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Design of Radar Signal for Two Target Detection

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Abstract
In this paper a new approach of signal design for two target detection is presented using poly-semantic sequences with larger code lengths to achieve optimal target detection in high resolution radar (HRR) systems in presence 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 two targets 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 detection performance 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 significant improvement in HRR target detection, which is achieved by coincidence detection.

I. Design of poly-semantic sequences

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

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

$$B = [b_j] \qquad (2)$$

and $$C = [c_j] \qquad (3)$$

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

$$S_2 = [a_j b_j] \qquad (4)$$

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

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

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

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

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

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 Hammingneighbour *ab initio*. This expedites the process of mono- alphabetic Hamming scan algorithm.

II. Performance Evaluation of pss

1. Noise Robustness:

To evaluate the noise performance, the poly-semantic sequences, which are perturbed by Gaussian noise at different η, are considered as input sequence. For range resolution ability, consider a target model when a dispersed echo is reflected from two targets located at sub-pulse delay apart (SPDA) of zero to $(N-1)$. Fig. 1 shows the output waveforms of poly-semanticsequences when two targets are at 50 SPDA and η = -10 dB. The targets can be detected even if the η falls to -15 dB. This is not possible with conventional sequences. Simulation results show that for HRR systems, poly-semantic sequences show better noise robustness when compared to conventional binary sequences.

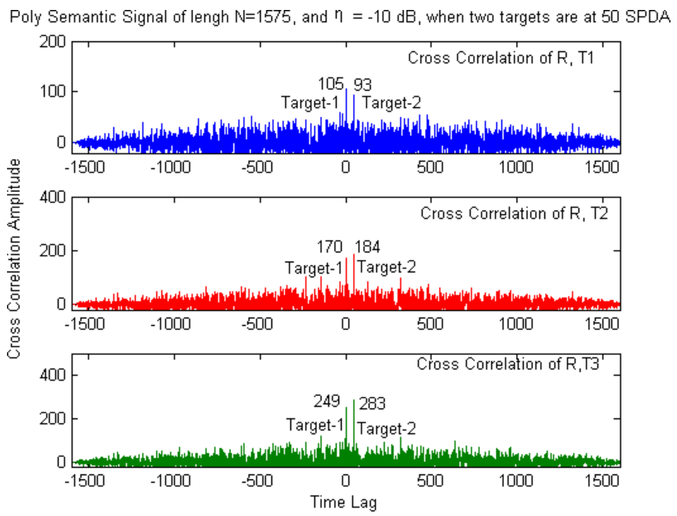

Fig. 1 Coincidence detection of the poly-semantic sequence at lengthN=1575 when η = -10 dB

2. Doppler tolerance:

When the target has a constant motion, a linear phase shift given by $d\phi = \sigma\pi / N, 0 < \sigma \leq 1$ proportional to target velocity will be added on to the received decoded sequence. The Doppler shift increases above0.5π/N, the performance of figure of merit deteriorates. When Doppler phase shift increases to 0.8π/N, the figure of merit falls below 0.3. Thus, the information due to target will be masked and it is not possible to identify the target. The proposed sequences have Doppler tolerance up to 0.7π/N with corresponding figure of merit of 0.3.

3. Combined effect of noise and Doppler shift:

When the signal encounters the joint effect of additive noise and Doppler shift due to a moving target, the phase shift variation in the received signal becomes non- monotonic function. In such a case some of the sub-pulses (randomly) in the sequences may have phase shift more than 0.5π/N. At threshold detection these sub-pulses undergo phase reversal. The performance of figure of merit decreases with the increase of such erroneous bits in the decoded sequence. This results into deterioration inthe performance of PSS detection.

4. Detection Performance:

Let us consider a K_a-band 30 GHz radar, transmitting apoly-semantic sequence of length N=1575 with pulse interval of 36.25 μs. The sub-pulse time interval is 50 ns (signal bandwidth is 20 MHz and range resolution is 7.5 m). At the receiver, the resultant waveform is multiply interpreted for coincidence detection. Thesimulation results show that the resulting coincidencedetection increases the detection performance of PSS with η below –15 dB.

Conclusions:

In this paper poly-semantic sequences are analyzed for the detection of two target in high-density additive noise and Doppler environment for the application of high resolution Doppler radar system. These results provide the evidence that the PSS with larger pulse compression ratios can achieve the range side lobe 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 at length N > 1638 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 PSS has significant advantage of noise interference and Doppler tolerance with η below20 dB at length N>4000. Another important advantage ofPSS is that their detection ability is further improved in noise free or noisy environment through coincidence detection scheme. The poly-semantic sequences at higher lengths with coincidence detection has noise and Doppler tolerances of η = -15dB and 0.7π/N respectively. While compared with poly-phase sequences, a poly-semantic sequence has achieved better noise rejection ability, higher range resolution and superior Doppler tolerance. These examining results lead PSS to be very suitable for the high-resolution Doppler radar systems. However, these advantages will be achieved with an additional affordable signal processing at the receiver.

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