Generation of Long Binary Sequences using PSO Algorithm

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Abstract

Biphase codes are more preferable in pulse compression radars because these codes are easy to implement with digital hardware, and needs less signal processing in the receiver. This paper presents the design of long binary coded signals, which have low side lobes. These sequences are optimized by using Particle Swarm Optimization (PSO) algorithm. Further sidelobes are minimized by using mismatch filter.

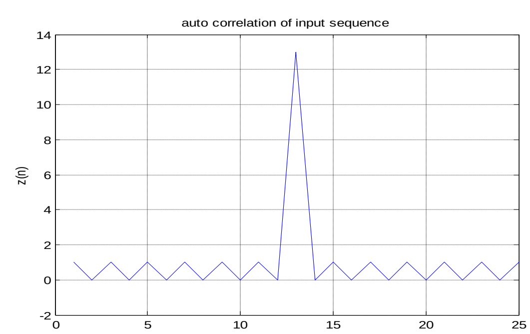
I. INTRODUCTION

There was a rapid growth in radar technology and systems during World War II. The major areas of radar applications includes military, remote sensing, air traffic control, law enforcement and highway safety, aircraft safety and navigation, ship safety and space [1]. Simple pulsed radar is limited in range sensitivity by the average radiation power and, in range resolution by the pulse length. The pulse compression theory has been introduced in order to get a high range resolution as well as a good detection probability at long ranges [2]. Pulse compression allows radar designers use of long duration waveforms to obtain high energy and simultaneously achieve the resolution of a short pulse by modulating the long transmitted pulse. The resolution is the ability of radar to distinguish targets that are closely spaced together in either range or bearing. The receiver matched filter output is the autocorrelation of the transmitted signal. If peak sidelobe level (PSL) at the output of the matched filter is not satisfactory, a mismatch filter can be used so as to reduce the side lobes further at a cost of introducing signal to noise ratio (SNR) mismatch loss. Low autocorrelation side lobes are required to prevent the masking of weak targets that occurs in the range side lobe of strong target. The internal modulation of transmitted pulse may be binary phase coding, polyphase coding, and frequency modulation. In this paper we are discussing the design of bi-phase codes for longer lengths, to achieve the high compression ratio.

II. BARKER CODED AND COMPOUND BARKER CODE

The binary code consists of a sequence of +1and -1. The phase of the transmitted signal alternates between 0 and 180° in accordance with the sequence of elements in the phase code. The order of the so called random 0 or π phases is in fact critical. The binary choice of 0 or π phase for each sub-pulse may be made at random. However, some random selections may be better suited than others for radar application. One criterion for the selection of a good "random" phase-coded waveform is that its autocorrelation function should have equal time side-lobes. The binary phase-coded sequence of 0 or π values that result in equal side-lobes after passes through the matched filter is called a Barker code. Fig. 1 shows the Autocorrelation Function (ACF) of the Barker code of length N=13. Barker codes of lengths more than 13 are not available. The maximum compression ratio that can be achieved through Barker codes is 13 only, which is not enough in many radar applications.

One of the popular ways of generating long binary sequences for high pulse compression ratio is Compound Barker codes. Compound Barker Codes is demonstrated using pair wise combinations of Barker Codes of length 5, 7, 11 and 13. If a code C_{N_1} of length N_1 is compounded with another code C_{N_2} of length N_2, the z-domain representation for such compounding is given by $C_{N_1,N_2} = C_{N_2}(z) \otimes C_{N_1}(z)$ Where $C_{N_1}(z)$ is the outer code and $C_{N_2}(z)$ is the inner code.



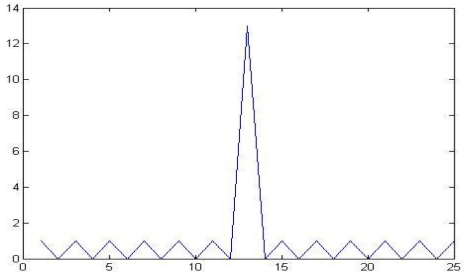


Fig. 1: Auto correlation of Barker code N=13.

In the time domain, the inner code is repeated a number of times equal to the number of bits in the outer code. In each repetition, the inner code is phase inverted or not depending on whether the corresponding bit in the outer is -1 or +1 respectively. Let us consider the Barker Codes of length 7 and 5 as B_7 = {1 1 1 -1 -1 1 -1} B_5= {1 1 1 -1 1}. Either of these codes could be compounded with the other to produce a code of length 35. If the outer code is length 5 and the inner code is length 7, the compound code is denoted by B_5 B_7, where represents the Kronecker product. The compound code is given by [1 1 1 -1 -1 1 -1 1 1 1 -1 -1 1 - 1 1 1 1 -1 -1 1 -1 -1 -1 -1 1 1 -1 1 1 1 1 -1 -1 1 -1]. Literature results [5-6] reveal that by using the compound Barker codes only compression ratio can be achieved but there is no improvement in sidelobe suppression.

