

CAREER: MINDWATCH: Multimodal Intelligent Noninvasive brain state Decoder for Wearable Adaptive Closed-loop architectures

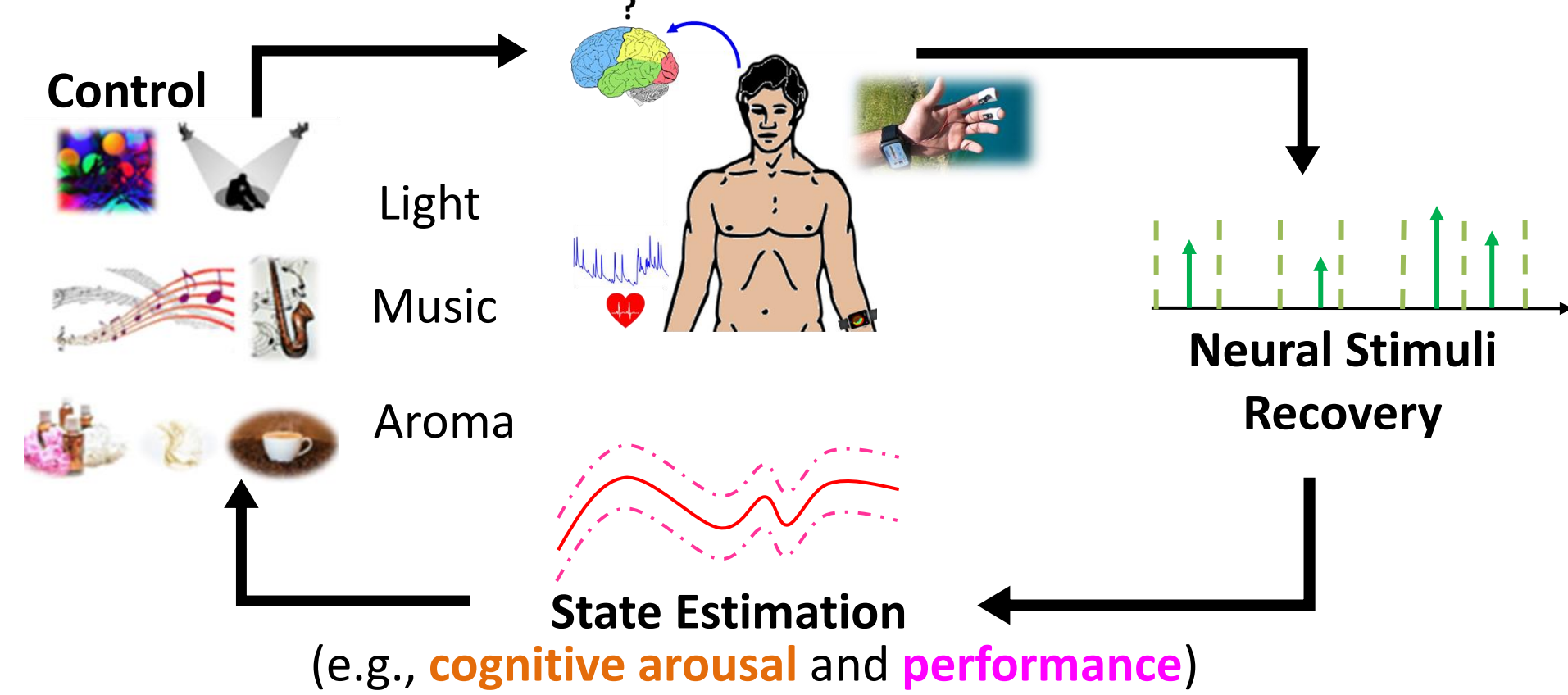
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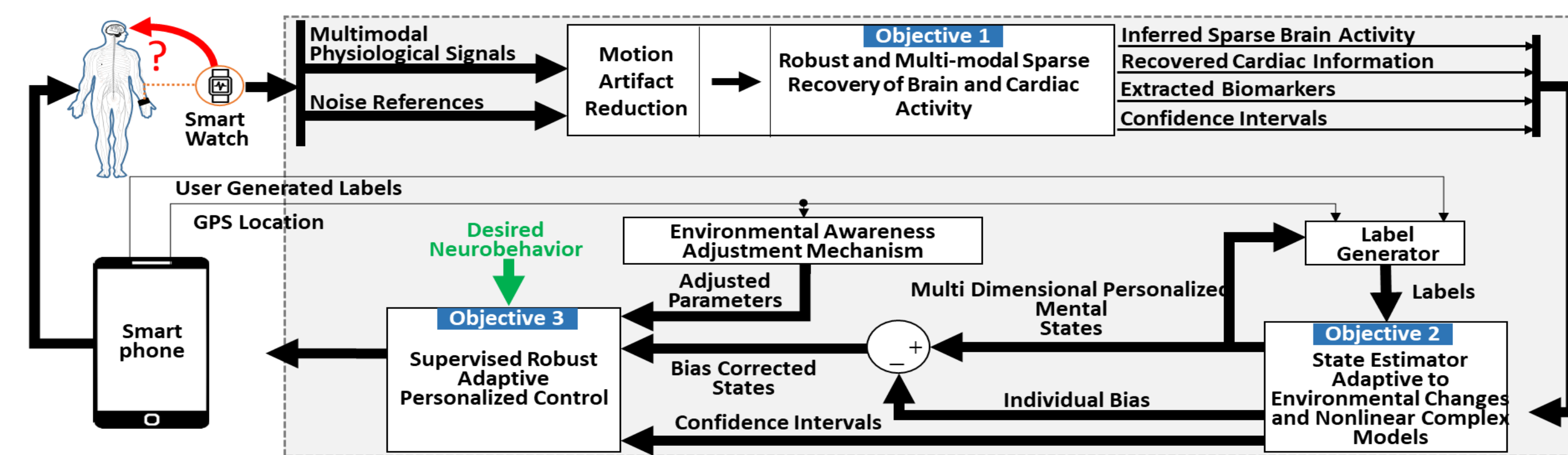
CHALLENGE

