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Performance Analysis of LMS Filter Using Chaotic and Barker Codes for Radar Target Detection

[1]Jami Venkata Suman and [2]J. Beatrice Seventline
[1]Department of ECE, GMR Institute of Technology, Rajam, India
[2]Department of ECE, GITAM Institute of Technology, Visakhapatnam, India

Abstract: Target detection and tracking play a very foremost role in space and underwater scenario. In this study, we presented a Least Mean Square filter based Radar Target Detection (LMS-RTD) Model is proposed to de-noising of pulse radar transmitted signal. In target detection, Radio Frequency (RF) energy is transmitted to and reflected from the reflecting object which has target status information. Signal generation and target detection of radar model is designed and simulated using MATLAB 2017a Simulink. Study of performance analysis of adaptive LMS filter using barker codes, combined barker codes, different binary chaotic sequences is also presented in this study. Implementation of an adaptive LMS filter using Verilog HDL and its analyses using Xilinx FPGA tool. On FPGA analysis, parameters such as total number of used LUT's and flips flops are reduced in the proposed adaptive LMS filter and improve the hardware and circuit computational complexity as compared with other existing methods.

Key words: Radar signal processing, target detection, chaotic codes, barker codes, MATLAB Simulink, adaptive LMS filter, Xilinx FPGA ISE, root mean square error, signal to noise ratio

INTRODUCTION

In recent days Radio Detection and Ranging (RADAR) has a major significance in the object detection and tracking in space applications. Radar is a system used for detecting the presence, direction, distance and speed of aircraft, ships and other objects by sending out pulses of high frequency electromagnetic waves that are reflected off the object back to the source. Mainly it refers to the technique of using radio waves to detect the presence of objects in the atmosphere (Mahafza, 2009; Skolnik, 1980). The radar signal de-noising is the key function in target detection and target tracking systems. LMS algorithm adjusts the filter coefficients to minimize the cost function. It is a class of adaptive filter used to mimic a desired filter by finding the filter coefficients that reveal to producing the least mean square of the error signal. Stanford University Professor Bernard Widrow has invented this LMS algorithm in 1960. It is a stochastic gradient descent method in that the filter is only adapted based on the error at current time. The block diagram of adaptive LMS filter is shown in Fig. 1. Eventually result can write in the form of three basic relations as follows (Jagan-Naveen *et al.*, 2010). Filter output:

$$y(n) = w(n)\times u(n) \quad (1)$$

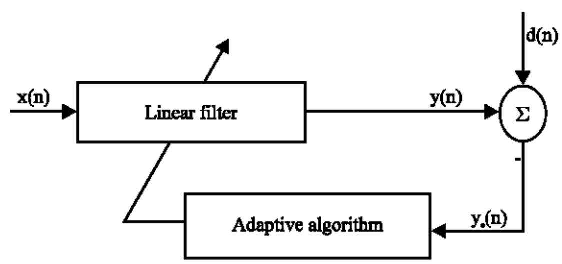

Fig. 1: Block diagram of adaptive LMS filter

Estimation error or error signal:

$$y_e(n) = d(n)-y(n) \quad (2)$$

Tap weight adaptation:

$$w(n+1) = w(n)+mu\ u(n)\ ye'(n) \quad (3)$$

Where:

- x(n) = Input digital signal
- y(n) = Output digital signal
- d(n) = Desired response
- $y_e(n)$ = Estimation error or error signal

In our surroundings, we have different kinds of signals such as natural, man-made, audio, video, speech,

Corresponding Author: Jami Venkata Suman, Department of ECE, GMR Institute of Technology, Rajam, India

image, communication, geophysical, sonar, radar, medical and musical signals while many are unwanted signals in a given situation. Anything that carries information is a signal and an engineering contest is a function that "conveys information about the behaviour or attributes of some phenomenon" and these signals might be necessary or unwanted that depends at that situation. Signal processing is an operation meant for extracting, enhancing, storing and transmitting useful information (Kumar, 2014). Hence, it tends to be application dependent. Adaptive filters are used in which we don't have constant filter coefficients and no prior information is known to us compared to conventional filters (Haykin and Widrow, 2003).

