The Application of orthogonality cross correlation algorithm in weak signal detection

Pengfei Hu, Liping Liu, Li Shen
Guizhou Institute of metrology
shineliuliping@seu.edu.cn

Abstract. In this paper, the Xilinx Artix-7 FPGA chip was used as the processor to submit an orthogonality cross correlation algorithm with strong anti-interference capacity that constructed two reference signals have a large amplitude and same frequency with the reception signal from transducer to search the weak signal in the transducer. It can prominently improve the Signal to Noise Ratio (SNR) of transducer information and exact the feature information of reception transducer. The processing time of this algorithm is short and able to ensure the real-time performance of data transmission in the measurement.

1. Introduction
Measurement while drilling (MWD) is the technology of acoustic wave propagation that used the elastic wave along the signal channel of drill-string. It is a data telemetry tools technology that can transmit the measurement data under the mine along the signal channel of drill column to super terranean. The propagation velocity of elastic wave in the signal channel of drill column is faster than the velocity in slurry and the dominant frequency is higher for the elastic wave which have high performance of carrier. But the capacity of acoustic propagation was susceptible to noise interference in environment and drilling operation to weaken. It is obvious that the attenuation signal is belong to the weak signal detection which challenges the data propagation and the designment of sound reception transducer and the pre-amplification circuit. Because of this, in our work, we designed a circuit of weak signal extraction with the capacity of strong anti-interference in any frequencies.

In this work, the Xilinx Artix-7 FPGA chip was used as the processor to submit an orthogonality cross correlation algorithm with strong anti-interference capacity that constructed two reference signals which have a large amplitude and same frequency with the reception signal from transducer to search the weak signal in the transducer. It can prominently improve the Signal to Noise Ratio (SNR) of transducer information and exact the feature information of reception transducer.

2. System designment of orthogonality cross correlation algorithm

2.1. The block diagram of extraction system
The block diagram of orthogonality cross correlation algorithm system is shown in figure 1. The $x_1(t)$ is the signal of reception transducer and $r_1(t)$ is the reference signal with same phase. The $r_2(t)$ is the orthogonality reference signal after 90° phase shifting. The two signals were processed by the multiplying unit to obtain signals of $V_{psd}$ and $V_{psd2}$, and after through the lowpass filter LPE1 and LPE2 to obtain the signals of $V_{psd12}$ and $V_{psd22}$. The composite value of amplitude and phase was calculated by the CORDIC IP core built in FPGA board. The core of the extraction system is keeping at the same frequency for the reference signal and the signal of reception transducer. The difficulty lies in...
how to filter the noise signal after the transformation from multiplying unit and the random distribution noise in the feature information of the frequency.

![Figure 1 The block diagram of extraction system.](image)

2.2. The design of multiplying unit
The multiplying unit is one core of cross correlation algorithm. The in-phase reference signal and orthogonality reference signal were taken as the multiplicand for the two multiplying unit. The multiplicator was the signal of reception transducer. Because of the same-frequency for reference signal and reception transducer information, the feature information was the frequency-doubling signal by the multiplying unit can be used directly.

2.3. The design of lowpass filter
The band of lowpass filter is more narrow, the performance of the SNR for the system is better, and corresponding the Q value of the filter is more large, but it would make the designment of the filter is very complex. As the previous design target, the frequency of reception transducer is 40Hz, the sampling frequency is 488Hz, the cut-off frequency of transmission band \( f_p \) is 0.5Hz, the cut-off frequency of attenuation band \( f_c \) is 2Hz, the passband ripple is 0.01dB, the stopband attenuation is 80dB. The designed filter has 301 grades by the MATLAB tools. It is a waste of resource of FPGA need to use the extraction, plastic and interpolation to achieve the lowpass filter designment by the method of down-sampling.

![Figure 2 Structure of Drop-Sample Frequency LPF](image)

The output signal of lowpass filter designed with the orthogonality cross correlation algorithm is direct current signal which is independent of the valve of the frequency of outputting signal sampling. After the forming filter, lowpass filter don’t need to use the interpolation to enlarge the sampling frequency that just need the extraction filter and forming filter. Therefore, in our research, we used the structure of HB and FIR to design the lowpass filter. At first, we used the HB half-band filter to process the signal from reception transducer after sampling to reduce the sampling radio of reception transducer information, and then, the low-grade FIR filer was used to process the signal. Then a filter performance with higher tolerance, transition band and stopband tolerance was designed to satisfy the requirement of forming and total filter. It can accurately and effectively extract the reception transducer information.

The MATLAB combined with FPGA can design the high performance lowpass filter has 10bit data-width for the transducer quantifiable data and 5 grade extraction method to extract the ratio of transducer information at 15.25Hz. The front 4 grade is HB half-band filter has the same amplitude-frequency response and the last grade is the ordinary FIR forming filter. The passband and stopband tolerance devi of the front 4-grade HB half-band filter is 1/4000, the passband and stopband tolerance dev of the last grade FIR forming filter is 0.001.

