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Phase estimation method using digital heterodyne and all phase FFT for improved accuracy of phase shift laser rangefinder

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Abstract

In general, the accuracy of a phase-based laser rangefinder is determined by the laser transceiver circuits and the phase estimation method. The higher accuracy of phase estimation is difficult due to harmonics, distortion caused by propagation of light in air, and errors caused by zero crossing. In this paper, we propose a digital heterodyne and phase estimation method by the all phase Fourier transform, which is a key link in improving the accuracy of the phase-shift laser range finder. In this paper, we have presented various scientific and technological problems in applying the phase estimation method by digital heterodyne and the all phase Fourier transform to the phase-shift laser angemeasurement using MATLAB.

Keywords: Heterodyne, All phase FFT, Phase estimation, laser range finder

Introductions

The phase-shift laser rangefinder is widely used for measuring, building and other purposes.

Recently, the research and application of the digital signal processing method to phase estimation method, one of the key problems in phase-based laser ranging, have been made more brisk in the world [1-17].

Several researchers have performed phase measurements by digital signal processing as a way to overcome zero error in phase laser rangefinder. The method of phase estimation can be divided into classical and digital signal processing methods [18-20].

In general, in digital systems, it is common to obtain the phase by obtaining the difference frequency in a heterodyne fashion, then pulsing the frequencies and then counting the time corresponding to the phase difference.

After converting the signals of the difference frequencies to digital signals and then performing FFT as a way to overcome the zero error, the phase estimation methods have be studied by several researchers. Then, the A/D conversion frequency, block size, and the change of phase estimation with the window function are described and the probable parameters are set.

Nextly, a correlation method was also studied for phase estimation. These studies didn't the phase estimation method by using the digital heterodyne method. In this study, a method for phase estimation using digital heterodyne and all phase Fourier transform is presented through simulation using MATLAB.

2. Phase estimation method

The digital heterodyne method is the method of digitizing and processing the transmitted and received signals rather than the analog signals. All signals in a digital signal processing system are sampled as discrete values, which are performed by the A/D converter [20-23].

Using these characteristics, a digital filter can be designed.

The harmonic input signal with amplitude A, frequency f1 and initial phase φ_0, respectively, is

$$s(t) = A\cos(\omega_1 t + \varphi_1) \quad (1)$$

The sampling signal is

$$S_S(t) = \delta(t - nT_S) \quad (2)$$

The sampling period and sampling frequency in Eq.2 are

$$T_s = \frac{1}{f_s} \quad (3)$$

The input signal sampled by the sampling signal can be expressed as

$$s(nT_s) = A\cos(2\pi f_1 nT_s + \varphi_1) = A\cos(2\pi \frac{f_1}{f_s} n + \varphi_1) \quad (4)$$

In Eq. 4, n is an integer.

Suppose that the frequency of the input signal is related to the reference frequency by

$$f_1 = f_s + \Delta f \quad (5)$$

When the sampling frequency is chosen as the reference frequency, the sampled signal is

$$s(nT_s) = A\cos(2\pi \frac{f_s + \Delta f}{f_s} n + \varphi_1) = A\cos(2\pi \frac{\Delta f}{f_s} n + \varphi_1)$$

$$= A\cos(2\pi \Delta f nT_s + \varphi_1) = A\cos(2\pi f_c n + \varphi_1) \quad (6)$$

Where

$\Delta f = f_1 - f_s$ and fc is the frequency of the transformation. From Eq. 6, if the condition of Eq. 5 is satisfied, the frequency of the sampled signal is converted to the frequency difference of the input signal and the sampling frequency.

