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A SURVEY ON PERFORMANCE OF CHAOTIC SEQUENCE USING MISMATCHED FILTER WITH DEIWO ALGORITHM

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ABSTRACT

Pulse compression is a well-established technique used in radar which is obtained by correlating the received reflection with input reference pulse. Matched and mismatched filter plays a unique role in pulse compression. The major drawback of pulse compression lies in its poor sidelobe reduction which can be overcome with a mismatched filter at the receiver. This paper extends the concept of Invasive weed optimization (IWO) algorithm with differential evolution to design the coefficients of the mismatched filter. IWO is a meta-heuristic algorithm with a dynamic optimization characteristic which follows randomness and compatibility in various environmental condition to find global optima. This method shows the diversion of the population with a heuristic global search of differential evolution (DE) method. IWO provides a global exploration search during iterations that improves the searching area of DE. Whereas at the same time DE acts as a reliable guide for IWO. In this paper, the chaotic sequence is considered as input to mismatched filter whose weights are designed with IWO and DEIWO algorithm because the characteristics of chaotic sequence are same as that of random sequence. It is observed from simulation results that the performance is improved with DEIWO compared to simply IWO. Better results are obtained when the sequence is processed through adaptive filters.

Keywords: matched filter, mismatched filter, pulse compression, peak sidelobe ratio, invasive weed optimization, differential evolution invasive weed optimization, adaptive filters.

1. INTRODUCTION

In modern radar systems, increased range resolution with limited peak power is achieved with pulse compression technique. The pulse compression not only increases the operating range of radar but also maintains the desired range resolution [1]. The transmission of long pulse increases the ability of detection while short pulse retains the range resolution. Pulse compression is achieved with matched filtering. The undesirable sidelobes at the output of matched filter may give false detection of target which is the major drawback of this technique. The weak target echoes will be properly distinguishable from stronger one if and only the sidelobes are at comparatively low level. Therefore, it is essential to reduce the sidelobes by using various optimization techniques [2]. The ratio of mainlobe peak to sidelobe peak, abbreviated as PSLR measured in dB, should be minimum to avoid undesired clutters at the output. Due to the requirement of increased value of peak sidelobe ratio (PSLR) of binary barker sequence, longer length binary sequences are generated and analyzed by Linder, Boehmer, Rao and Reddy [3,4,5]. But it is violating the minimum PSLR for longer sequences.

This leads to the necessity of multilevel sequence such as ternary code. It consists of three elements -1, 0, +1. Bateni and Mcgillen [6] discussed the characteristics of the ternary codes that are obtained from chaotic map. The chaos theory is widely used in chaotic systems which is highly sensitive to initial conditions [7,8]. Best code is filtered out according to their peak to sidelobe ratio i.e. code with low PSLR is considered as good sequence. Generally, optimization is applied to various kinds of pulse compression filters such as matched filter. Matched filtering produces unwanted sidelobes which can be overcome with the help of mismatched filter by proper design of filter coefficients. These coefficients are evaluated by using original cuckoo search algorithm and by enhanced versions of cuckoo search as reported earlier [9, 10, 11].

This paper investigates and compares the performance of the chaotic sequence that is obtained with chaotic map such as logistic map and improved logistic map. This analysis is carried out by using matched filter, mismatched filter and adaptive pulse compression filter. Here the weights of mismatched filter are computed by using Invasive Weed Optimization (IWO) method and Differential Evolution IWO (DEIWO) method. IWO is a population based and iteration-based algorithm suggested by Mehrrabian and Lucas in the year 2006 [12]. Weeds have a characteristic of heavily growth that causes severe hazard to other plants. At the same time, it is highly attractive due to its stability and adaptability. Therefore, this method is suitable for various optimization problem in different fields such as optimum design of antenna and telecommunication. It was reported earlier that the optimum performance is achieved with differential IWO [13], IWO with differential evolution algorithm and modified IWO. IWO was also employed with PSO and firefly algorithm for performance improvement.

This paper is formulated in following manner. Section II describes the original invasive weed optimization technique. The design steps of the proposed method which is the combination of DE and IWO is described in section III. Simulation and comparison results of optimal binary and ternary chaotic sequence are discussed in section IV. And finally we have some conclusions in section V.

