CS-358 Making Intelligent Things

Revised Project Proposal, “Robotic Hand Exoskeleton for Enhancing Fingering Skills and Agility of Pianists”

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1) Description and motivation

Motivation

Nowadays, hand exoskeletons are commonly used for rehabilitation therapy following health accidents such as strokes. Its efficacy in muscle memory training has the potential to be exploited in the fields of music, technology, and rehabilitation therapy.

Our project aims to facilitate muscle memory training of various piano techniques for pianists seeking to strengthen specific muscles and refine pianistic skills with greater efficiency. By using a lightweight hand exoskeleton, we can enforce specific positions at a given rhythm that allows the user to acquire a specific technique more quickly compared to traditional training.

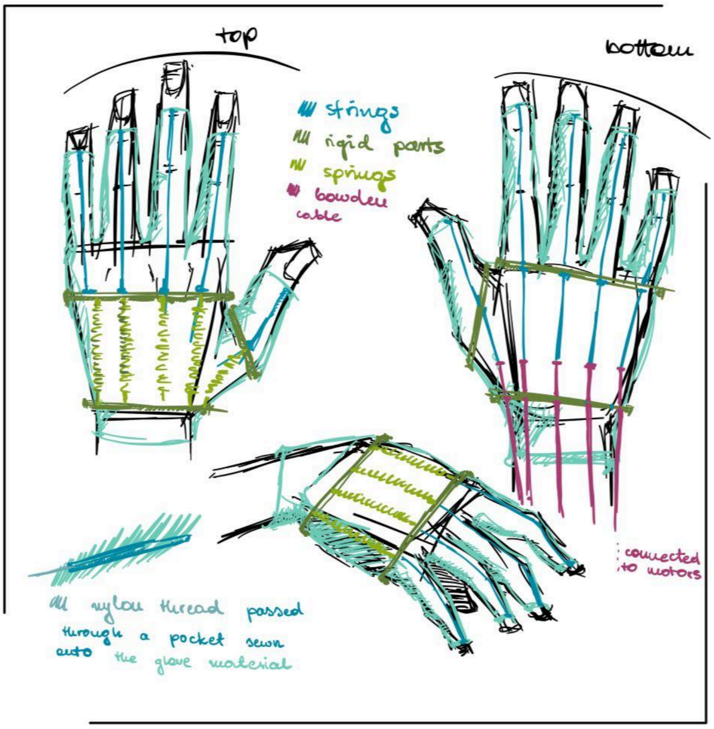
We want the user to be able to input a technique and a specific tempo that they wish to train using an accompanying software tied to the exoskeleton. This then allows the exoskeleton to reproduce the movements of the technique.

How we achieve this

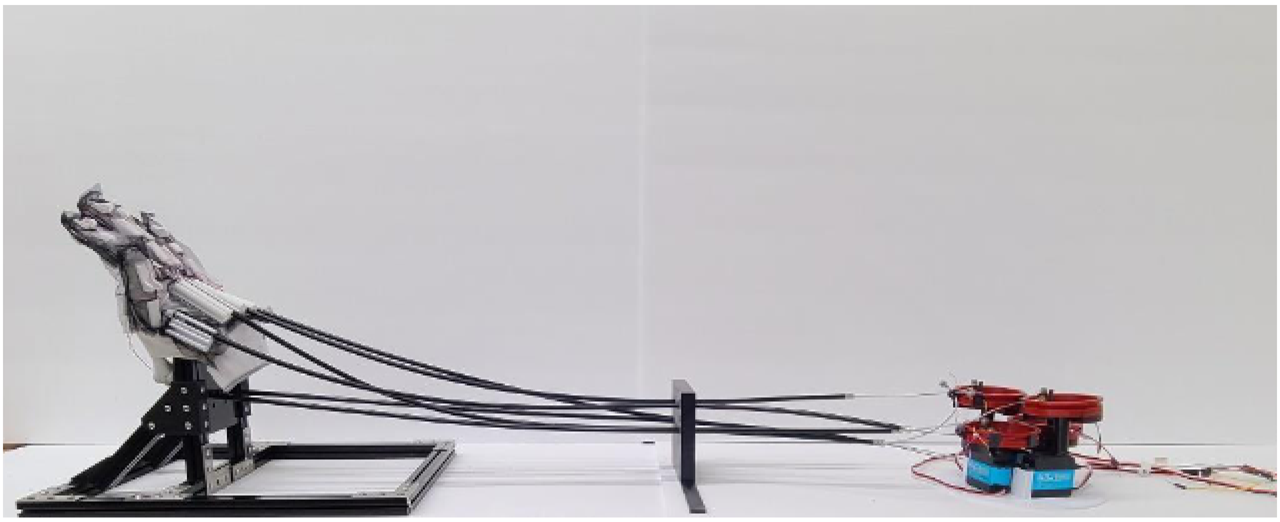
To let the user obtain pianistic skills with great efficiency, we build a hand exoskeleton that has both push and pull abilities onto the digits of the user. We also need to be able to gather data on the specific technique that needs to be reproduced in the exoskeleton, so that we can convert this information into mechanical instructions interpretable by the device. Finally, this needs to be nicely integrated into an interface (web for example) that facilitates the recording and replaying of sessions for the end user.