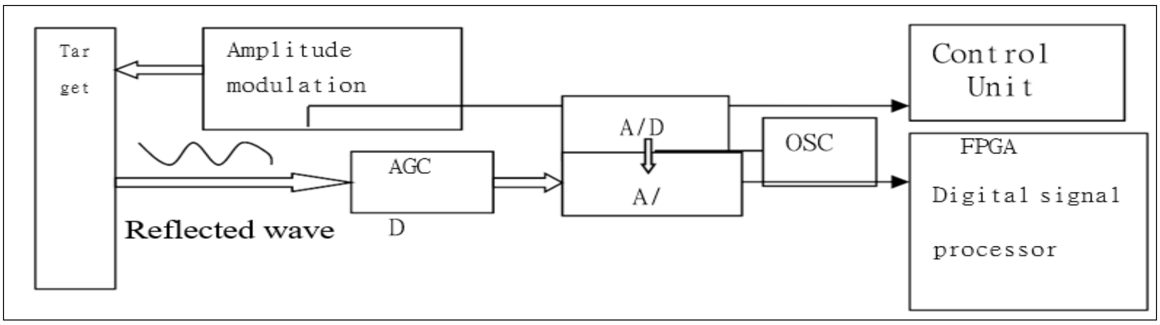

Fig 1: Block diagram of the phase estimation

The phase estimation scheme is shown by converting the transmitted and received signals simultaneously to the A/D conversion to the difference frequency.

Then the phase difference of the two signals is the phase difference we want to find. In practice, there is a risk of errors in harmonics and noise of various causes.

To overcome this, the use of the phase estimation method using Fourier transform can overcome the above drawbacks. However, in phase estimation, the FFT is not performed in the whole range, and the phase estimation at the frequency is associated with errors. The signal processing scheme of the double-window all phase Fourier transform is shown in Fig. 2. Let the input data sequence be 2N-1 data, x(1), …, x(2N - 1).

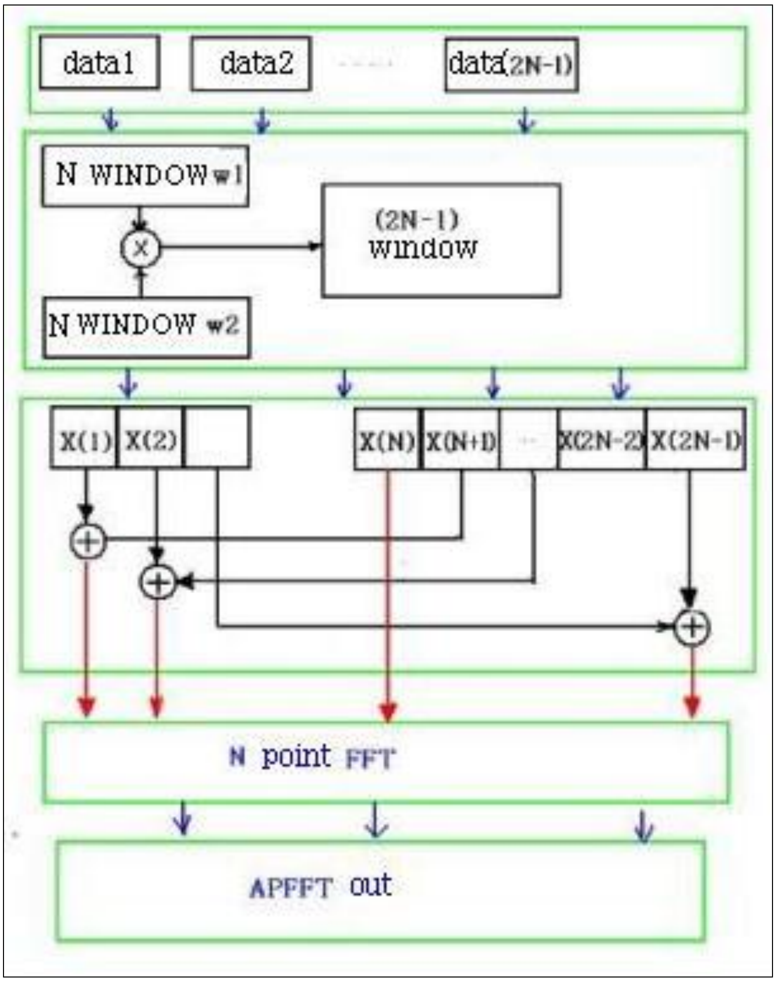

Fig 2: principle of the all phase Fourier transform

In the figure, w1 is a forward window, w2 is a backward window, and as a result, a window w(n)=w1(n)*w2(n) of length 2N-1 is formed.
Using this window, the data sequence {x(n)} becomes the data sequence {X(n)}={w(n)×x(n)}. Hence, the preprocessing data {xap(n)} for the two-window all phase Fourier transform is obtain ed as follows.

$$X_{ap}(n) = [\frac{N-n}{N}X(n+N) + \frac{n}{N}X(n)]w_N(n)$$

Then the DFT result of the preprocessed data {xap(n)} is the result of the all phase FFT.