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2. PROBLEM IDENTIFICATION

Two types of chaotic map code are considered as input to pulse compression filter which are obtained as follow:

Logistic Map: $x_{n+1} = r * x_n * (1 - x_n)$ (1)

Improved Logistic Map: $x_{n+1} = 1 - 2 * (x_n)^2$ (2)

Logistic Map shows its chaotic behavior with 'r' as 4 and with initial value of 'x' between 0 to 1 whereas for improved logistic the initial value of 'x' is between -1 to 1. Equation (1) and (2) generates random sequences which is converted to binary logistic map and improved logistic map code with only one optimization level chosen as 0.5 and 0 respectively. Similarly the ternary codes are obtained with quantization levels chosen as 0.3, 0.7 for logistic map and 0.7, -0.7 for improved logistic map sequences. The fitness function is peak sidelobe ratio that is defined in equation (3) below

$$\text{pslr} = 20 \log 10\ (1/(\text{Discrimination Factor})) \quad (3)$$

Discrimination Factor = mainlobe maximum/peak sidelobe
ASP = sidelobe peak

The best code with minimum objective function is cross-correlated with mismatched filter weight of length three times longer than that of input chaotic codes to achieve minimum peak sidelobe ratio.

If the Input chaotic code $x = [x_0, x_1, x_2 \ldots. x_N]$ thenFilter weights $F = [f_0, f_1, f_2, \ldots\ldots f_M]$, where M=3*N and F is arranged as [z F z], where z is a zero padded sequence of length N. Optimum sequence and the corresponding fitness function is obtained with the proposed method.

3. METHODOLOGY ADAPTED

A hybrid method is used in this paper that depends on the population diversity of IWO. This diversity in population improves the ability of global search and the heuristic nature increases the searching capability in local phase. The performance of this method was compared for various benchmark problems [14]. The block diagram of proposed method is clearly shown in Figure-1. The advantage of using this method is that it has high accuracy and faster convergence characteristics. Each weed represents a solution and number of weeds combined together to form a population. New weeds are generated in each iteration that depends on the fitness function of each weed. These weeds have the characteristics of random distribution over the entire search space. The weeds with best fitness value will survive for next generation and the remaining will eliminate.

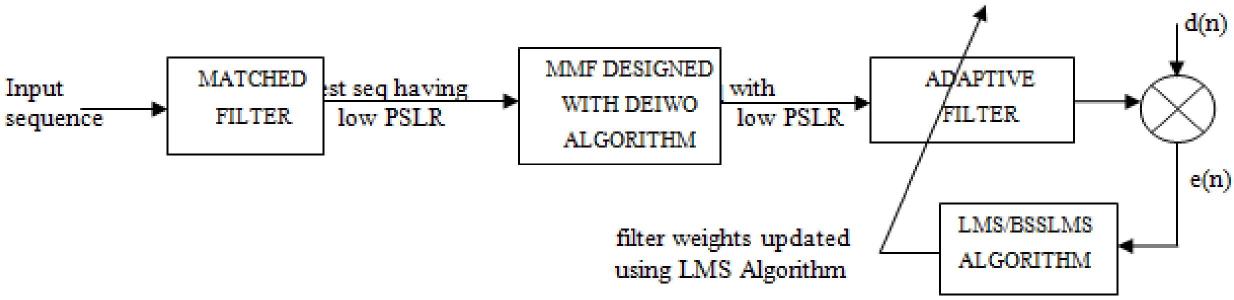

Figure-1. Block diagram representation of the proposed method.

The algorithm is clearly explained below.

Step 1: Initialization of population. A large number of solutions are initialized and spread over the search space which are assigned with random positions.

Step 2: New seeds are obtained as per the equation (4) below that is based on the fitness value of each weed.

$$weed = \frac{f - f_{\min}}{f_{\max} - f_{\min}}(w_{\max} - w_{\min}) + w_{\min} \quad (4)$$

where f represents fitness value of present weed, f_{max} and f_{min} are highest and lowest value of fitness. w_{max} and w_{min} are the maximum and minimum value of weed.

Step 3: The seeds are randomly spread at the neighborhood of parent weed in the search space with a mean of zero and changing variance. The standard deviation is obtained by making the square root of variance. This value is decreased in every iteration from $\sigma_{initial}$ to σ_{final} as defined in equation (5) below

$$\sigma_{pres} = \frac{(it_{\max} - it_{pres})^p}{(it_{\max} - 1)^p}(\sigma_{initial} - \sigma_{final}) + \sigma_{final} \quad (5)$$

where $it_{\max}$ and $it_{\min}$ are maximum and current iteration values respectively. $\sigma_{initial}$ and σ_{final} being the initial and final value of standard deviation. 'p' is the non-linear modulation index whose value is considered as 3.

