Sidelobe Minimization of Chaotic Pulse Compression Sequence Using BSSLMS Algorithm

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Abstract-The optimal sequences have many applications in communication systems such as spread spectrum and multiple access communication, sonar and radar because of its minimum peak sidelobe level. In this paper chaotic sequences are used for analysis because of the similarity in auto-correlation and cross correlation properties of these sequences with that of random white noise. Due to this, the chaotic sequences are used here to generate four phase sequences. These four phase sequences provide superior performances and their properties are similar to those of random four phase sequences. The improvement in the performance of these sequences are examined with the help of binary step size least mean square algorithm (BSSLMS). Least mean square algorithm is one of the most widely used adaptive algorithm due to its simplicity and stability. The major drawback lies in its relatively slow convergence rate. The performance of these sequences in terms of peak sidelobe ratio, autocorrelation sidelobe peak and mean square error were measured using LMS. The improvement of these performances is obtained with binary step size least mean square algorithm where two different step sizes are considered based on the estimation error. The convergence performance in terms of mean square error is compared by using proposed algorithm.

Keywords:

Sidelobe reduction; Chaotic Sequence; Adaptive Filters; LMS Algorithm; BSSLMS Algorithm; Peak sidelobe ratio; Mean square error.

I. INTRODUCTION

In radar signal processing pulse compression is one of the well-established technique. This technique is widely used to obtain high energy of a long pulse by keeping the range resolution of a short pulse. The practical problem of increasing the operating range of radar is overcome by using this technique, maintaining the desired range resolution. This can be achieved by transmitting the long pulse which is correlated with its received reflection. In pulse compression the received echo signal is passed through the matched filter whose output is periodic autocorrelation of the transmitted signal [1], [2]. Unfortunately range sidelobes appears at the output of the matched filter which are highly undesirable as they may cause false alarms or mask the mainlobe of the useful weaker echo signals. Hence modulation techniques are used for pulse compression such as linear frequency modulation and phase coded pulses [3]. The main drawback of pulse compression is the presence of sidelobes at the output of the matched filter on either side of the mainlobe which is a very narrow pulse. Therefore, the nearby weaker target echoes can be easily distinguished from the stronger one only when the sidelobes are comparatively at a lower level. Hence the sidelobe reduction is very much essential which is obtained by using various optimization techniques such as windowing techniques, adaptive filtering etc. The largest sidelobe in the output of the matched filter is known as peak sidelobe that is obtained from the autocorrelation pattern. The ratio of sidelobe maximum to peak of the mainlobe (PSR) should be as low as possible that causes suppression of unwanted clutters which is measured in db. Hence the design of filters used in radar has been a subject of considerable interest where lots of research work has been reported.

Earlier it was proved that the binary barker sequence exists upto a length of 13 having PSLR value of -22.3 dB [4]. But further improved value of PSLR is required in some applications. In this contest later Linder, Boehmer, Rao and Reddy obtained longer length binary sequence. But it was found that the PSLR value was not reduced much with length of the sequence [5], [6], [7]. The limitation of binary sequence comes when low value of PSLR is required with longer length sequence despite the fact that it can be easily generated, processed. Therefore, it was essential to switch over to four phase sequence. J.W. Taylor, Jr. and Blinchikoff, H. J. generated good quadriphase or four phase sequences using biphase to quadriphase transformation [8]. The maximum length of binary barker sequence is 13 and fourphase barker sequence is 15. Golomb S W, Scholtz R.A and Van De Vaart H generated four phase 15-bit Barker sequence is reported in [9], [10]. The four phase sequences provide high range resolution and good detection range. In this paper chaotic four phase sequence is used. Bateni and Mcgillen explained the use of chaotic sequence in spread spectrum communication and was well documented [11]. The comparison of PSLR values of different chaotic sequences is reported [12]. In this paper the performance of fourphase chaotic sequences is discussed by using binary step size least mean square algorithm.

