ACADEMIA ROMÂNĂ

SCOSAAR

REZUMATUL TEZEI DE ABILITARE

STUDIES AND RESEARCH ON THE MODERN PROCESSING OF ECG AND EEG BIOMEDICAL SIGNALS

Domeniul de abilitare: **Calculatoare și tehnologia informației**

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STUDIES AND RESEARCH ON THE MODERN PROCESSING OF ECG AND EEG BIOMEDICAL SIGNALS

This habilitation thesis presents the main results obtained and published by the candidate after obtaining the PhD degree in 2006. The doctoral thesis was entitled "***Contributions to biomedical signal processing***" and was conducted between 2002 and 2006 under the supervision of Prof. Dr. Eng. Liviu Goraş. The research activities following to the doctoral dissertation were carried out in the field of signal processing by mean of modern techniques of biomedical signals of ECG and EEG type, with applicability in two main fields, namely, compression and classification of signals.

In the biomedical signal compression field, two main directions are identified, which were addressed by the candidate in his research activities and are presented in five chapters of this thesis, namely: compression of ECG signals, compressed sensing of ECG signals using dictionaries specific to these signals, compressed sensing of EEG signals using dictionaries specific to these signals and reduction of the signal dimensionality with new techniques such as Locality Preserving Projections - LPP and Laplacian Eigenmaps - LE.

In the signal classification field, two major directions are identified, namely, the classification of normally acquired signals and the classification of biomedical signals that have a smaller dimensionality than the initial one, i.e., compared to that imposed by the sampling theorem.

The most important results obtained by the candidate in the research activities were validated by publication in several prestigious international journals listed Q1 and Q2 in the WOS database, (IEEE Transactions on Biomedical Engineering and Biosensors-Basel), as well as other journals with impact factor or in volumes of prestigious international conferences in the research fields of interest.

Chapter 1 presents some of the author's research on how to preprocess ECG signals in order to compress and classify these signals. Some techniques for ECG signals preprocessing and segmenting are presented, as well as the influence of features and the database used in classification. The topics presented in this chapter can be outlined in three different directions, namely, (i) presenting a new solution for ECG signal compression, (ii) improving the classification of multiclass data, and (iii) features selection based on the Laplacian score.

Chapter 2 presents the author's research in the field of compressed acquisition with applicability on electrocardiographic (ECG) biomedical signals. Thus, a detailed comparative study of two different approaches for the compressed acquisition of the ECG signals is presented. This study considers several acquisition techniques and several types of projection metrics used in the acquisition phase, as well as several dictionaries used in the ECG signal reconstruction phase. The effect of preprocessing on the results is also analysed. For both variants proposed by the author, the influence of the projection matrix in the final results was analysed, namely, several projection matrices were analysed: matrix with independent random elements and identically distributed (i.i.d.) with Gaussian distribution, Bernoulli type matrix, and projection matrix optimized for the private dictionary used in reconstruction. In addition, special attention was given to the way the dictionary is constructed, both methods having different ways of constructing. The advantages and disadvantages of each method and the choice of a method according to the available hardware and software resources are also presented.

Chapter 3 focuses on how to build dictionaries used in the reconstruction of the compressed acquired EEG signals. Similar with the ECG signals, dictionaries can be built for EEG signals that take into account the statistics and features of this type of signal or the patient's particularities. Starting from the alignment idea, which in the case of the ECG signal led to much improved results, for the EEG signal an alignment method was analysed and tested. Various dictionaries with EEG segments have been built, such as the patient-specific dictionary, the channel-specific dictionary, a predefined number of temporal specific dictionaries, or the Daubechies10 wavelet dictionary. For all these dictionaries, the obtained reconstruction results were compared. Another analysis was the influence of the acquisition matrix used in the reconstruction results. The conclusions of the analysis were that for small compressions (e.g. CR = 5: 1) the dictionary-based method with aligned EEG segments according to the stimulus in the spelling paradigm provided the best results. However, for large compressions (above 10: 1) the best method of acquisition is based on the dictionary with atoms of 1 sec size with P300 wave and NonP300 atoms. The disadvantage of this method is that the method also requires a realignment step for the reconstructed signals. Another definite conclusion is that the worst results are obtained when standard wavelet dictionaries were used. In the case of the universal mega-dictionary and the intra- and inter-patient analysis, the best results were obtained when the dictionary and test data came from the same subject but different EEG signals were used (i.e. for the dictionary EEG signals from the training phase were used and for the compressed acquisition EEG signals from the testing phase were used).

