EIGHT   PHASE OPTIMAL SEQUENCE DESIGN FOR MIMO RADAR USING PSO

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ABSTRACT

MIMO Radar   applications desire   a set of sequences with discretely low autocorrelation side lobe peaks and low cross correlation. Invade such sequences is a combinal   problem. If the autocorrelation and cross correlation are convenient in the aperiodic sense then there are hardly any theoretical aids available thus the problem of signal design referred to above is a defying problem for which many optimization algorithms are available those are,artificial bee colony(ABC), ant colony optimization algorithm, Genetic algorithm and particle swarm optimization algorithm   were reported in the journal papers . This paper intent at gadget of an efficient optimization algorithm is design to find an optimal solution for pulse compression radar .these sequences are useful for MIMO radar applications .The proposed optimization algorithm i.e particle swarm optimization algorithm for identifying the optimal pulse compression sequence .

Keywords: polyphase , orthogonal waveforms ,cross spectral density matrix(CSDM),MIMO Radar,ASP .

INTRODUCTION

A variety of waveforms has been used for radars till date. Several properties of radar waveforms have been discussed. Radar waveforms are application specific. The performance of radar depends on the properties of the waveform . An un-modulated or modulated continuous signal is used in continuous wave (CW) radar. Such a system can detect targets using Doppler offset, but range measurements become difficult. Since the radar transmits continuous waves, the need for secondary antenna for reception arises which is considered as another shortcoming of such a system. Pulsed radars could be coherent or non-coherent The Various characteristics of a radar system such as the accuracy, resolution, range, range-Doppler ambiguity etc. are decided by the radar waveforms. Thus, the choice of radar waveform decides the performance of the system. For example, the shorter the pulse width of the pulsed radar, the more accurate resolution the system has. But at the same time, short pulse cannot support a good detection range. These issues were solved by the technique of Pulse Compression. Pulse compression shares the idea of Transmitting a long pulse with some modulation embedded which spreads the energy over the bandwidth necessary for the required resolution. Pulse compressed waveforms have larger time bandwidth (BT) product compared to uncompressed pulses

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whose BT=1.The technique of pulse compression in waveforms is employed either in the form of Frequency coding or Phase coding.

An LFM signal is a frequency modulated waveform whose carrier frequency varies linearly with time, over a specific period. This is one of the oldest and frequently used waveforms. It finds application in CW and pulsed radars. Since an LFM waveform is a constant amplitude waveform, it makes sure that the amplifier works efficiently. Also, this waveform spreads the energy widely in frequency domain. In Non-linear Frequency Modulation the carrier frequency of the waveform is varied according to any non-linear law over time. The variation can be symmetrical or asymmetrical over time. Some of the nonlinear frequency modulations can be summed up as quadratic FM with even symmetry about the carrier frequency, quadratic FM with odd symmetry. With the advent of high speed digital hardware another class of signals evolved where the FM is digitally generated as a staircase stepped FM.

This can be broadly classified into binary and M phase coding. Following are various popular phase coded waveforms. First is Binary phase coding ,in this technique, the phase of any sub pulse takes any of the two alphabets values, either 1 or -1, according to the sequence. Various types of binary codes with good autocorrelation properties are used in bi-phase coding. Some of the commonly used codes are Barker codes, Maximal length sequences is 13. In poly phase coding the phase of the sub pulses takes any of the M- arbitrary values. Frank codes, p1 code, p2 code ,p3 code, and p4 coded waveform are some of the commonly used sequences in Polyphase coding technique. The range side lobes for polyphase coded waveforms are lower than that of binary-coded waveform of same length.

