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ORIGINAL RESEARCH

Optimization algorithms, an effective tool for the design of digital filters; a review

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Abstract

Nowadays, optimal and intelligent design approaches are vital in almost all areas of engineering. Scientists and engineers are attempting to make frameworks and models more proficient and intelligent. This paper deals with a detailed investigation on design of various digital filters using optimization algorithms. Generally digital filters are classified into two types which are FIR and IIR filters and are again classified into one dimensional, two dimensional and three dimensional filters for signal, image and video respectively. The design of a digital filter that satisfies all the required conditions perfectly is a challenging factor. So, apart from the conventional mathematical methods, optimization algorithms can be used to design optimal digital filters. IIR Filters are infinite impulse response filter; they have impulse response of infinite duration. FIR Filters are finite impulse response filters; they have impulse response of finite duration. In this paper we have discussed the design of various optimal digital filters based on various optimization algorithms, for processing of signal, image and video. The design of digital filters based on Evolutionary algorithms and swarm intelligence algorithms like Genetic Algorithm, Particle Swarm Optimization, Artificial Bee Colony Optimization, Cuckoo Search Algorithm, Differential Evolution, Gravitational Search, Harmony Search, Spiral Optimization, teaching–learning based optimization, wind driven optimization, hybridization of optimization algorithm are presented.

Keywords Optimized filter design · Evolved filter design · Filter design using metaheuristic optimization · Nature inspired filter design · Filter design using optimization · Bio inspired filter design · Filter design using heuristic search · Hybrid optimization algorithms

1 Introduction

Digital Filters are basically used to reduce or obtain certain aspects of the given signal. It is based on mathematical operations which are applied on the sample discrete time signal. Digital filters (Proakis and Manolakis 2007) are classified into types which are finite impulse response filter (FIR) and infinite impulse response filter (IIR). Based on the dimension of input signal these filters are further classified into two, which are one dimensional (1D) filters and two dimensional (2D) filters for signal and image processing respectively. Since FIR digital filters are inalienably stable and can have linear phase, they are commonly favoured over IIR filters. These FIR filters have numerous essential applications in digital signal and image processing.

The design of digital filter involves, determination of a set of filter coefficients which are satisfying the features, and are affecting its performance such as width of pass-band and stop band, attenuation of stop band, overall gain, cut-off frequencies and tolerable ripples in the pass band and stop-band. There are many conventional methods such as windowing functions as Butterworth, Chebyshev, Kaiser etc., transformation technique like bilinear transformation for filter design. Remez exchange algorithm proposed by Parks and McClellan and Steepest-descent method for optimization of digital filter development by selection of filter coefficients, but they are not suitable for FIR filter optimization because of the several reasons (Singh 2014).

An optimisation algorithm is fundamentally a strategy to locate the best feasible solution to a problem out of the different accessible solutions, there could be no single method

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for doing a thing but there could be various feasible ways. The procedure incorporates, evaluate the different solution sets on premise of criteria, rank the solutions in ascending or descending order and in this manner locate the best or worst among them.

The development of optimised filter coefficients are not new and a few endeavours have already been made for optimum filter design. Evolutionary optimization algorithms such as Genetic Algorithm (Kubasek et al. 2006), Artificial Bee Colony optimization (Akay and Karaboga 2011), Differential Evolution (Mondal et al. 2012c) and swarm intelligence algorithms like, PSO (Mandal et al. 2012a), and so on, are executed for the design of optimal digital filters. These methodologies are substantiated themselves very efficient (Kubasek et al. 2006) to (Kashihara 2013) by giving better control of performance parameters notwithstanding high stop band attenuation decreases the inaccuracy and improves the quality of response.

In this paper, very brief survey on development of different 1D and 2D digital FIR and IIR filters and various filter banks like quadrature mirror filter(QMF) and Wavelet filter bank using different optimisation algorithms like genetic algorithm (GA), differential evolution (DE), gravitational search algorithm(GSA), spiral optimisation (SO), teaching learning based optimisation (TLBO), Particle swam optimisation (PSO), artificial bee colony optimisation (ABC), harmony search (HS), cuckoo search (CS) are carried out. The Sect. 2 discusses related works, Sect. 3 discusses various digital filters, Sect. 4 discusses the basic concept of optimisation, Sect. 5 discusses a brief survey on design of digital filter using optimisation algorithms and finally,the summarisation is in Sect. 6.

2 Related works

As a digital filter is an integral part of a signal processing system. The design of digital filters using optimization algorithm is a prominent research area and varieties of reviews were included in the literature (Amrik Singh Singh 2014; Bhargava 2013; Sabbir and Antoniou 2006, Er Karamjeet Singh 2014; Nidhi Mishra 2015). Sabbir and Antoniou conducted a detailed study (Sabbir and Antoniou 2006) about the superiority of GA in digital filter design. They had stated so many advantages of GA and concluded that it is best suitable optimisation method for developing digital filters. A survey on design of optimal digital filters using GA, DE and PSO has been carried out in (Er. Karamjeet Singh 2014a; Nidhi Mishra 2015). But from the comparison in (Amrik Singh Singh 2014), it is found that the swam intelligence algorithms like PSO give better optimality than evolutionary algorithms like GA and DE.The author of (Amrik Singh Singh 2014), also suggested the hybridization of different optimization algorithms for better optimality. The Various methods for digital FIR filter design had studied in (Bhargava 2013) by Atul Bhargava. In his research, he had studied about FIR filter design based on artificial neural network, sequential quadratic programming (SQP) algorithms, windowing method, modified particle swarm optimization, Remez exchange algorithm and least-square method. Finally, he concluded that all of these methods have its own limitations and a new technique is to be introduced for filter design.

2.1 Digital filters

In signal processing, the capacity of a filter is to evacuate unwanted parts of the signal, for example, random noise, or to extricate valuable parts of the signal, for example, the segment is existing in a particular frequency range. Filtering is a procedure by which the frequency spectrum of a signal can be changed, reshaped or controlled to accomplish some required objectives. Based on the type of input and output, there are mainly two types of filters, analog filters and digital filters.

Because of number of points of interest over analog filters, digital filters are more in demanded in applications like high speed digital communication systems and in image processing systems. Based on the impulse response, digital filters are classified into two FIR (Tzeng 1998), and IIR (Kaur et al. 2013) filters. In case of dimension, digital filters are classified into one dimensional (1D) and two dimensional (2D) filters for processing signals and images.Another classification of digital filter based on relationship between input and output is low pass, high pass, band pass and band reject. An arrangement of different types of digital filters is known as a filter bank (Kubasek et al. 2006; Qiang et al. 2008a, b; Shark and Yu 2003a) and it has an important role in various signal and image processing applications.

2.2 Description of digital filters

2.2.1 Finite impulse response (FIR) digital filter

A finite impulse response (FIR) digital filter (Proakis and Manolakis 2007; Tzeng 1998) is one whose impulse response is of finite duration. The impulse response is" finite" because there is no feedback in the filter.

One dimensional FIR filter: a typical one dimensional (1D) FIR digital filter can be characterized in (Proakis and Manolakis 2007) by the transfer function $H(z)$ is,

$$H(z) = \sum_{n=0}^{N-1} h(n) z^{-n}. \tag{1}$$

Or

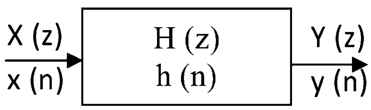

Fig. 1 Block diagram of 1D FIR filter

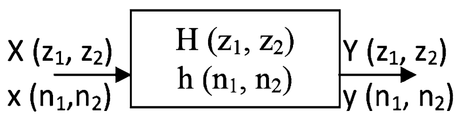

Fig. 2 Block diagram of a 2D FIR filter

$$H(z) = h(0) + h(1)z^{-1} + \cdots + h(n)z^{-(N-1)} \tag{2}$$

where N is the filter length of the impulse response $h(n)$. The block diagram of a 1D FIR filter is shown in Fig. 1 Here, the output in time domain y(n) is

$$y(n) = x(n) * h(n) \tag{3}$$

and the output in frequency domain Y(z) is,

$$Y(z) = X(z)H(z) \tag{4}$$

Where $x(n)$ and $X(z)$ are the input signals in time and frequency domain receptively. The frequency response of one dimensional FIR filter is;

$$H(\omega_k) = \sum_{n=o}^{N} h(n)e^{-j\omega_k n} \tag{5}$$

where $\omega_k = \frac{2\pi k}{N}$;$H(\omega_k)$ is the Fourier transform complex vector. This is the FIR filter frequency response. The frequency in $[0, \pi]$ is sampled with N points.

Two dimensional FIR filter Let the impulse response of a two dimensional FIR filter be $h(n_1, n_2)$ where $0 \le n_1 \le N_1 - 1$ and $0 \le n_2 \le N_2 - 1$, then the two dimensional transfer function $H(z_1, z_2)$ (Jayaraman and Veerakumar 2011) will be,

$$H(z_1, z_2) = \sum_{n_1=0}^{N_1-1} \sum_{n_2=0}^{N_2-1} h(n_1, n_2)z_1^{-n_1} z_2^{-n_2} \tag{6}$$

The block diagram of a 2D FIR filter is shown in Fig. 2 The output $Y(z_1, z_2)$ is,

$$Y(z_1, z_2) = Hz_1, z_2).X(z_1, z_2) \tag{7}$$

where $X(z_1, z_2)$ is the two dimensional input.

Substituting $z_1 = \exp(j\omega_1)$ and $z_2 = \exp(j\omega_2)$ in Eq. 6, we get the frequency response of a 2D FIR filter (S Jayaraman and Veerakumar, 2011) which is,

$$H(e^{j\omega_1}, e^{j\omega_2}) = \sum_{n_1=0}^{N_1-1} \sum_{n_2=0}^{N_2-1} h(n_1, n_2)e^{-j\omega_1 n_1} e^{-j\omega_2 n_2} \tag{8}$$

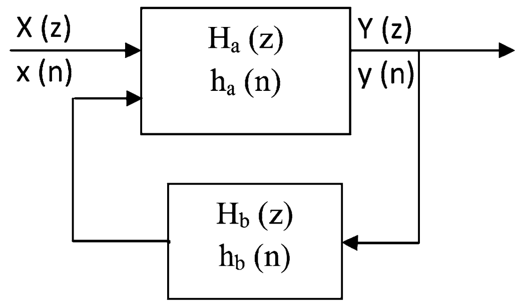

Fig. 3 Block diagram of 1D IIR filter

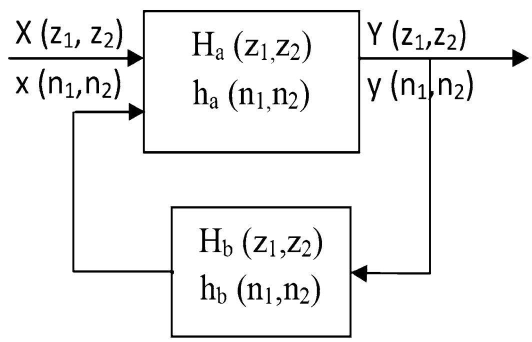

Fig. 4 Block diagram of 2D IIR filter

2.2.2 Infinite impulse response (IIR) digital filter

The traditional IIR filter is described by the following difference equation (Kaur et al. 2013):

$$y(n) = \sum_{k=0}^{M} p_k x(n-k) - \sum_{k=0}^{N} q_k y(n-k) \tag{9}$$

where p_k and q_k are the coefficients of the filter.

