Optimal Selection of interesting intracerebral epileptic signals by means of a multi-agents system.

Mamadou Lamine Ndiaye, Jean-Jacques Montois, Abel Kinie, Yann Jacquelet

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***Abstract*–The paper presents a distributed approach for the classification and selection of the interesting epileptic signals based on a dynamical vectorial analysis method. The objective is to limit the instantaneous workload by avoiding redundant computations and ensuring a better distribution of the load. Our approach deals with the information recorded during the intracerebral exploration and it exploits a dynamic selection of the interesting information to optimize processes without curtailing the information. We associated signal processing algorithms (spectrum analysis, causality measure between signals) approved in the analysis of the epileptic signal in a multi-agent system.**

I. Introduction

In Stereo-Electroencephalography (SEEG) exploration, we have physiological signals rich in information on the observed structures. These signals provide information on various peculiarities in the functioning of a structural entity, an organ or even a system. Their interpretation, for example, in the assistance of the diagnosis is multifactorial and is therefore, not easy; the normality for a given modality varies from subject to subject according to age, history and, for the same individual, it also depends on the type and protocols of examinations. The human intracerebral EEG can participate in a joint or hierarchical way as well as in a reproducible way in cognitive spots or in pathological processes. Moreover, previous studies were able to show that epileptic seizures originate from an area of the brain and propagate in a diffused manner towards other cerebral structures [1]. The critical discharges are not propagated in a simple manner with linear distribution taking preferential ways of connection, but they are always multidirectional. It is a multi-dimensional, multi-variable system, split up in a multitude of independent neural entities in mutual influence.

The signal processing today proposes approaches 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 established [3]. However the answers contributed by these methods are based on a series of computations and correlations applied to a small number of signals (sometimes selected visually) among the great number of signals available during the recording. This number can go up to 128. The principal difficulties are the dynamic, nonlinear character of the EEG signal, and the **combinatorial problem** induced by the vectorial analysis. An answer can be provided by the association of several disciplines to better apprehend not only the intrinsic characteristics of each epileptic signal, but also the combinatorial problem of vectorial analysis.

In this work, we propose a distributed and collaborative approach for the classification and instantaneous selection of the interesting signals to optimize the computations. The problem is approached here through a multi-agents system (MAS) [4][5], based on cooperative mechanisms at the micro level and the emergence of a global function at the macro level. The purpose of the global function is to generate the dynamics of similar structures and those which are synchronized by minimizing the computations number. The MAS, while limiting the quantity of data to be exploited, gives an interpretation as close as possible of an exhaustive analysis which would exploit the totality of the data. The agents' answer partially resolves the problem by acting locally; making the various computations (signal processing algorithms) according to control mechanisms [6] (strategies, organizations, cooperation and coordination of agents).

Paragraph 2 clarifies the formal frame of our work. It explains the problem dealt with and the "agentification" of the problem. The third point presents the MAS platform. The experimental results are presented in the fourth point and the last part proposes a discussion.

II. Agentification for the problem

The method consists in transposing this vectorial analysis problem coming from SEEG sensors in an agent space where the various entities of the system cooperate to resolve the problem. Thanks to a relevant organization of the signal processing algorithms, this leads to the emergence of the coordinated involvements of the cerebral structures involved in the epileptic seizure, analyzed through situated agents and specific agents of control.

We depart from the idea that we have to deal with a set of neuronal groups capable of presenting, on a given temporal window, paroxystic activities of various types and more or less pronounced interactions, leading to behaviour [7] of these groups. The MAS approaches are essential when it comes to building a complex system where computations are distributed and parallel, when the environment is evolutionary or when there is no algorithmic solution. 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 entails : *(i) characterizing each EEG channel $S_i(t)$*, *(ii) to determine the statistical relations between the various channels*, *(iii) studying the group organization according to the analysis of the signals*, and *(iv) connecting the notion of functional coupling between cerebral structures towards the quantities supplied by signal processing algorithms, supervised by the dedicated MAS.*

We thus associate to each signal S_i(t) (figure 1), a "signal agent" note A_{Si} and to each group of "signals agents" located in the same cerebral area, an "agent structure" note S_{Pi} (figure 2). The implemented approach is located, reactive, cooperative and decentralized. The collective intelligence, control mechanisms, coordination and signal processing algorithms are spatially distributed in the various system constituents. Each structure (intracerebral EEG) is associated with an agent, inside which the local processes of computation ("signals agents") and of interpretation ("structures agents") are implemented.