A. Linear Recursive Sequences

The another method of generating long binary sequences of length greater than 13 is using shift registers with feedback and modulo-2 arithmetic. This method generates pseudo random sequences of 1 and 0 of length 2^N-1, where N is the number of stages in shift registers [6]. Fig. 3, shows the ACF of the pseudo random sequence of length N=31, generated by using 5 shift registers that is 2^N-1. The major limitation of both the codes, that is compound Barker codes and linear recursive codes, only a fixed length of codes can be generated. Therefore, this paper discusses the generation of long binary sequences of any length using optimization technique. In next section we are discussing about the Particle Swarm Optimization (PSO) and its application in optimization of binary sequences.

III. PARTICLE SWARM OPTIMIZATION ALGORITHM

The Particle Swarm Optimization (PSO) algorithm is a biologically-inspired algorithm motivated by a social analogy. The algorithm and its concept of "Particle Swarm Optimization was introduced by James Kennedy and R ussel Ebhart, based on the social behavior of flock of birds in 1995 [7]. Every bird is a particle in hyper-dimensional search space. Also every particle has some sociopsychological nature by which it tries to enhance its scope of other particles. In PSO the swarm is a collection of particles in motion and every particle concerns a potential solution. The solution approaches the desired value as the particle moves with its knowledge of personal as well as global experience. To accomplish for this it has 2 parameters *i.e.* position and velocity of the particle.

$x_i(t) = i^{th}$ particle position at time slot 't'. (1)

$v_i(t) = i^{th}$ particle velocity at time slot 't'. (2)

In a particular iteration the position is updated as

$$x_i(t+1) = x_i(t) + v_i(t+1) \quad (3)$$

It can be understood from above expression that the velocity updates the position with the knowledge of globally exchanged information. Updating velocity, there are many methods for adopting PSO, Individual best PSO, Global best PSO and local best PSO. However, in the present work, global best PSO is considered as it is supposed to have good convergence criterion. In
Global best PSO, the velocity is updated with including the knowledge of the best particle's position in the flock.

$$v_i(t+1) = v_i(t) + \rho_1 (x_{i(pbest)} - x_i(t)) + \rho_2 (x_{gbest} - x_i(t)) \quad (4)$$

For above all the three cases the personal best is updated in iteration as follows

If Fitness $(x_i(t))$ < pbest(x_i)
then $x_{i(pbest)} = x_i(t)$
else x_i(pbest) remains with its value

Also in Global Best method the x_{gbest} is updated as

if Fitness $(x_i(t)$ < gbest
then $x_{gbest} = x_i(t)$

else x_{gbest} will retain its value.

The flow chart for optimization is shown in Fig. 2. The main advantage is, by using this method binary sequences of any length can be optimized unlike in the case of compound Barker codes or linear recursive sequences. Fig. 5 & Fig 7 are showing the ACF of optimized binary sequence of length N=31, and N= 63 respectively, which are achieved by using PSO algorithm.

IV. MISMATCHED FILTER

Further, the sidelobes of optimized sequences can be minimized by using mismatch filter at the cost of some signal-to-noise ratio (SNR) loss [8]. The binary sequence is given by

$$S = \{s_1 , s_2, s_3,\ldots,s_N\} \quad (5)$$

The filter elements are

$$H = \{h_1, h_2, h_3 \ldots h_M\} \quad (6)$$

where the elements are real and $N \leq M$. For simplicity we will assume that if N is odd then M is also odd, and when N is even M is also even. This implies that M − N is