- Rising **healthcare cost** and **accessibility** are a growing concern
- **Wearable devices** can be exploited for **patient monitoring** to recover rich information about internal physiological states for prognosis, diagnosis, & treatment



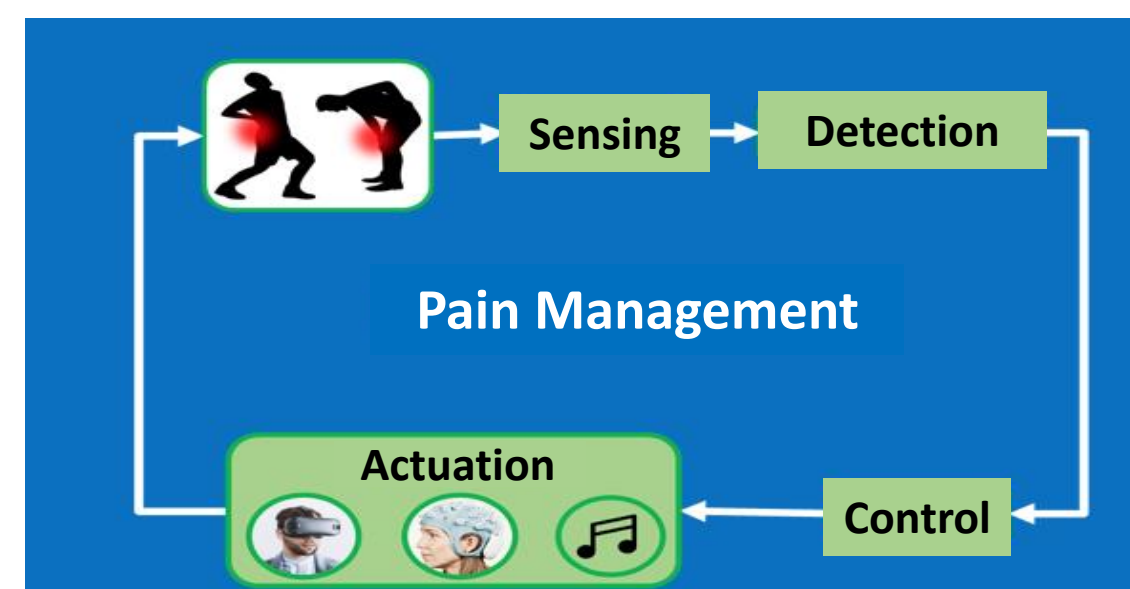
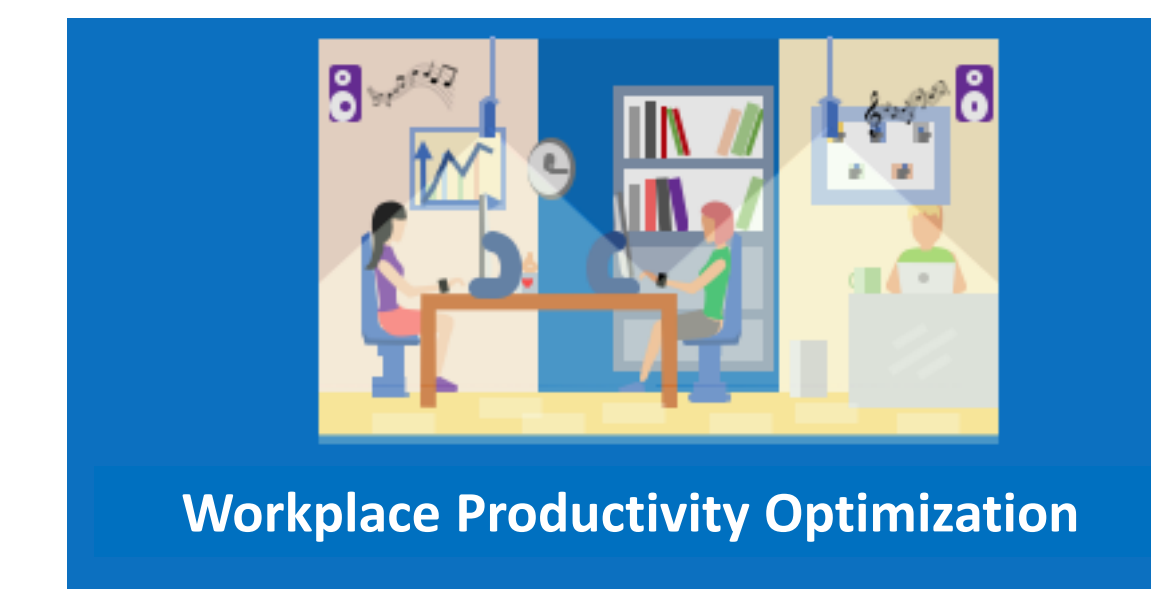
GOALS

