Efficient Design of Band pass Filter using Quantum Inspired Salp Swarm Algorithm

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ABSTRACT

This project presents the optimal design of digital FIR and IIR filters using evolutionary optimization methods. Some evolutionary optimization methods named as Salp Swarm Algorithm (SSA),Quantum inspired Salp Swarm Algorithm (QSSA), are discussed in this thesis work and have been used for the optimal design of Type-1 digital band pass FIR filters. In order to show the comparative effectiveness of the proposed algorithms, the simulation results have been compared with the already existing well established results. Further to demonstrate the efficacy of the proposed methods, these have been implemented via Simulink models in MATLAB.

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INTRODUCTION

1.1 Preamble

Filtering is the commonly used method in different signal processing applications. In the field of electronics, filters refer to the electronic devices that receiving input signals that allows only the required elements within a certain range of frequencies to transmit and attenuate the rest. Electronic filters have been categorized in the literature which is based on various criteria. Depending upon the type of components filters are classified as active and passive filters. Based on the characteristics of the impulse response, filters are categorized as Finite Impulse Response (FIR) or Infinite Impulse Response (IIR). Unlike IIR, FIR filters are non-recursive and the output due to impulse input fades away within a limited amount of time. FIR filters offer linear phase and greater stability and that is why it is highly preferred over IIR filters in many engineering applications [1-4].

There are also two classifications of filtering operation, depending on the nature of filters that can be categorized as analogue and digital. Digital filter circuits sample the analogue input signal and convert the sampled signal into a set of binary numbers, store the numbers in a memory and process them through a processing unit. The digital filters perform the frequency related operations such as low-pass, high-pass, band-reject, band-pass, and all-pass etc.. Also, the design specifications include cut-off frequency, sampling frequency of input signal, pass-band ripple, stop-band attenuation, type of filter and realization form etc..

Section 1.2 of this chapter presents literature survey in the field of optimization techniques. Section 1.3 reveals the motivation behind taking up this work and thesis organization.

1.2 Literature Survey

The primary objective of using meta-heuristic optimization algorithms in digital filter design is reducing the error between the ideal response and the approximated response known as (cost function) as much as possible. The benefits for developments of meta-heuristic algorithms are to eliminate the requirements of the conventional gradient-based design processes those are described below with some literature survey. Algorithms like Simulated Annealing [4], Genetic Algorithm [5-6], Artificial Bee Colony [7-11], Particle Swarm Optimization [12-20], Cuckoo Search

[21-24], Gravitational Search [25-29] etc. are significant innovations in the optimization paradigm.

In 2016, Mirjalili developed a new population based meta-heuristic optimization technique called Salp swarm Algorithm (SSA) for solving various kinds of optimization problems [30]. Since then several variants have been efficiently used for solving practical optimization problems like binary Salp swarm algorithm [31]. Apart from these SSA is employed on critical block path by reducing the manufacturing period for re-entrant job shop scheduling problem which is alternatively known as classical Non-deterministic Polynomial-time complete combinatorial optimization method [32]. Another proposed model on segmentation is applied for fish images by utilizing SSA technique [33]. Here, the actual segmentation component is constructed using Simple Linear Iterative Clustering structure with existing parameters, in order to find out the best optimal solution using Salp Swarm Optimization algorithm. Besides all these, SSA have been hybridized with different kinds of algorithms in order to develop newer, better and faster algorithms such as SSA with Particle Swarm Optimization [34] and SSA with Differential Evolution [35]. Most of these algorithms may not provide accurate results but give approximate and quite satisfactory solutions.

1.3 Thesis Motivation

Digital FIR filters have never been designed using Salp Swarm Algorithm (SSA), which was recently developed. As this work was initiated for optimizing the design of FIR filters on MATLAB using SSA, it was observed that the performance of this algorithm gives less satisfactory performances for lower order filter as well for higher order filter as the output filter response had higher amount of pass-band ripples and lower amount of stop-band attenuation. It is considered that the conventional SSA algorithm is less efficient for design of FIR filters. Hence, this matter motivated us to improve the performance of SSA in terms of FIR filter design. In order to achieve this goal, a new algorithm has been proposed in order to quantize the SSA algorithm with the laws of Quantum mechanics [36-37]. Moreover, we showed some supporting data and figures which are clearly figured out that FIR filters can be designed efficiently by using new proposed algorithm technique.

The complete organization of this Thesis is described below:

Chapter 2 describes the design of FIR filter using SSA with respect to scheme and modelling of FIR band-pass filters using fast and efficient optimization techniques. Also a new Quantum Inspired Salp Swarm algorithm (QSSA) is proposed for better performance of Type-1 BP FIR filter.

Chapter 3 describes the simulation results performance and also some comparison between QSSA and conventional SSA for designing of FIR filter which demonstrates and evaluates in this chapter.

Chapter 4 concludes the thesis with some possible future works.

CHAPTER 2

DESIGN OF FIR FILTER USING SALP SWARM ALGORITHM

DESIGN OF FIR FILTER USING SALP SWARM ALGORITHM

2.1 Introduction

In this chapter there are brief discussions on basics of filters and its applications on practical field as well as optimization techniques. Apart from this we are classified some others filter like Analog/Digital Filters Active/Passive Filters FIR/IIR Filters Linear/Nonlinear Filters. Also the performance of basic theory of Type-1 Band Pass FIR Filtersis compulsory tointerpret how digital filters are designed and used in practical field of applications.The main aspects of this chapter are to showing Problem formulation for FIR Filter and how the Band pass FIR Filter is designed by the conventional Salp Swarm Algorithm.

Band-pass (BP) filter is another category of filters based upon the domain or band of frequencies that are allowed to pass through by the filter. It passes frequencies within a particular range and attenuates the rest. An ideal BP filter response would have perfectly flat pass band without any ripple and would absolutely attenuate all the frequency components outside the pass band. Moreover, the transitionof the filter would be instantaneous in between the pass band and the stop band frequencies i.e., the transition width would be zero.

In this Chapter named Design of FIR Filter Using Salp Swarm Algorithm organized as follows: Section 2.2 of this chapter presents a basics description of FIR filter. In Section 2.3 gives details the problem formulation of FIR filter and in Section 2.4 there is brief description of conventional SSA is given. In Section 2.3, a new and better version of SSA named as Quantum Inspired Salp Swarm Algorithm (QSSA) has been proposed. The pseudo code and flowchart of the algorithm have been given in the same section.

2.2 Basics of FIR Filters

Finite Impulse Response (FIR) filter is a category of filters based upon characteristics of the impulse response of the filters. The impulse response of FIR filters becomes zero in a finite duration of time. FIR filter structure is efficient in terms of digitally implementing frequency response. FIR filters are usually implemented using delays, adders, and multipliers [38-39]. FIR filters are also called as ‘Feed-forward’, ‘Non-recursive’ or ‘Transversal’ filters.

The difference equation representation of FIR Filter is

$$y(n) = h(0)x(n) + h(1)x(n-1) + \ldots + h(N)x(n-N) \tag{2.1}$$

Where N = order of the filter

$N+1$= No. of the coefficients

$$H(z) = h(0) + h(1)z^{-1} + \ldots + h(N)z^{-N} \tag{2.2}$$

$$H(z) = \sum_{n=0}^{N} h(n)z^{-n} \tag{2.3}$$

where $h(n)$ is the impulse response.

$x(n)$ is the input signal and $y(n)$ is the output signal.

Figure 2.1 shows the basic block diagram of FIR filter of order N .

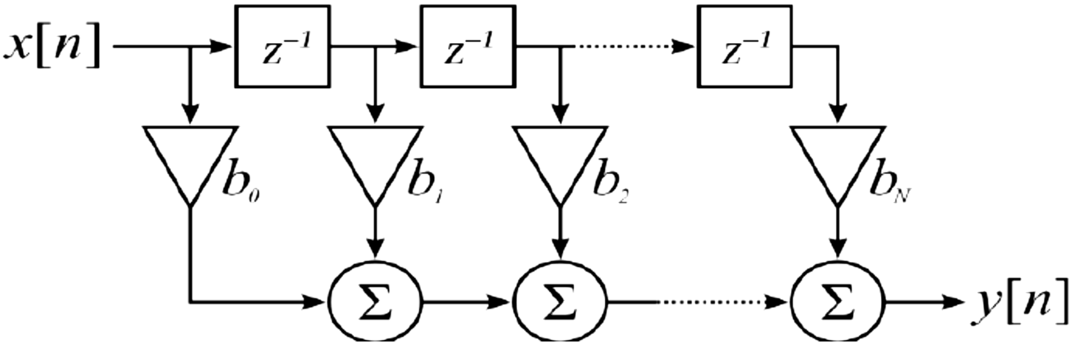

Fig. 2.1 Block Diagram of a FIR Filter.

2.2.1 Characteristics of FIR Filter

a. FIR Filter requires no feedback.
b. FIR filters are extensively used for tapping of higher order filters.
c. FIR filters are inherently stable.
d. FIR Filters delay characteristic is much better but more memory is required.

e. Pass band Edge Frequency- It defines the starting of the pass band i.e. the region where the signal is completely passed without any attenuation.
f. Stop band Edge Frequency- It defines the starting of the stop band region i.e. the region where the signal is completely attenuated or blocked, not allowed passing. The stop band frequency (F_S) is the frequency at which the minimum attenuation in the stop band is reached.

g. Ripple-Ripple is usually specified as a peak -to-peak level in decibels. It describes how little or how much the filter's amplitude varies within a band. Smaller amount of ripple represent more compatible response. Ripple in pass band should be as low as possible.

h. Bandwidth – Bandwidth is defined as the frequency width of the pass band of a filter. For a low pass filter, the bandwidth is equal to the cut-off frequency. For a band pass filter, the bandwidth is typically defined as the frequency comparisons between the upper band and lower band at -3 dB points.

i. Frequency Magnitude Response - A frequency domain description of how a filter interacts with input signals. The frequency magnitude response is a curve of filter attenuation (in dB) vs. frequency.

j. Transition Region - The frequency range between the pass band and the stop band of a digital filter. Transition region is sometimes called the transition band.

