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Performance Analysis of Synchronization Bit Errors for the Detection of a Target

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Abstract
In this paper a new approach of signal design for a target detection is presented using poly-semanticsequences with larger code lengths to achieve optimal target detection in high resolution radar (HRR) systems inpresence of high-density additive noise and Doppler environment. The notion of poly-alphabetic radar [1] [2]introduced earlier based on simultaneous multiple interpretations of pre-designed returned waveform, results into improved detection performance of binary pulse compression radar at the affordable cost of an additional signal processing. In fact, the central idea of poly-alphabetic radar signal is poly-semanticism, which was achieved through poly-alphabetism. In the earlierwork based on mono-alphabetic poly-semanticism [3],the problem of optimal target detection was discussed in the context of single target in noise free environment. In our approach, Optimal Binary Codes (OBC) and randomly generated codes are used to generate poly-semantic sequences. In this paper, the sequence is designed by considering a target with noisy and Doppler environment. The quantitative measures;Discrimination and Figure of merit suggested by Moharir [4] for binary sequences are used to evaluate the detectionperformance of the poly-semantic codes. The transmittedbinary sequence is optimized by employing poly- semantic Hamming scan algorithm such that each of the poly-semantic interpretations led to maximum discrimination or figure of merit. The design is completedin two steps: first one using restricted Hamming scan for interspersed binary sequences and the second, using a complete Hamming scan with an appropriate joint objective function (F). The results show a significantimprovement in synchronization bit errors for the detection of target.

I. Design of poly-semantic sequences

Consider, optimal binary codes or randomly generated binary codes of length N , given by

$S_1 = A = [a_j]$ (1)

$B = [b_j]$ (2)

and $C = [c_j]$ (3)

where, $j = 0,1,2,3...N-1$.

The elements of this sequence are drawn from alphabet $\{-1,+1\}$. The sequences S_2 and S_3 are given by

$S_2 = [a_j b_j]$ (4)

$S_3 = [a_j b_j c_j]$ (5)

where $j = 0,1,2,3...N-1$.

A selective Hamming scan algorithm is applied on the sequences S_2 and S_3 , so that the figure of merit of the sequence is optimized. The binary sequence S_3 is transmitted as a waveform. As S_3 is interspersed by binary sequences S_1 and S_2 , it is equivalent to three sequences with good autocorrelation properties being transmitted in the form of S_3 . On reception, the received waveform is decoded into binary sequence (R) and the cross correlation is computed in discrete mode. The decoded sequence R is cross correlated in the receiver with three predesigned sequences, given by

$T_1 = [a_0, 0, 0, a_1, 0, 0, a_2, 0, 0...a_{N-1}, 0, 0]$ (6)

$T_2 = [a_0, b_0, 0, a_1, b_1, 0, a_2, b_2, 0...a_{N-1}, b_{N-1}, 0]$ (7)

$T_3 = S_3 = [a_0, b_0, c_0, a_1, b_1, c_1, a_2, b_2, c_2 ...a_{N-1}, b_{N-1}, c_{N-1}]$ (8)

The Hamming scan algorithm is applied on T_1 , T_2 and T_3 for optimizing the joint asymptotic figure of merit F of the cross correlated of sequences S_3 & T_1 , S_3 & T_2 and S_3 & T_3 . The good figure of merit properties of these three interpretations are jointly used through coincidence detection for the detection of target. The poly-semantic radar signal in which the received binary sequence R is cross-correlated with three embedded sequences T_1 , T_2 and T_3 (or S_3) in three channels separately. The three cross correlation peaks in three channels are coinciding, which simultaneously indicates the presence of the target. It is also interesting toobserve from the results that the time side lobes in three channels do not align. This in turn reduces the degree of false alarm because of time side lobes in the return signal.

A. Hamming backtrack algorithm for mono-alphabeticPSS

The Hamming scan algorithm has been applied successfully to design of poly-alphabetic [1] and Bi-alphabetic [5] sequences with good aperiodic autocorrelation properties. To determine the poly- semantic mono-alphabetic sequences with low autocorrelation side lobes, a modified Hamming scan algorithm known as Hamming backtrack algorithm isdeveloped in the present study.