1. **Inferring** discrete brain-related events from **multimodal sensors** in **real-world** settings
2. **Decoding** multidimensional latent **neurobehavioral states** (e.g., **cognitive arousal** and **performance**)
3. Robust adaptive **supervised control** design for regulating neurobehavioral states



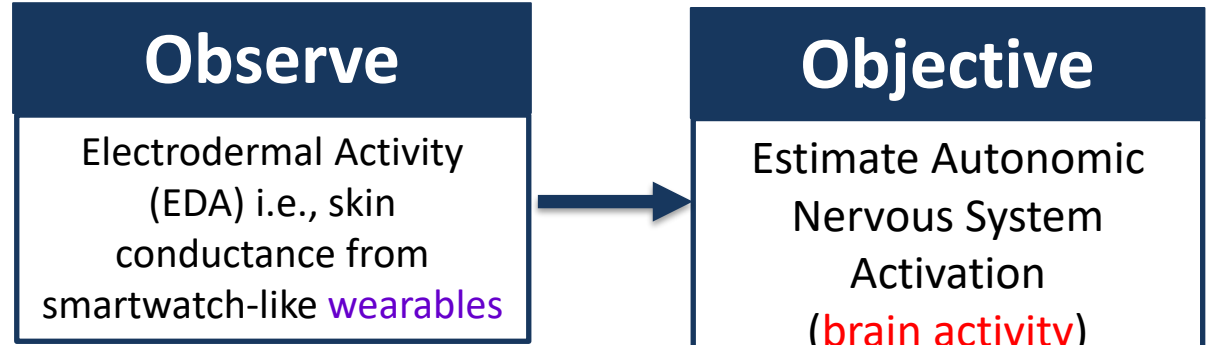
SCIENTIFIC IMPACT

- Multimodal system identification and **brain activity** recovery
- Interpretable adaptive tracking of **neuro-behavioral states**
- Personalized, reliable, **closed-loop control** of neuro-behavioral states



INFERENCE OF BRAIN ACTIVITY

Infer autonomic nervous system activation (**brain activity**) to track one's hidden **cognitive arousal** state in **real-time** using **wearable** devices.



