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The Optimal Design of Finite Impulse Response High Pass Filter Using Bee Colony Algorithm

Abstract. *— Digital filters serve an important role in digital signal processing. In this paper, the optimal design of a finite impulse response high-pass filter using the Bee Colony algorithm is discussed. The design of a finite impulse response (FIR) digital filter entails multi-parameter optimization. The goal of this study is to offer a way to high-pass the FIR filter utilizing an evolutionary heuristic search methodology known as the Bee colony algorithm using Kaiser windows. In order to find the most suitable beta and compare it to the designated beta. According to the simulation result, the suggested bee colony algorithm outperforms the original in terms of the main lobe, side lobe, and leakage factor for the 60th-order Kaiser window, and the simulation result of the high-pass filter shows that the side lobe obviously decreases.*

Streszczenie. *Filtry cyfrowe odgrywają ważną rolę w cyfrowym przetwarzaniu sygnału. W artykule omówiono optymalny projekt filtru górnoprzepustowego o skończonej odpowiedzi impulsowej z wykorzystaniem algorytmu Bee Colony. Konstrukcja filtra cyfrowego o skończonej odpowiedzi impulsowej (FIR) wymaga optymalizacji wieloparametrowej. Celem tego badania jest zaoferowanie sposobu na filtr górnoprzepustowy FIR z wykorzystaniem ewolucyjnej metodologii wyszukiwania heurystycznego znanej jako algorytm kolonii pszczół z wykorzystaniem okien Kaisera. Aby znaleźć najbardziej odpowiednią wersję beta i porównać ją z wyznaczoną wersją beta. Zgodnie z wynikami symulacji, sugerowany algorytm kolonii pszczół przewyższa oryginał pod względem listka głównego, listka bocznego i współczynnika nieszczelności dla okna Kaisera 60. rzędu, a wynik symulacji filtra górnoprzepustowego pokazuje, że listek boczny oczywiście maleje.* (***Optymalny projekt filtra górnoprzepustowego o skończonej odpowiedzi impulsowej z wykorzystaniem algorytmu kolonii pszczół***)

Keywords: evolutionary heuristic, high pass fir filter, bee colony algorithm, kaiser window
Słowa kluczowe: Heurystyka ewolucyjna, filtr górnoprzepustowy jodły, algorytm kolonii pszczół, okno Kaisera
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Introduction

Digital filtering is the core element of digital signal processing. The filters have two functions: signal separation (needed when a signal has been contaminated by an additional unwelcome signal, like noise), and signal restoration (used when the desired signal has been degraded for some reason). Either of these issues can be resolved by using analog or digital filters [1-8]. According to their impulse response, digital filters may be divided into two groups: finite impulse response (FIR) filters and infinite impulse response (IIR) filters. The FIR filters have a variety of qualities that make them interesting to a wide spectrum of researchers, and the FIR filters can be easily designed to have a linear phase by having the coefficients symmetric. Also, they is a lot of flexibility in shaping their magnitude response. Implementing them is simple and convenient. [9-19]. Many well-known filter design techniques exist, including the window method, the frequency sampling technique, and optimal filter design techniques. The window approach for designing digital filters is simple and fast. There are several types of window functions available, each of which may be used to satisfy different filter needs, such as ripples in the pass band and stop band, stop band attenuation, and transition width, such as Rectangular [20-21], Hanning [21-22], Kaiser [21-25], and Hamming [21]. Recent methods for the design of FIR filters employ evolutionary techniques that can be increased to be efficient, such as differential evolution (DE) [26], bee colony optimization (BCO) [27-31], particle swarm optimization (PSO) [32-36], ant colony optimization (ACO) [37-38], and bat optimization (BA) [36]. Meta-heuristic algorithms have been used to address optimization issues because they can locate a set of potential solutions (populations) to identify the optimal solution. In designs of high-pass finite-impulse-response filters in the MatLab program's Kaiser window. It was shown that as the beta value increases, the main lobe increases. The main lobe increase reduces the resolution of the frequency, and the test signal will exhibit frequency domain distortion. Therefore, it is desirable to reduce the width of the main lobe to get an effective filter.