ORTHOGONAL WAVE FORMS

Orthogonal poly phase code consists of Length of the sequence (N_c),set size of (L) and   Phase of the sequence (M). Signals which probably containing N_c sub pulses represented by a complex number sequence, the set of the sequence is given by

$$s_l(n) = e^{j\,\emptyset_l(n)} \tag{1}$$

Where n=1,2, …., N_c and   l=1, 2, …., L   Where $\emptyset_l(n)$, $(0 \leq \emptyset_l(n) < 2\pi)$ is the phase of sub pulse n of signal.

$$\emptyset_l(n) \epsilon \left\{ 0, \frac{2\pi}{M_c}, 2.\frac{2\pi}{M_c}, …, (M_c - 1).\frac{2\pi}{M_c} \right\} \tag{2}$$

$$\phi_l(n) = \{\psi_1, \psi_2, …, \psi_{M_c}\} \tag{3}$$

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Assume a set a poly phase codes with contains the set as N_c whose set size is L, one can briefly signify the phase values of S with following $L \times N_c$ phase matrix.

$$S(L, N_c, M_c) = \begin{bmatrix} \phi_1(1) & \phi_2(2) & \dots & \phi_1(N_c) \\ \phi_2(1) & \phi_2(2) & \dots & \phi_2(N_c) \\ \vdots & \vdots & & \vdots \\ \phi_L(1) & \phi_L(2) & \cdots & \phi_L(N_c) \end{bmatrix} \tag{4}$$

Here the phase sequence in row $(1 \leq 1 \leq L)$ is the sequence of polyphase signal , and complete elements in the matrix can be elected from the set of phases .From the cross correlation and autocorrelation distinguishing of orthogonal polyphase codes, we get.

$$A(\phi_l, k) = \begin{cases} \dfrac{1}{N_c} \sum_{n=1}^{N_c-1} \exp j[\phi_l(n) - \phi_l(n+k)] = 0 & 0 < k < N_c \\ \dfrac{1}{N_c} \sum_{n=-k+1}^{N_c} \exp j[\phi_l(n) - \phi_l(n+k)] = 0 & -N_c < k < 0 \end{cases}$$

For l=1, 2, …. L   (5)

$$C(\phi_l, k) \approx \begin{cases} \dfrac{1}{N_c} \sum_{n=1}^{N_c-k} \exp j\big[\phi_q(n) - \phi_p(n+k)\big] = 0 & 0 < k < N_c \\ \dfrac{1}{N_c} \sum_{n=-k+1}^{N_c} \exp j\big[\phi_q(n) - \phi_p(n+k)\big] = 0 & -N_c < k < 0 \end{cases}$$

For p≠q and p, q=1, 2, …   L   (6)

where $A(\varphi_l, k)$ and $C(\varphi_p, \varphi_q, k)$ are the aperiodic function of autocorrelation polyphase sequence S_l and the function of cross correlation sequences S_p and S_q .Where k defined as the discrete time index. Therefore, crafting of an orthogonal polyphase code made corresponding to the building of a polyphase matrix in equation 6 with $A(\varphi_l, k)$ and $C(\varphi_p, \varphi_q, k)$ constraints in equation 5 and equation 6.For the scheme of code sets of orthogonal polyphase used in MIMO radar systems, an the process of optimization is used not only to suppress the auto correlation side lobe peaks and the cross correlation peak but also to suppress the the total autocorrelation sidelobe energy and cross

correlation energy in equation 7 .Here λ is the weight factor if it is less than one means more weightage is given to auto-correlation and less weightage is given to cross-correlation.

$$E = \sum_{l=1}^{L} \sum_{k=1}^{N_c} |A(\phi_l, k)|^2 + \lambda \sum_{p=1}^{L-1} \sum_{q=p+1}^{L} \sum_{k=-(N_c-1)}^{N_c-1} |C(\phi_p, \phi_q, k)|^2$$

(7)

MIMO RADAR   SIGNAL MODEL

A. *Autocorrelation Function and Transmit Beam patterns*

In previous papers [5,7,8] it was shown how the choice of transmit waveform signal correlation could affect the transmit beam pattern of a MIMO radar. For an array independently transmitting narrowband wide-sense stationary waveforms, the transmit beam pattern function is

$$P_N(\theta) = A^H(\theta) R a(\theta)$$

(8)