SINGLE-CHANNEL BAYESIAN INFERENCE OF BRAIN ACTIVITY

BayesianEDA Algorithm

Iterative re-weighting while tuning sparsity using **generalized cross-validation** for **sparse recovery**

Filtering → Smoothing

Maximization step

Obtain **personalized** physiological parameters

BayesianEDA enables **near real-time** inference of autonomic nervous system activity

Bayesian Filter Approach:

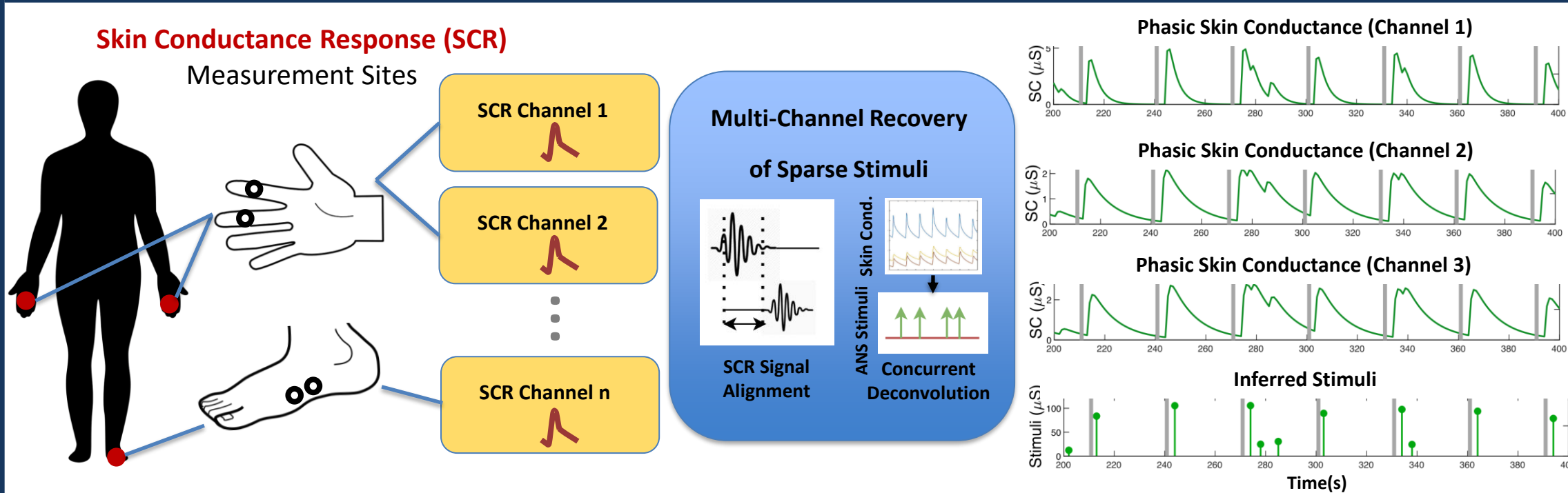
$$\min_k \sum_k (\lambda \|x_k - A x_{k-1}\|_1 + \frac{1}{2\sigma_v} \|y_k - C x_k\|_2^2) + \sum_j (\theta - \hat{\theta})^T \rho(\theta - \hat{\theta})$$

s. t. $R\theta \leq s$ → Physiological constraints Physiological priors

In Media: BayesianEDA (Amin & Faghii, PLOS Comp. Bio., 2022)

