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Report of research activities in fuzzy AI and medicine at USF CSE

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Abstract

Several projects involving the use of fuzzy and neuro-fuzzy methods in medical applications, developed by members of the Department of Computer Science and Engineering, University of South Florida, Tampa, Florida, are briefly reviewed. The successful applications are emphasized.

Keywords: Neuro-fuzzy system; Sudden infant death syndrome; Fuzzy logic

1. Introduction

The Department of Computer Science and Engineering (CSEE) at University of South Florida includes several scientists working in the field of fuzzy and neuro-fuzzy tools such as fuzzy clustering, fuzzy filtering, fuzzy image segmentation, fuzzy expert systems with medical applications, including diagnosis, monitoring, and rehabilitation. Recently, a research group, named *Neuro-Fuzzy Systems in Human-Related Sciences Group* was created. The group founding members are Kevin Browyer, Dmitry Goldgof, Larry Hall, Abraham Kandel, and Horia-Nicolai Teodorescu (currently the group manager). The Group organization is flexible, with a change of management taking place every 6 months.

2. Mission statement

Our research group was established to foster research, teaching, and academic cooperation in the field of neuro-fuzzy systems in human-related fields, namely in domains like

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medical sciences, biology, vision, speech processing, linguistics, psychology, and cognitive sciences. Based on the expertise of its individuals, the group is dedicated to the development of new fundamental knowledge, processes or procedures through research, promoting multi-disciplinary approaches. It is a claimed objective of the group to fuse various approaches, including fuzzy logic and fuzzy algebraic tools, hybrid neural networks, pattern recognition, non-linear dynamics, symbolic systems, and machine learning. Moreover, the group aims to integrating AI into various medical fields, including diagnosis, prostheses, image processing, rehabilitation and monitoring of patients. Also, the group aims to foster education in these fields.

3. Projects

Some of the recently carried projects include applications in medical fuzzy expert systems, image processing (mainly segmentation, in the frame of an AI in human brain segmentation project, and contour interpolation/data compression), respiration monitoring and respiratory event warning, tremor assessment, modeling of biological processes, and speech processing in view of medical applications. The projects were carried as, internal projects, independent research of some of the members (supported by start-up companies), or as international co-operation, mainly with the Romanian Academy and the Swiss Federal Institute of Technology, Lausanne, Switzerland. In this paper we do not report on all current or past researches performed in this department and the selection we performed is largely based on data availability.

3.1. Use of fuzzy methods in segmentation of tumor images [1–3]

Several methods, based on fuzzy information and knowledge in image segmentation, have been developed to detect brain and breast tumors. We briefly present only one of these methods. Further information can be obtained from the quoted resources and references.

A knowledge-based system integrated with unsupervised fuzzy clustering to automatically segment and label tumors in magnetic resonance slices of the human brain was developed. Slices are initially segmented by an unsupervised fuzzy c-means algorithm. The rule-based system uses model-based recognition techniques and further fuzzy clustering to iteratively locate tissues of interest. The system uses knowledge obtained during preprocessing. Further fuzzy re-clustering is aided by the use of initialization and training data created by the knowledge-based system. Over-clustering plays an important role. Providing more clusters than there are tissue types, the amount of under-segmentation was reduced and objects of interest are easier to find. The advantages of the proposed approach are demonstrated by the successful performance of the system, and the final segmentation of *Glioblastoma multiforme* tumor compared favorably with hand-labeled images of the tumor.

In another approach, using fuzzy rules for segmentation, fuzzy rules for partially segmenting MR images of the brain were built to operate on density weighted intensity feature images. The tissue thresholds determine the antecedent fuzzy sets of the rules. The thresholds were found via histogram analysis applied to each image slice to which the rules will be applied. The turning points in the histograms are essentially the approximate boundaries between tissue types. The turning points (peaks, valleys or the beginning of a hill) are automatically chosen on each test slice. From the turning points in the histogram, fuzzy rules to identify tissue classes such as white matter, gray matter, or bone, are generated. The rules and antecedent fuzzy sets were generated by examining the intersection of tissue types in the three intensity histograms. Based on the rules, the voxels are classified. An unclassified voxel (i.e. having a zero membership in all classes) is assigned a membership that is the average membership of its neighbors. If a voxel has a membership of 1.0 in a class A, while surrounding voxels have zero membership in that class, then the isolated voxel's membership to A is zeroed. This step is aimed at reducing classification errors. Finally, the voxel memberships in all classes are normalized to 1. The voxels that belong to classes with memberships greater than 0.8 are generally correctly assigned. The rest of the voxels are more problematic. Hence, we re-group them with a semi-supervised clustering algorithm, ssFCM. The voxels with membership greater than 0.8 are used as training voxels for ssFCM. The ssFCM algorithm works as fuzzy c-means (FCM) except that training voxels cannot change clusters and will always influence the cluster centroid to which they are assigned. The method has demonstrated advantages over other methods. More details can be found at (http://morden.csee.usf.edu/~hall/adrules/segment.html).

