seen in Figure 7. It should blink blue indicating that it is searching for a Bluetooth device.

2. When you are connecting to the exoskeleton for the first time, go to your computer's Bluetooth settings and add a Bluetooth device. When pairing, the name of your device will be XX_CLASSROOM_EDU_EXO_PRO where the XX is a number between 01 to 08 depending on which exoskeleton you have.

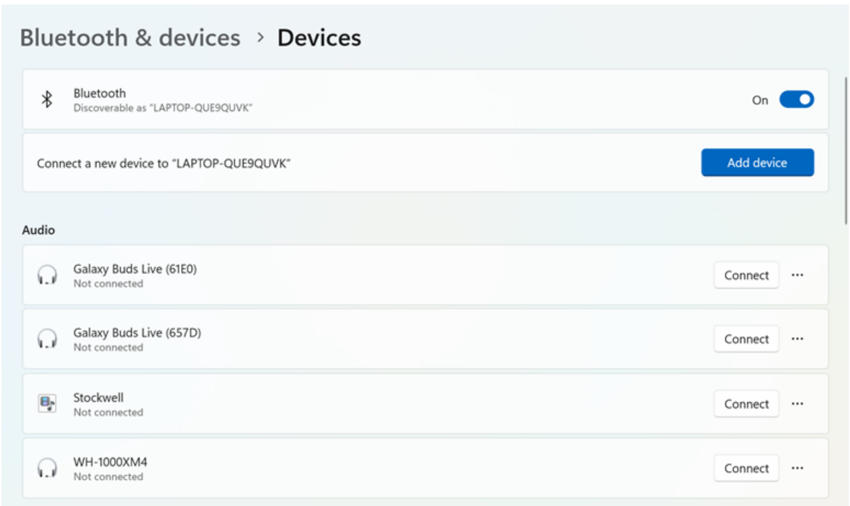

Figure 7: *Pairing to a Bluetooth device for the first time.*

3. In your computer's display settings set the screen size to 100%.

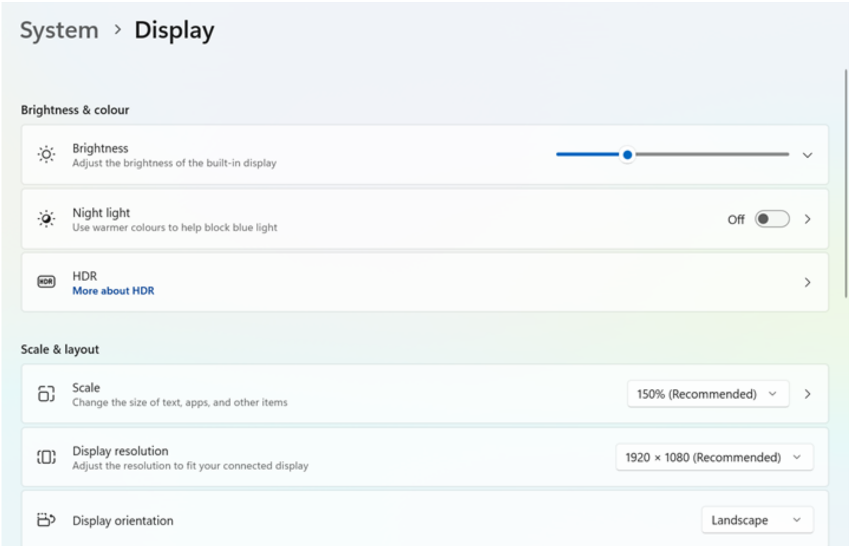

Figure 8: *Changing screen sizing.*

4. Open MATLAB, locate the BT_GUI file and double click on it. Or locate the file in your file explorer and select open with MATLAB. If you open the file in MATLAB's app designer, click run.
5. When the GUI is opened, choose the correct Bluetooth device, and click connect.

