Compact and Versatile Range-Finding Speedometer with Wide Dynamic Range

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Abstract A new laser diode range-finding speedometer is proposed, which is modulated by a pair of positive and negative triangular pulse current superimposed on a dc current. Since a target velocity is directly obtained form a pure Doppler beat frequency measured during the non-modulation period, the new sensor is free from the difficulties due to the critical velocity encountered in the previous sensor. Furthermore, the different amplitude of the two triangular pluses are so adjusted that the measurable range using only one laser head is greatly expanded to 10cm through 150cm, which is about two times that of the previous sensor. The measurement accuracy for velocity of ± 6mm/s through ± 20mm/s and for range is about 1%, and 2%, respectively. Because the new sensor can be operated automatically using a microcomputer, it will be useful for application of a 3-D range image measurement of a slowly moving object.

Keyword Sensor, Laser Diode, Self-mixing, Doppler beat, Mode-hop, Range-Finding Speedometer, Positive-Negative Triangular Pulse, 3-D range image

1. INTRODUCTION

A compact and versatile range-finding speedometer using a self-mixing laser diode (SM-LD) has been proposed and investigated by the authors[1]-[2]. We can simultaneously obtain the distance and the velocity of a moving target by measuring the mode-hop frequency of the mode-hop signal, which is produced by the mode hop of the external resonator consisting of the SM-LD and the moving target. Since the SM-LD was FM-modulated by a continous triangular wave current, there was a critical velocity dependent on the range. So, it was impossible to measure a target moving at a velocity near the critical volocity. Although the influence of the critical velocity can be removed by modulation with a triangular pulse current[2], the measurable range of the distance was restricted.

In this paper, a new range-finding speedometer is proposed, which is modulated by a pair of positive and negative triangular pulse current superimposed on a dc current. The positive pulse with a higher amplitude is suitable for measurement of a shorter distance, while the negative pulse with a smaller amplitude for a longer distance. Therefore, the measurable distance using only one laser head will be greatly expanded provided that the different amplitude of the two triangular pulses is properly adjusted. Since a target velocity is directly obtained from a pure Doppler beat frequency measured during the non-modulation period, the new sensor is also free from the difficulties due to the critical velocity.

A good measurement accuracy 1% and 2% for a wide range of both distance and velocity, respectively, could be obtained.

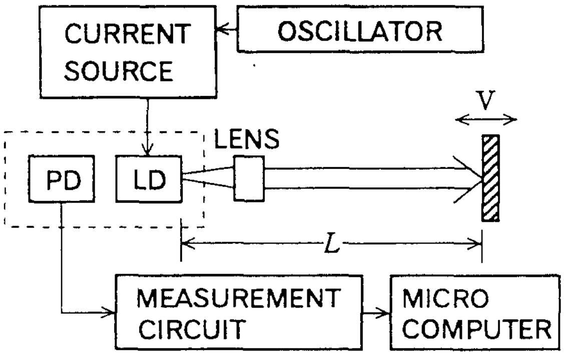

Fig.1 Schematic configuration of a range-finding speedometer.

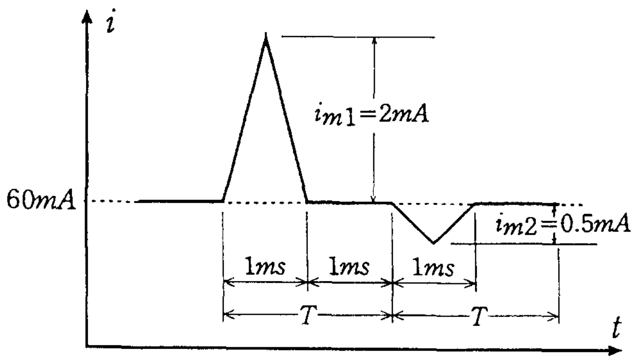

Fig.2 Modulation current waveform.

2.PRINCIPLE

2.1 Configuration of Range-Finding Speedometer

Figure 1 shows a schematic configuration of a new range-finding speedometer with a new modulation current source. The target carrying a sheet of white paper is translated back and forth by a linear rotary unit. The optical output of a laser diode (LD) is frequency modulated by a pair of positive and negative triangular pulse current superimposed on a dc current. The new modulation current waveform is shown in Fig.2.

2.2 Beat Signal and Signal Processing

The beat signal obtained from a photodiode (PD) cosists of three parts. The first part is a Doppler signal observed during the non-modulation period, the second and the third is a pseudo Doppler signal superimposed on the positive or the negative triangular pulse. The Doppler signal is purely due to the Doppler effect and it depends only on the target velocity except the light wavelength. While the frequency of the pseudo Doppler signal depends on both the target velocity and the distance to the target.