$x(n)$ and $y(n)$ are filter input and output. M and N are the number of filter coefficients, with $N \ge M$.

One dimensional FIR filter The transfer function of IIR filter (Kaur et al. 2013) in 1D form is stated as below;

$$H(z) = \frac{\sum_{k=0}^{M} p_k z^{-k}}{1 + \sum_{k=1}^{N} q_k z^{-k}} \tag{10}$$

The block diagram of a one dimensional IIR filter is shown below in Fig. 3. Here $x(n)$ and $y(n)$ are the input and output signals in time domain, and $X(z)$ and $Y\ (z)$ are the input and output in frequency domain.

Two dimensional IIR filter The transfer function of a 2D IIR filter (depicted in Fig. 4) is shown below (Mitiche and Adamou-Mitiche 2014; Mitiche et al. 2012) If $a(0, 0) = 1$, then the 2D transfer function is shown in Eq 11;

$$H(z_1, z_2) = \frac{\sum_{k_1,k_2 \in R_b} \sum b(k_1,k_2) z_1^{-k_1} z_1^{-k_2}}{1 + \sum_{k_1,k_2 \in R_a-(0,0)} \sum a(k_1,k_2) z_1^{-k_1} z_1^{-k_2}} \tag{11}$$

where $a(k_1, k_2)$ and $b(k_1, k_2)$ are coefficients of the filter. $R_a - (0, 0)$ Represents the region of support of $a(k_1, k_2)$ without the origin (0, 0) and R_b represents the region of support of $b(k_1, k_2)$.

2.2.3 Wavelet filter bank

An arrangement of FIR or IIR, low pass and high pass filters for spectral decomposition and composition of one dimensional or two dimensional signals, is called a filter bank. It has an important role in signal and image processing applications. In a wavelet filter bank (Shaheen et al. 2018), the information signal will pass through analysis filters. One of them, H_0, performs a low pass filtering operation and the other H_1 high pass one. Every filtering operation is followed by an up sampling by a factor of 2. And at the synthesis part, the signal is reproduced by first up sampling, then filtering and summing the sub bands.

The block diagram of a wavelet filter bank is shown in Fig. 5.

The output of analysis part (after down sampling) is

$$S(z) = \frac{1}{2}(H_0(z^{\frac{1}{2}})X(z^{\frac{1}{2}}) + H_0(-z^{\frac{1}{2}})X(-z^{\frac{1}{2}})) \tag{12}$$

$$D(z) = \frac{1}{2}(H_1(z^{\frac{1}{2}})X(z^{\frac{1}{2}}) + H_1(-z^{\frac{1}{2}})X(-z^{\frac{1}{2}})) \tag{13}$$

If $A(z) = \frac{1}{2}(H_0(z)F_0(z) + H_0(z)F_1(z))$ and $B(z) = \frac{1}{2}(H_0(-z)F_0(z) + H_0(-z)F_1(z))$, then the output $Y(z)$ is,

$$Y(z) = A(z)X(z) + B(z)X(-z) \tag{14}$$

The perfect reconstruction of $Y(z)$ means $X(z) = A(z)X(z) + B(z)X(-z)$ for all possible values of $X(z)$. The conditions of perfect reconstruction are;

$$H_0(-z)F_0(z) + H_1(-z)F_1(z) = 0 \tag{15a}$$

$$H_0(z)F_0(z) + H_1(z)F_1(z) = 2 \tag{15b}$$

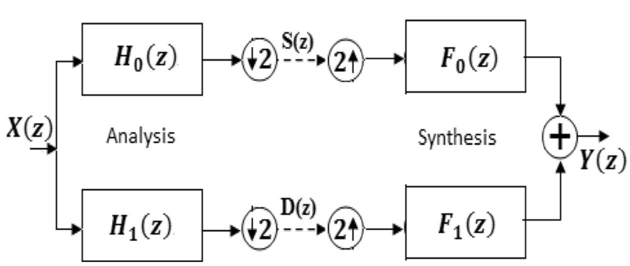

Fig. 5 Block diagram of a wavelet filter bank

This means that the synthesis low pass filter F_0 and high pass filter F_1 must be compatible to the analysis filters H_0 and H_1 to accomplish the perfect reconstruction of output.

3 Optimization algorithms

Optimization is a frequently encountered numerical issue in almost all engineering disciplines and an optimization algorithm is a process which is executed iteratively by looking at different solutions till an optimum or a reasonable solution is found. Basically there are two optimization approaches, deterministic and stochastic. The deterministic algorithms require massive computational efforts and may fail as the increase in problem size and this motivates the use of metaheuristic stochastic optimization algorithms as an algorithmically efficient option to deterministic algorithms. Metaheuristics algorithms are problem independent and works on the iterative enhancement of either a population of solutions or a single solution and employs randomization and local search for making solution of a given optimization problem. Almost of these metaheuristic algorithms were inspired from any one of natural phenomena; they are collectively known as nature inspired metaheuristic optimization algorithms. These algorithms work very well for problem solving issues in almost all engineering disciplines and become a motivating power for the development of artificial intelligence.

4 Digital filter design using optimization algorithms

Design of various digital filters using nature inspired metaheuristic optimization algorithms like genetic algorithm (GA) (Dey et al. 2010; Kubasek et al. 2006),], differential evolution (DE) (Mondal et al. 2012c), gravitational search algorithm (GSA) (Li, 2015), particle swam optimisation (PSO) (Mandal et al. 2012a; Mondal et al. 2012a), artificial bee colony optimisation (ABC) (Akay and Karaboga 2011), harmony search (HS) (Saha et al. 2013a), cuckoo search (CS) (Kumar and Rawat 2015; Singh and Josan 2014) etc. are discussed in this paper.

4.1 Digital filter design using genetic algorithm

Genetic algorithms (Han et al. 2016) are optimization algorithms that bear a resemblance to the natural selection (Dey et al. 2010; Kubasek et al. 2006).In a genetic algorithm, an arrangement of numbers which can be a solution to the problem is called as genome and an array of genomes is called as population. GA makes new generations by applying some genetic operators such as crossover and mutation to the genomes of a population. The design procedures using this algorithm are broadly proposed for the design of digital filters, because this technique is automatic, rapid, and gives filter realizations of near minimal computational complexity. In literature, it is found that all other existing methods of filter design do not possess all these features.The filter design using GA (Aggarwal et al. 2012; Ahmad 2008; Gentili et al. 1995; Karaboga and Cetinkaya 2003; Karaboga and Cetinkaya 2008; Kaur and Kaur 2012; Kubasek et al. 2006; Mastorakis et al. 2003; Oner 1998; Qiang et al. 2008a; Raaed Faleh Hassan 2013; Shark and Yu 2003a; Tzeng 1998; Xue et al. 2003) and for achieving better result, its variants (Jones et al. 2001a; Kaur et al. 2013; Lee et al. 1998; Sinha and Singh 2003; Tang et al. 1998; Zhao et al. 2014) are discussed in the literature.

To analyze the ability of GA in FIR filter design, initially a 1D FIR filter has been designed in (Oner 1998) using conventional mathematical method and its magnitude response has been plotted to achieve a desired response. And a simple GA has been used to optimize the filter coefficients and achieved a symmetric filter with the desired linear phase response. The crossover operator and mutation operator are the two important parameters in GA. An adaptive selection algorithm was used to improve the choice of these two parameters and using the improved GA, an FIR low pass filter was designed in (Zhao et al. 2014).In another way, the design requirements can be made as reference and look up table based method can be used to design an FIR low pass filter, but anyway for getting the better filter response, the adaptive GA is preferred (Zhao et al. 2014).A one dimensional FIR filter having 28th order coefficients were developed and designed in (Lee et al. 1998) using a modified genetic algorithm. As for the modification, every newly created offspring is evaluated using the canonical signed-digit (CSD) (Lee et al. 1998) constraints and also the different parent selection mechanisms of GA were compared, and found that all are showing equal performance. The two objective functions used in modified GA (Lee et al. 1998) are Minimax and Least mean square (LMS) error and found that Minimax strategy produce better filters than LMS.

An efficient genetic algorithm approach for the design of digital FIR filters with coefficients constrained to be sums of power-of-two terms is proposed in (Gentili et al. 1995). The GA based design technique is explained and compared experimentally with other design techniques such as simulated annealing algorithm (SA), Parks-McClellan algorithm, mixed integer linear programming(MILP) technique and by the proportional relation-preserve (PRP) design method, on several power-of-two FIR filter design cases. It can be seen that the GA technique is able to attain results as good as or better than the other methods (Gentili et al. 1995).To incorporate time domain and frequency domain constraints for obtaining filters with better responses, GA approach is better than McClellan-Parks algorithm (Tzeng 1998).GA can be used, not only for finding filter coefficients but also finding minimum number of taps in a digital filter structure (Raaed Faleh Hassan 2013).If the numbers of taps are minimized, then the number of multipliers and adders used in the FIR filter also minimized. Compared to the FIR filters designed using least-squares (LS) and equiripple methods, the FIR filter designed using GA shows the better cut off frequency and attenuation of ripples in pass band and stop band (Raaed Faleh Hassan 2013). Besides other filter design parameters, error functions like mean squared error (MSE), least mean squared error (LMS), mean absolute error (MAE) or a function to pull the zeros which are positioned out of the unit circle into the inside of the circle, in the pole zero diagram of a filter, can be used as objective functions(Karaboga and Cetinkaya 2003).While using these objective functions, besides obtaining the desired responses, the ripples in the pass band and in the stop band regions are also attenuated successfully (Karaboga and Cetinkaya 2003). While in the case of 2D FIR filters, the restrictions are high and more parameters must be evaluated. Keeping in mind the end goal to enhance the execution of customary GAs to deal with produce 2D filters with great response characteristics and incredibly decreasing the error criteria and CPU time, some inventive ideas are acquainted in (Boudjelaba et al. 2014) and reached a better performance than some conventional GA techniques. An FIR filter is designed using genetic algorithm (GM) and its comparison based on magnitude response, phase variation and phase delay is done with Blackman, Parks McClellan and Hamming window methods in (Aggarwal et al. 2012; Kaur and Kaur 2012) and concluded that out of each of the three strategies, GA offers a snappy, simple and programmed technique for designing low pass FIR filters that are near optimum in terms of magnitude response, frequency response and in terms of phase variation.

The unstability problem and the phase distortion taking place during the design process are significant disadvantages of IIR filters. While design using GA (Karaboga and Cetinkaya 2008), with three error functions mean squared error (MSE), least mean squared error (LMS) and minimax (mean absolute) error, simultaneously in the objective function causes a better filter design in terms of minimum phase response and stability. The design of an IIR filter using genetic algorithm under the mixed-criterion of H2 norm and norm using GA is compared with a conventional butterwort filter in (Xue et al. 2003) and found that the SNR and filtering performance of IIR filter is comparatively improved than conventional butterworth filter design.