Here $A^H(\theta)$ is the narrow-band transmit array steering vector parameterized by the angle θ and R is the zero-lag signal correlation matrix. Similarly, for an array transmitting wideband signals, the transmit beam pattern is

$$P_w(\theta) = \int A^H(\theta, f_c + f_\vartheta) \, S(f) a(\theta, f_c + f_\vartheta)$$

(9)

Again $A^H(\theta, f_c + f_\vartheta)$, is the narrowband transmit steering vector parameterized by the angle θ, but now specifically calculated at the frequency $f_c + f_\vartheta$. The matrix S(f) is the cross-spectral density matrix (CSDM) of the transmitted waveforms. It is defined as the element wise Fourier transform of the signal correlation matrix.

$$S(f) = \int_0^T R(\tau) e^{-j 2\pi f t} \, dt$$

(10)

Returning to the definition of the MIMO ambiguity function, we can identify the role of the transmit beam pattern. To begin, consider the second model simplification. The term $A_T^H(\theta_1) R^4(\theta_1 \theta_0, j) \, A_T(\theta_0)$ appears. If the two target parameters are equal, $\theta_1 = \theta_0$, this term becomes the transmit beam pattern. The dependence of the covariance function on j drops out is

$$R_{i,j}^2(\theta_1, \theta_1, j) = \int s_i \left(t - \tau_{i,j}(p_1) \right) s_i^*(t - \tau_{i,j}(p_1) dt)$$

$$= \int s_i(t) s_i^*(t - [\tau_{i,j}(p_1) - \tau_{i,j}(p_1)]) dt)$$

$$= \int s_i(t) s_i^*(t - [\tau_i(p_1) - \tau_i(p_1)]) dt)$$

$$= R_{i,j}^2([\tau_i(p_1) - \tau_i(p_1)]) \tag{11}$$

$$= \int s_{i,i}(f)\, e^{j2\pi\left(\tau_i(p_1)-\tau_i(p_1)\right)f}\, \mathrm{df} \tag{12}$$

Taking the result of above equation and substituting back into the quadratic form, one finds the expression for the wideband transmit beam pattern

$$A_T^H(\theta_1)R^2(\theta_1\theta_0,j)A_T(\theta_1) = \sum_{i=1}^{N_T}\sum_{I=1}^{N_T}\int s_{i,i}(f)\, e^{j2\pi\left(\tau_i(p_1)-\tau_i(p_1)\right)f}\, e^{j2\pi\left(\tau_i(p_1)-\tau_i(p_1)\right)f_c}\, df$$

$$= \int A_T^H(f_c + f)S(f)A_T(f_c + f)df \tag{13}$$

The above equation (9) is the same as equation (13) except for a slight notation difference. We find the presence of the parameter p1 instead of θ. The difference is that p1 is a true spatial parameter, whereas θ is only an angle parameter. If the far-field simplifications were applied, then the angle parameter θ would appear. Regardless, this equation is telling us how much gain one can expect for targets located at different points spatially. It is much easier to identify the transmit beam pattern in the narrowband simplification of the cross-correlation function . The quadratic form a $A_T^H(\theta_1)R(\Delta\tau,\Delta f)A_T(\theta_0)$ becomes the narrowband transmit beam pattern when $\theta_0 = \theta_1(\Delta\tau = 0, \Delta f = 0)$.

Now, if we return the above equation, we see that letting $\theta_0 = \theta_1$ results in the cross correlation function becoming a scaled version of the transmit beam pattern. This is actually just the autocorrelation function defined as

$$\Psi^2(\theta_1,\theta_0) = \sum_{j=1}^{N_R} a_{TR}^H(\theta_1)R^2(\theta_1,\theta_1,\mathrm{j})\, a_T(\theta_{1,})e^{-j2\pi\tau_j(p_1)(f_c+f_{\vartheta 1})}e^{-j2\pi i\tau_j(p_1)(f_c+f_{\vartheta 1})}$$