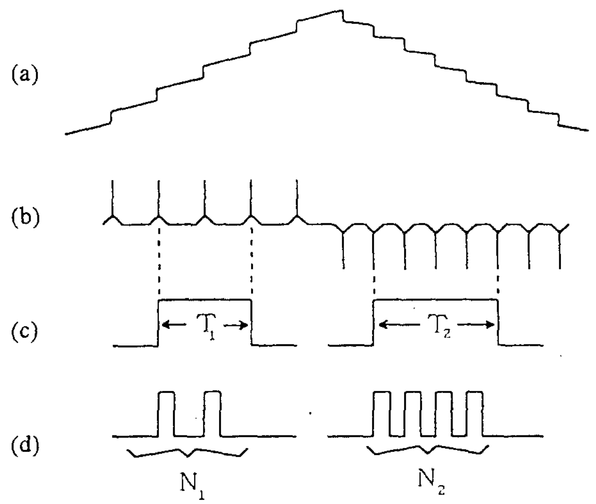

Fig.3 The pseudo Doppler signal waveform and some other signals observed at each point of the measurement circuit
(a) Output from PD
(b) Output from HPF
(c) Output from gate circuit
(d) Output from synchronous circuit

Figure 3(a) shows the pseudo Doppler signal, which is obtained from the PD during the positive triangular pulse. The output signal from the PD is produced by the optical power change due to the mode hop. The mode hop is caused by the self-mixing effect in the LD resonator, which occurs between the backscattered light from the target and the original light in the LD. The output signal (a) in Fig.3 is fed to a highpass filter, and the mode-hop pulse train (b) is produced. The pulse train is fed through a gate circuit with duration time T1 and T2, and the reshaped pulse train (d) is obtained from a synchronous cricuit. The reshaped pulse train for the negative triangular pulse is also obtained in the same manner, and which is counted and processed by a microcomputer, and the range and the velocity are calculated.

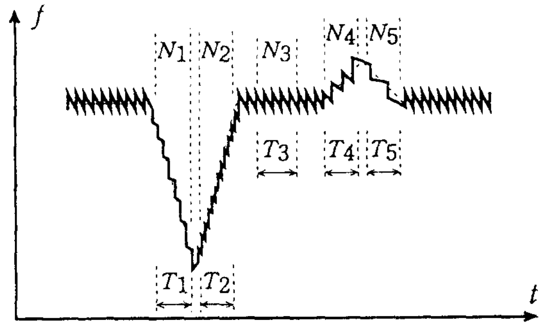

Fig.4 Optical frequency waveform of emitted laser light. (In case of departing target, i.e. V>0.)

2.3 Theoretical Equations

Figure 4 shows an optical frequency waveform of an emitted light from the laser diode when the LD is modulated by the new modulation current. When the Dopper beat number is N_3 in a duration time T_3, the Doppler beat frequency is N_3/T_3. So, the target velocity is given by

$$|V| = \frac{\lambda}{2} \times \frac{N_3}{T_3} \tag{1}$$

When the distance is shorter than 90cm, we employ the modulation current i_{m1} (the high amplitude triangular wave). At positive velocity when the target is moving away from LD, the pseudo Doppler beat frequency N_2/T_2 during the rising period is always greater than the pseudo Doppler beat frequency N_1/T_1 during the falling period. The beat frequency due to only distance is given by (N_2/T_2) - (N_3/T_3), which is independent of the critical velocity. Therefore, the range to the target is given by

$$L = \frac{cT}{4\Delta F_e i_{m1}}\left(\frac{N_2}{T_2} - \frac{N_3}{T_3}\right) = \frac{cT}{4\Delta F_e i_{m1}}\left(\frac{N_2}{T_2} - \frac{2|V|}{\lambda}\right) \tag{2}$$

for the case of $V \geqq 0$ and $L \leqq 90$cm.

Where c is the speed of light, T the half period of the modulation current waveform, ΔF_e the FM modulation efficiency (the change of frequency per unit current), i_m the hight of triangular pulse modulation current.

When the distance is longer than 90cm, we use the modulation current i_{m2} (the small amplitude triangular wave). The range to the target is given by

$$L = \frac{cT}{4\Delta F_e i_{m2}}\left(\frac{N_4}{T_4} - \frac{N_3}{T_3}\right) = \frac{cT}{4\Delta F_e i_{m2}}\left(\frac{N_4}{T_4} - \frac{2|V|}{\lambda}\right) \tag{3}$$

for the case of $V \geqq 0$ and $L \geqq 90$cm.

