Research on real-time laser range finding system

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Abstract: Phase-shift laser range finder, as a large-scale, high-precision measurement method, is widely used in industrial and military fields. The traditional laser range finder can not meet the need of real-time, high resolution measurement because of its low anti-jamming capability and time-consuming measurement. Owing to this, multi-channel transmitting and receiving system for phase-shift laser range finder based on parallel DSP was designed. Multi-frequency modulation laser can be transmitted and received at the same time, improving the measurement speed and avoiding the wrong data fusion because of target moving. The distance was got by measuring the phase difference between the measurement signal and reference signal, and the Doppler velocity of the target is got by measuring the measurement signal's frequency, The measurement signals reference signals were acquired by parallel AD convertors, the phase difference between them was calculated adopting all-phase FFT(apFFT). A new frequency correction method was proposed according to the amplitude spectrum acquired by apFFT, Amplitude spectrum is expanded into Taylor series and the correction value of frequency is calculated by relationship of spectrum lines. Monte Carlo simulation results proved that the new frequency correction method had higher resolution and better stability than Rife method and centro-baric method. The experiments is implemented on a precision guide of 3m-long, on the condition that the sampling frequency of AD converter is 937.5KHz, the apFFT transform point number is 4096, distance and velocity results can be obtained each 10ms, experiments prove that the distance measurement standard deviation better than 0.09mm and the velocity measurement standard deviation better than 0.022m/s are obtained. The system can meet the need of high accuracy ,real-time distance measurement of moving target.

Keywords: Laser range finder, multi-frequency modulation, parallel DSP, apFFT spectrum correction

I. INTRODUCTION

Phase-shift laser range finder, as a large-scale, high-precision measurement method, is widely used in industrial and military fields [1][2]. Given the stable phase measurement accuracy, if the frequency of measuring scale is higher, the ranging accuracy will be higher, and then the measurement range will be smaller. In order to solve the contradiction between the measuring range and the measurement accuracy, several light in different modulation frequencies are used to measure the same distance in this system. The measurement accuracy will be ensured by the higher frequency measuring scale, and the measuring range will be guaranteed by the lower one. As several measurements scales are launched in serial, Measuring time will increase, which can not perform real-time measurement [3]. In the phase-shift laser range finder system, the measurement accuracy of phase difference between emitted light and reflected light is one of the main determinants to ensure high precision distance measurement. Traditional automatic phase measuring method, which has zero-cross detection and pulse counting error[4]. And it is easy to be effected by drift error and harmonic interference. In order to eliminate harmonic error, additional devices such as light attenuation and complex automatic gain control circuit are necessary in the optics system, which complicate the system and retard the system control rate[5][6]. On more and more measurement occasions, it is required to acquire distance and speed information of target simultaneously, which cannot be contented by static measurement system. The above-mentioned problems must be solved to make phase laser ranging method meet new measurement need.

II. SYSTEM DESIGN

Based on the principal of phase laser ranging method, we designed multiple frequency modulation phase method laser ranging speed frame which is showed in Fig 1. DSP controls frequency synthesizer groups: DDS1, DDS2 and DDS3, which produced sinusoidal modulation signal at the frequencies f_1, f_2, f_3 respectively. The signal which combines the signals at three frequencies with DC bias signals can drive laser through driver. Then laser can emit modulated

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light which contained f_1, f_2, f_3. After emitted light reflected by the target mirror, the sinusoidal signal at f_1+f_{d1}, f_2+f_{d2}, f_3+f_{d3} can be obtained selecting by band-pass filter. Then these signals are mixed with frequency of f_1', f_2', f_3' respectively which are produced by direct DDS groups. And low frequency signal can be obtained after filtering. 6 channels paralleled AD converters acquire the reference and measurement signals at different modulation frequencies, send them to DSP1 DSP2 DSP3, and extract sine signal parameters with the spectrum analysis, to obtain the objective distance information and speed information.

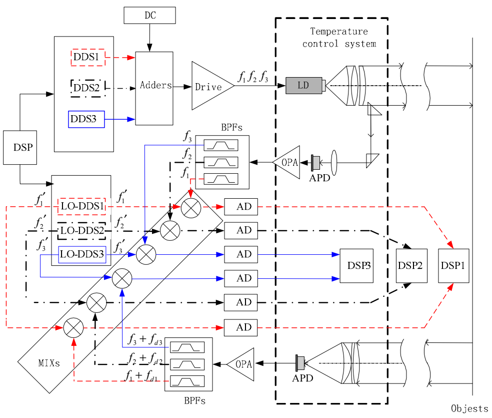

Fig.1 Multi-modulated frequency Dynamic laser range finding system based on parallel DSPs

