Co-operative Agents in Analysis and Interpretation of Intracerebral EEG Activity: Application to Epilepsy

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Abstract. The paper presents a distributed approach for the interpretation of epileptic signals based on a dynamical vectorial analysis method. The approach associates signal processing methods into a situated, reactive, cooperative and decentralized implementation. The objective is to identify and locate the various interictal and ictal epileptiform events (pathological and/or normal) contained in intracerebral EEG signals (one hundred recording channels in general) recorded in patients suffering from partial temporal lobe epilepsy. This approach associates some signal processing methods (spectral analysis, causality measurements, detection, classification) in a multi-agent system.

Keywords: Epilepsy, signal processing, agents and cooperative systems.

1 Introduction

Epilepsy is a disease characterized by brutal and excessive synchronization of neuronal population. In Stereo-Electroencephalography (SEEG) exploration, we have physiological signals rich of informations on the observed structures. These signals inform various peculiarities of the functioning of a structural entity, an organ or even a system. The human intracerebral EEG can participate in a joint; hierarchical and a reproducible way in cognitive spots or in pathological processes. It is also allowable to admit that some local dynamics taking part in a joint action of structures are different between themselves. Moreover, previous studies were able to show that certain epileptic seizures originate from an area of the brain and propagate in a diffuse way towards other cerebral structures [1]. It is about a multi-dimensional system, multi-variable, split up in a multitude of independent neural entities in mutual influence. The signal processing proposes approaches and answers today to better define the complex concepts of irritative zone and epileptogenic zone [2]. The concepts of topography ("*where is the source of the signal?* ") and of synchrony ("*are these two signals synchronous, thus reflecting a functional connectivity?*") are now clearly set up [3]. However the answers contributed by these methods is based on series of treatments and correlations applied to a small number of signals (selected visually sometimes) among the great number of signals available during the recording, a number which can reach 128. Our work asks the question of the network

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dynamics in terms of a succession of behaviour produced by inter-structures interactions. The problem is approached by a multi-agents system (MAS) [4], the agents answer partially the resolution of problem by acting locally; making the various computations (signal processing algorithms) according to some control mechanisms (strategies, organization, cooperation and coordination of agents).

The paragraph §2 clarifies the formal frame of our work. It explains the "agentification" of the problem. The third point presents the agents architecture, quantitative extraction information methods used by agents and various phases of the methodology. The experimental results and discussion are exposed in the fourth point.

2 Agentification for the Analysis of Epileptic Signals

We start from the idea that we have to deal with a set of neuronal groups being able to present, on a given temporal window, paroxystic activities of various types and interactions more or less pronounced leading to behaviour of these groups. We try to *approach them locally to be able to explain them globally*. Our work consists in studying a vectorial signal $S(t) = [S_1(t) \ldots S_M(t)]$ observed on an interval [0, T]. In other words, it consists : *(i) to characterize each EEG channel $S_i(t)$*, *(ii) to determine the statistical relations between the various channels*, *(iii) to study the organization of group according to the analysis of the signals*, and *(iv) to connect the notion of functional coupling between cerebral structures towards the quantities supplied by signal processing methods supervised by the dedicated multi-agent system (MAS).*

We so associated to each signal $S_i(t)$, a "signal agent" noted A_{S_i} and to each group of "signals agents" of the same cerebral area, a "structure agent" noted S_{P_i} (figure 1).

The collective intelligence, control mechanisms, coordination and signal processing algorithms are spatially distributed in the various constituents of the system. Each structure is associated to an agent, inside whom are implemented local computations processes ("signals agents") and of interpretation ("structures agents").