Step 4: This is the step where the competition appears between the plants to restrict the maximum number in a colony. At first, the speed of reproduction of plants is high. The reproduced plants will accommodate in the colony when the number of plants or weeds reaches maximum value of population. The seeds are then ranked together with the weeds. The weeds with large fitness are allowed to survive next to replicate.

DEIWO ALGORITHM

Start

Initialize random population that consists of DEIWO individuals

Define D-dimensional objective function

While iteration number <= maximum number of iteration

evaluate fitness of each individual's

Obtain the number of offspring of each individuals

$$weed = \frac{f - f_{\min}}{f_{\max} - f_{\min}}(w_{\max} - w_{\min}) + w_{\min}$$

update the standard deviation σ_{pres}

$$\sigma_{pres} = \frac{(it_{\max} - it_{pres})^p}{(it_{\max} - 1)^p}(\sigma_{initial} - \sigma_{final}) + \sigma_{final}$$

New seeds are obtained in the search space and add to the solution set.

If the number of weeds and seeds equals to size of population then truncate the population of weeds having higher fitness until it reaches maximum population

End if

Mutation process (individuals to mutate)

$$M_i^t = X_i^t + S * (X_{best}^t - X_i^t) + S * (X_{n1}^t - X_{n2}^t) \quad (6)$$

Crossover operation (individuals to crossover)

$$C_{i,j}^t = \begin{cases} M_{i,j}^t if rand \le CR \\ X_{i,j}^t otherwise \end{cases} \quad (7)$$

Selection of individuals based on their fitness value

$$X_i^{t+1} = \begin{cases} U_i^t & if\ \ objf(U_i^t) < objf(X_i^t) \\ X_i^t & otherwise \end{cases} \quad (8)$$

End while

Display the best weed (individual) and the best fitness value.

End

In IWO method, best weeds are selected from the population that consists of both weeds and seeds. As per Storn and Price the differential evolution method comprises of mutation, crossover and then selection operations [15, 16]. The advantages of DE such as simplicity, versatility, robustness and good dynamic searching capability makes it interesting to use with different optimization methods. However differential evolution invasive weed optimization (DEIWO) algorithm speed up the process by drifting each weed of present iteration towards the best individual. This increases the accuracy and speed of DEIWO compared to IWO method. The mutant vector in DE is obtained with eq (3) where X_{best}^t is the best solution from the present iteration. X_i^t, $X_{n1}^t$and $X_{n2}^t$are the individuals chosen in a random fashion such that $i \neq n_1 \neq n_2$. The scaling factor is a constant value chosen between 0 to 2. It restricts the increase in difference vector between the two random vectors.

New solutions are generated from parent and mutated vectors which is based on crossover operation. The crossover rate is constant and is chosen between 0 and 1. The population of next generation will be determined by the objective function. Finally, it is concluded that the searching capability of the optimization is enhanced with the combination of IWO along with DE.

4. SIMULATION RESULTS AND DISCUSSIONS

This paper represents the performance of binary and ternary chaotic sequence. Here random population is considered as the mismatched filter coefficients which are designed with different optimization techniques such as differential evolution, invasive weed optimization and the combination of DE with IWO. The number of iterations and population considered for design of mismatched filter is 200 each. The value of crossover rate and the scaling factor is chosen as 0.5 and 0.2 respectively for the design. The PSLR values are compared in table 1 and 2 for binary and ternary logistic and improved logistic codes respectively.

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Table-1(a). Analysis and PSLR comparison of Binary Logistic sequence using matched and mismatched filter