III. SIGNAL PROCESSING

The primary distance is R0,and the speed is v_r .In the system shown in Fig.1,the laser emission signal is the combining of multi sine wave:

$$S^{f_k}{}_{mea-k}(t) = A_{Aver} + \sum_{k=1}^{3} A_{mea-k}\cos\left(2\pi f_k t + \varphi_k\right) \quad (1)$$

A_{Aver} ——the average of the emission signal

f_k ——the transmitting frequency

φ_k ——primary phase of signals of different frequency $k=1,2,3$ and $f_3 > f_2 > f_1$

The reference signal after frequency selection is :

$$S^{f_k}{}_{Ref-k}(t) = A_{Ref-k}\cos\left(2\pi f_k t + \varphi_k\right) \quad (2)$$

Then signal of receiving light:

$$S^{f_k}{}_{R-mea}(t) = A_{R-mea-k} \times\cos\left(2\pi\left(f_k + f_{dk}\right)t - \frac{2\pi f_k\cdot 2R_0}{c} + \varphi_k\right) \quad (3)$$

Three groups of the local oscillator signals (LO) are:

$$S^{f_k'}{}_{lo}(t) = A_{lo-k}\cos\left(2\pi f_k' t + \varphi_{l0-k}\right) \quad (4)$$

A_{lo-k} 、 f_k' and φ_{l0-k} : Amplitude, frequency and phase of LO respectively, the k=1,2,3 and $f_3' > f_2' > f_1'$

LO and reference signals are multiplied by mixers , S_{ref-k} and S_{mea-k} can be got after filtering high frequency component by the low pass filter:

$$\begin{cases} S_{ref-k}(t) = \dfrac{A_{T-ref-k}A_{LO-k}}{2}\bullet \\ \cos\left[2\pi\left(f_k - f_k'\right)t + \left(\varphi_k - \varphi_{lo-k}\right)\right] \\ S_{mea-k}(t) = \dfrac{A_{R-mea-k}A_{LO-k}}{2}\bullet \\ \cos\left[2\pi\left(f_k - f_k' + \dfrac{2v_r f_k}{c}\right)t + \left(\varphi_k - \varphi_{lo-k} - 2\pi f_k\cdot 2R_0/c\right)\right] \end{cases}$$

(5)

From the equation above, the phase-shift of two signals contains the distance information, and the frequency contains the speed information. In the method of frequency spectrum analysis the frequency and phase can be get and then the distance and speed information can also be calculated [7].

A Measuring the Phase Shift of Reference and Measuring Signals with apFFT

The main character is the avoidance of the distance from harmonic wave and no error of 'amplitude-phase' when FFT is applied to do the frequency spectrum analysis. But under the influence of 'picket fence' effect and spectrum leakage ,the spectrum correction must be done to improve the accuracy. To decrease the influence of spectrum leakage in the process of FFT ,Professor zhaohuaWANG raised new concept of 'all phase FFT analysis', as it has not only good performance in restraining spectrum leakage but also 'phase stability'[8][9].There is no need the spectrum and the phase correction at the top of the spectrum. And the sine-signal's phase can be directly calculated. So, the 'phase stability' analyzed by 'all phase FFT' is used to measure phase shift of reference and measuring signals.

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B New Spectrum Correction Method Based on apFFT

Since transmitting and reflecting light signals content the speed information of target ,and the frequency of transmitting light signal is known. So, for the reflecting light signals, information of the discrete spectrum can be got by apFFT conversion operated to measure the phase of reflecting light signal. we can make full use of the information to estimate the actual frequency of measuring signals. Discrete spectrum ,which is signal frequency sine wave converted by FFT ,is a symmetric figure ,and the frequency center is f_0。

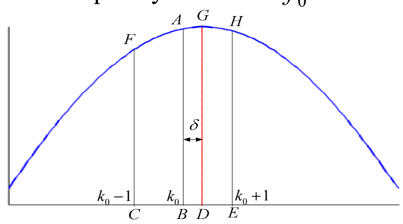

Fig.3 Frequency correction based on Taylor series expansion of amplitude spectrum

The normalization frequency deviation is assumed as δ ,using rectangle window function as filtering, and after the FFT of N point , the amplitude at spectrum line of K is A_k , and A_k can be written as:

$$A_k = \frac{N.a}{2} \frac{\sin\left[\pi(k - f_0 T)\right]}{\pi(k - f_0 T)} \quad (6)$$