3.2. Algebraic neuro-fuzzy systems for image processing [4,5]

In this project aimed to develop and test a new tool, namely algebraic fuzzy neural networks, in applications like signal filtering, classification, data interpolation and information compression. The algebraic fuzzy neural networks represent neural network with fuzzy neurons, the operations performed by the neurons being fuzzy algebraic operations, instead of the classic fuzzy logic operations. The weights (synapses) are represented by fuzzy numbers. Both sigmoidal and RBF (radial-basis function) neurons have been used. The input fuzzy numbers are either triangular or trapezoidal. The main difficulty in applying algebraic fuzzy neural networks is related to the training algorithm. Several algorithms that work under algebraic fuzzy operations have been developed and successfully demonstrated. The medical applications addressed included non-linear signal processing, and image processing. An example is the approximation of the blood microvessel internal diameter and wall thickness, based on microscopy images. The application consists in blood vessel image reconstruction and, subsequently, the prediction of flow variations along the vessel. The use of fuzzy methods is required by the imprecision related to the vessel boundary in the microscopic images. The technique has potential applications in the diagnosis of the circulatory system and in blood vessel re-constructive surgery. Solving the same task manually is tedious and expansive. Images were obtained based on 2D slices made at equal distances. The image is processed by conversion to gray levels and then the contrast is enhanced by classic techniques. After the selection of the regions including the blood vessel of interest, the image is processed in view to extract the information on the wall thickness and lumen (internal diameter). The wall is approximated in every point by a triangular fuzzy set representing the thickness. A sample image with the related explanation on defining the fuzzy thickness and diameters is shown in Fig. 1. These theoretical and software developments and applications were reported in several papers

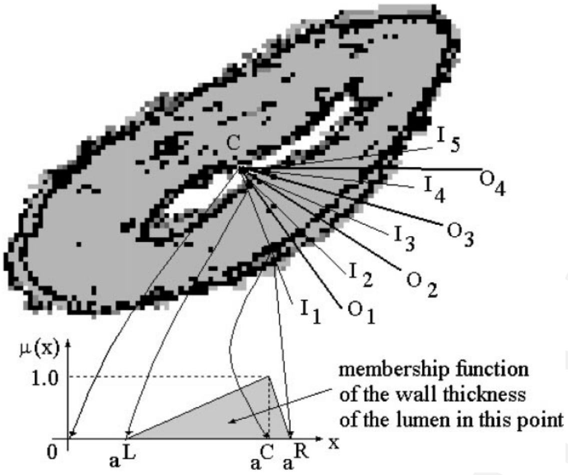

Fig. 1. Image of a section in a micro-vessel and the fuzzification of the thickness of the blood vessel wall. The uncertainty about the boundaries is accounted for by the use of a triangular fuzzy number (after an internal report, seminar for fuzzy systems ''Gr. C. Moisil'').

and partly summarized in a chapter [4]. This research was performed in co-operation with Dr. D. Arotaritei (Institute of Computer Science of the Romanian Academy) and the partial support of the Romanian Academy

3.3. Fuzzy fusing of classic and chaotic numerical parameters in a hand tremor rehabilitation system [6]

We developed a comprehensive methodology for tremor analysis, including classic and chaotic parameters, where the non-linear analysis complements the time–frequency analysis. We evidenced that tremor includes a significant chaotic component, and this component may be of interest in diagnosis and rehabilitation. Various practical aspects, from sensors to feedback procedures based on fuzzy logic, were solved and results incorporated in equipment and related software. Moreover, an experimental arrangement and dedicated software for tremor analysis and feedback for rehabilitation purposes was developed. Non-linear data analysis and a fuzzy method to process the signal, to assess the type of tremor, moreover to provide an easy to grasp feedback for rehabilitation purpose, were incorporated. The system for rehabilitation is based on fuzzy assessment of fused features of the tremor movements. Both classic and non-linear indices were fused into a few, easy to represent and grasp fuzzy measures. A neuro-fuzzy system for tremor control was also devised. The feedback should be easy to understand and learn, and should make use visual and audible information. To make it easy to learn, the information has to be appropriately compressed.

With the purpose of creating a feedback to help patients to become aware of the characteristics of the tremor of their limbs, moreover to help them controlling the tremor, we used a representation of the tremor by images and sounds. This representation is synthetic and is based on the linguistic and fuzzy valuation of the main parameters of the tremor. The use of linguistic and fuzzy valuations is justified by its simplicity (easy to understand by the patient), moreover by good information compression. The rules used to globally characterize the tremor take into account, among others, the tremor amplitude, main frequency, ratio low-to-high frequency power content, the correlation dimension and the irregularity of the signal. The rules establish the relations between the pattern in the space of the tremor signal space and the classes of the tremor signal. The results of the inference are defuzzified and used in the feedback. There are various feedback facilities under current evaluation with the system. Most of the research related to this topic has been supported by Techniques & Technologies Ltd. and by the Grant 7RUPJ-48689 from Swiss Research Founds (FNS), Switzerland.