The mechanical build

To create the hand exoskeleton, we use a combination of Bowden cables attached to nylon strings in order to pull the fingers inward of the palm and tension springs to pull them back.



For the tensioning system, we use 5 servo motors, one per finger digit so that all motions are accurate. This involves designing 3D parts for the tensioning system such as spools to rotate the strings and create tension. All hand parts would be attached to an elastic fabric glove to fit a wider range of hand sizes and shapes.



Project reference from [Reference 1]

For safety and testing purposes, we would use a 3D-printed mannequin hand during the earlier stage of the project development. An existing model is available here.

The software

1. Recording the data:

We first need to determine our source data which will be used to reproduce the technique played. Important factors include timing, force, and velocity. For this purpose, we have decided to use a MIDI keyboard as its MIDI interface allows us to gather information on when a key is pressed, how far it is pressed, and the velocity with which it is pressed, through MIDI messages that can be read over a USB connection to a computer.

Additionally, we can use computer vision with a smartphone camera to gather information on which finger pressed which key. In combination with the MIDI data, we should have enough information to reproduce the technique with a good degree of accuracy.

2. Interpreting the data:

Once we have acquired the data cited previously we need to process it through a coded interpreter, running on a computer, which will then output servo instructions to be executed using the Arduino UNO which connects the servo motors. This requires a careful analysis of the MIDI and computer vision data to obtain glove movement that mimics the recorded technique best.

Furthermore, we could also model our interpreter to translate only MIDI data (no computer vision) as many MIDI files are available online. This would allow users to train on a wider range of pieces which they are not familiar with. This would of course complexify the interpretation as we wouldn't have information on which fingers are used. But this could be inferred with some clever logic and be serviceable.

3. Using the device:

Finally, we will design and code a web app interface, using html, in order to facilitate the use of the device. It would allow the user to easily launch a recording session, visualize the recorded data, process it, and then send the instructions to the device to start a training session.

2) Work breakdown

- (3D design in Fusion)
- (Hardware)
- (Software)

<u>Week 7:</u>

- Task 1: 3D print the mannequin hand to experiment without risking physical damage. ♦
- Task 2: Design and print the servo motors' enclosure and fixation plate in Fusion ♦ ♦
- Task 3: Start coding the software : retrieve the MIDI data coming from the keyboard. Store the data for later use. ♦
- Task 4: Design and print the spools to be attached to the servo motors ♦ ♦

<u>Week 8:</u>

- Task 5: Design and print the 3D parts to attach the nylon strings to the fingers. ♦ ♦
- Task 6: Design and print the 3D part to hold the tension springs. ♦ ♦
- Task 7: Attach velcro patches to the dorsal part of the glove. ♦
- Task 8: Design and print the Bowden cable holders. ♦ ♦
- Task 9: Start coding the interpreter for the MIDI data to servo motors instructions. ♦
- Task 10: Design and print the hand holder. ♦ ♦

<u>Week 9:</u>

- Task 11: Cut the glove fingertips and attach 3D parts such as cables and spring holders. ♦
- Task 12: Attach the nylon strings to the Bowden cables and the servo spools. ♦
- Task 13: Assemble and connect the glove to the tensioning system, and fix it on the hand holder. ♦
- Task 14: Continue the interpreter, and experiment with recording and replaying movements to fine-tune the translation of MIDI to servo motor instructions. ♦

Milestone 1: The glove is fully assembled, movement is functional, and it can manually send commands to the servos to move the hand. The interpreter is partially coded. Estimated deadline: 28th April.