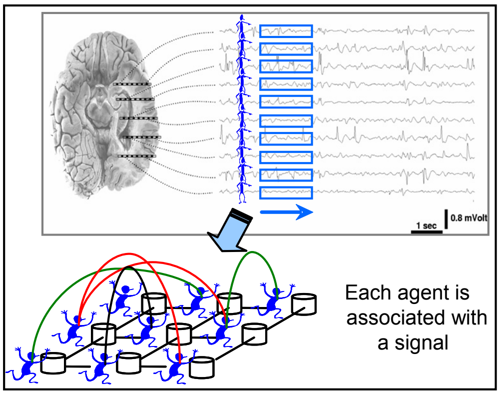

Fig. 1. Vectorial analysis of epileptic signals: Each agent has its own choices, knowledge, and algorithms processes.

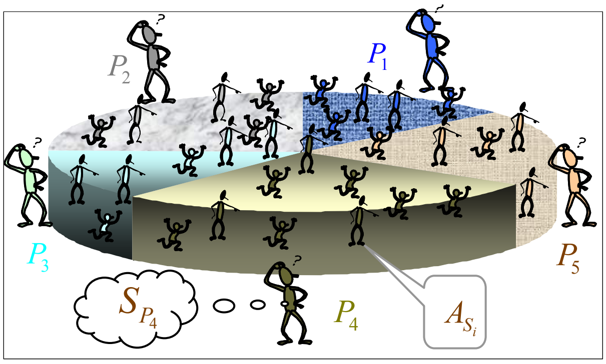

Fig. 2. Partitioning: the signals agents are supported in groups of agents belonging to the same cerebral area (according to their spatial location: electrode + depth of the contact) and an agent structure is associated with each partition.

III. MULTI-AGENT SYSTEM

The multi-agent system (MAS) is implemented in "Madkit" platform (Multi-agent development kit [8]). Our choice concerns hybrid architecture, distributed at two levels; a first level comprising reactive agents ("signals agents") which try to locate the interesting signals specifies by an auto-organized model and the second level established by cognitive agents ("structures agents") interpret the results obtained by the reactive agents. Control agents complete the system in terms of treatment control needs ("Scheduler agent", "Server agent" and "Observer agent").

The system aims to generate global information which characterizes the behaviors of groups [7] of signals belonging to different cerebral structures.

The analysis is made by cycle, in which the data is analyzed in parallel and synchronous way on a slippery window. A cycle corresponds to a following sequence: quantitative extraction information (perception) / selection of interesting agents (decision) / characterizations of the links between the agents (action).

A. *Quantitative extraction of information*

The "signals agents" represent the executive component of the system. They are responsible for carrying out the treatment results for the "structures agents". They provide quantitative information (individual properties and inter-agents properties). The individual properties of each "signal agent" are extracted by frequency activities 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.* The equations (1) and (2) respectively give the constituents of the characteristic vector and the coding of the scalar indicator. Each agent, according to the activity estimated on his current window, is associated with a scalar indicator $C_{S_i}(t)$ and a characteristic vector $\Gamma_{S_i}(t)$. The collective properties are characterized by similarity, statistical relations and synchronization measures between agents. The *similarities are* based on a euclidian distance measure between characteristic vectors. The *statistical relations* measure uses nonlinear intercorrelation coefficient [9] and the synchronizations measures between agents consist in the search for significant modifications of the characteristic and intrinsic properties. Each "signal agent" estimates its similarities between its characteristic vector of the present moment and that of the previous moment, and informs the global supervisor (agent "Observer") about this event. The "Observer" agent uses the temporal synchronization of the alerts to define the synchronization links between agents.