2.3 Problem Formulation for FIR Filter

The system function of FIR filter is represented by [40]:

$$H(z)=\sum_{n=0}^{M-1} h(n)z^{-n} \quad n=0,1,\ldots,M-1 \tag{2.4}$$

which consists of $(M-1)$ poles at origin and $(M-1)$ zeroes. Based on the coefficients of $h(n)$ a filter can exhibit different type of magnitude responses.

2.3.1 Error Function Representation

In reality, by changing degrees of favourable outcomes and minimizing the deviation of the designed magnitude response from the ideal, the desired filter is achieved. The weighted difference in stop-band and pass-band primarily defines the error function as given in [40]:

$$E(\omega)=W(\omega)[\ H_d\left(e^{j\omega}\right)-H_a\left(e^{j\omega}\right)\ ] \tag{2.5}$$

The error function $E(\omega)$, given by Parks-McClellan (PM) is represented in Eq. (2.5), where $W(\omega), H_d\left(e^{j\omega}\right), H_a\left(e^{j\omega}\right)$ are the weight vector, desired, and approximated frequency response respectively. Weight function $W(\omega)$ modulates the minimization of error.

In error function $E(\omega)$, the ratio between peak ripple at pass-band (δ_p) and stop-band (δ_s) cannot take different values. Thus, in order to overcome the flaws in this function, a modified error function is used in [40]:

$$U = \max_{\omega \le \omega_p}\left(|E(\omega)| - \delta_p\right) + \max_{\omega \ge \omega_s}\left(|E(\omega)| - \delta_s\right) \tag{2.6}$$

where ω_p , ω_s , δ_p and δ_s are the desired filter specifications. Now, the band-pass filter's ideal response can be denoted by [40]:

$$\begin{aligned} H_d\left(e^{j\omega}\right) &= 0 \quad 0 \le \omega \le \omega_{s1} \\ &= 1 \quad \omega_{p1} \le \omega \le \omega_{p2} \\ &= 0 \quad \omega \ge \omega_{s2} \end{aligned} \tag{2.7}$$

where ω_{s1}, ω_{s2} represent the first and the second stop-band frequencies of band-pass FIR filter. Similarly ω_{p1} and ω_{p2} are the first and the second pass-band frequency.

2.3.2 Type 1 Linear Phase FIR Filter

The frequency response function of FIR filter is represented by [40]:

$$H(e^{j\omega}) = \sum_{n=0}^{(M-1)} h(n) e^{-j\omega n}, \qquad -\pi < \omega \le \pi \tag{2.8}$$

Now linear phase constraint is described by [40]:

$$\angle H(e^{j\omega}) = -\tau_\phi \omega, \; -\pi < \omega \le \pi \tag{2.9}$$

Here τ_ϕ is a constant phase delay. Now for Type 1 filter, $h(n)$ has to be symmetrical, i.e. [40]:

$$h(n) = h(M-1-n), 0 \le n \le (M-1) \text{ with } \tau_\phi = \frac{M-1}{2} \tag{2.10}$$

where $h(n)$ shows symmetry about τ_ϕ and τ_ϕ is the index of symmetry [40]. The value of M, in Eq. (2.5), can take even or odd integer valuesin case of Type 1 and Type 2 filters respectively. The frequency response of Type 1 filter is:

$$H(e^{j\omega}) = \left[\sum_{n=0}^{(M-1)/2} a(n) \cos \omega n\right] e^{-j\omega(M-1)/2} \tag{2.11}$$

2.3.3 Objective Function Formulation for Band-Pass FIR Filter

The objective function for band-pass filter is considered as:

$$\phi = \beta * E_p + (1-\beta) * (E_{S1} + E_{S2}), 0 < \beta \leq 1 \tag{2.12}$$

where E_P, E_{S1}, and E_{S2} are calculated following Eqs. (2.13)- (2.15).

$$E_P = \frac{1}{\pi}\int_{\omega_{p1}}^{\omega_{p2}} (1-H(\omega))^2 d\omega = \left(\frac{\omega_{P2} - \omega_{p1}}{\pi}\right) - 2b_1^T P_1 + b_1^T Q_1 b_1 \tag{2.13}$$

$$E_{S1} = \frac{1}{\pi}\int_{0}^{\omega_{s1}} (H(\omega))^2 d\omega = b_1^T C_1 b_1 \tag{2.14}$$

$$E_{S2} = \frac{1}{\pi}\int_{\omega_{s2}}^{\pi} (H(\omega))^2 d\omega = b_1^T C_1 b_1 \tag{2.15}$$

where E_p represents pass-band error, E_{S1} and E_{S2} are the first and the second stop-band error respectively for band-pass filter.

Here $H(\omega) = b^T C(\omega)$, $b = [b_1, b_2, \ldots, b_{N/2}]^T$

P and Q can be defined as :

$$P = \frac{1}{\pi}\int_{0}^{\omega_p} \cos(A\omega) d\omega \tag{2.16}$$

$$Q = \frac{1}{\pi}\int_{0}^{\omega_p} \cos(A\omega)\cos(B\omega) d\omega \tag{2.17}$$

In case of pass-band error, the value of C can be measured from the formula as following:

$$C(m,n) = \frac{1}{\pi}\int_{\omega_s}^{\pi} \cos(A\omega)\cos(B\omega) d\omega \tag{2.18}$$

where $A = \frac{N-1}{2} - m, m = 0,1,\ldots(M-1)$

and $B=\frac{N-1}{2}-n, n=0,1,\ldots(M-1)$, and $H(\omega)$ is the magnitude response of FIR filter. Thus thegoal of our design is to minimize the objective function for band-pass filter as given in Eq. (2.12).

2.4 Design Methodologies of Salp Swarm Algorithm

2.4.1 Overview of Salp swarm algorithm

SSA is a new meta-heuristic algorithm introduced by Mirjalili. It mimics the navigating and foraging in deep oceans. The transition from real inspiration is discussed in following sections. SSA is a branch of meta-heuristic proposed by Mirjalili et al. for optimization problems over continuous domains. To mathematically model the salp chains, the population is first divided to two groups: pioneer and supporters. The pioneer is the salp at the front of the chain, whereas the rest of salps are contemplated as supporters which are shown in Fig. 2.2.

As the name 'Salp'suggests, the leader guides swarm and the followers goes along with each other (and pioneer directly or indirectly). Likewise to different swarm-based methods, the position of salps is determined in an *n*-dimensional foraging space where *n* is the number of variables of a particular problem. Thus, the position of all salps isgathered in a two dimensional matrix called *X*. It is also interpreted that there is a food origin called *F* in the searchregion as the swarm's object. The details of SSA can be found in Subsection [30].

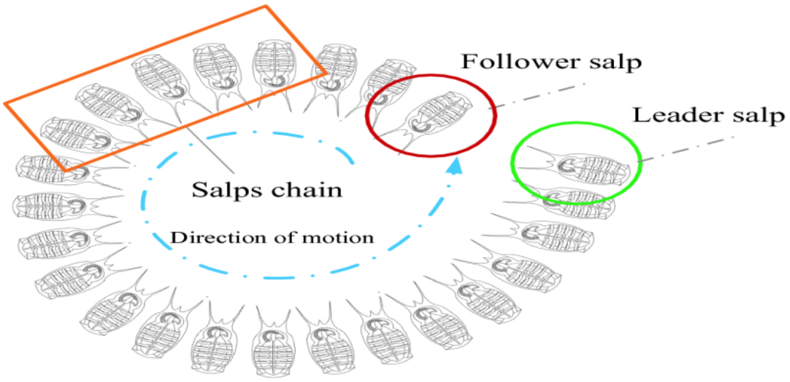

Fig. 2.2 Swarm of salps (salps chain)

2.4.2 Proposed mathematical model for moving Salp chains

According to the mathematical model of Salp chains we can compared to other swarm-based strategies, the position of Salps is distinguish in an *n*-dimensional tracking space where n is the accent of factors of a given matter. In this way, the orientations of all Salps are put away in a two-dimensional framework called X. It is correspondingly anticipated that there is a food source called F in the hunt space as the swarm's objective. To refresh the position of the pioneer the accompanying equation is proposed:

$$X_j^1 = F_j + c_1((ub_j - lb_j)c_2 + lb_j)\ \text{if}\ c_3 \geq 0 \tag{2.19}$$

$$X_j^1 = F_j - c_1((ub_j - lb_j)c_2 + lb_j)\ \text{if}\ c_3 > 0 \tag{2.20}$$

where X_j^1 shows the position of the first salp (pioneer) in the j^{th} dimension, F_j is the position of the food source in the j^{th} dimension denotes the upper bound j^{th} dimension lb_j denotes the lower bound of j^{th} dimension, c_1 , c_2 and c_3 are random numbers. The coefficient c_1 is an important parameter in SSA because it balances exploration and exploitation and it is expressed as:

$$c_1 = 2e^{-(\frac{4l}{L})} \tag{2.21}$$

where l is the current iteration and L is the maximum number of iterations. The parameter c_2 and c_3 are random numbers uniformly generated in the interval of [0, 1]. Also, their commandment on the upcoming position in *jth* dimension should be towards of forward infinity or backward infinity and also for the step size.

Because the time in optimization in iteration and also the variance between iterations is equal to 1when considering by $v = 0$ that equation can be expressed as follows:

$$X_j^i = \frac{1}{2}(X_j^i + X_j^{i-1}) \tag{2.22}$$

where $i \geq 2$ and X_j^i shows the position of i^{th} supporters salp in jth dimension. With Eqs. (2.19) and (2.22), the salp chains can be simulated.

