Real-time system for physiological oscillation phase-dependent stimulation

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Takeaways

Here we introduce an **integrated modular system** feasible for **real-time** data **acquisition**, data **analysis** and control of **neuro-modulatory stimulation** enabling **state dependent** and **closed-loop** controlled experiments without prediction.

Background

Planning **neuro-modulatory interventions** should consider **individual anatomy** to select suitable **targets** and to calculate **dosage** [1]

During the intervention, neuro-modulation interacts with **physiological** oscillatory activity coupled to the **state of the brain**

Consequently, neuro-modulatory interventions should be tailored to individually defined physiological patterns of interest by means of **brain state dependent stimulation** [2].

Innovation

Integrated modular system capable to

measure ExG (EEG, ECG, EMG), Acceleration (a_x, a_y, a_z)

analyze amplitude, frequency, latency, phase (without prediction) and

modulate via the control / trigger of tES / TMS

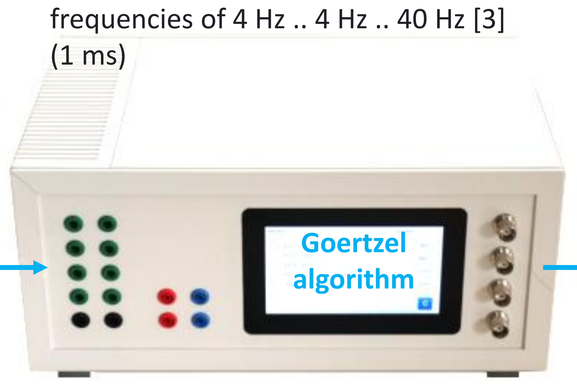
electro-physiological processes in **real-time**

Methods

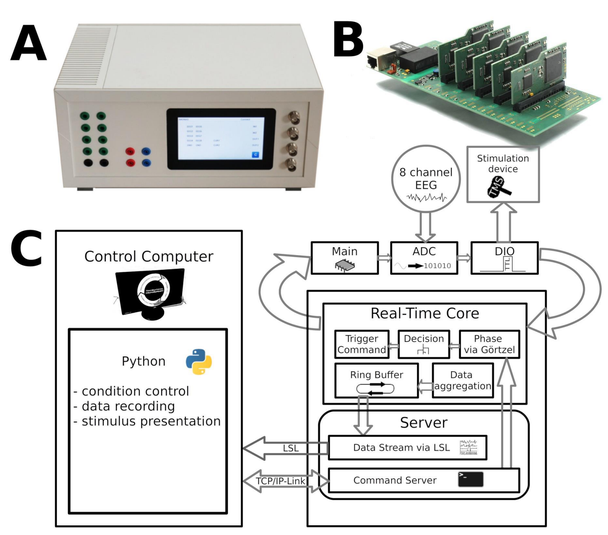
EEG acquisition:
1 ksps with 24 bit
(1 ms)

Phase detection of 0° .. 45° .. 315° for frequencies of 4 Hz .. 4 Hz .. 40 Hz [3]
(1 ms)

Send TTL
(1 ms)

EEG (F3, P3) → 

→ **Trigger DuoMAG XT-100 @ C3 45° a-p**



LOOP-IT system architecture [3]

Clients (ADC, MAIN, DIO) communicate with real-time core on time course of 1 ms

ADC EEG amplification & digitization

MAIN phase detection of target frequency

DIO trigger of TMS

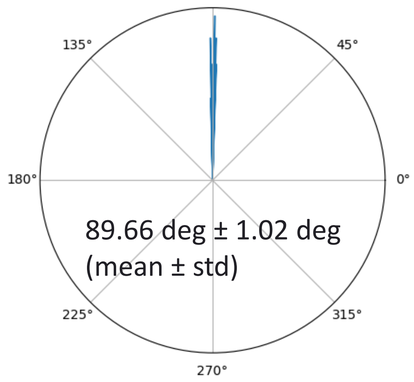
LSL data stream
(input, intermediate stages, output)

