2012 IACSIT Coimbatore Conferences
IPCSIT vol. 28 (2012) © (2012) IACSIT Press, Singapore

Digital Signal Processing using Barker Code for Application in Laser Range Finder

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Abstract. Signal detection at receiving end is always difficult, when signal is corrupted by noise. Conventional digital signal processing techniques are not capable to detect the signal corrupted with noise , particularly in low power laser range finder, where the received power is appreciably reduced due to atmospheric attenuation. A new digital signal processing technique using barker code for noise corrupted signal is discussed in this paper. In this signal processing technique, Barker 13 sequence has been used for pulse compression and for detecting correlation peak. This technique has been realized and tested on FPGA and important for low level detection of laser range finder receiver design.

Keywords. Barker Code, Signal detection, laser range finder, FPGA, correlation, SNR,HDL,PRF.

1. Introduction

Receiver signal processing is play an important role in semiconductor laser based Laser Range Finder(LRF) [1]-[2]. Signal detection becomes critical part of signal processing at the receiving end of Laser Range Finder as the return signal from the intended target is already corrupted from noise, i.e. received signal level is lower than the noise level. To extract this type of weak signal in this circumstances, threshold level should be very low and enhanced the false alarm rate in measurement of delay. In order to make receiving system robust to noisy environment, digital signal processing algorithms are required after pre analog processing. In this paper, we propose a simple and computationally efficient digital signal processing algorithm to encounter false alarms due to atmospheric turbulence and noises.

2. Overview of Principle And Algorithms

A Pulse Rangefinder emits one or multiple narrow pulses to the target. By measuring the time interval from emitting a laser pulse to receiving the echo pulse, the laser transmission distance can be calculated; accordingly the target can be located. Assumed that the time interval is T, the light speed is c and the target distance is d, then [2].

$$d = \frac{cT}{2} \quad (1)$$

Conventional high power Laser Rangefinders used a counter/timer to count the number of clock cycles of the time interval to measure time. The receiver block diagram presented in Fig.1 can only work in large

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SNR condition and detect targets only by a single pulse echo signal. They themselves can't improve the SNR. Digital signal processing technology was used in Pulsed Laser Rangefinder in recent years for improving the ranging ability. Digital signal processing method can use digital signal filtering, pulse accumulation technique and moving average to improve the echo signal SNR.

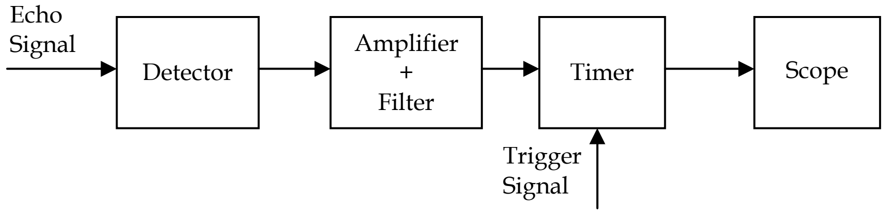

Fig.1 Rangefinder receiver block diagram

As literature reported that the cumulative binary detection algorithm(CBDA) is good option to detect the noise buried signal and for improving the SNR [3]. In CBDA method noise is uncorrelated and signal is correlated. In this method, a target signal is superimposed on the Gaussian distribution noise, its probability distribution horizontally moves by the intensity of the superimposed signal. Therefore, the mean of N-times accumulated cumulative probability distributions becomes pN, the standard deviation becomes $\sqrt{p(1-p)N}$, and the SNR is improved by $\sqrt{N}$ times. Other than CBDA. Lot of signal processing algorithms are available for detecting the weak signal [, but only theoretical description available. Nobody disclosed secrecy of the implementation level.

3. Proposed Digital Signal Processing Algorithm

The proposed digital signal processing algorithm presented here, we explored the idea of new digital signal processing using barker code for range finder application.

3.1. Pulse Compression

In this section, brief description of pulse compression techniques are presented. The pulse compression is a signal processing technique used to improve the accuracy and the signal-to-noise ratio (SNR) .

Mathematically explanations of pulse compression are following:-

Let consider a pulse

$$f(t) = \begin{cases} Ae^{i2\pi ft}, & 0 < t < T \\ 0, & elsewhere \end{cases} \tag{2}$$

Where A is the amplitude of pulse and T is the pulse width. The instantaneous power of the transmitted pulse is $P = |f(t)|^2$ and after integrating power get the energy:

$$E_t = \int_0^T P(t)dt = A^2 T \tag{3}$$

The same way calculate the energy of returning signal is :

$$E_r = KA^2T \tag{4}$$

Where K is attenuation constant.