II. GENERATION OF FOUR PHASE SEQUENCE

Chaos theory examines the different behavior that exists in non-linear deterministic dynamical systems. These systems are sensitive to initial conditions which is known as butterfly effect. According to the deterministic chaos behavior of the chaotic systems, a very small change in the initial condition causes a drastic change in the final solution with no random elements involved in this process. Various exhaustive search techniques are available which produce finite number of sequences. But there is a chance of neglecting some good sequences. Therefore, chaotic maps are used which generates infinite number of sequences of any length. Different types of chaotic maps are available that generates chaotic sequences. Some of them are Logistic map, Improved logistic map, Cubic map, Lorenz map, Henon map, Tent map and Quadratic map. The main advantage lies in its inherent security and greater number of sequence generation. In this paper only logistic map, improved logistic map, cubic map and quadratic maps are used to generate four phase sequences

A. *Logistic Map Sequence*

Logistic map is defined in equation (1) which is a prototype model that describes the chaotic behavior of a non-linear dynamic equation.

$$y_{n+1} = \mu * y_n * (1 - y_n) \quad (1)$$

$y_n \epsilon (0,1)$ & $\mu \epsilon (0,4)$

Where 'μ' is bifurcation factor that determines the stability, periodicity and chaotic. This equation generates inherently deterministic sequences. The system oscillates between different states that depend on the value of μ.

B. *Improved Logistic Map Sequence*

The equation (2) below represents improved logistic map.

$$y_{n+1} = 1 - 2*(y_n)^2, \ y_n \epsilon (-1,1) \quad (2)$$

C. *Cubic Map Sequence*

It is written in equation (3) below.

$$y_{n+1} = 4*(y_n)^3 - 3*y_n, \ y_n \epsilon (-1,1) \quad (3)$$

D. *Quadratic Map Sequence*

This sequence can be represented as below in equation (4).

$$y_{n+1} = 0.5 - 4*(y_n)^2, \ y_n \epsilon (-1,1) \quad (4)$$

A large number of sequences is generated by changing the initial condition for a particular length. Different quantization levels have chosen for different chaotic maps. For Logistic map sequence those levels are chosen as 0.25, 0.5 and 0.75. While for improved logistic map these levels are -0.6, 0 and 0.6, for quadratic map -0.25, 0, 0.25 and for cubic map 0.5, 0 and 0.4. According to these levels the subpulses are equivalently phased as +1, +j, -1 or –j. The generation of these sequence is very simple, fast and can be reproducible. A totally uncorrelated sequences are generated by varying the initial condition.

III. PROPERTIES OF OPTIMUM SEQUENCE

The properties of these sequence includes correlation function, peak sidelobe ratio etc

A. *Correlation Function*

The four phase chaotic sequences are passed through the matched filter whose output is given by

$$R(k) = \Sigma\, y_n * y_{n+k}$$

Where 'n' ranging from 0 to N-1-k and R(k) represents the auto-correlation function. The range of 'k' lies in the range -(N-1) to (N+1) and N is the length of the sequence. Different autocorrelation patterns are obtained that depends on initial condition. But the autocorrelation pattern of optimum coded waveform must have zero sidelobe and maximum peak for mainlobe.

B. *Peak Sidelobe Ratio (PSR)*

It is the most commonly used measure of performance and is defined as the ratio of sidelobe peak amplitude to peak of the mainlobe as in equation (6). These peaks are measured from the autocorrelation pattern. It is measured in decibels. It is defined by

$$PSR = 20 * \log_{10} (\max R(k)/R(0)) \quad (6)$$

$$SP = \max R(k) \text{ where } k \neq 0 \quad (7)$$

Here SP in equation (7) represent the peak value of the sidelobe in the autocorrelation pattern, whose value must be low to make PSLR low. And the best sequences are chosen according to low PSLR value. Also it is the reciprocal of the discrimination factor. These sidelobes can be reduced with some additional weights after the matched filter that is obtained by using optimization algorithm or by designing a mismatched filter from the given codes.