Sequence Length	Matched Filter (dB)	PSLR of Random Population (dB)	PSLR of MMF with only DE (dB)	PSLR of MMF using only IWO (dB)	PSLR of MMF using DEIWO (dB)	PSLR using Adaptive filter (LMS) (dB)	PSLR using Adaptive filter (BSSLMS) (dB)
20	-16.4782	-14.3055	-20.6216	-18.9617	-25.3759	-30.0369	-40.6799
25	-18.4164	-16.2757	-22.5634	-20.7330	-26.5337	-30.8817	-38.7570
30	-17.5012	-16.4539	-22.4159	-20.4853	-26.7083	-31.3749	-31.7677
35	-16.9020	-16.9773	-21.5218	-20.0437	-25.4497	-28.2796	-29.6233
40	-18.0618	-17.1545	-21.0614	-19.2790	-25.1935	-27.9467	-28.9678
45	-17.5012	-15.8342	-19.4342	-17.9855	-22.3442	-26.1201	-26.0444
50	-18.4164	-16.9328	-20.7828	-19.6124	-23.9075	-25.4759	-25.8386
60	-17.5012	-16.8504	-20.1229	-18.5141	-23.7672	-25.672	-26.3309
70	-17.8171	-17.1756	-20.0666	-19.7833	-22.5118	-23.4193	-25.4327
80	-18.9769	-18.1925	-19.8289	-19.6604	-22.2955	-23.1899	-25.0857
90	-18.2570	-17.7837	-20.3877	-19.4323	-23.2311	-25.3693	-25.5101
100	-19.1721	-17.6248	-20.2345	-19.4268	-22.9224	-26.0898	-26.0499
150	-19.4394	-18.7662	-20.2981	-20.4362	-23.1546	-25.2362	-26.2388
200	-20	-19.2072	-21.2475	-20.7822	-23.7771	-25.3339	-26.3752
250	-20	-19.3020	-21.1253	-20.5793	-23.5831	-25.5895	-27.5971
300	-20.5993	-20.2605	-21.8290	-21.3466	-24.3513	-25.8248	-26.4605

Table-1(b). Analysis and PSLR comparison of Binary Improved Logistic sequence using matched and mismatched filter.

Sequence Length	Matched Filter (dB)	PSLR of Random Population (dB)	PSLR of MMF with only DE (dB)	PSLR of MMF using only IWO (dB)	PSLR of MMF using DEIWO (dB)	PSLR using Adaptive filter (LMS) (dB)	PSLR using Adaptive filter (BSSLMS) (dB)
20	-16.4782	-15.2404	-21.8979	-18.6100	-24.9343	-29.8926	-35.0410
25	-18.4164	-16.2478	-22.6725	-19.9583	-25.7799	-29.6133	-33.1534
30	-17.5012	-16.8193	-20.1354	-18.9792	-23.0102	-27.7382	-29.8533
35	-16.9020	-16.5089	-20.3174	-19.5518	-23.4720	-25.8122	-27.2821
40	-18.0618	-16.6394	-21.1740	-18.9781	-24.7122	-25.7824	-27.5318
45	-17.5012	-16.1462	-20.8309	-19.2331	-25.2166	-28.5622	-28.2053
50	-18.4164	-17.2490	-20.7678	-19.2679	-23.7782	-25.4880	-25.7790
60	-18.6611	-16.9046	-19.8802	-18.9733	-22.6954	-24.6152	-25.3190
70	-18.8402	-17.5987	-20.4199	-19.5850	-24.3100	-27.1711	-27.4962
80	-18.0618	-16.8463	-19.4891	-18.9584	-23.0837	-25.5974	-25.5857
90	-19.0849	-17.4662	-19.7114	-19.1615	-22.3729	-24.7740	-25.2162
100	-18.4164	-17.6953	-19.7625	-19.3895	-22.4421	-23.9185	-24.0210
150	-19.4394	-18.5200	-20.6990	-20.5539	-23.9083	-25.6238	-26.6292
200	-19.5762	-18.8516	-20.5859	-20.4238	-22.7666	-24.4907	-25.3265
250	-20.3546	-19.8945	-21.8085	-21.4839	-24.2620	-25.3749	-25.8039
300	-20.9151	-20.0452	-21.7644	-21.3591	-24.1618	-25.2523	-25.9494

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As per the results obtained in Table-1, the peak sidelobe ratio of best binary logistic sequence of length 20 is -16.4782 dB which when passed through the mismatched filter whose weights are designed only with differential evolution method, the dB value is increased to -20.6216. And by using only invasive weed the PSLR value increased to -18.9617dB. But when the same code is given as input to MMF which is employed with the differential evolution along with invasive wed optimization for finding the filter elements, the PSLR value is raised to -25.3759 dB. In order to further increase the PSLR of the optimized sequence from MMF, it is processed through adaptive filter. Here the adaptive filter weights are modified and updated as per least mean square method or binary step size least mean square algorithm. It is observed that with a few number of iterations the performance is improved for any length of sequence. The peak sidelobe ratio of barker code of length 13 is increased to -32.24 using the hybrid DEIWO method whose value is -22.2789 at the output of matched filter which is shown in Figure-2.

