Neural/Cloud Interface to Extend Human-Computer Interaction for WebXR Applications

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This thesis is submitted for the degree of
Bachelor of Science (Honours), Web Development

Abstract

Different HCI possibilities in VR applications: 6 degrees of freedom, controllers, hand tracking, treadmill, joysticks, etc. The goal of VR is full immersion, which means that human sensory input and output must be as natural as possible, e.g. high-resolution screens, spatial high definition audio, etc.

Some interaction still relies on intermediaries such as pressing buttons on the controller or a joystick etc. Some are useful, but others are relics of today's computing: mice with pointers, keyboards, etc. They are intermediaries because technology in the 1970s was not yet ready to develop, for example, reliable multi-touch screens for the first wave of personal computers. The same thing is already happening in VR with, e.g. the hand controllers, as hand tracking was still a long way from becoming trustworthy.

But there are still interaction possibilities where the use of, e.g. our hands becomes very limited or uncomfortable, e.g. moving distant objects in a virtual 3D space, so it makes sense to use, e.g. a joystick. As with sensory information to achieve full-immersion in VR, there are countless opportunities and possibilities to achieve it.

With my work, I use a proprietary in-ear EEG sensor to extend the interaction possibilities with the help of the brain and facial artefacts like eye movement etc., to make the experience in the virtual world more natural in the meaning of using sensory output from our body and brain to interact with a virtual world.

There are several possibilities to use an in-ear located EEG sensors, e.g. eye movement, chewing, speaking, blinking, brain waves etc. More draft information coming soon.

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Chapter 1

Introduction

1.1 Background

There has been a long-standing interest in developing neural interfaces, systems that sense electrical impulses from the nervous system and use them to intercommunicate with the human brain. Successful research into the development of technologies that enable neural interfaces has been going on for decades (Vidal, 1977). Progress has accelerated significantly in the past few years, especially since the advent of modern processing capabilities such as in deep learning with convolutional neural networks (CNN) or generative adversarial networks (GAN) (Gonfalonieri, 2019). In particular, a related discipline called brain-computer interfacing (BCI), a field focused on the direct interaction between brains and computers, has accumulated much momentum since the popularity of companies like Neuralink and Kernel.

One aspect of neural interfaces is hardware tailored to the human body. Whether it is an invasive sensor, such as in electrocorticography (ECoG), a method which uses electrodes placed on the surface of the brain, or a non-invasively placed sensor on the body, such as in electroencephalography (EEG). Both methods measure electrical activities produced by neurons; however, with decreasing spatial precision, the farther the electrode is placed from the brain, the more body structures (e.g. bones) are between firing neurons and the measuring sensor. The other aspect is software that reads and interprets data of these hardware sensors. Both aspects present their own set of challenges and complexities. Nonetheless, complete and applicable neural interfaces work in practice and have been used for many years in patients with neurological disorders (BrainGate, n.d.). There are also consumer and non-clinical neural interfaces available, such as the Neurosity and OpenBCI products, which aim to democratise the use of EEG sensors by offering low-cost hardware and simple-to-use software.

This thesis will focus on the software aspect of non-invasive neural interfaces and the challenges and complexities that arise in the given context of modern software engineering for production-ready end-user facing brain-computer interface applications.

Fig. 1.1: Les Baugh, an amputee, is using a neural interface to control two robotic arms with his thoughts (Campbell, 2014).

1.2 Relevance

The possibilities of connecting the human brain with computers are almost limitless because one has to think that we are the brain, that our own perception of reality, all our feelings, memories and actions are supposed to be contained in the electrical impulses of our brain. The ability to communicate directly with our thoughts and the outside world — whether through digital or physical objects — is a fantastic prospect. There are several use cases: Controlling prosthetic limbs for amputees (Murphy et al., 2017), communication for people with locked-in syndrome (Chaudhary et al., 2022), diagnosing neurological problems and improving the mental capacities of elderly patients (Belkacem et al., 2020) are promising examples, to name a few.