IV. ADAPTIVE SYSTEMS

Adaptive filters are combination of various types of filters like finite impulse response filters, infinite impulse response filters, single input filters. multiple input filters, linear nonlinear filters. These filters have many applications such as signal prediction, noise cancellation, biomedical applications, adaptive antenna arrays, sonar, radar applications, signal processing and control applications [13], [14]. Adaptive filters are generally represented by the transfer function which is controlled by variable parameters. These parameters are adjusted according to the optimization algorithms. Generally, all adaptive filters are digital filters and due to the complexity in the optimization algorithm it requires continuous changes in some of the parameters. So the adaptive filter is incorporated with feedback and that is in the form of error signal. Most commonly used adaptive algorithms are least mean square algorithm, recursive least square algorithm. In the design implementation least mean square algorithm is generally used due to its simplicity in implementation and stability [15] [16]. There are six performance measures in adaptive systems that can be any of the following parameter

1. Filter length
2. Computational complexity
3. Convergence rate
4. Stability
5. Mean square error
6. Robustness

*Filter length***-** The length of a filter determines how accurately a system can be modelled using adaptive filter. The convergence rate depends on filter length. If the filter length increases the number of computations get increased which causes decrease in maximum convergence rate. By increasing or decreasing the computation time the stability of the system will be effected. Filter length also affects the mean square error value. By adding poles or zeroes the stability of a system can be improved. For this the maximum step size or maximum convergence rate has to be decreased to maintain stability. If system has too many poles and/or zeros, then it will have the potential to converge to zero but at the same time the calculations will be more that will affect the maximum convergence rate.

Computational Complexity- The performance of the system is being affected by the hardware limitations in a real time system. A simplistic algorithm requires less number of hardware resources than a complex algorithm. Computational complexity is particularly important in real time adaptive filter applications. When a real time system is being implemented, there are hardware limitations that may affect the performance of the system. A highly complex algorithm will require much greater hardware resources than a simplistic algorithm.

Convergence Rate- The convergence characteristic of LMS algorithm depends on the autocorrelation of the input. The rate at which the filter response converges to its resultant state is measured with convergence rate. Generally, the adaptive systems require faster convergence rate. There is a trade-off between this convergence rate and other performances. The increase in convergence rate causes decrease in stability and vice versa that makes the adaptive system to diverge instead of converge. Hence in relation to other performance matrices the convergence rate can only be considered not by itself with no regards to the rest of the system.

Stability- There are very few adaptive stable systems which can be physically realizable. In most of the adaptive system stability is most important performance measure. The stability of an adaptive system is determined using initial conditions, transfer function and the step size of the input. Generally, these systems are marginally stable.

Minimum Mean Square Error- The Mean square error measures how well a system adapts to desired solution. The minimum value of MSE indicates the accurate modelling of adaptive system which can be predicted, adapted and converged to desired solution. The value of MSE should not be large. The factor that are used to determine the minimum value of MSE are order of the adaptive system, quantization noise and gradient error.

Robustness- It is the measure of how well a system resist both input and quantization noise. The robustness of a system depends stability of the system.

But in this paper, the performance and their comparison is analyzed in terms of convergence and mean square error. The stability of the system requires fast convergence with minimum value of mean square error. This concept is being verified with chaotic sequence as input to matched filter followed by adaptive system.

The basic block diagram of adaptive filter is shown in figure 1 which consists of an input vector, here that is the output of the matched filter, the desired response and an estimated error. The estimated error is used to update the coefficients of the filter which is the difference between desired response and adaptive filter output. These coefficients of the filter changes from one input sequence to another and with length of the filter.