Quantitative extraction information provides an exploitable description at the control level for the selection of best "signals agents". Each "signal agent", according to its intrinsic properties and previous relations with the other agents, is in a state of activation or inactivity. The MAS uses the global configuration of the "signals agents" to activate selection strategies of "signals agents" carrying the best information (of group).

$$\Gamma_{S_i}\left(E_{i\varepsilon_0}, E_{i\varepsilon_1}, E_{i\varepsilon_2}, \cdots, E_{i\varepsilon_7}, E_{i\varepsilon_8}\right) \qquad E_{i\varepsilon_k} = \frac{e_{i\varepsilon_k}}{e_{i\varepsilon_T}} \tag{1}$$

$e_{i\varepsilon_k}$ is the energy in the band ε_k k = 0, 1, …, 8 and $e_{i\varepsilon_T}$ represents the total energy of the signal. $0 \leq E_{i\varepsilon_k} \leq 1$ is the percentage of the total energy in ε_k bands. The ε_k are the wavebands classically used in epilepsy.

$$C_{S_i}(t) = 2^0 * E_{i\varepsilon_0} + 2^1 * E_{i\varepsilon_1} + \cdots + 2^8 * E_{i\varepsilon_8} \tag{2}$$

B. Selection of the best "signals agent"

The MAS limits its instantaneous workload by avoiding redundant computations and ensuring a better distribution of the load. To that end, at every point in time, it must select the quantity of data to be exploited so as to provide the objective elements of a rigorous clinical interpretation.

The selection criterion, based on the redundancy information contained in various explored structures, is applied to identical groups of structures of the same cerebral area. To that effect, the similar agents of the same cerebral area gather to elect single representative agent. The selection criterion of this leader is based on that which has the best individual properties (by set of priorities the activated first, greatest scalar indicator or greatest total energy). Only the leaders by group are entrusted with evaluating the links between agents belonging to different cerebral zone.

C. Characterization of link between agents

The links between agents located in different structures are characterized by the three collective properties methods. Each "signal agent" representing a group has to pronounce on its links of similarity, statistical relations and synchronizations with the others leaders. The leaders use their local data bases to retain their affinities, discard their rejections and ignore the elements the similarities of which need to be verified through other methods. Each leader disseminates the contents of its local data bases to all the members of its affinities and this enables all the agents of the system to update their data bases. The measurement of statistical degrees of links between investigated structures effected on local entities defines the links between the bows of the graph produced by the system at the global level [11] and whose knots represent the various investigated structures.

D. Cooperation of agents to face uncertainty

The grouping of the similar agents is based on a collaborative classification of agents, which is itself based on variations between individual properties. Agents have clear information on the acceptance situations or the refusal situations (blatant similarity or differences) but must be based on the other agents and information which they receive to decide to unite with or separate from the other agents. The "signal agent" thus appeals to a cooperative behaviour to make its decision concerning the uncertainty situations (between acceptance and rejection). The less precise the information, the more the agents are confronted with uncertainties situations. To mitigate these uncertainties, agents collect additional information using the co-operative behaviour of diffusion [10]. They are based on the information sent by their affinities to mitigate the uncertain situations. Each agent has three data bases (reject, uncertainty and accept) in which it will classify the other agents according to the distance calculated or received from another agent.

Reject contains the list in which the agent registers its neighbours with which it doesn't want to form a homogeneous group.

Uncertainty contains the list in which it will put its acquaintances with which it does not know yet whether to accept or reject them. This ambiguity will be solved using the co-operative behaviour of diffusion.

Accept contains the list of the acquaintances with which it wishes to form a similar group.

The classification of "agent signal" is carried out according to the rule described by the algorithm in figure 3.

```
if d(Asi,Asj) < ηAccept then
        Accept (Asj)
        sendMessage(Asj)
else if  d(Asi,Asj) > ηReject then
        Reject (Asj)
        sendMessage(Asj)
else
        Uncertainty (Asj)
        diffusion (local data bases)
        sendMessage(Asj)
end if
```

Fig. 3. Algorithm of collaborative classification between agents

IV. Results

The data used in this study emanate from 4 patients (P1 to P4) suffering from a temporal lobe epilepsy and candidates for surgical treatment. For each patient, the system produces a layer coloured spatio-temporo-spectral and a graph symbolizing the various links of the network formed by the various cerebral structures involved in the epileptic processes [11]. The following paragraphs analyze the results of the collaborative classification and selection of interesting agents at the level of various patients. We observe, for the continuation of the paper, by AAS for the number of agents associated with the signals registered for the analyzed seizure, by MAA for the maximum number of agents activated and by AGL for the maximum number of agents selected as group leaders.