Block Sizing and Window Setting
When N is set to 32, 64, 128, 256, 512, 1024, 2048, 4096, and 8192, the phase error betwee n the FFT and the all phase FFT is considered, and in comparison with the block size N.

Table 1: The phase error with block N when Gaussian noise is added

No	block	apFFT error(°)	FFT error
1	32	-0.0293976756871786	2.07113010900257
2	68	-0.0467635668851898	1.41452076213135
3	128	0.0235250936913616	-0.574903988122358
4	256	0.00211383093505901	-0.704834531517619
5	512	0.0599829935265888	0.201648867917783
6	1024	-0.0251621652420937	0.0949232928702628
7	2048	0.00160027992797041	-0.0341412824270009
8	4096	0.00206324780060640	-0.0286311999126099
9	8192	-0.00055654003849304	0.00740697184919270
10	16384	-0.00089564708156831	-0.0178661837036742

As can be seen, the phase error according to block size decreases, we can see the phase error of the all phase FFT decreases fully from N=256.

To perform the all phase FFT, we perform the operation with the windowfunction, and the phase difference estimation according to the window fu nction is affected by some degree.

The window is compared with 17 windows embedded of MATLAB. The phase error of each win dow is analyzed in the case of sample score 8192, as shown in Table 2

Table 2: The errors and error diverations with each window (N=8192)

No	N=8192 Window's name	No noise Averag e-error (°)	Noise Average-error (°)	Noise Error-diveration	Order
1	'bartlett'	-2.88E-12	0.000433583	0.004732648	4
2	'barthannwin'	-5.26E-13	0.000467671	0.005043668	6
3	'blackman'	-3.41E-13	0.000582176	0.005757455	11
4	'blackmanharris	-2.98E-13	0.000699069	0.006476591	16
5	'bohmanwin'	-2.84E-13	0.000607388	0.005918931	12
6	'chebwin'	-8.96E-10	0.00067245	0.006313276	14
7	'flattopwin'	-1.56E-11	0.00146665	0.01028996	17
8	'gausswin '	-3.48E-08	0.000470101	0.005016471	7
9	'hamming'	-9.63E-08	0.00043818	0.004820288	5
10	'hann'	-3.98E-13	0.000483748	0.005156196	8
11	'kaiser'	-4.32E-06	0.000500423	0.004141117	9
12	'nuttallwin'	-4.48E-12	0.00068732	0.006403783	15
13	'parzenwin'	-4.55E-13	0.00066279	0.006258286	13
14	'rectwin'	-4.71E-06	0.000512228	0.004138488	10
15	'taylorwin'	-6.43E-07	0.000393668	0.004418861	2
16	'tukeywin'	-4.97E-13	0.000385518	0.004451822	1
17	'triang'	-1.55E-12	0.000433535	0.004732293	3

When N = 8192, if the transmission frequency is 40 MHz, the distance corresponding to 1°is g iven by 3.75m/180°= 0.0208m/1°

The angular step for 1 mm is about 0.0479° in the calculation, and 0.0048° in the consideration of 1/10 resolution.

Looking at the tables above, we can see that when N = 8192, all windows are satisfied with steps of approximately 1/10 to 1/5.

Considering that the frequency can be reduced, we implement the all phase FFT using the 'kaiser window' when N = 8192.

