'92 KACC 1992. 10. 19~21

# IMPROVEMENT OF SELF-MIXING SEMICONDUCTOR LASER RANGE FINDER AND ITS APPLICATION TO RANGE-IMAGE RECOGNITION OF SLOWLY MOVING OBJECT

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## ABSTRACT

An infrared range finder using a self-mixing laser diode (SM-LD), which has been proposed and developed by the authors, can measure not only a range of a moving target but its velocity simultaneously. In this paper, described is that the precise mode-hop pulse train can be obtained by employing a new signal processing circuit even when the backscattered light returning into the SM-LD is much more weaker. As a result, the distance to a tilted square sheet made from aluminium or white paper, which is placed 10 cm through 60 cm from the SM-LD, is measured with accuracy of a few percent even when the tilting angle is less than 75 degrees or 85 degrees, respectively.

And in this paper, described is the range-image recognition of a plane object under the condition of stand-still. The output laser beam is scanned by scanning two plane mirrors equipped with each stepping motor. And we succeeded in the acquisition of the range-image of a plane object in a few tens of seconds. Furthermore, described is a feasibility study about the range-image recognition of a slowly moving plane object.

## 1.INTRODUCTION

A new self-mixing type semiconductor laser range finder has been developed, which measures simultaneously a distance to a moving object and its velocity.(1),(2) In the range measurement hitherto, the plane surface of a target under measurement was set vertically to the light beam. And the maximum measurable range was limited to about 1m, because the signal processing circuit did not have a sufficient sensitivity.

In this paper, we devised a new signal processing circuit which enables us to obtain a precise mode-hop pulse train even when the target surface is tilted against the beam axis about 80 degrees, or when the target is placed as far as 2.5 m ahead of the laser.

On the basis of the above-mentioned results, we discuss a feasibility study about the range-image recognition of a slowly moving plane object. The laser output beam is scanned in 2-dimensional plane by scanning two plane mirrors equipped with each stepping motor. As a first step of research, a contour line of a plane target under the condition of standstill is measured successfully in a few tens of seconds.

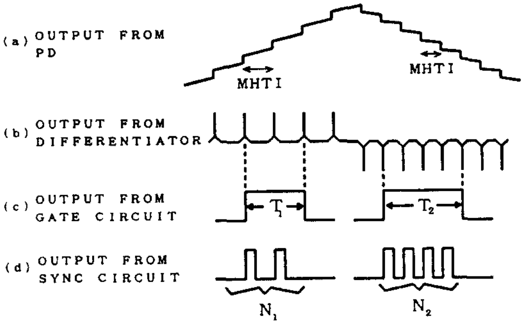


Fig.2 Principle and measurement method of range and velocity.

## 2. RANGE MEASUREMENT

Figure 1 shows schematic configuration of experimental setup for a range finder. The light back-scattered from the target into the laser diode (LD) causes external cavity mode hops, which produce some successive discontinuities in the output light. The LD is modulated by a triangular wave current, and the target is translated by a linear rotary unit.

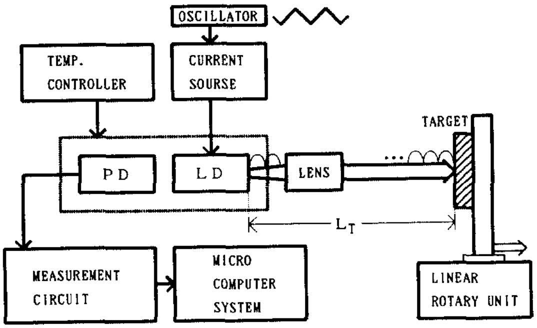


Fig.1 Schematic configuration of experimental setup for a range finder.

