

Guest Editorial

Introduction to the Special Section on Computational Intelligence in Medical Systems

I. INTRODUCTION

RECENT technological advances in medicine have facilitated the development of complex biomedical systems including sophisticated biomedical signal devices and instruments, medical imaging equipment, and computer-aided diagnosis (CAD) tools enabling the better delivery of healthcare services. In parallel, computational intelligence, incorporating neural computing, fuzzy systems, evolutionary computing, and more recently, rough sets, and autoimmune systems have emerged as promising tools for the development, application, and implementation of intelligent systems.

In the last ten years, there has been a significant effort in the application of computational intelligent techniques in numerous biomedical systems. These cover applications in medical decision-making [1], biosignal analysis, and biomedical engineering at large [2], medical imaging [3]–[5], bioinformatics [6], [7], and others. All these systems underlie the impact of these technologies in the biomedical domain.

The aim of this special issue is to focus on the most recent applications of computational intelligent systems in medicine. Papers in this special issue cover innovative applications of computational intelligence in the following physiological systems: skin, skeletal, muscular, central nervous, peripheral nervous, systems of special senses (eye), cardiovascular, respiratory, and reproductive.

A total of 45 papers were submitted for this special issue that were reviewed by at least three reviewers. Following the recommendations of the guest editors and the Editor-in-Chief, 19 papers were accepted for publication. The accepted papers were organized under the topics: General, Computational Biology, Biosignal Analysis, and Medical Imaging, with two, three, seven, and seven papers in each topic, respectively. Some of these papers (10 in total) have been published earlier by mistake, unfortunately in previous issues of the IEEE TRANSACTIONS ON INFORMATION TECHNOLOGY IN BIOMEDICINE. All the accepted papers are briefly summarized in the following section.

It is generally accepted that, nowadays, health services are facing a number of complex interacting and multifactorial challenges [8]. To address these issues from the information and communication technologies (ICTs) perspective, the World Health Assembly (WHA) adopted an eHealth Strategy for the World Health Organization (WHO) [9]. The resolution documented that the use of ICT for health is one of the most rapidly growing application areas in health today. Moreover, it was proposed that automated or semiautomated systems that support

decision-making in a clinical environment would be very useful for the better support of healthcare services.

In parallel with the WHO activities, the European Commission (EC) in 2004 adopted the eHealth action plan [10], as well as subsequent directives [11], that cover a wide spectrum of eHealth services, ranging from cross-border interoperability of electronic health record systems, to electronic prescriptions and health cards, to new information systems that are targeting to reduce waiting times and errors to facilitate a more harmonious and complementary European approach to eHealth. These initiatives, as stated in the Prague Declaration of the EU Member States, stress the need to keep the momentum so that the potential advantages of gradual deployment of ICT in the health sector are not compromised by barriers of legal, technical, economic, or any other nature. At the same time, it is considered crucial that the benefits of eHealth applications and services are further enhanced and properly distributed among all the relevant stakeholders, patients and healthcare professionals, society, and the economy.

To facilitate the provision of better, and more efficient and effective eHealth services as documented before, sophisticated and advanced medical systems based on computational intelligence have to be developed. Although significant steps have been carried out in this direction in the last two decades, the need still exists that intelligent medical systems be developed, covering a wider spectrum of services, and most importantly, be thoroughly evaluated before their deployment in clinical practice. The papers in this special issue cover a wide range of applications, demonstrating the promising potential of computational intelligence in medical systems.

II. PAPER SUMMARIES

A. General

The paper by King *et al.* [12] (appearing in this issue) deals with the development of a wireless sensor glove for the assessment of surgical skills. The paper presents a wireless sensor platform for the capture of laparoscopic hand gesture data and a hidden Markov model (HMM) based analysis framework for optimal sensor selection and placement. Detailed experimental validation is provided to illustrate how the proposed method can be used to assess surgical performance improvement over repeated training.

The paper by Sampat *et al.* [13] proposes an empirical methodology for the assessment of three-class classifiers. The assessment of classifier performance is critical for the fair comparison of methods, including considering alternative models or parameters during system design. For two-class classification

problems, receiver operating characteristic analysis provides a clear and concise assessment methodology for reporting performance and comparing competing systems. While several methods have been proposed for assessing the performance of multiclass problems, none has been widely accepted. Based on 4 three-class case studies and the three popular classification techniques, the following conclusions were derived: 1) the method proposed by Scurfield provides the most detailed description of classifier performance and insight about the sources of error in a given classification task, and 2) the methods proposed by He and Nakas also have great practical utility as they provide both the volume under a three-class receiver operating characteristic surface (VUS) and an estimate of the variance of the VUS. These estimates can be used to statistically compare two classification algorithms.

