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Elimination of noise on transcranial Doppler signal using IIR filters designed with artificial bee colony – ABC-algorithm

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ABSTRACT

Biomedical signals are usually contaminated by noise generated from sources such as power line interference and disturbances produced by the movement of the recording electrodes. Also the signal-to-noise ratio of biomedical signals is usually quite low. In addition, biomedical signals often interfere with each other. Therefore, the filters employed for eliminating noise and interference are significant in the medical practice. Digital infinite impulse response (IIR) filters have shorter filter length than the finite impulse response (FIR) filters with the same frequency characteristic. Therefore, in this work, an approach based on digital IIR filters are described for the elimination of noise on transcranial Doppler by using artificial bee colony (ABC) which is a popular swarm based optimization algorithm introduced recently. Moreover, the performance of the proposed approach is compared to particle swarm optimization algorithm.

1. Introduction

Doppler ultrasound is a device allowing non-invasive measurement of blood flow velocity to diagnose vascular diseases. The blood flow velocity is determined by measuring the Doppler shift from red blood cells. The Doppler signal has a time-varying random character because the signal back scattered from the blood has a random spatial distribution [1]. Traditionally, the spectrogram obtained using short-time Fourier transform (STFT) is computed to analyse Doppler signal [2]. In literature, there are several spectrogram indices, such as S/D (the ratio of systolic maximum velocity to end diastolic velocity), PI (pulsatility index) and RI (resistive index) and several waveforms, such as the mean and maximum frequency waveform and the spectral width waveform extracted from the Doppler signal to diagnose the vascular diseases [3–5]. The Doppler spectrogram indices are obtained from the maximum frequency waveform of the spectrogram [6,7]. Internal or external noise to the system causing extra frequency will affect the estimation resolution of the maximum frequency waveform. Therefore, denoising the Doppler ultrasound signal is a basic and very important step for further processing [8,9].

A common signal processing system is the filter which can be employed for noise elimination process. Filters are designed either off-line or on-line. Off-line filter designers assume that the signal characteristics are fully known depending on the prior knowledge of the signal and noise. Design of digital filters with irrational transfer functions is difficult, and their implementation is also costly. Even though a causal filter can be found to approximate any given magnitude response, the order of the filter may become very large. It is clear that the larger the order, the more computation the filters require. Therefore, this may impose a restriction in real-time computation. Moreover, it will also be more costly if it is implemented with dedicated hardware. Thus in practice, it is desired to design a filter with an order as small as possible. However, if specifications are tight, then the required filter gets more complex [10]. In terms of structure, there are two groups of filters: finite impulse response (FIR) and infinite impulse response (IIR) filters. IIR filters can demonstrate a better performance than FIR filters with the same number of coefficients [11,12]. However, it has two main problems in the design: (i) filter error surface can be multi-modal; (ii) filter might become unstable [13,14]. The filter stability can be controlled by bounding the parameter space in a convenient value range. The multi-modal error surface might cause conventional design algorithms to be stuck at a local minimum. In order to avoid this problem and discover the global optimum, design methods based on global optimization algorithms are proposed for IIR filters.

Global optimization algorithms inspired of swarm intelligence have become a research interest to many scientists from several fields particularly for last two decades. The algorithms based on swarm intelligence simulate the intelligent behaviors of natural swarms such as flock of birds, colony of ants or termites, colony of honey bees, etc. Particle Swarm Optimization (PSO) algorithm

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is a swarm based optimization technique inspired by social behavior of bird flocking [15]. The PSO algorithm was first introduced by Eberhart and Kennedy in 1995 and employed particularly to solve numerical optimization problems. PSO maintains a swarm of particles each of which represents a potential solution to the problem [16]. Ant colony optimization (ACO) simulates the foraging behavior of ant colonies and a possible way between the nest and the food source corresponds to a possible solution to the problem [17]. Motivated by the foraging behavior of honeybees, in 2005 artificial bee colony (ABC) algorithm was originally introduced for solving numerical optimization problems [18]. Although ABC is a relatively new swarm intelligence-based optimization approach, it has been applied to solve several problems from different application areas [19]. ABC is simple, quite robust and flexible optimization algorithm [20,21]. In this work, a novel approach based on ABC algorithm is proposed to denoise Doppler signal using IIR filter. The paper is organized as the following: Section 2 describes ABC algorithm in detail. Section 3 provides an overview of the noise cancellation process. In Section 4, the application of the proposed method based on ABC to the noise cancellation problem is described and its performance is compared to PSO algorithm, and then the simulation results are discussed.