Figure 2 shows the photodiode (PD) output signal and the other signals obtained during the process in the measuring circuit. The principle and method of range measurement are summarized as follows. The output signal (a) from PD is differentiated by a high pass filter (HPF), or a new differentiator (DIF) to give the mode hop pulse train (b). The pair of measuring gate pulses have widths of $T_1$ and $T_2$, which are counted using a clock. The number of the mode hop time interval (MHTI) $N_1$ and $N_2$ are counted. Then the distance $L_T$ to the target and the velocity $V_T$ are given by the equations (1)-(3),

$$1/T_M=(N_1/T_1+N_2/T_2)/2 \qquad (1)$$

$$L_T=cT/(4\Delta F i_m T_M) \qquad (2)$$

$$V_T=\lambda(N_2/T_2-N_1/T_1)/4 \qquad (3)$$

where $T_M$ is the mean value of the $N_1+N_2$ mode hop intervals, c the light velocity, T the period of the triangular wave, $\Delta F$ the effective frequency modulation efficiency, $i_m$ the peak-to-peak amplitude of the modulation current and $\lambda$ the light wavelength.

When the previous signal processing circuit was used, some of the pulses in the mode hop pulse train (b) sometimes dropped out because the step height in the PD output signal became inadequate in case that the backscattered light was very weak.

Figure 3 shows a block diagram of a

new differentiator (DIF) circuit with enhanced sensitivity. With this new DIF circuit, the amplified PD output signal is subtracted by the modulation triangular signal, and after passing through an HPF and a comparator it becomes a precise mode hop pulse train even when the backscattered light is much more weak.

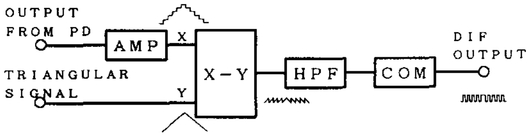


Fig.3 Block diagram of a new differentiator (DIF) circuit with enhanced sensitivity.

Figure 4 shows the maximum inclination angle of a square sheet object as a function of range. When the inclination angle is adjusted less than the maximum the precise mode hop pulse train can be obtained using the new circuit or the previous circuit. With the new circuit, the maximum inclination angle reaches 85 degrees and 75 degrees for the object made from white paper and aluminium sheet, respectively.

Figure 5 shows the measured range and its error versus range when the new circuit is used. The maximum measurable range is extended to 2.5 m with accuracy 1.2 %.

## 3. RANGE-IMAGE RECOGNITION

Figure 6 shows the schematic configuration of a laser beam scanner. The laser beam is scanned in 2-dimensional plane by scanning two plane mirrors, which are controlled by each stepping motor.

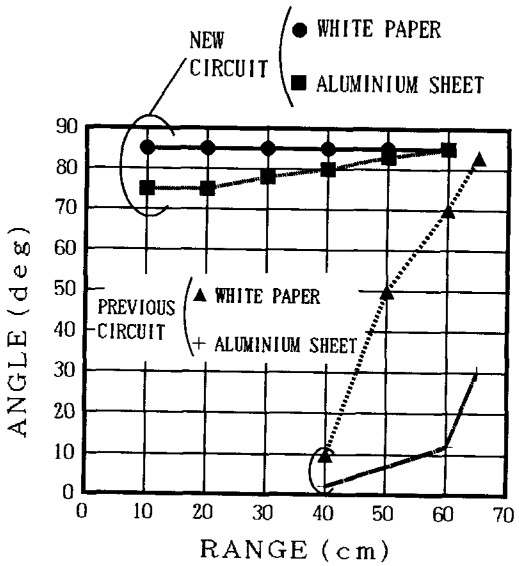


Fig.4 Maximum inclination angle of a square sheet object as a function of range. When the inclination angle is adjusted less than the maximum the precise range can be obtained.

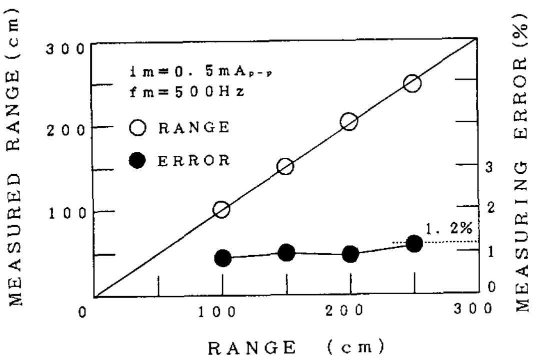


Fig.5 Measured range and its error versus range when the new circuit is used.