The analysis of the instantaneous workload of the system (figure 4) shows a significant reduction of the combinatorial problem. For P1 patient, AAS = 89, MAA = 65 (73% of AAS) and AGL = 25 at most (38% of MAA). For the P2 patient, AAS = 95, MAA = 45 (47% of AAS) and AGL = 20 at most (44% of MAA). For the P3 patient, AAS = 96, MAA = 24 (25% of AAS) and AGL = 14 at most (56% of MAA). For the P4 patient, AAS = 93, MAA = 43 (46% of AAS) and AGL = 18 at most (41% of MAA). The validity of this decimation is justified by equivalence at the global level of the computation of the totality of active "signals agents" and that which is exploited only by the leaders.

Another important result relates to the leaders' dynamics. The consultation of the leaders at various points reveals that they are not fixed. Indeed the agent selected as leader of a group of a given cerebral localization varies from an agent to another (figure 5). This result calls to question the choice based on a simple visual analysis. The analysis of the leaders' localization also shows the extent of the paroxystic discharges of the various patients.

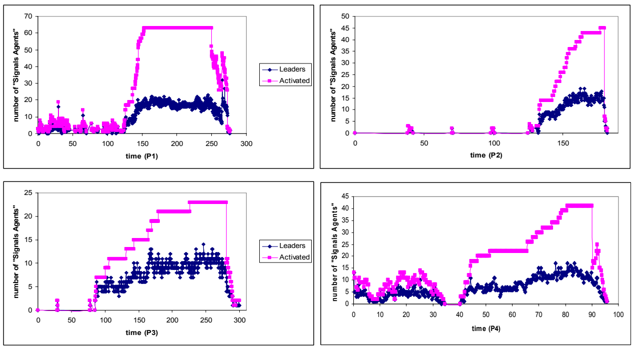

Fig. 4. Dynamics of the instantaneous load of the system (number of active agents and those which are selected to carry out the computations). Only an active agent is elected leader by a group of similar agents of the same cerebral zone.

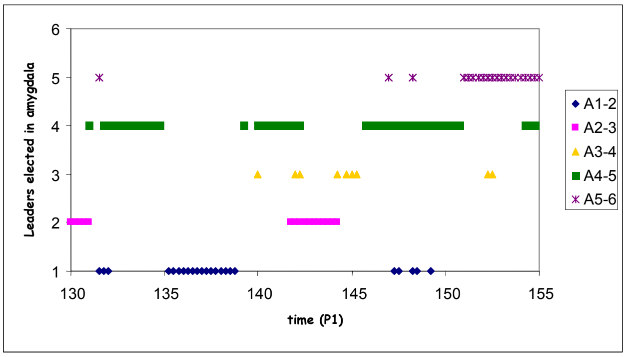

Fig. 5. Dynamics of the movement of the leaders of the cerebral structure targeted (Amygdala) in situations of strong loads.

V. Conclusion and Future Work

The structuralization agents facilitate the building of a generic, global, complete and automatic analytical method. It is based on a distributed and cooperative approach, and proposes a vectorial analysis on the great number of signals, by distributing the various computations between different autonomous agents. The collaborative classification method perfectly illustrates the interest of this approach.

*A*gents are allowed to identify the activities contained in each EEG signal, to select the interesting signals and present the spatiotemporal dynamics of these activities during the seizure. The selection of the best channels makes it possible to control and optimize the various computations but also to ensure that system evolves towards the aims in view. The subsets of ways activated simultaneously during the seizure appear from the 3 groupings formed by the MAS. Our approach makes it possible to loosen the progressive involvement of the mutual interactions between the cerebral regions. Channels mainly engaged in the release of the process of seizure are clearly made known and channels secondarily involved are also effectively referred to.

The perspectives of this work concern a more significant exploitation of the potentialities of the cooperative agents approach by integrating more information a priori about the cerebral anatomy, the structures of targeted interests. It would also be interesting to more interactivity between the system and its user.

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