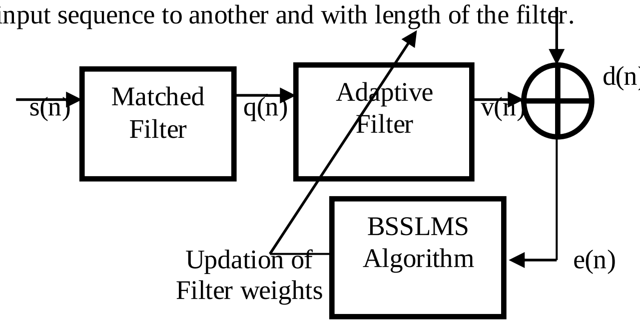

Fig.1. Basic Block Diagram of Adaptive System

V. LMS ALGORITHM

LMS algorithm is a search algorithm whose convergence characteristics are examined to determine the range of convergence factor. Based on this factor the stability will guaranteed. The optimum filter weights can be obtained by updating the filter weights using optimization algorithm such as least mean square algorithm. The following equation represents the least mean square algorithm.

Input vector $S(n) = [\, x(n), x(n-1), \ldots x(n-p+1)]^T$

Eror estimation $e(n) = d(n) - S^T(n) * Q(n)$

Adaptation of weight vector

$Q(n+1) = Q(n) + 2*\mu * S(n) * e(n)$

Filter output $z(n) = Q^T(n) * S(n)$

Q(n) represents the weight vector of the adaptive filter, S(n) is the input vector, e(n) is the error signal, is the step size parameter or the convergence factor and d(n) is the desired signal. p is the order of the filter. The mean square error in case of LMS requires convergence factor that must be chosen to adequately comply the stability. In this paper this step size parameter is obtained from two different values that based on error estimation which is explained in the proposed method.

VI. BINARY STEP SIZE LMS ALGORITHM IN ADAPTIVE SYSTEM

The main drawback of LMS is its slow convergence rate [15], [17]. To overcome this problem, the method adapted in this paper is binary step size least mean square algorithm where the updating of weights of the filter is carried out with a small modification. The main purpose of the updating weights is to achieve optimized performance measures such as minimum peak sidelobe ratio (PSR) and autocorrelation sidelobe peak (SP). This is carried out in the feedback path of closed loop adaptive filters.

In this paper adaptive filter is chosen as LMS adaptive filter with a small change in the updating of filter coefficients in LMS algorithm. Particularly the step size parameter is updated according to the error value. The value of step size is obtained from two values, delta and deviation. And based on this concept this method is identified as binary step size LMS (BSSLMS) algorithm. When the error increases the previous value the step size will be delta + deviation and when it decreases step size will become delta-deviation [18].

In this paper the value of delta is chosen as 0.09 and deviation as 0.004. Using this method fast convergence can be obtained.

VII. SIMULATION

The analysis and comparison of peak sidelobe ratio and autocorrelation sidelobe peak is being done for logistic map, improved logistic map and cubic map without implementing LMS, with LMS and with BSSLMS. Table 2 shows the comparison of the PSLR and SP measures using LMS and BSSLMS algorithms for different length sequences. Simulation is done by using Matlab. The characteristics of adaptive algorithms mainly depend on mean square error which is compared using proposed method.

