Improved design of binary orthogonal code for MIMO radar

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Proposed is a novel algorithm to design binary orthogonal code for MIMO radar. On the premise of maintaining the orthogonality of each code, we can obtain the binary code set with a lower autocorrelation sidelobe peak (ASP) and cross-correlation peak (CP). Simulation results show that the algorithm is effective.

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1. Introduction

Multiple Input Multiple Output (MIMO) radar performance is strongly dependent on waveform design. Many researchers used simulated annealing or genetic algorithms [1-3] to obtain the codes with superior autocorrelation and cross-correlation function properties; however, the orthogonality of each code isn't hold. Namyoon et al. proposed the method of designing orthogonal pulse compression code set which maintaining the orthogonality of each code [4]. In this paper, we show how binary orthogonal code set is optimized using Genetic Algorithm (GA) on the premise of keeping the orthogonality of each code; the simulation results are compared with [4].

2. Signal model and algorithm

Consider a binary code set with code length N and set size M as expressed by [5]

$$\{s_m(n) = e^{j\phi_m(n)}, n = 1, 2, \cdots, N\}, m = 1, 2, \cdots, M \qquad (1)$$

where $\phi_m(n)$ ($\phi_m(n) \in \{0, \pi\}$) is the phase of sub-pulse n of signal m in the signal set. Thus, the cross-correlation function of orthogonal binary codes can be defined as:

$$C(s_p, s_q, k) = \begin{cases} \dfrac{1}{N}\sum\limits_{n=1}^{N-k} s_q(n)s_p(n+k), & 0 \le k < N \\ \dfrac{1}{N}\sum\limits_{n=-k+1}^{N} s_q(n)s_p(n+k), & -N < k < 0 \end{cases} \qquad (2)$$

where p, $q = 1, \cdots, M$ and k is the discrete time index. When $p = q$, $C(s_p, s_p, k)$ becomes the autocorrelation function, we write as $A(s_p, k)$.

With the method of [4], the iteration of the proposed algorithm is used to achieve better performance; but in this paper, a novel chromosome coding is constructed to enable us to use GA for optimization on the premise of maintaining the orthogonality of each code. To not only minimize ASP and CP but also minimize the total autocorrelation sidelobe energy and cross-correlation energy, the cost function is designed as [2]:

$$\begin{aligned} E = & \sum_{m=1}^{M} \max_{k \ne 0} |A(s_m, k)| + \sum_{p=1}^{M-1}\sum_{q=p+1}^{M} \max_{k} |C(s_p, s_q, k)| \\ & + \sum_{m=1}^{M}\sum_{k=1}^{N-1} \max_{k \ne 0} |A(s_m, k)|^2 + \sum_{p=1}^{M-1}\sum_{q=p+1}^{M}\sum_{k=-(N-1)}^{N-1} |C(s_p, s_q, k)|^2 \end{aligned} \qquad (3)$$

Fig. 1 provides the flow chart of proposed algorithm.

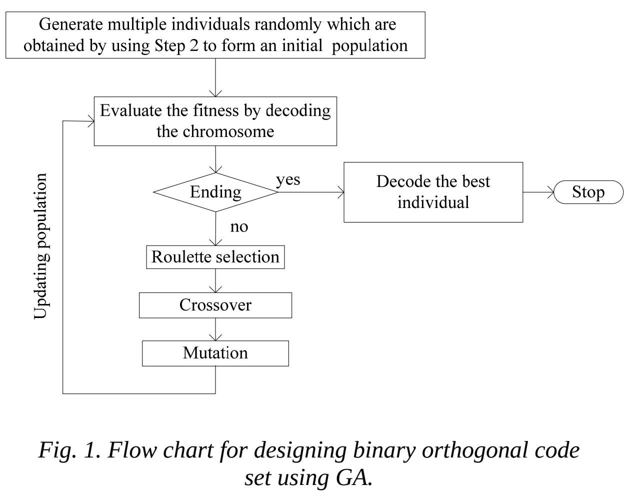

Fig. 1. Flow chart for designing binary orthogonal code set using GA.

Basic design steps of applying GA are summarized as follows:

***Step1**:* Generate a $N \times N$ Hadamard matrix $\mathbf{W}$ since its rows are mutually orthogonal. The first row of $\mathbf{W}$, which is with all the columns valuing 1, can be discarded quickly because it dose not satisfy the condition of binary code. Then the remainders, we write as $\tilde{\mathbf{W}}$, will be used in the following steps. Note that all elements of $\tilde{\mathbf{W}}$ have binary phase.