<u>Week 10:</u>

- Task 11: Finish the interpreter for the MIDI data to servo motors instruction. ♦
- Task 12: Do end-to-end testing, record then replay, all using MIDI data, fine-tune and debug. ♦ ♦
- Task 13: Start coding the web app interface. ♦
- Task 14: Fix any potential hardware-related problems. ♦

<u>Week 11:</u>

- Task 15: Record video with a smartphone and transfer it to a PC in real time. ♦
- Task 16: Start coding computer vision to detect individual finger presses. ♦
- Task 17: Continue the web app interface, should be able to start recording and replaying directly from it, and also visualize MIDI data in real time. ♦

Milestone 2: The web app interface allows registering key presses through MIDI and replaying them through the glove manually. Which fingers to press which keys are manually set. Estimated deadline: 12th May.

<u>Week 12:</u>

- Task 18: Continue computer vision development, should be able to precisely determine which fingers are pressing a key at a certain time. ♦
- Task 19: The web app interface should be able to display the computer vision visualization in real time. ♦
- Task 20: Start coding the combination of the MIDI data with the computer vision data to generate motor instructions for the right fingers automatically. ♦

<u>Week 13 :</u>

- Task 19: Finish the implementation of the computer vision data in the interpreter. ♦
- Task 20: Fine-tune every aspect of the project if it is not already as intended. ♦ ♦

Milestone 3: The interpreter is linked with computer vision to automatically map keypresses to fingers, a video feed is also integrated into the web app interface. Estimated deadline: 26th May

Optional goals: The hand exoskeleton can replay without computer vision by inferring which finger is pressed. If for some reason we cannot get computer vision to nicely work we can drop it and base everything on the MIDI data. But it can also be a useful feature even if computer vision is working.

3) Bill of materials

#	Item name	Quantity (Price/item)	Redundancy
1	Arduino Uno Board (in stock)	1 (5.-)	0
2	Stretch Gloves size M	1 (14.90)	1
3	Bowden cables	5 (1.67)	5
4	Tension springs	5 (0.6)	5
5	Servo motors DMS15 (in stock)	5 (5.-)	2
6	Nylon strings	1 (7.-)	0
7	MIDI keyboard	1 (97.-)	0
8	Velcro tape	1 (6.45)	0
9	Sewing kit	1 (8.90)	0

This table gives the number and price of each item we would need for the project and the number of spare parts we want to have some margin of error for testing and experimenting.

4) Risk Assessment

Risk 1: Thumb Movements

There's a risk that the device could restrict the freedom of movement of the fingers or not accurately translate the intended motions, especially that of the thumb.

Solution: Adapt the springs with a given hand dimension to have a natural feeling of playing the piano.

Risk 2: Computer Vision

Implementing computer vision to accurately track finger movements and key presses on a piano in real time could be challenging due to varying lighting conditions and the speed of finger movements.

Solution: Drop computer vision and instead, design a clever algorithm to infer finger positions based on the MIDI data. The timing and ID of the key pressed can be used to deduce which fingers are used.

Risk 3: Springs are not suited

It is possible that when assembling the hand exoskeleton it turns out that springs are not adequate to pull back the fingers as they could feel unnatural and uncomfortable to the user.

Solution: We could make the nylon strings wrap around the hand so they are connected to other Bowden cables on the dorsal side of the glove, we can then adapt the tensioning system to be able to pull in opposite directions.

5) Bibliography

1) Wearable Assistive Hand Exoskeleton for Activities of Daily Living

2) DextrEMS: Increasing Dexterity in Electrical Muscle Stimulation by Combining it with Brakes

3) Fully Wearable Actuated Hand Exoskeleton for Assistance in Daily Life and Therapy

4) Hybrid-Exoskeleton-Glove

5) Hand Exoskeleton for Rehabilitation