Applied Soft Computing 37 (2015) 245–254

Contents lists available at ScienceDirect

Applied Soft Computing

journal homepage: www.elsevier.com/locate/asoc

Fuzzy logic in the gravitational search algorithm enhanced using fuzzy logic with dynamic alpha parameter value adaptation for the optimization of modular neural networks in echocardiogram recognition

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ARTICLE INFO

Article history:
Received 15 December 2014
Received in revised form 14 August 2015
Accepted 18 August 2015
Available online 28 August 2015

Keywords:
Modular neural network
Gravitational search algorithm
Pattern recognition
Echocardiograms
GSA
Fuzzy logic

ABSTRACT

In this paper the main goal is to find the optimal architecture of modular neural networks, which means finding out the optimal number of modules, layers and nodes of the neural network. The fuzzy gravitational search algorithm with dynamic parameter adaptation is used for optimizing the modular neural network in a particular pattern recognition application. The proposed method is applied to medical images in echocardiogram recognition. One of the most common methods for detection and analysis of diseases in the human body, by physicians and specialists, is the use of medical images. Simulation results of the proposed approach in echocardiogram recognition show the advantages of using the fuzzy gravitational search in the optimization of modular neural networks. In this case the proposed approach provides a very good 99.49% echocardiogram recognition rate.

1. Introduction

In recent years, the interest in algorithms inspired by natural phenomena has grown considerably. It has been shown by many researchers that these algorithms are well suited to solve complex problems. For example genetic algorithms (GAs) are inspired on Darwinian evolutionary theory [33], ant colony optimization (ACO) mimics the behavior of ants foraging for food [13], and particle swarm optimization (PSO) simulates the behavior of flocks of birds [8,19]. In addition, simulated annealing (SA) is designed by use of thermodynamic effects [20], the artificial bee colony algorithm (ABC) is an optimization algorithm based on the intelligent foraging behavior of a honey bee swarms [18]. On the other hand, the bat algorithm (BA) is inspired by the echolocation behavior of microbats [39], etc. In this paper we consider the gravitational search algorithm (GSA), which is a metaheuristic optimization method based on the laws of gravity and mass interactions [26]. There exists different works concerning the gravitational search algorithm, but only the most important and relevant for this paper will be considered [14,24,40]. There also exists a previous proposal of a fuzzy gravitational search algorithm (FGSA), and its application to the optimal design of multimachine power system stabilizers (PSSs). The FGSA based-PSS design is validated for two multimachine systems: a 3-machine 9-bus system and a 10-machine 39-bus. In this case, fuzzy logic is used to speed up the final stages of the process and find the accurate results in a shorter time, even for very large problems. In the proposed GSA the fuzzy-based mechanism and fitness sharing are applied to aid the decision maker to choose the best compromise solution from the Pareto front [42]. However, we have proposed in this work a new and different fuzzy gravitational search algorithm (FGSA) to dynamically change the alpha parameter values and give a different gravitation and acceleration values to each agent in order to improve its performance, which is presented in [29]. This approach is now considered here in this paper to design optimal modular neural networks (MNNs) for pattern recognition, which has not been considered previously in other works.

Research in medical imaging has grown considerably in the last years as it is normally a non-invasive diagnosis method. Therefore, we are considering the application of the FGSA method to design the optimal architecture of modular neural networks (MNNs), which means finding out the optimal number of modules, layers and nodes of the neural network designed for echocardiogram recognition. In this case, we are using a database of echocardiograms that contains images of disease and healthy patients. This paper focuses on the field of nature inspired computation and several approaches have been previously proposed for the optimization of modular neural networks [21,22,25,34,36,37]. A modular neural network for medical diagnosis is presented in [12,27], a MNN for pattern recognition is also shown in [16,23], preprocessing and segmentation techniques of medical images are presented in [38,41] and finally some medical applications using echocardiograms are presented in [1,9,11,30].

The main problem in these medical applications is that normally there are many speckle noise points on the ultrasound images. So the resulting images are contaminated with this noise that corrodes the borders of the cardiac structures [5]. This characteristic turns difficult to perform image processing, and even more achieving the level of accuracy for pattern recognition needed in these applications. Besides this kind of noise, other factors influence the outcome of ultrasound image recognition. However, the disease recognition problem is complicated by the heart's non-rigid motion. Furthermore, the poor imaging quality of 2D echo videos due to low contrast, speckle noise, and signal dropouts, also cause problems in achieving image interpretation [17].

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http://dx.doi.org/10.1016/j.asoc.2015.08.034
1568-4946/

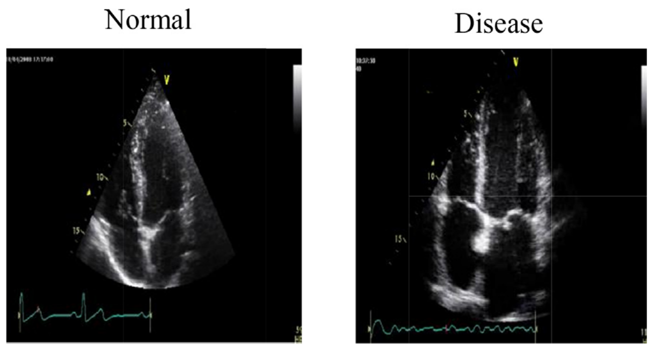

Fig. 1. (left) Echocardiographic frames from normal; (right) motions of the heart for disease patients.