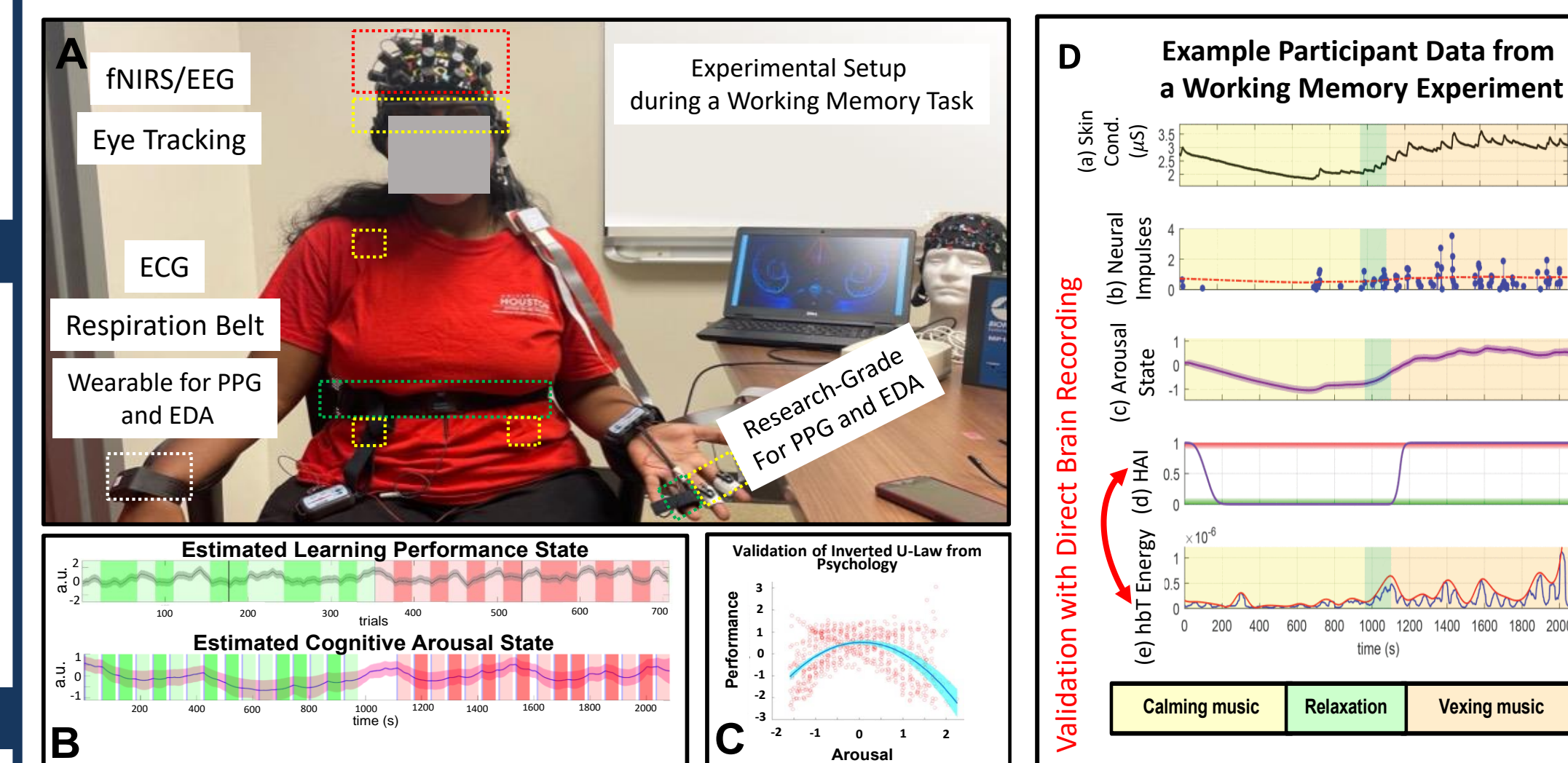
"This study represents the next step or next generation of biofeedback monitoring. This would allow real time individual information about how the brain is processing and reacting to stressful events. This builds on decades of work looking at physiological response to stress."
- David A. Merrill, MD, PhD, psychiatrist and director of the Neuroscience Institute's Pacific Brain Health Center, Providence Saint John's Health Center.

