MANCHESTER 1824
The University of Manchester

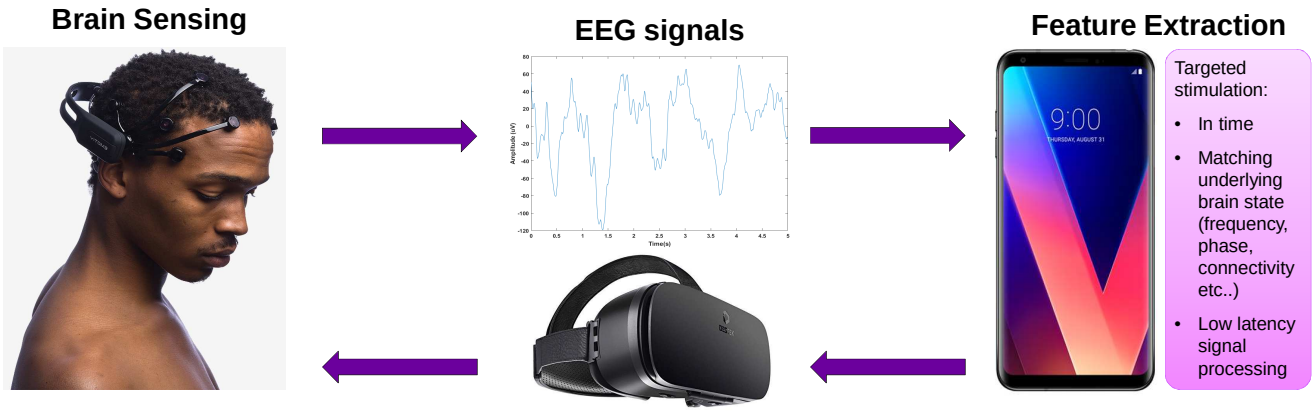
Closed loop neuromodulation using EEG based Brain Computer Interfaces

1. Motivation

1. **Chronic Pain:** This is a global epidemic which costs the U.S. government more than 200 billion USD. Under half the population in the UK suffer from chronic pain and one of the major problems is the dependence and overuse of addictive prescription drugs like Opioids, which have no long term therapeutic value. Just in the US alone, 60,000 people died in 2016 due to these prescription drugs, which have led to an urgent need for non-addictive safe to use therapies with minimal side-effects.
2. **Sleep Engineering:** Sleep is crucial for general health and a third of our lives are spent sleeping. However, up to one in 10 people in the UK suffer from insomnia. Drug based solutions such as sleeping pills have various side-effects and can become addictive. As such, there has been a surging interesting in non-drug based solutions. 'Sleep Engineering' then involves the use of technology to enhance sleep quality. Within this scope, one particular area is the use of sounds played at precise points in sleep, to increase memory consolidation.

2. Background

- **Neuromodulation:** For both chronic pain and sleep, recent research has shown neuromodulation to be an effective form of treatment, which is cheap, safe and with minimal side effects, compared to drugs. This involves the use of external stimuli such as light, sounds or currents, that are tuned to modulate brain activity for therapeutic effects. However, a major limitation is the inter-intra subject variability in therapeutic effects. To account for this, a suitable solution is the use of brain-state dependent stimulation, where features extracted from the user's EEG is used to drive stimulation.
- **Closing the loop:** For sleep, recent work has shown that placing auditory tones at specific phases of the EEG, improves memory consolidation during sleep. Similarly, for chronic pain, flickering light at the alpha range (8-13 Hz) reduces the perception of pain significantly. Closed loop platforms are needed here to find out relevant features that may improve therapeutic effects.



3. Closed loop platforms

Initial work focused on developing a platform for phase-locked auditory stimulation for the sleep application. The Phase Locked Loop (PLL) was used to extract EEG phase in real-time. Offline analysis on 21 subject's sleep data, resulted in a promising phase error of 12.6+/-9.1 degrees, when targeting the peak (Figure 1 and 2). For chronic pain, a smartphone app was designed and tested, which provides auditory, visual and tactile stimulation at the alpha range (Figure 3). For both applications, the platforms will be ported to a smartphone, to power 'in the wild' experiments, and to deliver therapy at the user's own homes.

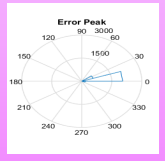


Figure 1: Phase error

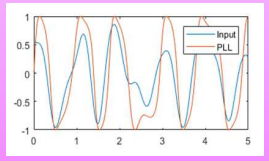


Figure 2: EEG signal (input) vs PLL output

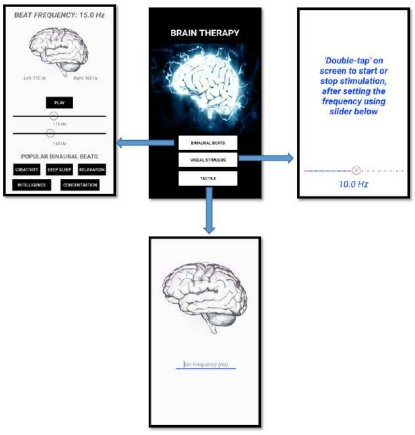


Figure 3: Smartphone stimulation app

5. Conclusion

In conclusion, progress has been made towards the development of a closed loop auditory stimulation platform and a stimulation app, for the sleep and chronic pain applications, respectively. Future work would involve:

1. **Chronic pain:** Closing the loop using Alpha phase and frequency and higher order features such as brain connectivity measures. These will be used by our clinical collaborators in their trials.
2. **Sleep:** Porting the offline platform to a smart-phone based one.

Both these would result in a series of smart-phone based therapies, that are driven by the user's on-going brain activity. This would empower current hypothesis driven neuromodulation experiments and help address the variability problem.

Sensing, Imaging and Signal Processing Group
School of Electrical and Electronic Engineering
The University of Manchester

For details contact: ***Nikhil Kurian Jacob***
E-Mail: ***nikhilkurian.jacob@postgrad.manchester.ac.uk***
Supervisor: ***Dr. Alexander J. Casson***;
E-Mail: ***alex.casson@manchester.ac.uk***

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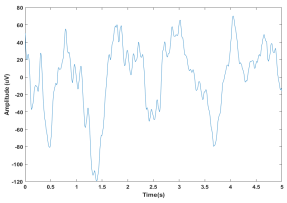
Brain Sensing

EEG signals



Brain Stimulation

Feature Extraction

Targeted stimulation:

- In time
- Matching underlying brain state (frequency, phase, connectivity etc..)
- Low latency signal processing