As illustration we show in Fig. 1 (right), the image of a heart with cardiac amyloidosis, which is a myocardial disease characterized by extracellular amyloid infiltration throughout the heart. The cardiac amyloidosis has a wide spectrum of clinical manifestations, but the most frequent presentation is heart failure. We also show in Fig. 1 (left) the image of a healthy heart.

This paper presents an approach using fuzzy logic in the gravitational search algorithm (FGSA) for optimal architecture design of MNNs. This means finding out the optimal number of layers and nodes of the neural network to recognize if the image corresponds to a person with a heart disease or is an image of a person with a normal heart. The FGSA method was originally applied to 15 benchmark mathematical functions in [29] and now it is applied in pattern recognition using MNNs. In this paper, as a difference to other papers in echocardiogram recognition, which use an active shape model (ASM) to model shape and texture information in an echo frame, we use modular neural networks to directly perform this same task. The motion information derived by tracking ASMs through a heart cycle is then projected into the Eigen-motion feature space of the viewpoint class for matching [7].

The rest of the paper describes this approach in detail and is organized as follows. In Section 2, we describe some of the works related to image recognition in echocardiography and basic concepts related to this subject. In Section 3 we describe the modular neural network architecture and the database of echocardiograms for recognition and the pre-processing of the databases that are used. In Section 4 the experimental results are presented. Finally, in Section 5 the conclusions of this work are offered.

2. Background and basic concepts

There are different recent works about echocardiograms [2,32,35], but only the most important and relevant (based on their goals and methodology) for the subject of this paper will be mentioned in this section as related work.

2.1. Previous works

As related work we can find the use of modular neural networks for person identification using segmentation and the iris biometric measurement. In this case the modular neural network architecture is used as a system for identifying persons based on the human iris. In this system, the human iris database is enhanced with image processing methods, and the coordinates of the center and radius of the iris are obtained to make a cut of the area of interest by removing the noise around the iris [16].

Shahram et al. proposed an approach for the automatic identification of the views of the heart from the content of echocardiogram videos. In this approach the structure of the heart is represented by the combination of its parts (chambers) under the different views. The statistical variations of the parts in the constellation and their spatial relationships are modeled using Markov Random Fields models [28].

Jacob et al. [3] proposed a shape-space-based approach for tracking myocardial borders and quantifying regional the left-ventricular function applied in echocardiography. They present a new semi-automatic method for quantifying the regional heart function from two-dimensional echocardiography.

Sugioka et al. [31] proposed a method based on patterns to detect cardiac structures using active contours in echocardiographic images.

Comaniciu [10] proposed a methodology for tracking cardiac edges in echocardiographic images using information extracted from the images. In this work it was proposed a formulation with a complete fusion of all the information for achieving robust shape tracking, and optimally resolving uncertainties from the system dynamics.

Shams et al. [43] proposed a novel version of GSA, named clustered-GSA, and it was proposed to reduce complexity and computation of the standard GSA. This algorithm originated from calculating the central mass of a system in nature and improves the GSA by reducing the number of objective function evaluations. The clustered GSA is evaluated on two sets of standard benchmark functions and the results are compared with several heuristic algorithms and a deterministic optimization algorithm.

There is also previous work on a fuzzy gravitational search algorithm (FGSA), for optimal design of multimachine power system stabilizers (PSSs). The FGSA based-PSS design is validated for two multimachine systems: a 3-machine 9-bus system and a 10-machine 39-bus. Therefore, fuzzy logic is used to speed up the final stages of the process and find the accurate result in a shorter time, this even for very large problems. In the proposed GSA the fuzzy-based mechanism and fitness sharing are applied to aid the decision maker to choose the best compromise solution from the Pareto front [42].

In this paper we propose an approach to find the optimal architecture of modular neural networks, which means finding out the optimal number of modules, layers and nodes of the neural network with the fuzzy logic gravitational search algorithm. The FGSA is initially considered with dynamic increase of the alpha value. In addition the fuzzy gravitational search algorithm is also considered with a decrease alpha value approach, which means that the alpha values are decreased as the number of iterations increase. The proposed approach, as well as its use differs from the previous mentioned related works. The proposed method is applied for recognition of medical images.

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2.2. Echocardiography

Echocardiography is an important diagnostic aid in cardiology for the functional assessment of the heart. During an echocardiogram exam, a sonographer images the heart using ultrasound by placing a transducer against the patient's chest. Reflected sound waves reveal the inner structure of the heart walls and the velocity of blood flow. Since these measurements are typically made using 2D slices of the heart, the transducer position is varied during an echo exam to capture different anatomical sections of the heart from different viewpoints [6].

Echocardiography is often used to help diagnose cardiac diseases related to regional and wall motion as well as valvular motion abnormalities. It also provides images of cardiac structures and their movements giving detailed anatomical and functional information about the heart [7].

2.3. Noise in ultrasound

Speckle is a characteristic phenomenon in laser, synthetic aperture radar images, or ultrasound images. Its effect is a granular aspect in the image. Speckle is caused by interference between coherent waves that, backscattered by natural surfaces, arrive out of phase at the sensor [4,15]. Speckle can be described as random multiplicative noise. It hampers the perception and extraction of fine details in the image. Speckle reduction techniques can be