MULTI-CHANNEL OPTIMIZATION-BASED INFERENCE OF BRAIN ACTIVITY



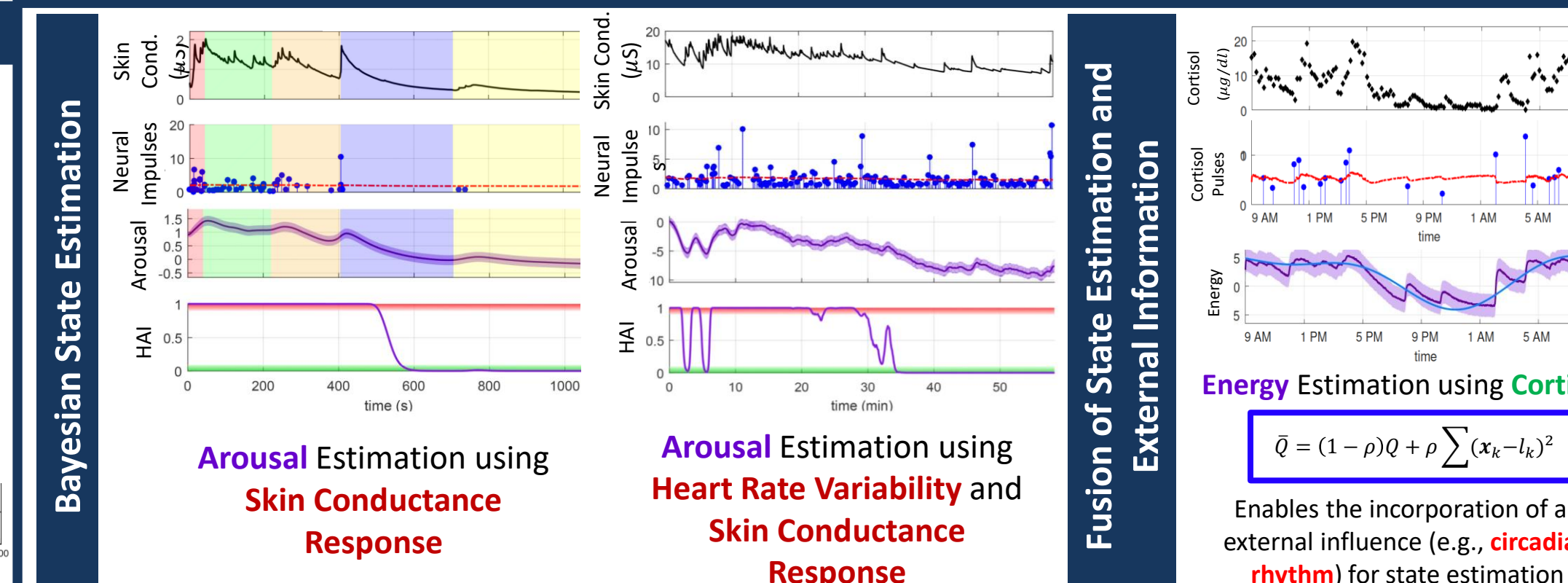
DECODING NEUROBEHAVIORAL STATES

MUSIC-MODULATED WORKING MEMORY EXPERIMENT



- Quantitatively verified the **inverted U-law** from psychology that links one's **cognitive performance** and **cognitive arousal** states.
- **Arousal estimates** from skin conductance agree with functional near-infrared spectroscopy (**fNIRS**) **blood flow (brain imaging)** data from **prefrontal cortex**.