Chapter 4 presents the classification performance for electrocardiographic (ECG) and electroencephalographic (EEG) signal classes processed for different degrees of dimensionality reduction. The results obtained with different classification methods were analysed and discussed. Three dimensionality reduction techniques were investigated, namely: Laplacian Eigenmaps (LE), Locality Preserving Projections (LPP) and compressed sensed (CS). The first two methods are related to multiple learning, while the third refers to the acquisition and reconstruction of the signal from random projections under the assumption of signal sparsity. The aim of the study was to evaluate the benefits and disadvantages of the different methods and to find out to what extent they can be considered remarkable. The evaluation of the effect of dimensionality decreasing was made taking into account the classification rates for the biosignals processed in the new spaces. In addition, the accuracy of the classification of the initial input data was assessed against the corresponding accuracy in the new spaces using different classifiers.

The main conclusions of the analysis regard the choice of the combination of dimensional reduction techniques and classification algorithms to achieve reasonable classification results even for small or very small dimensions for both ECG and two classes of EEG signals. The choice of the reduction rate depends on the motivation of the analysis. Thus, if it is wanted to reconstruct the initial signal, the CS method will be adopted; if the reduction of the space to 2D or 3D is targeted in order to understand the data, the LE method will be chosen, while if the goal is to reduce the dimensionality by about 10 to 12 times or to classify the new data in the reduced space without recalculating the initial signals, the LPP method will be used.

Chapter 5 presents the possibility of classifying biomedical signals purchased in tablets directly in this small space, without the need to reconstruct the ECG or EEG signal. The classification in compressed space for the ECG signal is an important advantage when using dictionaries specific to the pathologies for the reconstruction of the original signals, because once identified the class to which the pattern belongs allows the use of that dictionary specific to that class. Another important aspect is that with the acquisition of a compressed signal based on a random matrix, the classification of the compressed signal provides additional information about the nature and type of the original signal. Thus, both compressed and original cardiac models were classified. Similar results were obtained in the original space with those in the compressed space. To validate the correctness of the results, two classifiers were tested, an MLP and a KNN. Thus, it is found that if an advantageous architecture is chosen for the MLP network, it is found that the two classifiers behave similarly in terms of classification performance.

For EEG signals and acquisition in compressed space topic, the possibility of EEG signals classifying (from the spelling paradigm) into EEG segments containing P300 waveform and EEG segments without P300 waveform was analysed, the classification taking place directly on the compressed acquired segments. This classification is the key element in a BCI spelling system. Thus, starting from a method proposed by Hoffmann, based on gradient boosting, the possibility of classifying the collected EEG signals was tested. The possibility of classification using Deep Learning neural networks was also studied, the results obtained in terms of classification being very close to those got using the gradient boosting approach. The results obtained with both tested methods confirm the hypothesis that close neighbourhoods in the initial space remain close also in the compressed space. This result allows the classification of the directly compressed acquired signals and it is useful in medical applications where only the class of a signal is necessary and not its shape.

Section II of the thesis illustrates the evolution and development of the candidate's academic career from the perspective of research activity. This chapter highlights the most important research directions that will be addressed in the field of signal processing and how to attract research funding by participating at competitions either in national and international research or for improving the equipment of laboratories.

The candidate's experience gained during her scientific research career as well as the experience gained as a project director or member of the implementation team or through numerous scientific papers published in prestigious journals and international conferences, will focus on strengthening the research team by attracting new members, especially from doctoral students. Thus, the attraction of students will be achieved through the good collaboration of the candidate with university professors from the Faculty of Bioengineering and the Faculty of Electronics, Telecommunications and Information Technology. This fruitful collaboration is proved by the scientific papers published together with professors from those faculties but also by the collaboration of a PN II Partnerships project - coordinated by UMF Iași in partnership with the Romanian Academy - Theoretical Informatics Institute and Gh. Asachi Technic University - Faculty of Electronics, Telecommunications and Information Technology.

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I thank Prof. Dr. Eng. Liviu Goraş for the support and advice given during the elaboration of the doctoral thesis, the habilitation thesis, as well as for the constant support throughout this period. He was like a third parent through the advice and patience he gave me in our research activities done together.

I thank Acad. Horia-Nicolai Teodorescu and Director Dr. Vasile Apopei for the good collaboration and development of the research activity within the Institute of Theoretical Informatics.

I would like to thank all the collaborators over the years for their support in the research grants and for their involvement in many scientific papers developed and published by our team.

I am also grateful to the entire staff of the Institute of Theoretical Informatics for facilitating a pleasant atmosphere in terms of research activity.

Special thanks to my family for their support and understanding over the years.