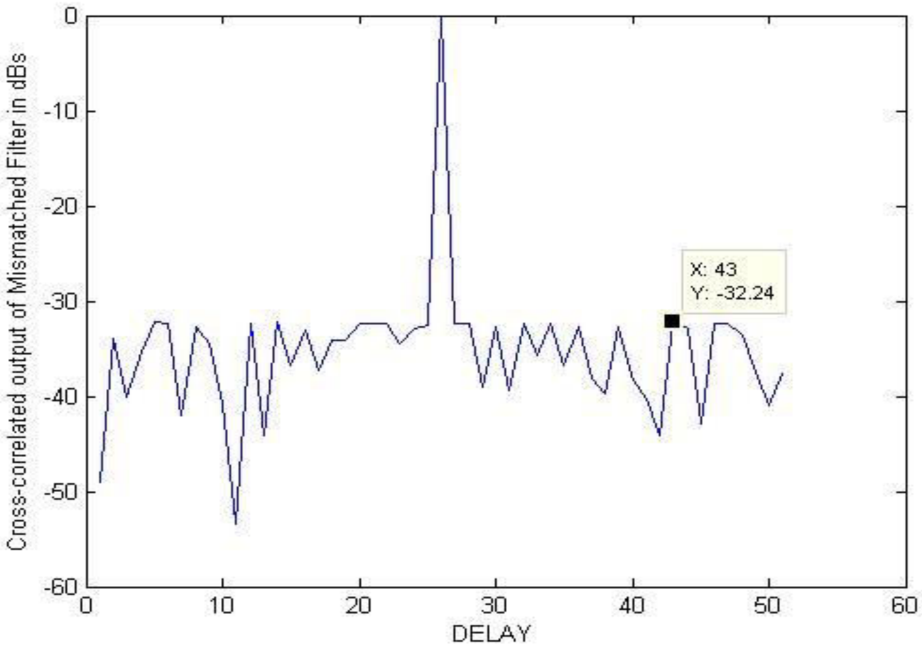

Figure-2. Cross-correlated output of mismatched filter for ternary code of length 13.

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Table-2(a). Analysis and PSLR comparison of Ternary Logistic sequence using matched and mismatched filter.

Sequence Length	Matched Filter (dB)	PSLR of Random Population (dB)	PSLR of MMF with only DE (dB)	PSLR of MMF using only IWO (dB)	PSLR of MMF using DEIWO (dB)	PSLR using Adaptive filter (LMS) (dB)	PSLR using Adaptive filter (BSSLMS) (dB)
20	-17.5012	-15.1240	-24.3929	-19.9698	-29.0226	-49.7561	-45.5735
25	-16.4782	-14.5218	-20.9163	-18.3002	-24.6362	-27.3090	-37.3501
30	-17.6921	-15.1649	-21.8993	-19.4175	-25.7697	-29.6538	-30.6408
35	-18.4164	-15.8573	-21.7018	-19.5131	-26.4945	-29.1971	-30.0180
40	-17.7860	-15.3900	-19.7657	-18.8301	-22.6680	-23.7464	-25.6976
45	-16.6502	-15.9787	-20.4304	-19.1340	-23.8004	-25.6618	-26.4979
50	-18.8402	-16.3616	-21.7901	-19.8730	-24.5901	-27.2999	-27.7705
60	-17.6921	-16.0438	-19.3898	-18.1122	-23.2430	-23.9950	-24.8441
70	-18.5884	-16.5810	-19.5533	-19.0973	-22.5844	-24.2807	-24.8342
80	-18.2155	-17.2239	-19.5583	-18.4266	-22.6102	-25.0428	-25.4860
90	-18.4597	-16.9586	-19.8447	-18.9832	-23.2286	-25.3531	-26.3502
100	-18.5314	-17.4556	-19.7282	-18.8815	-23.1624	-25.1898	-25.3590
150	-19.2442	-18.6567	-19.8999	-19.6063	-22.7913	-24.7738	-25.0999
200	-20.2848	-18.8820	-21.1017	-21.1437	-24.0224	-26.2381	-26.5874
250	-19.8618	-19.2446	-21.2114	-21.0043	-24.1525	-26.3006	-27.1366
300	-20.5993	-19.6808	-21.5381	-20.8969	-23.3645	-25.4575	-26.0666

Table-2(b). Analysis and PSLR comparison of Ternary Improved Logistic sequence using matched and mismatched filter.