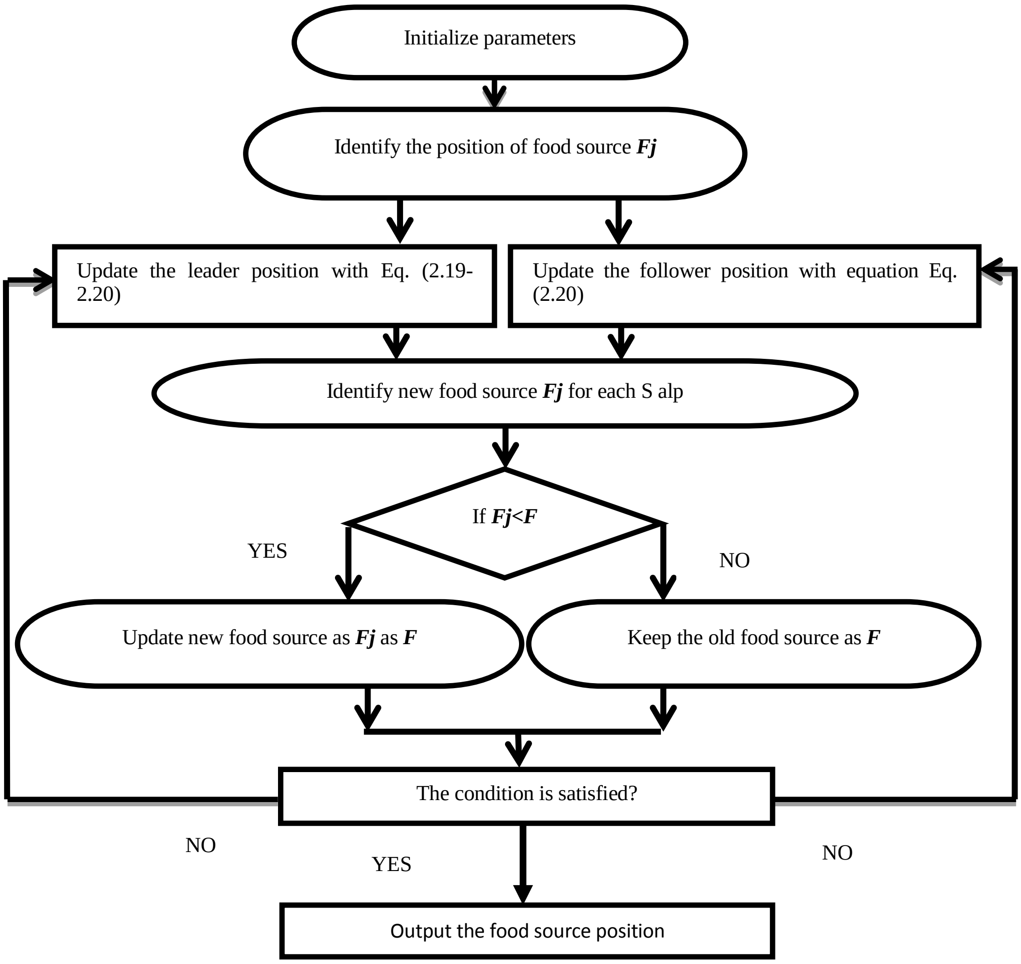

Fig. 2.3 Flowchart of SSA Algorithm

2.4.3 Pseudo Code of Salp Swarm Algorithm

```
Initialize the salp population $x_i (i = 1,2,...,n)$ considering $ub$ and $lb$
while (end condition is not satisfied)
Calculate the fitness of each exploring agent (salp)
    $F$ =the leading search agent
        Amend $c_1$ by Eq. (18)
            For each salp $x_i$
                If $i == 1$
                    Amendthe position of the pioneer salp by Eq. (2.19)
                Else
                    Amend the position of the supporter's salp by Eq. (2.22)
                End
            End
        Amend the salps based on the upper and lower bounds of variables
    End
return $F$
```

2.5 Design Methodologies of Quantum Inspired Salp Swarm Algorithm

Although the SSA can provide good accuracy in comparison with some other existing algorithms, it still has some limitations like getting trapped in some locally optimal solutions or less adequate convergence speed and accuracy. Moreover, it is not suitable for highly complex applications. This provides with sufficient scope for developing newer techniques that improves upon the performance of SSA. To sufficiently overcome these limitations, a new variant of SSA inspired by the laws of quantum mechanics has been proposed here.

2.5.1 Design Modification of BPF FIR Filter Using QSSA

Here, the Quantum Inspired SSA (QSSA) based algorithm is applied for the design of Type 1 BPF to achieve satisfactory performance with less computational effort. QSSA also exhibits better convergence as compared to SSA. Here the suggested QSSA method introduces such modifications in the standard algorithm:

The Eqs (2.20) and (2.21) are quantized and hybridized by the original position update equations which have been given in sub section (2.4.2) with respect to Eqs (2.16) and (2.19).

So, the new position update equations for the improved algorithm are:

$$X_{i,jnew}^{k} = F_j + c_1((ub_j - lb_j)c_2 + lb_j) + \alpha \times abs(mbest_k^j - X_{i,j}^{k}) \times \ln(\frac{1}{u}) \text{ If } c_3 \geq 0 \quad (2.23)$$

$$X_{i,jnew}^{k} = F_j - c_1((ub_j - lb_j)c_2 + lb_j) + \alpha \times abs(mbest_k^j - X_{i,j}^{k}) \times \ln(\frac{1}{u}) \text{ If } c_3 > 0 \quad (2.24)$$

where $\alpha =$ any numerical constant,

$$mbest_k^j = \frac{1}{N}\sum_{i=1}^{N} X_{i,j}^{k}; \; j = 1,2,\ldots,d \qquad (2.25)$$

d-dimensional vector describing the average position of all the particles at iteration "*t*"

N= Total number of objects

$u = rand(x, y)$ where *x*, *y* are a natural numbers.

(The other variables of these position update equations have already been described in sub section 2.4.2)Hence, this time in optimization is iteration, the variance between iterations is also equal to 1, and considering by $v = 0$.

Therefore and the equation can be expressed as follows:

$$X_j^i = \frac{1}{2}(X_{jnew}^i + X_{jnew}^{i-1}) \tag{2.26}$$

where $i \geq 2$ and Y_j^i shows the position of i^{th} supporters salp in j^{th} dimension.

2.5.2Pseudo Code of Quantum Inspired Salp Swarm Algorithm

```
Initialize the salp population $x_i (i = 1,2,...,n)$ considering $ub$ and $lb$ with $C_1$
Do
    Evaluate the cost function for each agent with absolute value
While (t < maximum iterations)
    Evaluate the mbest of all the particles through Eq. (2.25)
    Update the positions of the followers through Eq. (2.26)
Return the optimum (best) solution obtained
```

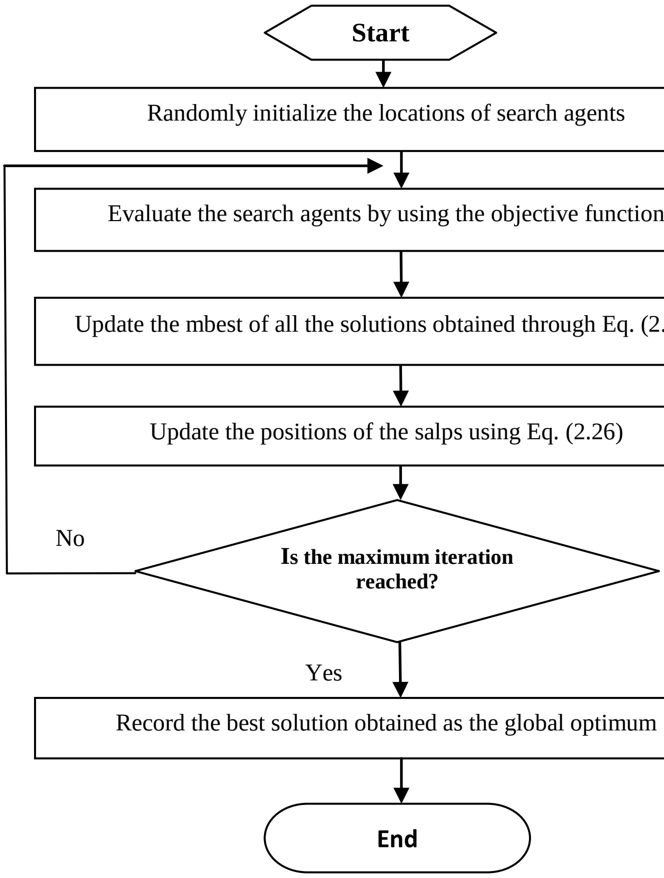

Fig. 2.4Flowchart of QSSA Algorithm

2.6 Summary

Digital filters are extremely stable due to their inherent mathematical construction. On the other hand, due to the finite tolerances, the frequency responses of similar analoguefilters are never exactly same. This chapter starts with brief descriptions of FIR and BP filters. Then the chapter proceeds with a sufficiently detailed presentation of the design methodologies of FIR filters in the form of evolutionary optimization algorithms such as Salp Swarm Algorithm (SSA). After that, in the following section a newerversion of the conventional SSA is proposed named as QSSA.Also, there are some major reasons behind its superiority over SSA that has been discussed in this section.

CHAPTER 3

RESULTS ANALYSIS AND DISCUSSION

CHAPTER 3

RESULTS ANALYSIS AND DISCUSSION

3.1Introduction

This chapter presents the problem formulation of Type-1 band-pass FIR filter. Simulation results and analysis of designing FIR filter QSSA are provided in the later part of the chapter. QSSA is a better and faster version of Salp Swarm Algorithm (SCA). SSA is a simple, population based robust evolutionary algorithm but has the problem of sub-optimality. QSSA has overcome the above disadvantage faced by SSA. The simulation results show that QSSA outperforms SSA not only in terms of magnitude response but also in terms of convergence speed and thus proves itself to be a promising candidate for FIR filter design.

In this Chapter named Result analysis and discussion is organized as follows: Section 3.2 describes the comparison of Convergence Profiles between SSA and QSSA using some benchmark functions; Section 3.3 presents Design specifications of FIR filter and gives comparison of filter responses between SSA and QSSA. Finally in Section 3.4 summarization of results and discussions of this chapter.

3.2 Comparison of Convergence Profiles between SSA and QSSA

There are few benchmark functions are tested using proposed QSSA which exhibits better performance than SSA. There are two types of benchmark functions: Unimodal and Multimodal.

In Table 3.1 and Table 3.2 the details of unimodal and multimodal functions are given respectively.