As an efficient modification to ordinary genetic algorithm for the design of IIR filters, a new hierarchical multilayer gene structure for the chromosome formulation is proposed in (Tang et al. 1998) and found that this scheme is a competent tool for the design in this area. The design of 2D IIR filters is attempted in (Mastorakis et al. 2003) by using GA, advantages over the other conventional methods that the stability of designed filter is introduced as the appropriate constraint and being analyzed from the beginning of procedure. And this technique discovers a better approximation of the transfer function than other conventional methods. A multi criterion optimization using real-coded genetic algorithm (RCGA) is applied to design the optimal and stable low-pass, high-pass, band-pass, and band-stop IIR filters in (Kaur et al. 2013) and achieved the different performance necessities like minimization of the Lp-norm approximation error and magnitude of the ripples in pass band and stop band.

The design of a two-channel digital filter bank having perfect reconstruction and high precision is done using GA technique in (Kubasek et al. 2006), from a basic low pass filter. An optimal biorthogonal wavelet filter bank has been developed from a 9/7 wavelet filter based on the image compression optimization using GA, is proposed in (Qiang et al. 2008a) and shows feasible results in compression ratio, while comparing with Antoninis 9/7 wavelet basis. An orthonormal wavelet filter banks having optimal shift-invariant property is proposed in (Shark and Yu, 2003a). As an alternative to find filter coefficients using multi objective function, finding a set of angles to gratify the single shift-invariant objective function is done, and a relationship has been set up between the angles and coefficients of filters. An extraordinary imperative was additionally executed to recognize unfeasible solutions there by restricting the quest for the optimum, in view of the natural evolution mechanisms, inside of the wavelet sub-space. While comparing with the classical Daubechies wavelet filter bank, the filter bank proposed in (Shark and Yu 2003a) shows better performance in the denoising of non-stationary signals. The design of one dimensional wavelet using GA is investigated in Hill et al. (2001) by Yvette Hill, Steven G. O Keefe and David V. Thiel. They have designed a continues wavelet transform for identification of cloud to ground (CG) strokes and finally it concluded that GA is computationally modest which allows the location improvement of wavelets for tailor made identification. A language-based genetic algorithms (GAs) for the design of biorthogonal wavelets inside of the connection of a lifting paradigm is proposed in (Jones et al. 2001a), showing that the GA-designed wavelets, which straight forwardly force a characterization based fitness function, which outperforms different wavelets based on the customary design techniques. An optimal wavelet filter bank for biomedical signals with any waveforms were developed using GA technique in (Masoodian et al. 2012).The proposed wavelet filter bank in (Masoodian et al. 2012) has 8-coefficient-filters and shows the best signal to noise ratio (SNR) than classical wavelets such as Daubechies and Coiflets, in the case of denoising ECG signals. The Breeder genetic algorithm has been used to find the optimal weighting coefficients for the wavelet and the matched filters that comprises a composite wavelet matched filter in (Sinha and Singh 2003). While comparing the performance of composite wavelet matched filter in (Sinha and Singh 2003) with the phase only filter and the classical matched filter, the execution of the composed filter is better for higher estimations of input SNR and can be utilized as a part of an optical correlator to discriminate two classes of input images for fingerprint-based user reorganization security frameworks. A nearly linear phase orthogonal filter banks for a lossy image coding scheme is proposed in (Boukhobza et al. 2013a) based on multi objective GA with the coding gain, frequency selectivity and the group delay characteristics as the objective functions. And the results shown that the filter bank proposed in (Boukhobza et al. 2013a) outperforms the Daubechies orthogonal filter banks in most of the test cases.

The design of fractional-delay FIR filters, asymmetric FIR filters, multiplier less FIR filters, IIR equalizers and filters along with a least-squares method using GA has been done and its correlations with comparable designs attained by classical techniques are examined in (Ahmad, 2008). After the comparison, the improvements found in filters are raised stop band attenuation, with a reduction of the pass band ripple, and on account of delay equalizers, the linearity in phase response is enhanced. The main demerit of GA technique is that, it is a slow process and required a large amount of computation. However, this can be made excellent up to a limit by using speedy hardware systems.

Adaption of 1D biorthogonal wavelet bases to a specific application using co evolutionary genetic algorithm has been done in (Grasemann and Miikkulainen 2004).This algorithm has performed good results in signal compression. An orthonormal multi objective GA has been used in (Shark and Yu 2003b) Adaption of 1D biorthogonal wavelet bases to a specific application using co evolutionary genetic algorithm has been done in (Grasemann and Miikkulainen 2004).This algorithm has performed good results in signal compression. A language based genetic algorithm has been used for the development of 1D wavelet filters in (Jones et al. 2001b). These filters outperformed other filters in the application of signal classification.

A genetic algorithm based optimum biorthogonal 9/7 wavelets has been developed in (Qiang et al. 2008c) and used with spiht for image compression. The results has been compared with Antoninis 9/7 wavelet basis and obtained significant improvements. Rather than single objective GA, multi objective GA based near orthogonal filter banks for lossy image compression has been introduced by Boukhobza et al. (2009b), (2013b, c) and (2009a). These filter banks had achieved a significant improvement in compression ratios compared to the 9/7 filer banks of JPEG2000 and db4 wavelets. Vaithiyanathan et al. evolved two sets of optimal wavelet coefficients (Vaithiyanathan et al. 2014) using GA. Among the two set of filter coefficients, one set is for high frequency and the other set is for low frequency components. The authors declared that these evolved filter coefficients outperformed the existing methods in PSNR performance.

An adaptive filtering methodology using gentetic algorithm to improve the quality of image reconstruction, has been proposed in (Moore et al. 2005b). From the results, it is observed that the evolved filter outperforms the discrete wavelet transforms and decreased the mean square error. Salvador et al. (2010) expressed the initial studies on simplifying the computing requirements of an evolutionary algorithm at implementation on embedded systems for dwt based image compression. From the results, it is observed that the algorithm effectively reduced the computing requirements with little compromise in the result. Further in (Salvador et al. 2011), the authors implemented the adaptive wavelet transform based compression in FPGA devices.

As a continuation to the previous efforts (Peterson et al. 2007c; Babb et al. 2008b). Babb et al. (2008a) evolved the coefficients of DB4 wavelet filters for improving their features in satellite image processing and obtained better results compared to their previous works. In addition to these Babb et al. further demonstrates in (Babb et al. 2009a) that MSE has been reduced an average of 33.78.

A genetic group search optimizer (GGSO) based optimal wavelet filter coefficients has been derived in (Ellappan and Samson Ravindran 2016) for medical image compression. This has been used with SPIHT and Huffman encoding to achieve the compression. The results demonstrate that this method retains the important features of MRI images at high compression rates.

4.2 Digital filter design using particle swarm optimization algorithm

Particle swarm optimization (PSO) (Su and Zhao 2017; Sundhari and Anita 2015) is a computational knowledge oriented, stochastic, population-based global optimization method proposed by Kennedy and Eberhart in 1995.It is inspired by the common activities of grouping the birds, searching for food. The term particle indicates the folks in a swarm, for example, birds in a flock. PSO has been broadly connected to numerous designing optimization zones because of its uncomplicated concept, distinctive searching method, and proficiency in computation and easiness in implementation.PSO is shown to be better than GA (Ababneh and Bataineh 2008) with a especially effortless concept of computation and design paradigm of digital filters.

Design and comparison of a linear phase FIR filter using PSO, GA and ParksMcClellan (PM) have been carried out in (Ababneh and Bataineh 2008) with using two design cases. In the first case, length of the filter, frequencies of stop band and pass band and the ratio of the ripples in pass band and stop band are considered. In the second case, a feasible size of ripples in pass band and stop band as well as the other three filter particulars are considered.The later condition is not obviously considered by the ParksMcClellan (PM) algorithm. Moreover, the results (Ababneh and Bataineh 2008) demonstrated that the PSO outperforms GA.

A digital FIR filter is proposed in (Kumar et al. 2013) by finding the frequency response and optimal filter coefficients by using the PSO. While comparing with the conventional windowing techniques, the PSO achieved fast convergence speed and minimized error function (Kumar et al. 2013). For achieving the specification of a desired optimal linear phase digital FIR low pass filter (Singh 2014), a set of coefficients of an ideal filter, were optimized using the combined approach of PSO with constriction factor. While comparing with some other approaches, the proposed approach in (Singh 2014) is superior to others. Ashutosh and Kasambe evaluated the performance of GA and PSO for IIR filter design (Ashutosh and Kasambe 2013). The responses of the designed filters were plotted and compared coefficients obtained with the desired value of coefficients. The authors finally concluded that the filter designed using PSO produce a response which is nearest to the response of the desired filter.

Quantum-behaved particle swarm optimization (QPSO), chaotic particle swarm optimization (ChPSO) and cultural particle swarm optimization (CuPSO) are global stochastic optimization algorithms that can be used to find out more speedily the global optima of a given problem than the conventional PSO. So the FIR low pass and band pass filters were designed using QPSO in Fang et al. (2006) outperforms the filters designed using conventional PSO and GA. And those filters were designed using ChPSO (Zhao et al. 2011) and CuPSO (Zhao and Gao 2009) outperforms the filters designed using conventional PSO and QPSO.

Adaptive Particle Swarm Optimization (APSO) (Saha et al. 2013b) and novel particle swarm optimization (NPSO) (Mandal et al. 2012b, c) algorithms are the enhanced versions of the conventional PSO algorithm and these algorithms are applied to the design of optimal FIR low pass filter (Mondal et al. 2012b; Saha et al. 2013b) and band pass filter in (Mandal et al. 2012b). Comparison of the results of PM, RGA and PSO, the APSO and NPSO show the best performance (Mandal et al. 2012b; Mondal et al. 2012b; Saha et al. 2013b) as in the case of magnitude response, minimum stop band ripple and maximum stop band attenuation with the tightest transition width.

The optimal coefficients of a highly non linear FIR high pass filter and a linear phase digital band pass FIR filter is derived from a novel approach of PSO called Craziness based Particle Swarm Optimization (CRPSO) in (Mandal et al. 2012a) and (Beant Singh, 2015).The filter derived from CRPSO produced the highest stop band attenuation and the lowest stop band ripple and same transition width with a very small increase in the pass band ripple compared to the filters derived from PM algorithm, RGA and ordinary PSO.The velocity vector and swarm updation of the conventional PSO algorithm, are modified and a novel PSO (NPSO) and an improved PSO (IPSO) is proposed in (Mondal et al. 2012a, 2011) for improving the quality of solution. And the results in (Mondal et al. 2012a, 2011) were demonstrated the superiority in performance of the linear phase digital high pass FIR filter compared to those filters designed using RGA, DE and conventional PSO. An optimal design of high pass FIR filter having linear phase response is proposed in (Mandal et al. 2011) using PSO with Constriction Factor and Inertia Weight Approach (PSO-CFIWA).To explore more effectively the solution space, another FIR high pass filter using PSO with Constriction Factor and Inertia Weight Approach and wavelet mutation (PSOCFIWAWM) is proposed in (Saha et al. 2012a).The comparison of simulation results in (Saha et al. 2012a) indicates that the filter developed through PSOCFIWA-WM outperforms the other filters obtained from PM,RGA,PSO and PSO-CFIWA.