In case of negative velocity when the target is approaching LD, the pseudo Doppler beat frequency N_1/T_1 during the falling period is always greater than the pseudo Doppler beat frequency N_2/T_2 during the rising period. Then the beat frequency due to only distance is given by (N_1/T_1) - (N_3/T_3) or by (N_5/T_5) - (N_3/T_3).

Therefore, the range is given by

$$L = \frac{cT}{4\Delta F_e i_{m1}}\left(\frac{N_1}{T_1} - \frac{N_3}{T_3}\right) = \frac{cT}{4\Delta F_e i_{m1}}\left(\frac{N_1}{T_1} - \frac{2|V|}{\lambda}\right) \qquad (4)$$

for the case of $V \leqq 0$ and $L \leqq 90$cm, and

$$L = \frac{cT}{4\Delta F_e i_{m2}}\left(\frac{N_5}{T_5} - \frac{N_3}{T_3}\right) = \frac{cT}{4\Delta F_e i_{m2}}\left(\frac{N_5}{T_5} - \frac{2|V|}{\lambda}\right) \qquad (5)$$

for the case of $V \leqq 0$ and $L \geqq 90$cm.

The positive or negative velocity can be identified by comparing N_1/T_1 to N_2/T_2.

When $N_1/T_1 \leqq N_2/T_2$, the velocity is identified positive, $V \geqq 0$, that is the target is moving away from the LD.

When $N_1/T1 \geqq N_2/T_2$, it results in $V \leqq 0$, that is the target is approaching LD.

Figure 5 shows the relationships between range and mode-hop frequency when the target is standing at various modulation current. The 2mA current is suitable for measurement of a shorter distance, while the 0.5mA current for a longer distance.

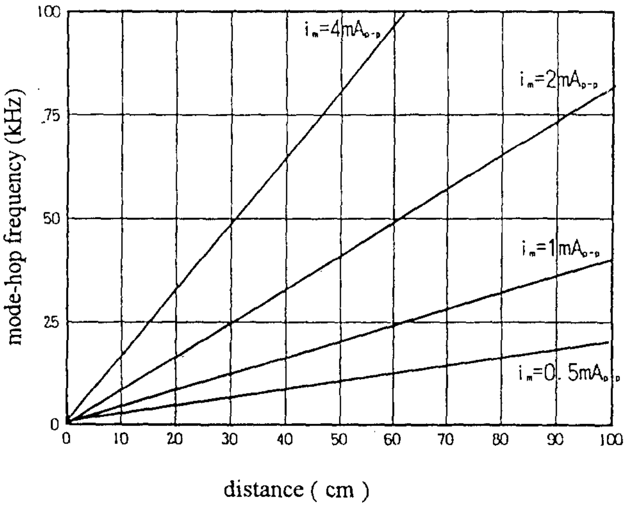

Fig.5 Relationships between range and mode-hop frequency when the target is standing at various modulation current.

3. MEASUREMENT RESULTS

The laser diode (LD) used in the measurement is an AlGaAs Type (Sharp LT021MF) with wavelength λ = 780 nm and the maximum output power 10mw. The LD is temperature stabilized, and its output power is 4.3mW at i=60mA.

3.1 Measured Range Error for Standing Target

When V=0, the error of distance measurement is indicated by normalized standard deviation as shown in Fig.6. We can measure the distance from 10cm to 150cm with error within 1%. When the distance gets longer, the obtained signal of mode-hop becomes smaller, so the error becomes larger by the influence of the nosie. Moreover, because at a short distance of 10cm, the number of mode-hop in the duration gate time becomes less, the error becomes larger.

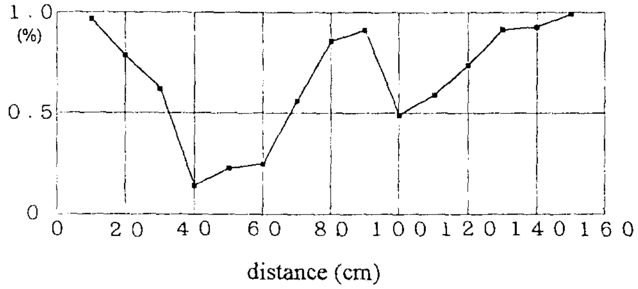

Fig.6 Measured range error versus range when the target is standing.

3.2 Measured Error of Range and Velocity for Moving Target

Velocity errors measured when the target is moving away from the LD at a various constant velocity is shown in Fig.7. And range errors measured under the similar condition is shown in Fig.8. When the target is approaching LD, the measured error of velocity and range are shown in Fig.9 and Fig.10, respectively. Measured range error was within 1% for velocities ± 6mm/s – ± 20mm/s, and mesared velocity error was within 2% for various constant speed.

