

# Performance of Ternary Sequence using Basic Cuckoo Search Algorithm



K. Renu, P. Rajesh Kumar

**Abstract:** Matched filtering is broadly used in various radar applications and communication fields whose output indicates some range sidelobes which may mask some stronger targets. This problem can be overcome by using mismatched filter after the matched filter which increases the performance that is in terms of peak sidelobe ratio. The proposed algorithm is suitable to obtain superior performance in range resolution and detection range simultaneously. The characteristics of chaotic codes such as auto-correlation and cross-correlation are same as random codes. So the input is considered as binary and ternary chaotic sequence which is undergone matched filtering process which is then undergo mismatched filter for further reduction in the sidelobe levels. The design of mismatched filter is adapted with cuckoo search algorithm that uses Lévy distribution. It is observed that the performance of the ternary sequence is significantly improved at the output and this method is extended to various length of ternary sequences.

**Keywords:** Autocorrelation function (ACF), Cuckoo Search(CS) method, Matched Filtering(MF), Mismatched filter(MMF), Pulse compression, Peak sidelobe ratio(PSLR).

## I. INTRODUCTION

With the necessity of restriction in peak power the resolution of short pulses is obtained using pulse compression. There is a constant need of increasing the accuracy and range resolution in modern radar and ultrasonic systems which can be met by using pulse compression technique. Matched filtering is the best example of pulse compression which creates unwanted sidelobes. The existence of range sidelobes is the major drawback of pulse compression which decreases the range resolution for closely spaced targets and results in weak sidelobe suppression [1]. The valuable message or information is masked with these sidelobes that results in unwanted gain. Most of the research work has been completed in the design of radar filters that suppresses these range sidelobes. This problem is overcome by using mismatched filter (MMF) at the receiver. The output of the mismatched filter is the cross-correlation meaning thereby correlation between the input sequence and the receiver filter weights [2]. In this paper the length of the mismatched filter is assumed to be thrice the length of the input code.

Recently Nunn [3] proposed that the optimization should start with the signal that is having low peak and integrated sidelobe levels. As per this idea N. Levanon designed a mismatched filter that optimizes both peak sidelobe ratio and integrated sidelobe ratio [4]. Ackroyd and Ghani optimized the design of mismatched filter by using least square method where the outputs of ideal and inverse filter are compared [5]. Afterwards Zoraster reported the design of mismatched filter whose filter coefficients are optimized in order to maximize amplitude of mainlobe level and reduce the sidelobe level [6].

The study of mismatched filter is more demanding whose coefficients can be obtained by cross-correlation of different input codes such as barker, binary and ternary chaotic sequences [7]- [9]. The study of those sequences in terms of peak sidelobe ratio was discussed earlier [10]- [12]. The deterministic nature of this chaos generates various sequences with a small change in initial condition [13], [14]. Here chaotic equation is used to generate input sequences. In radar, phase coding is one of the method that combines transmitted signal and the information that is to be compressed at the receiver. The autocorrelation of these signal attains small value of peak sidelobe level in its output pattern.

This paper is organized with two techniques of design of mismatched filter. First one design is directly by using differential evolution (DE) algorithm and the second method is by using cascade filter which is the combination of two mismatched filters. In cascaded filter the filter coefficients are optimized first with the help of differential evolution and then with cuckoo search method. Finally, the performance of the ternary chaotic sequence is studied when the output from mismatched filter is given as input to adaptive filter.

## II. PROBLEM FORMULATION

In pulse compression, the transmitted signal in the form of codes represents the phase of the carrier. Phase coded pulse compression is mainly used to increase the resolution and accuracy in pulse radar system which depends on sidelobe level. These sidelobe levels can be reduced with proper design of mismatched filter weights. This paper interprets the basic cuckoo search algorithm that is used to obtain optimum filter weights. The implementation procedure of this algorithm is similar to that of particle swarm optimization (PSO) and differential evolution (DE) technique which are proposed earlier [15], [16] that reduces the sidelobe levels at its output.

