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Algorithm Design for Improving Performance of Microprocessor-Controlled Sonar Buoy Performing Surveillance of Underwater Objects

Sualtı Nesnelerinin Gözetimini Gerçekleştiren Mikroişlemci Kontrollü Sonar Şamandıra Performansını Artırmak İçin Algoritma Tasarımı

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Abstract
An improved design software-based replica correlator method within the microprocessor-controlled sonar buoy systems has been proposed which improved the performance of detecting objects underwater. In the sea or ocean, the microprocessor-controlled buoy is provided to be automatically wirelessly scan for removal of underwater information and transmit it wirelessly to the main control station for additional processing and ultimate decision. In this study, sonar buoy performance and system design proposal with 7-31 cell replica correlation are presented. Although the digital delay lines are used to minimize the complexity of hardware-based replica correlator, the proposed software replica-correlated system within microprocessor-controlled buoys, has improved the performance.

Keywords: Buoy, microprocessor control, replica correlation, sonar, underwater surveillance

Öz
Sualtında bulunan nesneleri gözetlemek amacıyla uygulanan mikroişlemci kontrollü sonar şamandıra sistemlerinin performansı için geliştirilmiş bir tasarım yaklaşımı önerilmiştir. Denize veya okyanus içerisinde, mikroişlemci kontrollü şamandıra, sualtı bilgisinin çıkarılması için otomatik olarak taranması ve daha ileri işlem ve nihai kontrol eylemi sağlanması amacıyla bir uzak yer istasyonuna kablosuz olarak iletilmesi sağlanır. Bu çalışmada, 7-31 hücre replika korelasyonunu içeren sonar şamandıra performansı ve sistem tasarım taslağı sunulmuştur. Donanımsal replika korelatörünün karmaşıklığı, dijital gecikme kanalları kullanılarak en aza indirilmesine rağmen, önerilen mikroişlemci kontrollü şamandıra, yazılım aracılığıyla replika korelasyonu gerçekleştirilmiş ve geliştirilmiş sistemle performans artırılmıştır.

Anahtar Kelimeler: *Şamandra, mikroişlemci kontroller, replika korolasyon, sonar, sualtı gözetim*

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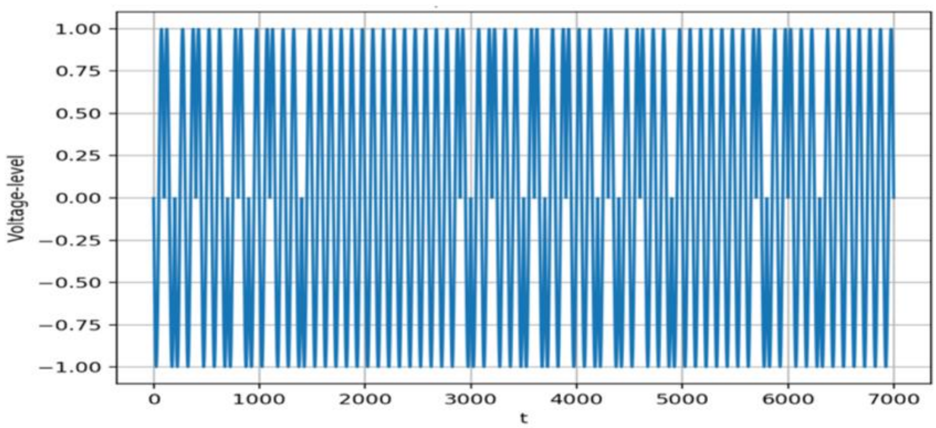
1. Introduction

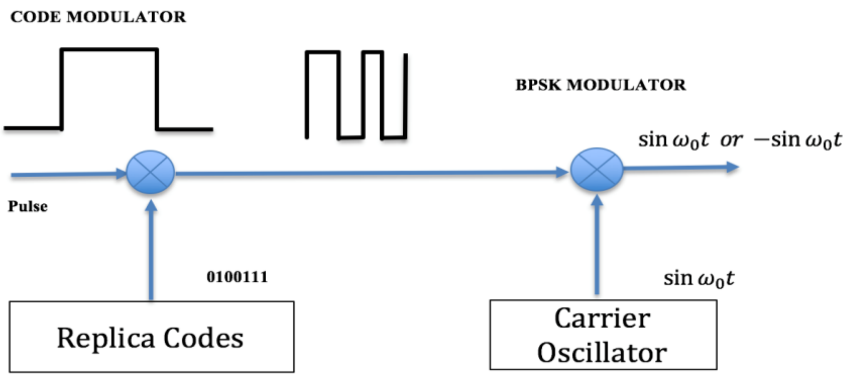
The sonar buoys systems, which is placed on the surface of the ocean is used to detect the object and get continuously present information for a long time. The noise types that affect the sonar system performances are impulse noise and colored noise. The presence of these noises affects the detection process in letting the systems to generate false alarms under different ambient conditions. The SNR values are decreased by the attenuation of the acoustic wave in the medium and the limited power output for wave transmitted by transducer. Detection of targets is an important concern in radars and sonars. In this aspect several approaches have been attempted (Skolnik, M.I., 2000; Sarkar, N., 2004; Taub, H., Saha, G. and Schilling, D. L., 2008) in the past. In pulse type systems, one approach to improve the detection process is to apply replica correlation (Balasubramanian, K. and Arica, S. ,1993; Balasubramanian, K., Camur, H. and Rajaravivarma, 1999; Balasubramanian, K., 2000, 2005, 2006). As a further attempt improving the design considerations of the replica correlation detection is now reported.