COGNITIVE STATE ESTIMATION

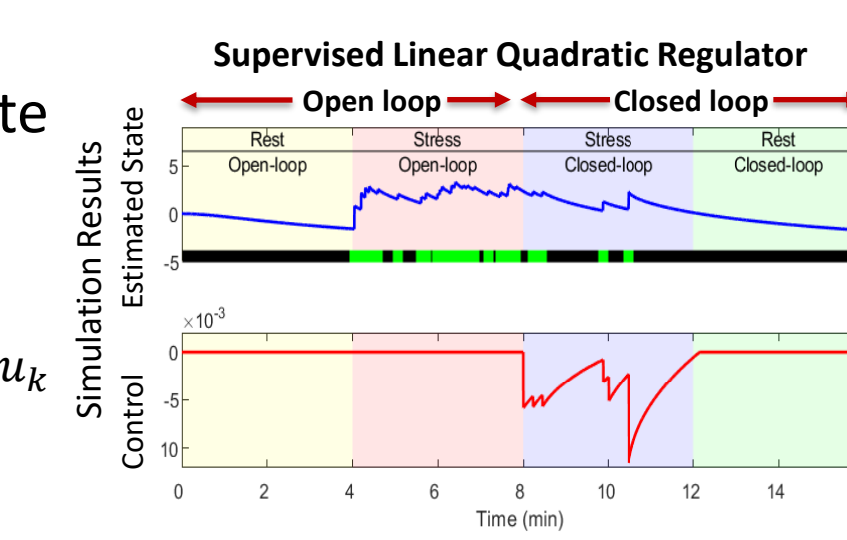


CLOSED-LOOP CONTROL

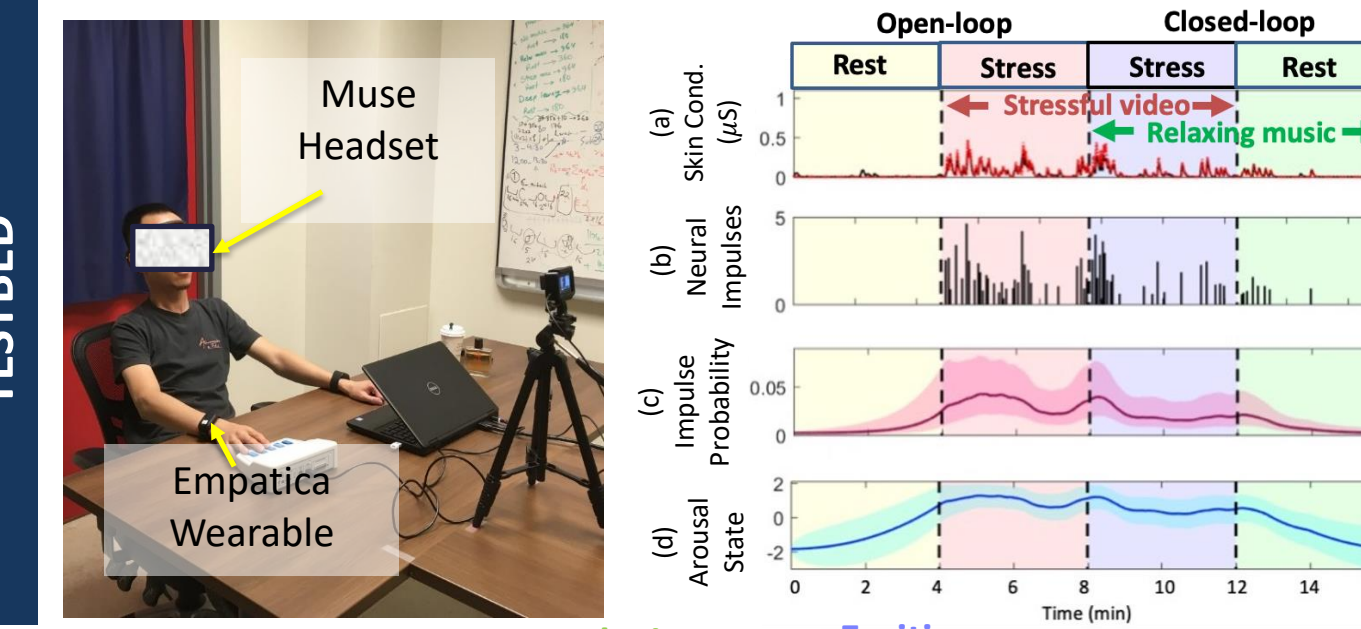
SUPERVISED CONTROL ARCHITECTURE

Supervised update of Q and R

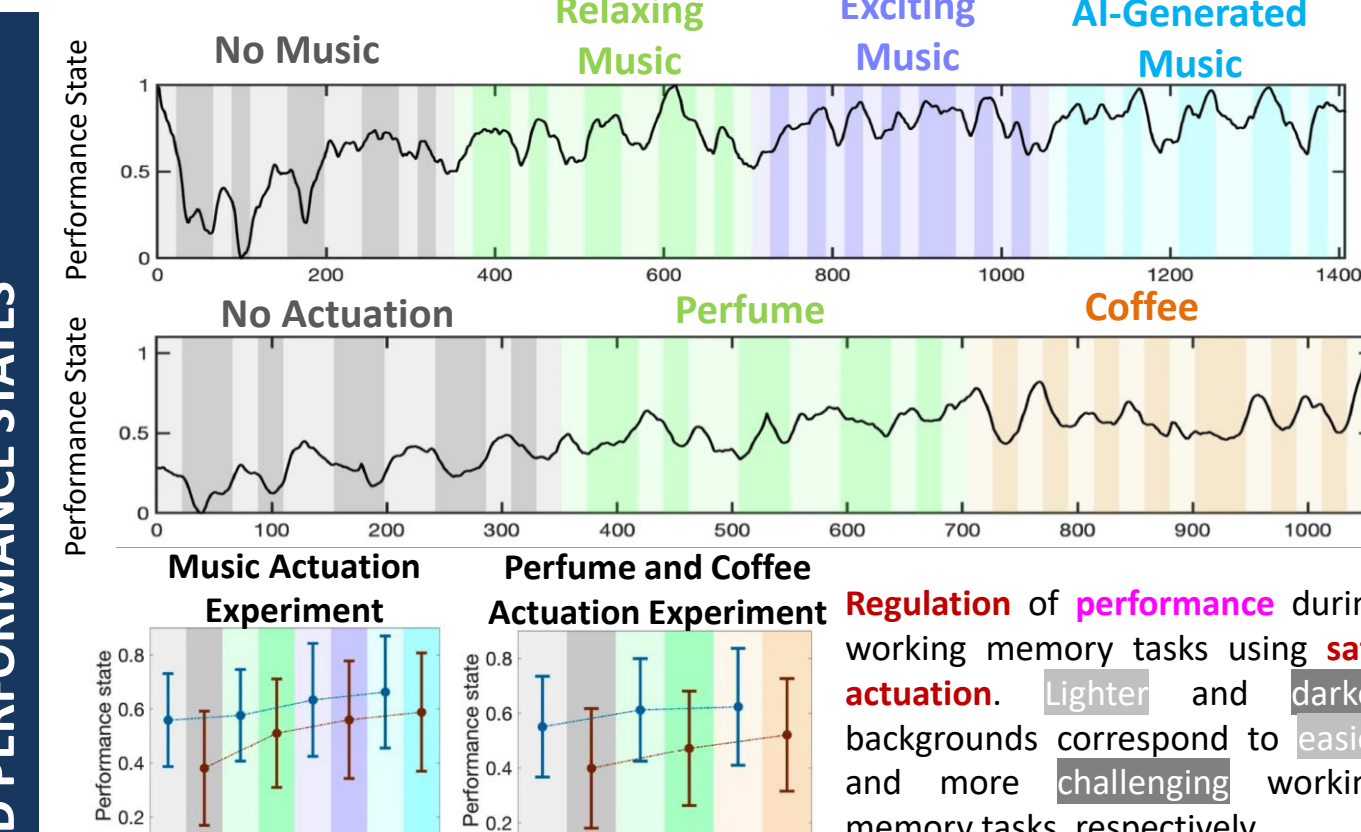
$$J = \sum_{k=1}^{T-1} x_k^T Q x_k + u_k^T R u_k$$



EXPERIMENTAL TESTBED



REGULATION OF COGNITIVE AROUSAL AND PERFORMANCE STATES



In Media: Regulation of Cognitive States (Azgomi & Faghii, Scientific Reports, 2023)

EDUCATION AND OUTREACH IMPACT

Publications: Journal papers: **17**, Peer-reviewed conference papers: **7**; Pending Patent: **1**; Provisional Patents: **2**

- Integration of research into a graduate course resulted in **5** of these **peer-reviewed publications** (2 conference & 3 journal).
- Created **22 educational videos** and **13 open-source code repositories**
- Released a **publicly available toolbox** for Bayesian filtering analysis (8 classes of filters) on GitHub
- Collected and shared **Wearable Exam Stress** and **Regulation of Cognitive States Datasets** on **PhysioNet**, a repository of freely-available medical research data.
