Epoch-based Entropy : A Statistical EEG Marker for Alzheimer's Disease Detection

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Context

- Numerous studies in the literature demonstrated that electroencephalography (EEG) associated with appropriate signal processing methods can bring valuable information on normal and impaired brain networks [1].
- EEG have been largely employed to investigate AD-related alterations in terms of functional connectivity assessment
- The proposed measures in the literature share two main drawbacks:
  - They do not address the problem of EEG non-stationarity
  - They do not consider EEG signal as a multidimensional time series
  - They quantify the spatial relationship between EEG signals without considering the complete alterations due to AD : reduction of complexity

Epoch-based Entropy (EpEn)

- EpEn measures the information content or the disorder of multivariate EEG signals at two levels simultaneously, using a Hidden Markov Model :
  - at the time level : it quantifies the information content on piecewise stationary epochs of signals over time;
  - at the spatial level: it quantifies the functional connectivity in terms of the heterogeneity of piecewise stationary epochs between multi-channel EEG signals.
- Each observation z in a given epoch S_i is considered as a realization Z_i of a random variable Z that follows a given observation probability distribution $P_i(z)$ modeled by the Gaussian mixture.

$$H^*(Z_i) = -\sum_{z \in S_i} P_i(z).log_2 P_i(z) \qquad EpEn(Z) = \frac{1}{N}\sum_{i=1}^{N} H^*(Z_i)$$

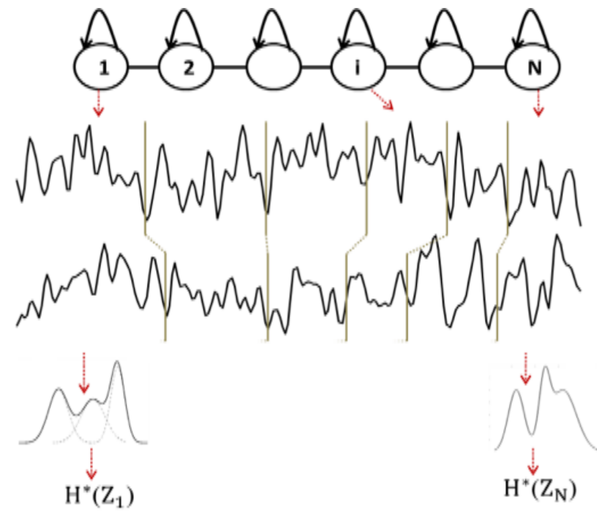

Fig. 1. EEG signal modeling with HMM

- In [2], the efficiency of EpEn was investigated in terms of its robustness to noise, its sensitivity to sampling frequency and to variations of hyper-parameters. We showed that EpEn (AUC=0,90) is more efficient for AD detection compared to correlation dimension (AUC=0,80) and Shannon entropy (AUC=0,74) used for complexity assessment.

EpEn as a functional connectivity measure

- We compared EpEn to four functional connectivity measures [3].
- Study population: 22 subjects with subjective cognitive impairment (SCI), 28 Mild AD patients (AD), and 22 patients with mild cognitive impairment (MCI).
- Recording at Charles-Foix hospital (France) with a Deltamed EEG acquisition system using 30 electrodes.

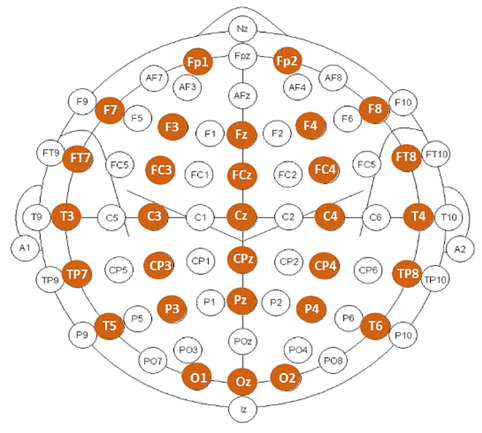

Fig. 2. Distribution of the 30 electrodes on the scalp

Table 1. Best performance with SVM classifier when discriminating AD from SCI with each EEG feature, considering a combination of two brain regions and

AD vs. SCI	Coherence	Phase synchrony	Granger causality	Mutual Information	EpEn
Accuracy	70%	72%	74%	70%	98%
Sensitivity (AD)	59.1%	63.6%	54.5%	89.3%	95.5%
Specificity (SCI)	78.6%	78.6%	89.3%	45.5%	100%

Table 2. Best performance with SVM classifier when discriminating AD from MCI with each EEG feature, considering a combination of two brain regions.

AD vs. MCI	Coherence	Phase synchrony	Granger causality	Mutual information	EpEn
Accuracy	68 %	64 %	58 %	74 %	100 %
Sensitivity (AD)	60.7 %	85.7 %	60.7 %	96.4 %	100 %
Specificity (MCI)	77.3 %	36.4 %	54.6 %	45.5 %	100 %

Conclusion

- The statistical measure is by far a more reliable and discriminant feature for AD detection, on our experimental data.
- The originality of this statistical measure lies on the fact that it allows a better estimation of the spatio-temporal characteristics of EEG signals merged into a single figure.
- The structure of the HMM is suitable for modeling neural dynamics underlying the observed multidimensional EEG time series.

[1].H. Hampel, N. Toschi, C. Babiloni, F. Baldacci, et al. Alzheimer Precision Medicine Initiative (APMI). Revolution of Alzheimer Precision Neurology. Passageway of Systems Biology and Neurophysiology, J Alzheimers Dis., 64(s1):S47-S105, 2018.
[2] N. Houmani, F. B. Vialatte, G. Dreyfus, Epoch-based entropy for early screening of Alzheimer's disease, Int. J. of Neural Systems, Vol. 25, Issue 8, 2015, 1550032.
[3] N. Houmani, M. Abazid, K. De Santiago, J. Boudy, et al., EEG signal analysis with a statistical entropy-based measure for Alzheimer's disease detection, open access book, Advances in Signal Processing: Reviews, Book Series, Vol. 2 published by IFSA Publishing, S.L., accepted, 2021.

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