If σ is the standard deviation of the noise in the echo signal then signal to noise ratio(SNR) is given by:

$$SNR = \frac{E_r}{\sigma} = \frac{KA^2T}{\sigma} \tag{5}$$

From equation (5) SNR is directly proportional to pulse width i.e. longer pulse width better SNR.

The accuracy of the system is given by:

$$\delta d = \frac{cT}{2} = \frac{c}{2B} \tag{6}$$

Where δd is the accuracy, c is the speed of light, T is the pulse width and B is the system bandwidth. From equation (6) accuracy is directly proportional to pulse width i.e. shorter the pulse better accuracy. Longer pulse better SNR and shorter pulse better accuracy, these two statements are conflicted to each other. To achieve better SNR and better accuracy we transmit longer pulse that has the bandwidth corresponding to a short pulse. This is the reason why pulse compression is used in radar systems. The pulse compression ratio is defined as the ratio of the uncompressed pulse width to the compressed pulse width, or the product of the pulse spectral bandwidth (B) and the uncompressed pulse width (T).The pulse compression ratio (PCR) is given by:

$$PCR = BT \quad (7)$$

From above discussion, in pulse compression a long pulse of duration T is divided into N time slots of length τ:

$$\tau = \frac{T}{N} \quad (8)$$

The amplitude of each time slot is chosen to be either 0 or 1. The returning echo signal is passed through a matched filter. The output of the matched filter will be a pulse of width τ with an amplitude N times greater than that of the uncompressed pulse. The optimum sequence to divide a longer pulse into sub pulses is Barker sequence. The Barker sequence is a low autocorrelated binary sequence and used for synchronization purpose in communication. This type of binary sequence has optimal aperiodic autocorrelation property. The autocorrelation property can be characterized by the relation between the mainlobe to the highest sidelobe, peak sidelobe(PSL) and merit factor. The lower the PSL and higher the merit factor, better the auto correlation properties of the binary sequences. Barker codes have an exceptional feature that the maximum sidelobe value of the autocorrelation function is 1, as shown in Fig.2 i.e. PSL=1 and main sidelobe=13. The longest known Barker code is 13 for PSL=1 with good autocorrelation properties. We used the Barker 13 sequence for implementation of algorithm. The overall accuracy improvement is 13 fold and consequently signal to noise ratio is also increased.

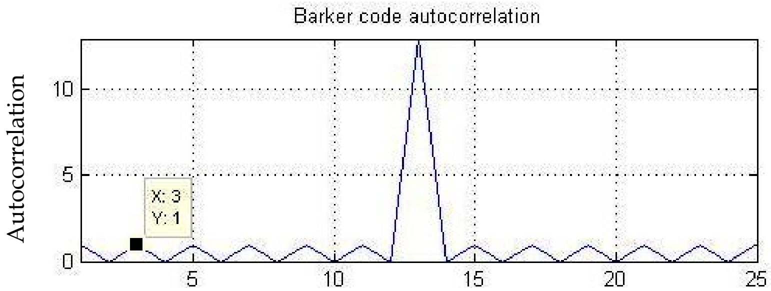

Fig. 2 Autocorrelation of Barker sequence length N=13.

3.2. Description of Signal Processing Algorithm

The main steps of the signal processing algorithm are given below.

1. Store original code (Barker) in i[th] static register.
2. Shift returning signal through a shift register upto j[th] times at clock frequency and store it in another register.
3. Apply the corresponding elements in the two register to the optimum matched filter inputs.
4. Apply the outputs of all the matched filters to an AND gate.
5. Observe the position where cross correlation successful.
6. Calculate the delay between i[th] and successful correlation position.
7. Obtain range data from eqn.(1) and step 6.

By applying above step false alarms due to atmospheric attenuation and noise are reduced.

4. Implementation

Fig.3 shows the hardware implementation of signal processing algorithm. The Barker sequence generator generate parallel Barker 13 sequence and Barker sequence modifier convert the parallel Barker 13 sequence into serial sequence. The output of Barker sequence modifier is PWM (pulse width modulator) kind output, using for driving the laser diode driver and laser transmitted towards the target. After certain time delay, we detect echo signal with the help of photo detector from the target, which is totally buried inside the noise. The digitized bit sequence is obtained from analog front end. By using the shift register and correlator , correlation peak can detect and counter counts the number of clock cycles with reference to initial trigger point and range data can be calculated by eqn(1). Correlator is a optimum matched filter and used for enhancing the signal to noise ratio. The algorithm has been implemented with the help of hardware description language(HDL) and FPGA (Field programmable gate array).

