Non-linear Kalman filtering techniques for estimation and prediction of rat sleep dynamics

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Our laboratory has ongoing efforts to utilize model based controller-predictor systems to better understand the non-linear dynamics of the brain, with particular attention to sleep and seizure. Towards this end, we have implemented several published and novel computational models of the brain to investigate its behavior in a variety of different states (i.e. sleep vs. wake). These models have been modified so that they simulate the sleep dynamics of our experimental rodents within small sampling times. We have implemented these models in an Unscented Kalman Filter (UKF) framework to serve as duplicate source and tracker models and show that the UKF-based data assimilation algorithm we have developed is extremely robust and can reconstruct hidden dynamics even when the tracker model is intentionally made inadequate. In parallel with these computational efforts, we have obtained a feature set of experimental data from our continuously cabled rodents and have used these features to classify state of sleep and to develop a seizure prediction algorithm. Several of these discrete and continuous features are then used as the noisy observables in the implemented UKF framework to recursively reconstruct all of the inaccessible variables of the dynamic sleep model. Results from this reconstruction are promising and allow us access to hidden variables, such as sleep driven changes in neurotransmitter concentrations that would be hard or impossible to measure directly from our rodents. Furthermore, we have augmented our algorithm to make short-time predictions of sleep state. We then use these predictions of sleep-state transitions to improve the performance of our seizure prediction algorithm by reducing the confounding effect of sleep state on seizure prediction.

Recent published literature has begun to illuminate the intimate link between seizure and sleep, a relationship with a long clinical history in human patients. It is becoming increasingly clear that in order to predict and control seizure dynamics, we must first be able to grasp the non-linear dynamics of sleep and sleep-state transitions. Thus, our work bridges experimental and control theory techniques to investigate a crucial missing link which will give us insight into the dynamics of seizures and may drastically improve seizure prediction.