It may appear evident that neural interfaces can significantly impact the field of therapeutics and accessibility for a small subset of the human population. However, one can envision not only alleviating deplorable living conditions but also improving the lives of

healthy people through more natural or efficient ways of interacting with things or by directly altering human brains for certain benefits. Because most current neural interface applications concentrate on the first aspect of therapeutics and accessibility, other use cases, such as stimulating the brain to improve concentration, modifying cognitive load, or even uploading new knowledge directly into the brain, may appear to be science fiction ideas.

Regardless, many intelligent people — research labs or even entire companies — are developing neural interface hardware and software aimed at the general population without conditions that envision a future for such use cases in the long term. The applicability of a neural interface system to the mainstream will depend on several factors, presumably an important factor of which is the hardware's form factor. Nonetheless, the totality of the ecosystem in which the software resides is a valuable aspect that should not be overlooked.

1.3 Research question
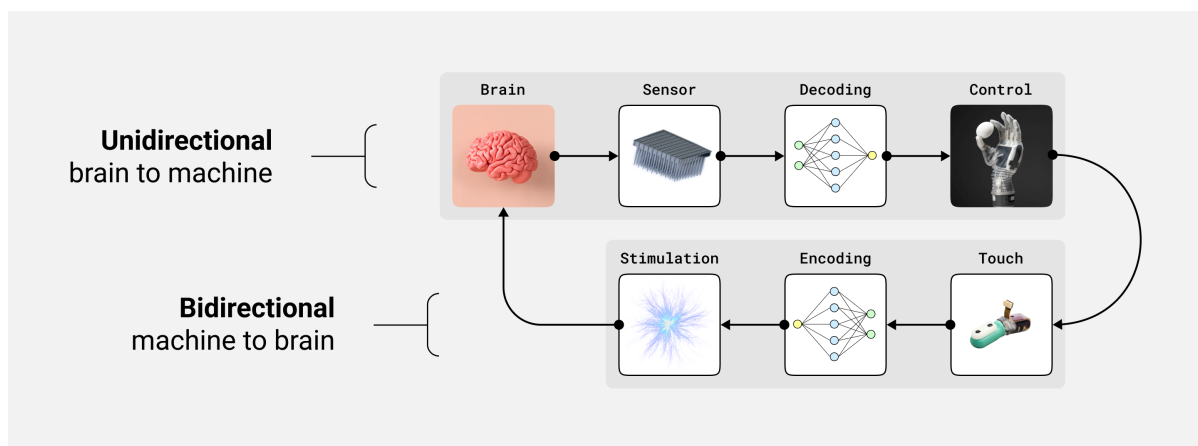
Fig. 1.2: Difference between an unidirectional and bidirectional neural interface and its components (own representation, 2022).

Whether it is a bidirectional and invasive neural interface with the potential to be implanted on a large scale, as e.g. Neuralink is aiming to do, or a unidirectional and non-invasive interface in various form factors that are also aimed at the mass market, such as in a pair of glasses or a pair of headphones, the data collected from the brain would always need to be processed, contextualised, and classified to produce an intelligible output — be it in real-time or deferred processing. The research question of the present thesis is on determining what technical components such a software system would require to be production-ready and suitable for a mass-market product. The emphasis is on a holistic

view of such a system, which means that the entire technology stack is taken into account in answering the research question.

Furthermore, most current neural interface software systems in production, for example, for an interface implanted in a living patient, are typically run in a local environment, i.e. the software system and its components are typically located on a physically nearby computer, usually connected by a cable, to reduce latency and avoid complexities introduced by a wireless protocol. There is already interesting research on wireless mobile brain-computer interfaces (mBCI) by Minguillon et al. (2017) or possible implications of human brain/cloud interfaces (B/CI) by Martins et al. (2019) or by Angelica et al. (2021), which analyse bringing future large-scale brain-computer interface software systems into the cloud.