$$= \sum_{j=1}^{N_R} a_{TR}^H(\theta_1)R^2(\theta_1,\theta_1,\mathrm{j})\, a_T(\theta_1)$$

$$= N_R \int a_T^H(p_1, f_c + f)S(f)a_T(p_1, f_c + f)df$$

$$= \emptyset(\theta_1) \tag{14}$$

OPTIMIZATION ALGORITHMS FOR MIMO RADAR

Many optimization algorithms have been developed for solving various types of engineering problems. Popular optimization algorithms include modified particle swarm optimization, neural networks, genetic algorithms, and fuzzy optimization. The modified particle Swarm concept originated as a simulation of simplified social systems. The Particle Swarm Optimization algorithm is basically a population-based stochastic search algorithm and provides solutions to the complex non-linear optimization problems. PSO has the benefits of being more efficient when compared to most other optimization algorithms.

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SIMULATION RESULTS

In this paper optimal sequence for MIMO Radar using Particle Swarm Optimization Algorithm is carried out. In the present work, Particle Swarm Optimization Algorithm is to optimize the eight phase polyphase coded sequence to achieve good auto correlation and cross- correlation properties . On the basis of algorithm the poly-phase , eight phase coded sequences are set with lengths varying from 7 to 128 and number of transmitting ,receiving antennas are L=3 and L=4. The Maximum autocorrelation sidelobe peak (ASP) and Maximum cross correlation peak (CP) values obtained using proposed algorithm is compared with literature values. The results shows an advance in Autocorrelation Sidelobe Peak (ASP)s . It infers that sequences generated by Particle Swarm Optimization Algorithm have good correlation properties.

Table.I Auto Correlation Side Lobe Peaks of Six Phase Synthesized Sequence Sets with L=3, and Sequence Length N= 40 to 128.

S.No	Length of Sequence	Max(ASP) Reported	Max(ASP) Literature
1	40	0.0052	0.079
2	48	0.0049	0.075
3	51	0.0036	0.080
4	60	0.0036	0.074
5	65	0.0025	0.076
6	70	0.0024	0.076
7	75	0.0017	0.077
8	80	0.0022	0.076
9	85	0.0018	0.070
10	100	0.0015	0.067
11	110	0.0012	0.069
12	120	0.0010	0.067
13	128	0.0011	0.066

The auto correlation side lobe peak values obtained for different length of the sequences .the average value of ASPs is 0.0023 it is better than the literature values.
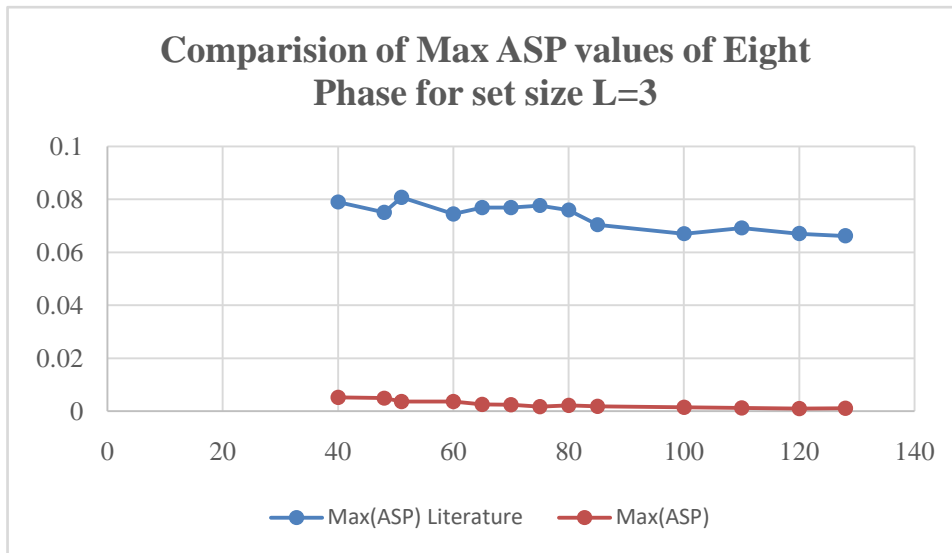
Figure 1. Max (ASP) values of Eight phase sequence set L=3 designed using PSO compared with literature values

Table II Auto Correlation side lobe peaks of Six phase synthesized sequence sets with L=4, and Sequence length N= 7 to 117.

