CENTRE BORELLI

école normale supérieure paris–saclay
UNIVERSITÉ PARIS-SACLAY

Internship proposals - 2021/2022

Contact

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Our laboratory This internship will take place at the Centre Borelli (ENS Paris Saclay/Université Paris Saclay, CNRS, Université de Paris, SSA, INSERM). The Borelli Center is a multidisciplinary research unit focusing on all applications of mathematics, neuroscience and biomedical research. It brings together multidisciplinary teams of mathematicians and experts in medicine, physics, mechanics, biology, and engineering, to conduct research actions motivated by real data and use cases from science and industry. It offers courses of excellence in applied mathematics, neurosciences, ergonomy and bioengineering on promising themes with high technological and societal stakes.

The societal stakes are considerable and offer many opportunities to the student who will choose this project in the field of the interface of engineering sciences, computer science, new technologies and medicine, ... In case of success, the internship may be the subject not only of scientific publications but also of a valorization project.

Environement The trainee will have the opportunity to be fully integrated into an interdisciplinary team of medical doctors, mathematicians, neuro-scientists, statistical modelers and computer scientists. The internship will take place at ENS Paris Saclay (Gif sur Yvette) and Université de Paris (Paris). The trainee will attend weekly seminars of the MLMDA team. The duration of the internship is between 4 and 6 months and the trainee will be paid according to the standard internship wage (around 600 euros per month).

1 Graph signal processing for the study of arm movements

Human movement is a complex phenomenon that involves neurological, neurophysiological and biomechanical aspects. In the last decade or so, light and inexpensive sensors have made it possible to easily and accurately measure the motion of a body segment, either from optical technologies (Kinect, Vicon, Coda Motion) or from inertial units (accelerometers, gyrometers). It is therefore now possible to compare existing biomechanical models with real, reliable data, potentially available in large quantities. These new data also allow to consider new innovative mathematical models and to rethink the classical conception of the human body as an articulated skeleton. In particular, and in a rather distant disciplinary field, the modeling of 3D structures, used in particular in coding and compression of 3D objects for video games or virtual reality, has recently undergone a revolution with the appearance of a new disciplinary field: Graph Signal Processing (GSP).

This new paradigm consists in conceiving a multivariate signal not as a simple temporal series, but in using the links that exist between the different dimensions of the signal (modeled here as a graph) in order to better take advantage of the structure of the signal. In concrete terms, if we record the position of ten or so points on the human body, we need to study not only the general movement of the body over time, but also how this movement will impact the links between the different segments, the correlations and synergies that appear and disappear over time, the active and inactive zones, etc... The objective of the internship is to develop and apply methods issued from the Graph Signal Processing (GSP) framework to the problem of movement analysis with motion capture sensors. In particular, in collaboration with clinicians, we have recorded several dozens of arm movements on a cohort of 30 subjects with motion capture sensors and we seek to find similarities and anomalies between occurrences of the same movements. The following questions will be investigated:

- Graph learning : What is the *good* graph structure to use in order to take advantage of the natural synergies between the sensors during natural arm movements ?
- Graph dictionary learning : How can we decompose the movements into localized and smooth components ? Could it be used to automatically classify/cluster the movements ?
- Anomaly/Similarity detection : How can we detect anomalies and similarities between occurrences of the same movements, while taking into account the graph structure ?

Keywords: Graph Signal Processing, biomedical signal processing, graph inference, dictionary learning, anomaly detection

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[2] Thanou, D., Shuman, D. I., & Frossard, P. (2014). Learning parametric dictionaries for signals on graphs. IEEE Transactions on Signal Processing, 62(15), 3849-3862.

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2 Pattern recognition/extraction in time series. Application to the study of Nystagmus

The study of eye movements and their pathologies can help researchers better understand the control mechanisms at work in the visual nervous system. The development of inexpensive sensors to record eye movements has opened up new opportunities to quantify these movements. In this internship, we propose to focus on a particular eye movement, the Nystagmus. This movement – which can impair vision in young children – is not clearly understood by ophthalmologists. Automatic characterization of different types of Nystagmus could help researchers better understand the cause of these movements and treat them. This project includes aspects related to learning, signal processing, optimization and computer science.

During this internship, the trainee will use convolutional dictionary learning to learn typical waveforms associated with nystagmic movements. The starting point of the internship will be to apply pattern extraction techniques such as convolutional dictionary learning to oculometric signals recorded in infants at Necker to automatically extract the typical shapes due to Nystagmus. This task is tricky as several additional movements are recorded simultaneously such as saccades or voluntary eye movement. The second part of the internship will be related to the automatic labeling and characterization of these typical shapes, thanks to the confrontation with the medical nomenclature.

Keywords: convolutional dictionary learning, pattern recognition, detrending, eye movement

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[3] C. Lalanne, M. Rateaux, L. Oudre, M. Robert and T. Moreau. Extraction of Nystagmus Patterns from Eye-Tracker Data with Convolutional Sparse Coding. In Proceedings of the International Conference of the IEEE Engineering in Medecine and Biology Society (EMBC), Montreal, Canada, 2020.