Table 3.1Unimodal benchmark functions

Function	Dim	Range
$g_1(x)=\sum_{i=1}^{D} x_i^2$	30	[-100,100]
$g_2(x)=\sum_{i=1}^{D}\lvert x_i\rvert+\prod_{i=1}^{D}\lvert x_i\rvert$	10	[-10,10]
$g_3(x)=\sum_{i=1}^{D}(\sum_{j-1}^{i} x_j)^2$	10	[-100,100]
$g_4(x)=\max\{\lvert x_i\rvert, 1\le i\le n\}$	10	[-100,100]
$g_5(x)=\sum_{i=1}^{D-1}[100(x_{i+1}-x_i^2)^2+(x_i-1)^2]$	10	[-30,30]
$g_7(x)=\sum_{i=1}^{D} ix_i^4+random[0,1]$	10	[-1.28,1.28]

Table 3.2 Multimodal benchmark functions.

Function	Dim	Range
$g_9(x)=\sum_{i=1}^{D}[x_i^2-10\cos(2\pi x_i)+10]$	10	[-5.12,5.12]
$g_{10}(x)=-20\exp(-0.2\sqrt{\frac{1}{D}\sum_{i=1}^{D}x_i^2})-\exp(\frac{1}{D}\sum_{i=1}^{D}\cos(2\pi x_i)+20+e$	10	[-32,32]
$g_{11}(x)=\frac{1}{4000}\sum_{i=1}^{D}x_i^2-\prod_{i=1}^{D}\cos(\frac{x_i}{\sqrt{i}})+1$	10	[-600,600]
$g_{12}(x)=\frac{\pi}{\Pi}\{10\sin(\pi y_1)+\sum_{i=1}^{D-1}(y_i-1)^2[1+10\sin^2(\pi y_{i+1})]+(y_n-1)^2\}+\sum_{i=1}^{D}u(x_i,10,100,4)$ $y_i=1+\frac{x_i+1}{4}$ $u(x_i,a,k,m) = \begin{cases} k(x_i-a)^m & x_i>a \\ 0 & -a<x_i<a \\ k(-x_i-a)^m & x_i<-a \end{cases}$	10	[-50,50]
$g_{13}(x)=0.1\{\sin^2(3\pi x_1)+\sum_{i=1}^{D}(x_i-1)^2[1+\sin^2(3\pi x_i+1)]+(x_n-1)^2[1+\sin^2(2\pi x_n)]\}+\sum_{i=1}^{D}u(x_i,5100,4)$	10	[-50,50]

Now these benchmark functions are tested using proposed QSSA which exhibits better performance than SSA as illustrated in Fig. 3.1-3.11.

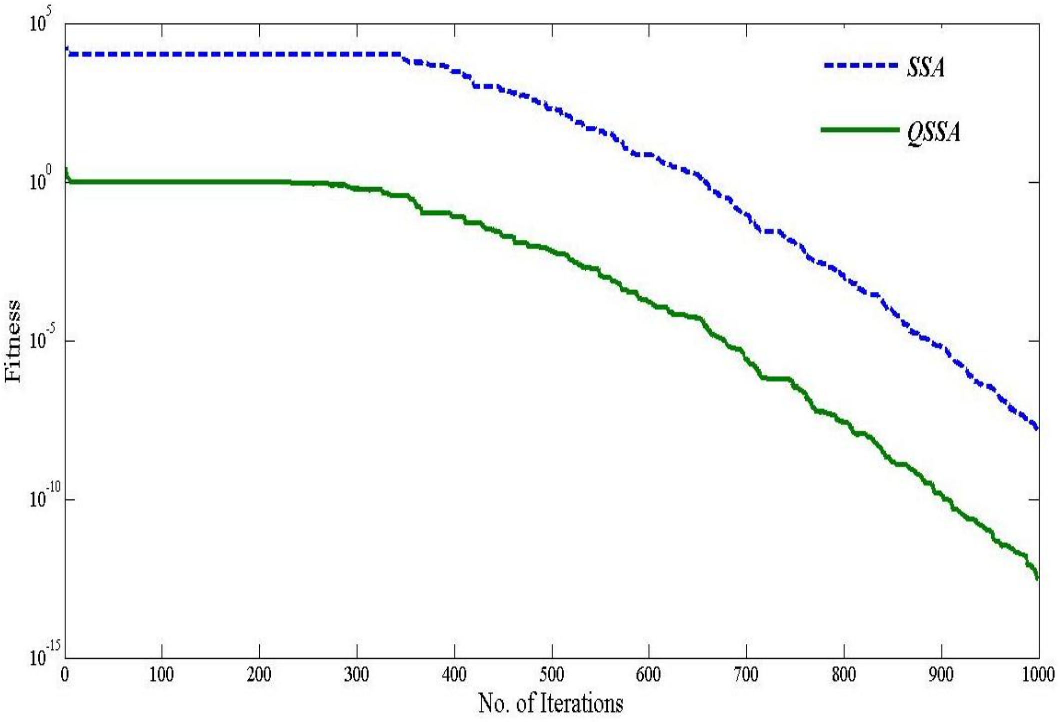

Fig. 3.1 Convergence curves (semi log) of SSA and QSSA for function $g_1(x)$

The dimension, upper bound and lower bound for this above function are 30, 100, and -100 respectively.

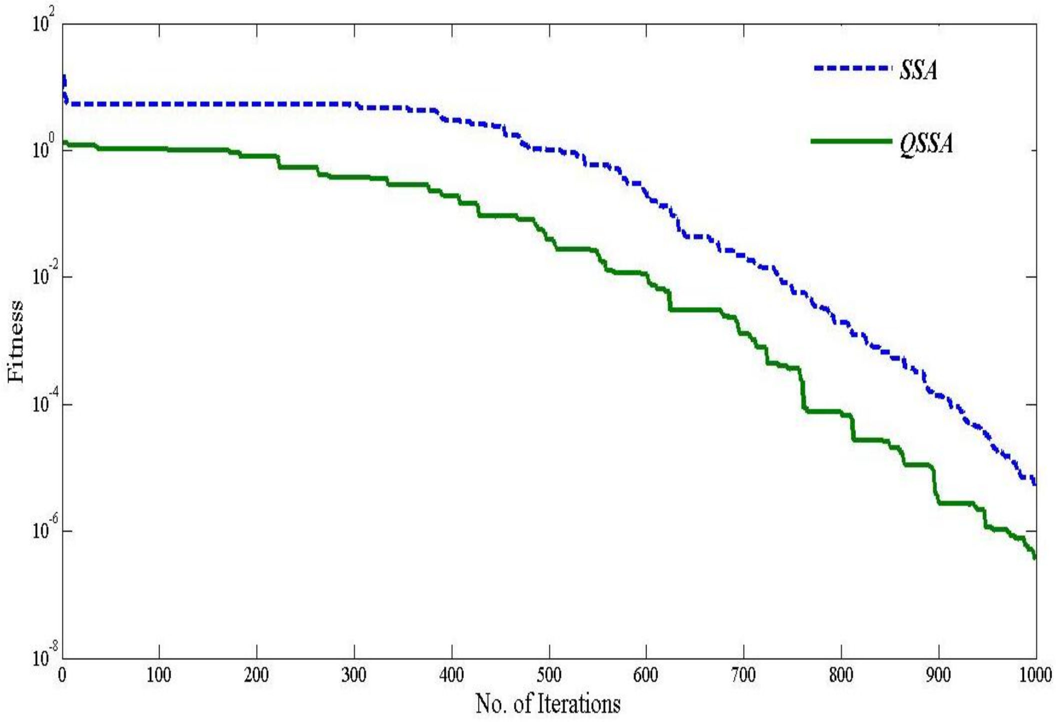

Fig. 3.2 Convergence curves (semi log) of SSA and QSSA for function $g_2(x)$

The dimension, upper bound and lower bound for this above function are 10, 10, and -10 respectively.

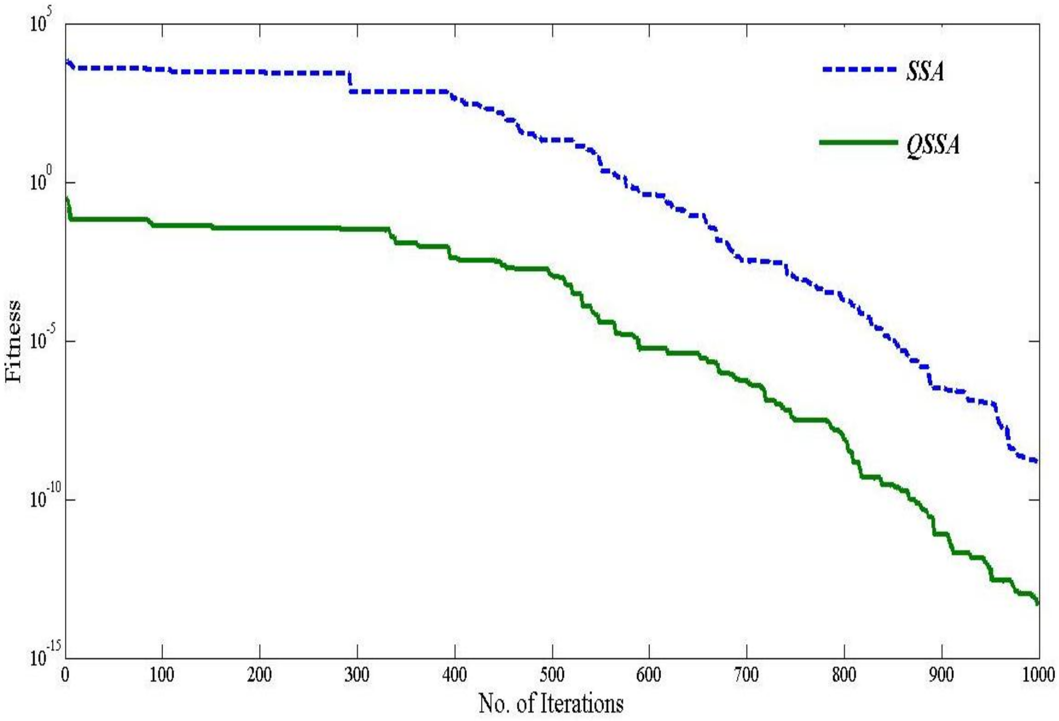

Fig. 3.3 Convergence curves (semi log) of SSA and QSSA for function $g_3(x)$

The dimension, upper bound and lower bound for this function are 10, 100, and -100 respectively.

