NeuroPatch: A Wearable, Minimally Invasive Bidirectional Photoacoustic Neural Interface for Ultra-Low-Latency Brain-Computer Interaction

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Non-invasive BCIs such as EEG and fNIRS are limited by low spatial resolution and high latency, while invasive neural implants require surgery and pose biocompatibility risks. Existing closed-loop neuromodulation systems require craniotomy, cost $40,000–$80,000, and remain inaccessible to the 3.4 billion people affected by neurological disorders. To address this, I developed NeuroPatch, a noninvasive photoacoustic neural interface with integrated focused ultrasound neuromodulation for closed-loop BCI applications. NeuroPatch uses microneedle-assisted dual-wavelength NIR excitation at 750nm and 850nm and a 24-channel PVDF array for ultrasonic detection. Membrane-potential-dependent photoacoustic signals are processed through a convolutional autoencoder, temporal attention filtering, and a physics-informed neural network to recover membrane-potential dynamics while suppressing hemodynamic artifacts. The PVDF array is time-multiplexed through transmit-receive switches to deliver focused ultrasound pulses activating mechanosensitive ion channels, enabling excitatory or inhibitory neuromodulation via pulse parameter tuning. At under $500, NeuroPatch is far more accessible than existing systems at $40,000–$80,000. Validation achieved 0.62mm localization error, SNR exceeding 14.3dB, 1.8cm detection depth, and 6.8ms latency, with modulation hardware validated and thermal safety confirmed below FDA thresholds. NeuroPatch combines sub-millimeter photoacoustic sensing, membrane potential reconstruction, and non-invasive neuromodulation in a single wearable: the first surgery-free solution for closed-loop neural therapy.

Awards Won: