HIGH RESOLUTION RANGEFINDER WITH PULSED LASER BY UNDERSAMPLING METHOD

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ABSTRACT

A high resolution rangefinder with a pulsed laser by using an undersampling method has been developed. It employs a temperature-compensated crystal oscillator (TCXO) to produce 15 MHz reference frequency signal. In this system a repeated 8 ns pulse light with 8.5 KHz pulse width is generated by a synthesizer where the frequency is changed by 100/99 times the reference frequency. The reference frequency is undersampled by the repeated pulse light signals from a target. As a result, the reference frequency can be precisely reproduced at a low frequency of 85 Hz. The distance between the rangefinder and its target is then obtained from the phase difference between the reproduced low frequency signal from the target and an internal reference signal within the rangefinder.

The rangefinder developed here shows good performances. Measurement resolution is better than 1 mm, and non-linearity is within ±1 mm. This pulsed laser rangefinder can measure up to 7000 m, and has been routinely used in worldwide surveying applications.

1. INTRODUCTION

Laser rangefinders employing pulsed time-of-flight techniques are widely used in industrial and surveying applications. Principle of this technique is based on measurement of round trip time of pulsed light between the laser rangefinder and its target.

It is well known that there are two methods for measuring distances by range-finders that employ intensity-modulated lights: one is phase difference method and the other is pulse method. In the phase difference method the measuring light is modulated into a continuous carrier wave where the required distance is calculated from the phase difference of the light which is reflected from the target. In the pulse method, on the other hand, the distance is obtained from turnaround time of a light pulse between rangefinder and the target.

In the field of surveying for several kilometer measurement range the precision required is of ±2 mm or ±3 mm class. This degree of precision corresponds to the time resolution of ±10 ps or ±20 ps. In order to satisfy this time resolution by counting the clock pulses of an oscillator, the oscillator would need to be specified for very high frequency range that could exceed tens of gigahertz. Therefore, in the phase difference method and in the pulse method some interpolation techniques are used to measure high speed phenomenon with frequency lower than the frequency of the clock.

Historically, the interpolation technique using heterodyne method has been used for the phase difference method since the very early days [1]. However, the development of pulse method took quite a while because of the unavailability of a suitable interpolation technique for pulsed lights.

Recently, some interpolation techniques have been introduced for the pulse method by J'ozef Kalisz [2]. Time-to-amplitude conversion represents an effective technique to interpolation methods which converts repeated short times to corresponding voltages by charging a capacitor. Unfortunately, the precision remains in the order of ±20 ps [3]. The reason is that the precision is dependent on signal processing performance that relates to the linearity and stability of the capacitor voltage on the picosecond time scale during the operation on real time.

In this paper a distance-measuring equipment employing an undersampling method is proposed. The method can convert a high clock frequency into a low frequency. It can also measure the high speed phenomenon by using extended time scale in spite of the use of pulsed light. Thus, the measurement of high precision with high resolution becomes possible.

Undersampling method is a well known technique and is proposed elsewhere. For example, there are receivers that use direct IF-to-digital techniques [4], and

there are rangefinders using Phase-Shift Estimation as reported by S. Poujouly, et al [5]. Applications using the pulse method, however, have not been reported.
This paper describes the principle of undersampling, system configuration, and provides some experimental results on the newly developed rangefinder.

2. SYSTEM

A schematic diagram of the developed rangefinder is shown in Fig.1. The system consists of temperature -compensated crystal oscillator (TCXO /15 MHz), synthesizer, divider, Driver and Pulsed Laser Diode （PLD）, avalanche photodiode (APD), amplifier, comparator, band-pass-filter, A/D converter, CPU, and memory.

The repeated 8.5 KHz pulse light with 8 ns pulse-width is generated by a synthesizer of which the frequency is changed by 100/99 times that of the reference frequency (TCXO/15 MHz).

Timing of repeated pulse light with 8.5 KHz from the target is defined as a center of gravity of pulse-width which is obtained from a special circuit (details not described here). At this timing, the signal of band-pass-filtered TCXO is sampled by A/D converter.

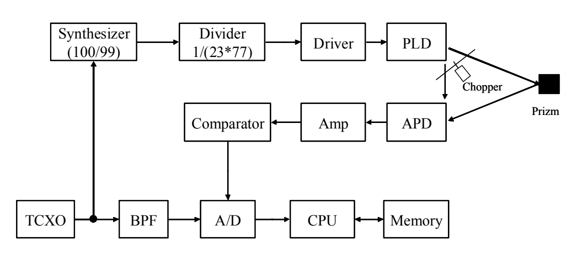

Fig.1 Block diagram of the pulsed laser rangefinder with the undersampling method

Table.1 Specification of the circuit system

f_{TCXO} [Hz]	15×10^{6}
Light source	Pulsed Laser Diode
Power [W]	3.5
Drive Current[A]	20
Pulse width [sec]	8×10^{-9}

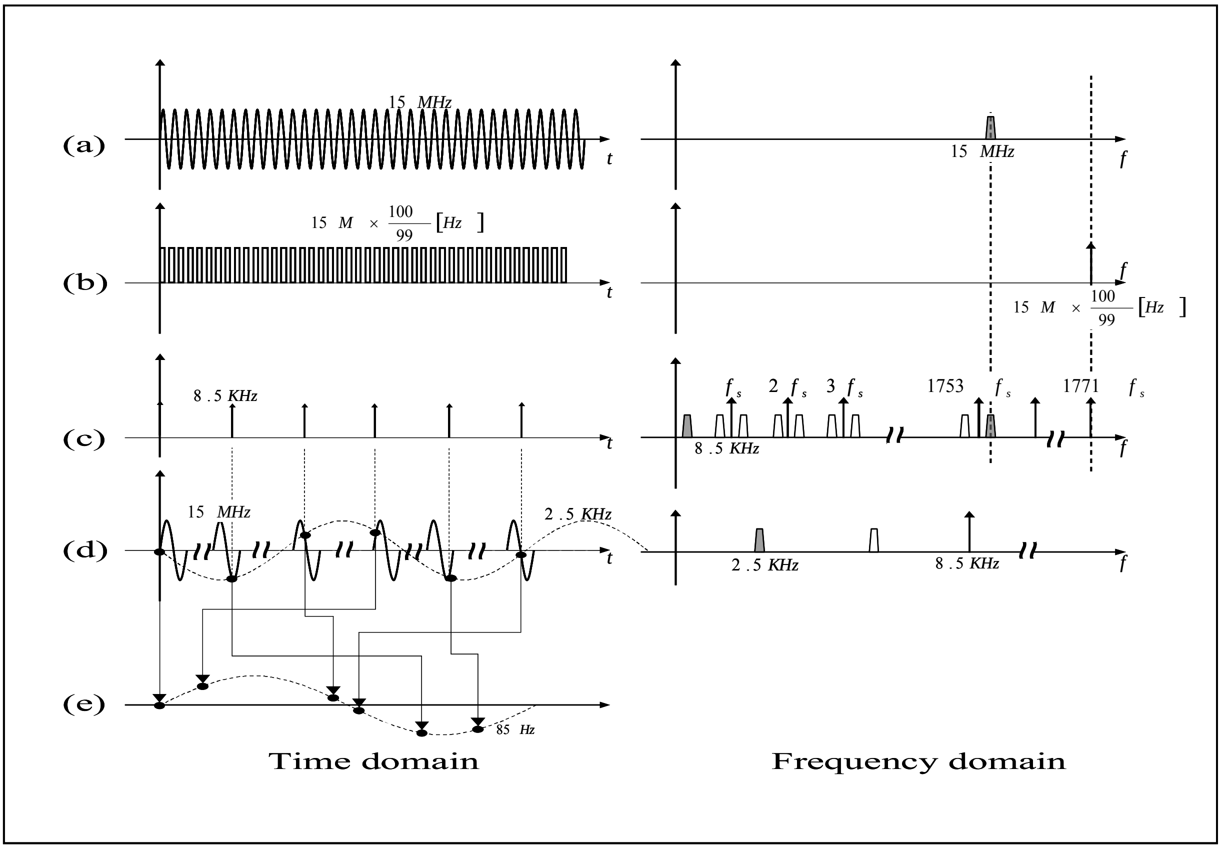

Fig.2 Process of undersampling in time and frequency domains ((a): Signal of band-pass-filtered TCXO, (b): Output signal of synthesizer, (c): Sampling clock, (d): Detail view of sampling, (e): Rearrangement of the sampling data of (d))

The reference frequency of 15 MHz is undersampled by the signals of repeated pulse light from the target.

Figure.2 shows the process of undersampling in time domain and in frequency domain. Sinusoidal wave in Fig.2 (a) shows band-pass-filtered TCXO signals. Figure 2(b) shows rectangular output signal of synthesizer. Frequency of this rectangular output signal is 100/99 times of TCXO.

Figure 2(c) shows sampling clock of 8.5 KHz which is generated from reception timings of light of repetition light pulses from the target. Figure 2(d) shows relationship between signal of band-pass-filtered TCXO of 15 MHz (a) and sampling clock of 8.5 KHz (c). The dot markers in Fig. 2(d) mean sampling time and the broken lines mean frequencies obtained by undersampling. The sampled data in Fig. 2(c) are rearranged in order of phase shifts as shown in Fig. 2(e) where the frequencies correspond to low frequencies of 85 Hz.

A process of calculating the distance is as follows. A phase between the low frequency sinusoidal wave for rearranged sample data and that of the internal reference signal in the rangefinder corresponds to the desired distance. A period of the low frequency is equal to 10 m as derived by the following equation:

$$L = \frac{1}{2} C \frac{1}{f_{TCXO}} = 10[m] \qquad (1)$$

Here L is the distance, C is the velocity of light, f_{TCXO} is the frequency of the reference frequency. The distance D to the target can be expressed as,

$$\theta_{ext} = \tan^{-1} \frac{\sum_{k=1}^{100} f_{ext}(k) \cos\left(\frac{2\pi}{100} \times k\right)}{\sum_{k=1}^{100} f_{ext}(k) \sin\left(\frac{2\pi}{100} \times k\right)} \qquad (2)$$

$$\theta_{ref} = \tan^{-1} \frac{\sum_{k=1}^{100} f_{ref}(k) \cos\left(\frac{2\pi}{100} \times k\right)}{\sum_{k=1}^{100} f_{ref}(k) \sin\left(\frac{2\pi}{100} \times k\right)} \qquad (3)$$

$$D = \frac{\theta_{ext} - \theta_{ref}}{2\pi} \times 10[m] \qquad (4)$$

For the distance larger than 10 m the time difference between the pulse emission time and the received pulse time is measured by counting the clock pulses of the TCXO, and then the distance can be obtained by adding the distances from time difference and D value of Eq. (4).

3. RESULT

Figure 3 shows the measured results of undersampling. Figure 3(a) shows time-series data of 100 samples. Figure 3(b) shows first 10 data of 100 undersampling points and where the broken line is a regenerated frequency of 2.5 KHz in the base-band region obtained by undersampling.

Figure 4 shows reproduced sampling results for a period of the low frequency by rearranging the data in the order of phase shifts (by using 100 samples of Fig. 3(a)). It is confirmed that band-pass-filtered TCXO signal is regenerated into the low frequency of 85 Hz with 100 data.

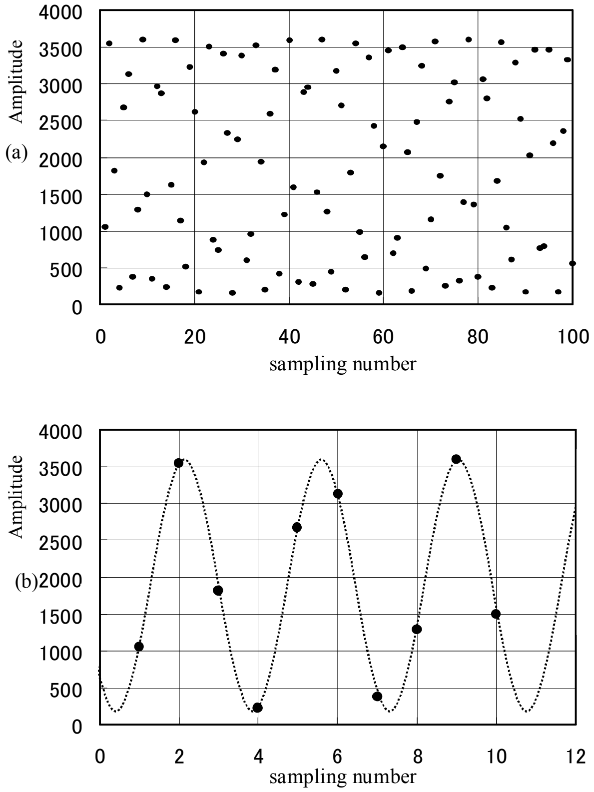

Fig.3 Results of undersampling ((a): Time-series data of 100 samples, (b): Result of undersampling in first 10 data).

To measure undersampling process stability, a pseudo-rangefinder was conducted in a circuit system. Output of the divider was directly connected to A/D converter in shown Fig. 1 so as to use it as a trigger for the A/D converter. Figure 5 shows the stability of pseudo-rangefinder. It is clarified that undersampling process shows good stability and its standard deviation of error is σ=0.3 mm (it corresponds 2 ps). It is considered that the residual error comes from the synthesizer instability.

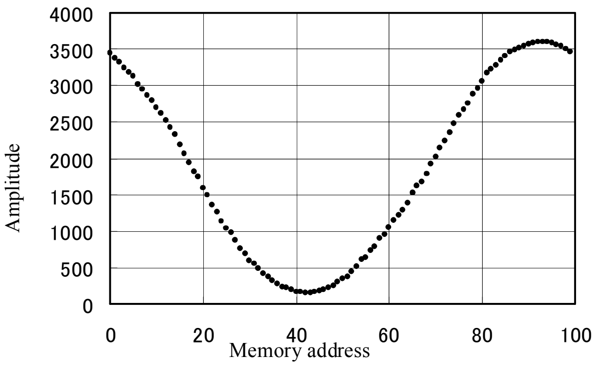

Fig.4 Reproduced sampling results for a period of the low frequency by rearranging the data in order of the phase shifts

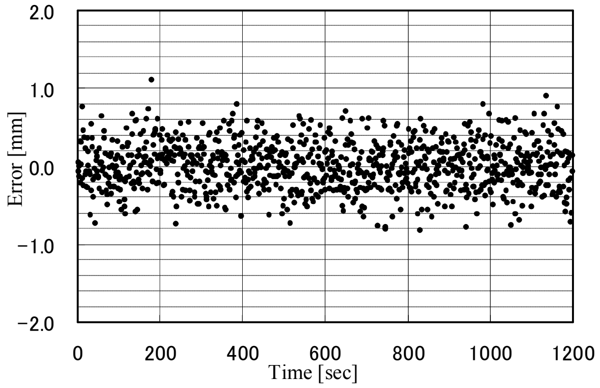

Fig.5 Stability of the undersampling process circuit

Figure 6 shows nonlinearity of developed rangefinder. Measured distances were varied from 1 m to 45 m. And measured results were compared with a commercially-sold laser interferometer. It is evident that nonlinearity and resolution are better than ±1mm and 1mm, respectively.

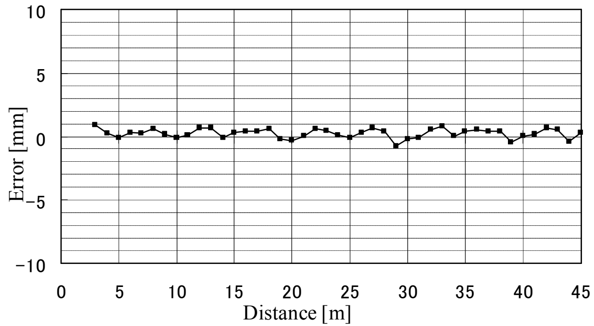

Figure 6 Nonlinearity of the rangefinder

4. CONCLUSION

A high resolution and high precision rangefinder by using pulsed laser has been developed by introducing high-resolution interpolation technique that is based on undersampling method. To obtain good measurement accuracy and resolution, low frequency of 85 Hz is generated from a reference frequency signal of 15 MHz by undersampling at timing of received repetition pulses from the target.

As a result, ±1 mm nonlinearity and 1 mm measurement resolution have been attained. Some improvements are still needed such as reductions in shot noise of APD, thermal noise of amplifier, and in jitter of pulse emission that can result in better performances.

This technology is incorporated into a commercially-sold rangefinder (Pulse Total Station GPT series). This pulsed laser rangefinder can measure up to 7000 m, and has been routinely used in worldwide surveying applications.

ACKOWLIGEMENTS

The authors would like to thank Dr. T. Tojo of Topcon for advice, fruitful discussion and encouragement throughout this work.

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