2. Replica Correlator

Replica correlation technique in radars and sonars is used to improve the probability of signal detection. The transmitted acoustic pulse consists *n* cells packet. In the proposed model '*n*' is chosen optimal pattern look-up table as lies between 7 and 31. The cells pattern is evaluated as a bit stream design + or 0 showing in-phase and – or 1 showing the out-phase of the Continuous Wave (CW) sinus wave incurring a phase shift of 180°. This technique involves in using binary phase shift keyed signal as a packet incorporated in the duration of the on-going pulse. Figure 1(a) shows the phase shift keyed signal pattern (Balasubramanian, K., 2000) present during the pulsing period. Figure 1(b) shows the block diagram of the replica correlator code encodes for carrier signal to receiver.



(a)



(b)

Figure 1. Replica correlation **(a)** CW coded signal binary phase shift keying. **(b)** block diagram of replica code encoded carrier signal.

The echo Binary phase shift keyed signal pass through and propagates up to the end of the delay channel (Balasubramanian, K. and Cihan, K., 1994; Balasubramanian, K., Gayathri,K.B. and Camur,H., 1999) with taps located at seven regular intervals. Each tap is connected with a DAC (Digital to Analogue Converter) to get the analogue equivalent of the delay produced in respective taps. Internally, analogue inverters are connected at taps 4, 5 and 7 such that inversion takes place in the reverse order {1 0 1 0 0 1 0} of the transmitted pattern. When the incoming signal reaches the last cell, at the instant of traversing it, the signal gets boosted up *n* times of the original amplitude. Figure 2 illustrates Replica correlated output for ΔT-7 Cell Pattern. The target is detected by comparing the signal amplitude with an appropriate threshold.

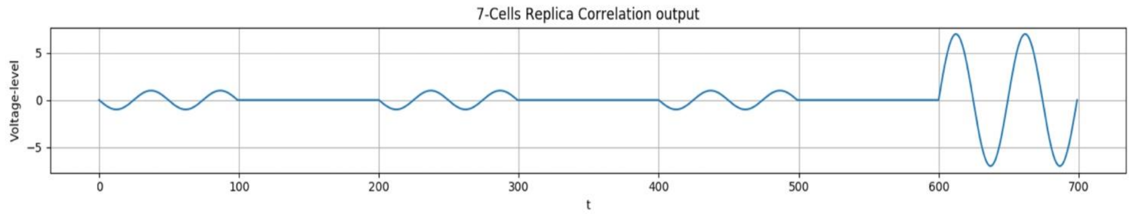


Figure 2. Replica correlated output for ΔT-7 cell pattern

3. Replica Correlator Algorithm Design

On the basis of replica correlation automatic cell pattern setting is an important concern for easy detection of targets. This pattern gets the signal boosted up in the last cell and suppresses it at lowest possible level in all other cells. The software finds the signal levels during *n*-pulse periods for all the set patterns and assesses the best pattern needed for the given *n*. Figure 3 and Figure 4 illustrate how to calculate the magnitude and cell pattern control function. Embedded software defined radio (SDR) module uses optimal pattern for given *n*-cells packet for SONAR buoys for custom needs.

$$K_i = \sum_{n=1}^{i} p_n \, x_{(i+1-n)} \tag{1}$$

if x_i indicates the bi-phase worth of the received signal falling in i^{th} cell and p_n indicates the polarity of the amplifier connected to the j^{th} faucet of the electrical circuit the output completed at the summing amplifier at numerous cells throughout the propagation of the signal within the electrical circuit is expressed in (1) whereby K_i indicates the amplitude of the summing amplifier at the i^{th} cell of the incoming signal. *n*-cell pattern K_i calculation Lower Triangular Matrix algorithm is designed and implemented as given in Figure 5.