The PSO algorithm with improved inertia weight approach (PSOIIW) is proposed in (Mukhopadhyay et al. 2012) and demonstrated the simulation results to prove the superiority of this approach in the development of FIR band stop filter. The optimum coefficients of Low-pass and High-pass IIR filters using PSO is presented in (Singh and Arya, 2012) and compared those filters in the case of performance with other filters derived from GA and FDA tool of matlab. The results in (Singh and Arya, 2012) demonstrated the supremacy of PSO. The Development of an optimal linear phase FIR filters using PSO and HS is proposed in (Shirvani et al. 2009) and concluded the superiority of PSO in fastness and the order of computation.

4.3 Digital filter design using harmony search optimization algorithm

The HS algorithm depends on natural musical execution forms that happen when an artist scans to the superior condition of harmony, for example, that amid jazz impromptu creation. Jazz extemporization tries to discover musical satisfaction harmony (an immaculate state) as dictated by a tasteful standard, pretty much as the optimization procedure looks to locate a global solution (an impeccable state) controlled by an objective function. The pitch of every musical instrument decides the stylish quality, pretty much as the objective function worth is dictated by the arrangement of qualities allotted to every outline variable. The development of optimum filters coefficients using harmony search algorithm (Wan et al. 2018) is proposed in (Chandra and Chattopadhyay, 2014; Ghosh et al. 2009; Nirmala and R., 2015; Saha et al. 2013a).

An optimized image filter developed using HS algorithm is proposed in (Nirmala and R., 2015), for denoising the impulse noise from a corrupted image.A multimodal FIR filter design using opposition based harmony search (OHS) algorithm is proposed in (Saha et al. 2013a) and compared with other filters designed using PM, RGA, PSO and DE. The simulation results in (Saha et al. 2013a) demonstrates that the filter designed using OHS made better performance than others regarding magnitude response, minimised stop band ripple, and maximised stop band attenuation with a very little descent in the transition width.

The design of a digital filter using another variation of the fundamental Harmony Search Algorithm called Bandwidth Adaptive Harmony Search (BAHS) algorithm is presented in (Ghosh et al. 2009).And the frequency responses of the optimal LP, HP, BP and BS filters developed in (Ghosh et al. 2009) is approximately equal to ideal responses and showing superior to filters developed using Taguchi Immune Algorithm (TIA) optimization algorithm.

4.4 Digital filter design using differential evolution algorithm

Another worldview in EA family is differential evolution (DE) proposed by Storn and Price in 1995. As with other evolutionary algorithms, DE (Li and Wang 2015) takes care of optimization problems by evolving a population of candidate solutions utilizing alteration and selection operators. DE uses floating-point instead of bit-string encoding of population individuals, and arithmetic operations instead of logical operations in mutation, in contrast to classic GAs. Various designs of digital filters using differential evolution algorithm is discussed in (Chandra and Chattopadhyay 2014; Er. Karamjeet Singh 2014b; Karaboga 2005; Karaboga and Cetinkaya 2005; Mondal et al. 2012c).

Despite the fact that DE algorithm has further simple structure than GA, for the same population size and number of generations, the filters derived from DE algorithm demonstrates a greater efficiency in phrases of magnitude response and for this reason LMS error. Additionally, in the simulations (Karaboga 2005; Karaboga and Cetinkaya 2005), it is visible that DE is considerably faster than GA for locating the most optimum digital filter. With an aid of different mutation approaches of Differential Evolution (DE) algorithm, the outline of a multiplier-less low-pass finite impulse response (FIR) filter is proposed and realized on Field Programmable Gate Array (FPGA) in Chandra and Chattopadhyay (2014) and substantiated its matchless quality in execution by contrasting with some existing algorithms and GA based filters. The differential evolution algorithm is modified by including wavelet mutation to it and developed an FIR filter in Mondal et al. (2012c) and this filter performed fine in terms of maximized attenuation in stop band, minimized ripple pass band and magnitude response.

4.5 Digital filter design using artificial bee colony algorithm

Artificial bee colony (ABC) algorithm is an optimization method which simulates the smart foraging conduct of honey bees. A set of honey bees is referred to as swarm which will successfully accomplish duties via social cooperation. There are three types of bees in ABC algorithm, called employed bees, onlooker bees, and scout bees. The employed bees search food around the food supply in their reminiscence; in the meantime, they share the information of these food sources to the onlooker bees. The onlooker bees tend to opt for excellent food sources from those discovered through the employed bees. The food source that has larger excellence (fitness) could have an enormous chance to be selected by way of the onlooker bees than the one of smaller excellence. The scout bees are interpreted from a couple of employed bees, which relinquish their food sources and search new ones.

The ABC algorithm based lower-order and higher-order digital IIR filters are offered in Karaboga (2009) and the performance of the proposed procedure has been compared with conventional optimization algorithms like LSQ-nonlin and PSO. From the simulation results in Karaboga (2009), it is observed that the approach based on the ABC algorithm seems an alternative for developing digital low and higher order filters.

The design of a two-channel QMF banks having linear phase response is proposed in Agrawal and Sahu (2015) using ABC algorithm. The simulation results (Agrawal and Sahu 2015) unmistakably show that proposed strategy gives enhanced execution as far as smallest peak reconstruction error. Furthermore, displays better results for larger tap QMF banks created utilizing PSO, DE and other surely understood techniques and algorithms.

4.6 Digital filter design using cuckoo search algorithm

Cuckoo search (CSA) is a meta-heuristic algorithm motivated from the bird cuckoo; these are the" Brood parasites" birds. It never constructs its own particular home and lays their eggs in the home of another host bird settle.Some host birds can draw in straightforwardly with the interfering cuckoo. On the off chance that the host bird recognizes the eggs that are not their egg then it will either discard that eggs from its nest or just freed its nest and manufacture another nest. In a nest, each egg symbolizes to a solution and cuckoo egg symbolizes to a new and great solution. The attained solution is another solution in view of the current one and the change of a few attributes. In the least difficult frame each nest has one egg of cuckoo in which each nest will have numerous eggs speaks to an arrangement of solutions.

The advantage of making use of CSA for finding filter coefficients lies correctly that linear phase FIR low pass filter developed using this method (Singh and Josan, 2014) offers expanded characteristics corresponding to a nearly flat pass band and better stop band attenuation. The optimal coefficients of a fractional delay-infinite impulse response (FD-IIR) filter is determined using CSA algorithm in Kumar and Rawat (2015) and its simulation results were compared with GA and PSO asserted that the CSA based approach outperforms GA and PSO, in less significant magnitude and phase error, higher enhancement in fast rate of convergence etc.

4.7 Digital filter design using bat algorithm

Bat Algorithm is based on the echolocation habits of bats. Each and every bat has an interesting capacity to search out its prey in complete darkness. This algorithm is developed on this hunting conduct of bats. Bats are mammals with wings and they're born with the developed potential of echolocation. Echolocation is a unique style of sonar, used by the bats to hinder obstacles, notice prey, and pinpoint their area in the dark. Bats emit a high sound frequency to listen the echo that bounces back from the neighbouring objects. The frequency is associated with their food gathering systems. The idealization of the echolocation connected with bats can be made clear as follows. Bats use echolocation to feel distance. They renowned the ranges/spaces between prey and surrounded obstacles in some superb approaches. Bats fly randomly with velocity at position with a constant frequency f_{min}, varying wavelength and loudness to seek for prey. They can naturally conform the wavelength of their transmitted pulses and change the rate of pulse emanation in the scope of [0, 1], contingent upon the nearness of their objective.

The ordinary PSO and Bat Algorithm are adopted to receive the premier coefficients of low move FIR lters of order 20 and 24 in Severino et al. (2015). The performance of BA and PSO algorithms are weighed against with the classical Parks and McClellan (PM) lter design algorithm, which is a deterministic method. For this evaluation, viewed the ripples in lters pass band and stop band, transition width and statistical information. The simulation results in Severino et al. (2015) substantiated that the proposed lter design approach utilizing BA algorithm outperforms PM and PSO.

4.8 Digital filter design using gravitational search algorithm

GSA is a heuristic algorithm based on Newton's laws of gravitation and mass. Newton's Law expresses that, every

Table 1 Summary of Optimized FIR Filters

Reference	Algorithm	Filter specifications
Oner (1998)	GA	One dimensional
Zhao et al. (2014)	GA	1. One dimensional
		2. Low pass
Lee et al. (1998)	Modified GA	One dimensional
Gentili et al. (1995)	GA	One dimensional
	SA	
	PMCC	
	MILP	
Tzeng (1998)	GA	One dimensional
	PMCC	One dimensional
Raaed Faleh Hassan (2013)	GA	Two dimensional
Kaur and Kaur (2012)	GA	Two dimensional
Aggarwal et al. (2012)	GA	Two dimensional
Ahmad (2008)	GA	Fractional-delay
		Asymmetric
		Multiplier less
Kumar et al. (2013)	PSO	One dimensional
Singh (2014)	PSO	One dimensional
		Low pass filter
Fang et al. (2006)	QPSO	One dimensional
Zhao et al. (2011)	ChPSO	One dimensional
Zhao and Gao(2009)	CuPSO	One dimensional
Saha et al. (2013b)	APSO	One dimensional
		Low pass
Mondal et al. (2012b)	Novel PSO	One dimensional
		Low pass
Mandal et al. (2012b)	Novel PSO	One dimensional
		Band pass filter
Mandal et al. (2012a)	CRPSO	One dimensional
		Linear phase
		Band pass
Beant Singh(2015)	CRPSO	One dimensional
		Band pass
Mondal et al. (2012a)	Novel PSO	One dimensional
		High pass
Mondal et al. (2011)	Novel PSO	Linear phase
		High pass
		One dimensional
Mandal et al. (2011)	PSO-CFIWA	High pass
		Linear phase response
		One dimensional
Saha et al. (2012a)	PSOCFIWA-WM	High pass
		One dimensional
Mukhopadhyay et al. (2012)	PSOIIW	Linear phase
		Band stop filter
		One dimensional
Manadal et al. (2011)	PSO-HS	Linear phase
		One dimensional

Table 1 (continued)

Reference	Algorithm	Filter specifications
Saha et al. (2013a)	OHS	Multimodal
		One dimensional
Karaboga et al. (2005)	DE	Fixed point
		One dimensional
Chandra et al. (2014)	DE	Multiplier-less
		Low-pass
		One dimensional
Mondal et al. (2012c)	DE with WM	One dimensional
Severino et al. (2015)	PSO and BA	Low pass
Saha et al. (012b)	GSA	Low pass
		One dimensional
Luitel et al. (2008)	PSO	Linear phase
	DEPSO	One dimensional
Vasundhara et al. (2013)	HRPSODE	One dimensional
Mandal et al. (2014b)	HADEPSO	Linear phase low pass
		Linear phase high passs
Mandal et al. (2014a)	ADEPSO	Linear phase, low pass
		Linear phase high passs
Yadwinder Kumar (2013)	GA	Low pass
	PSO	
	Hybrid GA-PSO	
Arun Sharma (2015)	Hybrid PSO-GSA	Low pass
	GA	
	PSO	
Aggarwal et al. (2016)	HPSOGSA	2D FIR filter
	RCGA	
	PSO	
	GSA	

particle in the universe attracts every other particle with a force that is directly proportional to the product of their masses and inversely proportional to the square of the distance between them. GSA can be considered as a collection of objects whose have masses proportional to their value of fitness function. During execution, all masses pull in one another by influence of the gravity between them. The heaviest mass has the greatest force of attraction. So the heavier masses, which are nearly closes to the global optimum attracts other masses proportional to their distances. The heavy masses, symbolizes good solutions, and hence moves more gradually than lighter ones, this is the operation of the algorithm. The design of IIR filters as well as rational nonlinear filters using GSA, GA and PSO are introduced in Rashedi et al. (2011).The results of simulations were compared and substantiated effectiveness of GSA technique.