This paper builds on the bee colony optimization method used in this study to construct a digital high-pass FIR filter. In order to find the most suitable beta and compare it to the specified beta, simulate through a Kaiser window using a high-pass filter and compare the results. This design requires that the main lobe be fixed to its original value or reduced in size, and the side lobe must be decreased using the Kaiser window by the beta value obtained from the bee colony method.

Materials and methods

Kaiser Window

The Kaiser window is a particular type of tuneable window function that offers independent control of the main lobe width and ripple ratio. However, the Kaiser window has the drawback of having a greater level of computational complexity since it makes use of Bessel functions. The Kaiser window functionality is as follows:

$$w[n] = \frac{I_0\left[\beta\sqrt{1-\left[\frac{n}{N/2}-1\right]}\right]}{I_0(\beta)} \tag{1}$$

In this case, β is an adjustable parameter that regulates the minimum attenuation $A_{sb} = -20log_{10}(\delta_s)$ in the filter stopband and may be predicted extremely precisely as

$$\beta = \begin{cases} 0.1102(A_{sb} - 8.7) & for\ A_s > 50 \\ 0.5842(A_{sb} - 21)^{0.4} + 0.07886(A_{sb} - 21) & for\ 21 \le A_s \le 50 \\ 0 & for\ A_s < 21. \end{cases} \tag{2}$$

The minimal filter order required to achieve the desired stopband attenuation may be calculated using the following formula:

$$N = \frac{2.056A_{sb}-16.4}{2.285(\Delta\omega)} \tag{3}$$

When N is the filter order and Δw is the width of the smallest transition region.

High-pass finite-impulse-response filter design

The fundamental benefit of the FIR filter construction is that it may provide frequency responses that are perfectly linear-phase. The digital FIR filter is distinguished by the following characteristics:

$$H(z) = \sum_{n=0}^{N} h(n) z^{-n}, n = 0,1 \dots N \tag{4}$$

Where N is the order of the filter with (N+1) coefficients, and h(n) is the impulse response of the filter. The values of h (n) dictate the kind of filter, such as low pass, high pass, band pass, and so on. This paper presents the design of a FIR high-pass filter using the bee colony algorithm with beta and filter order (N).

Bee colony Algorithm

The bee approach is a productivity method inspired by bees seeking nectar in order to obtain solutions. Bee species are classified into two types: tiger bees and worker bees. The scout bee's task is to discover a nectar source at random and locate a source of nectar within the scope of possible answers. When the Scout bee discovers the solution, it returns to the beehive. Bees use varied dance styles to communicate with other bees in the hive, indicating the amount and direction of the nectar supply. The employee bee then returns to the beehive. The quantity of worker bees varies with the amount of nectar and the distance traveled. The following steps are included in the bee colony algorithm:

Step 1: As stated in Table 2, determine the variables in the bee algorithm.

Step 2: A random sample of pollinating scout bees (n) was picked to determine the beta parameters and set the number of iteration cycles NC=0.

Step 3: Evaluate the outcomes of the scout bee search. Will be displayed in descending order. This will make it easier to pick an appropriate response. And select the best answer (m).

Step 4: Separate the (m) responses into two groups. The first group got the best answer (e), whereas the second group got the second-best answer (m-e).

Step 5: Limit your search to the best response area (m).

Step 6: Have the employed bees (nep) look for answers around (e) and a number of employed bees (nsp) look for answers around (m-e). And evaluate the results of the employed bee search responses at each site. and select the best answer from each source.

Step 7: Use the bee colony method to optimize the design of the detailed response filter by testing the evaluation values of the bee search response at each source (from step 6).

Step 8: Examine the stopping conditions. Stop the search if the prerequisites are satisfied. If the condition is not fulfilled, increase the number of iterations by NC = NC + 1, where the condition is the maximum iteration.

Step 9: Assign scout bees (n-m) the task of finding new replies. and then return to step 2.