	Amplitude Calculation										
Sum of Cols	1	0	0	0	0	0	0	0	0	0	0
	1	1	0	0	0	0	0	0	0	0	0
	1	1	1	0	0	0	0	0	0	0	0
	1	-1	-1	-1	0	0	0	0	0	0	0
	1	1	-1	-1	-1	0	0	0	0	0	0
	1	1	1	-1	-1	-1	0	0	0	0	0
	1	-1	-1	-1	1	1	1	0	0	0	0
	1	-1	1	1	1	-1	-1	-1	0	0	0
	1	1	-1	1	1	1	-1	-1	-1	0	0
	1	-1	-1	1	-1	-1	-1	1	1	1	0
	1	-1	1	1	-1	1	1	1	-1	-1	-1
Ki = {	11	0	-1	0	-1	0	-1	0	-1	0	-1 }

Figure 3. K_i calculation by lower triangular matrix for 11-cells pattern

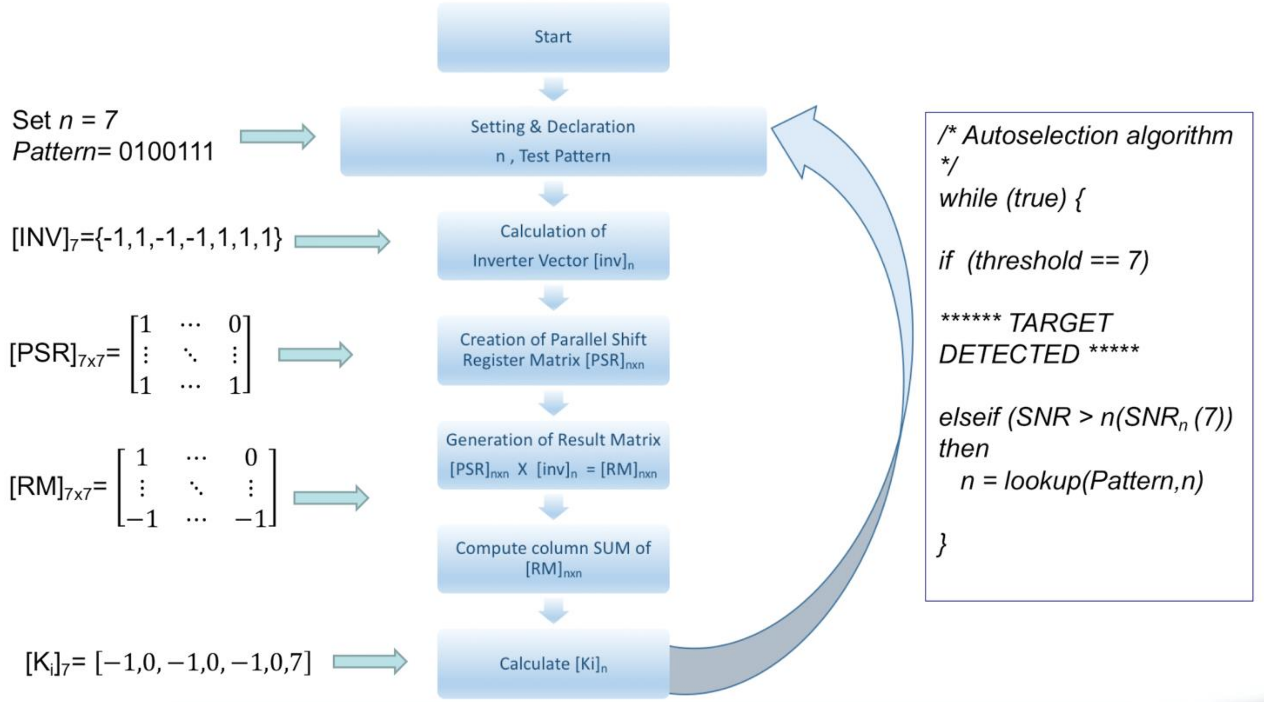


Figure 4. Sonar buoy SDR system block diagram and detection process.

```
Set _PATTERN_;
int N = _PATTERN_.Length ;
var _INV_ = new int[N + 1]; //InvereterVector
var _PSR_ = new int[N + 1, N + 1]; //ParallelShiftRegister Matrix
var _AMP_ = new int[N + 1, N + 1]; //Aplitude Matrix
var _Ki_ = new int[N + 1]; //Ki Result
int j=0, k=0;
for (int col = N-1; col >= 0; col--) {
  for (int row = (N-1) - col; row >= 0; row--) {
        _PSR_[j, k] = _INV_[row];
        if (_PSR_[j, k] == 0) _PSR_[j, k] = -1;
        k++; }
    k = 0,j = 0;
    j++; }
// Creating Lower Triangual Matrix
for (int col = N; col >= 0; col--) {
    for (int row = N - col; row >= 0; row--) {
        _AMP_[j, k] = _PSR_[j, k] * _INV_[N - col];
         k++; }
    k = 0;
    j++; }
// _Amplitude binnary Matrix calculation
for (int col = 0; col <= N; col++) {
    for (int row = 0; row <= N; row++)
        _Ki_[col] += _AMP_[row, col]; //calculated output levels Ki index voltage
  }
```

Figure 5. Algorithm for Ki replica pattern calculation

Table 1. gives optimum cell pattern for selected lengths ranging from 7 to 31 cells and presents the voltage level (Kuren, E., and Cellatoglu, A., 2017).

Table 1. Optimal cell patterns for look up table

Cell Density *n*	Optimal-Cell Pattern	Voltage Level
7	0100111	1
9	111001101	3
11	10110111000	1
13	1111100110101	1
15	101011001100000	3
17	11110001000100101	3
19	1000010000101110100	3
21	111111000110010010101	3
23	10000100001000101110100	3
25	1111110001110010010010101	3
27	111000011101110111011010010	3
29	10001011000101100001001111011	3
31	1110111001110000101101100100010	5

4. Dynamic Setting of Cells Length for Custom Needs References

Depending upon the requirements, as demanded by the situation, our software automatically finds the optimal pattern *n* and sets the packet as 7-cell pattern under low range and low noise environment or even 31-cell pattern under long range noisy environment. Considering an application of sonar buoys (Balasubramanian, K., 2006) launched in the sea or ocean for underwater exploration the selection of the value of *n* helps in optimizing the system performance. Figure 6. shows simplified block diagram of a sonar buoy.

