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A Novel Crosstalk Elimination Method for Sonar Ranging System in Rescue Robot

Zhenjing Yao*, Jingsong Yang, Shucong Liu

Institute of Disaster Prevention Science and Technology, Beijing 101601, China

Abstract

Ultrasonic crosstalk can cause false distance measurements and reduce the work efficiency of sonar ranging system. To enhance the performance of sonar ranging system in rescue robot, quadrature phase shift keying (QPSK) excitation sequences modulated using chaotic codes are proposed to fire sonar sensors. In order to obtain the best echo correlation characteristics, a genetic algorithm (GA) is used to optimize the initial values of the chaotic codes. Real experiments have been implemented using a sonar ranging system consisting of eight-channel SensComp 600 series electrostatic sensors excited with 2 ms QPSK sequences. Experimental results show that the optimized QPSK excitation sequences can make eight channels sonar ranging system work together without crosstalk.

Keywords: Crosstalk, Sonar, Chaotic codes, QPSK, Genetic algorithm;

1. Introduction

Ultrasonic sensors have been commonly used for distance measurement because of their low price and simple hardware interface. To get distance information of 360° panorama, a sonar ranging system consisting of multichannel ultrasonic sensors is required in a rescue robot. One problem with the simultaneously triggered ultrasonic sensors is crosstalk, where one ultrasonic sensor receives echo transmitted by another sensor [1]. Usually, the crosstalk results in the false time-of-flight (TOF) measurement.

To eliminate the crosstalk, researchers constructed different excitation sequences to assign each ultrasonic sensor a recognizable signature. Jörg and Berg [2] first used pseudorandom codes to give each

* Corresponding author. Tel.: +86-015097610643.
E-mail address: yaozhenjing000@126.com.

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ultrasonic sensor a symbol. The 13-bit Barker codes were adopted to construct excitation sequences for ultrasonic sensors [3]. But the available Barker codes limit their application. Chaotic pulse position modulation (CPPM) signal was applied to fire the ultrasonic sensor [4]. The binary phase shift keying (BPSK) signals modulated using complementary sequences were transmitted the ultrasonic sensor [5].

To obtain the best echo correlation characteristics, optimization methods have been utilized to construct excitation sequences in sonar ranging system. Griep *et al*. [6] used a global optimization method to select suitable coded signal for multiple-user sonar ranging system. Meng *et al*. [7-8] adopted a genetic algorithm (GA) to optimize short PPM triggering sequences in order to improve correlation characteristics. Yao *et al*. [9] applied nondominated sorting genetic algorithm II (NSGA-II) to optimize chaotic pulse position width modulation (CPPWM) excitation sequences in order to sharpen the autocorrelation and flatten the cross-correlation as well as to maximize echo energy.

The remainder of this paper is organized as follows. Section 2 explains the principle of the QPSK excitation sequence. The GA based QPSK excitation sequences optimization method is introduced in Sect. 3. Section 4 presents the experiments and results. Finally, the conclusions are described in Sect.5.

2. The principle of QPSK excitation sequence

Chaotic codes have characteristics such as sensitivity to small changes in initial conditions, sharp autocorrelation and flat cross-correlation functions. The chaotic codes are applied to modulate carrier phase in this paper. In quadrature phase shift keying (QPSK) excitation sequence, the phase of a constant amplitude and frequency carrier signal moves between 0, 90, 180 and 270 degrees. The symbols “00”, “01”, “10” and “11” are represented by 0, 90, 180 and 270 degrees of carrier signal, respectively.

Figure 1 shows a schematic diagram illustrating QPSK, where $c(t)$ is the baseband signal, T_s is symbol width, $q_1(t)$, $q_2(t)$, $q_3(t)$ and $q_4(t)$ are the carrier signals with 0, 90, 180 and 270 degrees, respectively. In this paper, the c(t) using chaotic codes, either 1 or 0, is determined using the Ulam–von Neumann transformation [10]shown as follows.

$$y_k = 1 - 2y_{k-1}^2, y_k \in (-1,1), k = 1,2,...,n \qquad (1)$$

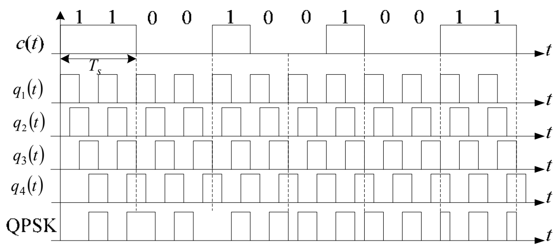


Fig. 1. The schematic diagram of QPSK

3. The GA based QPSK excitation sequences optimization

Given the length of the QPSK sequence, symbol width and carrier frequency, a GA is used to optimize the chaotic codes to obtain the best echo correlation characteristics. The procedure is presented in the following steps.

Step 1: The initial parent population $A_{P\times Q}$ is generated randomly, where P is the population size and Q is the float-code length. Let $P = 100$, $Q = M$, M is the channel number of sonar ranging system, and the maximum generation number is set to 100.