The Hamming backtrack scan algorithm starts with the binary sequence S3 and derives three sequences T1 , T2 and T3 for finding the asymptotic figure of merit F1 , F2 and F3 . The F1 , F2 and F3 are obtained by cross correlation of the sequences S_3 & T_1 , S_3 & T_2 and S_3 & T_3 respectively. The asymptotic figure of merit is monotonic function of discrimination D of the correlated function of the given sequence. The mono-alphabetic poly-semantic Hamming scan induces mutations in the elements of S_3 , Viz., + → -, - → + and looks at the first order Hamming neighbours of all the elements in the sequences. A mutation in the element of S_3 , in turn induces mutation in the corresponding element of the sequences T_1 , T_2 and T_3 . The algorithm computes the sum of asymptotic figure of merit F_1 , F_2 and F_3 of all the first order Hamming neighbours of S_3 and picks up the mono-alphabetic sequence, which results in largest value of $F = (F_1 + F_2 + F_3)/3$.

The autocorrelation due to each perturbation of the binary sequence is calculated merely taking into account the changes required in the original autocorrelation instead ofcalculating the aperiodic autocorrelation of the Hamming neighbour *ab initio*. This expedites the process of mono- alphabetic Hamming scan algorithm.

II. Detection and Correction of Synchronization Errors

Earlier work on poly-alphabetic radar signals [5] emphasizes the possibility of an effective and accurate detection of the target using coincidence detection strategy, which is the result of multiple interpretation of the decoded binary sequence at the receiver. Here, the target return sequence is decoded into binary format so that the decoded sequence is subjected to poly-gram reading. The proposed coincidence detection scheme works presuming that the poly-gram reading at the receiver is performed with proper synchronization. The bigram reading can be off by one bit and trigram reading can be off by one or two bits of the decoded binary sequence. This happens owing to the fact that the bigram and trigram readings are dependent on the pre-designed binary decoded sequence at the receiver. Thus detection and correction of poly-gram synchronization errors in poly-alphabetic sequence failed for the reliable detection of a single target. In other words, the coincidence detection fails, if the detected sequence is wrongly synchronized at the receiver.

However, in poly-semantic radar signal design, this limitation would be overcome as no poly-gram reading is employed during the frame work of signal design problem. The effect of the synchronization bit errors decreases the amplitude of the central peak with no loss of information of the central peaks in the channels.
Fig.1 shows the poly-semantic sequence of length 90 without synchronization errors

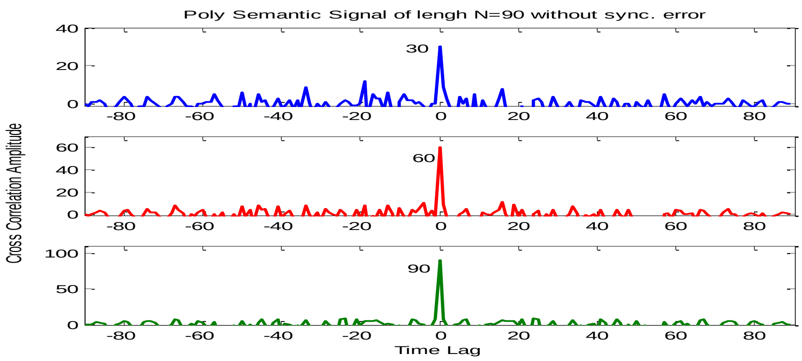
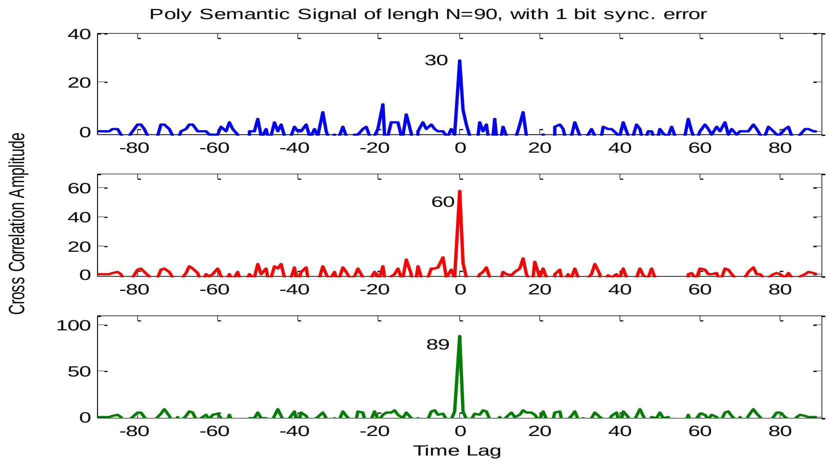