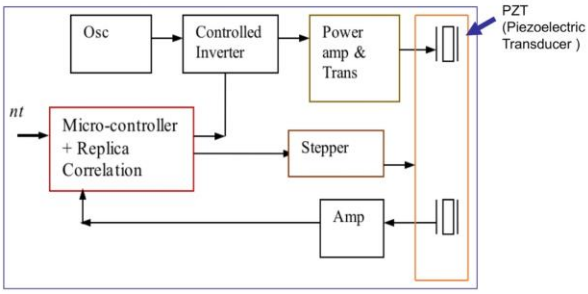


Figure 6. Simplified schematic of sonar transceiver

Herein *nt* indicating the type number of the buoy is given as an input to microcontroller, which in turn finds best cell density number (*n*) from a lookup table available in memory and calls the algorithm to set the cell pattern. The pattern is sending serially to a controlled inverter to generate the BPSK signal (Balasubramanian, K., 1998) accordingly. The source for CW input is a phase set oscillator (Osc). The BPSK generated is power amplified and fed to a transmitter Piezoelectric Transducer (PZT) for producing acoustic wave in under water medium. The reflected acoustic wave from a target is picked by receiver PZT and amplified. The processes of finding the envelope of the replica-correlation output, threshold detection and range estimation are all done in microcontroller. Also, the microcontroller issues drive signal to stepper motors driving the PZTs for producing angular sweeping of the acoustic beam. In reality, a set of buoys is thrown in sequence in a selected area for underwater exploration. Depending upon the distance from the shore, the buoy needs a particular cell density *n* for achieving optimal requirements. The value of *nt* need be fed into software in accordance with the type of buoy thrown at that instance.

5. Probability of Detection and Performance Analysis

The probability of detection depends on the probability of false alarm and the signal to noise ratio (Skolnik, M.I., 2000; Kuren, E., and Cellatoglu, A., 2017) of received signal. In addition, the level of the received signal plus noise depends on the number of cells *n* present in the transmitted pulse packet. The relationship between the probability of detection and *n* is almost linear. Therefore, with the larger *n* detecting the desired target on a threshold would be easy. This is seen in Figure 2. The sonar buoy works in underwater sea or ocean where the level of background noise is unknown. More noise would be added up with the signal when the distance of the target increases. Therefore, detection performance of targets under the coverage of desired range would be important. Figure 7. and Figure 8. show the performance under different ranges of noisy environment. Gaussian Noise (AWGN) is added to the signal and performance is evaluated.

