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

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2019-Expected May 2023,
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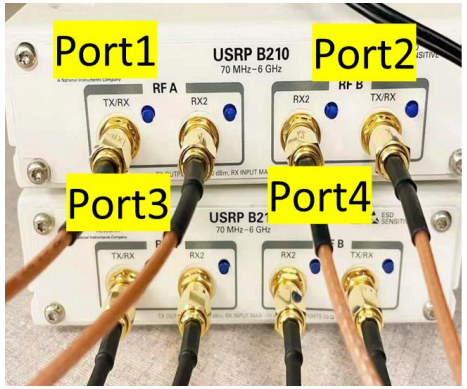
Eye Movement

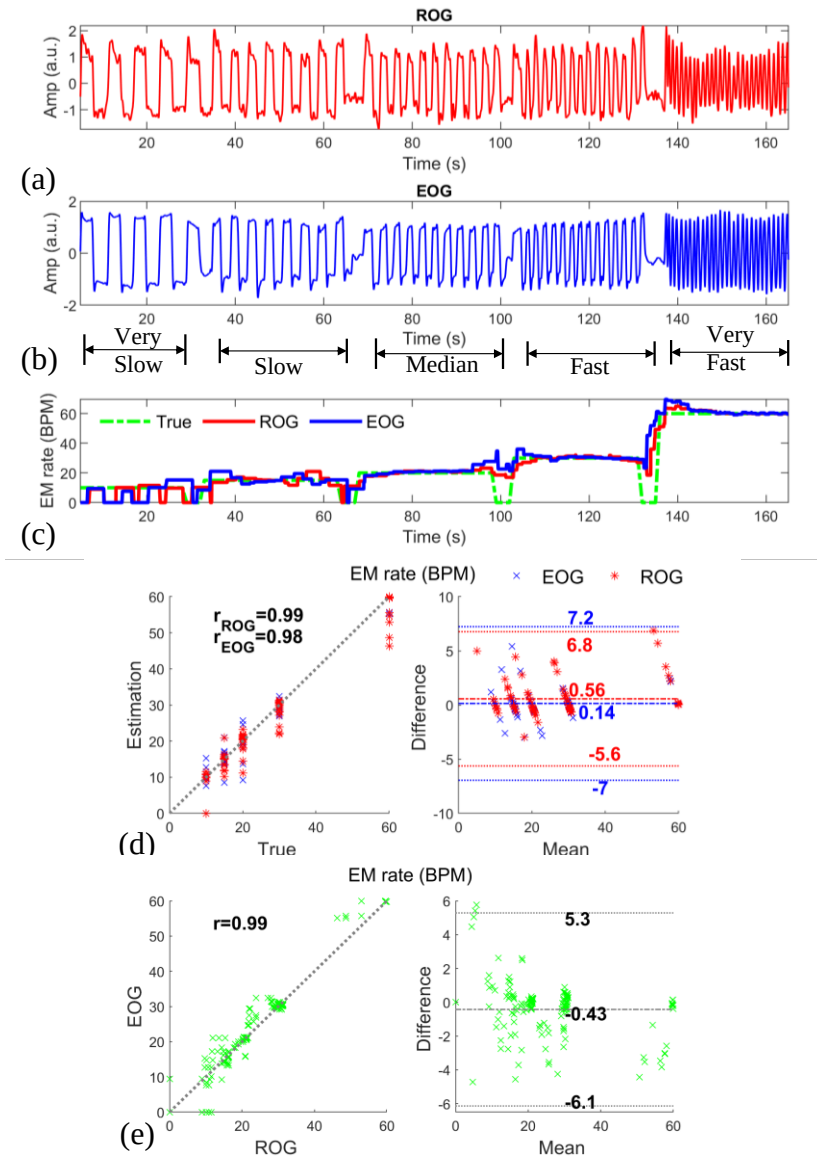
- **Applications of Eye movement tracking:**
  - Human Computer Interaction (HCI)
  - Monitoring sleep and dream stages
  - Emotion, cognition and perception
  - Control of assistive devices
- **Limitations of current systems:**
  - **Camera-based methods:** Privacy, complexity, occlusions, and eyes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

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.



