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Unsupervised learning and feature extraction of Alfvén activity in fusion plasmas

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Fusion plasma devices have generated in the past years large amounts of shots exhibiting Alfvén activity, which is usually detected using external magnetic sensors (Mirnov coils), but also by other diagnostics. The behaviour of Magnetohydrodynamic (MHD) modes is commonly analysed through spectrograms from Mirnov signals. However, extracting physical information of individual mode activity from the entire spectrogram remains in most situations a tedious manual task. In addition, in view of the application of supervised machine learning algorithms [1], large collections of manually labelled datasets are needed. These needs motivate the work presented here, where we explore the possibilities of automatically labelling MHD modes using unsupervised learning.

Based on the observation that MHD modes are generally sparse in the frequency domain, several approaches are discussed. First, a mode decomposition of the time signals based on a dictionary encoding [2] is proposed, allowing the use of clustering algorithms for labelling MHD modes in TJ-II stellarator signals [3]. In other words, this algorithm can decompose the signal in a collection of waveforms which can be grouped identifying mode types. The proposed algorithm [2] has been adapted to be accelerated with GPUs, increasing speed by a factor of ten, and particularly reducing the memory usage, avoiding allocation of the dictionary matrix with a size of the order of terabytes. Moreover, we show on Fig. 1-2 that the addition of other diagnostic signals, such as electron density, plasma current, or plasma energy, can enrich the information used by the clustering, leading to more meaningful identified clusters.

Second, different time-frequency representations, such as wavelet analysis [4] or the Hilbert-Huang transform [5] are also employed to extract features from JET tokamak's Mirnov data [3]. The results reveal that instantaneous frequency representations are necessary for study micro time scale characteristics of signals like sawteeth or pellet injections. Moreover, we show on Fig. 3 that the use of discrete wavelet transform on spectrograms enables a reliable mode clustering process, as stationary modes can be de-noised and studied independently of frequency-sweeping (chirping) modes.

The GPU-accelerated unsupervised learning algorithms presented here and applied to fusion experimental data can provide unprecedented feature extraction of fusion diagnostics. The results would allow the automatic analysis of individual modes at different time scales, and the isolation of each mode signal from background noise by tuning the regularization and scale hyper parameters. Future work is required for hyperparameter tuning, incorporate mode numbers and examine the physical meaning of mode clustering.

REFERENCES

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