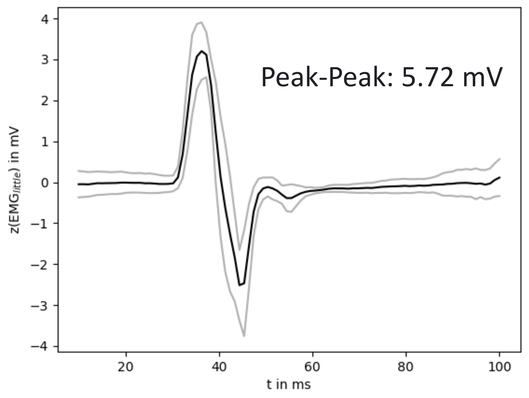
TCP/IP control commands

Results

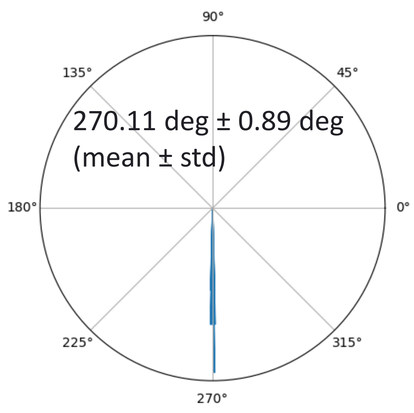
TMS triggered to **EEG phase**

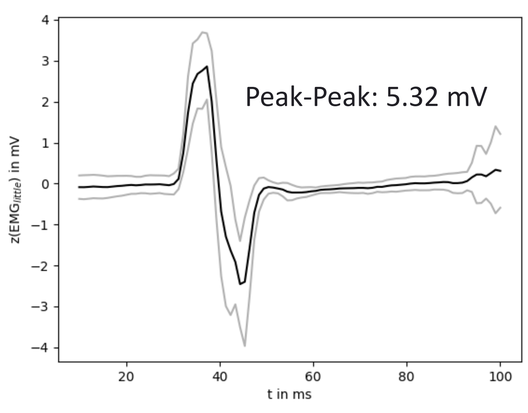
90 degrees @ 10 Hz



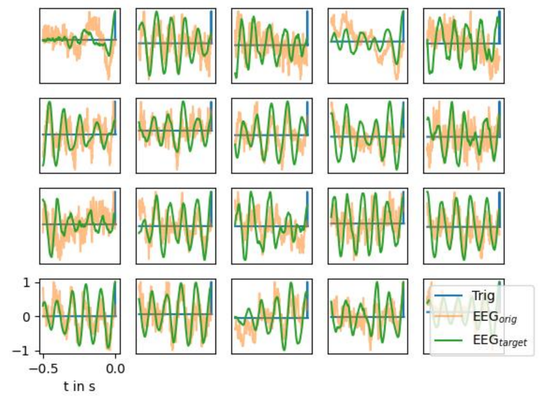


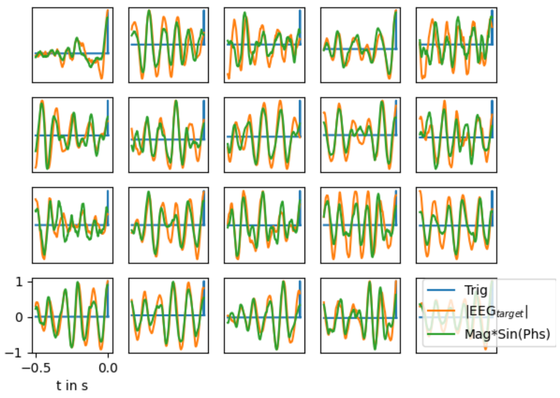
270 degrees @ 20 Hz

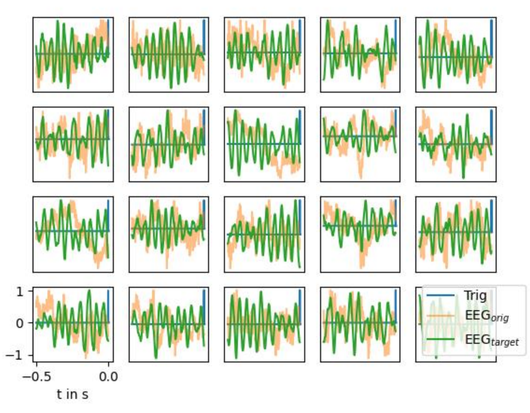


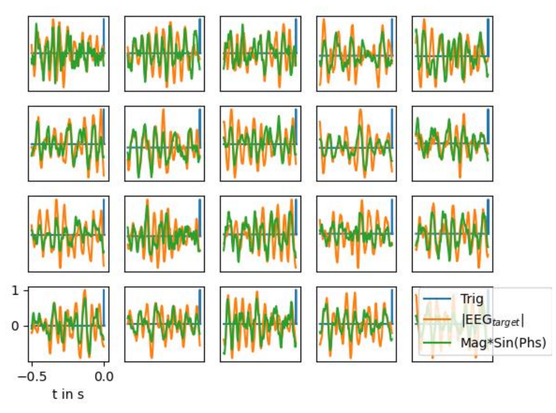


Waveforms from 20 trials









Target phase was triggered with high accuracy (std below 2 degrees)

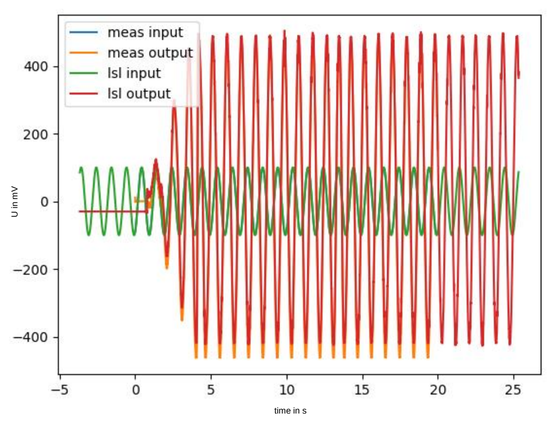
Goertzel algorithm:

coherency above .85 between filtered and reconstructed signals
(based on amplitude and phase)

crrelation above 95% between pure sine wave (input) and reconstructed signals

tACS adapted for **tremor cancellation**

correlation analysis for phase detection from dominant oscillation recorded by accelerometer



Conclusion

Integrated modular system feasible for

real-time data acquisition
data analysis
control of neuro-modulatory stimulation
with fixed 3 ms round trip time

enabling **state dependent** and **closed-loop** controlled **experiments**

References

[1] Hunold, A., Haueisen, J., Nees, F., & Moliadze, V. (2023). Review of individualized current flow modeling studies for transcranial electrical stimulation. *Journal of Neuroscience Research*, *101*(4), 405-423.
[2] Bergmann, T. O. (2018). Brain state-dependent brain stimulation. *Frontiers in psychology*, *9*, 2108.
[3] Guggenberger, R., Gebuehr, J. S., Keute, M., & Gharabaghi, A. (2023). Phase-specific stimulation of the human brain with real-time measurement instead of prediction. *bioRxiv*, 2023-04..

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