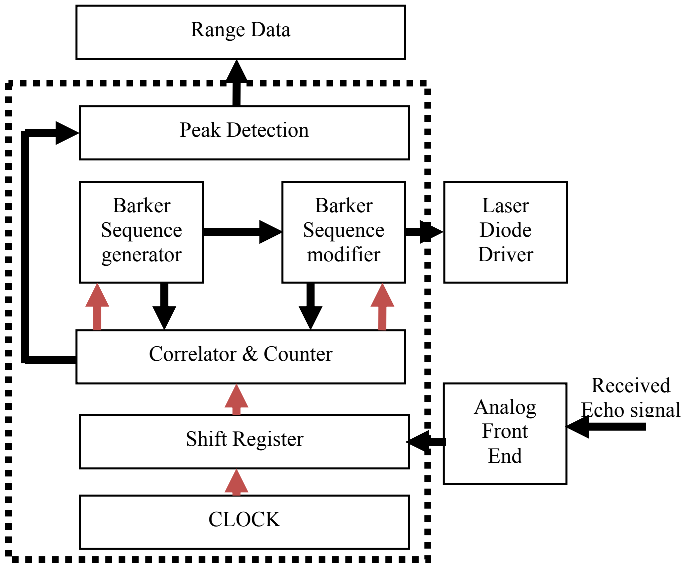

Fig. 3 Algorithm Implementation

5. Algorithm Testing And Results

Fig.4 shows the algorithm testing setup. To test the algorithm reliability, an extra digital delay line HDL module implemented alongwith previously implemented design. The delay line provide the fixed delay between transmitted and received sequence. The delay can be varied by changing the delay index. In actual system , the received signal is corrupted by noise. Therefore, a noise generator added the Gaussian noise in output of delay line, where signal and noise are un correlated to each other. The received sequence modifier is a shift register. As trigger signal apply the Barker sequence generator triggered and found correlation peak as discussed in section 4. Measure the delay between rising edge of trigger signal and position, where the correlation peak occur. Verify the measure delay with actual delay that are given by delay line. The design has been realized on Vertex-4 Xilinx FPGA. Table 1 show the delay measurement results for 100 MHz clock frequency and 13o ns pulse width trigger signal at 1 MHz pulse repetition frequency. Fig.5 show the actual algorithm hardware testing results under simulated condition for 30 MHz clock frequency and 433 ns pulse width trigger signal at 10 KHz pulse repetition frequency.

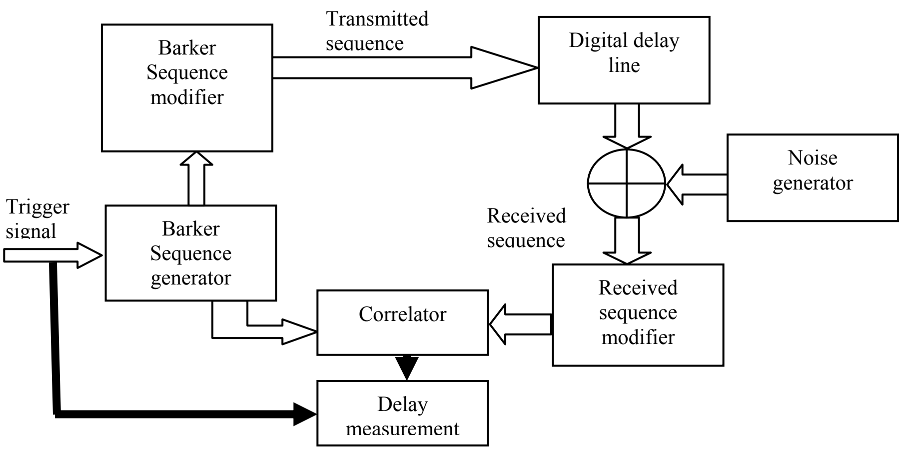

Fig. 4 Algorithm Testing

From Table 1 following observations are observed

$$\text{Average Time Offset } (\Delta t \text{ ns}) = \frac{1}{N}\sum_{i=1}^{N} \Delta t = 207.11 \text{ ns} \quad (9)$$

$$\text{Average Clock Cycles} = 20.71 \quad (10)$$

$$\text{Variance } \sigma_{\Delta t}^{2} = \frac{1}{N}\sum_{i=1}^{N}(\Delta t - ave\Delta t)^{2} = 20.69 \text{ ns}^{2} \quad (11)$$

$$\text{Standard Deviation } \sigma_{\Delta t} = \sqrt{\frac{\sum_{i=1}^{N}(\Delta t - ave\Delta t)^{2}}{N}} = 4.54 \text{ ns} \quad (12)$$