TABLE I. COMPARISON OF PSR AND SP OF LOGISTIC SEQUENCE

Seq Length	Logistic Map						Maximum MSE with LMS	Maximum MSE with BSSLMS
	Peak Sidelobe Ratio			Sidelobe peak				
	Without LMS	With LMS	With BSSLMS	Without LMS	With LMS	With BSSLMS		
20	-16.9897	-20.9041	-26.2199	0.1414	0.0901	0.0489	1.4789	1.0297
30	-18.4030	-20.9452	-27.5065	0.1202	0.0897	0.0421	1.0009	0.6575
40	-17.8915	-22.0895	-22.8983	0.1275	0.0786	0.0717	0.7963	0.5188
50	-18.2974	-20.7550	-21.8258	0.1217	0.0917	0.0810	0.6649	0.4165
60	-18.4030	-22.5696	-22.8429	0.1202	0.0744	0.0721	0.5629	0.3484
70	-18.8402	-22.7522	-23.7333	0.1143	0.0728	0.0651	0.4637	0.2954
80	-18.9237	-23.6136	-23.0711	0.1132	0.0660	0.0702	0.4065	0.2572
90	-19.2171	-20.6714	-21.3440	0.1094	0.0926	0.0857	0.3633	0.2297
100	-19.4692	-23.2072	-23.3520	0.1063	0.0691	0.0680	0.3274	0.2070
200	-21.1776	-25.3362	-25.5020	0.0873	0.0541	0.0531	0.1676	0.1039
300	-22.5529	-26.5432	-26.6855	0.0745	0.0471	0.0463	0.1128	0.0692
400	-22.6660	-26.3176	-27.1127	0.0736	0.0483	0.0441	0.0849	0.0518
500	-23.3348	-26.9295	-27.7652	0.0681	0.0450	0.0409	0.0680	0.0416
600	-23.8604	-26.8464	-27.5499	0.0641	0.0455	0.0419	0.0556	0.0344
700	-24.2302	-26.0457	-27.2222	0.0614	0.0499	0.0435	0.0494	0.0298
800	-24.8293	-28.1852	-28.8868	0.0574	0.0390	0.0359	0.0427	0.0260
900	-25.1037	-28.5746	-29.4080	0.0556	0.0373	0.0339	0.0386	0.0232
1000	-25.3820	-28.0365	-28.7080	0.0538	0.0396	0.0367	0.0347	0.0208
2000	-27.9156	-31.0486	-31.5155	0.0402	0.0280	0.0266	0.0171	0.0104
3000	-28.9491	-29.9156	-31.6205	0.0357	0.0319	0.0262	0.0115	0.0069
4000	-30.0390	-32.7509	-33.4144	0.0315	0.0230	0.0213	0.0087	0.0052
5000	-30.6168	-32.6713	-34.0678	0.0295	0.0233	0.0198	0.0069	0.0042

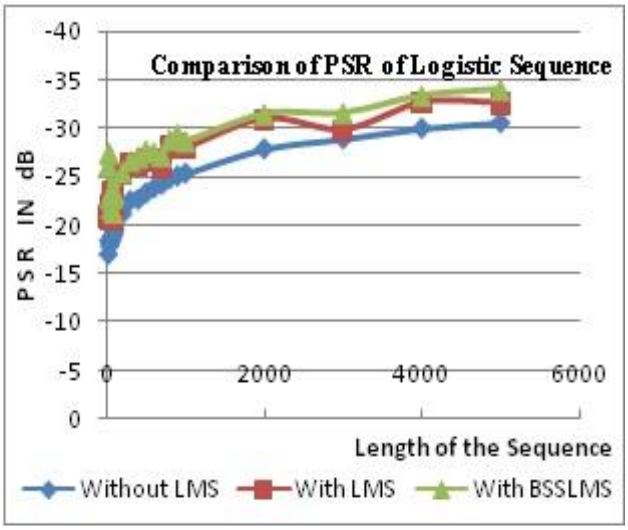

Fig.2. PSR value comparison with the proposed algorithm

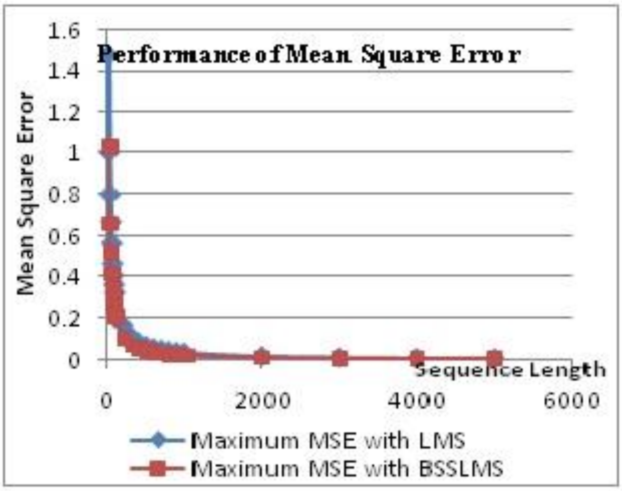

Fig. 3.MSE behavior of Logistic Sequence with BSSLMS algorithm

Figure 2 shows the variation of peak sidelobe ratio with the length of the sequence. It is significant that the proposed method gives better PSR value of -34.0678 for sequence length of 5000 compared to its value with least mean square algorithm that is -32.6713. Whereas Figure 3 represents characteristic of mean square error and a better result has observed by using binary step size LMS algorithm.