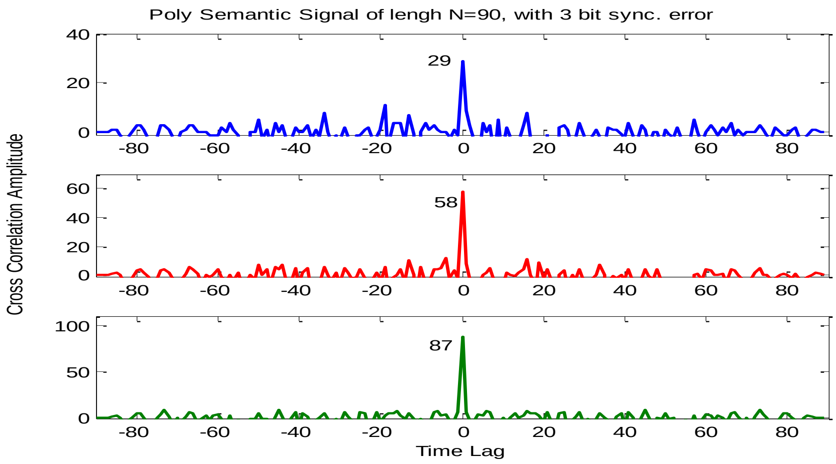
Fig.1 Poly-semantic sequence of length 90 without synchronization bit errors.

The poly-semantic sequence of length 90 without synchronization bit errors in coincidence detection, the cross-correlation peaks in the three channels synchronized simultaneously indicating the presence of the target. The amplitude of cross-correlation peaks in the three channels does not decrease.

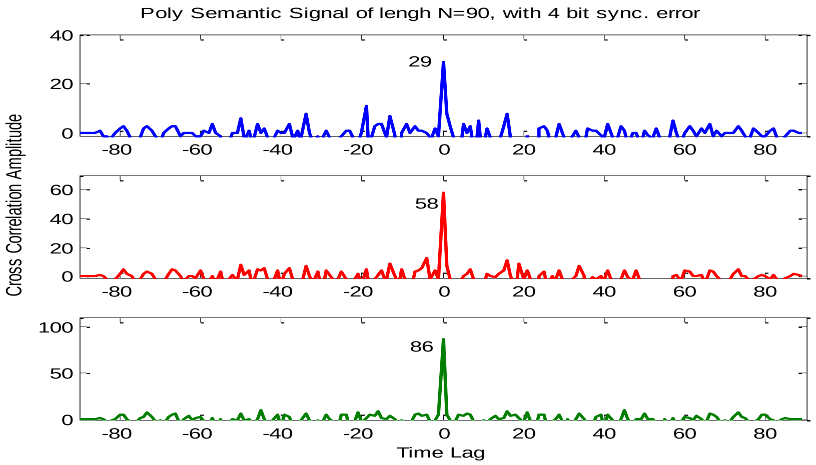
Fig.2 shows the poly-semantic sequence of length 90 with synchronization error of (a) 1 bit (b) 3 bit and (c) 4 bit



(a)



(b)



(c)

Fig.2 Poly-semantic sequence of length 90 with synchronization error of (a) 1 bit (b) 3 bit (c) 4 bit.