Table 1

Delay Line Index	Ideal Time Delay(ns)	Measured Time Delay(ns)	Time Offset(Δt)(ns)	Clock Cycles Offset
10	100	308	208	20.8
15	150	364	214	21.4
20	200	408	208	20.8
25	250	460	210	21
30	300	512	212	21.2
35	350	560	210	21
40	400	600	208	20.8
45	450	656	206	20.6
50	500	700	211	21.1
60	600	808	208	20.8
70	700	904	204	20.4
80	800	1010	210	21
90	900	1100	200	20
100	1000	1200	200	20
120	1200	1400	212	21.2
130	1300	1480	200	20
150	1500	1700	200	20

From table 1 and fig. 5 , the range computation time is around 20 clock cycle , which may be either in nanosec or in microsec. But accuracy in from table 1 is ±2 m and from fig. 5 is ± 5 m. Another important point both observations are unaffected by pulse repetition frequency(PRF) variations. Finally , SNR of 13 dB has been achieved from proposed algorithm with very fast computation time.

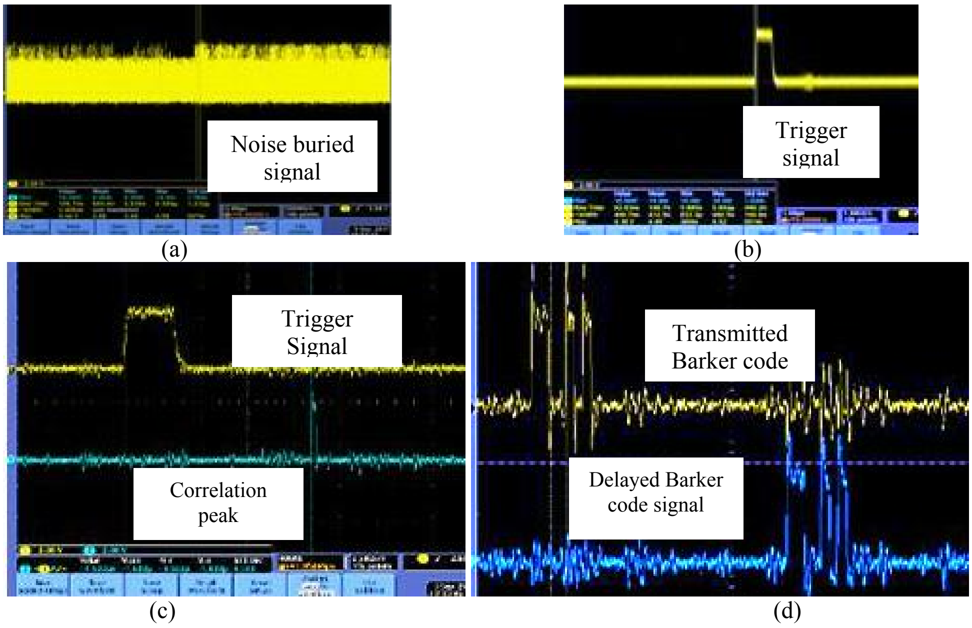

Fig.5 (a) Received Noise Buried Signal (b) Input Trigger Signal 433 ns (c) Trigger Signal and Correlation Peak (d) Transmitted Barker Code and Delayed Barker Code

6. Conclusion

Signal detection in low transmitted power laser range finder receiver suffer from false alarm , when received signal from the target is buried inside the noise. This new digital signal processing reduce the false alarm, improve SNR and improve the accuracy. The results presented in this paper show the advantage of proposed algorithm that it is independent of PRF(pulse repetition frequency) and range computation time is few microseconds. Although, the some false alarm problem showed beyond certain noise level. The algorithm has been checked under simulated conditions and it is proposed to use this algorithm in futuristic laser range finder.

7. Acknowledgements

We thank Shri S.S. Sundaram, Director IRDE for permitting us to publish this work. The authors would like to acknowledge the encouragement given by Dr. A.K. Gupta, Outstanding Scientist, IRDE, Dehradun.

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