Autocorrelation sidelobe peak is another parameter that has compared for all the maps with different lengths in all the tables. The value of ASP has to be reduced to discriminate the sidelobes from mainlobe. This makes the value of peak sidelobe ratio most significant. It is observed in figure 4 that by using binary step size LMS the peak of sidelobe is reduced for any length of the sequence.

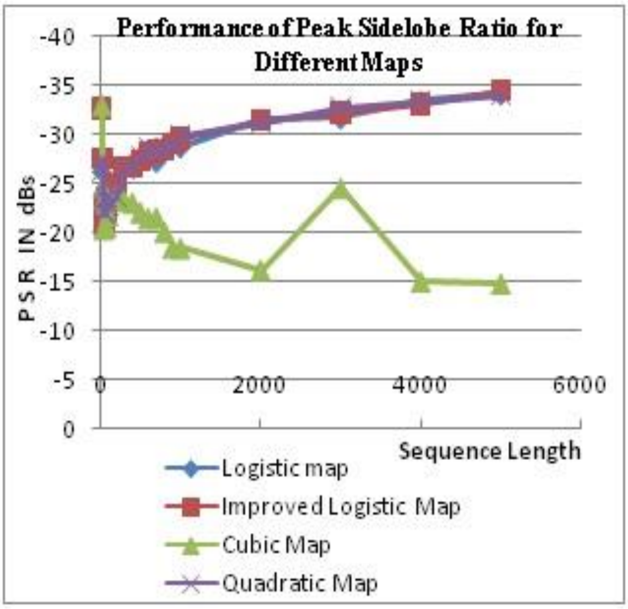

Fig.4 PSR values for different chaotic sequences using BSSLMS Algorithm

TABLE II. COMPARISON OF PSR AND SP OF IMPROVED LOGISTIC SEQUENCE

Seq Length	Improved Logistic Map						Maximum MSE with LMS	Maximum MSE with BSSLMS
	Peak Sidelobe Ratio			Sidelobe peak				
	Without LMS	With LMS	With BSSLMS	Without LMS	With LMS	With BSSLMS		
20	-16.9897	-24.9549	-32.5325	0.1414	0.0565	0.0236	1.3999	1.0100
30	-18.4030	-20.9452	-27.5065	0.1202	0.0897	0.0421	1.0009	0.6830
40	-18.0618	-19.2514	-22.9110	0.1250	0.1090	0.0715	0.8204	0.5249
50	-18.4164	-20.5422	-20.8949	0.1200	0.0939	0.0902	0.6065	0.4063
60	-19.0309	-22.7541	-23.2045	0.1118	0.0728	0.0691	0.5567	0.3476
70	-19.0487	-23.2206	-22.9229	0.1116	0.0690	0.0714	0.4747	0.2963
80	-19.0309	-22.3510	-22.1898	0.1118	0.0763	0.0777	0.4150	0.2598

90	-19.5424	-24.2675	-23.6220	0.1054	0.0612	0.0659	0.3733	0.2309
100	-20.1323	-23.0796	-23.3315	0.0985	0.0701	0.0681	0.3249	0.2072
200	-21.0100	-24.7436	-24.9527	0.0890	0.0579	0.0565	0.1620	0.1026
300	-22.0219	-25.5071	-26.6235	0.0792	0.0530	0.0466	0.1129	0.0691
400	-22.8978	-25.7407	-26.6947	0.0716	0.0516	0.0463	0.0858	0.0521
500	-23.7018	-26.7921	-27.3022	0.0653	0.0458	0.0431	0.0680	0.0416
600	-24.2758	-27.3132	-28.0356	0.0611	00431	0.0396	0.0564	0.0345
700	-24.6051	-27.6473	-28.2409	0.0588	0.0415	0.03887	0.0501	0.0299
800	-25.0407	-28.1943	-28.3530	0.0560	0.0389	0.0382	0.0435	0.0261
900	-25.3027	-28.5373	-29.0476	0.0543	0.0374	0.0353	0.0381	0.0231
1000	-25.6848	-28.5387	-29.5136	0.0520	0.0290	0.0334	0.0345	0.0209
2000	-27.5845	-30.4355	-31.3338	0.0418	0.0223	0.0271	0.0174	0.0104
3000	-28.9948	-31.5197	-32.1562	0.0355	0.0198	0.0247	0.0116	0.0070
4000	-30.0240	-31.6582	-32.9621	0.0315	0.0261	0.0225	0.0087	0.0052
5000	-31.0688	-33.5288	-34.3457	0.0280	0.0211	0.0192	0.0069	0..0042