Eye movement frequency detection

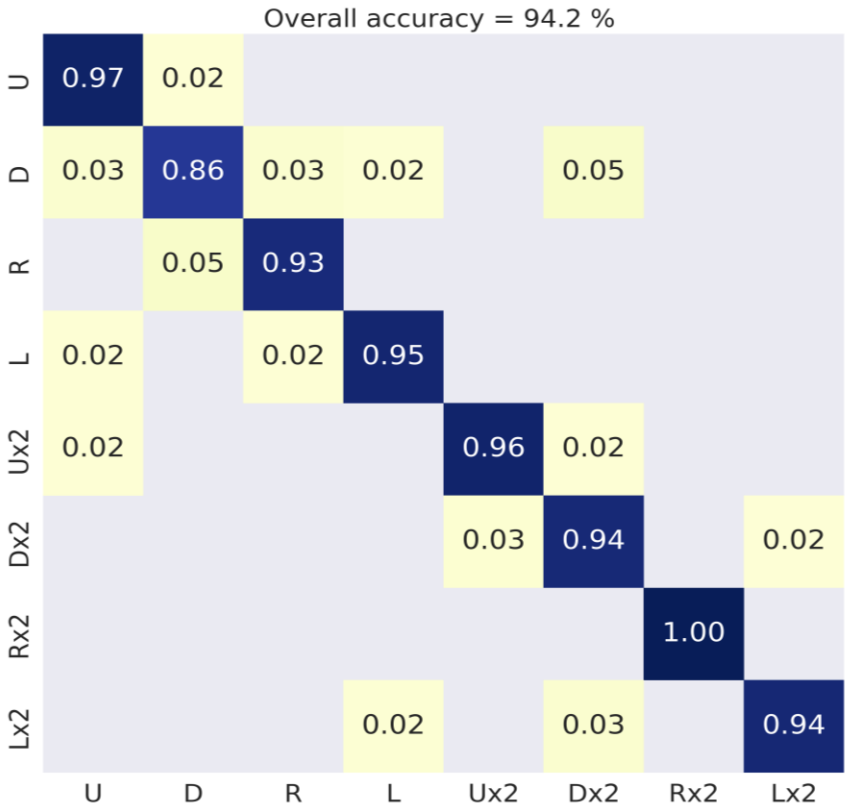


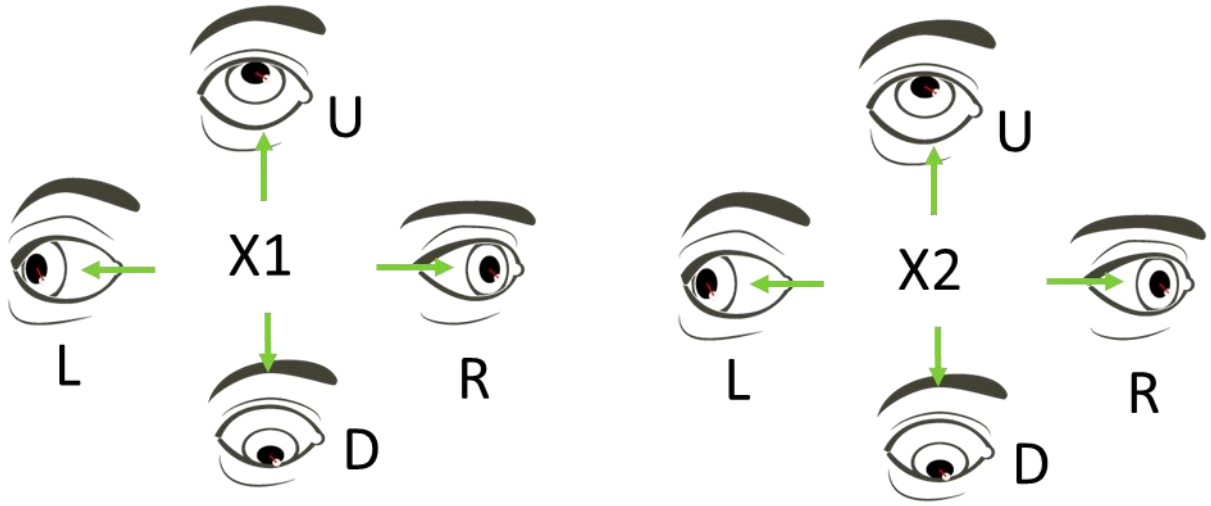
EM frequency estimation.
(a) ROG amplitude from Tx3- Rx3 and
(b) EOG waveform samples.
(c) EM rate in BPM. Correlation and agreement
(d) between the ground truth and estimation from ROG and EOG, and
(e) between ROG and EOG.
Left: The scatter plot with denoted Pearson's correlation coefficient. Right: The Bland-Altman plot for biases and limits of agreement.

Correlation and Statistics of the eye movement estimation 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

Eye movement direction detection





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