The aperiodic autocorrelation function of binary and ternary sequences that uses alphabets  $\pm 1$  and  $0$ ,  $\pm 1$  respectively for positive delays 'k' as in (1) below

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$$S_k = \sum_{i=0}^{N-1-k} a_i a_{i+k} \quad \text{for } k = 0, 1, 2, \dots, N-1 \quad (1)$$

Equation (1) represents the output of matched filter. However, the output of mismatched filter is defined in (2).

$$G_k = \sum_{i=0}^{M-1} h_i a_{i-k} \quad (2)$$

for 'k' ranging from  $-(N-1)$  to  $(M-1)$

Here 'N' represents length of the binary or ternary sequence and 'M' represents length of filter.

#### A. Objective Function:

In radar performance analysis peak sidelobe level is one of the most important parameter. The peak sidelobe ratio at the In radar performance analysis peak sidelobe level is one of the most important parameter. The peak sidelobe ratio at the output of matched filter is compared with the peak sidelobe ratio of mismatched filter along with peak of the sidelobe. The output of mismatched filter is observed as asymmetric.

The normalization of the output of the mismatched filter restricts all sidelobe levels to be less than or equal to one. The optimized mismatched filter results in minimization of sidelobes. The objective function compared in this work is defined in (3)

$$PSLR = 20 * \log_{10} \frac{|sideobe\ maximum|}{|mainlobe\ maximum|} \quad (3)$$

$$Mainlobe\ maximum = \max(S_k) \text{ or } \max(G_k)$$

### III. PROPOSED ALGORITHM

The method adapted in this paper is represented in the block diagram as shown in Fig. (1) that uses differential evolution along with cuckoo search algorithm for the design of cascaded mismatched filter. Cuckoo search method is a meta-heuristic evolutionary optimization algorithm inspired by Yang and Deb (2009) [17] which follows brood parasitic behaviour of cuckoo species found in nature. It is an algorithm which has been successfully adapted to solve various number of problems in different areas.

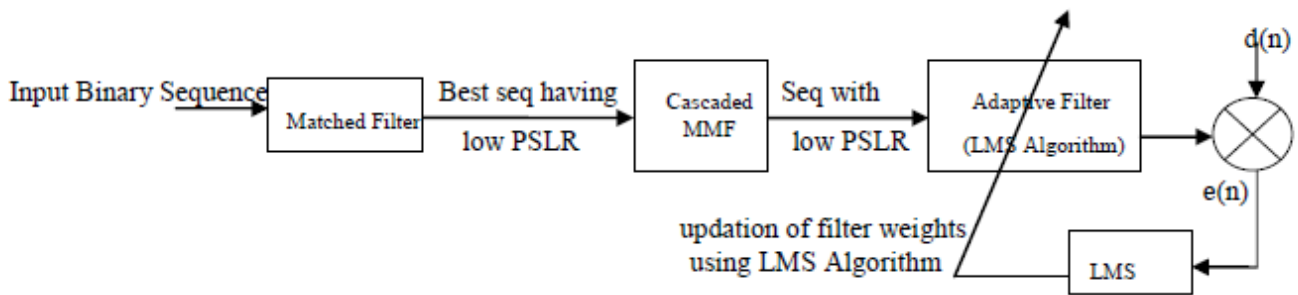


Fig. 1 Block diagram representation of proposed work

Cuckoos have the capability of aggressive reproduction nature that makes cuckoos lay their eggs in host bird's nest. But if it discovers that the eggs are not inherent then those eggs will be thrown away or the cuckoo will destroy its own nest and make a new nest somewhere. The inherency is checked by the probability 'p<sub>a</sub>'.

Cuckoo search deals with the grouping of searching process in two phases. They are global phase and local phase. The global phase corresponds to exploration whereas local phase describes the exploitation. In global phase Lévy flight is used for random walk instead of Gaussian walks which is having some features such as heavy tail, infinite mean and variance [18]. This increases the exploration capability of searching efficiently. However local phase is carried out with the selection of two random walks or solutions that is controlled by a certain probability. Many cuckoos follow Markov chain, a random walk, where the next position is evaluated by using present location of cuckoo and the probability of transition to next position.