Conventional GSA and GSA with wavelet mutation (GSAWM) based design of 8th order infinite impulse response (IIR), low pass (LP), high pass (HP), band pass (BP),and

Table 2 Summary of optimized IIR filters

Reference	Algorithm	Filter specifications
Karaboga et al. (2008)	GA	One dimensional
Xue et al. (2003)	GA	One dimensional
		Butterworth
Tang et al. (1998)	GA	Two dimensional
Mastorakis et al. (2003)	GA	Two dimensional
Kaur et al. (2013)	GA	Two dimensional
Ahmad (2008)	GA	Equalizers and filters
Ashuthosh et al. (2013)	GA	One dimensional
	PSO	One dimensional
Singh and Arya (2012)	PSO	Low-pass
		High-pass
		One dimensional
Gosh et al. (2009)	BAHS	One dimensional
Karaboga et al. (2005)	DE	One dimensional
Rashedi et al. (2011)	GSA	One dimensional
Saha et al. (2014)	GSA	One dimensional
Li (2015)	GSA With WM	One dimensional

Table 3 Summary of optimized filter banks

Reference	Algorithm	Filter specifications
Kubasek et al. (2006)	GA	Two-channel filter bank
Qiang et al. (2008a)	GA	Biorthogonal
Shark and Yu (2003a)	GA	Orthonormal
Hill et al. (2001)	GA	One dimensional
Jones et al. (2001a)	GA	Biorthogonal
Sinha and Singh (2003)	BGA	Composite wavelet matched filter

band stop (BS) filters are proposed in Li (2015), Saha et al. (2014). Extensive simulation outcomes in Li (2015), Saha et al. (2014) verify that the proposed process making use of GSA and GSAWM outperforms over GA and PSO, in terms of quality output, sharpness at cut-off, smaller ripple in pass band, higher attenuation in stop band, and additionally the fastest convergence speed with guaranteed stability.

Different optimization algorithms like RGA, PSO, DE and the GSA have been connected for the optimal design of linear phase FIR low pass digital filters in (Saha et al. 2012b). And the results of simulation demonstrate the predominance and optimization viability of the GSA over the aforementioned optimization techniques.

4.9 Digital filter design using hybrid optimization algorithms

The optimization algorithms can be hybridized to improve its performance. The hybridization process includes, the outcome of one optimization algorithm will be processed by operators of another optimization algorithm.

The hybridized algorithm of DE and PSO seems to be a hopeful tool for the design of FIR filters and which outperforms the conventional PSO based FIR filters (Luitel and Venayagamoorthy 2008). But in (Vasundhara et al. 2013) a hybridization of Radom PSO(RPSO) and DE outperforms it. DE is a basic and strong evolutionary algorithm but occasionally causes instability issue; PSO is likewise a basic, population based hearty evolutionary algorithm yet has the issue of sub-optimality. The hybridization of ADE and PSO (Mandal et al. 2014a, b) can conquer the above individual weaknesses confronted by both the algorithms and is utilized for the configuration of linear phase low pass and high pass FIR filters. A linear phase FIR and IIR low pass and high pass filters were developed using a hybridized algorithm of Adaptive differential evolution and particle swarm optimization (ADEPSO) in (Mandal et al. 2014a). The simulation results indicates that ADEPSO is more productive in effectively optimizing the filter coefficients. And gives better magnitude response and in addition the least error esteem when contrasted with other algorithms.

The numerical stability of an optimization algorithm is having critical importance in the design filter. The design examples in (Yadwinder Kumar 2013) make use of a hybridized GAPSO algorithm which performs better in comparisons to GA and PSO based design. In Arun Sharma (2015), the design of digital Low pass FIR filter is introduced utilizing hybrid PSO and GSA algorithm. PSOGSA utilizes the ability of exploration and exploitation of GSA and PSO individually. The desired filter determinations are attempted to accomplish with this algorithm and the simulation results have been contrasted with GA and MPSO based digital filters. The simulation results uncover that the proposed design strategy for FIR low pass filter utilizing PSOGSA is superior to the GA and MPSO as far as optimization of filter coefficients and additionally the rate of convergence.

Aggarwal et al. (2016) had implemented fractional derivative constraints (FDCs) for the design of 2D FIR filters with quadrantally even symmetric properties using a hybrid optimization algorithm of PSO-GSA (HPSOGSA). To show the efficiency of the proposed technique, a comparative examination has been performed with another four optimization algorithms, in particular RCGA, PSO, GSA and HPSOGSA. The results uncover that the HPSOGSA outperforms GSA, PSO and RCGA in all instances of FDCs.

The search efforts in (Moore et al. 2005b) has been improved by using improved fitness function, improved evolutionary system consists of global search using GA and local optimization using generalized pattern search algorithm (GPS) in (Peterson et al. 2006b). These evolving coefficients sets outperformed the standard DWTs in image reconstruction process in the compression.

Table 4 Summary of Evolved filters for particular application

Reference	Algorithm	Filter bank type	Application
Babb et al. (2009b)	CMA-ES	EMF	Satellite image compression
Grasemann and Miikkulainen (2005)	CoE GA	Optimized wavelet	Fingerprint image compression
Moore and Babb.(2008)	DE	EMF	Fingerprint image compression
Moore et al. (2011)	GA	EMF	Aerospace image compression
Peterson et al. (2011)	GA	EMF	Image processing (defense)
Babb and Moore.(2007)	GA	EWF	Fingerprint image compression
Babb et al. (2005)	GA	EWF	Image compression
Moore (2005a)	GA	EMF	Image compression
Moore et al. (2005a)	GA	EMF	Image compression
Moore et al. (2005b)	GA	EMF	Image compression
Moore and Marshall (2005)	GA	EMF	Image compression
Qiang et al. (2008c)	GA	Optimized wavelet	Image compression
Boukhobza et al. (2009b)	GA	Optimized filter banks	Image compression
Vaithiyanathan et al. (2014)	GA	Optimized wavelet	Image compression
Boukhobza et al. (2009b)	GA	OBFB	Image compression
Boukhobza et al. (2013c)	GA	Linear phase filter banks	Image compression
Moore et al. (2006b)	GA	Evolved filter banks	Lossy image compression
Peterson et al. (2006a)	GA	EWF	Lossy image compression
Moore et al. (2004)	GA	EWF	Lossy image compression
Babb et al. (2007)	GA	EWF	Lossy image compression
Peterson et al. (007d)	GA	EWF	Lossy image compression
Moore and Babb (2006a)	GA	EWF	Lossy image compression
Peterson et al. (2006b)	GA	EWF	Lossy image compression
Peterson et al. (2007a)	GA	EWF	Lossy image processing
Miller et al. (2011)	GA	EMF	Medical image compression
Peterson et al. (2007b)	GA	EWF	Military grade image compression
Peterson et al. (2007c)	GA	EWF	Satellite image compression
Peterson et al. (2007c)	GA	EWF	Satellite image compression
Babb et al. (2008a)	GA	EMF	Satellite image compression
Babb et al. (2008b)	GA	EMF	Satellite image compression
Ellappan et al. (2016)	GGSO	EWF	Satellite image compression
Sherlock and Monro (1996)	SA	EWF	Fingerprint image compression
Boukhobza et al. (2013a)	GA	LPOFB	Lossy image compression
Moore (2006)	GA	Evolved MRA transform	Signal compression
Moore (2005b)	GA	EWF	Signal compression
Moore (2005c)	GA	EWF	Signal processing
Marshal and Moore (2004)	GA	EWF	Signal processing
Neretti and Intrator (2002)	GBO	Optimized wavelet	Signal processing
Masoodian et al. (2012)	GA	Optimal wavelet filter bank	Biomedical signal processing
Paul et al. (2012)	GA	Evolved wavelet	ECG classification
Paul et al. (2015)	GA	Evolved wavelet	heart beat classification
Shanavaz and Mythili (2010)	GA	Evolved wavelet	Fingerprint image compression
Shanavaz and Mythili (2012)	GA	Evolved wavelet	Cropped fingerprint image compression
Shanavaz and Mythili (2013)	GA	Evolved wavelet	Cropped fingerprint image compression

5 Summary of literature

The tabular summary of all the previous works related to design of digital filters using metaheuristic optimization algorithms has been listed here in Tables 1, 2, 3 and 4. In Table 4, the development of various evolved filters such as evolved multiresolution filter banks (EMF), evolved wavelet filters (EWF), linear phase orthogonal filter banks (LPOFB), Optimized biorthogonal filter banks (OBFB) and other optimal filters, which are developed for specific application, has been summarized. The most of works listed in the literature were based on GA. But from the literature, it has been observed that the other filters based on PSO, GSA, DE, BAT and hybridized optimization algorithms were outperformed the GA based filters.

6 Conclusion

The design of digital filters is now changing from conventional mathematical design to intelligent algorithms based design. A detailed investigation in the design of various one and two dimensional digital filters have been carried out in this paper. From the literature, we can absolutely state that all the methodologies discussed in this paper and it will give optimal result when it is compared to the traditional mathematical designs. The evolutionary algorithms such as GA, and DE, and swarm intelligence algorithms such as PSO, BAT and GSA are found to be superior to other algorithms in terms of optimal result. It is also found that more enhanced results were obtained, while replacing the fundamental algorithms by hybrid or other sophisticated algorithms. This is because of enhancement in optimization algorithms will lead more accuracy. So to accomplish better performance in digital filter design, utilization of more advanced algorithms or development of better optimization algorithm by hybridizing the existing algorithms or introducing new sort of ideas is required.

