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Research Experience

I am Rakesh Malladi, a final year PhD student in Electrical and Computer Engineering at Rice University. I obtained my undergraduate degree in Electrical Engineering from Indian Institute of Technology (IIT) Madras. I am looking for full-time opportunities in machine learning and signal processing. The overarching goal of my work over the last decade is developing algorithmic tools to determine and quantify the relationships between data recorded from multiple sensors, a very important problem in healthcare, internet of things and many other industrial applications. Here is a brief summary of some of my recent projects.

1 Ph.D. Thesis

In my PhD research, I applied my expertise in machine learning and signal processing to develop algorithms for optimal real-time closed loop electrical simulation based treatments for epilepsy. More specifically, I worked on developing algorithms and techniques to infer temporal and spectral structure from data obtained from brains of epilepsy patients. I developed estimators of directed information to infer the temporal causal connectivity and estimate seizure onset zone (Section 1.1). I developed a new metric, mutual information in frequency, to estimate and analyze the cross-frequency coupling during the progression of seizures (Section 1.2).

1.1 Inferring Causal Connectivity in Data using Directed Information

The goal of this project is to estimate the causal connectivity between data recorded from multiple sensors in a system using directed information. Two data streams are causally connected, if the past values of one stream can reduce the uncertainty in the predicting the future value of the other. In most real-world systems like signals recorded from brain, the underlying model of the data is unknown. I, therefore, developed a model-based (or parametric) and data-driven (or nonparametric) estimators to estimate directed information from data [1]. The model-based approach is based on multivariate autoregressive process. The data-driven approach is based on estimating the joint probability distribution function using kernel density estimation. I used these estimators on the ECoG recordings from brains of epilepsy patients to show that ECoG data are nonlinearly related and correctly infer the spatial regions where the seizures originate in these patients.

1.2 Cross-Frequency Coupling between Stochastic Processes

The goal of this project is to determine whether frequency components in time series data recorded from multiple sensors are independent or not, and if not, quantify the dependence. Existing methods work when data is linearly related. However, the data is not linearly related in general and I developed a novel information theoretic metric, referred to as mutual information in frequency, to detect and quantify the dependence across frequency [2]. I proposed data-driven (or nonparametric) estimators for this metric using kernel density estimation and k-nearest neighbors. I used this metric to investigate the cross-frequency coupling during seizures from electrocorticographic (ECoG) recordings in epilepsy patients and found that high-frequency oscillations become more synchronized during seizures, when compared to before and after seizures.

2 Breathing Rate Estimation from Sensor Data

This work was done during my internship at LivaNova (formerly Cyberonics). The goal of this project is to estimate breathing rate from signals recorded by a triaxial accelerometer and develop an early warning system to prevent sudden unexpected death in epilepsy patients (SUDEP). The key hypothesis behind this project is that SUDEP can be prevented if we can detect apnea in epilepsy patients immediately after seizures. To this end, I focussed on estimating breathing rate from signals recorded by a triaxial accelerometer attached to the chest of the subjects. I developed a solution using change point detection, feature selection and parametric modeling using multivariate autoregressive processes and MUSIC (multiple signal classification) algorithms. The performance of my proposed solution was benchmarked from breathing rate estimates obtained using abdominal belt sensor. The algorithms I developed will be integrated into Proguardian device for real-time estimation and monitoring of breathing rate in epilepsy patients.

3 Mathematical Modeling of Ultrasound Waves to Estimate Thickness

This work was done during my internship at Texas Instruments. The goal of this project is to develop algorithms to detect the health of various structures using ultrasound guided-wave propagation. Ultrasound guided waves are generated by exciting a piezoelectric sensor, which are recorded by another sensor. In contrast with methods based on finite element methods, I developed a mathematical model of signal recorded at the sensor [3]. The parameters of the proposed model are estimated using experimentally recorded signals by regression using a maximum likelihood estimator, which minimizes the l_2 norm. The thickness is estimated by generating a dictionary of signals for various thickness from the proposed model and a greedy search for the thickness that minimizes the l_2 norm between the recorded signal and the signals in the dictionary. The performance of the proposed algorithm is validated on aluminum plates.

References

[1] R. Malladi, G. Kalamangalam, N. Tandon, and B. Aazhang, "Identifying seizure onset zone from the causal connectivity inferred using directed information," *IEEE Journal of Selected Topics in Signal Processing*, vol. 10, no. 7, pp. 1267–1283, Oct 2016.

[2] R. Malladi, D.Johnson, G. Kalamangalam, N. Tandon, and B. Aazhang, "Measuring cross-frequency coupling using mutual information and its application to epilepsy," *to be submitted to IEEE Transactions on Signal Processing.*

[3] R. Malladi, A. Dabak, and N. K. Murthy, "Modelling ultrasound guided wave propagation for plate thickness measurement," in *SPIE Smart Structures and Materials+ Nondestructive Evaluation and Health Monitoring.* International Society for Optics and Photonics, 2014, pp. 90 630Q–90 630Q.