Chaos theory is a field of mathematics focused on the non linear deterministic dynamical systems behaviour. Chaos is highly sensitive to initial conditions. This effect is popularly referred to as the butterfly effect. It is having applications in several disciplines including physics, engineering, economics, biology and philosophy. A very small disturbance in initial condition produces a drastically different final solution for the chaotic system and the long-term prediction is not possible. This happens even though these systems are deterministic, meaning that their future behaviour is fully determined by their initial conditions with no random elements involved in this process. This behaviour is known as deterministic chaos or simply chaos (Devaney, 1992). A chaotic dynamical system is deterministic, bounded system that exhibits randomness behaviour through its initial sensitive conditions (Mahaseth and Anuradha, 2013; Ashtari *et al.*, 2007). Since, in practice initial conditions can never be specified with infinite precision. The random Chaos sequences can be generated using various logistic, improved logistic, tent, cubic and quadratic chaotic maps (Heidari-Bateni and McGillem, 1992; Hilborn, 1994). In this study an attempt is made to generate binary sequences using these maps and their properties at different lengths are studied for improving the performance of radar target detection. Pitchaiah proposed the high-speed Implementation of Distributed Arithmetic (DA) based architecture for adaptive LMS filter. It is not given precious results because of required time and hardware complexity (Pitchaiah and Sridevi, 2015).

MATERIALS AND METHODS

LMS-RTD methodology: In the recent days, moving targets detection and tracking have become challenging. To increase the accuracy of the target detection in the free space environment, we have implemented an efficient de-noising algorithm in this LMS-RTD method. In order to de-noise the signal, an algorithm is applied to the received noisy signal, so that, it can suppress the color noise which is affected due to environmental disturbances occurred in the free space. The target detection efficiency is directly proportional to the de-noising algorithm efficiency. In this study, MATLAB 2017 a Simulink is used to model the radar transceiver and free space environment. The implementation of de-noising algorithm used for the LMS is done by using Verilog-HDL and it is synthesized by using Xilinx FPGA tool.

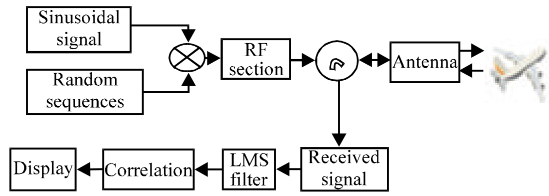

Fig. 2: Block diagram of the proposed LMS-RTD methodology

Figure 2 represents the block diagram of the proposed methodology, it has a signal generator system includes sinusoidal signal and barker codes, combined barker codes and binary phase coded chaotic sequences using logistic, improved logistic, quadratic, cubic and tent maps. These barker codes have various lengths such as 2, 3, 4, 5, 7, 11 and 13. For improving the radar target detection performance and increase the efficiency of operation, binary chaotic phase and barker sequences are used to modulate the sine wave.

The block diagram proposed method consists of the radio frequency section, switch, antenna, received signal, LMS filter, correlation and display. In this method, the modulator send the sinusoidal signal through the RF section and then after over the antenna. As shown in Fig. 2, the transmitter sends the radio signal through the antenna and then it is passed through the free space for detecting objects. The radar pulse with high velocity has to hit the target and it is reflected back. Depending on the echo signal velocity, object velocity and its position from the base station are detected. The environmental disturbances are the cause for the suppression of the signal and this can be rectified by using adaptive LMS filter. After the filtering process the detected object parameters are processed then analyzed according to that the position will be determined.

Binary phase code generation using chaotic maps: A Chaotic dynamical system is a bounded, deterministic system that exhibits random-like behavior through its sensitive dependence on its initial conditions. The use of chaotic signals in radar has received a lot of attention in the recent years because they behave like noise have a wide band and are easy to generate. In mathematics, a chaotic map is a map (= evolution function) that exhibits some sort of chaotic behavior. Maps may be parameterized by a discrete-time or a continuous-time parameter. Discrete maps usually take the form of iterated functions. Chaotic maps often occur in the study of dynamical systems.