The peak value of spectral line k_0+1 is $A_{FFT}(k_0+1)$,the spectral line number is k_0 ,and the corresponding amplitude is $A_{FFT}(k_0)$,while the amplitude of spectral line k_0-1 is $A_{FFT}(k_0-1)$ .they can be expanded by Taylor series:

$$\begin{cases} A_{FFT}(k_0) = \frac{N.a}{2} \cdot \left(1 - \frac{[\pi\delta]^2}{3!} + \frac{[\pi\delta]^4}{5!} - \frac{[\pi\delta]^6}{7!} + D\right) \\ A_{FFT}(k_0+1) = \frac{N.a}{2} \cdot \left(1 - \frac{[\pi(1-\delta)]^2}{3!} + \frac{[\pi(1-\delta)]^4}{5!} - \frac{[\pi(1-\delta)]^6}{7!} + D\right) \\ A_{FFT}(k_0-1) = \frac{N.a}{2} \cdot \left(1 - \frac{[\pi(1+\delta)]^2}{3!} + \frac{[\pi(1+\delta)]^4}{5!} - \frac{[\pi(1+\delta)]^6}{7!} + D\right) \end{cases} \quad (7)$$

D is the high order rounding quantity.when it is cut to δ^2 , from the equation,we can get:

$$\delta = \frac{A_{FFT}(k_0-1) - A_{FFT}(k_0+1)}{2\left[A_{FFT}(k_0-1) + A_{FFT}(k_0+1) - 2A_{FFT}(k_0)\right]} \quad (8)$$

In this system ,the measuring signal after apFFT conversion ,the amplitude of spectral line of k_0 , k_0-1 , k_0+1 is respectively $Y_{apFFT}(k_0)$, $Y_{apFFT}(k_0-1)$, $Y_{apFFT}(k_0+1)$.

At the same spectral line ,the equation can be got :

$$\begin{cases} Y_{apFFT}(k_0) = A_{FFT}(k_0)^2 \\ Y_{apFFT}(k_0-1) = A_{FFT}(k_0-1)^2 \\ Y_{apFFT}(k_0+1) = A_{FFT}(k_0+1)^2 \end{cases} \quad (9)$$

Then:

$$\delta = \frac{\sqrt{Y(k_0-1)} - \sqrt{Y(k_0+1)}}{2\left[\sqrt{Y(k_0-1)} + \sqrt{Y(k_0+1)} - 2\sqrt{Y(k_0)}\right]} \quad (10)$$

f , the signal frequency after correction, is :

$$f = \begin{cases} (k_0+\delta)\times(f_s/N) & |\delta| < 0.5 \\ (k_0+0.5)\times(f_s/N) & \delta > 0.5 \\ (k_0-0.5)\times(f_s/N) & \delta < -0.5 \end{cases} \quad (11)$$

The Rife method in the article [10], the centro-baric method in article[9] and the system here can be compared .when SNR(Signal to Noise Ratio) of the inputting signal is 0dB,the sampling number is 2047,that is to say ,the number for Fourier transform is 1024.,and the sampling frequency fs=1024,the normalization frequency leakage is between 0 to 0.5,varying in the step of 0.01,1000 times Monte Carlo simulation experiments are done ,then the root-mean-square of the frequency estimated of three methods is shown in Fig.4 when the signal is windowed by hanning functions.

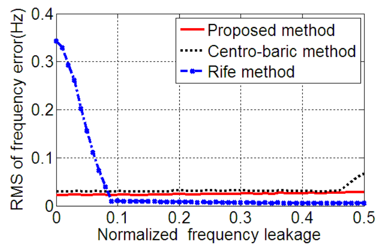

Fig.4 Monte Carlo simulation results when signal windowed by Hanning (SNR=0dB)

When signal is windowed by Hanning function ,the

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root-mean-square of the frequency estimated of double spectral line method varies most in the whole range of frequency leak, the centro-baric method next ,and the method of this article is more steady. When signal windowed by Hanning ,if the frequency leak is a bit less than 0.1, the accuracy of centro-baric method is higher ,while larger than 0.1,the Rife method is more accurate.

In the laser measuring system, as the target is moving ,under the condition of the same sampling frequency and number, the normalization frequency deviation $\delta \in [-0.5, 0.5]$.To get steady speed measuring accuracy in the whole measuring range ,the method in the article is the best.

IV. EXPERIMENTS AND RESULTS

The modulation frequency used in this system is 75MHz, 7.5MHz and 75KHz, and accordingly, the frequency of LO signals are 74.996MHz、7.496MHz and 71KHz . Hanning double-windows is added to reference and measuring signals. The frequency of signal after frequency mixing and LPF(low pass filtering) is about 4KHz. AD7677 is applied to sample data and sampling frequency is 937.5KHz, and the apFFT method is applied to get the phase-shift as the every sampling number is 8191 ,that is to say ,the final number for apFFT conversion is 4096.Then the sampling time for every measurement is only 8.373ms,which means the system give the measurement results every 10ms.