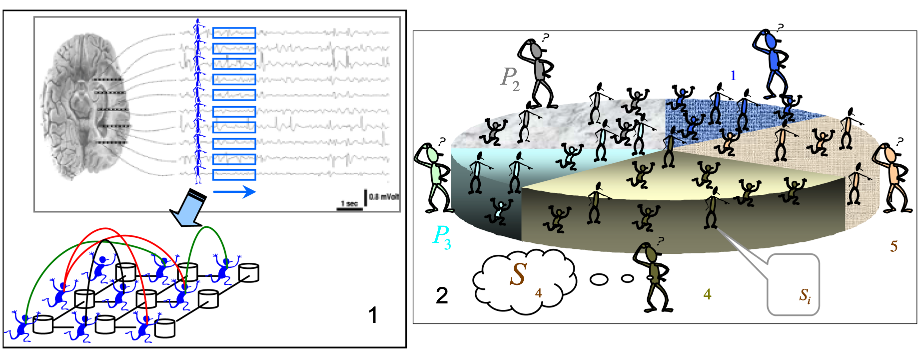

Fig. 1. 1) Vectorial analysis of epileptic signals: each agent has its own choices, knowledge, and algorithms processes. 2) Partitioning: the "signal agent" are supported in groups of agents belonging to the same cerebral area and a "structure agent" is associated to each partition.

3 Multi-Agent System Proposed

The multi-agent system (MAS) is implemented in "Madkit" platform (Multi-agent development kit [6]). Our choice concerned hybrid architecture distributed on two levels; a first level consisted of reactive agents ("signals agents") which try to locate the interesting signals specified by an auto-organized model and the second level established by cognitive agents ("structures agents") which interpret the results realized by the reactive agents. Control's agents complete the system for needs of software treatment ("Scheduler agent", "Server agent" and "Observer agent"). The interactions between signal processing algorithms and MAS are offered in 4 stages which blend the general architecture philosophy.

3.1 Quantitative Extraction Information of Each Agent

This first stage consists in extracting the individual properties of each signal agent. The frequency activities is characterize, in 3 phases on a slippery window : *(i) evaluation of the power spectral density of the signal $S_i(t)$ in defined frequency band, (ii) construction of a characteristic vector for each signal $S_i(t)$ and iii) numeric coding of the vector in a scalar indicator*. Each agent, according its activity, is associated to a scalar indicator and a *characteristic* vector. The signals agents are then grouped by similarity according to 4 classifications methods: *(c_i) Supervised classification using learning classes defined a priori. (c_{ii}) Supervised classification using a Fuzzy approach classification algorithm. (c_{iii}) Pseudo- supervised classification based on the scalar indicator. (c_{iv}) Unsupervised classification, based on euclidian distance between characteristic vectors associated to the agents*.

3.2 Selection of the "Signals Agents"

The selection results from three agent's behaviours grouping-diffusion-decimation. Each signal agent has two local data bases "localGroup" and "localOutGroup" where it registers respectively its remarkable similarity (affinity) and its remarkable differences (rejection). The *grouping behaviour* results from the necessity of grouping together similar signals agents of the same group. Signal agent can be also brought to spread its group by diffusion its local bases according to the criterion "*I accept in my base each agent similar to one of my affinities if he is not already registered in my rejections*" *and* "*I refuse to integrate a group where is registered one of my rejections*". This *diffusion* process takes place at first in a local context (inside a partition). Each group of similar agents so formed is considered as a unique entity carrying the same information from where comes the idea of a sole representative by group. This *decimation behaviour* is activated in each partition (structure agent) to elect the best representatives of the structure.

3.3 Characterization of Connectivity Between Structures

The links between structures are characterized by three measures: similarity, statistical relations and synchronizations between agents. The *similarity* measure is based on a euclidian distance between characteristic vectors. Each leader of group has to evaluate its links with the others leaders. The leaders use on their local data bases to retain their affinities, to reject their rejections and to ignore the elements of which similarities is to be verified by other methods. The s*tatistical relations* measure uses the nonlinear intercorrelation coefficient [5] to characterize the degrees of links between investigated structures. This measure made on local entities defines the links between the bows of the graph produced by the system at the global level. The *synchronization* is based on significant modifications of the intrinsic properties in each signal. The "Observer" agent leans on the temporal synchronization of the alerts received to define the links of synchronizations between agents.