For the synchronization bit error of poly-semantic sequence of length 90 with 1 bit, 3 bit and 4 bit, the cross-correlation peaks coincided simultaneously in the three channels detecting the presence of a target. It is observed that only small decrease in the amplitude of cross-correlation peaks occurs.

Fig.3 shows the poly-semantic sequence of length 90 with half fold synchronization bit errors.

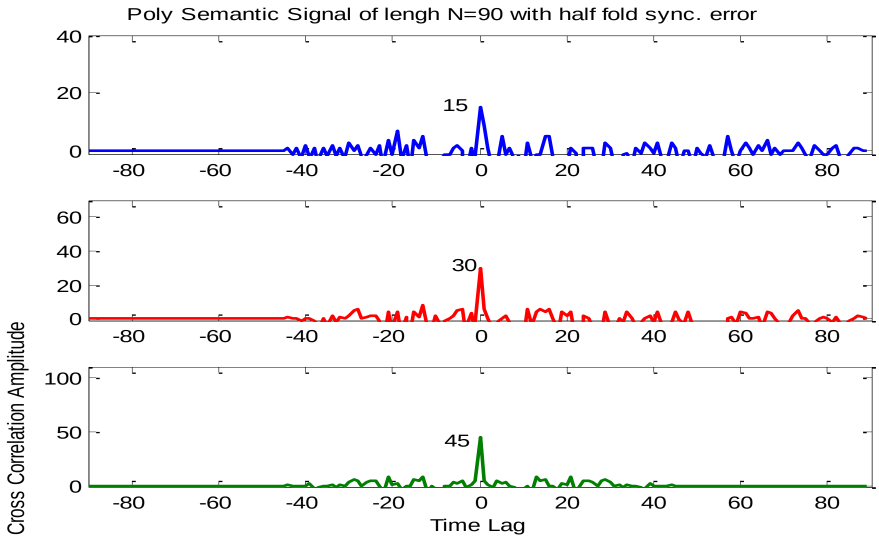


Fig.3 Poly-semantic sequence of length 90 with half fold synchronization bit errors.

It is observed that the amplitude of the cross-correlation peaks decreases in the three channels with no loss of target information in the channels. The results clearly indicate that the poly-semantic sequences detect the presence of a target.

Table 1 Effect of central peak values ρ(0) in coincidence detection of poly-semantic sequence of length 90 with synchronization bit errors.

No. of Synchronization bit errors in received decoded sequence	Central peak values ρ(0)		
	S1	**S2**	**S3**
No Sync. error	30	60	90
1-bit	30	60	89
2-bit	30	59	88
3-bit	29	58	87
4-bit	29	58	86
6-bit	28	56	84
10- bit	27	54	80
Half-fold	15	30	45
60-bit	10	20	30

Table 1 shows the effect of synchronization bit error on the amplitude of the cross-correlation peaks for poly-semantic sequence of length 90 for a single target.

III. Conclusions:

In this paper poly-semantic sequences are analyzed for the detection of a target in synchronization bit errors. These results provide the evidence that the PSS withlarger pulse compression ratios can achieve the range sidelobe level below 14.78 dB. This is significance improvement over conventional pulse compression sequences and poly-phase alphabetic sequences whichprovide side lobe level of 13.42 dB under noise free environment. This advantage arises because when the binary sequence is designed using 2nd order HBT algorithm, it performs recursive search such that the multiple interpretations of PSS of larger length reinforce each other through matched filtering and coincidence detection. The advantage of PSS is that their detection ability is further improved in noise free or noisy environment through coincidence detection scheme. In poly-phase sequences, the coincidence detection fails, if the detected sequence is wrongly synchronized at the receiver.

In poly-semanticsequence the effect of the synchronization bit errors decreases the amplitude of the central peak with no loss of information of the central peaks in the channels for detection of a target. These examining results lead PSS to be very suitable for the detection of target with synchronization bit errors. However, these advantages will be achieved with an additional affordable signal processing at the receiver.

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