With the above analysis it is concluded that the working capability of cuckoo search algorithm depends on three factors. First factor is the Lévy flight global random walk obtained by using exploration search. Second factor is local random walk that is based on exploitation search and the third is the switching probability. The switching probability is one of the essential factor that determines the scope of exploitation and exploration. The main purpose of this

technique is to get a potentially better solution. Each egg represents one solution.

The above three factors of cuckoo search help to generate new solutions for ith cuckoo in Lévy flight using global random search and local random search which are given in (4) & (5).

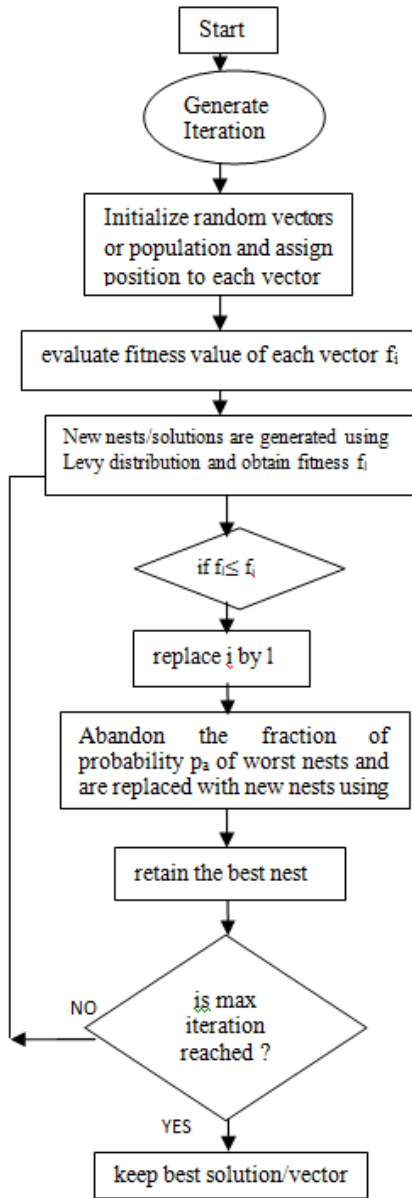
$$x_i^{t+1} = x_i^t + \alpha \otimes Lévy(s, \lambda)(x_{best} - x_i^t) \quad (4)$$

$$x_i^{t+1} = x_i^t + \alpha \otimes H(p - \epsilon) \otimes (x_j^t - x_k^t) \quad (5)$$

Where  $x_i^{t+1}$  and  $x_i^t$  defines current and preceding solution respectively and 'α' is the factor that determines the step size. The symbol  $\otimes$  represents entry wise multiplication.  $x_j^t$  &  $x_k^t$  are the random solutions and  $Lévy(s, \lambda)$  is the step lengths distribution which is based on probability distribution as in (6) below that has an infinite variance and mean.

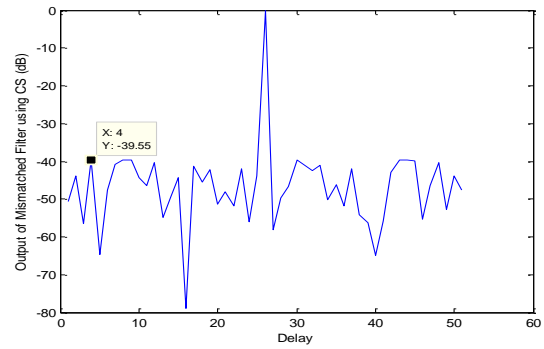
$$Lévy(s, \lambda) = \frac{\lambda \Gamma(\lambda) \sin(\frac{\pi \lambda}{2})}{\pi} \frac{1}{s^{(1+\lambda)}} \quad (6)$$