Step 2: The objective function values of individuals are ordered and then mapped to fitness values. The objective function $ObjV$ is defined as follows,

$$ObjV := \max\left(R_{a\text{-max}}, R_{c\text{-max}}\right) \tag{2}$$

$$R_{a\text{-max}} := \max\left(R_{ii}(m)\right) \;\; i = 1,\ldots,M, m = 0,\ldots N-1-\delta \tag{3}$$

$$R_{c\text{-max}} := \max\left(R_{ij}(m)\right) m = 0,1,2,\ldots 2N-1, i = 1,\ldots M, j = 1,\ldots M, i \neq j \tag{4}$$

$$R_{ii}(m) = \begin{cases} \sum_{n=0}^{N-m-1} x_{n+m}^{i} x_{n}^{i} & m \geq 0 \\ R_{ii}(-m) & m < 0 \end{cases}, i = 1,\ldots,M \tag{5}$$

$$R_{ij}(m) = \begin{cases} \sum_{n=0}^{N-m-1} x_{n+m}^{i} x_{n}^{j} & m \geq 0 \\ R_{ij}(-m) & m < 0 \end{cases}, i = 1,\ldots M, j = 1,\ldots M, i \neq j \tag{6}$$

where $R_{a\text{-max}}$ is the maximal side-lobe among autocorrelation functions, $R_{c-\max}$ is the maximal peak among cross-correlation functions, $R_{ii}(m)$ is the autocorrelation function of the *i*th echo sequence, $R_{ij}(m)$ is the cross-correlation function of the ith and *j*th echo sequences, 2δ is the width of the main-lobe of the autocorrelation function, x_n^i, x_{n+m}^i are the nth and (n+m)th sampling point of the *i*th echo sequence, respectively, x_n^j is the *n*th sampling data point of the *j*th echo sequence, and *N* is the total number of samples in the echo sequence.

Step 3: The selection operator is applied to select individuals as the new population.

Step 4: The crossover and mutation operators are used to generate the offspring population.

Step 5: The offspring population is combined with the current generation population and selection is performed to set the individuals for the next generation. Repeat Step 2 to Step 5 until the maximum generation number is reached.

4. The experiments and results

4.1. The experimental setup

The hardware schematic diagram for one channel of the sonar ranging system is shown in Fig. 2. The excitation sequence was sent from the FPGA (field-programming gate array). The ultrasonic sensor was fired to transmit ultrasound by the amplified QPSK sequence. After band-pass filtering, automatic gain amplification and shaping circuit, the polarity correlation between the reference echo sequence and the binary echo sequence was realized. Finally, the distance between ultrasonic sensor and obstacle was calculated if the echo sequence was identified to be from the ultrasonic sensor's own transmission.

In our experiments, the SensComp 600 series instrument-grade electrostatic sensor was used. Its central frequency and frequency band are 52 kHz and [40, 70] kHz, respectively. The echo sequences are sampled with a period of 1 μs . The reference echo sequence was sampled which reflected from an acrylic board placed 40 cm in front of sonar sensor.

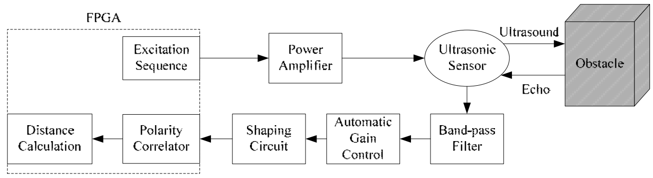
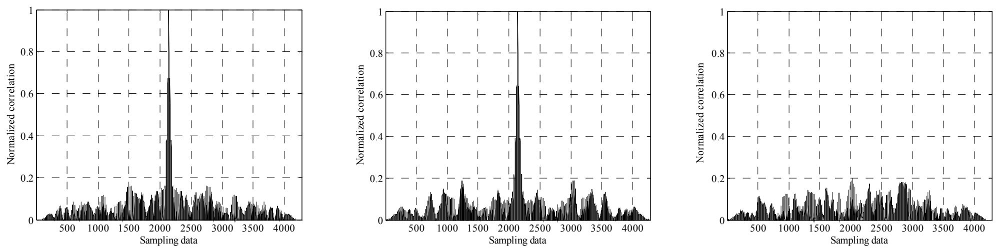


Fig. 2. Hardware schematic diagram for one channel of the sonar ranging system

4.2. The results and discussions

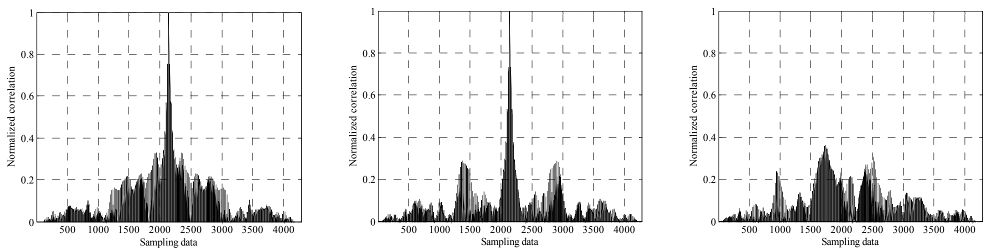
The eight-channel sonar ranging system needs eight QPSK sequences, whose length is 2 ms in our experiments. The symbol period of QPSK sequences was set to 55.2 μs. After 100 generations of selection, crossover and mutation, the best echo correlation characteristics result for the optimized QPSK sequences was 0.2676.