As an example, all parameters are analyzed using a MATLAB program with a cut-off frequency of 10800 Hz, a sampling frequency of 48000 Hz, a filter order of 60, and a parameter beta ranging from 0, 2, 4, and 6. The measured frequency response of the Kaiser window function is shown in Fig. 1, and Table 2 provides the main lobe width, relative side lobe attenuation, and leakage factor. From table 2, it shows The main lobe width increases as the parameter beta increases, and the leakage factor also drops when the relative side lobe attenuation decreases.

Table 1. The parameters are used in the bee colony algorithm.

variable	Description	parameter value
n	Numbers of scout bees.	50
m	The number of nectars with the volume of nectar from the search of scout bees (n)	25
e	The number of nectars with the largest amount of nectars from the selected number of sources (m)	10
n_{ep}	The number of employed bees to locate the nectar source (e)	20
n_{sp}	The number of bees employed to locate the nectar source (m-e)	30
n_{gh}	size of the scope of the search for each source of nectar.	0.5
NC	Repeat Count.	15

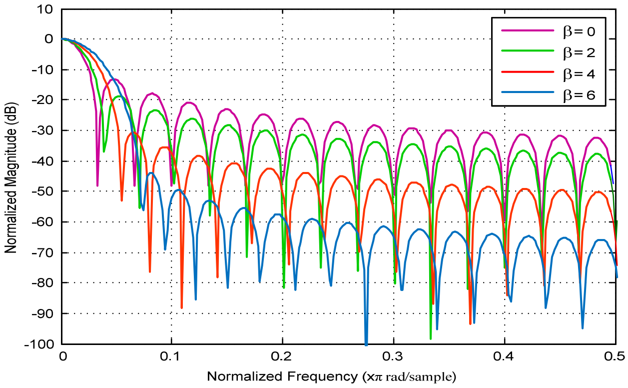

Fig.1. Magnitude response plot of Kaiser's window

Table 2. shows the main lobe width, relative side lobe attenuation, and leakage factor with the Kaiser window function.

Variable parameter beta	Length of Window function	Time Domain		Frequency Domain		
		Max. Amp	Min. Amp	Mainlobe width (-3dB)	Relative side lobe Attenuation	Leakage Factor
0	60	1	1	0.027344	-13.3 dB	9.17 %
2			0.44	0.031250	-18.7 dB	2.39 %
4			0.09	0.039063	-30.6 dB	0.11 %
6			0.01	0.046875	-44.1 dB	0 %

The parameters in Table 2 are used in a high-pass filter with a cut-off frequency of 10800 Hz, a sampling frequency of 48000 Hz, a filter order of 60, and a parameter beta of 0, 2, 4, and 6. As can be observed from Fig. 2 and Table 3, a rise in beta causes the main lobe to expand while side lobe attenuation decreases and transition bandwidth increases. The Kaiser window and the high-pass filter design both provide equivalent outcomes.

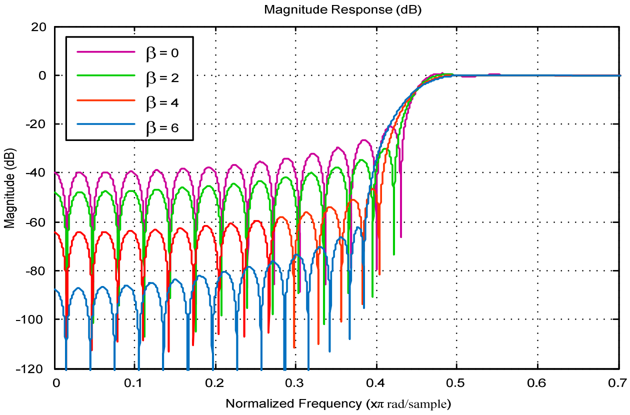

Fig.2. High pass FIR filter using Kaiser's window

Table 3. Kaiser window function is used to calculate the transition bandwidth, main lobe width (-3 dB), and side lobe attenuation in a high-pass finite-impulse-response filter.

Variable parameter beta	Length of Window function	Transition bandwidth	Mainlobe width (-3dB)	Sidelobe attenuation (dB)	
				Sidelobe max	Sidelobe min
0	60	0.0240833	0.4571544	-21.78241	-39.92366
2		0.0345506	0.4589907	-30.16711	-47.77296
4		0.0560413	0.4619280	-46.56368	-64.34294
6		0.0782670	0.4644597	-62.14711	-87.45897

Table 4 shows the main lobe width, relative side lobe attenuation, and leakage factor with the Kaiser window function and using the parameters improved with bee colony optimization.