Sequence Length	Matched Filter (dB)	PSLR of Random Population (dB)	PSLR of MMF with only DE (dB)	PSLR of MMF using only IWO (dB)	PSLR of MMF using DEIWO (dB)	PSLR using Adaptive filter (LMS) (dB)	PSLR using Adaptive filter (BSSLMS) (dB)
20	-20.8279	-15.2076	-24.7072	-19.2745	-27.7727	-44.6704	-40.7204
25	-19.0849	-13.8772	-22.2104	-18.1822	-25.9200	-30.4853	-34.0412
30	-19.0849	-15.2492	-20.1745	-18.3092	-23.0545	-27.3920	-32.1130
35	-18.5884	-15.3779	-19.8901	-17.8243	-24.3757	-26.1537	-26.9240
40	-18.5884	-15.7786	-19.8691	-18.4452	-24.0554	-26.5327	-27.2484
45	-18.4164	-15.8212	-19.6208	-18.6102	-22.2927	-25.1560	-25.9789
50	-18.4164	-15.4050	-19.3622	-18.2019	-22.3791	-24.3280	-24.4543
60	-18.7570	-15.7816	-19.3122	-18.1838	-23.1708	-25.8939	-25.7660
70	-18.5884	-15.6827	-19.8800	-18.4525	-23.5842	-25.2189	-25.8517
80	-19.0849	-17.1120	-19.9658	-19.2165	-23.3626	-25.1514	-25.4393
90	-18.6900	-16.8754	-19.2369	-18.4456	-22.9711	-25.1813	-25.0949
100	-19.0849	-17.2759	-19.7207	-19.2671	-22.7956	-24.6006	-24.9426
150	-19.6680	-18.0523	-19.9905	-19.5928	-22.9848	-24.7989	-25.0755
200	-20.7485	-18.8845	-20.4732	-20.4780	-23.5403	-24.8563	-25.2267
250	-20.7618	-18.6937	-20.6546	-20.5067	-24.0724	-25.7903	-25.8980
300	-20.9399	-19.0896	-20.9415	-20.8723	-23.8818	-25.1518	-25.4495

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The normalized cross-correlated dB output of mismatched filter elements for the optimized input ternary sequence of length 20 is shown in Figure-3. It is clear from figure that it is not symmetric like the auto-correlation pattern obtained from the matched filter. Figure-4 and Figure-5 shows the output of matched and mismatched filter using DE, IWO and DEIWO method along with adaptive filters.

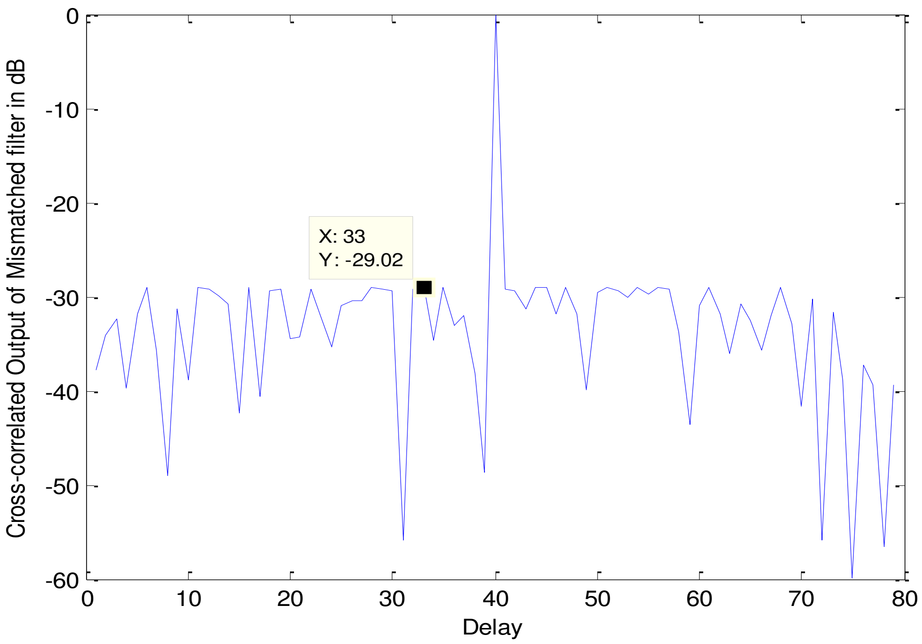

Figure-3. Cross-correlation output of MMF for sequence length 20.