- **2 PhD** and **1 Masters'** students currently under supervision. **3 PhD** students & **2 Masters'** students graduated, and **6 Undergraduate** projects (Honors' Thesis, REU, Summer Undergraduate Research Fellowship) were completed under PI's supervision. **3 Capstone** teams designed wearables for emotion monitoring.
- PI gave several **laymen talks** about this research to general audience & broader community
- PI outreached to next generation of engineers at the **International Summer School on Bio-X: Data Science and Engineering in Medicine and Biology**
- PI was featured as a panelist at the **2023 IEEE EMBS Inaugural Women in Biomedical Engineering Forum**
- Computational Medicine Lab Won First Place in the **2023 NYU Tandon Research Excellence Exhibit** for the MINDWATCH Project
- PI was recognized as **MIT Technology Review 2020 Innovator under 35**. (**FuturoProssimo** has predicted that MINDWATCH research has a high potential for a **Nobel prize**).

SOCIETAL AND QUANTIFIED IMPACT

- **71% of US workers** reported feeling lonely or isolated in the wake of the COVID-19 pandemic
- **32% of US adults** and **50% of young adults** report symptoms of anxiety or depression
- **88% of US physicians** want patients to monitor their health at home
- **35% of US employers** use medical wearable technology to facilitate wellness programs