Variable parameter beta	Length of Window function	Time Domain		Frequency Domain		
		Max Amp	Min . Amp	Mainlobe width (-3dB)	Relative side lobe Attenuation	Leakage Factor
0	60	1	1	0.027344	-13.3 dB	9.17 %
0.6455			0.90		-13.9 dB	7.9 %
1.3248			0.67		-15.8 dB	4.96 %
2			0.44	0.031250	-18.7 dB	2.39 %
2.3468			0.34		-20.5 dB	1.51 %
2.5732			0.29		-21.7 dB	1.1 %
4			0.09	0.039063	-30.6 dB	0.11 %
4.4224			0.06		-33.4 dB	0.05 %
4.7098			0.03		-35.3 dB	0.03 %
6			0.01	0.046875	-44.1 dB	0 %
6.5418			0.009		-47.7 dB	0 %
7.0549			0.005		-51.3 dB	0 %

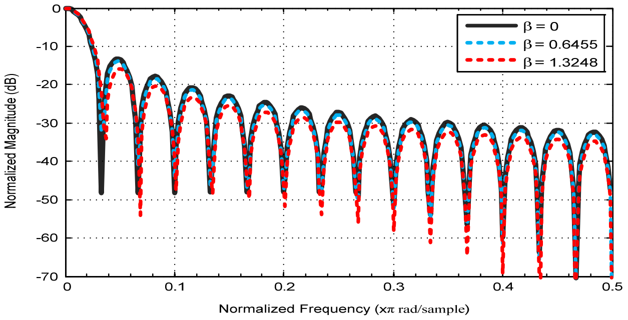

Fig.3. Magnitude response plot of Kaiser's window function using Bee colony Algorithm at Beta = 0, 0.6455, 1.3248.

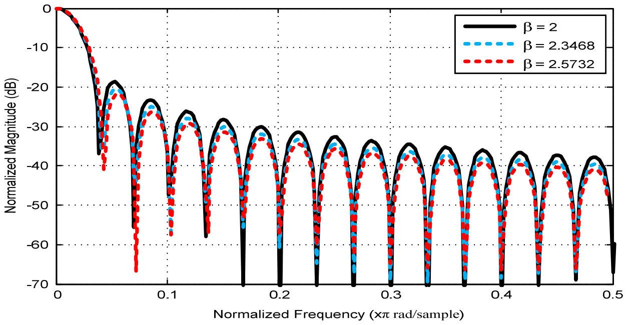

Fig.4. Magnitude response plot of Kaiser's window function using Bee colony Algorithm at Beta = 2, 2.3468, 2.5732

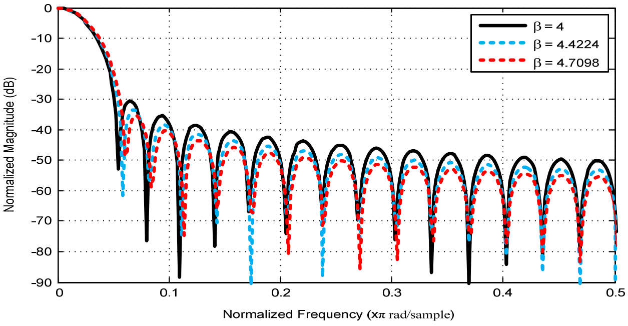

Fig.5. Magnitude response plot of Kaiser's window function using Bee colony Algorithm at Beta=4, 4.4224, 4.7098