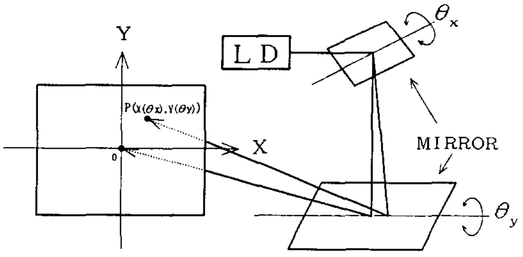


Fig.6 Schematic configuration of a laser beam scanner.

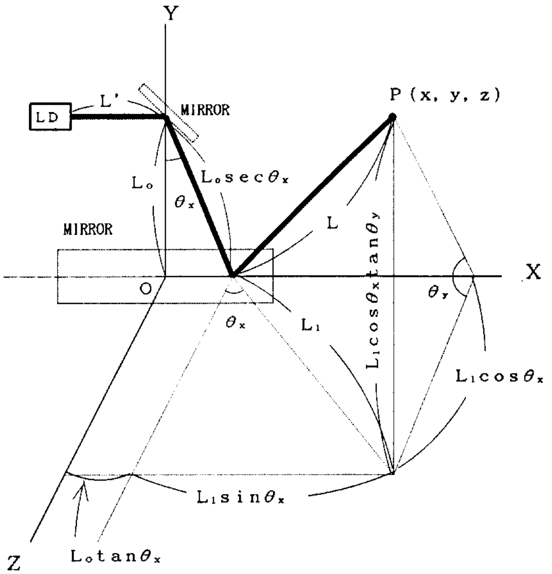


Fig.7 Geometrical arrangement of a range-image measurement system.

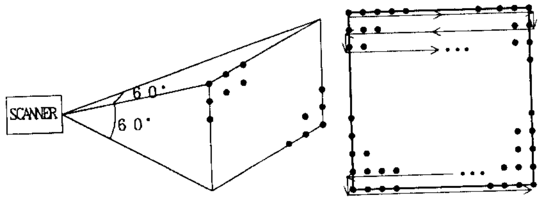
Figure 7 shows a geometrical arrangement of the range-image measurement system. The coordinates of a reflecting point P(x,y,z) on the target are determined from the measured total length $L_T$ along the beam path and the known angles of $\theta_x$ and $\theta_y$. The coordinates x, y and z are given as follows;

$$L_1=(L_T-L'-L_0\sec\theta_x)/(1+\cos^2\theta_x\tan^2\theta_y)^{1/2} \quad (4)$$

$$x=L_0\tan\theta_x+L_1\sin\theta_x \quad (5)$$

$$y=L_1\cos\theta_x\tan\theta_y \quad (6)$$

$$z=L_1\cos\theta_x \quad (7)$$



(a) Scanning Area (b) Scanning Sequence

Fig.8 Scanning area and scanning sequence for obtaining range-image data.

The 3-D velocity vector $\mathbf{V}=(V_x,V_y,V_z)$ of the target moving along a straight line can be determined from the optical axis components of three vector velocities $\mathbf{V}_p$, $\mathbf{V}_q$ and $\mathbf{V}_r$ measured at three independent points on the target surface. The relation between $\mathbf{V}_p$, $\mathbf{V}_q$, $\mathbf{V}_r$ and $\mathbf{V}$ are given as follows;

$$\mathbf{V}_p=(V_{px},V_{py},V_{pz})$$
$$=V_T(\mathbf{r}(x,y,z)-\mathbf{r}(L_0\tan\theta_x,0,0))/L \quad (8)$$

$$\mathbf{V}_q=(V_{qx},V_{qy},V_{qz}) \quad (9)$$

$$\mathbf{V}_r=(V_{rx},V_{ry},V_{rz}) \quad (10)$$

$$\begin{pmatrix} V_{px} & V_{py} & V_{pz} \\ V_{qx} & V_{qy} & V_{qz} \\ V_{rx} & V_{ry} & V_{rz} \end{pmatrix}\begin{pmatrix} V_x \\ V_y \\ V_z \end{pmatrix}=\begin{pmatrix} V_{px}^2+V_{py}^2+V_{pz}^2 \\ V_{qx}^2+V_{qy}^2+V_{qz}^2 \\ V_{rx}^2+V_{ry}^2+V_{rz}^2 \end{pmatrix} \quad (11)$$