**B. Basic Cuckoo Search Algorithm Flowchart**



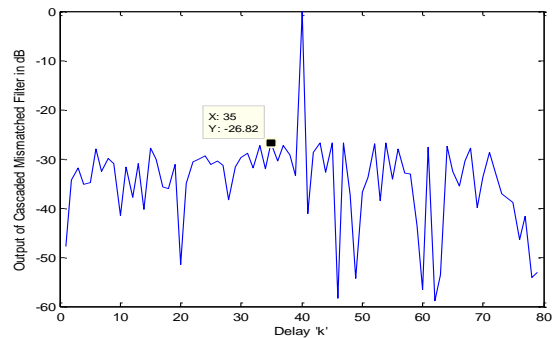
**IV. SIMULATION RESULTS**

A detailed analysis of the performance of ternary sequence is carried out with mismatched filter. In this paper random population is considered as input of mismatched filter. The weights of the cascaded filter are optimized with the help of differential evolution and cuckoo search method simultaneously. The ternary sequence of length 20 has the PSLR value of -17.5012dB. But by using cascaded mismatched filter this value is decreased to -26.8222 dB. The output of MMF is asymmetric about the delay 'k'. In all this analysis the population size and the number of iterations are taken as 200 each. The switching probability is considered as 0.5. Further optimization of the performance is achieved at the output of adaptive filter whose coefficients are updated with least mean square algorithm. The cross-correlation of optimized code which is having lowest sidelobe ratio is considered as input to adaptive filter. With a very less number of iterations the PSLR value is reduced to -53.9799 dB.



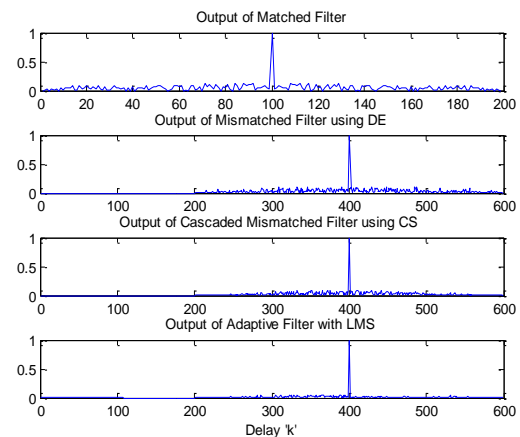
**Fig. 2 cascaded Mismatched Filter output for barker code**

Fig. (2) and Fig. (3) shows the output from cascaded mismatched filter for 13-bit barker code and ternary sequence of length 20.



**Fig. 3 Output response of proposed Mismatched Filter for Ternary sequence of length 20**

The output response of matched filter, mismatched filter with differential evolution and the mismatched filter with cuckoo search method for the sequence length 100 is shown in Fig. (4).



**Fig.4 Graphs obtained at output of matched, mismatched and adaptive filter for ternary sequence of length 100**

The comparison of peak sidelobe ratio obtained from the output of matched filter for chaotic sequences of different lengths and from mismatched filter is shown in I &II. The graphical comparison corresponds to tables are shown in Fig. (5) and Fig. (6).

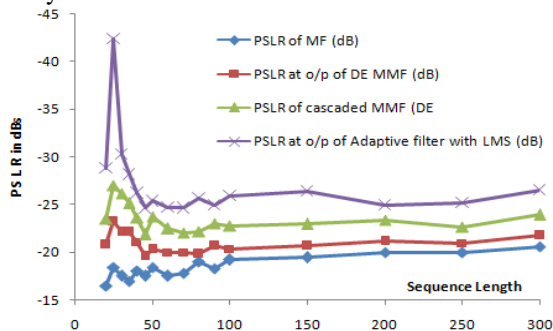
**Table. I Comparison of PSLR of Binary sequence from MF, cascaded MMF and adaptive filter**