1.4 Goals

Previous research on brain/cloud interfaces has tended to focus on speculations based on hypothetical scenarios in the future, usually based on the premise of other developed technologies such as neural nanorobotics, vital advances in 5G, or the presence of super-computers in the cloud, e.g. for the augmentation of the human brain, or a communication network for brain-to-brain interfacing (BTBI), and are thus rather distant from today's pertinence. To distinguish the research presented in this thesis, we coin the term neural/cloud interface (N/CI), which refers to a holistic software interface that connects a neural interface device to the cloud and then to other neural interfaces, software applications, cloud systems, or physical devices.

The primary hypothesis is that a neural/cloud interface is feasible with modern software technologies, requiring only theoretical groundwork based on empirical engineering in a deployable and producible system. This thesis looks at the process and lessons learned from developing a N/CI in the industry for an actual mainstream-capable neural interface device for a BCI end-user application to shed more light on this.

The overall goal of this thesis is to give the reader an overview of the definition of a N/CI, its components, and the lessons learned in building a reproducible production-grade, mainstream-ready and end-user facing NC/I application with a non-invasive, unidirectional neural interface hardware, with the effective end-user application example code incorporating the N/CI open-sourced as part of the thesis. In addition to the overall goal, the thesis aims to illustrate a powerful demonstration of the possibilities of BCIs on the World Wide Web for virtual reality (VR) or augmented reality (AR) applications running in a browser environment in order to exemplify how to extend the human-computer interaction (HCI) for future 3D applications when combined with a BCI.

Chapter 2

Context

2.1   Landscape

Chapter 3

Methodologies

Skizzieren der akademischen Methodik (kurz und projektbezogen) und der geplanten Vorgehensweise. Begründung der vorgesehenen Workflows, Hard- und Softwaretools. Definition von Phasen (Iterationen) mit Kontrollpunkten für Fortschritt, Feedback und Reflexion respektive die Weiterentwicklung. Möglicher Umfang: ca. 10-20

3.1   Participants

Forty-three patients of the psychiatric clinic with diagnosed major depression (12 male, Mage = 36.35, SDage = 7.92) participated in this study for monetary compensation (10 USD).

3.2   Design

- The study used a between-subject design (treatment group, control group) with the depression score on the XXX depression scale as dependent variable. - The study used a within-subject design (pre-treatment measurement, post-treatment measurement) with the depression score on the XXX depression scale as dependent variable. - The study used a mixed design with the between-subject factor group (treatment, control) and the within-subject factor time (pre-treatment, post-treatment). The depression score on the XXX depression scale served as the dependent variable.

3.3   Materials

- Three types of materials were used. First,. . . Second,. . . Third,. . .

3.4   Procedure

- Before the experiment started, participants were randomly assigned to two groups: the X group and the Y group. - The experiment consistent of two phases. In the first phase,. . . . . .

In the second phase,..... . - The order of these two phases was counterbalanced - First, participants had to... next... subsequently... finally... - Simultaneously,... - After participants finished X, they...

3.5 Data Analysis

- First, they were randomly assigned to treatment and placebo group - Both groups: 60 minutes intervention - Treatment group: first,... next,... - Placebo group: first, ... next,... - Finally, they filled out the depression questionnaire

3.6 Goals

o Did you describe everything that is needed to replicate your research? o Did you cite the sources of your methods or paradigms?

Chapter 4

Implementation

4.1 Lorem ipsum

Umfassende und anschauliche (idealerweise Bildmaterial, Screenshots, Zwischenstände. Auch Fehlschläge dokumentieren) Dokumentation, was genau getan / erstellt / programmiert / produziert / etc. wurde. Welche Auffälligkeiten gab es? Welche Entscheidungen wurden getroffen? Welche Änderungen / Einschränkungen / Erweiterungen wurden vorgenommen?