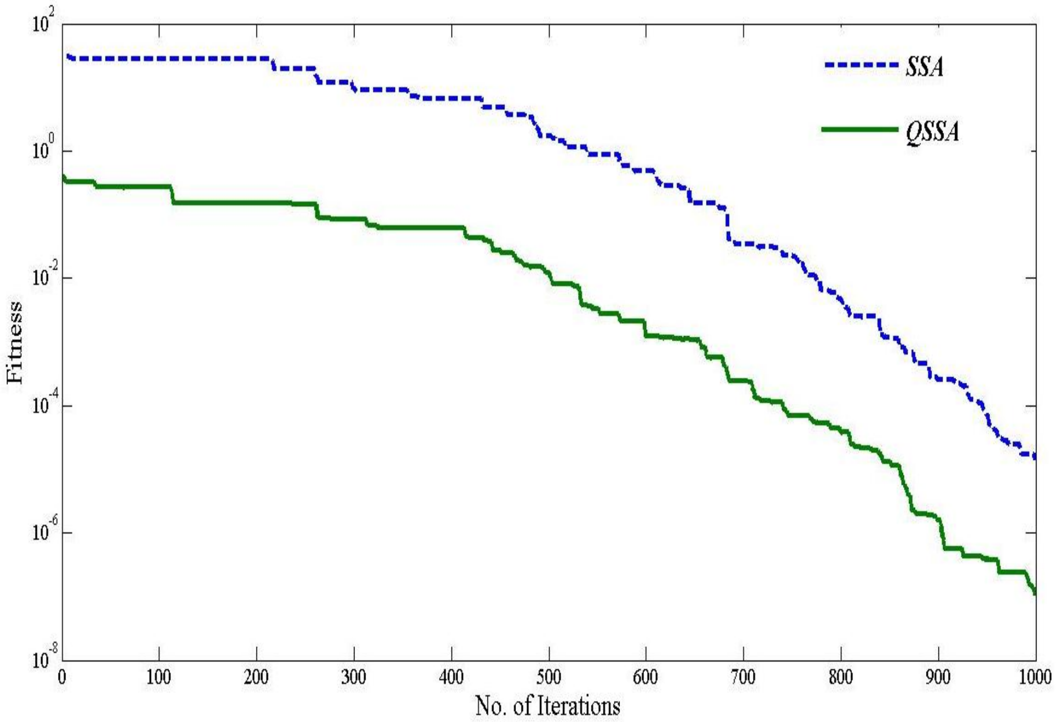

Fig. 3.4 Convergence curves (semi log) of SSA and QSSA for function $g_4(x)$

The dimension, upper bound and lower bound for this function are 10, 100, and -100 respectively.

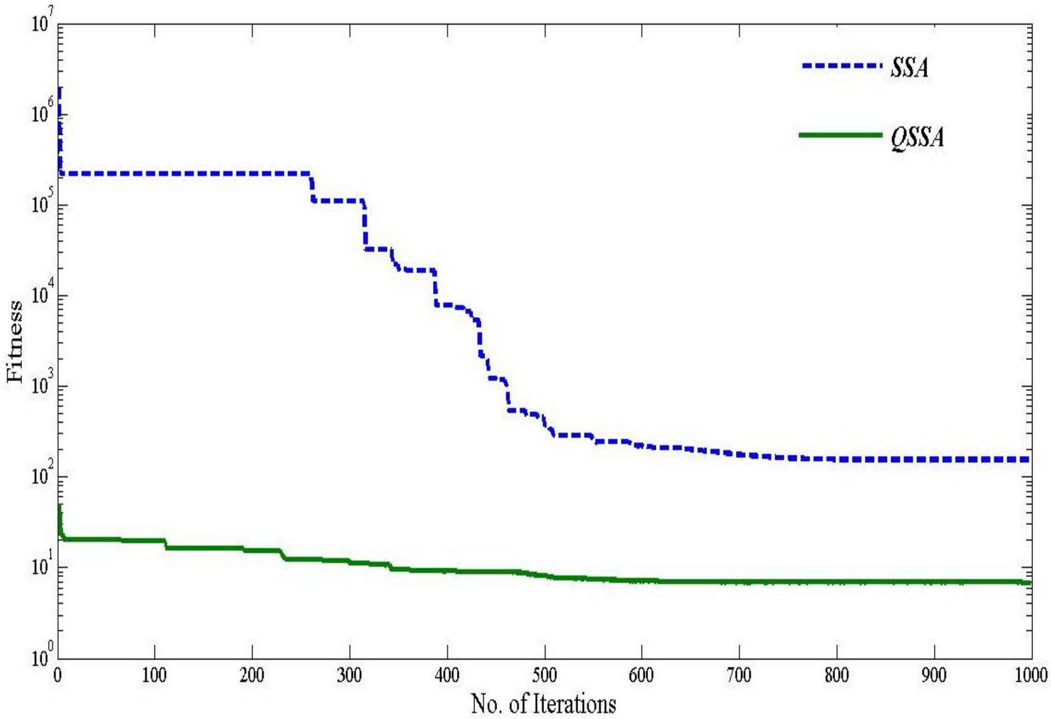

Fig. 3.5 Convergence curves (semi log) of SSA and QSSA for function $g_5(x)$

The dimension, upper bound and lower bound for this function are 10, 30, and -30 respectively.

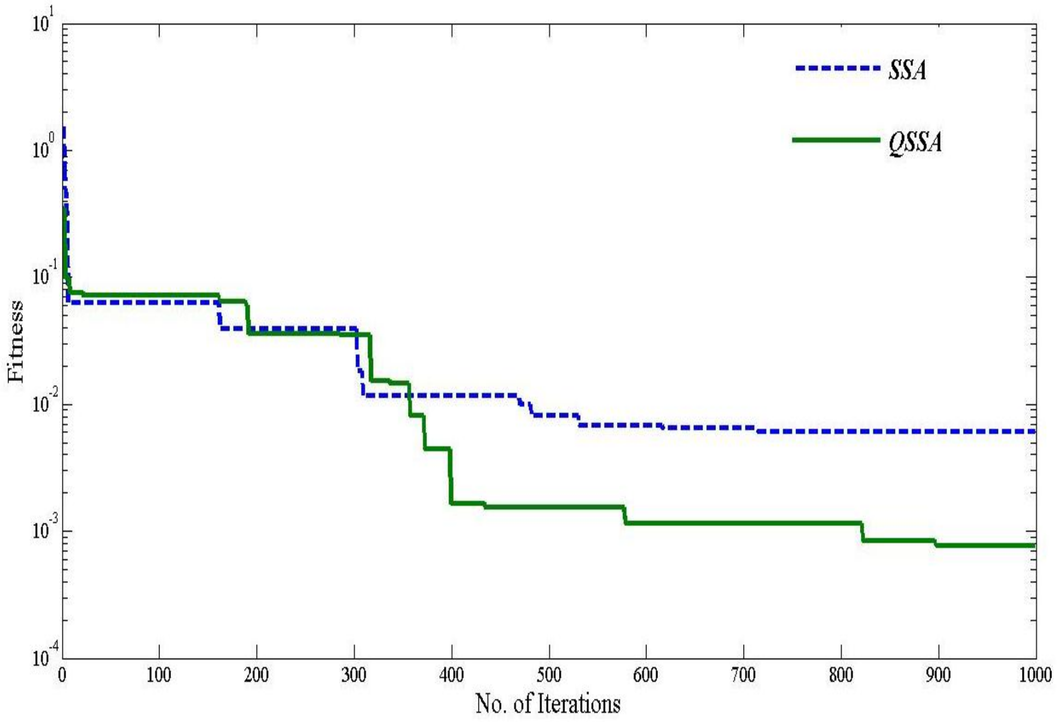

Fig. 3.6 Convergence curves (semi log) of SSA and QSSA for function $g_7(x)$

The dimension, upper bound and lower bound for this function are 10, 1.28, and -1.28 respectively.

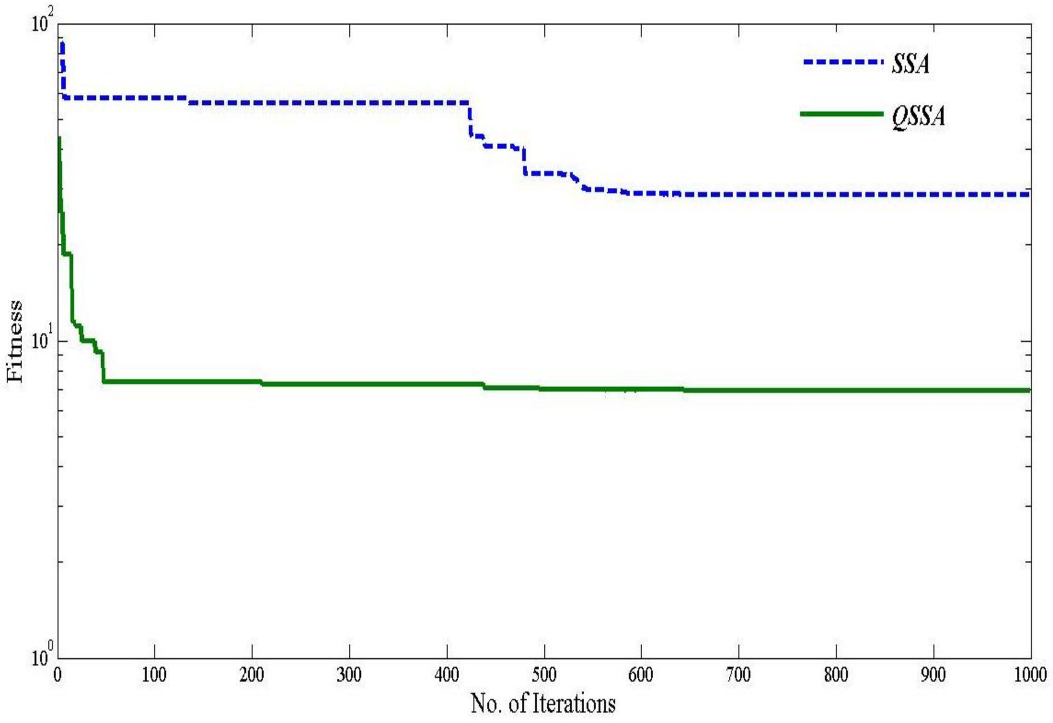

Fig. 3.7 Convergence curves (semi log) of SSA and QSSA for function $g_9(x)$

The dimension, upper bound and lower bound for this function are 10, 5.12, and -5.12 respectively.

