A novel radiooculogram (ROG) for eye movement sensing with eyes closed

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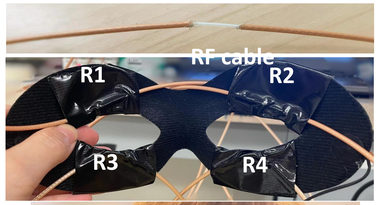
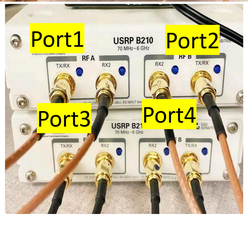
Eye movement (EM)

- **Applications of Eye movement tracking:**
  - Human Computer Interaction (HCI)
  - Monitoring sleep and dream stages
  - Emotion, cognition and perception
  - Control of assistive devices
- **Limitations of current systems:**
  - **Camera-based methods:** Privacy, complexity, occlusions, and eyes shut under low light.
  - **Electrooculogram (EOG):** Low user comfort and skin irritation due to electrodes; interferences due to leaky neural signals.

Radiooculogram (ROG): Setup

- ROG: **near-field** coherent sensing (NCS) of RF signals to monitor the internal muscles during EM.
- Electromagnetic energy was coupled **deep inside the body**, and tissue motion was modulated on the channel characteristics.
- One ROG sensing unit consisted of a notched miniature coaxial RF cable, where the metal shield of the middle part was removed.
- Four sensors at different positions around the eyes for more observation diversity. Multiple-input multiple-output **(MIMO)** was adopted to explore $N^2 = 16$ channels from $N = 4$ sensing units.
- The ROG RF transceiver was implemented by software-defined radios (SDR) with f_{RF} at 1 GHz. RF power < -10 dBm or 0.1 mW, well under the safety limits.



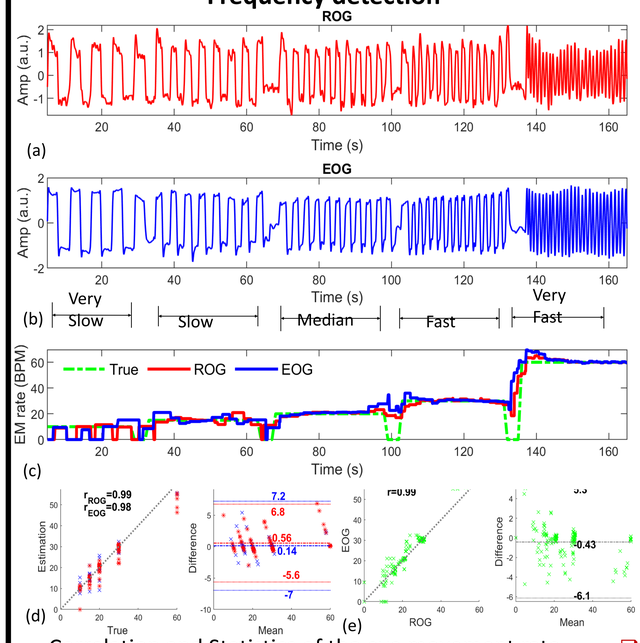


ROG advantages

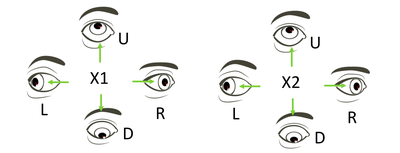
- **Improved user comfort**: ROG can operate without direct skin contact, such as integration into the eyeglasses frame or a sleep mask or a masquerade.
- **Unmediated sensing of directional EM:** EOG measures neural stimulus for muscle activity; ROG directly measures the muscle motion. EOG and ROG can be used together to retrieve the full loop of stimulation and actuation.
- **Baseline for sleep REM detection**: Camera-based methods are problematic for sleep rapid eye movement (REM), ROG can operate with eyes open or closed without privacy concern.

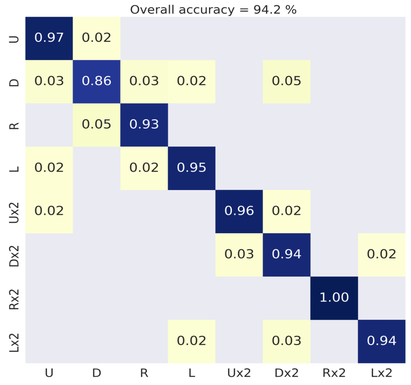
EM frequency and direction estimation

Frequency detection



Direction detection





The confusion matrix showing the overall accuracy of 94.2% for EM direction detection on all 5 subjects.

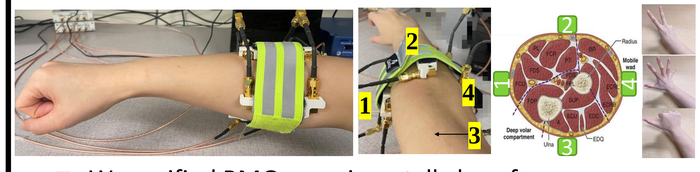
Correlation and Statistics of the eye movement rate

Subject No.	r_{ROG}	m± σ (BPM)
1	0.987	0.70 ± 2.90
2	0.986	0.75 ± 3.02
3	0.985	1.04 ± 3.21
4	0.982	1.00 ± 3.11
5	0.984	1.46 ± 3.26
Mean	0.985	0.99 ± 3.10

- We validated accurate measurement of EM frequencies and directions by a human study of **5** participants with selected longitudinal experiments.
- We further benchmarked ROG with synchronous EOG as the baseline comparison and physiological correlation.

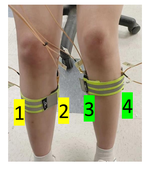
More: muscle monitoring by Radiomyography (RMG)

Forearm RMG for hand gesture recognition



- We verified RMG experimentally by a forearm wearable sensor for hand gesture recognition.
- RMG can recognize 23 gestures with an average accuracy up to 99% on 8 subjects.

RMG for leg muscle tracking



- RMG on lower legs can monitor body postures and can be applied for balance training and fall warning.

Future applications

Applications of ROG: Biomedical: baseline for future **sleep REM monitoring** in clinical studies, Blink detection for wakefulness and tremor; HCI applications: Cybersickness detection, eye tracking, and blink interaction.