The same analysis is continued for other chaotic map discussed in this paper and the results are shown in Table 3, 4 and 5 for improved logistic map sequence cubic map sequence and quadratic map sequence respectively.

TABLE III. COMPARISON OF PSR AND SP OF CUBIC SEQUENCE

Seq Length	Cubic Map						Maximum MSE with LMS	Maximum MSE with BSSLMS
	Peak Sidelobe Ratio			Sidelobe peak				
	Without LMS	With LMS	Without LMS	With LMS	Without LMS	With LMS		
20	-16.4782	-24.1586	-32.8168	0.1500	0.0620	0.0229	1.5278	1.0379
30	-17.5012	-20.7538	-24.6640	0.1333	0.0917	0.0585	1.0752	0.6979
40	-17.8915	-20.7482	-20.3745	0.1275	0.0917	0.0958	0.7924	0.5150
50	-17.8516	-21.0612	-23.5184	0.1281	0.0885	0.0667	0.6801	0.4204
60	-17.7097	-21.7976	-23.5373	0.1302	0.0813	0.0665	0.5498	0.3469
70	-18.7728	-22.7380	-23.1199	0.1152	0.0730	0.0698	0.4635	0.2947
80	-18.0618	-20.6565	-20.6045	0.1250	0.0927	0.0933	0.4199	0.2604
90	-18.7106	-23.4583	-23.0054	0.1160	0.0672	0.0708	0.3778	0.2320
100	-18.3863	-20.9712	-21.7425	0.1204	0.0894	0.0818	0.3527	0.2103
200	-18.9877	-22.7877	-23.7377	0.1124	0.0725	0.0650	0.1778	0.1054
300	-18.4030	-20.6902	-23.1944	0.1202	0.0924	0.0692	0.1187	0.0700
400	-18.3250	-21.8775	-23.0167	0.1213	0.0806	0.0707	0.0887	0.0524
500	-18.0766	-22.1883	-22.0478	0.1248	0.0777	0.0790	0.0704	0.0418
600	-18.0928	-21.8035	-21.4480	0.1246	0.0813	0.0846	0.0586	0.0349
700	-17.3302	-20.4733	-21.4997	0.1360	0.0947	0.0841	0.0513	0.0300
800	-16.6930	-19.1931	-20.0841	0.1463	0.1097	0.0990	0.0450	0.0263
900	-16.2734	-17.9242	-18.4739	0.1536	0.1270	0.1192	0.0397	0.0233
1000	-16.0813	-18.7229	-18.4385	0.1570	0.1158	0.1197	0.0356	0.0209
2000	-14.8404	-16.3071	-16.2395	0.1811	0.1530	0.1542	0.0180	0.0105

3000	-14.7654	-18.8675	-24.4993	0.1827	0.1139	0.0596	0.0127	0.0072
4000	-14.2305	-15.0911	-15.0894	0.1943	0.1760	0.1760	0.0091	0.0053
5000	-13.9749	-14.8569	-14.8604	0.2001	0.1808	0.1807	0.0073	0.0042