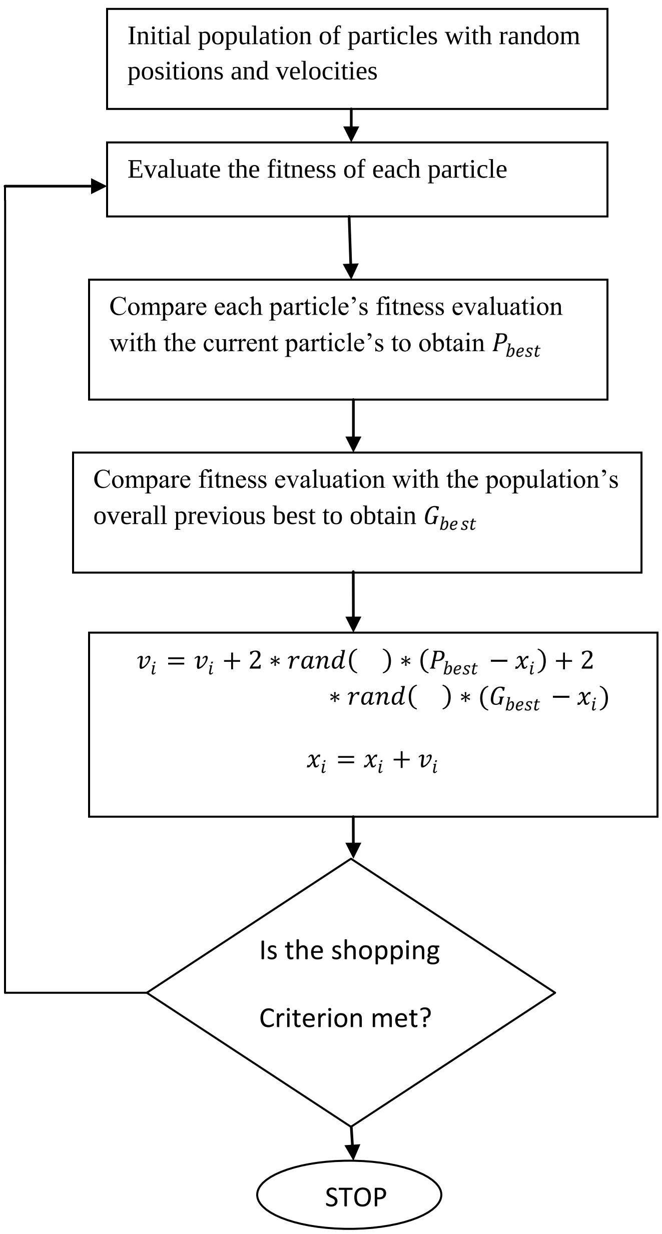


Fig. 2. Flow Chart of Optimization Process of PSO

Always Even, Hence (M −N)/2 = z is an integer.

We will now define Z as an all-zero sequence of length z, and create a zero-padded signal sequence of length M = N + 2z given by

$$S_0 = \{Z\ S\ Z\} \quad (7)$$

Clearly, the sequences H and S_0 are both of equal length M. We will also assume that the filter is designed so that the cross-correlation R_k (H, S_0) between H and S_0 will peak at zero delay (k = 0). R_k (H, S_0) is not necessarily symmetric around zero delay.

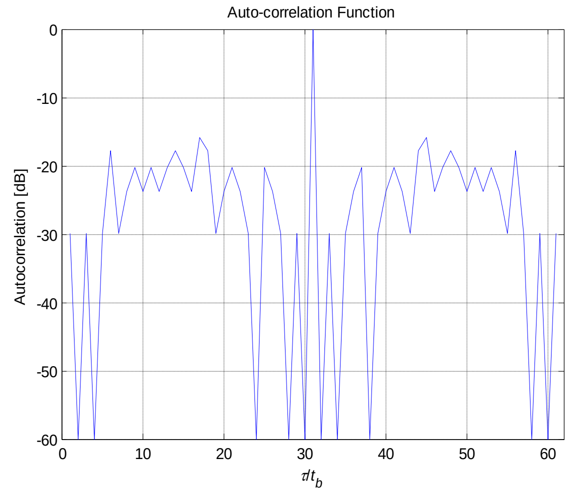


Fig 3. ACF of Linear Recursive Sequence, N=31

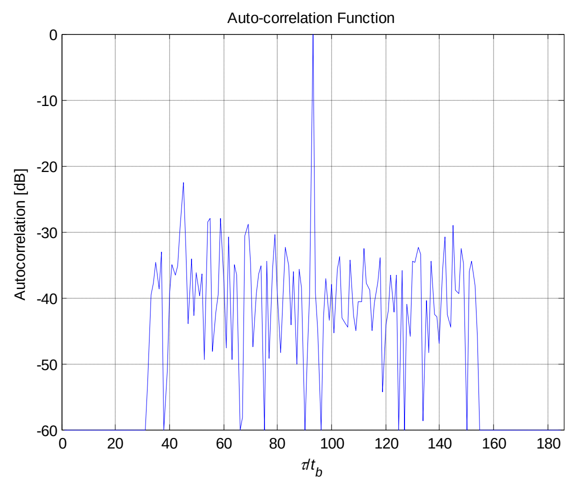


Fig. 4. Output of Mismatch Filter N=31, M=93 (Linear Recursive sequence)