Figures 3 and 4 illustrate echo correlation results of the optimized QPSK and unoptimized QPSK sequences, respectively. The horizontal coordinate in Figs. 3-4 are sampling data, and the sampling period is 1 μs, and the vertical coordinate is the normalized correlation.



(a) (b) (c)

Fig. 3 Echo correlation results of two optimized QPSK. (a) autocorrelation function of echo 1; (b) autocorrelation function of echo 2; (c) cross-correlation function of echo 1 and echo 2.



(a) (b) (c)

Fig. 4. Echo correlation results of two unoptimized QPSK. (a) autocorrelation function of echo 1; (b) autocorrelation function of echo 2; (c) cross-correlation function of echo 1 and echo 2.

Comparing subfigures (a) and (b) in Figs. 3-4, we can see that the optimized QPSK sequences have lower sidelobe of echo autocorrelation functions than that of the unoptimized ones. At the same time, from Figs. 3(c) and 4(c), we can also find that the peak value of echo cross-correlation function of the optimized QPSK sequences is lower than that of the unoptimized QPSK sequences. In other words, the optimized QPSK sequences have the better echo correlation characteristics than that of the unoptimized QPSK sequences.

4.3. Distance measurement result

The distance measurement result based on QPSK excitation sequence for echo sequence 1 is illustrated in Fig.5, in which the first peak is generated by the autocorrelation of the polarized reference echo sequence, and the second one is produced by cross-correlation between the received echo and the reference echo sequence. The distance obtained in Fig.5 is nearly equal to the real distance of 40 cm.

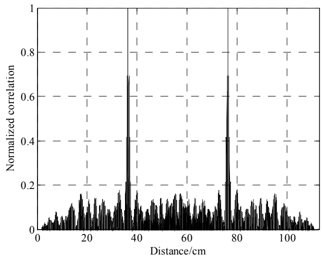


Fig. 5. Distance measurement result based on QPSK excitation sequence

5. Conclusion

The optimized chaotic QPSK excitation sequences are proposed to trigger ultrasonic sensors for multichannel sonar ranging system. The proposed method considers getting the best echo correlation characteristics using GA optimization. Experiments demonstrate that the optimized QPSK excitation can get better results than unoptimized CPPM excitation. The eight-channel ultrasonic ranging system with the optimized chaotic QPSK excitation sequences can work together without crosstalk. Future work will increase the channel number of sonar ranging system to obtain distance information of lager space.

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References

[1] Meng Q, Yao F, Wu Y. Review of crosstalk elimination methods for ultrasonic range systems in mobile robots. In: International Conference on Intelligent Robots and Systems, United States: Institute of Electrical and Electronics Engineers Inc., 2006, p.1164-1169.

[2] Jörg K, Berg M. Sophisticated mobile robot sonar sensing with pseudo-random codes. *Robotics and Autonomous Systems* 1998;25:241-251.

[3] Ureña J, Mazo M, García J, Hernández Á, Bueno E. Correlation detector based on a FPGA for ultrasonic sensors. *Microprocessors and Microsystems* 1999;23:25-33.

[4] Fortuna L, Frasca M, Rizzo A. Chaotic pulse position modulation to improve the efficiency of sonar sensors. *IEEE Transactions on Instrumentation and Measurement* 2003;52(6):1809-1814.

[5] Alvarez F, Ureña J, Mazo M, Hernández Á, García J, Marziani C. High Reliability outdoor sonar prototype based on efficient signal coding. *IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control* 2006;53(10):1862-1871.

[6] Griep K, Ritcey J, Burlingame J. Poly-phase codes and optimal filters for multiple-user ranging. *IEEE Transactions on Aerospace and Electronic Systems* 1995; 31(2):752-767.

[7] Meng Q, Lan S, Yao Z, Li G. Real-time noncrosstalk sonar system by short optimized pulse position modulation sequences. *IEEE Transactions on Instrumentation and Measurement* 2009;58(10):3442-3449.

[8] Meng Q, Yao Z, Peng H. Improvement of energy efficiency via spectrum optimization of excitation sequence for multichannel simultaneously triggered airborne sonar system. *Review of Scientific Instruments* 2009; 80(12):124903-1-124903-7.

[9] Yao Z, Meng Q, Li G, Lin P. Non-crosstalk real-time ultrasonic range system optimized chaotic pulse position-width modulation excitation. In: IEEE International Ultrasonics Symposium, United States: Institute of Electrical and Electronics Engineers Inc., 2008, p. 729-732.

[10] Jiang Y. On Ulam-von Neumann transformations. Communications in Mathematical Physics 1995;172(3):449-459.