Learning through kinaesthetic collaboration and brain synchrony

Main priority theme: collaborative spaces
Secondary priority theme: Collaboration with intelligent systems

A key challenge in robotics is to improve the cooperation between humans and robots. Our approach is to focus on the haptic modality, which plays an important role in human-human interaction. Haptics has been found especially advantageous to teach/learn hand skills. However, this modality is little explored in human-robot interaction. In this thesis, the candidate will identify and characterize kinaesthetic signals in human-human interaction that can be captured, recognized and used by robots. To achieve this, he or she will use EEG (ElectroEncephaloGram) to connect the understanding of kinaesthetic information during joint kinaesthetic actions with the neural mechanisms of joint agency. This investigation will involve computational modelling and be performed in the context of hand gesture learning.

The project specifically aims at studying the role of the communication of the system's intentions as a vector of gesture learning, but also at proposing a new communication medium, the kinaesthetic way, to improve the abilities of robots. The kinaesthetic modality has already been explored for guiding expert task such as laparoscopic surgery (Overtoom et al. 2019). Our ambition involves identifying the information necessary for the ability to teach hand gestures to systems during tasks requiring joint action. This information will then be leveraged to explore the benefits of the kinaesthetic modality in the process of learning hand gestures. This project will rely on new theoretical frameworks, but also on new technical solutions allowing this sensory modality to support human-robot cooperation.

Consider one person guiding another one. It could be a dancer guiding his/her partner, a mentor guiding an intern to perform a surgical operation, or an operator guiding another operator to learn to manipulate a tool. In all these examples, there is subtle cooperation relying on implicit communication of intention. This communication can be visual (e.g. eye-contact), audio (with oral instruction) but also kinaesthetic (involving movement, and forces).

Approach and methods

The originality of this approach will be to explore the notion of gesture learning with different level of kinaesthetic modality and explore if it has an effect on inter-brain synchronization.

A passive kinaesthetic modality means that the system is composed of mechanical part only. In contrary, active kinaesthetic modality assumes that there are actuators able to modify the transmission of gesture based on the task. For instance, an active strategy could be to make it harder for a body part to move when it goes in the wrong direction and enhance movement while going in the correct direction according to the task.

Kinaesthetic communication allows transmission of the information at different levels of complexity. Several protocols have been proposed to better understand this non-verbal communication mechanism based on the physical interaction between humans, notably in psychology. Through the study of joint action, it has been shown (Sebanz & Knoblich 2009) that communication is formed through kinaesthetic information. This co-constructed communication makes it possible to predict the movement and improve the efficiency of the task. This prediction is called “Sense of joint Agency”. On one hand, recent work (Shiraishi and Shimada 2021) has shown that this “sense of joint agency” can be observed alongside inter-brain synchronization. They have shown this phenomenon in a turntaking task but not in a kinaesthetic scenario. We would like to observe it in cooperation where movements are physically connected.

On the other hand, Nishida et al 2022 have shown that with a passive kinaesthetic linkage, the learning of the piano can be improved. But they did not explore its effect on brain activity though imaging.

Our first research question is to find whether inter-brain synchronization can reflect the quality of learning in kinaesthetic tasks such as piano or dance learning. The second research question is about the potential benefits of active kinaesthetic strategies compared to passive ones. To address these questions, the PhD project will explore quantitative methods to measure inter-brain synchronization and look for computational models of passive and active strategies.

Feasibility

The supervising team of this PhD is composed of David Gueorguiev (Researcher), expert in computational neuroscience and haptics, Ludovic Saint-Bauzel (Associate-Professor, HDR) is expert in robotics, especially in kinaesthetic devices development, Gilles Bailly (Research Director, HDR) is specialized in human-computer interface and is an expert in gesture learning. They are all part of ISIR, a robotics and intelligent systems institute that is already equipped with haptic robots, EEG systems. The PhD project will potentially foster collaboration with Fabrizio De Vico Fallani from the Paris Brain Institute.

References

Overtoom, E. M., Horeman, T., Jansen, F. W., Dankelman, J., & Schreuder, H. W. (2019). Haptic feedback, force feedback, and force-sensing in simulation training for laparoscopy: A systematic overview. *Journal of surgical education*, *76*(1), 242-261.

Sebanz, N., & Knoblich, G. (2009). Prediction in joint action: What, when, and where. *Topics in cognitive science*, *1*(2), 353-367.

Shiraishi, M., & Shimada, S. (2021). Inter-brain synchronization during a cooperative task reflects the sense of joint agency. *Neuropsychologia*, *154*, 107770.

Nishida, J., Tanaka, Y., Nith, R., & Lopes, P. (2022, October). DigituSync: A Dual-User Passive Exoskeleton Glove That Adaptively Shares Hand Gestures. In *Proceedings of the 35th Annual ACM Symposium on User Interface Software and Technology* (pp. 1-12).

Expected profile of the candidate

The expected profile is a student with a master's degree in neuroscience, computer science or a relevant discipline. The student has to have a background EEG experimentation, computational modelling, and human-computer interaction.

Desired skills: experience in programming (Matlab, python and/or C/C++), statistical analysis, knowledge of psychophysical methods

Curiosity for interdisciplinary research and robotics are strong assets for this project.