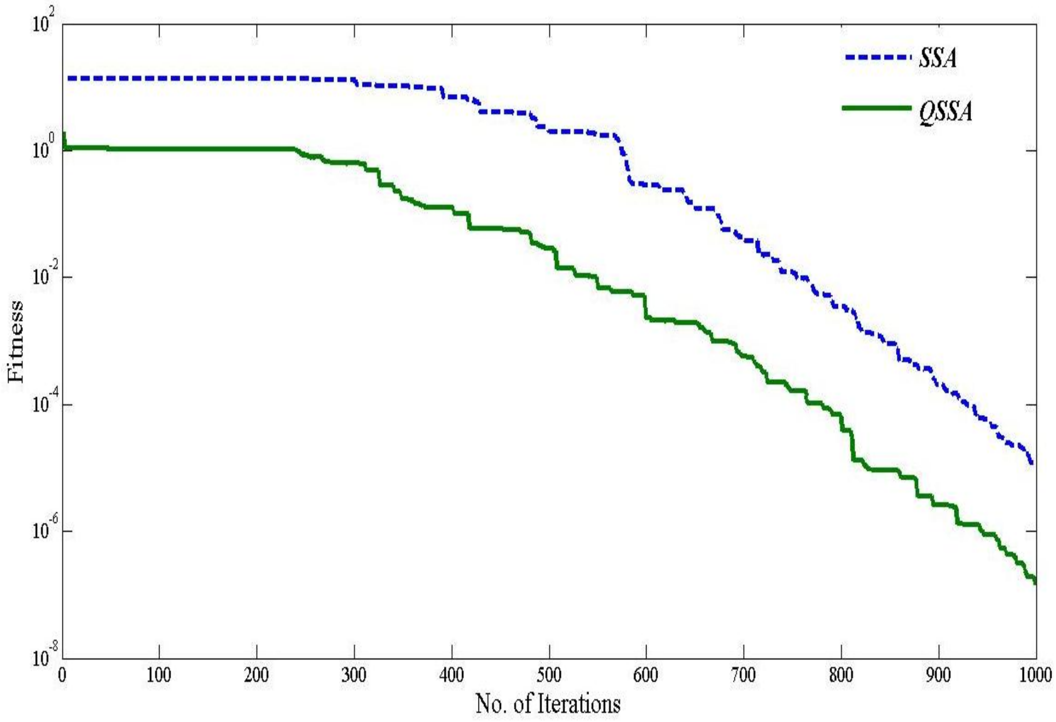

Fig. 3.8 Convergence curves (semi log) of SSA and QSSA for function $g_{10}(x)$

The dimension, upper bound and lower bound for this function are 10, 32, and -32 respectively.

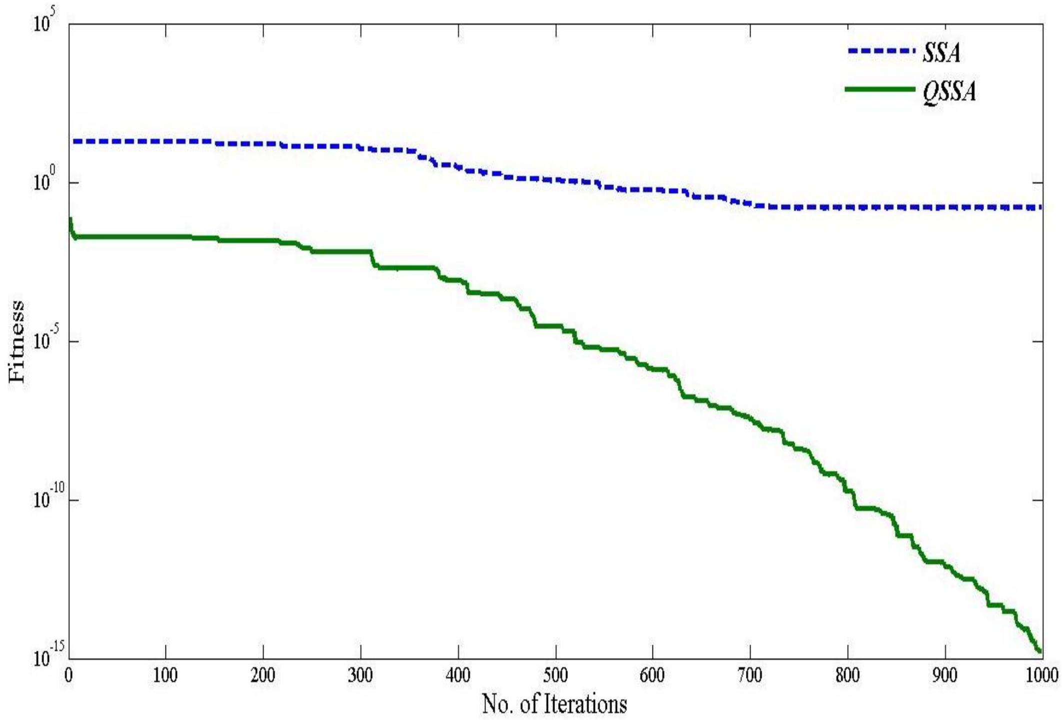

Fig. 3.9 Convergence curves (semi log) of SSA and QSSA for function $g_{11}(x)$

The dimension, upper bound and lower bound for this function are 10, 600, and -600 respectively.

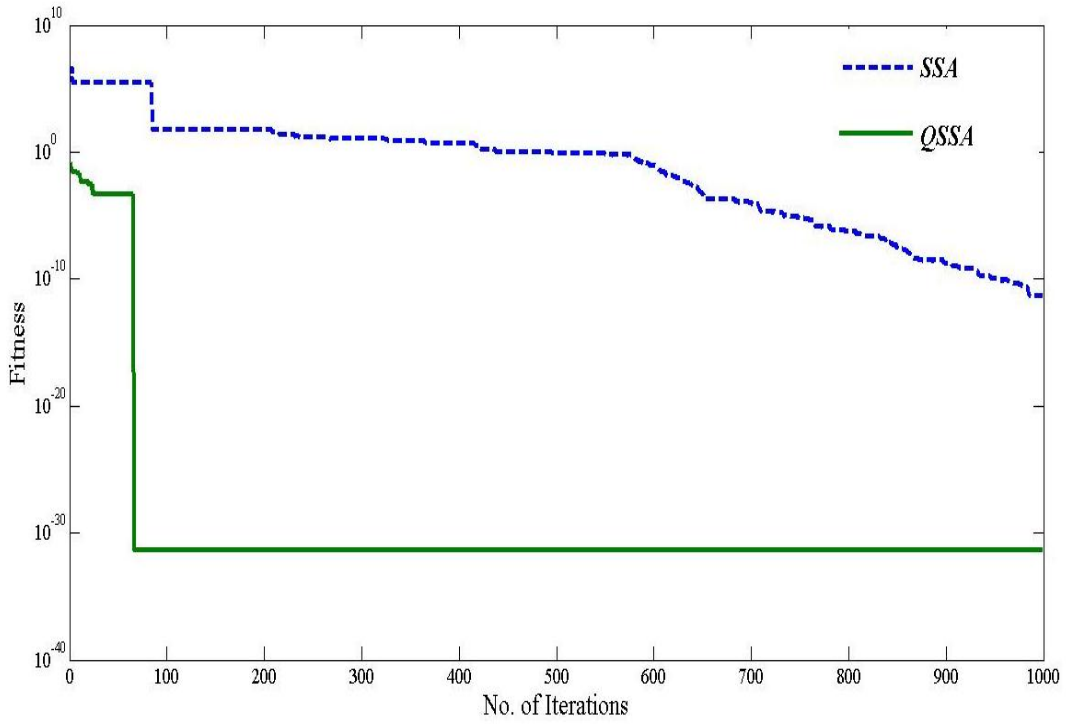

Fig. 3.10 Convergence curves (semi log) of SSA and QSSA for function $g_{12}(x)$

The dimension, upper bound and lower bound for this function are 10, 50, and -50 respectively.

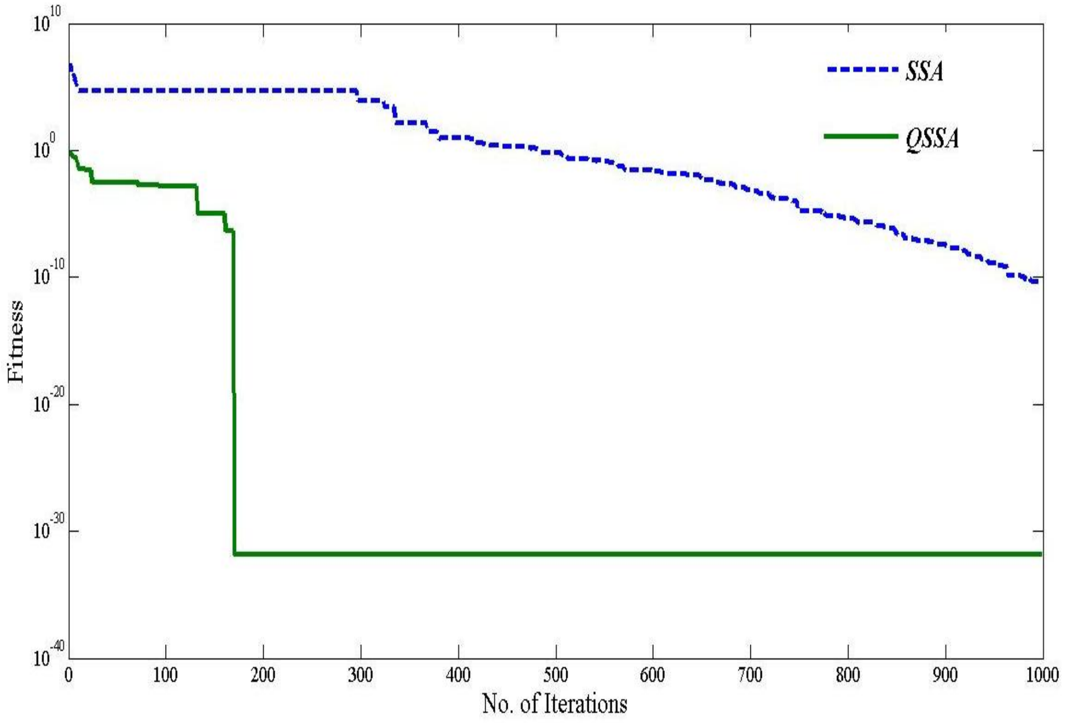

Fig. 3.11 Convergence curves (semi log) of SSA and QSSA for function $g_{13}(x)$

The dimension, upper bound and lower bound for this function are 10, 50, and -50 respectively.