References

Ababneh JI, Bataineh MH (2008) Linear phase fir filter design using particle swarm optimization and genetic algorithms. Dig Signal Process 18(4):657–668. https://doi.org/10.1016/j.dsp.2007.05.011

Aggarwal A et al (2016) Optimal design of 2d fir filters with quadrantally symmetric properties using fractional derivative constraints. Circ Syst Signal Process 1:45. https://doi.org/10.1007/s00034-016-0283-x

Aggarwal S, Gagneja A, Panghal A (2012) Design of fir filter using ga and its comparison with hamming window and parks mcclellan optimization techniques. International Journal of Advanced Research in Computer Science and Software Engineering 2(7):132–136. https://scholar.google.co.in/scholar?hl=en&as_sdt=0%2C5&q=Design+of+FIR+Filter+Using+GA+and+its+Comparison+with+Hamming+window+and+Parks+McClellan

Agrawal S, Sahu O (2015) Artificial bee colony algorithm to design two-channel quadrature mirror filter banks. Swarm Evolut Comput 21:24–31. https://doi.org/10.1016/j.swevo.2014.12.001

Ahmad SU (2008) Design of digital filters using genetic algorithms. PhD thesis, University of Victoria. http://hdl.handle.net/1828/1294

Akay B, Karaboga D (2011) Wavelet packets optimization using artificial bee colony algorithm. In: Evolutionary computation (CEC), 2011 IEEE Congress on, IEEE, pp 89–94, https://doi.org/10.1109/cec.2011.5949603

Arun Sharma RK (2015) Design of optimum linear phase low pass fir filter using hybrid pso and gsa evolutionary algorithm. Int J Technol Res Eng 2(12):3017–3020. http://ijtre.com/images/scripts/2015021221.pdf

Ashutosh P, Kasambe P (2013) Performance evaluation of evolutionary algorithms for digital filter design. Int J Sci Eng Technol 2(5):398–403. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.402.4079&rep=rep1&type=pdf

Babb B, Moore F (2007) The best fingerprint compression standard yet. In: Systems, man and cybernetics. ISIC. IEEE International Conference on, IEEE, pp 2911–2916. https://doi.org/10.1109/icsmc.2007.4414224

Babb B, Becke S, Moore F (2005) Evolving optimized matched forward and inverse transform pairs via genetic algorithms. In: Circuits and systems. 48th Midwest Symposium on IEEE, pp 1055–1058. https://doi.org/10.1109/mwscas.2005.1594286

Babb BJ, Moore FW, Marshall P (2007) Evolved multiresolution analysis transforms for improved image compression and reconstruction under quantization. In: Computational Intelligence in Image and Signal Processing, 2007. CIISP 2007. IEEE Symposium on, IEEE, pp 202–207. https://doi.org/10.1109/ciisp.2007.369318

Babb B, Moore F, Peterson M, Lamont G (2008a) Evolving better satellite image compression and reconstruction transforms. In: Proceedings of the 10th annual conference companion on Genetic and evolutionary computation, ACM, pp 1901–1906. https://doi.org/10.1145/1388969.1388997

Babb B, Moore F, Peterson M, Lamont G (2008b) Improved satellite image compression and reconstruction via genetic algorithms. In: SPIE Europe Security and Defence, International Society for Optics and Photonics, pp 711405–711405. https://doi.org/10.1117/12.799891

Babb B, Moore F, Peterson M (2009a) Optimized satellite image compression and reconstruction via evolution strategies. In: SPIE defense, security, and sensing, international society for optics and photonics. pp 73470O–73470O. https://doi.org/10.1117/12.817700

Babb BJ, Moore FW, Peterson MR (2009b) Improved multiresolution analysis transforms for satellite image compression and reconstruction using evolution strategies. In: Proceedings of the 11th Annual Conference Companion on Genetic and Evolutionary Computation Conference: Late Breaking Papers, ACM, pp 2547–2552. https://doi.org/10.1145/1570256.1570359

Beant Singh DS (2015) Craziness based particle swarm optimization algorithm for digital band pass fir filter. Int J Adv Res Comput Sci Softw Eng 5(6):1133–1139. http://ijarcsse.com/Before_August_2017/docs/papers/Volume_5/6_June2015/V5I6-0439.pdf

Bhargava A (2013) A survey report for design of fir filter with different method. Int J Sci Eng Technol Res 2(2):461. https://pdfs.semanticscholar.org/652f/614d4ec4a8f95166d57a5c3b74998328a44f.pdf

Boudjelaba K, Ros F, Chikouche D (2014) Adaptive genetic algorithm-based approach to improve the synthesis of two-dimensional finite impulse response filters. Signal Process IET 8(5):429–446. https://doi.org/10.1049/iet-spr.2013.0005

Boukhobza A, Ahmed AT, Bounoua A, Taleb N (2009a) A filter banks design using a multiobjective genetic algorithm for embedded image coding scheme. In: Image and Signal Processing and Analysis, 2009. ISPA 2009. Proceedings of 6th International Symposium on, IEEE, pp 776–781. https://doi.org/10.1109/ispa.2009.5297647

Boukhobza A, Bounoua A, Ahmed AT, Taleb N (2009b) A filter banks design using a multiobjecive genetic algorithm for an image coding scheme. In: Image Processing (ICIP), 2009 16th IEEE

International Conference on, IEEE, pp 1933–1936. https://doi.org/10.1109/icip.2009.5413533
Boukhobza A, Ahmed AT, Taleb N, Bounoua A (2013a) Optimization design of orthogonal filter banks for image coding via multi-objective genetic algorithm. Department of Electronics, UHBC University. https://projet.liris.cnrs.fr/coresa10/actes_coresa_2010/poster/133.pdf
Boukhobza A, Ahmed AT, Taleb N, Bounoua A (2013b) Optimization design of orthogonal filter banks for image coding via multi-objective genetic algorithm. Department of Electronics, UHBC University. https://projet.liris.cnrs.fr/coresa10/actes_coresa_2010/poster/133.pdf
Boukhobza A, Bounoua A, Taleb-Ahmed A, Taleb N (2013b) Design of biorthogonal filter banks using a multi-objective genetic algorithm for an image coding scheme. Circuits, Syst Signal Process 32(4):1725–1744. https://doi.org/10.1007/s00034-012-9534-7
Chandra A, Chattopadhyay S (2014) Supremacy of differential evolution algorithm in designing multiplier-less low-pass fir filter. Int J Electr Electr Sci Eng 8(2):1–10. https://waset.org/Publication/supremacy-of-differential-evolution-algorithm-in-designing-multiplier-less-low-pass-fir-filter/9997723
Dey AK, Saha S, Saha A, Ghosh S (2010) A method of genetic algorithm (ga) for fir filter construction: design and development with newer approaches in neural network platform. Int J Adv Comput Sci Appl 1(6):87–90. https://doi.org/10.14569/ijacsa.2010.010614
Ellappan V, Samson Ravindran R (2016) Optimal filter design of wavelet transform to an adaptive medical image compression technique using genetic group search optimizer. J Med Imaging Health Inf 6(2):484–493. https://doi.org/10.1166/jmihi.2016.1708
Er Karamjeet Singh GK (2014) Evolutionary approach for filter design: a review. Int J Adv Res Comput Sci Softw Eng 4(6):160–162. http://ijarcsse.com/Before_August_2017/docs/papers/Volume_4/6_June2014/V4I6-0147.pdf
Fang W, Sun J, Xu W, Liu J (2006) Fir digital filters design based on quantum-behaved particle swarm optimization. In: Proceedings of the first international conference on innovative computing, information and control-volume 1, IEEE Computer Society, pp 615–619. https://doi.org/10.1109/icicic.2006.77
Gentili P, Piazza F, Uncini A (1995) Efficient genetic algorithm design for power-of-two fir filters. In: Acoustics, speech, and signal processing, 1995. ICASSP-95., 1995 International Conference on, IEEE, vol 2, pp 1268–1271. https://doi.org/10.1109/icassp.1995.480470
Ghosh S, Kundu D, Suresh K, Das S, Abraham A (2009) Design of optimal digital iir filters by using a bandwidth adaptive harmony search algorithm. In: Nature and biologically inspired computing, 2009. NaBIC 2009. World Congress on, IEEE, pp 481–486. https://doi.org/10.1109/nabic.2009.5393362
Grasemann U, Miikkulainen R (2004) Evolving wavelets using a coevolutionary genetic algorithm and lifting. In: Genetic and evolutionary computation—GECCO. Springer, pp 969–980, https://doi.org/10.1007/978-3-540-24855-2109
Grasemann U, Miikkulainen R (2005) Effective image compression using evolved wavelets. In: Proceedings of the 7th annual conference on Genetic and evolutionary computation, ACM, pp 1961–1968. https://doi.org/10.1145/1068009.1068338
Han J, Zhao X, Qiu C (2016) A digital image watermarking method based on host image analysis and genetic algorithm. J Ambient Intell Hum Comput 7(1):37–45. https://doi.org/10.1007/s12652-015-0298-3
Hill Y, OKeefe S, Thiel D (2001) An investigation of wavelet design using genetic algorithms. In: Microelectronic Engeneering Research Conference, URL https://maxwell.ict.griffith.edu.au/school/merc/Hill.pdf
Jones E, Runkle P, Dasgupta N, Couchman L, Carin L (2001a) Genetic algorithm wavelet design for signal classification. IEEE Trans Pattern Anal Mach Intell 8:890–895. https://doi.org/10.1109/34.946991
Jones E, Runkle P, Dasgupta N, Couchman L, Carin L (2001b) Genetic algorithm wavelet design for signal classification. IEEE Trans Pattern Anal Mach Intell 23(8):890–895. https://doi.org/10.1109/34.946991
Karabo˘ga N, C¸etinkaya B (2003) Optimal design of minimum phase digital fir filters by using genetic algorithm. In: 3rd International Conference on Electrical and Electronics Engineering, pp 176–179, URL http://emo.org.tr/ekler/cf9d6bd14a20958_ek.pdf
Karabo˘ga N, C¸etinkaya B (2005) Efficient design of fixed point digital fir filters by using differential evolution algorithm. In: Computational intelligence and bioinspired systems. Springer, pp 812–819. https://doi.org/10.1007/11494669 99
Karaboga N (2005) Digital iir filter design using differential evolution algorithm. EURASIP J Appl Signal Process 2005:1269–1276. https://doi.org/10.1155/asp.2005.1269
Karaboga N (2009) A new design method based on artificial bee colony algorithm for digital iir filters. J Franklin Inst 346(4):328–348. https://doi.org/10.1016/j.jfranklin.2008.11.003
Karaboga N, Cetinkaya B (2008) design of minimum phase digital llr filters by using genetic algorithm. Engineering intelligent systems for electrical engineering and communications 16(1):61–68. https://scholar.google.co.in/scholar?hl=en&as_sdt=0%2C5&q=Design+of+minimum+phase+digital+lIR+filters+by+using+genetic+algorithm&btnG=
Kashihara K (2013) Automatic design of a novel image filter based on the ga-em algorithm for vein shapes. In: Systems, man, and cybernetics (SMC), 2013 IEEE International Conference on, IEEE, pp 3897–3902. https://doi.org/10.1109/smc.2013.665
Kaur P, Kaur S (2012) Optimization of fir filters design using genetic algorithm. Int J Emerging Trends Technol Comput Sci (IJETTSC) 1(3):228–232. https://scholar.google.co.in/scholar?hl=en&as_sdt=0%2C5&q=Optimization+of+FIR+Filters+Design+using+Genetic+Algorithm&btnG=
Kaur R, Patterh MS, Dhillon J (2013) Digital iir filter design using real coded genetic algorithm. Int J Inf Technol Comput Sci (IJITCS) 5(7):27. https://doi.org/10.5815/ijitcs.2013.07.03
Kubasek R, Smekal Z, Gescheidtova E, Bartusek K (2006) Design of two-channel half-band bank of digital filters using optimization methods. In: Networking, International Conference on Systems and International Conference on Mobile Communications and Learning Technologies, 2006. ICN/ICONS/MCL 2006. International Conference on, IEEE, pp 151–151. https://doi.org/10.1109/icniconsmcl.2006.75
Kumar M, Rawat TK (2015) Optimal fractional delay-iir filter design using cuckoo search algorithm. ISA Trans 59:39–54. https://doi.org/10.1016/j.isatra.2015.08.007
Kumar PU, Sarma GK, Das SM, Kamalnath M (2013) Design of optimal digital fir filter using particle swarm optimization algorithm. In: Advances in computational science, engineering and information technology. Springer, pp 187–196. https://doi.org/10.1007/978-3-319-00951-319
Lee A, Ahmadi M, Jullien G, Miller W, Lashkari R (1998) Digital filter design using genetic algorithm. In: Advances in digital filtering and signal processing, 1998 IEEE Symposium on, IEEE, pp 34–38. https://doi.org/10.1109/adfsp.1998.685690
Li D (2015) Design of two-dimensional recursive iir filters using cooperative quantum particle swarm optimization with dynamic varying search area and l´evy flights. J Comput Theor Nanosci 12(9):2678–2686. https://doi.org/10.1166/jctn.2015.4162
Li X, Wang G (2015) Optimal band selection for hyperspectral data with improved differential evolution. J Ambient Intell Hum Comput 6(5):675–688. https://doi.org/10.1007/s12652-015-0285-8
Liu G, Li Y, He G (2010) Design of digital fir filters using differential evolution algorithm based on reserved genes. In: IEEE