TABLE IV. COMPARISON OF PSR AND SP OF QUADRATIC SEQUENCE

Seq Length	Quadratic Map						Maximum MSE with LMS	Maximum MSE with BSSLMS
	Peak Sidelobe Ratio			Sidelobe peak				
	Without LMS	With LMS	Without LMS	With LMS	Without LMS	With LMS		
20	-16.9897	-20.9041	-26.2199	0.1414	0.0901	0.0489	1.4789	1.0297
30	-18.4030	-20.9542	-27.5065	0.1202	0.0897	0.0421	1.0009	0.6830
40	-17.8915	-22.0895	-22.8934	0.1275	0.0786	0.0717	0.7963	0.5188
50	-18.2974	-20.7550	-21.8258	0.1217	0.0917	0.0810	0.6649	0.4165
60	-18.5733	-22.4660	-23.5600	0.1179	0.0753	0.0664	0.5378	0.3452
70	-18.7728	-21.8001	-21.9706	0.1152	0.0813	0.0797	0.4573	0.2936
80	-18.7676	-23.2221	-23.2019	0.1152	0.0690	0.0692	0.4211	0.2620
90	-19.5424	-22.6995	-23.6781	0.1054	0.0733	0.0655	0.3831	0.2323
100	-19.3181	-24.1087	-22.8040	0.1082	0.0623	0.0724	0.3349	0.2080
200	-21.3966	-24.1087	-23.6615	0.0851	0.0623	0.0656	0.1630	0.1027
300	-22.1467	-25.6241	-26.3794	0.0781	0.0523	0.0480	0.1133	0.0694
400	-22.7470	-25.6294	-26.6629	0.0729	0.0523	0.0464	0.0859	0.0520
500	-23.3161	-26.6741	-27.6104	0.0683	0.0464	0.0416	0.0705	0.0419
600	-23.8928	-27.4642	-28.5147	0.0639	0.0423	0.0375	0.0571	0.0347
700	-24.2302	-27.4307	-28.1116	0.0614	0.0425	0.0393	0.0499	0.0298
800	-24.9210	-27.6036	-28.5809	0.0567	0.0417	0.0372	0.0425	0.0259
900	-25.0622	-28.2327	-28.5948	0.0558	0.0388	0.0372	0.0381	0.0231
1000	-25.4166	-28.1988	-29.8561	0.0536	0.0389	0.0322	0.0344	0.0208
2000	-27.5190	-30.4684	-31.1404	0.0421	0.0300	0.0277	0.0173	0.0104
3000	-29.0935	-31.8358	-32.6242	0.0351	0.0256	0.0234	0.0115	0.0069
4000	-29.9361	-32.3821	-33.3576	0.0319	0.0240	0.0215	0.0087	0.0052
5000	-30.6775	-32.8039	-33.9734	0.0292	0.0229	0.0200	0.0070	0.0042

CONCLUSION

Optimum four phase chaotic sequences are generated whose performance is analyzed in terms of peak sidelobe ratio and autocorrelation sidelobe peak for different length of the sequences. This analysis is estimated for logistic map, improved logistic map and cubic map by using proposed algorithm. The performance measures are compared and analyzed without LMS, with LMS and with binary step size LMS. It is being observed that improved results are obtained with the proposed algorithm compared to LMS algorithm with a few number of iterations. Due to these improved results, it has wide applications in communication s. But in case of cubic map sequence the PSR is not decreasing uniformly. With LMS algorithm the PSR for Logistic sequence of length 5000 is -32.6713 dB whereas its value using binary step size LMS algorithm for the same length sequence is -34.0678 dB. This improvement is mainly due to reduction in the SP value. The proposed algorithm also provides significant results in obtaining minimum value of mean square error with fewer numbers of iterations for different length of the sequences. The rate of convergence also becomes fast compared to LMS. The lesser is the value of mean square error the better is the rate of convergence. LMS algorithm takes considerable amount of time for computation and also become complex because of the same step size parameter whereas in case of BSSLMS with variable step size, improved results are obtained in terms of peak sidelobe ratio and peak of the sidelobe. Also minimum value of mean square error is obtained in smaller interval of time. With the above discussion it is concluded that the proposed algorithm outperforms well compared to well-known LMS algorithm.

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