Chaotic maps often generate fractals. Although, a fractal may be constructed by an iterative procedure, some fractals are studied in and of themselves as sets rather than in terms of the map that generates them. This is often because there are several different iterative procedures to generate the same fractal. Since, in practice initial conditions can never be specified with infinite precision, the behavior of a chaotic system is unpredictable and therefore, noise like (Seventline *et al.*, 2010; Sridevi *et al.*, 2012). Chaotic sequences can be generated using different types of chaotic maps. Some of the maps are:

- Logistic map
- Improved logistic map
- Cubic map
- Tent map
- Quadratic map

Logistic map: The logistic map is a polynomial mapping (equivalently, recurrence relation) of degree 2, often cited as an archetypal example of how complex, chaotic behavior can arise from very simple non-linear dynamical equations. As a part of discrete-time demographic model this logistic map was popularized in a seminar 1976 paper by the biologist Robert May and this map is analogous to the logistic equation first created by Pierre François Verhulst. Mathematically, the logistic map is written:

$$x(n+1) = f[x(n)] = \mu x(n)(1-x(n)) \quad (4)$$

where, μ is constant and is called the bifurcation parameter $\mu \in (0.\ 4)$ and $x \in (0.\ 1)$. The behaviour depends on the value of μ in the equation. When $\mu = 4$ the logistic map exhibits chaotic behaviour.

Improved logistic map: This map described by Eq. 5:

$$x(n+1) = f[x(n)] = 1-2\ x(n)^2 \quad (5)$$

where $x(n) \in (-1,\ 1)$. This equation shows the chaotic behaviour of initial value x(0) varying from 0-1. When x (0)>1 as n tends to infinity, x(n) also tends to infinite.

Table 1: Barker codes

No. of panels	Barker code
2	+1 -1
2	+1 +1
3	+1 +1 -1
4	+1 +1-1 +1
4	+1 +1+1 -1
5	+1 +1 +1 -1 +1
7	+1 +1 +1 -1 -1 +1 -1
11	+1 +1 +1 -1 -1 -1 +1 -1 -1 +1 -1
13	+1 +1 +1 +1 +1 -1 -1 +1 +1 -1 +1 -1+1

Cubic map: This map described by Eq. 6:

$$x(n+1) = f[x(n)] = x(n)^3-3x(n) \quad (6)$$

where $x(n) \in (-1,\ 1)$ and $\mu = 4$.

Tent map: Tent maps are widely used for chaos based applications because it is a discrete-time piecewise-affine input/output characteristics curve such as true random number generation. This map described by Eq. 7:

$$x(n+1) = f[x(n)] = \mu x(n)[1-2x(n)-0.5] \quad (7)$$

where $x(n) \in (0,\ 1)$ and $\mu = 0.5$.

Quadratic map: This map is described by the following Eq. 8:

$$x(n+1) = f[x(n)] = 0.5-\mu x(n)^2 \quad (8)$$

where $x(n) \in (-1,\ 1)$ and $\mu = 4$.

Binary phase code generation using barker and combined barker codes: The known nine barker codes are represented in Table 1. Combined barker code method involves phase coding with one Barker code within each segment of another Barker code. For example, the Barker code of length 3, B_3, may be combined with that of length 4, B_4, to create a code of length 12:

$$B_{43} = B_4 \otimes B_3 = (1\ 1\text{-}1\ 1,\ 1\ 1\text{-}1\ 1,\text{-}1\ \text{-}1\ 1\ \text{-}1) \quad (9)$$

Note that $B_{nm} = B_n \otimes B_m$ is the Kronecker product. Note that B_{nn} is not used because partial correlations are high (Adams and Losiewicz, 2004).

Implementation of proposed method: The proposed method was designed and simulated in MATLAB R2017a Simulink to obtain the de-noised signal by using adaptive LMS filter. Xilinx ISE tool is used to find the number of flip-flops, slices and LUTs. A number of iterations were performed to de-noising radar signal and to obtain the minimized values of RMSE and better values of SNR.

RESULTS AND DISCUSSION

Table 2 and Fig. 3 are the performance analysis of the parameters such as number of slice, LUTs and flip flops for LMS algorithm which is getting from Virtex-4 Xilinx ISE FPGA tool. From this result Table 3 and Fig. 3, we can easily understand that the number of LUTs and flip-flop's can be reduced in proposed LMS method as compared with existing methods. Due to the reduction of those parameters, the area can be optimized in LMS filter. Furthermore, the proposed LMS method minimizes used number of LUTs and flip-flop's as compared with existing algorithms.

Table 4 shows the performance analysis of RMSE values using LMS algorithm for different phase code sequences. As discussed earlier, the entire system is modelled by using MATLAB Simulink environment. The Simulink provides customizable block libraries, a graphical editor and solvers for simulating and modelling dynamic systems.