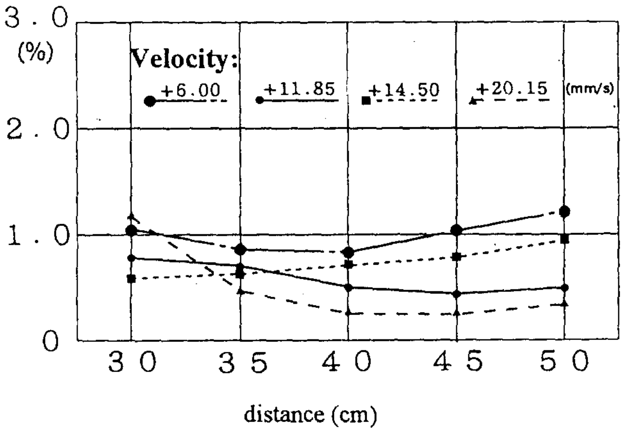

Fig.7 Measured velocity errors versus range when the target is moving away from LD at a various constant velocity. (V>0)

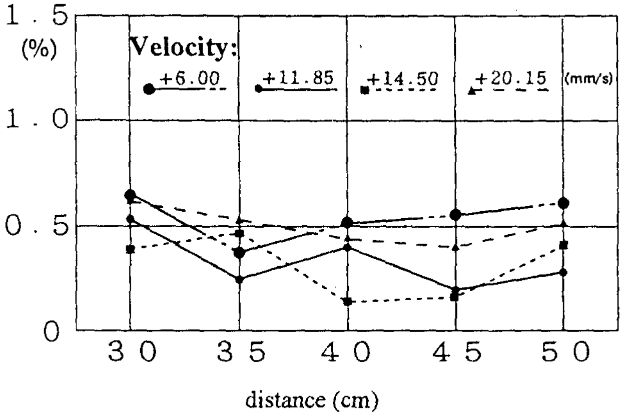

Fig.8 Measured distance errors versus range when the target is moving away from LD at a various constant velocity. (V>0)

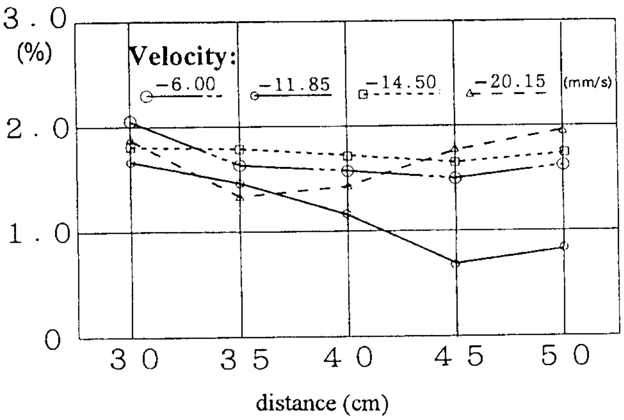

Fig.9 Measured velocity errors versus range when the target is approaching LD at a various constant velocity.(V<0)

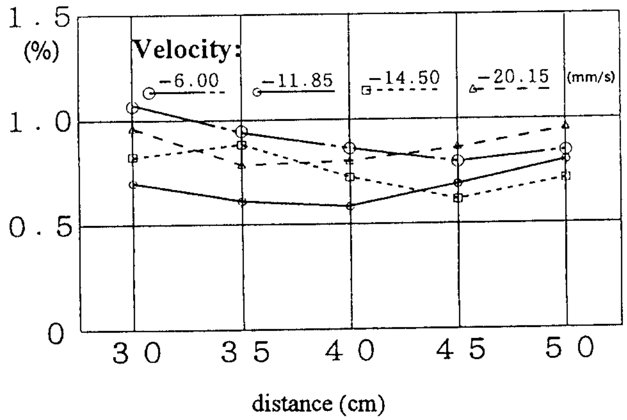

Fig.10 Measured distance errors versus range when the target is approaching LD at a various constant velocity. (V<0)

4.CONCLUSION

The proposed new range-finding speedometer employing a pair of positive and negative triangular pulse current modulation has been found to free from the difficulties due to the critical velocity, and to have a good measurement accuracy 1% and 2% for a wide range of both distance and velocity, respectively.

We need to solve the problem of noise to improve the performance of the range-finding speedometer.

Because the sensor can be operated automatically without regarding to the velocity direction and the distance by the use of a microcomputer, it will be useful for application of a 3-D range image measurement of a slowly moving object.

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