3.4 Characterization of Spatio-temporal Dynamic

The characterization of the spatiotemporal dynamics looks for a global interpretation based on the local modifications of connectivity between structures. Each agent structures pronounces on its links with the other structures all the time and on its possible modifications of connectivity with regard to the previous moments. The combination of all the propositions, by the agent "Observer", produces a graph at the global level. This graph follows the spatiotemporal dynamics of the analyzed seizure. The observation of the modifications between successive graphs (distances between graphs) allows characterizing the organizational dynamics modifications.

4 Results

The data used in this study result from 5 patients suffering from lobe temporal epilepsy and candidates for surgical treatment. The system produces for each patient a layer spatio-temporo-spectral coloured and a graph symbolizing the various connectivity

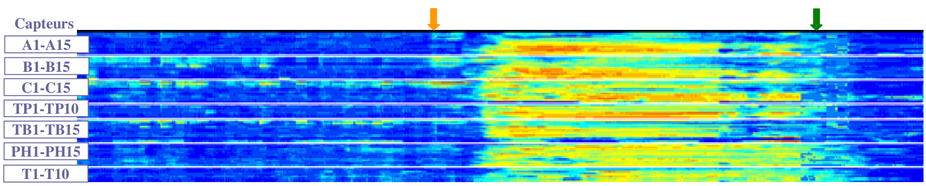

Fig. 2. Spatio-temporo-spectral tablecloths of P1. The "cold" and "warm" colours coding respectively the "low frequency" and the "high frequency" activities. The contacts of electrodes are numbered from 1 to 15 since the internal extremity until the external extremity.

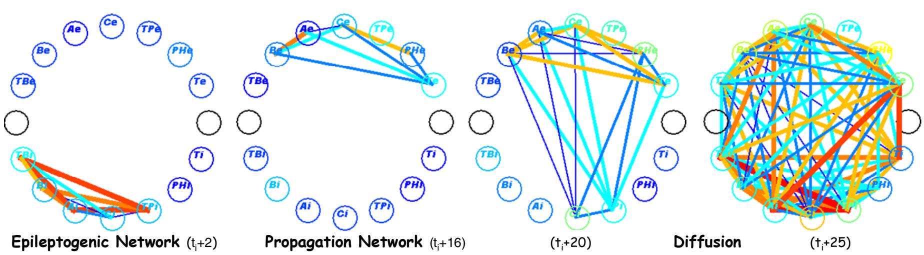

Fig. 3. Graphs of the couplings between structures for P1. The "structures agents" are knots and links between "signals agents" symbolize bows.

of the network formed by the various cerebral structures involved in the epileptic processes. The following paragraphs analyze the results at the first patient.

The analysis of the layer spatio-temporo-spectral (figure 2), coupled with that of the graphs (figure 3) produced by the system lets appear a network organization in the seizure of this patient. This organization includes the hippocampus (Bi and Ci), the internal temporal pole (TPi) and the entorhinal cerebral cortex (TBi). The analysis of P1 puts in evidence the much localized critical activities and a very net implication of a big number of canals SEEG in the distribution of the paroxystic discharge. A systematically premature role of the Hippocampus and the entorhinal cerebral cortex is observed at this patient. A spontaneous synchronization appears at the moment t_i+2 (figure 4) between various internal structures of the temporal lobe (beginnings of the epileptogenic network). This synchronization propagates secondarily in the external structures (temporo-basal cerebral cortex (TBe), gyrus T2 (Be, Ae) and in the external temporal pole)) and becomes widespread in the other investigated structures.

5 Conclusion

We associated in our platform approved signal processing algorithms and cooperative MAS. *A*gents identify the activities contained in each EEG signal, to select the interesting signals and to present the spatiotemporal dynamics of these activities during the seizure. The analysis of this dynamics loosens spatio-temporo-spectral layers and statistical couplings graphs between groups of signals also follow the organization of epileptogenic network. Our approach loosens the progressive involvement of mutual interactions between the cerebral regions. Channels mainly engaged in the release of the process of seizure are clearly made known and channels secondarily implied are also indeed referred.

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