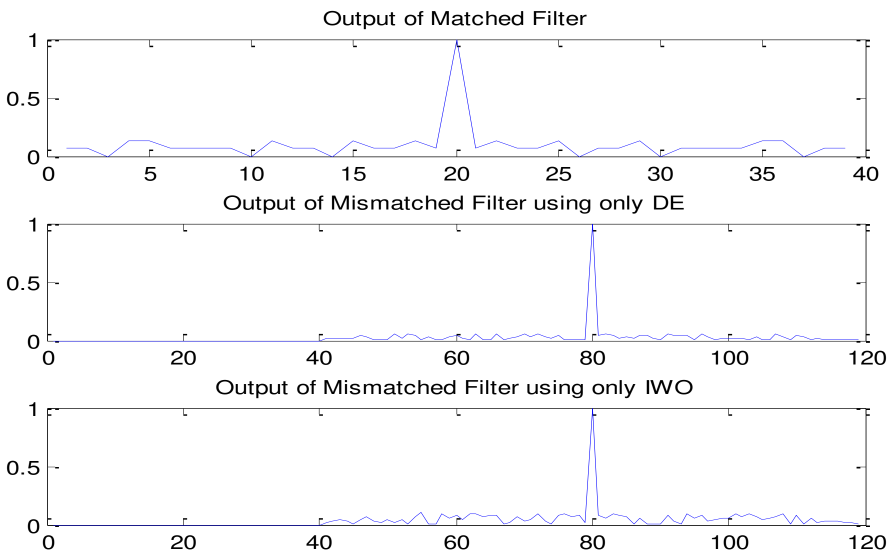

Figure-4. Output of MF, MMF of ternary code of length 20 with DE and MMF with IWO.

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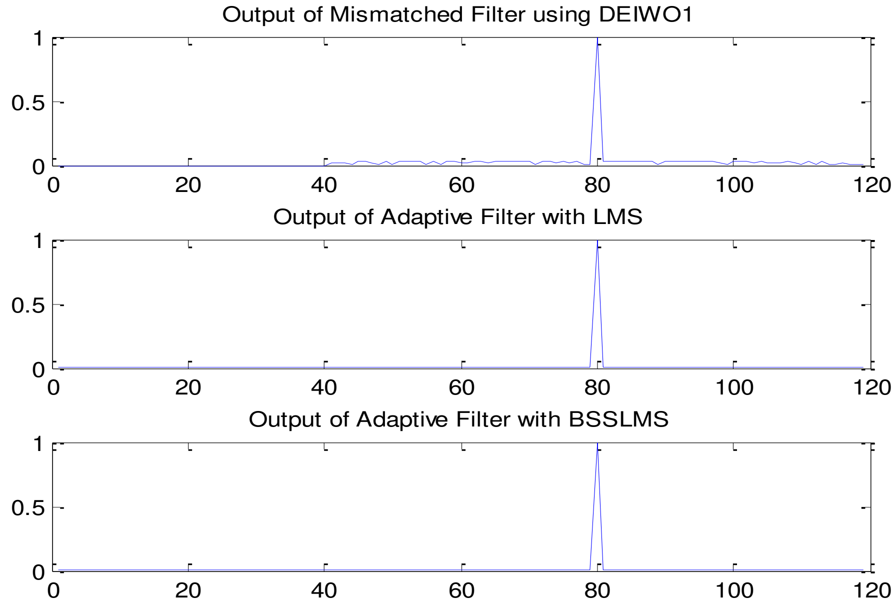

Figure-5. Output of mismatched filter of ternary code of length 20 with DEIWO and adaptive filters.

Figure-6 and Figure-7 shows the simulation results and analysis of binary and ternary logistic sequence of different lengths compared in Table-1(a) and Table-2 (a) respectively.

