Robust, Compact Forehead EEG with E-Tattoo Electrodes

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Introduction

- Electroencephalography (EEG) is a non-invasive method of monitoring human brain activity [1]
- EEG signal quality is validated using impedance testing, a method of determining contact resistance between the skin and electrodes [2]
- Commercially available wet gel electrodes collect high-quality data yet can dry out and become unreliable for longer periods of time [3]
- Conventional EEG systems that use wet electrodes, such as Brain Vision, use an inconvenient setup and a head cap unsuitable for mobile applications and longer usage [4]
- Dry electrodes are superior to wet electrodes in terms of subject comfort and longevity yet have a higher contact impedance and noisier signal [3]

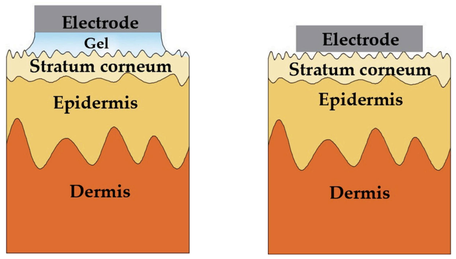

Figure 1: Wet gel electrode (left) and dry electrode (right) setup on human skin [3]

Research Goal

Our goal is to develop a compact, forehead EEG system with dry electrodes that collect measurements comparable in quality to that of a conventional EEG system while performing better in robustness over a period of time, convenience, and comfort.

Methods

- Two types of dry electrodes are fabricated through curing a composite mixture of conductive Carbon Nanotubes (CNT) and Ecoflex polymer in solutions of 1 wt% and 2 wt% CNT
- E-tattoo electrodes are made through laser-cutting serpentine patterns on Au-PI and G-PO film
- Skin on the subject's forehead is cleansed with soap and water and exfoliated with an abrasive
- Two of each dry electrode type are applied equidistantly on the forehead
- Electrochemical analyzer measures contact resistance every 15 minutes for 1 hour
- Best performing dry electrodes from Step 3 and liquid gel electrodes are applied on the forehead and solid gel electrodes are applied behind both ears for grounding and reference points
- Contact impedance is measured every 1 hour for 7 hours using the Brain Vision system

Results & Discussion

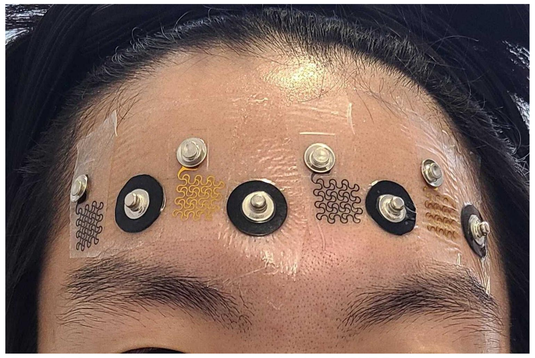

Figure 2: Set up of impedance testing for 1 wt% CNT-Ecoflex composite, 2 wt% CNT-Ecoflex composite, Au-PI film, and G-PO film.

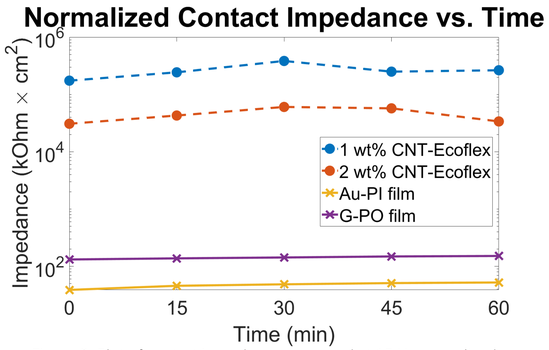

Figure 3: Plot of contact impedance measured at 15 Hz normalized over the area versus time.

- Contact impedance is inversely proportional to the contact surface area between the skin and the electrode, thus the measurements were normalized to account for differences in surface area
- Au-PI film performs the best out of all types of dry electrodes, with contact impedance ranging from 38.9 kΩ to 52.4 kΩ, followed by the G-PO film, which ranges from 132.1 kΩ to 152.1 kΩ. Au-PI film and G-PO film will be measured simultaneously with the Brain Vision liquid gel electrodes for 7 hours
- Figure 3 shows a slight increase in the impedance for all four types throughout the first hour of application

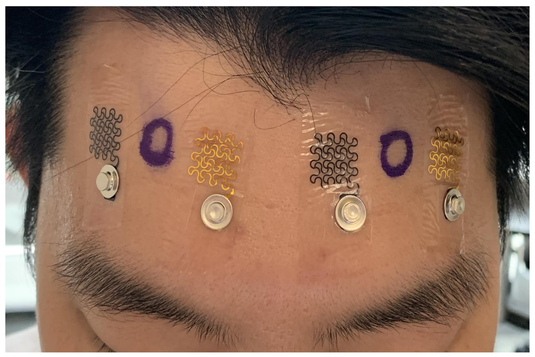

Figure 4: Set up of impedance testing for Au-PI film and G-PO film using the Brain Vision System.