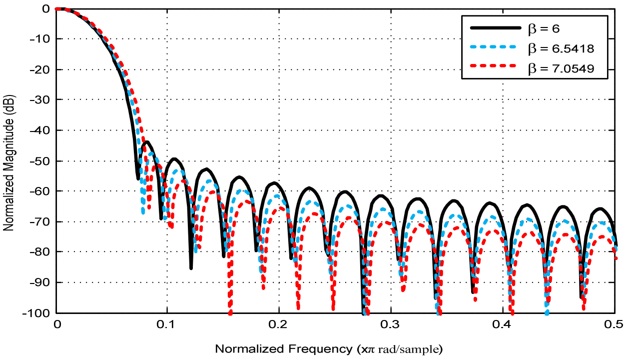

Fig.6. Magnitude response plot of Kaiser's window function using Bee colony Algorithm at Beta=6, 6.5418, 7.0549

Figs. 3-6 display the Kaiser window function's measured frequency response when using the bee algorithm. Table 4 displays the leakage factor, side lobe attenuation, and main lobe width. According to Table 4, when the parameter beta increases from 0 to 1.3248, the main lobe width stays the same at 0.027344, but the side lobe attenuation decreases from -13.3 dB to -15.8 dB, and the leakage factor decreases from 9.17% to 4.96%. While the parameter beta increases from 2 to 2.5732. The main lobe width stays the same at 0.031250, the side lobe attenuation decreases from -18.7 dB to -21.7 dB, and the leakage factor drops from 2.39% to 1.1%. Parameter beta increases from 4 to 4.7098, but the main lobe width stays the same at 0.039063, the leakage factor drops from 0.11% to 0.03%, and side lobe attenuation drops from -30.6 dB to -35.3 dB. and parameter beta rises from 6 to 7.0549, the main lobe width stays the same at 0.046875, but the side lobe attenuation falls from -44.1 dB to -51.3 dB, and the leakage factor stays unchanged.

Figs. 7–10 display the high-pass finite-impulse-response filter's measured frequency response when using the Bee algorithm. Table 5 displays the transition bandwidth and side lobe attenuation. According to Table 5, when the parameter beta increases from 0 to 1.3248, the transition bandwidth value increases from 0.0240833 to 0.0289991, and the side lobe attenuation decreases from -21.78241 dB to -25.74206 dB. While the parameter beta increases from 2 to 2.5732, the transition bandwidth value increases from 0.0345506 to 0.0402483, and the side lobe attenuation decreases from -30.16711 dB to -34.65221 dB. Parameter beta increases from 4 to 4.7098, the transition bandwidth value increases from 0.0560413 to 0.0699726, and the side lobe attenuation decreases from -46.56368 dB to -52.16200 dB. and parameter beta rises from 6 to 7.0549, the transition bandwidth value increases from 0.0782670 to 0.0902198, and the side lobe attenuation decreases from -62.14711 dB to -71.17314 dB.

Table 5 shows the transition bandwidth, main lobe width (-3 dB), and side lobe attenuation with the high-pass finite-impulse-response filter and using the parameters improved with bee colony optimization.

Variable parameter beta	Length of Window function	Transition bandwidth	Mainlobe width (-3dB)	Sidelobe attenuation (dB)	
				Sidelobe max	Sidelobe min
0	60	0.0240833	0.4571544	-21.78241	-39.92366
0.6455		0.0253061	0.4573904	-22.77106	-40.87151
1.3248		0.0289991	0.4580666	-25.74206	-43.67156
2		0.0345506	0.4589907	-30.16711	-47.77296
2.3468		0.0379171	0.4595068	-32.82506	-50.24173
2.5732		0.0402483	0.4598480	-34.65221	-51.95864
4		0.0560413	0.4619280	-46.56368	-64.34294
4.4224		0.0607742	0.4625005	-49.92946	-68.51495
4.7098		0.0699726	0.4628778	-52.16200	-71.50985
6		0.0782670	0.4644597	-62.14711	-87.45897
6.5418		0.0843548	0.4650765	-66.63231	-97.01792
7.0549		0.0902198	0.4656385	-71.17314	-110.4903

