Multimodal Sensing Sleeve for Rehabilitation

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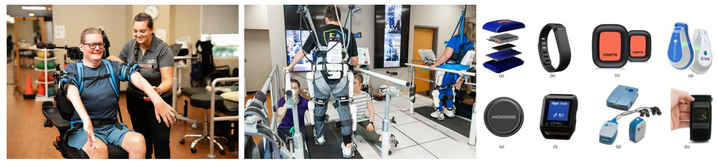
Wearable Intelligence Lab

Motivations & Background

Physical rehabilitation sensing technologies play a critical role in:

- enhancing patients' recovery through real-time monitoring
- help doctors evaluate the effectiveness of rehabilitation treatment



Current Limitations

- Traditional Physical Rehabilitation Device
  - Bulky → Limit patients' movement & Reduce doctors' evaluation accuracy
- Current Wearable Device for Physical Rehabilitation
  - Can't measure muscle activity & joint bending angles simultaneously
  - Can't be applied to different joints

Proposal: A novel **multimodal smart sleeve** with a customized **portable sensing circuit** for muscle activity monitoring and joint angle measurement

Methodology

Muscle Activity Measurement

- **Electrical Impedance Tomography (EIT)**
  - A circular array of electrodes
  - Current Injection into the opposite electrodes
  - Voltage Measurement between adjacent electrodes
  - Bones, blood, muscles have different impedance
  - Recover the structure of muscles
- **Electromyography (EMG)**
  - Measure and Amplify the change of myoelectrical signals

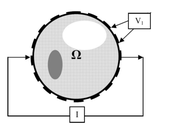


Fig. Working Principle of EIT

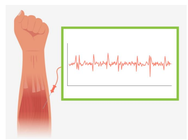


Fig. Illustration of EMG

Joint Bending Angle Measurement

- **Capacitive Sensing (Cap)**
  - When bending, area (A) ↑, and distance (d) ↓ → Capacitance (C) ↑

$$C = \varepsilon \frac{A}{d}$$

  - Change of the capacitance → Bending angles: $C = \frac{Q}{V}$

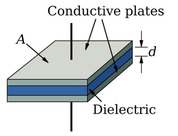


Fig. Schematic of Parallel Plate Capacitor

Sleeve Design

Techniques and Materials

- Knitting: Stretchable & Comfortable & Washable
- Electrode: Standard Steel Conductive Yarn
- Non-conductive areas: Acrylic Yarn

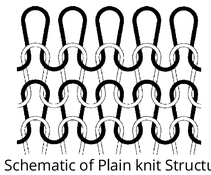
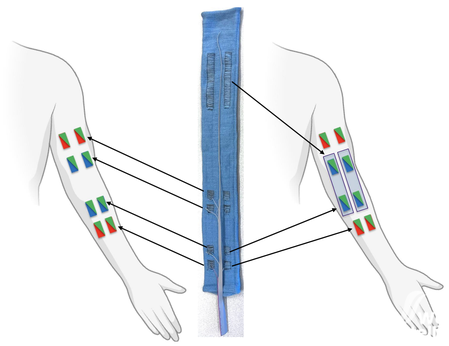


Fig. Schematic of Plain knit Structure

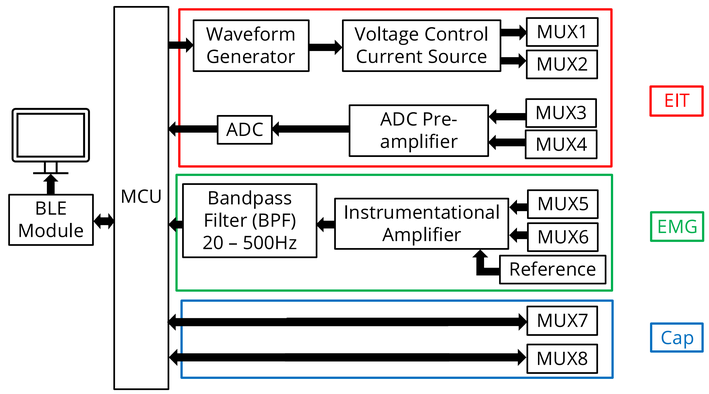
Electrode Placement



- EIT Electrodes
- EMG Electrodes
- Cap Electrodes (one side)
- Electrode Shared by EIT and EMG
- Electrode Shared by Cap and EMG
- Cap Electrode (another side), Silicon Dielectric

Double-layer nested structure

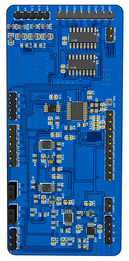
Multimodality Sensing Circuit Design

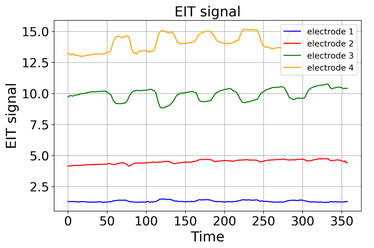


Results

PCB Design: Stack EIT, EMG, MUX boards to Motherboard (Power supply & Cap)

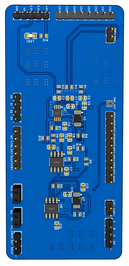
EIT

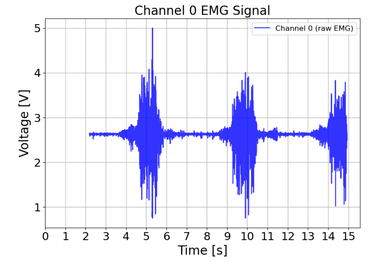




EIT signal when Thumb bending multiple times

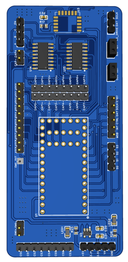
EMG

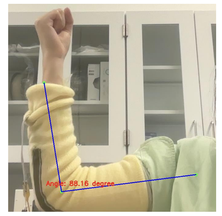


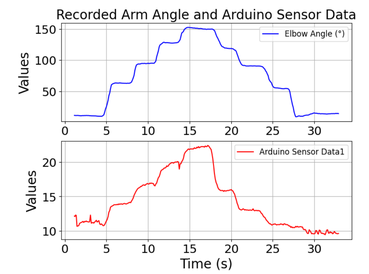


EMG signal from bicep when arm bending 3 times

Cap (Motherboard)







The relationship between bending angle and capacitance

Future Work

- Optimize PCB
- Leverage more electrodes for higher accuracy
- Design sleeves that are adaptive to different size of arms
- Apply similar designs to joints such as fingers and knees

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References

[1] Yiyue Luo, Kui Wu, Tomás Palacios, and Wojciech Matusik. 2021. KnitUI: Fabricating Interactive and Sensing Textiles with Machine Knitting. In Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems (CHI '21). Association for Computing Machinery, New York, NY, USA, Article 668, 1–12. https://doi.org/10.1145/3411764.3445780

[2] Junyi Zhu, Yuxuan Lei, Aashini Shah, Gila Schein, Hamid Ghaednia, Joseph Schwab, Casper Harteveld, and Stefanie Mueller. 2022. MuscleRehab: Improving Unsupervised Physical Rehabilitation by Monitoring and Visualizing Muscle Engagement. In Proceedings of the 35th Annual ACM Symposium on User Interface Software and Technology (UIST '22). Association for Computing Machinery, New York, NY, USA, Article 33, 1–14. https://doi.org/10.1145/3526113.354570