4. Conclusion

In phase laser range finder, the phase estimation method is very important for accuracy determination. In this paper, we propose a phase estimation principle using digital heterodyne and all phase Fo urier transform. We have presented a circuit diagram that can realize digital digital heterodyne and all phase Fourier transform. If it is used for distance measurement, we demonstrated that this metho d hasa resolution of 0.1 mm with sampling number N = 8192 using the kasier window function w hen modulating frequency f=40MHz. This method has the advantage of overcoming various errors, s uch as errors caused by the transmission and reception of laser light, and it can be widely used fo r distance precision measurement.

References

1. Kawakami T, Endo M. Adaptive multifrequency modulation method for an advanced laser range finder. IEEE Trans Instrum Meas. 1994;43(6):857-860.
2. Wei GQ. Active self-calibration of hand-mounted laser range finders. In: Proceedings of the 1997 IEEE International Conference on Robotics and Automation. 1997. p. 2789-2794.
3. Maatta K. Profiling of hot surfaces by pulsed time-of-flight laser range finder techniques. Appl Opt. 1993;32(27):5334-5342.
4. Bhattacharya P. Semiconductor Optoelectronic Devices and Optics. 2nd ed. New Jersey: Prentice Hall; 1997.
5. Minoni U, Rovalti L. High performance front-end electronic for frequency-modulated continuous-wave interferometers. IEEE Trans Instrum Meas. 1999;48(6):1191-1196.
6. Fujima I, Iwasaki S, Seta K. High-resolution distance meter using optical intensity modulation at 28 GHz. Meas Sci Technol. 1998;9(9):1049-1052.
7. Bazin G, Journet B. A new laser range finder based on FMCW-like method. In: IEEE Instrumentation and Measurement Technology Conference; 1996 Jun 4-6; Belgium. p. 90-93.
8. Barwood G, Rowley R. High-accuracy length metrology using multiple-stage swept-frequency interferometry with laser diode. Meas Sci Technol. 1998;9(9):1036-1041.
9. Bartolini A, Bordone R, Fantoni R. Development of a laser range finder for the Antarctic plateau. In: Proceedings of EARSeL-SIG-Workshop LIDAR; 2000 Jun 16-17; Dresden, Germany.
10. Hoelzlwimmer S, Zamorano-Calderon I, Prager S, Gros N. Distance measuring device. 2016 Jan 28. p. 1-10.
11. Heesun Y, Kyihwan P. Development of a laser range finder using the phase difference method. Proc SPIE. 2015;6049:544-546.
12. Poujouty S. Laser range finder based on fully digital phase-shift measurement. In: Instrumentation and Measurement Technology Conference; 2002. p. 1773-1776.
13. Yang H. Phase noise influence in a dual-frequency laser phase-shift range finder. IEEE Photonics J. 2018;10(1).
14. Zhang F. Simultaneous measurements of velocity and distance via a dual-path FMCW lidar system. Opt Commun. 2020;474:126066.
15. Chicharo JF. A sliding Goertzel algorithm. Signal Process. 1996;52(3):283-297.

16. Cordoneanu D. A stopping condition to empirical mode decomposition based on the Goertzel algorithm for detecting frequency-based faults. UPB Sci Bull Ser D. 2021;83(4).
17. Khodadadi R. Designing optical beam filter and detector based on photonic crystals structure by FMCW method. Int J Eng Res Appl. 2012;2(6):214-224.
18. Nejad SM. Comparison of TOF, FMCW and phase-shift laser range finding methods by simulation and measurement. Q J Technol Educ. 2006;1(1):n.p.
19. Jacob S. A digital heterodyne laser interferometer for studying cochlear mechanics. J Neurosci Methods. 2009;179(2):271-277.
20. [Missing reference number 20 - consider reviewing your source list.]
21. Fast-recovery of the amplitude and phase of short optical pulses using a frequency-swept source based heterodyne measurement. IEEE Photonics J. 2018;10(3).
22. Garrido M. The feedforward short-time Fourier transform. IEEE Trans Circuits Syst II Exp Briefs. 2016;63(9):868-872.
23. Gatet L. Real-time surface discrimination using an analog neural network implemented in a phase-shift laser rangefinder. IEEE Sens J. 2007;7(10):1402-1408.