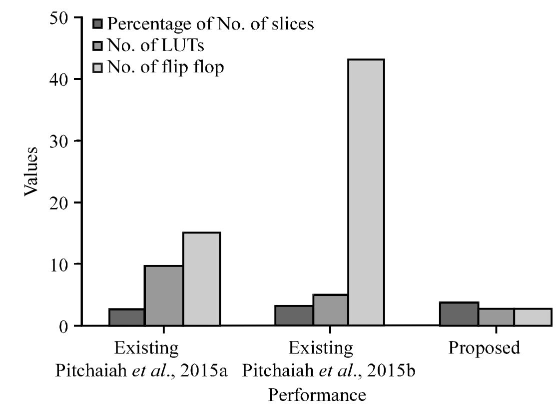

Fig. 3: Hardware performance of slices, LUTs and flip flop for different algorithms using bar graph

It is integrated with MATLAB, enabling to incorporate MATLAB algorithms into models then export simulation results to MATLAB for more analysis. The LMS algorithm target detection tracking model consists of radar transmitter (sine wave, repeating square star, rate transition 1 and 2 and product) selector, switch, target, receiver part (buffer, mean, product1 and LMS filter). In this study, the modulator will send the signal through the selector after this radar signal over the target as shown in Fig. 4. It is transmitted towards the target to detect objects which are in space. The radar pulse with high velocity has hit to target and it is reflected back.

Depending on the reflected or received signals velocity, target velocity from the base station can be measured. Finally, the detected object parameters are processed, analyzed of the target and motion will be determined. Figure 5a shows the modulated sine wave sequence which is used to transmit towards the target with respect to time. Figure 5b shows the noisy signal which is affected by additive white Gaussian noise. Figure 5c shows the radar de-noised signal using LMS filter. Figure 5d shows the detected target location in terms of distance from transmitter.

Table 2: Proposed LMS algorithm implementation using Virtex-4 Xilinx ISE FPGA

Filter order	Algorithms	No. of slices	No. of LUTs	No. of flip flop
16-tap	11a	732/28800	2714/28800	449/2997
16-tap	11b	888/28800	1376/28800	681/1583
8-tap	LMS	208/5,472	272/10,944	288/10,944

Table 3: RMSE performance of LMS algorithm

Bit length	SNR = 25.33434719406 (RMSE)			
Binary phase codes	7 bit	11 bit	13 bit	26 bit
Barker and combined codes B_7, B_{11}, B_{13}, $B_{13}\otimes B_2$	0.70623066133	0.70555994884	0.70674015723	0.70674015723
Logistic map	0.70630264587	0.70630264587	0.70630264587	0.70630264587
Improved logistic map	0.70697267621	0.70619494157	0.70744866110	0.70675038383
Cubic map	0.70618388559	0.70601876429	0.70566915414	0.70538498161
Quadratic map	0.70818263279	0.70490419624	0.70631226371	0.70648245332
Tent map	0.70630264587	0.70630264587	0.70630264587	0.70630264587

Table 4: RMSE performance of LMS algorithm

Bit length	SNR = 25.33434719406 (RMSE)			
Binary phase codes	55 bit	65 bit	77 bit	143 bit
Barker codes $B_{11}\otimes B_5$, $B_{13}\otimes B_5$, $B_{11}\otimes B_7$, $B_{13}\otimes B_{11}$, $B_{13}\otimes B_{13}$	0.70615120610	0.70563591339	0.70600346587	0.70618617079
Logistic map	0.70630264587	0.70630264587	0.70630264587	0.70630264587
Improved logistic map	0.70538395029	0.70621856097	0.70564133416	0.70564133416
Cubic map	0.70624705585	0.70581332822	0.70658060676	0.70658060676
Quadratic map	0.70567381557	0.70721657960	0.70736735119	0.70736735119
Tent map	0.70630264587	0.70630264587	0.70630264587	0.70630264587