2. Artificial Bee Colony algorithm

In 2005, Karaboga introduced a bee swarm algorithm Artificial Bee Colony – ABC – which simulates the intelligent foraging behavior of real honey bees [18]; and Basturk and Karaboga compared its performance with that of some other well-known population based optimization algorithms [20,21]. The detailed pseudocode for ABC algorithm can be given as the following:

1: Initialize the population of solutions: $x_{i,j}$, $i = 1, \dots, SN$ (SN: the number of solutions in the population), $j = 1, \dots, D$ (D: the number of optimization parameters).
2: Evaluate the population of solutions by using Eq. (2)
3: cycle = 1
4: **REPEAT**
5: Produce new solutions (food source positions) $\upsilon_{i,j}$ in the neighborhood of $x_{i,j}$ for the employed bees using formula (1)

$$v_{ij} = x_{i,j} + \Phi_{ij}(x_{i,j} - x_{k,j}) \tag{1}$$

k is a randomly produced index, Φ_{ij} is a random number in the range $[-1, 1]$ and evaluate them.
6: Use the greedy selection between x_i and v_i
7: Generate the probability values p_i for the solutions x_i by using their fitness values using Eq. (2)

$$p_i = \frac{fit_i}{\sum_{i=1}^{SN} fit_i} \tag{2}$$

where fit_i is the fitness value of the solution i.
In order to calculate the fitness values of solutions, the following equation is employed:

$$fit_i = \frac{1}{1 + J_i(w)} \tag{3}$$

where $J(w)$ is the cost function to be minimized.
8: Generate the new solutions v_i for the onlookers from the solutions x_i, selected depending on p_i, and evaluate them
9: Use the greedy selection process between x_i and v_i
10: Determine the abandoned solution, if exists, and replace it with a new randomly produced solution x_i for the scout using Eq. (4)

$$x_{ij} = \min_j + \text{rand}(0, 1) \times \left(\max_j - \min_j\right) \tag{4}$$

11: Memorize the best solution achieved so far
12: cycle = cycle + 1
13: **UNTIL CYCLE** = Maximum Cycle Number (MCN)

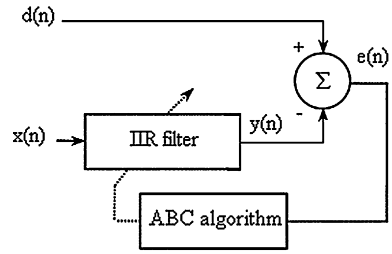

Fig. 1. Block diagram of the proposed noise cancellation system.

3. Proposed noise cancellation approach

Noise cancellation is a basic problem being faced in many applications such as speech processing, signal enhancement, biomedical signal and image processing. It can be stated as the extraction of a desired signal from a noisy, corrupted signal by negating the noise [22]. Fig. 1 demonstrates the structure of the noise canceler system based on ABC algorithm.

Noise elimination is the process of removing noise from the noisy image. The block diagram of the noise elimination system is shown in Fig. 1. As shown in Fig. 1, the image $d(n)$ is the contaminated image containing both the original image, $s(n)$, and the Gaussian noise $n(n)$, assumed uncorrelated with each other. $x(n)$ is processed by the digital filter to produce an estimate $y(n)$ of $n(n)$. An estimate of the desired signal, $e(n)$, is then obtained by subtracting the digital filter output, $y(n)$, from the contaminated image.

The transfer function of IIR filter in Fig. 1 is given as

$$H(z) = \frac{\sum_{i=0}^{M} b_i z^{-i}}{1 + \sum_{i=1}^{N} a_i z^{-i}} \tag{5}$$

where b_i and a_i are the coefficients of the filter and N ($\geqslant M$) is the filter order. The coefficient vector can be represented as in the following string form,

$$w = [b_0 b_1 \cdots b_M a_1 a_2 \cdots a_N]^T \tag{6}$$

In order to design a stable IIR filter, its all poles must be inside the unit circle. In the simulation study, due to its power spectrum properties an additive white Gaussian noise is used as a noise signals. White noise has an infinite power covering infinite range of frequencies.

The error signal $e(n)$ is the difference between the noisy signal and the IIR filter output. Error is computed and then fed back to adaptation algorithm. Then, the filter coefficients are adjusted by the algorithm so that the given cost function is minimized. The cost function used here is the mean squared error (MSE) and defined as

$$J(w) = \frac{1}{N} \sum_{n=1}^{N} \left[d(n) - y(n)\right]^2 = E\left[\left|e(n)\right|^2\right] \tag{7}$$

where E represents the expected value. As stated by Eq. (3), the fitness value of a solution is computed as

$$fit_i = \frac{1}{1 + J_i(w)} \tag{8}$$

where $J_i(w_i)$ is the cost function value calculated when the parameter set w_i is used to design the filter.