3.4. Applications to monitoring the respiration of infants: SIDS prevention [7]

This application was developed in the frame of a start-up (Sensitive Technologies LLC). The system, based on two patents [7] is aimed to monitor infants aged 0 to 24 months that may be at risk of sudden infant death syndrome (SIDS), yet are living a normal life within their family. The difficulty of the problem relates to the restrictions on sensors (they should be completely non-obtrusive and should collect data without contact) and to the need to make a highly reliable alarming. Previously known systems for monitoring either respiratory signals, or movements of a subject during sleep and especially for detecting SIDS-related apnea typically employ accelerometers and simple electronics or sleep analysis software for analyzing data received from sensors. Such systems have shortcomings, including unreliability in event detection, largely due to inability to distinguish between respiratory movements and other movements.

Beyond using a novel type of sensor, the system developed for this product uses several sensors, and a data fusing, pattern recognition system based on neuro-fuzzy techniques. The monitoring system includes a sensor for detecting the respiration and a second sensor for detecting the presence and movement of the infant or proximal objects around the crib. A third acceleration sensor helps to discriminate between the movements of the crib frame induced by external factors and movements induced by respiration. Signal from the sensors are processed to extract respiration- and non-respiration-related signals and the respiration-related signal patterns are compared to normal patterns. The system fuses the data from various sensors and makes aggregated decisions to generate specific warnings for specific respiratory events. The overall processing is able to take into account ''secondary'' factors empirically known to influence the respiration stop risk. Such factors are the ambient temperature, SIDS-related family history of the infant, age of the infant, sex, birth-weight, drug therapy history, infectious state of the infant, mother's age and smoking status of the mother. To cope with the large amount of data, the uncertainty about the data, and the wide range of circumstances that influence the decision, the decision process is based on a fuzzy knowledge-base. Various levels of warnings are available.

3.5. Other projects

An interface system has been developed for creating a feedback by vibro-tactile stimuli and images to help correct pronunciation, with the aim to offer a feedback during training of hearing disabled children. The assessment of the pronunciation involved a fuzzy knowledge-base. The device converts speech-related information into visual and tactile information.

In another project, models for biological processes have been developed based on chaotic neuro-fuzzy systems [8].

4. Future trends

We believe that a better understanding of the non-linear properties of fuzzy and neuro-fuzzy systems with defuzzification, and of the dynamics of fuzzy iterated processes is essential for the evolution of the field. At the same time, the improved understanding and theoretical foundations of non-linear methods in medicine condition the use of fuzzy and neuro-fuzzy systems in medicine[1]. Both fields lack yet the desirable theoretical development.

Our current and planned projects include the following.

- Further application of neuro-fuzzy methods to medical image processing.
- Further application of neuro-fuzzy systems in control of prostheses and use of artificial life (AL) technologies, including evolvable hardware for neuro-fuzzy systems.
- A comparative analysis of dynamical neuro-fuzzy systems in modeling applications is under progress. The analysis is aimed to throw light on some new concepts related to chaos in neuro-fuzzy systems, and similarities to biologic, economic and social processes.
- An analysis of errors in hardware implementations of neuro-fuzzy systems is under progress. The aim is to determine which solutions are better suited for specific applications.
- A tentative project refers to the analysis of the dynamics associated to a knowledge processing systems. The concept of dynamics associated to a knowledge processing systems (KPSs) is addressed in the context of medical applications. The dynamic analysis is specifically applied to fuzzy KPSs, including fuzzy knowledge bases (FKBs), fuzzy decision-making and decision support systems (FDSs) and fuzzy expert systems (FESs). Applications envisaged range from diagnosis to treatment to anesthesia control to nutrition. A testing methodology aiming to assess the expected dynamic behavior is presented.

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[1] The volumes given in "Further reading" section in bibliography may interest the reader looking for applications of fuzzy and neuro-fuzzy systems in medicine. These volumes include chapters on several significant projects around the world involving fuzzy and neuro-fuzzy systems in medical applications. The web pages related to tour department including links to several papers are also given in this section.

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[13] http://morden.csee.usf.edu/ailab/hall.html Web page of the laboratory for AI/Dr. Hall; links to several papers on fuzzy logic in image processing. http://morden.csee.usf.edu/KB-Papers/IJCAI/ijcai.html is a page related to the above, presenting some easy to follow explanations on fuzzy techniques in image processing.

[14] http://marathon.csee.usf.edu/~kwb/medical-imaging.html Announcement of a Mammography Image Analysis Research Database.

[15] http://marathon.csee.usf.edu/ The Computer Vision/Image Analysis Research Laboratory at the University of South Florida (Dr. Goldgof).

[16] http://www.Sensitivetech.com/ Web page of Sensitive Technologies LLC, USA; presents basics of the technology used in infants monitoring for SIDS prevention.