RESEARCH ADVANCES AT A²VI-LAB

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Abstract

The Acquisition, Analysis, Visualization and Imaging laboratory, A²VI-Lab, is at the Department of Life, Health and Environmental Sciences of the University of L’Aquila. It was established in 1995 and, since then, the research activity is mostly centred on the study, development and testing of algorithms for signal acquisition and processing, image reconstruction, enhancement, filtering, analysis and visualization, in particular for medical applications. Eight people are currently involved in the research activity: the head of the laboratory, 3 Ph.D. students, three undergraduate students and a technician. Several research collaborations are active. The research projects are financed by public funds, private companies and foundations. A²VI-Lab holds also a portfolio of national and international patents. In what follows, two of the active research projects are presented.

1. Introduction

The A²VI-Lab, is at the Department of Life, Health and Environmental Sciences of the University of L’Aquila. The research activity is on the following medical applications: 1) Acquisition and coding/decoding schemes for Magnetic Resonance Imaging (MRI); 2) Advanced classification approaches for weak electroencephalography (EEG) signals from self-induced emotions; 3) Signal deconvolution, image reconstruction and noise reduction; 4) Image analysis: registration, automatic image interpretation and features extraction.
for radiotherapy, tele-rehabilitation, angiography and histology; 5) Simulation and optimization of magnetic and electromagnetic fields.

In what follows the first two points are detailed.

2. **Signal acquisition and coding strategies for MRI**

Adaptive acquisition techniques (AAT), have been studied and tested for radial tomography at A²VI-Lab (Figure 1) [1] [2] [3] [4] [5] [6] [7]. They are based on the calculation of the information content of an initial set of projections, followed by the selection, during the acquisition progress, of new angular directions where the information content is maximum. With AAT, it was theorized and tested experimentally that the Nyquist theorem could be violated if the sample (the unknown image) had some internal symmetries or a smooth profile [1]. The resulting AATs were also patented with the contribution of National Institute for the Physics of Matter (INFM) [2]. Since then, we started the study of innovative forms of Adaptive Compressed Sensing strategies (ACS) [4] [5] [6] [7]. With respect to the classical compressed sensing strategy, ACS had the following advantages: the collected ACS projections, though apparently random, follow the most informative directions and the resulting image is better reconstructed though non-linear optimization; the sparsity of the unknown image is efficiently estimated during the acquisition process; the number of directions is greatly reduced by eliminating redundancies. Studies are still in progress, in collaboration with Luigi Cinque, Daniela Iacoviello and their groups, and these arguments are the subjects of an upcoming research.

*Figure 1.* Regular undersampling (left) and Entropy-based AAT sampling (right): in AAT, the number of sampled directions is reduced and their orientation depends on the image information distribution.
Besides ACS, also innovative coding/decoding strategies have been studied and tested for MRI at A²VI-Lab. In MRI, linear magnetic field spatial variations are used to spatially codify the signal. Each voxel of the sample, irradiated with a radio-frequency signal of frequency proportional to the voxel magnetic field, returns a signal oscillating at the same frequency and amplitude proportional to the number of protons in that location. The frequency of the signal, that is the magnetic field, defines the reconstructed position of the voxel. The presence of static magnetic field inhomogeneities introduces distortions and artefacts in the images: this is the reason why magnets are very narrow and claustrophobic. The innovative coding/reconstruction algorithm proposed at A²VI-Lab [8] [4] is based on the assignment of different time varying frequencies (accelerations) to different spatial positions. Being really promising and efficient, the method has been patented [9] before its publication. The idea is to separate the coding effects (temporal variations of the magnetic field), from those, temporally invariants, due to static magnetic field inhomogeneities. The technique is used both for coding (Figure 2) and for decoding (Figure 3) the signal. The proposed algorithm: reduces the costs of magnet construction and shimming; allows the construction of open magnets; increases the Field of View of the existing scanners; produces undistorted images.

3. EEG signal processing and BCI construction

A Brain Computer Interface (BCI) is a computer based communication system that analyses signals generated by voluntary neural activity of the central nervous system. The subject, thinking at an intention, generates voluntary brain signals to be translated into commands for an output device, thus giving a new channel of output to the brain. The neural activity useful for BCI is measured by electroencephalography (EEG). The existing BCIs for disabled subjects are based on signals produced by sensory-motor rhythm amplitudes or
Figure 3. Decoding strategy. The collected signal (A) is first non linearly repositioned over the time axis (B); then it is linearly interpolated (C) and subsampled (D). The resulting signal is used for image reconstruction.

induced by external stimuli (visual, auditory, or tactile). Recently, we have proposed a new promising paradigm that used the signals generated by emotions, in particular from the disgust produced by remembering an unpleasant odor [10], to be used as the basis for an alternative communication tool, a BCI [11], for severely disabled people who cannot use common paradigms. In the same time, we have proposed a specific classification method, based on the analysis of the power spectrum of the signal [12][13], very effective but only usable for binary classification. For this reason, we have proposed a general, multi-class, and completely automatic classification method [14][15]. The method, a two stages algorithm, is in the framework of machine learning: the Principal Component Analysis (PCA) theory is applied to avoid redundancy in the set of features whereas the classification of the selected features, and therefore of the signals, is obtained by the Support Vector Machine (SVM). The classification accuracy is above 90%. The proposed BCI [11] has been also tested on a subject in minimally conscious state [16] with good results. The project has been funded by a private foundation. Studies are in progress to obtain unambiguous brain activation maps (both in terms of subsets of activation channels and in terms of subsets of activation frequency bands and features) for the most primitive emotional states in order extend our results to other applications, ranging from security related systems (such as emotive fingerprints or deception detection tools), to affective computing (to enrich the social interaction and the computer usage with emotive information), emphatic robots, and marketing.

References