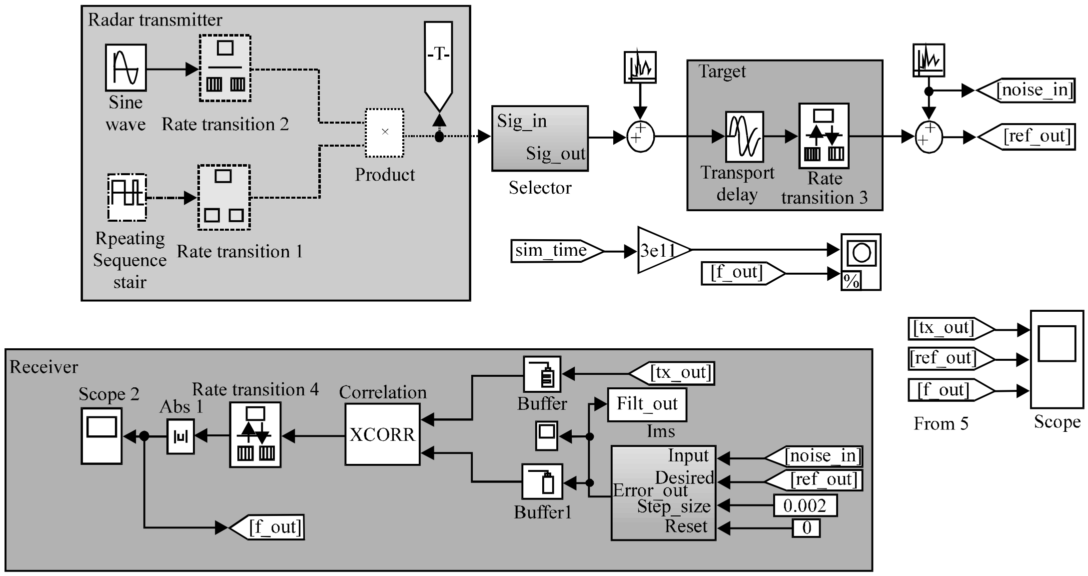

Fig. 4: Proposed target detection tracking model using MATLAB Simulink

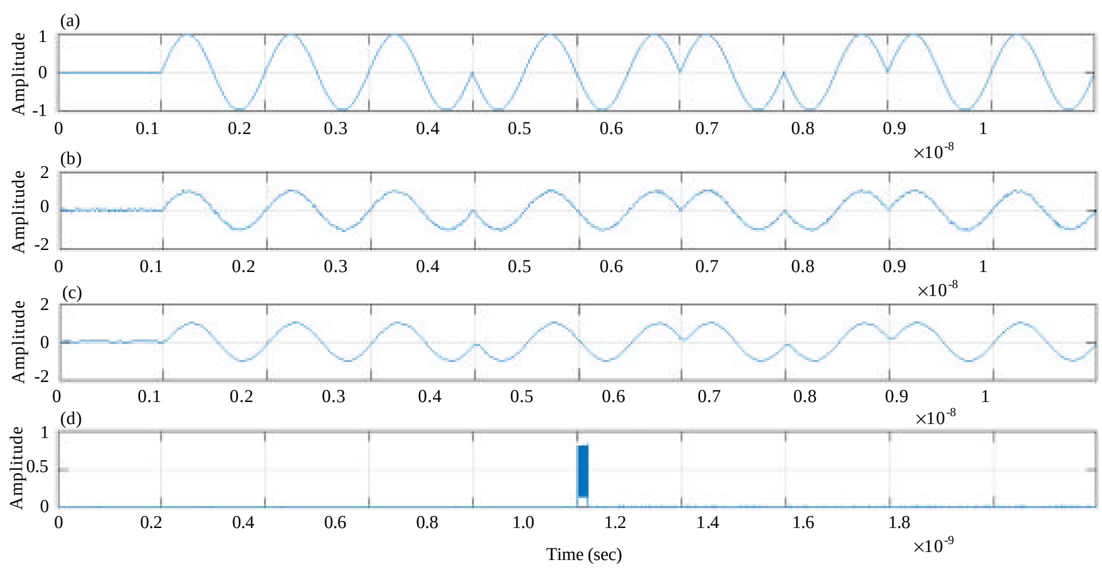

Fig. 5: a) Transmitted signal; b) Noisy signal; c) De-noised signal and d) Detected target signal