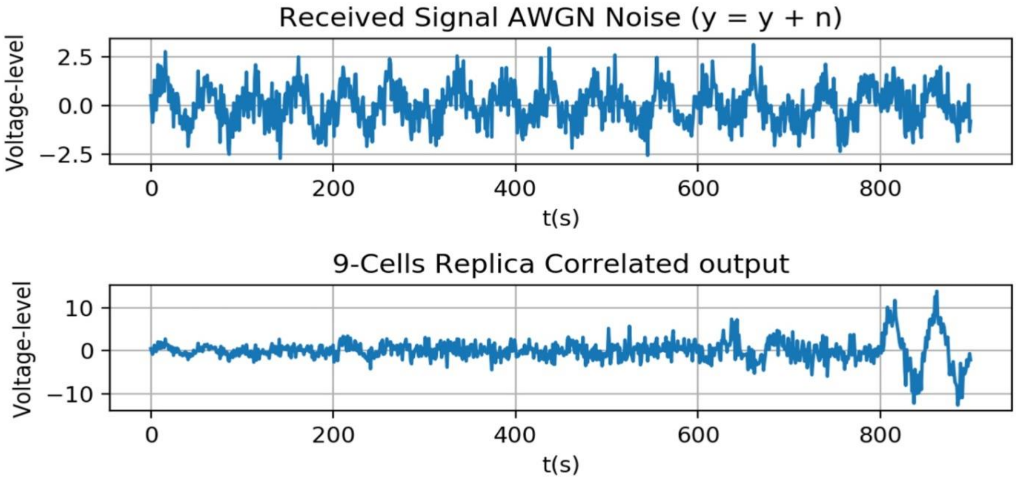


Figure 7. Performance evaluation with Gaussian noise (AWGN SNR_{db}=0) is added to transmitted signal.

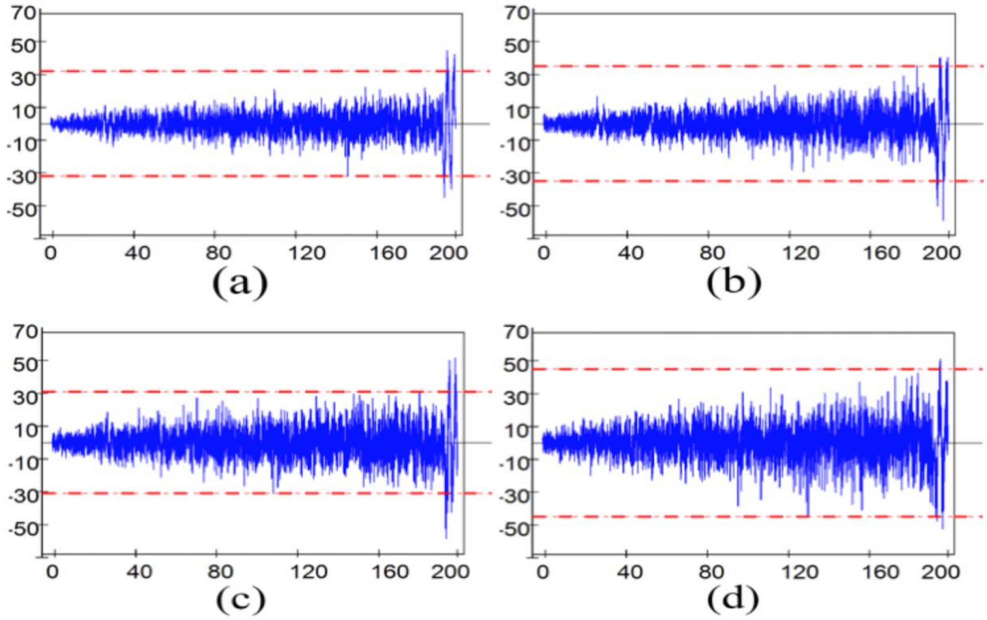


Figure 8. Performance analysis replica correlated output under different noise environment. **(a)** 31-cells pattern with 200% noise. **(b)** 31-cells pattern with 400% noise. **(c)** 31-cells pattern with 600% noise. **(d)** 31-cells pattern with 800% noise

6.Conclusion

In certain microprocessor-controlled target detection systems replica correlation technique is used with hardware-based control as well as software-based control. The hardware-based replica correlation employs digital delay line and becomes complex in complexity when the cell density *n* increases. The software replica correlation on the other hand uses FIFO memory to gather the data required for processing. While processing is performed almost instantaneously there is a very small delay is introduced in software method for processing. Nevertheless, with recent high-speed processors the time delay becomes negligible value. The complexity contributed in software method is mainly due to the growth size of FIFO memory occupying larger memory space. With the latest technological developments available in practice the complexity and cost factor would decrease well compared to hardware methods.

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