State and parameters estimation of nonlinear dynamical networks for seizure detection and localization using EEG data

Taous Meriem Laleg
INRIA, centre de Saclay
taous-meriem.laleg@inria.fr

Epilepsy is the third most common neurological disorder after Alzheimer's disease and stroke. According to the World Health Organization (WHO), epilepsy affects more than 65 million people worldwide, with more than 200,000 new cases diagnosed each year. This disease is characterized by transient and unexpected electrical disturbances of the brain or excessive neuronal discharges of its electrical activity. Different brain modalities are used in the study of epilepsy, such as electroencephalogram (EEG), magnetoencephalogram (MEG), and intracranial electroencephalogram (iEEG). Prediction and localization of the seizure is a challenging problem that attracted the research community. In particular, the detection of the Seizure-Onset Zone (SOZ) is essential for identifying the neuronal regions for surgical resection or for neurostimulation. Both resection and neurostimulation are defined as efficient alternatives to pharmacological treatments, which fail in 25 à 33% of the cases due to the resistance of the organism. Therefore, controlling the spreading of the epileptic seizure dynamics has been a point of interest, where closed-loop control based on intracranial electrical stimulation is applied at the early evolution stage of epilepsy. However, this requires the accurate detection and localization of the seizure onset zone [1].

Understanding the seizure propagation dynamics helps in defining efficient control loops for controlling the spread of the seizure and also for identifying the SOZ. The seizure dynamics models are known to be highly nonlinear and complex [2]. A well-known model that consists of large-scale networks of nonlinear differential equations with delay called *epileptor* will be studied in this project [3, 4, 5]. This patient-specific network includes various types of delays that affect the accuracy of the modeling. In particular, we will be interested in the estimation of the state and parameters of the model, which is a crucial phase in analyzing the seizure propagation. In addition, the controller loops usually depend on the states, when some of the existing references suppose that the state is known and measurable, there are some states in the *epileptor* model which are not accessible for measurements. In this study, we will, in particular, extend the conventional observer design theory to the *epileptor* network of nonlinear dynamical equations with delay, such as high gain observers. We will also have a particular interest in designing estimators with finite-time convergence, a particularly appreciated property for real-time applications. The methods will be validated using the virtual epileptic patient and publicly available dataset [6].

References

[1] Moosavi, S. A., Truccolo, W. (2023). Linear Feedback Control of Spreading Dynamics in Stochastic Nonlinear Network Models: Epileptic Seizures. In 2023 11th International IEEE/EMBS Conference on Neural Engineering (NER) (pp. 1-6). IEEE.

[2] García-Laencina, P. J., Rodríguez-Bermudez, G. (2015). Analysis of EEG signals using nonlinear dynamics and chaos: A review. Applied Mathematics & Information Sciences, 2309-2321.

[3] Song, J. L., Li, Q., Pan, M., Zhang, B., Westover, M. B., Zhang, R. (2020). Seizure tracking of epileptic EEGs using a model-driven approach. Journal of neural engineering, 17(1), 016024.

[4] Guan, Y., Zhang, X. (2022). Dynamics of a coupled epileptic network with time delay. Mathematical Modelling and Control, 2(1), 13-23.

[5] El Houssaini, K., Bernard, C., and Jirsa, V., The Epileptor Model: A SystematicMathematical Analysis Linked to the Dynamics of Seizures, Refractory Status Epilepticus, and Depolarization Block, eNeuro, 2020.

[6] Makhalova, J., Medina Villalon, S., Wang, H., Giusiano, B., Woodman, M., Bénar, C., Bartolomei, F. (2022). Virtual epileptic patient brain modeling: Relationships with seizure onset and surgical outcome. Epilepsia, 63(8), 1942-1955.