congress on evolutionary computation, IEEE, pp 1–7. https://doi.org/10.1109/cec.2010.5586425
Luitel B, Venayagamoorthy GK (2008) Differential evolution particle swarm optimization for digital filter design. In: Evolutionary computation, 2008. CEC 2008. (IEEE World Congress on Computational Intelligence). IEEE Congress on, IEEE. pp 3954–3961. https://doi.org/10.1109/cec.2008.4631335
Mandal S, Kar R, Mandal D, Ghoshal SP (2011) Swarm intelligence based optimal linear phase fir high pass filter design using particle swarm optimization with constriction factor and inertia weight approach. World Academy of Science, Engineering and Technology, International Journal of Electrical, Computer, Energetic, Electronic and Communication Engineering 5(8):1111–1116. https://www.idc-online.com/technical_references/pdfs/electrical_engineering/Swarm%20Intelligence.pdf
Mandal S, Ghoshal SP, Kar R, Mandal D (2012a) Design of optimal linear phase fir high pass filter using craziness based particle swarm optimization technique. J King Saud Univ Comput Inf Sci 24(1):83–92. https://doi.org/10.1016/j.jksuci.2011.10.007
Mandal S, Mallick P, Mandal D, Kar R, Ghoshal SP (2012b) Optimal fir band pass filter design using novel particle swarm optimization algorithm. In: Humanities, Science and Engineering Research (SHUSER), 2012 IEEE Symposium on, IEEE, pp 141–146. https://doi.org/10.1109/shuser.2012. 6268827
Mandal D, Kar R, Ghoshal SP (2014) Digital fir filter design using fitness based hybrid adaptive differential evolution with particle swarm optimization. Nat Comput 13(1):55. https://doi.org/10.1007/s11047-013-9381-x
Marshal P, Moore F (2004) Evolving novel coefficient sets for optimized reconstruction of quantized one-dimensional (1-d) and two-dimensional (2-d) signals. 2004 visiting faculty research program (vfrp) in-house work at afrl/ifta. Tech. rep., DTIC Document. https://doi.org/10.21236/ada435968
Masoodian S, Bazrafshan A, Mashhadi HR (2012) Biomedical signal denoising by adaptive wavelet design using genetic algorithms. In: Electrical engineering (ICEE), 2012 20th Iranian Conference on, IEEE, pp 1590–1593. https://doi.org/10.1109/iraniancee.2012.6292614
Mastorakis NE, Gonos IF, Swamy M (2003) Design of two-dimensional recursive filters using genetic algorithms. IEEE Trans Circ Syst I Fund Theory Appl 50(5):634–639. https://doi.org/10.1109/tcsi.2003.811019
Miller C, Moore F, Babb B, Peterson MR (2011) Improved reconstruction of quantized ct scans via genetic algorithms. In: Evolutionary Computation (CEC), 2011 IEEE Congress on, IEEE, pp 2293–2299. https://doi.org/10.1109/cec.2011.5949900
Mitiche L, Adamou-Mitiche ABH (2014) An efficient low order model for two-dimensional digital systems: application to the 2d digital filters. J King Saud University-Comput Inf Sci 26(3):308–318. https://doi.org/10.1016/j.jksuci.2014.03.003
Mitiche L, Adamou-Mitiche ABH, Kacem O, Sima V (2012) Model reduction of 2-d iir filters. J Signal Inf Process 3(04):438. https://doi.org/10.4236/jsip.2012.34057
Mondal S, Vasundhara RK, Mandal D, Ghoshal S (2011) Linear phase high pass fir filter design using improved particle swarm optimization. World Acad Sci Eng Technol 60:1620–1627. https://doi.org/10.1109/scored.2011.6148765
Mondal S, Chakraborty D, Kar R, Mandal D, Ghoshal SP (2012a) Novel particle swarm optimization for high pass fir filter design. In: Humanities, Science and Engineering Research (SHUSER), 2012 IEEE Symposium on, IEEE, pp 413–418. https://doi.org/10.1109/shuser.2012.6268874
Mondal S, Ghoshal S, Kar R, Mandal D (2012b) Novel particle swarm optimization for low pass fir filter design. WSEAS Trans Signal Process 3:111–120. https://doi.org/10.1109/shuser.2012.6268874
Mondal S, Ghoshal SP, Kar R, Mandal D (2012c) Differential evolution with wavelet mutation in digital finite impulse response filter design. J Optim Theory Appl 155(1):315–324. https://doi.org/10.1007/s10957-012-0028-3
Moore F (2005a) Evolved multiresolution transforms for optimized image compression and reconstruction under quantization. Tech. rep., DTIC document. https://apps.dtic.mil/dtic/tr/fulltext/u2/a451265.pdf
Moore FW (2005b) A genetic algorithm for optimized reconstruction of quantized one-dimensional signals. In: Proceedings of the 7th annual conference on Genetic and evolutionary computation, ACM, pp 1599–1600. https://doi.org/10.1145/1068009.1068278
Moore FW (2005c) A genetic algorithm for optimized reconstruction of quantized signals. In: Evolutionary Computation, 2005. The 2005 IEEE Congress on, IEEE, vol 1, pp 105–111. https://doi.org/10.1109/cec.2005.1554673
Moore FW (2006) Evolved transforms for signal compression and reconstruction under quantization. In: Defense and security symposium, international society for optics and photonics, pp 62280T–62280T. https://doi.org/10.1117/12.668380
Moore F, Babb B (2006a) Revolutionary image compression and reconstruction via evolutionary computation, part 2: multiresolution analysis transforms. WSEAS Trans Signal Process 2(9):1209–1214. https://pdfs.semanticscholar.org/27e9/bcaf376ff26a1b179101465f662c776bdb30.pdf
Moore FW, Babb BJ (2006b) Evolved transforms for improved image compression and reconstruction under quantization. In: Proceedings of the 6th WSEAS International Conference on Signal, Speech and Image Processing, Citeseer, pp 127–134. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.590.2636&rep=rep1&type=pdf
Moore FW, Babb B (2008) A differential evolution algorithm for optimizing signal compression and reconstruction transforms. In: Proceedings of the 10th annual conference companion on Genetic and evolutionary computation, ACM, pp 1907–1912. https://doi.org/10.1145/1388969.1388998
Moore F, Marshall P (2005) Evolving next generation signal compression and reconstruction transforms via genetic algorithms. In: Proceedings of the 7th annual workshop on Genetic and evolutionary computation, ACM, pp 190–192. https://doi.org/10.1145/1102256.1102302
Moore F, Marshall P, Balster E (2004) Adaptive filtering in the wavelet transform domain via genetic algorithms. Tech. rep., DTIC Document. https://doi.org/10.21236/ada427113
Moore F, Babb B, Becke S, Koyuk H, Lamson III E, Wedge C (2005a) Genetic algorithms evolve optimized transforms for signal processing applications. Tech. rep., DTIC Document. https://doi.org/10.21236/ada437529
Moore F, Marshall P, Balster E (2005b) Evolved transforms for image reconstruction. In: Evolutionary Computation, 2005. The 2005 IEEE Congress on, IEEE, vol 3, pp 2310–2316. https://doi.org/10.1109/cec.2005.1554982
Moore F, Babb B, Aldridge S, Peterson MR (2011) Evolving matched forward and inverse transforms for improved lossy compression of images from mars. In: Systems, Man, and Cybernetics (SMC), 2011 IEEE International Conference on, IEEE, pp 484–489. https://doi.org/10.1109/icsmc.2011.6083712
Mukhopadhyay A, Kar R, Mandal D, Mandal S, Ghoshal S (2012) Optimal design of linear phase fir band stop filter using particle swarm optimization with improved inertia weight technique. In: Computer Science and Software Engineering (JCSSE), 2012 International Joint Conference on, IEEE, pp 168–173. https://doi.org/10.1109/jcsse.2012.6261946
Neretti N, Intrator N (2002) An adaptive approach to wavelet filters design. In: Neural Networks for Signal Processing, 2002.

