Whole Night Sleep Monitoring
With A Low-Cost In-Ear Wearable Device

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Fig 1. Polysomnography as the current “Gold Standard” for sleep study with many wired sensors attached on the patient’s body.

Fig 2. LIBS and its relative position to the sources of EEG, EOG, and EMG that we are interested in.

Fig 3. LIBS architecture and its sleep staging application

Challenges:
1. Mixed signal challenge: The biosignal captured by LIBS is composed of the original EEG, EOG, and EMG signals and noise, which
   - Overlap in both the amplitude and frequency domains
   - Vary across subjects and recording times
2. Design challenge:
   - Human ear canal is small and easily deformed by facial movements.
   - EEG, EOG, and EMG signals have low amplitude.

We introduce our system named LIBS. In LIBS:
- It takes the in-ear single-channel biosignal and adaptively decompose into EEG, EOG, and EMG signals without loss of their physiological information using a supervised non-negative matrix factorization technique.
- It guarantees a comfortable and safe feeling while being worn as it is made of a combination of thin, soft, and highly conductive materials.

Libs – AN IN-EAR BIO-SENSING SYSTEM

System Design:
- Real earphone design
- Training Sleep Stage Classifier
- Feature Selection
- Non-negative Matrix Factorization Model
- Template Matix Generation
- In-Ear Mixed Signal Separation
- Data Preprocessing
- Feature Extraction
- Sleep Staging

Fig 4. Sleep Study Experiment

Libs Performance in Reality

“Gold Standard” PSG
- 38 hours of sleep studies
- 3 females and 5 males

Fig 5. Eye movement detection

Fig 6. Facial muscle contraction detection

Fig 7. Audio steady-state response (ASSR)

Fig 8. Steady-state visually evoked Potential (SSVEP)

Fig 9. Alpha rhythm detection

Fig 10. Signal separation performance by LIBS

In-Ear Signal Acquisition Validation

Future of Libs

- Autonomous Audio Steering
- In-home Sleep Monitoring
- Leurability Evaluation
- Sleep-correlated Diseases
- Distraction & Distress Detection
- Eating Habit Monitoring
- Human-Computer Interaction

Contact Us
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Develop a wearable bioelectrical sensing system that is
- Significant to reduce the number of wired electrodes
- Able to measure all EEG, EOG, and facial EMG signals at the same time
- Potential for both human computer interaction and self-care health applications
- Less intrusive, comfortable, light-weight, and cost-effective

Existing Hi-Tech Solutions

Mobile Apps
- Inaccurate
- Inconvenient
- Uncomfortable

Wearable Devices
- Able to capture only a single signal (e.g. EEG)