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Optimal filter design using an improved artificial bee colony algorithm

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ABSTRACT

The domain of analog filter design revolves around the selection of proper values of the circuit components from a possible set of values manufactured keeping in mind the associated cost overhead. Normal design procedures result in a set of values for the discrete components that do not match with the preferred set of values. This results in the selection of approximated values that cause error in the associated design process. An optimal solution to the design problem would include selection of the best possible set of components from the numerous possible combinations. The search procedure for such an optimal solution necessitates the usage of Evolutionary Computation (EC) as a potential tool for determining the best possible set of circuit components. Recently algorithms based on Swarm Intelligence (SI) have gained prominence due to the underlying focus on collective intelligent behavior. In this paper a novel hybrid variant of a swarm-based metaheuristics called Artificial Bee Colony (ABC) algorithm is proposed and shall be referred to as CRbABC_*Dt* (Collective Resource-based ABC with Decentralized tasking) and it incorporates the idea of decentralization of attraction from super-fit members along with neighborhood information and wider exploration of search space. Two separate filter design instances have been tested using CRbABC_*Dt* algorithm and the results obtained are compared with several competitive state-of-the-art optimizing algorithms. All the components considered in the design are selected from standard series and the resulting deviation from the idealized design procedure has been investigated. Additional empirical experimentation has also been included based on the benchmarking problems proposed for the CEC 2013 Special Session & Competition on Real-Parameter Single Objective Optimization.

1. Introduction

The effective choice of circuit components in the domain of analog filter design is of paramount importance. Traditional designs include choosing the components to be equal to each other and this result in significant simplification of the design process. Nevertheless, the components like capacitors or resistors are available in terms of multiples of certain series like E12, E24, E48, E96 and E192, with their respective range of tolerances and component values. Keeping in mind the associated

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cost constraints and the need for an efficient design, the resistor and capacitor values are chosen from these series. Since the values of the components are selected from a set of finite values associated with each series, a thorough search must be performed so that the resulting deviation in the search process is minimized. The search for an optimal set of component values from the numerous possible combinations appears to be an exhaustive process, thus diverting the attention towards the application of those heuristics which combines high efficiency with minimal computational time.

The necessity for an efficient search process has led practitioners to rely on Evolutionary Algorithms (EAs) [4], which mimic the process of natural evolution by simulating operators like mutation, crossover, recombination etc. The application of EAs in the domain of filter design has now gained widespread cognizance among the researchers as a potential topic of exploration and many notable works have been performed in this regard. A new design method for two dimensional recursive filters was explored by Mastorakis et al. [26] using Genetic Algorithm (GA) [15] by formulating the design problem as a constrained optimization problem and explored the application of metaheuristics in the design procedure of Infinite Impulse Response (IIR) filters. The applicability of GA in the design process of state variable filter was explored by Horrocks and Spittle [16] with the resistor values being selected from the E12 series. Vural et al. [39] investigated the performance of some existing EAs in the domain of analog filter design, primarily Butterworth [40] and state variable filter [41] synthesis. Chang et al. [8] proposed a novel tree based representation along with genetic programming for passive filter design. Xu and Ding [46] introduced an adaptive immune GA that combined both GA with immune algorithm for the purpose of improving the diversity, convergence speed in order to obtain an efficient system of EA based circuit design. Wang et al. [42] tested the combination of both Particle Swarm Optimization (PSO) [22] and Finite Element Method and used in the design process of microwave filters, having arbitrary geometries. Karaboga and Cetinkaya [21] explored the possibility of application of ABC algorithm [17–19] in the design process of adaptive Finite Impulse Response (FIR) and IIR filters. Das and Vemuri's [13] circuit synthesis framework for the passive analog circuits, based on a GA, was devised for obtaining the topology and the component values simultaneously. Sheta [36] used Differential Evolution (DE) [12,37,29] algorithm to select the elements of passive and active filter structures. Das and Konar [10,11] made use of modern swarm intelligent metaheuristics for 2-D IIR filter design.

This paper primarily investigates the applicability of a novel variant of the ABC algorithm called CRbABC_*Dt*(Collective Resource-base ABC with Decentralized tasking), which utilizes an artificial adaptive communication mechanism and a decentralized, directed exploration via neighborhood based dynamics towards the obtaining optimal solution. Our proposed algorithm has been tested on two design problems of a fourth order VCVS Butterworth filter and a second order state variable filter (SVF). The design problems have been formulated by considering the components (capacitors, resistors) from specified series. The results of our proposed algorithm have been compared with 6 existing algorithms which have reported competitive performance for global optimization.

The rest of the paper is organized as follows. Section 2 details the analog filter structures followed by the conventional design procedure in Section 3. A vivid description of the design problem formulation is provided in Section 4. Subsequent sections include elucidation of the classical ABC algorithm in Section 5 and its improved variant is proposed in Section 6. The associated experimental design and results are analyzed in Section 7 along with comparison on standard CEC '13 benchmark. Finally Section 8 concludes the paper.

2. Low pass analog active filter structures

Analog filters [32,35] are primarily devices that allow passage of electrical signals within a particular frequency range or at a particular frequency by restricting the passage of others. These filters are considered as the building blocks of many communication system, where they are used in wide range of applications in varying ranges of frequencies. Applications are manifold including speech processing, channel selection, demodulation of signals, separating the signal from the noise, etc. Active analog filters utilize op-amps as the active component, which are combined with resistors and capacitors in certain arrangements to obtain desired filter response characteristics.

Active analog filters enjoy a significant advantage over the passive design due to their ability to be packed in a miniaturized format owing to efficient IC design. In spite of this, several limitations exist in the form of slew rate, unwanted noise, gain bandwidth product, etc.

The types of filter generally include the given categories- high pass, low pass, band pass and band reject.

- *Passband gain*: Pass band gain is defined in the frequency range of interest and is ideally considered to be unity or at a fixed value.
- *Cutoff frequency*: Cutoff frequency determines the frequency at which the response makes a transition between pass band and stop band.
- *Quality factor*: Quality factor determines the sharpness of the response curve.

An ideal low pass filter is characterized by a uniform pass band up to a certain frequency called *cut-off frequency* after which the higher order frequency components are attenuated. Ideal low pass filter characteristics include sharp distinction between the pass band and stop band as shown in the Fig. 1. The two low pass filter designs considered in this paper, namely state variable and Butterworth, are detailed below.