Proceedings of the 2002 12th IEEE Workshop on, IEEE, pp 317–326. https://doi.org/10.1109/nnsp.2002.1030043
Nidhi Mishra NJ (2015) Literature review on fir filter optimization. International Journal of Digital Application & Contemporary Research 4(1). https://pdfs.semanticscholar.org/33ca/d37bf96053d1510f2927891721d3166f51ab.pdf
Nirmala P (2015) Optimization of image denoising filters using harmony search—an experimental analysis. Middle-East J Sci Res 23:305–308. https://doi.org/10.5829/idosi.mejsr.2015.23.ssps.113
Oner M (1998) A genetic algorithm for optimisation of linear phase fir filter coefficients. In: Signals, systems & computers, 1998. Conference Record of the Thirty-Second Asilomar Conference on, IEEE, vol 2, pp 1397–1400. https://doi.org/10.1109/acssc.1998.751556
Paul B, Shanavaz K, Mythili P (2012) Towards the development of a new wavelet for ecg classification. In: Power, signals, controls and computation (EPSCICON), 2012 International Conference on, IEEE, pp 1–5. https://doi.org/10.1109/epscicon.2012.6175283
Paul B, Shanavaz K, Mythili P (2015) A new optimized wavelet transform for heart beat classification. J Mech Med Biol 15(05):1550081. https://doi.org/10.1142/s0219519415500815
Peterson M, Lamont G, Moore F (2006a) Evaluating mutation operators for evolved image reconstruction transforms. In: Proceedings of the eighth annual genetic and evolutionary computation conference (GECCO2006), vol 7, pp 08–12. http://www.cs.bham.ac.uk/~wbl/biblio/gecco2006etc/papers/wksp132.pdf
Peterson MR, Lamont GB, Moore F (2006b) Improved evolutionary search for image reconstruction transforms. In: Evolutionary Computation, 2006. CEC 2006. IEEE Congress on, IEEE, pp 2880–2887. https://doi.org/10.1109/cec.2006.1688671
Peterson MR, Lamont GB, Moore F, Babb B (2007a) Variation operator performance for evolved image reconstruction transforms. In: Systems, Man and Cybernetics, 2007. ISIC. IEEE International Conference on, IEEE, pp 2917–2922. https://doi.org/10.1109/icsmc.2007.4414225
Peterson MR, Lamont GB, Moore F, Marshall P (2007b) Evolving military-grade image transforms using state-of-the-art variation operators. In: Defense and security symposium, international society for optics and photonics, pp 65630H–65630H. https://doi.org/10.1117/12.720920
Peterson MR, Lamont GB, Moore F, Marshall P (2007c) A satellite image set for the evolution of image transforms for defense applications. In: Proceedings of the 9th annual conference companion on Genetic and evolutionary computation, ACM, pp 2901–2906. https://doi.org/10.1145/1274000.1274031
Peterson MR, Lamont GB, Moore F, Marshall P (2007d) Targeted filter evolution for improved image reconstruction resolution. In: Proceedings of the 9th annual conference on genetic and evolutionary computation, ACM, pp 2137–2144. https://doi.org/10.1145/1276958.1277371
Peterson MR, Horner T, Moore F (2011) Evolving matched filter transform pairs for satellite image processing. In: SPIE defense, security, and sensing, international society for optics and photonics, pp 80590L–80590L. https://doi.org/10.1117/12.884312
Proakis J, Manolakis D (2007) Digital signal processing. Prentice Hall international editions. Pearson Prentice Hall, Upper Saddle River. https://doi.org/10.1093/med/9780190259631.003.0015
Qiang L, Li L, Qingli R, Hongjun H (2008a) Optimization design of biorthogonal filter banks for image compressing. In: Information science and engineering, 2008. ISISE'08. International Symposium on, IEEE, vol 2, pp 539–543. https://doi.org/10.1109/isise.2008.336
Qiang L, Li L, Qingli R, Hongjun H (2008b) Optimization design of biorthogonal filter banks for image compressing. In: Information science and engineering, 2008. ISISE'08. International Symposium on, IEEE, vol 2, pp 539–543. https://doi.org/10.1109/isise.2008.336
Qiang L, Li L, Qingli R, Hongjun H (2008c) Optimization design of biorthogonal filter banks for image compressing. In: Information science and engineering, 2008. ISISE'08. International Symposium on, IEEE, vol 2, pp 539–543. https://doi.org/10.1109/isise.2008.336
Raaed Faleh Hassan ASA (2013) Design of finite impulse response filters based on genetic algorithm. Diyala J Eng Sci 06(03):28–39. https://www.iasj.net/iasj?func=article&aId=82500
Rashedi E, Nezamabadi-Pour H, Saryazdi S (2011) Filter modeling using gravitational search algorithm. Eng Appl Artif Intell 24(1):117–122. https://doi.org/10.1016/j.engappai.2010.05.007
S Jayaraman SE, Veerakumar T (2011) Digital Image Processing. Tata McGraw-Hill Education Sabbir U, Antoniou A (2006) Design of digital filters using genetic algorithms. In: 6th IEEE international symposium on signal processing and information technology. https://pdfs.semanticscholar.org/4bca/88151efa276f4093c8167179b65bc7101cbb.pdf
Saha SK, et. al. (2012b) Gravitational search algorithm in digital fir low pass filter design. In: Emerging Applications of Information Technology (EAIT),2012 Third International Conference on, IEEE, pp 52–55. https://doi.org/10.1109/eait.2012.6407860
Saha SK, et. al (2013b) Adaptive particle swarm optimization for low pass finite impulse response filter design. In: Communications and signal processing (ICCSP), 2013 International Conference on, IEEE, pp 19–23. https://doi.org/10.1109/iccsp.2013.6577006
Saha SK, Kar R, Mandai T, Kumar N, Ghoshal SP (2012a) Optimal linear phase fir high pass filter design using psocfiwa-wm. In: Information and Communication Technologies (WICT), 2012 World Congress on, IEEE, pp 768–773. https://doi.org/10.1109/wict.2012.6409178
Saha S et al (2013) Efficient and accurate optimal linear phase fir filter design using opposition-based harmony search algorithm. Sci World J. https://doi.org/10.1155/2013/320489
Saha SK et al (2014) Gravitation search algorithm: application to the optimal iir filter design. J King Saud Univ Eng Sci 26(1):69–81. https://doi.org/10.1016/j.jksues.2012.12.003
Salvador et. al. (2010) Evolutionary design and optimization of wavelet transforms for image compression in embedded systems. In: Adaptive hardware and systems (AHS), 2010 NASA/ESA Conference on, IEEE, pp 171–178. https://doi.org/10.1109/ahs.2010.5546265
Salvador R, Moreno F, Riesgo T, Sekanina L (2011) Evolutionary approach to improve wavelet transforms for image compression in embedded systems. EURASIP J Adv Signal Process 1:973806. https://doi.org/10.1155/2011/973806
Severino AG, Linhares LL, de Araujo FM (2015) Optimal design of digital low pass finite impulse response filter using particle swarm optimization and bat algorithm. In: Informatics in control, automation and robotics (ICINCO), 2015 12th International Conference on, IEEE, vol 1, pp 207–214. https://doi.org/10.5220/0005545902070214
Shaheen AM, Sheltami TR, Al-Kharoubi TM, Shakshuki E (2018) Digital image encryption techniques for wireless sensor networks using image transformation methods: Dct and dwt. J Ambient Intell Hum Comput, pp 1–18. https://doi.org/10.1007/s12652-018-0850-z
Shanavaz K, Mythili P (2010) An improved technique for evolving wavelet coefficients for fingerprint image compression. In: Communication Control and Computing Technologies (ICCCCT), 2010 IEEE International Conference on, IEEE, pp 665–669. https://doi.org/10.1109/iccccct.2010.5670756
Shanavaz K, Mythili P (2012) Evolution of better wavelet coefficients for fingerprint image compression using cropped images. In: Advances in computing and communications (ICACC), 2012

International Conference on, IEEE, pp 126–129. https://doi.org/10.1109/icacc.2012.28
Shanavaz K, Mythili P (2013) Faster techniques to evolve wavelet coefficients for better fingerprint image compression. Int J Electr 100(5):655–668. https://doi.org/10.1080/00207217.2012.720944
Shark LK, Yu C (2003) Design of optimal shift-invariant orthonormal wavelet filter banks via genetic algorithm. Signal Process 83(12):2579–2591. https://doi.org/10.1016/j.sigpro.2003.07.001
Sherlock BG, Monro DM (1996) Optimized wavelets for fingerprint compression. In: Acoustics, speech, and signal processing, 1996. ICASSP-96. Conference Proceedings. IEEE International Conference on, IEEE, vol 3, pp 1447–1450. https://doi.org/10.1109/icassp.1996.543934
Shirvani A, Khezri K, Razzazi F, Caro L (2009) Designing linear phase fir filters with particle swarm optimization and harmony search. In: Signal processing, image processing and pattern recognition. Springer, pp 193–200. https://doi.org/10.1007/978-3-642-10546-3 24
Singh AP (2014) Design of linear phase low pass fir filter using particle swarm optimization algorithm. Int J Comput Appl 98(3):40–44. https://doi.org/10.5120/17166-7229
Singh R, Arya SK (2012) Optimization of iir digital filters using particle swarm optimization. In: Proceedings of the international conference on communication, information & computing technology (ICCICT), IEEE, pp 1–7. https://doi.org/10.1109/iccict.2012.6398172
Singh A, Grewal NS (2014) Review on fir filter designing by implementations of different optimization algorithms. Int J Adv Inf Sci Technol 31(31):171–175. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.677.4505&rep=rep1&type=pdf
Singh T, Josan HS (2014) Design of low pass digital fir filter using cuckoo search algorithm. Int J Eng Res Appl 4(8):72–77
Sinha A, Singh K (2003) Design of a composite wavelet matched filter using breeder genetic algorithm. Optical review 10(4):251–254. https://doi.org/10.1007/s10043-003-0251-0
Su S, Zhao S (2017) A hierarchical hybrid of genetic algorithm and particle swarm optimization for distributed clustering in large-scale wireless sensor networks. J Ambient Intell Hum Comput. https://doi.org/10.1007/s12652-017-0619-9
Sundhari RM, Anita DR (2015) An optimized fir filter design using particle swarm optimization. Aust J Basic Appl Sci 9(20):11–19. http://www.ajbasweb.com/old/ajbas/2015/June/11-19.pdf
Tang KS, Man KF, Kwong S, Liu ZF (1998) Design and optimization of iir filter structure using hierarchical genetic algorithms. Ind Electr IEEE Trans 45(3):481–487. https://doi.org/10.1109/41.679006
Tzeng S (1998) Design of multi-bandpass fir digital filters by genetic algorithm approach. Department of Electronic Engineering, Kaoyuan Institute of Technology. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.565.9408&rep=rep1&type=pdf
Vaithiyanathan D, Seshasayanan R, Kunaraj K, Keerthiga J (2014) An evolved wavelet library based on genetic algorithm. Sci World J. https://doi.org/10.1155/2014/494319
Vasundhara Mandal D, Ghoshal SP, Kar R (2013) Digital fir filter design using hybrid random particle swarm optimization with differential evolution. Int J Comput Intell Syst 6(5):911–927. https://doi.org/10.1080/18756891.2013.808427
Wan C, Yuan X, Dai X, Zhang T, He Q (2018) A self-adaptive multi-objective harmony search based fuzzy clustering technique for image segmentation. J Ambient Intell Hum Comput. https://doi.org/10.1007/s12652-018-0762-y
Xue L, Rongchun Z, Qing W (2003) Optimizing the design of iir filter via genetic algorithm. In: Neural Networks and Signal Processing, 2003. Proceedings of the 2003 International Conference on, IEEE, vol 1, pp 476–479. https://doi.org/10.1109/icnnsp.2003.1279314
Yadwinder Kumar E (2013) Design of optimum digital fir low pass filter using hybrid of ga & pso optimization. International Journal of Advanced Research in Computer Science and Software Engineering 3(9):685–692. https://pdfs.semanticscholar.org/115a/b3aa4915185549dcb488a432934bc6e9602a.pdf
Zhao Ax, Tang Xj, Zhang Zh, Liu Jh (2014) The optimal design method of fir filter using the improved genetic algorithm. In: Industrial Electronics and Applications (ICIEA), 2014 IEEE 9th Conference on, IEEE, pp 452–455. https://doi.org/10.1109/iciea.2014.6931206
Zhao Z, Gao H (2009) Fir digital filters based on cultural particle swarm optimization. In: Proc. 2009 International Workshop on Iriformation Security and Application (IWISA 2009), Qingdao, China, Citeseer, pp 252–255. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.403.9230&rep=rep1&type=pdf#page=270
Zhao Z, Gao H, Liu Y (2011) Chaotic particle swarm optimization for fir filter design. In: Electrical and Control Engineering (ICECE), International Conference on, IEEE, pp 2058–2061. https://doi.org/10.1109/iceceng.2011.6057672

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