B. Computational Biology

In their paper, Tang *et al.* [14] present a new algorithm, Fuzzy Granular Support Vector Machine—Recursive Feature Elimination (FGSVM-RFE), that was designed for the selection of multiple highly informative gene subsets for cancer classification and diagnosis. Empirical studies on three public datasets demonstrated that FGSVM-RFE outperforms state-of-the-art approaches. Specifically, the independent testing accuracy for the prostate cancer dataset was significantly improved, using only eight genes, which were annotated by Onto-Express to be biologically meaningful.

In their review, Oulas *et al.* [15] present an overview of existing computational methods for identifying micro-RNA (miRNA) genes and assessing their expression levels in cancer. The discovery of thousands of genes that produce noncoding RNA (ncRNA) transcripts in the past few years suggested that the molecular biology of cancer is much more complex. MicroRNAs (miRNAs), an important group of ncRNAs, have recently been associated with tumorigenesis by acting either as tumor suppressors or oncogenes. Given that the experimental prediction of miRNA genes is a slow process, because of the difficulties of cloning ncRNAs, experimental approaches provide a number of computational tools trained to recognize features of the biogenesis of miRNAs that have significantly aided in the prediction of new miRNA candidates. Computational approaches provide valuable clues as to which are the dominant features that characterize these regulatory units and which genes are their most likely targets. Moreover, through the use of high-throughput expression profiling methods, many molecular signatures of miRNA deregulation in human tumors have emerged.

The paper “Computer-aided diagnosis of capillary thyroid carcinoma using an artificial immune system” by Delibasis *et al.* [16] (appearing in this issue) proposes the utilization of a CAD system based on the artificial immune systems (AISs) to assist the task of thyroid malignancy diagnosis. The proposed algorithm is applied on fine-needle aspiration data from 2016 subjects with verified diagnosis, and has exhibited average specificity higher than 99%, 90% sensitivity, and 98.5% accuracy.

C. Biosignal Analysis

The paper by Lai *et al.* [17] (appearing in this issue), “Computational intelligence in gait analysis: A perspective on current

applications and future challenges,” surveys current signal processing and computational intelligence methodologies followed by gait applications ranging from normal gait studies, disorder detection to artificial gait simulation. In this paper, recent systems focusing on the existing challenges and issues involved in making them successful have been described. Moreover, new research in sensor technologies for gait is examined, which could be combined with these intelligent systems to develop more effective healthcare solutions.

The paper by Apiletti *et al.* [18] presents a flexible framework that performs real-time analysis of physiological data to monitor the subject in his/her daily activities in the hospital environment. The framework supports the ubiquitous monitoring that could also be executed on mobile devices for different diseases. The effectiveness and flexibility of the proposed framework has been demonstrated on 64 patients affected by different critical illnesses in the intensive care unit.

The use of SVMs for automated recognition of obstructive sleep apnea syndrome from electrocardiogram recordings is proposed in the paper by Khandoker *et al.* [19]. A total of 125 sets of nocturnal ECG recordings acquired from normal subjects (obstructive sleep apnea (OSAS) –) and subjects with OSAS (OSAS+), each of approximately 8 h in duration, were analyzed. Features extracted from successive wavelet coefficient levels after wavelet decomposition of signals due to heart rate variability (HRV) from RR intervals and ECG-derived respiration (EDR) from R waves of QRS amplitudes were used as inputs to the SVMs. Independent test results on 42 subjects showed that SVMs correctly recognized 24 out of 26 OSAS+ subjects and 15 out of 16 OSAS– subjects (accuracy = 92.85%). The results demonstrate considerable potential in applying SVMs in an ECG-based screening device that can aid a sleep specialist in the initial assessment of patients with suspected OSAS.

The paper by Delgado-Trejos *et al.* [20] present a methodology for dimensionality reduction oriented toward the feature interpretation for ischemia detection. The proposed dimension reduction scheme consists of three levels: projection, interpretation, and visualization. First, a hybrid algorithm is described that projects the multidimensional data to a lower dimension space, gathering the features that contribute similarly in the meaning of the covariance reconstruction in order to find information of clinical relevance over the initial training space. Next, an algorithm of variable selection is provided that further reduces the dimension, taking into account only the variables that offer greater class separability, and finally, the selected feature set is projected to a 2-D space in order to verify the performance of the suggested dimension reduction algorithm in terms of the discrimination capability for ischemia detection. The ECG recordings used in this study are from the European ST-T database and from the Universidad Nacional de Colombia database. In both cases, over 99% feature reduction was obtained, and classification precision was over 99% using a five nearest neighbor classifier (5-NN).

Shin *et al.* [21] present an automatic detection system for the assessment of cough sounds related to the subject’s health condition, and their classification as symptomatic or asymptomatic. A hybrid model was proposed that consists of an artificial neural network (ANN) model and an HMM. The ANN model is based

on the energy cepstral coefficient analysis of cough sounds obtained by filter banks based on the human auditory characteristics, whereas the output of this model and a filtered envelope of the signal were the input to an HMM that processed the temporal variation of the sound signal. The proposed system when compared with the conventional HMM using Mel-frequency cepstral coefficients improved recognition rates on low SNR from 5 down to -10 dB.