The experiment is done on the a precision guide of 3m-long ,as shown in the Fig.5,which including target mirror,3m reference measuring machine, emission and receiving optical path and temperature-control system ,electrical system and PC. Since laser diode unit, which is the emission device ,and the APD, which is the receiving device, are both temperature sensitive device, the system designs the temperature-control system .

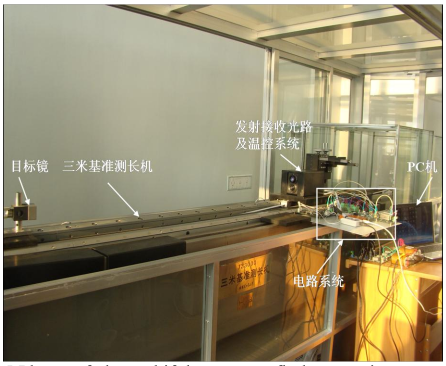

Fig.5 Phtoto of phase-shift laser range finder experiment system

On a precision guide, two points are set ,respectively 2815.00mm and 1525.00mm,The measurement results of 100 times are shown in Fig.6 and Fig.7.

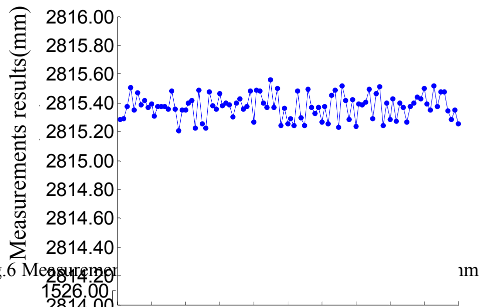

Fig.6 Measuremen ... mm

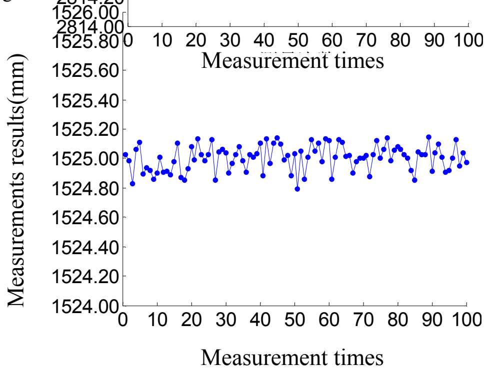

Fig.7 Measurement results when distance is fixed at 1525.00mm

From the experiment results, the average of the measured distance are respectively 2851.01 and 1525.00mm, as the standard deviation 0.08mm and 0.09mm. It's proved that the designed system can realize the high precision distance measurement.

In the dynamic measurement, the target mirror is 3000.00mm away,while it is moving towards the measuring terminal at the speed of 0.200m/s. In order to evaluate speed performance, after the target mirror moving steady(about 0.5s), the measurement begin.The system gives the distance and speed of the target,and the measuring time is 8s. Fig.8 and Fig.9 are the

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corresponding speed and distance measurement results.

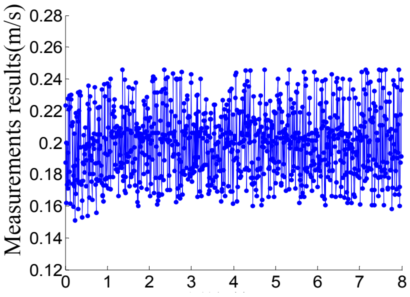

Fig.8 Experiment data of dynamic velocity measurement

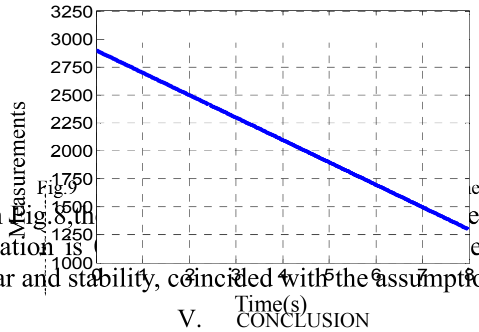

Fig.9 [illegible] ent

In Fig.8,th[illegible] e standard deviation is [illegible] ents good linear and stability, coincided with the assumption.

V. CONCLUSION

Multi-frequency modulation laser limits the improvement in the measurement speed in phase-shift laser range finder. The multi-frequency modulation laser being transmitted and received at the same time. The proposed system changes the laser transmission method, modulated laser transmitted in parallel instead of in serial, which saves measuring time and realizes measurement for moving target .To improve the resolution of range and speed measurement, the concept of apFFT is introduced into the system of phase-shift laser range finder, that improves the resolution of measurement for phase of the signal ,and then a new spectrum correction method ,the Signal amplitude spectrum expanded by Taylor series, is put forward on the base of discrete amplitude spectrum of signal. The experiment proved that the designed system in this article has the ability to get high resolution of range and speed measurement. The whole system has the good application prospect in the fields that need real-time distance and speed measuring.

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