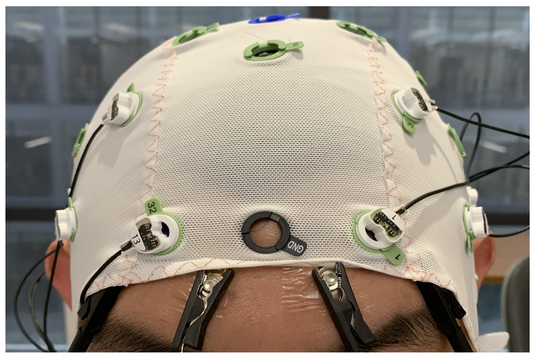

Figure 5: Set up of impedance testing for liquid gel electrodes using the Brain Vision head cap.

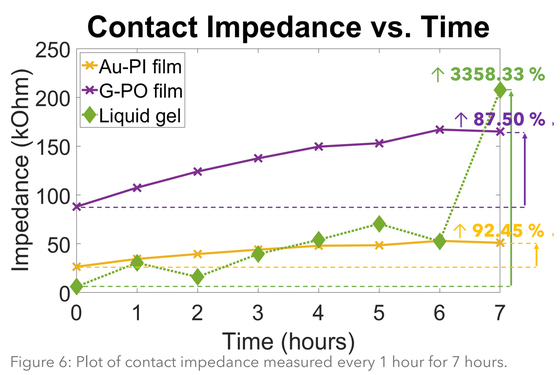

Figure 6: Plot of contact impedance measured every 1 hour for 7 hours.

Change of Contact Impedance Over 7 Hours

Time (hours)	Au-PI film		G-PO film		Liquid gel	
	Impedance (kOhm)	% Change from Hour 0	Impedance (kOhm)	% Change from Hour 0	Impedance (kOhm)	% Change from Hour 0
0	26.5	0	88	0	6	0
1	34.5	30.19	107.5	22.16	30.5	408.33
2	39.5	49.06	124	40.91	16	166.67
3	44	66.04	137.5	56.25	39.5	558.33
4	48	81.13	149.5	69.89	54	800.00
5	48.5	83.02	153	73.86	70.5	1075.00
6	53	100.00	167	89.77	52.5	775.00
7	51	92.45	165	87.50	207.5	3358.33

- Liquid gel starts out with a very low contact impedance, but the value increases rapidly after 1 hour and steadily increases over 5 more hours. After 7 hours of application, the impedance skyrockets to a value of 3358.23 % higher than the original reading
- Au-Pi film and G-PO film electrodes both experience a steady increase in contact impedance for the duration of 7 hours, but the change does not exceed 100 % from the original reading

Conclusion

- Both manufacturing processes for the CNT-Ecoflex composite and film e-tattoo electrodes yielded appliable and measurable electrodes
- Film e-tattoo electrodes conform better to the forehead skin texture than the CNT-Ecoflex composite electrodes, leading to a much lower contact impedance
- Z-direction impedance was lower in the film e-tattoo electrodes than in the CNT-Ecoflex electrodes due to having a thinner overall material thickness
- Following superiority in performance, Au-PI and G-PO film electrodes were selected over the CNT-Ecoflex electrodes for comparison to wet gel electrodes
- Au-PI and G-PO film both maintained consistent quality of EEG signals collected while the liquid gel electrodes deteriorated over time as the liquid gel evaporated
- The quality of the Au-PI film electrodes' long-term performance was comparable to the short-term performance of the wet gel electrodes, showing potential for the development of a commercial alternative to Brain Vision using dry electrodes
- While Brain Vision is applicable to all regions of the scalp, extended research must be done on applying dry electrodes to other regions of the scalp to determine consistency in performance across different locations
- Future applications of the e-tattoo EEG system will focus on using the Au-PI film e-tattoos to collect EEG data from the forehead to perform mental workload and vigilance classifications

Acknowledgments

Special thanks to Professor Nanshu Lu and graduate student mentors Heeyong Huh and Andrew Repetski.

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