The heartbeat time series classification with SVMs was investigated by Kampouraki *et al.* [22]. Statistical methods and signal analysis techniques are used to extract features from the signals. The SVM classifier is favorably compared to other neural-network-based classification approaches by performing leave-one-out cross validation. The performance of the SVM with respect to other state-of-the-art classifiers is also confirmed by the classification of signals presenting very low SNR ratio. Finally, the influence of the number of features to the classification rate was also investigated for two real datasets. The first dataset consists of long-term ECG recordings of young and elderly healthy subjects. The second dataset consists of long-term ECG recordings of normal subjects and subjects suffering from coronary artery disease.

The detection of recorded epileptic seizure activity in EEG segments using time–frequency analysis was investigated in the paper by Tzallas *et al.* [23] (appearing in this issue). The use of time–frequency analysis is justified given that seizure evolution is typically a dynamic and nonstationary process, and the signals are composed of multiple frequencies, where visual and conventional time–frequency (t - f) based methods have proven to be of rather limited application. In this paper, the short-time Fourier transform (STFT) and several t - f distributions (TFDs) were used to calculate the power spectrum density (PSD) of each segment, compute the signal segment fractional energy on specific t - f windows, and then classify the EEG segment (existence of epileptic seizure or not) using ANN. The methods were evaluated using three classification problems obtained from a benchmark EEG dataset, and qualitative and quantitative results are presented.

D. Medical Imaging

Calhoun and Adali present a computational approach that facilitates the feature-based fusion of brain multitask or multimodal medical imaging data [24] (appearing in this issue). A multivariate computational approach is proposed using independent component analysis that attempts to study how function and structure are related in the same region of the brain utilizing temporal EEG information and spatial functional MRI (fMRI) information.

Gilliam *et al.* propose a method for the study of cardiac motion recovery via active trajectory field models [25]. Recent advances in tissue motion imaging techniques, including displacement encoding with stimulated echoes (DENSE) in cardiac magnetic resonance (cMR) imaging, enable to directly quantify cardiac displacement and produce accurate spatiotemporal measurements of myocardial strain, twist, and torsion. The associated analysis of DENSE cMR and other tissue motion imagery, however, represents a major bottleneck in the study of intramyocardial mechanics. This paper proposes an automated

motion recovery technique termed *active trajectory field models* (ATFMs) geared toward these new motion imaging protocols, offering quantitative physiological measurements without the pangs of manual analyses.

The paper by Jinshan *et al.* [26] presents a review of recent advances on mammography CAD systems for the assessment of breast cancer. Breast cancer is the second most common and leading cause of cancer death among women, and its incidence has increased in recent years. The purpose of this paper is to provide an overview of recent advances in the development of CAD systems and illustrate how these systems can play a key role in the early detection of breast cancer, targeting in the reduction of the death rate among women with breast cancer. The paper covers the detection of calcifications, detection of masses, detection of architectural distortion, detection of bilateral asymmetry, image enhancement, and image retrieval.

Maulik provides a summary of the use of genetic algorithms in segmenting medical images [27]. Here, medical image segmentation is first mapped into an optimization problem, where genetic algorithms are used for finding the global optimal.

An application of computational intelligence methods for identifying exudate pathologies in diabetic retinopathy is presented by Osareh *et al.* in [28]. Their approach involves segmentation using fuzzy c -mean clustering, a genetic-based algorithm for feature ranking, and multilayer neural network classification. For 300 retinal images, the method gave 96% sensitivity and 94.6% specificity.

An application of a region Bayes classifier and vector median filtering is used to improve chromosome classification accuracy in [29]. The method was shown to improve classification accuracy by 10% on a set of 183 six-channel chromosome images.

In their paper, Maglogiannis and Doukas [30] (appearing in this issue) provide an overview of advanced computer vision systems for skin lesions characterization, aiming mostly at the early detection of skin cancer, and more specifically, at the recognition of malignant melanoma tumor. In this paper, the state of the art in such systems is reviewed by first presenting the installation, the visual features used for skin lesion classification, and the methods for defining them. Then, it is described how to extract these features through digital image processing methods, i.e., segmentation, border detection, color, and texture processing, and present the most prominent techniques for skin lesion classification. The paper reports the statistics and the results of the most important implementations that exist in the literature, while it compares the performance of several classifiers on the specific skin lesion diagnostic problem and discusses the corresponding findings.

III. CONCLUDING REMARKS

Concluding, given the rapidly growing aging population, the increased burden of chronic diseases, the offering of innovative and demanding healthcare services, and the ever increasing healthcare costs, there is a strong and urgent need for the development, implementation, and deployment in everyday medical practice of computational intelligence systems and services in support of the citizen. It is anticipated that technological advances both in medical systems and computational intelligence

will support the further development of these systems for the offering of more advanced healthcare services that would also facilitate their deployment at a world-wide scale.

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