The amplitude-frequency response of the front 4-grade HB half-band filter and the last grade FIR forming filter is shown in figure 3.
2.4. **Cordic coordinate system transformation circuit**

Cordic algorithm is the digital calculation method of rotation of coordinates that submitted by J.D.Volder in 1959 at the first time primarily used to calculate the trigonometric function, hyperbolic curve, exponent and logarithm. This algorithm used the basic addition and shift operation to replace the multiplication that enable the vector rotation and orientation to calculate without the trigonometric function, multiplication, exponent, inverse trigonometric and extraction of a root function. Xilinx provides the free IP core for the user. In our works, we used the Xinlinx Cordic IP core to convert the Cartesian coordinates to polar coordinate system.

3. **Results and Discussion**

The frequencies of 0.4Hz, 2Hz, 25Hz, 50Hz at the single frequency of sinusoidal signal for simulation testing data and superposed signal with Gauss While Nosie sequence was input the lowpass filter that exacted and filtered by forming filter, the oscillogram at the time and frequency domain as illustrated in following figure4. The original composite signal just has a the single frequency of sinusoidal signal at 0.4Hz. The upper limit margin frequency of transmission band was fp equal to 0.5Hz and the lower limit margin frequency of transmission band was fc equal to 2Hz are realized.

The Artix-7 FPGA development board was taken as the core-board to realize the orthogonality cross correlation algorithm. The excitation signal at 40 Hz overlay the Gauss White Noise was transferred to digital signal by the AD9226 A/D interface board and AD9767 D/A interface board in the FPGA board. The reference signal was supplied by DDS in the development board. In the figure 5, the green line is on the behalf of the 40Hz signal source with the noise and the blue line represent to the results of signal through the orthogonality cross correlation algorithm which is obvious direct current output.
4. Conclusion
In our experiments, we have studied the application of orthogonality cross correlation algorithm in the weak signal detection and extraction. In this system, the reception information of transducer was transformed to amplitude in direct current and phase position with standard of reference signal. Results showed that it is effective to use orthogonality cross correlation algorithm to reduce the noise information and to enhance the SNR of the reception transducer. Through the calibration of other company, it has an output dynamic rang with 100 dB by the application of orthogonality cross correlation algorithm. Even though the amplitude of noise signal is much larger than the amplitude of signal from reception transducer, but owing to the uncorrelated reference signal, the noise signal was effective filtrated when through the low pass filers. The orthogonality cross correlation algorithm was processed to 8 clock period by 4 half-band filters and processed to 12 clock period by the forming filter that has the total extraction time in 78 ms which has the better performance to ensure the real-time of data transmission in the measurement process.

Acknowledgment
The authors are grateful for the valuable help of our co-workers. The authors would like to acknowledge the financial support provided by the National Natural Science and Guizhou Science and Technology Departments. (No. QKH2016108, No. QKH20192881).

References
[1] Maddala S. A simulator for depicting and comparing adaptive algorithms in signal processing[M]. 2011.
[2] Gui G, Xu L, Ma W, et al. Robust adaptive sparse channel estimation in the presence of impulsive noises[C] IEEE International Conference on Digital Signal Processing. IEEE, 2015:628-632.
[3] Karthik G V S, Fathima S Y, Muhammad Z U R, et al. Reply to Comments on Efficient Signal Conditioning Techniques for Brain Activity in Remote Health Monitoring Network[J]. 2015:1.
[4] Digital Signal Processing with Field Programmable Gate Arrays U. Meyer-Baese
[5] Michael J.Schauber.Measurement of mutual inductance from the frequency dependence of impedance of AC coupled circuits using a digital dual -phase lock-in amplifier[J].American Journal of Physics,2008, 76(2):129-132.
[6] F.K.Title,A.A.kosterv,L.Dong,D.Thomazy,S.Overby.QEPAS for chemical analysis of multi-component gas mixtures[J],Applied Phsics B-Lasers and Optics,2010,10):649-659.
[7] Weel M,Kumarakrishnan A.Laser-frequency stablilization using a lock-in amplifier[J].Canadian Journal of Physics,2002,80(12):1449-1458.
[8] Cristiano Azzolini,Alessandro Magnanini,Matteo Tonelli,Giovanni Chiorboli,Carlo Morandi,A COMS vector lock-in amplifier for sensor applications[J].Microelectronics Journal,2010,11(8):449-557.
[9] Ramunas Augulis,Donatas Zigmantas. Two-dimensionl electronic spectroscopy with double modulation lock-in detection: enhancement of sensitivity and noise resistance[J].Optics Express, 2011， 19（14）: 13126-13133
[10] M. Gabal, N. Medrano, B. Calvo, P. A. Martinez, S. Celma, M. R. Valero. A Complete low voltage analog lock-in amplifier to recover sensor signals buried in noise for embedded applications [J]. 2010, 5: 74-77.