S.No	Length of Sequence	Max(ASP) Reported	Max(ASP) Literature
1	7	0.0625	0.079
2	13	0.0456	0.0751
3	17	0.0268	0.0720
4	21	0.0123	0.0731
5	29	0.0177	0.0721
6	31	0.0149	0.0769
7	37	0.0094	0.0777
8	45	0.0085	0.0762
9	49	0.0085	0.0744
10	53	0.0066	0.0731
11	61	0.0069	0.0792
12	87	0.0076	0.0771
13	95	0.0085	0.0762
14	97	0.0056	0.0741

The auto correlation side lobe peak values obtained for different length of the sequences .the average value of ASPs is 0.0069 it is better than the literature values.
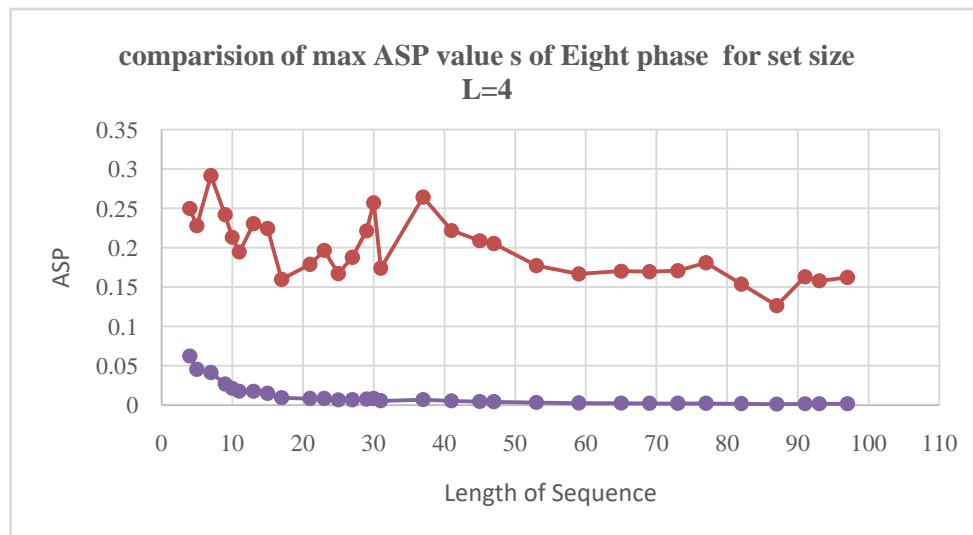
Figure 3. Max (ASP) values of Eight phase sequence set L=4 designed using PSO compared with literature values.

Table I compares the obtained values of ASPs with literature values. ASPs of Eight phase synthesized sequence sets with three transmitting antennas (L=3) , and Sequence length varying from N= 40 to 128 are tabularized and Table II compares the obtained values of ASPs with literature values. Auto correlation side lobe peaks of four transmitting antennas (L=4) synthesized sequence sets ,and Sequence length various from N= 7 to 117. Fig. 1 and Fig.2 illustrates the Max (ASP) values of L=3 and L=4 designed using Particle swarm optimization algorithm compared with literature values .

CONCLUSION

Properties of Auto correlation side lobe peaks of Eight phase produced order sets with three and four transmitting antennas for Sequence length N= 7 to 128 is obtained and compared with the literature values. From the design result, it   concludes that the results obtained have great improvement in ASPs things of all the sequence lengths. In order to carry out the implementation of particle swarm optimization algorithm for the optimization of orthogonal poly phase sequences   is developed for MIMO radar.

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