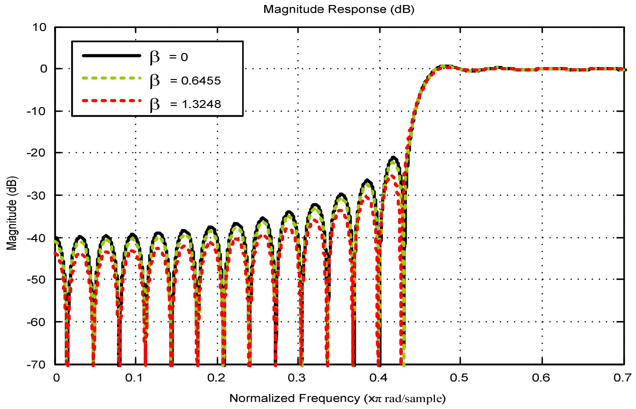

Fig.7. High pass FIR filter using Kaiser's window at Beta=0, 0.64556, 1.3248

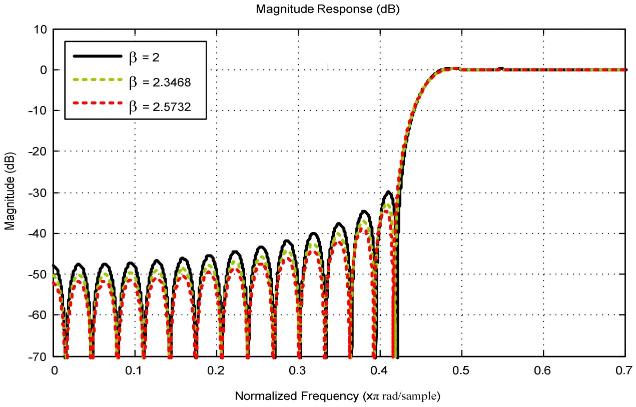

Fig.8. High pass FIR filter using Kaiser's window at Beta=2, 2.3468, 2.5732

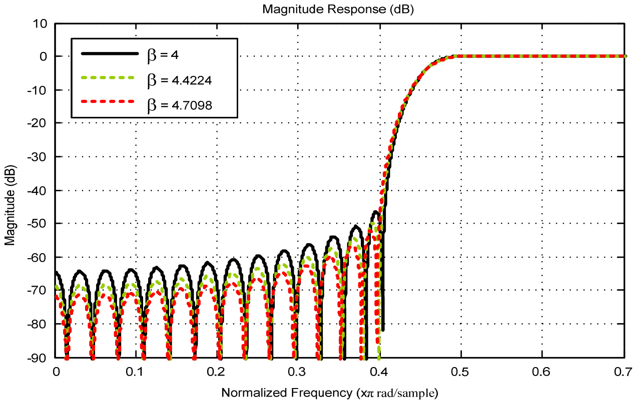

Fig.9. High pass FIR filter using Kaiser's window at Beta=4, 4.4224, 4.7098

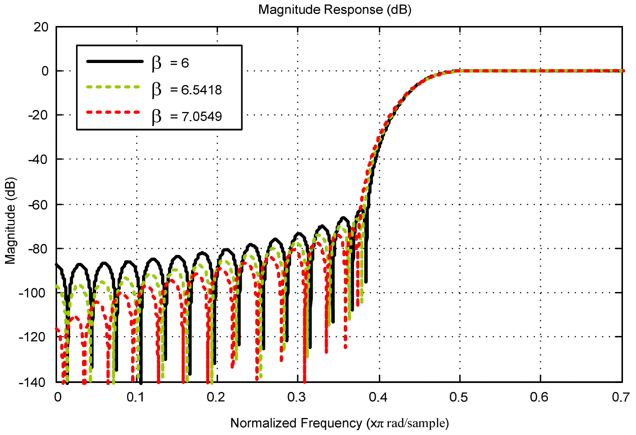

Fig.10. High pass FIR filter using Kaiser's window at Beta=6, 6.5418, 7.0549

Conclusions

In this paper, the bee colony optimization method is used to construct a digital high-pass FIR filter. In order to find the most suitable beta and compare it to the designated beta. The design of the FIR filter with Kaiser Windows improves with bee colony optimization, showing that when the beta increases, the main lobe value remains constant while the side lobe and the leakage factor decrease. After that, parameters improved with bee colony optimization were used to design the high-pass filer. The simulation result of the high-pass filter shows the transition bandwidth and main lobe width only show a slight change, while the side lobe clearly decreases, which results in the filter being more efficient.

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