PROJECT SUMMARY

Overview:

Epilepsy is a neurological disease that affects approximately 1% of world?s population. In the US alone, this equates to 1.5 million people. In thirty percent of cases, drugs are effective mitigating the side effects of the disease. When drugs do not work, there are two alternatives. The most severe is removing brain tissue, which is effective for an additional ten percent of patients. A less severe option is to install a neurostimulation device whose electrical discharges change the ?brain-environment? and possibly prevent a seizure to occur. For a long time, these devices operated in open-loop, but recently the research pivoted towards closing the loop. In other words, these devices became brain-machine-brain interfaces since they sense brain activity, upon which they decide on how and when to deliver a stimulus to the brain. Lastly, these devices are bio-cyber-physical systems and are still in their infancy, which presents several opportunities and challenges to be addressed from a cyber-physical systems? lens.

The PI proposes to study if it is possible to quantify (from a dynamical systems? perspective) the evolution of brain towards ?abnormal? behavior (e.g., epileptic seizure-onset), since this is key when assessing the efficacy of the control stimulus in mitigating the seizure. Nonetheless, in order to be reliable, such a criterion needs to be interpretable by the medical and neuroscience society. With such a quantification mechanism, the PI proposes to investigate how to adapt the classifiers/predictors, that ultimately are to be deployed in a low processing unit with limited sensing capabilities (i.e., current neuro-stimulators). Thus, it requires the development of the fundamental science and methodological considerations that can take full advantage of the underlying technology. The PI proposes to achieve these goals by developing tools in the intersection of the following domains: (i) analysis of large-scale dynamical systems and model reduction (to attain a metric that quantifies and assess the evolution of the brain activity towards a seizure, and cope with the limited computational capabilities of the neurostimulation device); (ii) machine learning to classify/predict seizures (using an interpretable assessment metric); and (iii) control theory and discrete optimization to address the limited sensing capabilities.

Intellectual Merit:

The present line of research aims to improve the efficiency of neurostimulation devices to be used to mitigate the symptoms associated with epilepsy. Additional, it aims to establishing guidelines on how to formalize a problem to be addressed by a brain-machine-brain interfaces. By doing so, we generate new tools to analyze the dynamics of the underlying phenomena that leads to a seizureonset. Hence, providing new understanding of its beginning and ending, as well as its transient, to the medical and neuroscience community. Furthermore, the proposed approaches are crafted to the specific application, while keeping in mind the possible generalizability to other CPS devices and diseases.

Broader Impacts:

The present research will directly impact the quality of life of the patients that qualify for the implementation of the neurostimulation devices, i.e., 450,000 patients. Specifically, the brain will be stimulated by the neurostimulation device less often due to the smaller occurrence of false positives, and the battery will last longer, which implies that the patient would not need to enroll in a new surgery to replace the battery. Furthermore, the detector and predictors can interact with other technology (e.g. a cell phone app) that will inform the patient when a seizure is about to start such that the patient can do accommodations to mitigate the side effects of the convolutions. On the other front, the nature of the interdisciplinary work will broaden the use of the tools developed across physicians and neuroscientists, and teach invaluable lessons on how to combine different aspects in the undergraduate and graduate curricula to prepare the next generation of scientist and engineers. Lastly, the same methodological considerations can be envisioned for other brain-machine-brain interfaces. For example, the deep brain stimulation that is used in the context of reducing gait, stiffness and shaking in Parkinson?s, and approved by Food and Drug Administration to treat depression and migraines. Besides, new insights are likely to be attained towards the enhancement of neural wearables at large for either leisure (e.g. computer gaming) or medical applications (e.g., prosthetic devices).