3.3 Design Specifications of FIR Filter

This section discusses the implementation of band-pass filter with the following parameter settings: $\omega_{s1} = 0.2\pi$, $\omega_{p1} = 0.3\pi$, $\omega_{p2} = 0.7\pi$, and $\omega_{s2} = 0.8\pi$ .The complete design work is performed using MATLAB 2018B.The type-I band pass filter has been designed as a minimization problem following Eqs. 3.21-3.27. The proposed algorithm is used here to minimize the objective function mentioned in Eq. 3.21.

3.3.1Comparison of Filter Responses between SSA and QSSA

This section shows the magnitude response curve of Type-1 Band-pass FIR filter of order 18 for SSA and QSSA in Fig. 3.12 and also Fig. 3.13 does the same for order 28. Both of the figures show that QSSA improves the response over SSA. The same can also be inferred from the values of attenuation at stop-band $\left(A_s\right)$ and pass-band ripple $\left(R_p\right)$ as provided in Table 3.3 and Table 3.4. For order (N) is **18**, the population size (N_P) is taken **20** and the No. of functional evaluations (NOFE) is **50000** and for order **38**, N_P is taken **20** and the No. of functional evaluations (NOFE) is **150000.**

Therefore in case of order 18, the population size (N_P) is taken **20** and the No. of functional evaluations (NOFE) is **50000** of Type 1 BPF, QSSA provides 31.0178 dB, 1.2474 dB A_s and R_p respectively. But SSA provides 30.8916 dB, 1.2633 dB A_s and R_p respectively. Hence the ripple obtained in QSSA is less than that conventional SSA method. Thus for design of Type-1 band-pass FIR Filter proves the effectiveness of QSSA.

Table 3.3 Simulation results for Type 1 BPF with order (N) = 18

N	Np	NOFE	Method	As (in dB)	Rp (in dB)
18	20	50000	SSA	30.8916	1.2633
			QSSA	**31.0178**	**1.2474**

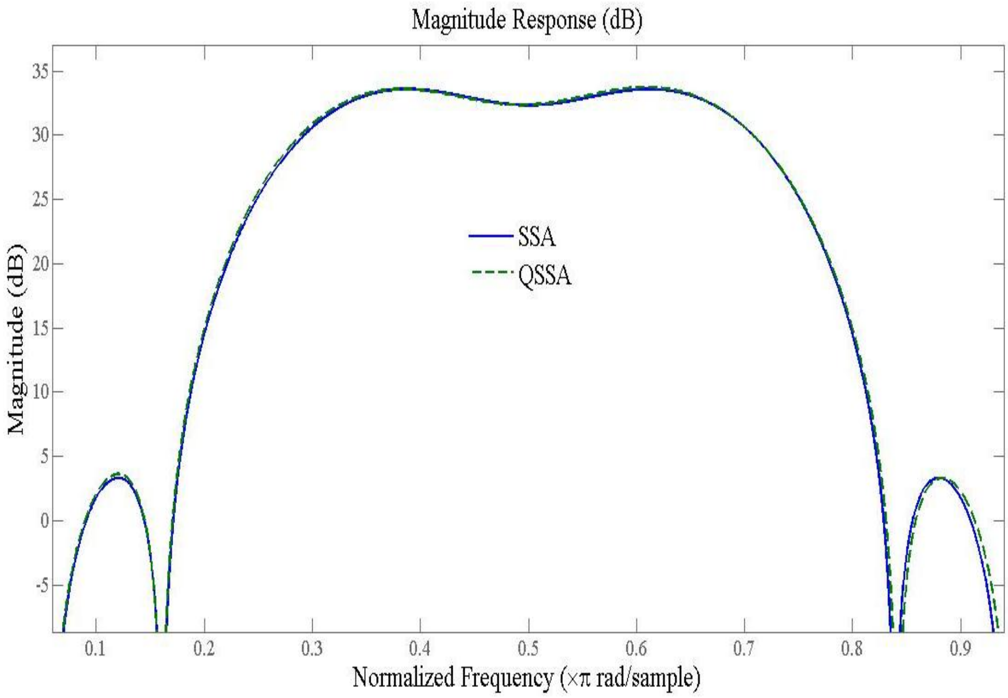

Fig. 3.12 Response of BPF with order (N) =18

It is very much evident from figure 3.12 that QSSA provides better transition than conventional SSA method.

Now, in case of order 38, the population size (N_P) is taken 20 and the No. of functional evaluations (NOFE) is 150000 of Type 1 BPF, QSSA provides 40.2284 dB, 0.1437 dB A_s and R_p respectively. But SSA provides 38.6269 dB, 0.3538 dB A_s and R_p respectively. Hence the ripple obtained in QSSA is less than that conventional SSA method. Thus for design of Type-1 band-pass FIR Filter proves the effectiveness of QSSA.

Table 3.4 Simulation results for Type 1 BPF with order (N) = 38

N	Np	NOFE	Method	As (in dB)	Rp (in dB)
38	20	150000	**QSSA**	**40.2284**	**0.1437**
			SSA	38.6269	0.3538

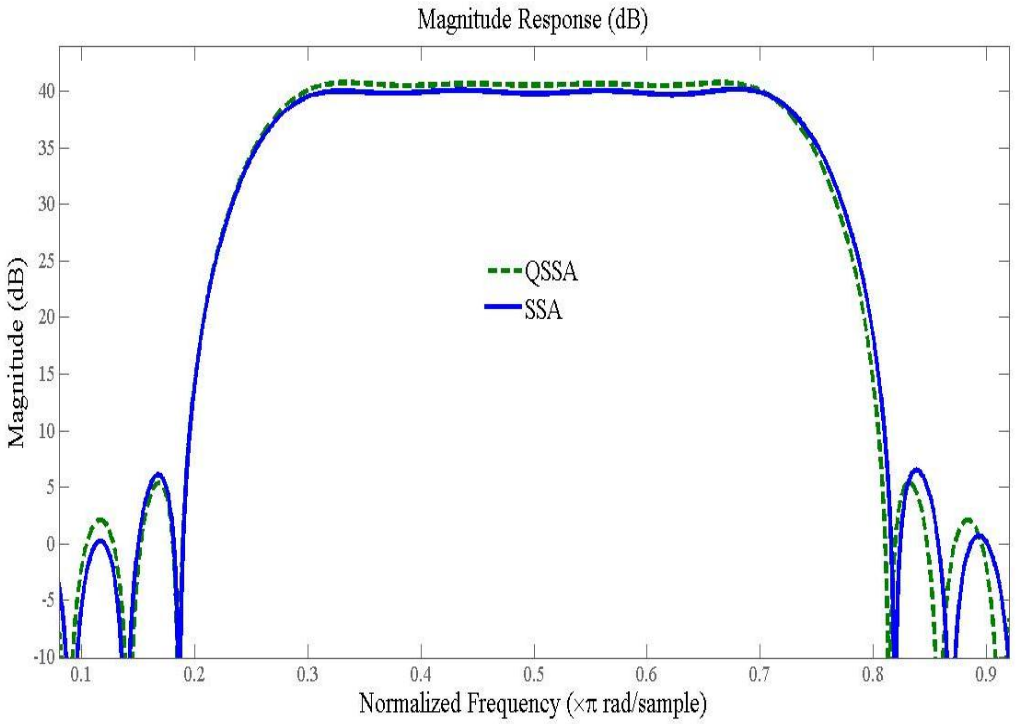

Fig. 3.13 Response of BPF with order (N) =38

It is very much evident from figure 3.13 that QSSA provides better transition than conventional SSA method.

3.4 Summary

In this paper, Quantum InspiredParticle Swarm Optimization withSalp Swarm Algorithm known as Quantum Behaved Salp Swarm Algorithm (QSSA) is used for the design of 18th and 38th order FIR filters. It is revealed that QSSA has the ability to converge to the best quality near optimal solution and possesses the best convergence characteristics among the algorithms. It is observed from the above given tables and figures that QSSA is more efficient in successfully optimizing the filter coefficients. QSSA gives better magnitude response as well as the lowest error value as compared to other algorithms. Thus QSSA proves itself to be a viable candidate for the optimal design of Type-1 BP FIR filters.

CHAPTER 4

CONCLUSION & FUTURE ASPECTS

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CONCLUSION & FUTURE ASPECTS

In this project work a novel optimization algorithm named as Quantum Inspired Salp Swarm Algorithm (QSSA) is proposed and it is used for the design of digital FIR filters. From the simulation results, discussed in Chapter 3, it can be easily verified that the proposed algorithm is more efficient than the conventional Salp Swarm Algorithm. The proposed QSSA method offers the higher stop-band attenuation and lower pass-band ripple as compared to the existing SSA. Apart from this we have also tested some benchmark functions to exhibit better convergence property of QSSA as compared with SSA. Hence, the proposed work can be considered an efficient technique for the design of Type-1 band-pass FIR filters.

Although, two optimization methods have been discussed in this thesis for designing of digital FIR filters but there are still opportunities to improve the design performance of the digital filters. Few recently developed optimization algorithms can also be used for the further reduction in design error of FIR filters and enhance the convergence speed. Moreover, the proposed algorithm can be implemented on FPGA (Field Programmable Gate Array) platform with reduced area, less power consumption, and less time delay.

The finding of the work has been accepted for publication as per details given below:

S. Chowdhury, P. Venkateswaran et al., "Design of Band-pass FIR Filter using Improved Sine Cosine Algorithm and its Implementation on FPGA", IEEE Region 10 Symposium, TENSYMP 2019, IEEE Kolkata Section, Kolkata, June 7 – 9, 2019.