Length of Seq	PSLR of MF (dB)	PSLR at o/p of DE MMF (dB)	PSLR of cascaded MMF (DE & CS) (dB)	PSLR at o/p of Adaptive filter with LMS (dB)
20	-16.4782	-20.7694	-23.4621	-28.8162
25	-18.4164	-23.1768	-26.9825	-42.3336
30	-17.5012	-22.0723	-26.1239	-30.2388
35	-16.9020	-22.1175	-25.0939	-28.1379
40	-18.0618	-21.0548	-23.5701	-26.1982
45	-17.5012	-19.5825	-21.8294	-24.6039
50	-18.4164	-20.3219	-23.7248	-25.3596
60	-17.5012	-19.9886	-22.4364	-24.6779
70	-17.8171	-19.9730	-22.0204	-24.6177
80	-18.9769	-19.8334	-22.1476	-25.6174
90	-18.2570	-20.6223	-22.9698	-24.9429
100	-19.1721	-20.3294	-22.7254	-25.8682
150	-19.4394	-20.6149	-22.9106	-26.4011
200	-20	-21.1325	-23.3471	-24.9530
250	-20	-20.9692	-22.5978	-25.1684
300	-20.5993	-21.7702	-23.9172	-26.5242

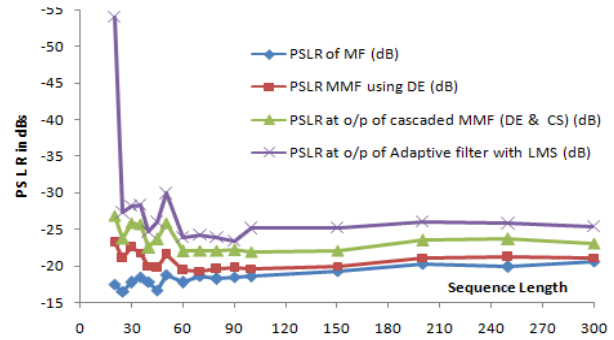
**Table. II Comparison of PSLR of ternary sequence from matched and mismatched filter**

Length of Seq	PSLR of MF (dB)	PSLR MMF using DE (dB)	PSLR at o/p of cascaded MMF (DE & CS) (dB)	PSLR at o/p of Adaptive filter (dB)
20	-17.5012	-23.1829	-26.8222	-53.9799
25	-16.4782	-21.0678	-23.7660	-27.2731
30	-17.6921	-22.4974	-25.8191	-28.1449
35	-18.4164	-21.7863	-25.6473	-28.3533
40	-17.7860	-19.9883	-22.5042	-24.6469
45	-16.6502	-19.7456	-23.6289	-26.0254
50	-18.8402	-21.5472	-25.8885	-29.8739
60	-17.6921	-19.4415	-21.9843	-23.9048
70	-18.5884	-19.3255	-22.0322	-24.2507
80	-18.2155	-19.5677	-22.1040	-23.8932
90	-18.4597	-19.7554	-22.1352	-23.3868
100	-18.5314	-19.6092	-21.9533	-25.1449
150	-19.2442	-19.9618	-22.0920	-25.2078
200	-20.2848	-21.1365	-23.4703	-26.0545
250	-19.8618	-21.2470	-23.6532	-25.7810
300	-20.5993	-21.1012	-23.0367	-25.3911

It is observed from the figure that the value of peak sidelobe ratio is increased with the mismatched filter than with matched filter. When the ternary sequence with good PSLR is given as input to cascaded MMF in which first filter is designed with the help of differential evolution and second filter is designed by using cuckoo search method, the peak sidelobe ratio is significantly improved. The detailed analysis can be observed from the tables.



**Fig.5 Comparison of PSLR of Binary Sequence**



**Fig.6 Comparison of PSLR of ternary sequence**

**V. CONCLUSION**

In this paper cuckoo search algorithm is proposed to estimate the performance of binary and ternary chaotic sequence. The effectiveness of this algorithm demonstrates the improvement in the performance. The design of mismatched filter using PSO and DE has been reported in literature survey. The PSLR of cascaded mismatched filter are compared with that of differential evolution algorithm. It is found from the analysis that it supplies more robust and precise results as compared to DE MMF. The filter length should proportionally increase with length of the sequence. But it causes some difficulties in practical applications and system complexity also increases. This work is proposed for barker, binary and ternary chaotic codes and observed the PSLR values at lower lengths only. It is also observed that with increase in number of iterations the value of PSLR will proportionally increase.

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