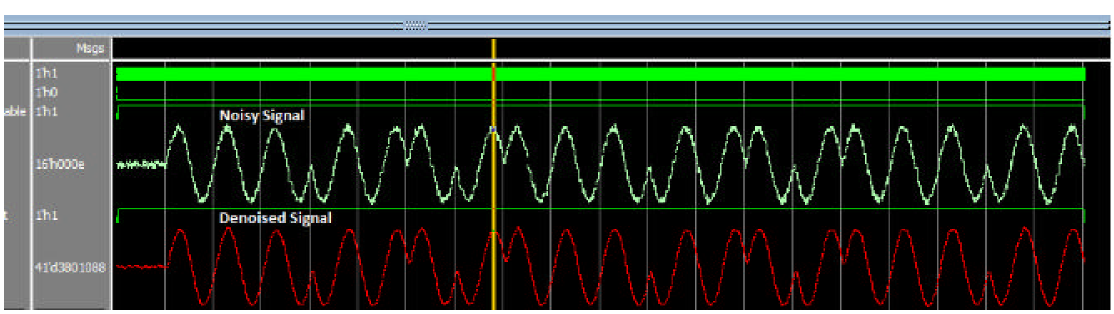

Fig. 6: LMS filter results using Modelsim tool

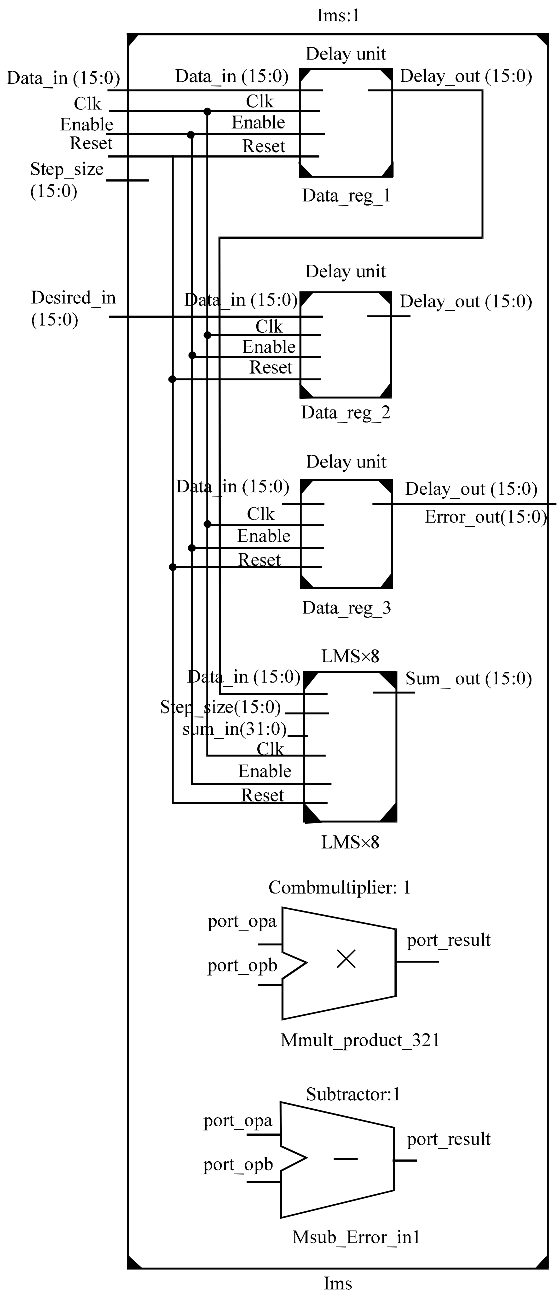

Fig. 7: RTL schematic of LMS filter

Figure 6 shows the simulation waveforms which is obtained after simulation of RTL Verilog code in Modelsim. In this, first sinusoidal signal is the noisy signal and the second signal is de-noised signal using LMS filter. The RTL schematic of LMS filter is shown in Fig. 7. This schematic obtained from Simplify pro by using Verilog HDL code which is written for LMS.

CONCLUSION

This study presented a study of performance analysis of adaptive LMS filter using different phase coded radar signals such as barker, combined barker and chaotic binary codes for radar target detection. In order to validate the proposed LMS-RTD design with other existing designs, RMSE and SNR values are evaluated by using MATLAB Simulink, number of slices, LUTs and flip-flops are evaluated using Xilinx ISE FPGA tool.From the simulation results, we are concluded that these binary phase codes give good performance in proposed LMS-RTD design. These codes are used to minimize the root mean square error and improve the performance of signal to noise ratio. From Xilinx ISE FPGA simulation results, proposed model details were estimated very precisely than other existing models.

RECOMMENDATION

In future, we can improve the hardware and computational complexity with less number of LUT's, flip-flops of de-noising algorithm using optimization techniques.

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