REFERENCES

[1] A. Aggarwal, T. K. Rawat, and D. K. Upadhyay, “Design of optimal digital FIR filters using evolutionary and swarm optimization techniques”, *AEU - International Journal of Electronics and Communications*, Vol. 70, No. 4, pp. 373–385, 2016.

[2] Y. Ozbay, B. Karlik, and A.R. Kavsaoglu, “A windows-based digital filter design”, *Math. Comput. Appl*, Vol. 8, No. 3, pp. 287–294, 2003.

[3] J. Radecki, J. Conrad, and E. Dubois, “Design of multidimensional finite-wordlength FIR and IIR filters by simulated annealing”, *IEEE Transactions on Circuits and Systems - II,* Analog and Digital Signal Processing, Vol. 42, No. 6, pp. 424 - 431, 1995.

[4] N. Benvenuto, M. Marchesi, and A. Uncini, “Applications of simulated annealing for the design of special digital filters. IEEE Transactions on Signal Processing”, Vol. 40, No. 2, pp. 323-332, 1992.

[5] F. Gonos and I. A. Stathopulos, “Estimation of multilayer soil parameters using genetic algorithms”, *IEEE Transactions on Power delivery*, Vol. 20, No. 1, pp. 100 - 106, 2005.

[6] N.E. Mastorakis, I. F. Gonos, and M.N.S Swamy, “Design of two dimensional recursive filters using genetic algorithms”, *IEEE Trans. Circ. Syst. I – Fundamental Theory of Application.*, Vol. 50, No. 5, pp. 634–639, 2003.

[7] G. Zhu and S. Kwong, “Gbest-guided artificial bee colony algorithm for numerical function optimization”,*Elsevier, Applied Mathematics and Computation*, Vol. 217, No. 7, pp. 3166 - 3173, 2010.

[8] M.S. Kiran, H. Hakli, M. Gunduz, and H. Uguz, “Artificial bee colony algorithm with variable search strategy for continuous optimization”, *Information Sciences*, Vol. 300, pp. 140 - 157, 2015.

[9] D. Karaboga and B. Akay, “A comparative study of Artificial Bee Colony algorithm”, *Applied Mathematics and Computation*, Vol. 214, No. 1, pp. 108–132, 2009.

[10] D. Karaboga and B. Basturk, “Artificial Bee Colony (ABC) Optimization Algorithm for Solving Constrained Optimization Problems”, Springer-Verlag Berlin Heidelberg, Vol. 4529, pp. 789–798, 2007.

[11] W. Gao, S. Liu, and L. Huang, “A global best artificial bee colony algorithm for global optimization”, Journal of Computational and Applied Mathematics, Vol. 236, No. 11, pp. 2741–2753, 2012.

[12] Z. Zhao, H. Gao, and Y. Liu “Chaotic particle swarm optimization for FIR filter design”, *in Proc. of 2011 International Conference on Electrical and Control Engineering*, pp. 2058 – 2061,Yichang, 2011.

[13] Y. Fu, M. Ding, and C. Zhou, “Phase Angle-Encoded and Quantum-Behaved particle Swarm Optimization Applied to Three-Dimensional Route Planning for UAV”, *IEEE Transactions* on *Systems, Man, and Cybernetics – part A: Systems and Humans,* Vol. 42, No. 2, pp. 511 - 526, 2012.

[14] Y. Marinakis and M. Marinaki, “A Hybrid Multi-Swarm Particle Swarm Optimization algorithm for the Probabilistic Traveling Salesman Problem”, *Computers & Operations Research*, Vol. 37, No. 3, pp. 432 - 442, 2010.

[15] S. Dhabal and S.Sengupta, “Efficient design of high pass FIR filter using quantum-behaved particle swarm optimization with weighted mean best position. Computer”, *in Proc. of Third International Conference on Communication, Control and Information Technology (C3IT),* Hooghly, pp. 1-6, 2015.

[16] M. Kumar and T. N. Sasamal, "Design of FIR filter using PSO with CFA and inertia weight approach", *in Proc. of International Conference on Computing, Communication & Automation*, Noida, pp. 1331-1334,2015.

[17] J. M. P. Langlois, “Design of linear phase FIR filters using particle swarm optimization”, *in Proc. of 22nd Biennial Symposium on Communications*, pp. 172-174, 2004.

[18] J. Sun, W. Xu, and B. Feng, “A global search strategy of quantum-behaved particle swarm optimization”, *in Proc. of IEEE Conference on Cybernetics and Intelligent Systems,* Vol. 1, pp. 111–116, 2004.

[19] A. Banks, J. Vincent, and C. Anyakoha, “A review of particle swarm optimization. Part II: hybridization, combinatorial, multicriteria and

constrained optimization, and indicative applications", *Natural Computing*, Vol. 7, No. 1, pp. 109-124, 2008.

[20] M. Najjarzadeh and A. Ayatollahi, "FIR Digital Filters Design: Particle Swarm Optimization Utilizing LMS and Minimax Strategies", *in Proc. of IEEE International Symposium on Signal Processing and Information Technology*, pp. 129-132, 2008.

[21] H. Gandomi, X. S. Yang, and A. H. Alavi, "Cuckoo search algorithm: a metaheuristic approach to solvestructural optimization problems", *Engineering with Computers*, Vol. 29, No. 1, pp. 17 - 35, 2013.

[22] S. Walton, O. Hassan, K. Morgan, and M. R. Brown, "Modified cuckoo search: A new gradient free optimisation algorithm", *Elsevier, Chaos, Solitons & Fractals*, Vol. 44, No. 9, pp. 710 - 718, 2011.

[23] X. S. Yang and S. Deb, "Cuckoo Search via Lévy Flights", *in Proc. of IEEEWorld Congress on Nature & Biologically Inspired Computing (NaBIC)*, Coimbatore, pp. 210–214, 2009.

[24] X. S. Yang and S. Deb, "Engineering Optimization by Cuckoo Search", *Mathematical Modelling and Numerical Optimization*, Vol. 1, No. 4, pp. 330–343, 2010.

[25] S. Duman, U. Guvenc, Y. Sonmez, and N. Yorukeren, "Optimal power flow using gravitational search algorithm", *Elsevier, Energy Conversion and Management*, Vol. 59, pp. 86 - 95, 2012.

[26] M. Khajehzadeh, M. R. Taha, A. El-Shafie, and M. Eslami, "A modified gravitational search algorithm for slope stability analysis", *Engineering Applications of Artificial Intelligence*, Vol. 25, No. 8, pp. 1589 - 1597, 2012.

[27] T. Chakraborti, K. D. Sharma, and A. Chatterjee, "A novel local extrema based gravitational search algorithm and its application in face recognition using one training image per class", *Engineering Applications of Artificial Intelligence*, Vol. 34, pp. 13-22, 2014.

[28] E. Rashedi, H. Nezamabadi-pour, and S. Saryazdi, "GSA: A Gravitational Search Algorithm", *Information Sciences*, Vol. 179, No. 13, pp. 2232–2248, 2009.

[29] E. Rashedi, H. Nezamabadi-pour, and S. Saryazdi, “Filter modeling using gravitational search algorithm”, *Engineering Applications of Artificial Intelligence*, Vol. 24, No. 1, pp. 117-122, 2011.

[30] S. Mirjalili, A. H. Gandomi, S. Z. Mirjalili, S. Saremi, H. Faris, and S. M. Mirjalili, “Salp Swarm Algorithm: A bio-inspired optimizer for engineering design problems”, *Advances in Engineering Software*, Vol. 114, pp. 163-191, 2017.

[31] H. Faris, M. M. Mafarja, A. A. Heidari, I. Aljarah, A. M. Al-Zoubi, S. Mirjalili, and H. Fujita, “An efficient binary Salp Swarm Algorithm with crossover scheme for feature selection problems”, *Knowledge-Based Systems*, Vol. 154, pp. 43-67, 2018.

[32] Z. X. Sun, R. Hu, B. Qian, B. Liu, and G. Che, “Salp Swarm Algorithm Based on Blocks on Critical Path for Reentrant Job Shop Scheduling Problems”, *in Proc. of International Conference on Intelligent Computing*, pp. 638–648, 2018.

[33] A. Ibrahim, A. Ahmed, S. Hussein and A. E. Hassanien, “Fish image segmentation using Salp Swarm algorithm”, *in Proc. Of International Conference on Advanced Machine Learning Technologies and Applications*, pp. 42-51, 2018.

[34] G. I. Sayed, G. Khoriba, and M. H. Haggag, “A novel chaotic salp swarm algorithm for global optimization and feature selection”, *Applied Intelligence*, Vol. 48, No. 10, pp.3462-3481, 2018.

[35] S. Ahmed, M. Mafarja, H. Faris, and I. Aljarah,“Feature selection using salp swarm algorithm with chaos”,*in Proc.of the 2nd International Conferenceon Intelligent Systems, Metaheuristics & Swarm Intelligence*,pp. 65-69, 2018.

[36] K.H. Han and J.H.Kim, “Genetic quantum algorithm and its application to combinatorial optimization problem”, *in Proc. of the 2000 Congress on Evolutionary Computation*, Vol. 2, pp. 1354-1360,2000.

[37] K. H. Han and J.H.Kim, “Quantum-inspired evolutionary algorithm for a class of combinatorial optimization”, *IEEE transactions on evolutionary computation*, Vol. 6, No. 6, pp.580-593, 2002.

[38] A. G. Dempster and M.D.Macleod, “Use of minimum-adder multiplier blocks in FIR digital filters”, *IEEE Transactions on Circuits and Systems II: Analog and Digital Signal Processing*, Vol. 42, No. 9, pp.569-577, 1995.

[39] D. R. Morgan and J.C. Thi, “A delayless subband adaptive filter architecture”, *IEEE Transactions on Signal Processing*, Vol. 43, No. 8, pp.1819-1830, 1995.

[40] V.K. Ingle and J.G. Proakis, “Digital signal Processing using MATLAB”, Chapter 7,*Brooks/Cole Publishing Co.*, 1st Edition, pp. 228-234,1999.