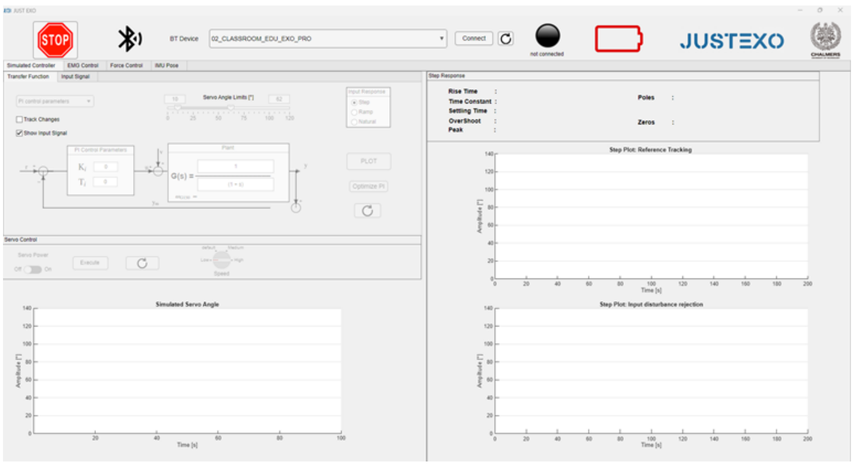

Figure 9: *Connecting to the Bluetooth device.*

The power button on the exoskeleton and the indicator in the GUI should change color to either green, yellow or red depending on the battery level.

3 Force controller

3.1 Introduction

Force control enables systems to detect and respond to external forces, making them adaptable to environmental changes or user force input [2]. This concept is widely used across engineering, from rehabilitation to industrial applications [5]. In rehabilitation, exoskeletons use force control to either assist in or add resistance to patients' intended motions [2]. By using exoskeletons we can allow for movements that the patient otherwise could not perform, avoid over-extension, relieve physiotherapists' work burden, and gradually reduce the assistance as the patient regains strength [2, 1].

Additionally, it might be useful in industrial settings for workers where the motor in the exoskeleton helps them in movements when the sensors detect forces or strains that would otherwise be harmful to the worker's body, thus preventing injuries [3].

The Classroom Exo uses strain gauges at the wrist cuff to detect forces, see Figure 1. When these sensors experience deformation due to a force, they change their resistance, altering the voltage over them [6]. These sensors allow the exoskeleton to detect a voltage difference when an upward force exceeds a threshold and subsequently flex the elbow joint. Similarly, exceeding a downward threshold causes the elbow joint to extend, moving the arm to a straighter position.

3.2 Force controller setup

The exoskeleton should be put on before starting this part.

1. Choose the "Force control" tab, and then the "Threshold" tab, which can be seen in Figure 10.

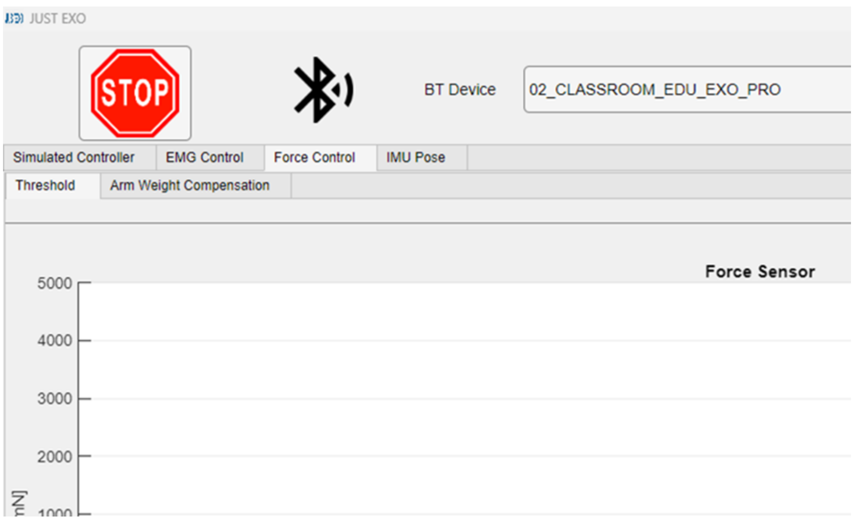

Figure 10: *Choosing the force control tab (red) and the threshold tab (blue).*

2. At the bottom of the tab, you can see the force control parameters. Where you can change the upper and lower threshold force limits, the servo motor speed, and the applied filter. See Figure 11.

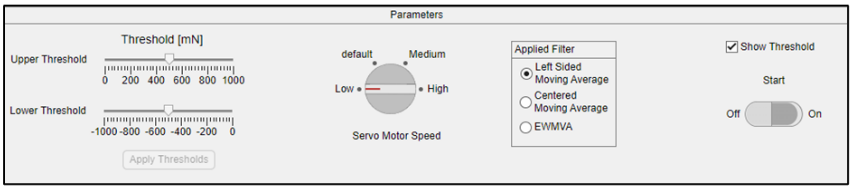

Figure 11: *The tunable force control parameters.*

3. Ensure the "show threshold" box which you can see in Figure 11 is checked to see when the force on the wrist cuff exceeds the upper or lower threshold. 4. Click start. When trying out the force control by flexing and extending your arm you should see something like this:

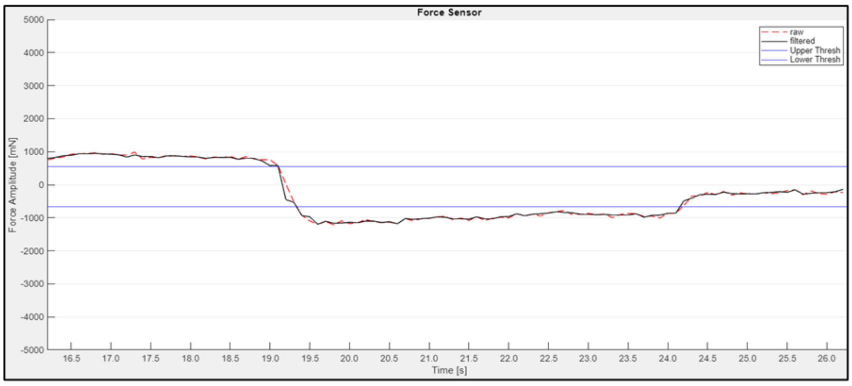

Figure 12: *Force sensor data.*

5. When changing the threshold values, make sure to click "apply thresholds" and turn the start button off and then on again.

3.3 Exercises

Attention

OBS! You can break pieces of the exoskeleton. Don't try to exceed thresholds by more than necessary.

This section outlines a series of exercises to be completed during the allotted lab time. These exercises are designed to deepen your understanding of how Force control can be applied in combination with the Classroom Exo. The results of the exercises must be documented in a separate report. The question exercises are meant to be discussed within a group.

3.3.1 Default sensitivity

Test the default threshold settings (lower threshold = -500 mN, upper threshold = 500 mN) to understand what force control feels like.

Tasks:

1. Flex your bicep to exceed the higher threshold and see how the elbow joint flexes.
2. Try to straighten your arm, exerting force in the other direction exceeding the lower threshold causing the joint to straighten.

Question:

1. Is there a maximum and minimum angle of the elbow flexion and how does this play into user safety?

3.3.2 Rehabilitation scenario

To simulate a rehabilitation scenario we will now increase the sensitivity of the system.

Tasks:

1. Set the lower threshold value to -100, and set the upper threshold to 100.
2. Now try to flex your arm and extend it. How is it different from the default threshold settings?

Questions:

1. In what real-life use-cases for exoskeletons would there be for high-sensitivity sensing of forces?
2. Experiment with different thresholds. Can you find a usable threshold for the use case you thought of? If you couldn't find a usable threshold, why?

3. In a rehabilitation setting, how can lower versus higher sensitivity affect the users in terms of support and safety?
4. Are there any other safety risks in this use case?

3.3.3 Worker scenario

In this section, we will simulate an industrial worker as a user by setting the thresholds so we have a low-sensitivity system.

Tasks:

1. Try setting the lower threshold to a higher setting and the upper threshold to a lower value. A suggestion would be to set the lower threshold to a value close to -1000, and the upper threshold to 1000.
2. Test it out, what does it feel like?

Questions:

1. In what real-life use cases for exoskeletons would there be for low-sensitivity sensing of forces?
2. Experiment with different thresholds, which ones do you think work best for this scenario and why? If you couldn't find a usable threshold, why?
3. How does a lower versus higher sensitivity affect the users in this use case in terms of support and safety in this use case?
4. Are there any other safety risks in this use case?

3.3.4 Servo speed

We will now experiment with servo speed and reflect on the uses.

Tasks:

1. Set the speed to low, medium, and then high.
2. Test it out, what does it feel like?

Questions:

1. What would be the benefit or drawback of having a static servo speed?
2. What would be the benefit or drawback of having a dynamic servo speed?
3. Reflect on this in terms of use case and safety.

3.4 Discussion

For the best learning experience, feel free to discuss the results your group obtained from each step between groups to gain understanding and new perspectives.

1. What differed between your answers and the answers of other groups?
2. Why did your answers or conclusions differ?
3. Did your discussions between groups lead to new insights or ideas? If so, what were they?

4 Typical errors and Troubleshooting

In this section, we present typical errors and issues encountered during testing of the Classroom Exo.

1. If you experience that the exoskeleton arm switches between extending and contracting, almost vibrating, it might be because the upper and lower thresholds are too close to each other.
2. If the thresholds are not showing or the signal is not showing after changing the thresholds, then click "apply thresholds" and turn the start button off and then on again. Wait for the signal to appear.

Hint

You can find a more comprehensive Troubleshooting documentation in the Manual on our GitHub!

References

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