[4] Jas, M., Dupré La Tour, T., Şimşekli, U., and Gramfort, A. (2017). Learning the Morphology of Brain Signals Using Alpha-Stable Convolutional Sparse Coding. Advances in Neural Information Processing Systems (NIPS), pages 1099–1108.

3 Machine learning for the study of physiological data recorded during general anesthesia and intensive care monitoring

General Anesthesia (GA) is a drug-induced, reversible condition with three commonly accepted goals: lack of experience of surgery, nociceptive blockade and immobility for the needs of surgery. In 2010, 11.3 millions of anesthesia procedures were performed in France. However, despite numerous progresses in the understanding of GA mechanisms, some questions remain unanswered like the precise mechanisms of awakening after a GA, the long term effects of anesthesia or the common pathway of all anesthetics. The aim of this project is to use electroencephalogram (EEG) signatures, physiological signals (ECG, respiratory variables,...) and machine learning tools in order to better understand the phenomena involved during GA and intensive care. In particular, the goal of our study is to precisely quantify and predict recovery in order to further investigate its nature and time course, which remains debated. GA recovery is often considered as a passive process : as the anesthetics are eliminated, the reactivation of the neuronal circuits affected by GA would simply mirror their deactivation. But is it true ? Could we find some traces of GA in the EEG of patients, even several hours after they woke up ?

We have continuously recorded the EEG signals and several other physiological variables of 30 patients under GA with a 32-channel EEG device, from 1 hour before their sedation up to 3 hours after their awaking (when it is generally assumed that the recovery period is over). The objectives of this internship is to develop machine learning tools to analyze this database, but also to investigate the situation where the subject is monitored in intensive care. We are in particular interested in predicting the level of sedation in order to assess the depth of anesthesia but also to predict the awaking of the subject.

The internship will combine aspects from signal processing but also from time series analysis and prediction (Hidden Markov Models and variants).

Keywords: prediction models for time series, Hidden Markov models, signal processing, EEG data

[1] C. Dubost, P. Humbert, L. Oudre, C. Labourdette, N. Vayatis, P.-P. Vidal. Quantitative assessment of consciousness during anesthesia without EEG data. Journal of Clinical Monitoring and Computing, 2020

[2] Cohen, M. X. (2015). Comparison of different spatial transformations applied to EEG data: A case study of error processing. International Journal of Psychophysiology, 97(3), 245-257.

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[5] P. Humbert, C. Dubost, J. Audiffren, L. Oudre. Apprenticeship Learning for a Predictive State Representation of Anesthesia. IEEE Transactions on Biomedical Engineering, 67(7):2052-2063, 2020.

4 Pupillometric data and eye movements: Extraction of information for the detection and diagnosis of ophthalmologic and neurologic pathologies

Pupillary activity and continuous eye movements of any individual constitute a privileged observation window to assess the existence of ophthalmic or neurological pathologies, and cognitive behavior (e.g. attention). The measurement of these variables with an eye-tracking device is simple, and allows the collection of a large set of data on diverse populations, for which the development of innovative treatment methods is necessary. The internship project aims to develop signal analysis tools to extract relevant information to characterize these pathologies, and to use the derived variables with deep learning approaches to identify objective physiological markers to identify individuals affected by these diseases. The data available for this project were collected during clinical studies conducted on different sites and healthy subjects or patients affected by various ophthalmological diseases (Glaucoma, Retinitis Pigmentosa, AMD, Stargardt disease). These chronic pathologies, frequent and particularly disabling, do not initially cause significant visual loss and are therefore only detected late, too late to be treated. In these clinical studies, rapid pupillometric tests (1 minute per eye), based on frequency marking of different regions of the visual field, have been developed. Preliminary analyses of the pupillometric and oculomotor data collected indicate that these signals present "signatures" of these pathologies. Ultimately, the project aims to use these pupillometric tests in clinical routine to predict the existence of these pathologies before the visual losses that often lead to blindness.

The internship will consist in developing tools for processing these signals, in particular time-frequency analysis, change-point detection and spectral estimation techniques.

Keywords: spectral estimation, signal processing, change-point detection, time-frequency analysis

[1] Lamirel, C., Ajasse, S., Moulignier, A., Salomon, L., Deschamps, R., Gueguen, A., ... & Lorenceau, J. (2018). A novel method of inducing endogenous pupil oscillations to detect patients with unilateral optic neuritis. PloS one, 13(8), e0201730.

[2] Yang, Y., Peng, Z., Zhang, W., & Meng, G. (2019). Parameterised time-frequency analysis methods and their engineering applications: A review of recent advances. Mechanical Systems and Signal Processing, 119, 182-221.

[3] Hupé, J. M., Lamirel, C., & Lorenceau, J. (2009). Pupil dynamics during bistable motion perception. Journal of vision, 9(7), 10-10.

[4] Najjar, R. P., Sharma, S., Atalay, E., Rukmini, A. V., Sun, C., Lock, J. Z., ... & Milea, D. (2018). Pupillary responses to full-field chromatic stimuli are reduced in patients with early-stage primary open-angle glaucoma. Ophthalmology, 125(9), 1362-1371.