Chapter 5

Results

5.1 Ergebnisse: Präsentation des konkreten Endergebnisses. Kompakte Zusammenfassung des Projekts unter Berücksichtigung der anfänglichen Zieldefinition. Wichtig ist dabei, dass man eine kritische Betrachtung der faktischen Resultate vornimmt (Evaluation). Hier ist ein Soll-Ist-Vergleich zur Zielsetzung aus Kapitel 1 mit kritischer Stellungnahme gewünscht. 5.2 Zusammenfassung: Es soll eine Zusammenfassung der Arbeit geschrieben werden und ein Fazit in Bezug auf das Projekt dessen Bedeutung (Relevanz und Nutzen) gezogen werden. Weiterhin soll eine Kritische Betrachtung der eigenen Vorgehensweise erfolgen. Abschließend soll ein Ausblick auf weitere Projektideen, die sich im Rahmen der Arbeit ergeben haben, gegeben werden (Folgeprojekte, Veröffentlichungen, Verwertung). Empfohlener Umfang: ca. 15-20

5.1 Steps Before The Analysis

- Before we analysed the data, we removed all reaction times that were larger than 2000 ms (2% of all observations) based on the assumption that such reaction times are unlikely to reflect spontaneous responses. - The data of two participants were excluded from the analyses because they did not complete the whole study. - Functional images were re-aligned, unwarped, corrected for slice timing, and spatially smoothed using an 8 mm smoothing kernel.

5.2 Main Results

- First, we investigated whether X (research question) - We used an Independent samples t test with groups as independent variable and the depression score as dependent variable - The results showed that the difference between the groups/ conditions was significant - The results showed a significant correlation between... - The results showed a significant interaction between... - Specifically, the average depressions score was lower in the treatment group (M=3.45, SD = 2.18) compared to the placebo group (M=4.83, SD = 2.02).

5.3 Figures And Tables

Add figures to make important results easier to interpret or to provide more information. Use tables to add extensive amounts of information that would be hard to read in text-form.

5.4 Goals

o Did you describe everything that is needed to replicate your results? o Did you describe all pre-processing steps before the main analyses? o Did you mention to which research question each analysis belongs? o Did you avoid interpreting your results? o Did you add figures for making your key results easy to understand (or are they very simple)? o Did you add tables for extensive amounts of (numerical) information?

    o Does your discussion go from specific (interpretation) to broad (implications)? o Did you draw conclusions with reservations? ("A possible interpretation is. . . ") o If you expressed a preference for one explanation over another, did provide clear support for this preference? o Did you describe how your research connects to previous research? o Did you make clear what your research adds to existing research? o Did you describe how your research advance our understanding or how they may inspire future applications? o Did you clearly admit limitations before qualifying them? o Did you remind the reader of the value/implications of your research at the end? o Did you include some pointers for future research? (optional)

5.5 Conclusion

- We investigated whether depression can be treated by training a positive focus - Our findings confirm this - Novel perspective on depression - More research needed, more treatments that follow this approach should be developed

Chapter 6

Discussion

6.1 Summary

- Research question: Does the REFOCUS treatment work? - Study: treatment group and placebo group with self-reported depression measured afterwards - Findings: Depression was lower after the REFOCUS treatment compared to placebo

6.2 Interpretation

- Explanation 1: REFOCUS treatment reduced depression - Explanation 2: placebo treatment increased depression - However, explanation 2 is unlikely because the same placebo was used in studies A, B, C and there it didn't increase depression

6.3 Integration

- Previous research focused on the question of how unprocessed traumas could cause depression - We are the first who tested the "focus" explanation of depression

6.4 Implications

- It is widely believed that depression is caused by unprocessed traumas - Our findings offer a novel perspective: depression is caused by information processing style - Hence, new approach, new line of research to understand depression, new types of treatment

6.5 Limitations

- We had no measure of depression prior to the treatment - Reason: asking people to score their depression twice can lead to problems (references) - Consequence: we don't know

whether depression decreased in treatment group (explanation 1) or increased in placebo group (explanation 2) - However, as mentioned before, it is unlikely that depression increased - Sample size was relatively low - Reason: it's hard to find enough people with a major depression - However, our results were significant despite the low sample size. This speaks to the effectiveness of the treatment

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Appendix A

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Appendix B

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