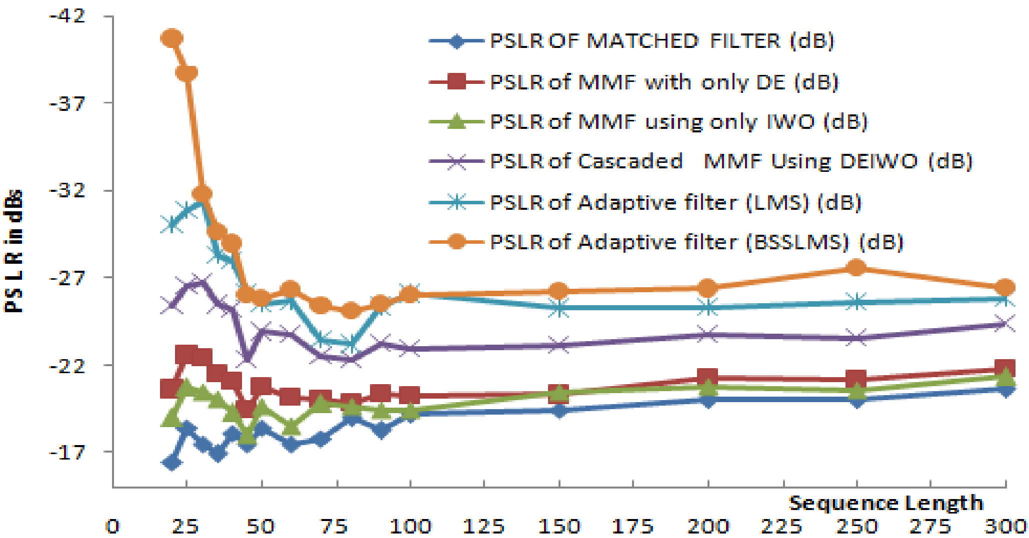

Figure-6. PSLR Comparison of Binary Logistic Sequence of different length.

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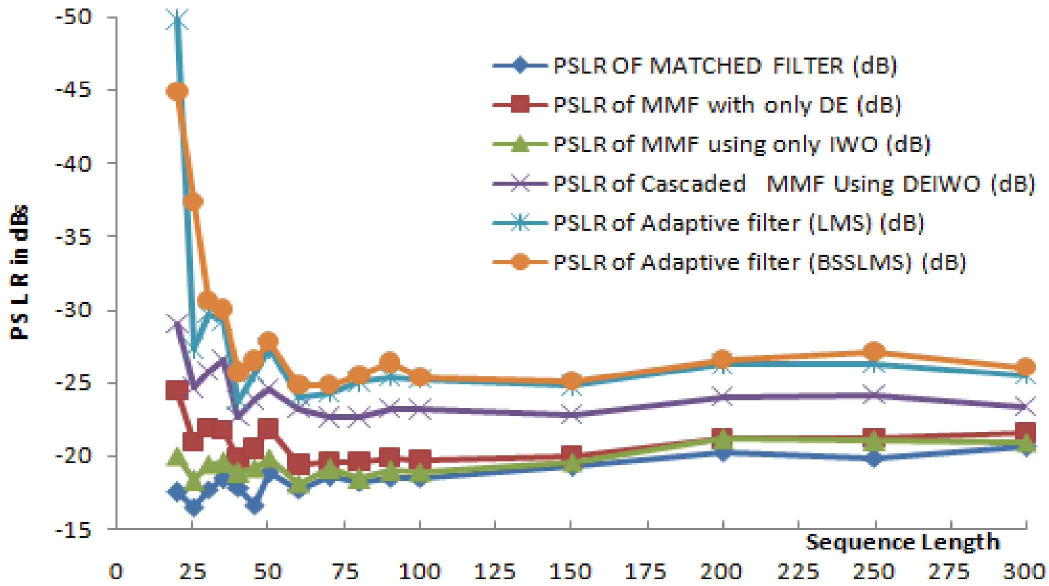

Figure-7. PSLR Comparison of Ternary Logistic Sequence of different length.

5. CONCLUSIONS

This paper deals with a hybrid DEIWO algorithm where differential evolution algorithm is integrated with invasive weed optimization technique. The proposed technique is very efficient for the design of mismatched filter coefficients to improve the performance of binary and ternary chaotic sequences. In this approach the measurement of peak sidelobe ratio is done first with matched filter using autocorrelation function and then the comparison is continued by cross-correlating the best chaotic sequence with mismatched filter elements. These are evaluated with DE, IWO and then with newly proposed hybrid optimization technique. The results are very promising. The evolution of directions of weeds depends on the information obtained from DE. Minimized value of PSLR for barker code of length 13 is achieved with MMF using DEIWO which is -32.24 dB. The results shows that reduced value of PSLR is obtained for lower lengths of binary or ternary codes than larger. For larger length sequences the filter length should proportionally increase but it causes difficulty in practical implementations. From the tabular analysis it is concluded that the value of PSLR of all the proposed sequences are significantly improved using the proposed method followed by the adaptive filters with a very small number of iterations.

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