***Step2**:* To reduce sidelobe and maintain the orthogonality of the rows of $\tilde{\mathbf{W}}$, permute the columns of $\tilde{\mathbf{W}}$ randomly to obtain matrix $\mathbf{Q}$ (Operation 1); select M ($M \le N-1$) rows from $\mathbf{Q}$ randomly (Operation 2). Consequently, rearrange the integers from 1 to N randomly to obtain a $1 \times N$ random array which can represent the first operation; chose M integers from $1,\cdots,N-1$ randomly to form a $1 \times M$ random array which can represent the second operation. Stack the latter array on the right-hand side of the former array to construct a $1 \times (N+M)$ GA's chromosome (individual). To illustrate the novel construct method, an individual with $N = 10$ and $M = 2$ is given in Fig. 2. Because the method of chromosome coding in this paper is different from of common coding, the original crossover and mutation operators need to be modified.

***Step3**:* Initialize a population, each individual of which is encoded according to *Step2*.

***Step4**:* Use (3) to evaluate the fitness function by decoding the chromosome according to inverse process of *Step2*.

***Step5**:* The operators we used include roulette wheel operator, modified uniform crossover operator and modified mutation operator.

***Step6**:* If an acceptable fitness is not reached, go back to *Step4*; else, stop the GA and decode the best chromosome.

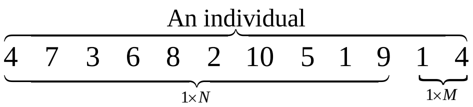

Fig. 2. An individual with $N = 10$ and $M = 2$.

3. Simulation results and discussion

Table 1 lists the two sequences for the designed binary orthogonal code set with $N = 40$ and $M = 2$, and the normalized aperiodic autocorrelation curve and cross-correlation curve for the two sequences are plotted in Fig. 3 and Fig. 4, respectively. As illustrated in Fig. 4, the cross-correlation curve reaches 0 when $k = 0$ in(2), which means the designed code set is orthogonal to each other.

Table 1. Binary orthogonal code sequences.

	Binary orthogonal code sequences
Code 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,-1,-1,1,1,1,1
Code 2	-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,-1,1,1,1,1,-1,1

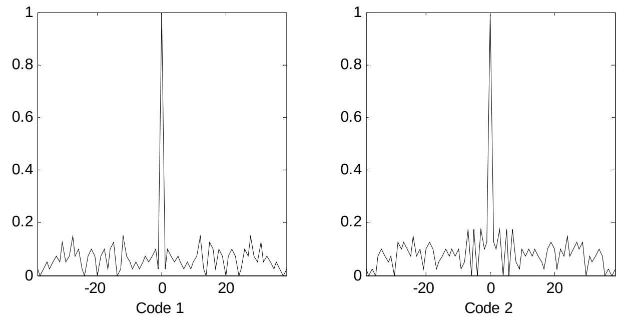

Fig. 3. Autocorrelation curve of sequences with $N = 40$ and $M = 2$.

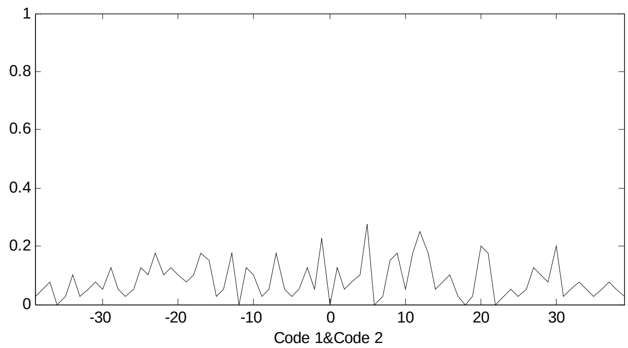

Fig. 4. Cross-correlation curve of sequences with $N = 40$ and $M = 2$.

The ASP and CP of the designed of designed orthogonal binary code sequences are shown in Table 2. The diagonal entries of the table are ASPs, and the off-diagonal entries are CPs. The recalculated ASPs and CPs of Namyoon's [4] orthogonal binary-phase pulse compression codes (OBPPCC) with $N = 40$ and $M = 2$ are shown in Table 3. Comparing the values of Table 2 and Table 3, it can be seen that the ASPs and CPs of the designed binary code set in this paper are lower than Namyoon's [4]. Especially the ASP of Code 1 is about 2.5dB less than Namyoon's [4]. This means that the algorithm of this paper could suppress the ASP and CP better while keeping the orthogonality of each code.

Table 2. ASPs and CPs of designed binary orthogonal code sequences.

	Code 1	Code 2
Code 1	0.15	0.275
Code 2	0.275	0.175

Table 3. Recalculated ASPs and CPs of OBPPCC with $N = 40$ and $M = 2$ [4].

	Code 1	Code 2
Code 1	0.2	0.3
Code 2	0.3	0.2

4. Conclusion

In this study, the proposed algorithm applies the orthogonality of Hadamard matrix and constructs a novel chromosome coding which enable us to employ the GA algorithm for optimization and it can improve the performance of ASP and CP.

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