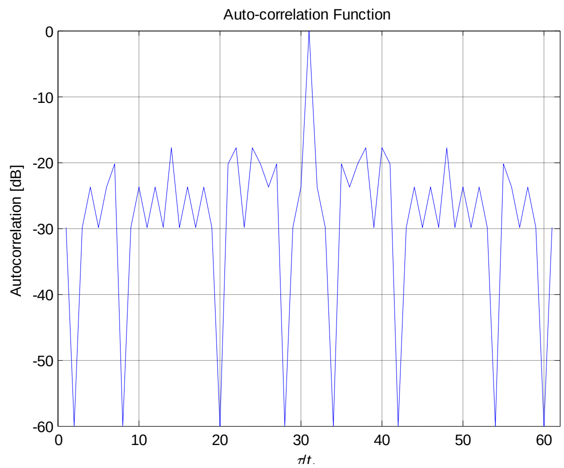


Fig 5. ACF of Optimized Sequence using PSO, N=31

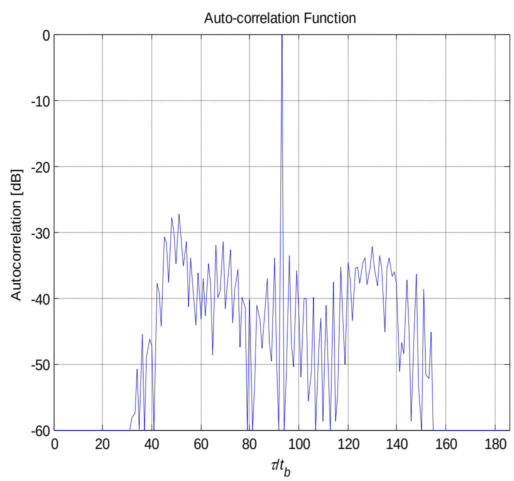


Fig 6. Output of Mismatch Filter N=31, M=93 (PSO optimized sequence)

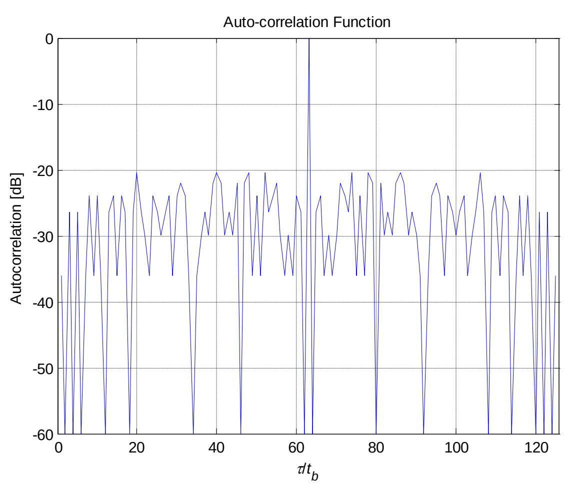


Fig 7. ACF of Optimized Sequence using PSO, N=63

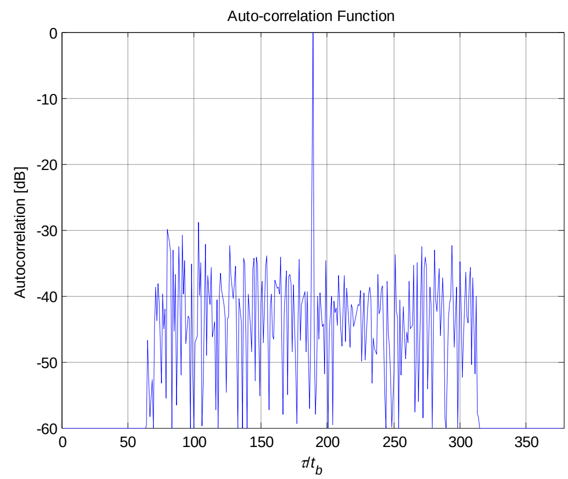


Fig 8. Output of Mismatch Filter N=63, M=189 (PSO optimized sequence)

V. RESULTS AND CONCLUSION

The objective is mainly to demonstrate the capability of the PSO algorithm in the generation of binary sequences of any length with good auto-correlation properties. These sequences are widely used in pulse compression radar for improving system performance. Figs 3-8, show that the results obtained by using PSO are better than the sequences generated by LRS method for the same sequence length. Additionally, sidelobes can be further suppressed by using mismatch filter. One can also observe that as the length of sequence increases, sidelobe suppression in mismatch filter is also increases.

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