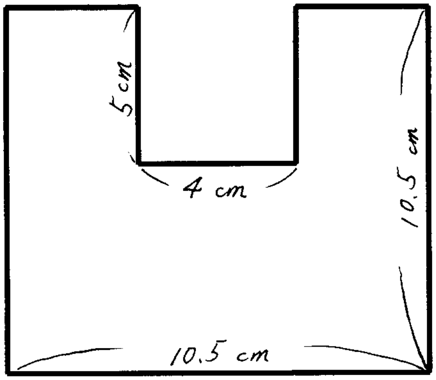
Figure 8 shows a feasible scanning area and scanning sequence for obtaining range-image data. Feasible scanning angles along X or Y axes are 60 degrees. Although it takes about 1 second to simply sweep the scanning area without pauses, and 2 more seconds to calculate each range of 16 x 16 points in the scanning area, obtaining 16 x 16 range data by the actual intermittent scanning requires at least total of 12 seconds. By cooperating the laser range finder with the laser scanner we can obtain a contour line of a tilted plate moving slowly along a straight line in a few tens of seconds.

## 4. ACQUISITION OF RANGE-IMAGE DATA

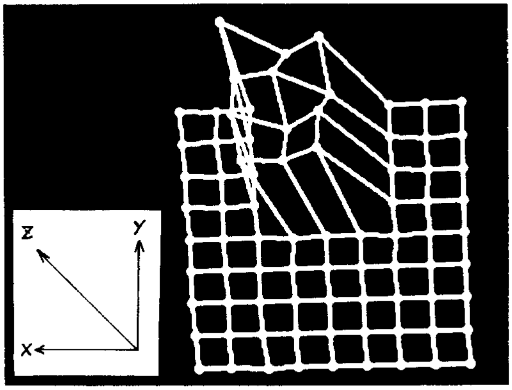
As a first step of range image recognition, we measured a white plane paper target, which is set nearly vertically to the light beam under the condition of standstill. Figure 9(a) shows the target which is measured by the proposed system, and Fig. 9(b) shows a measured range image represented on a CRT. To simplify the signal processing, the light beam was scanned only to just cover the square target plane of 10.5cm x 10.5cm, where the x and y scanning angle was 17.3 and 17.3 degrees, respectively. The diameter of the beam focussed onto the target was about 1 mm.

The measured range of each point is shown as a range difference from the target plane (z=30cm), which is selected as the reference.

Each of the measured points behind the reference plane is plotted as a tip point of an arrow drawn from the lattice point on the reference plane. The length of the arrow is proportional to the depth, which is the positive distance from the reference plane along z-axis. The direction of the arrow is parallel with a z-axis shown in Fig.9(b). The measured points in the eliminated part of the target are about 30cm behind the reference plane. This is because many pseudo mode hop pulses were produced at the output of the new differentiator due to random noise, despite that the eliminated part is not illuminated by the laser beam. And the all measurement needed 25 seconds including display time.



(a) FIGURE OF TARGET



(b) MEASUREMENT RESULT

Fig.9 Figure of target (white plane paper) and measured range image represented on CRT.

In order to evaluate measurement accuracy, we measured Z values at 11 x 11 points of another white plane paper target which is settled at Z=30cm plane. Figure 10 shows experimental results of standard deviation of Z values versus the number of averaging times. The horizontal axis represents the number of averaging times of measurement at 1 point, while the vertical axis represents the standard deviation calculated from all Z values at 11 x 11 points of the plane target. The parameter represents the delay time, which is defined as the time interval between a pause of the stepping motor and restart of range measurement. The delay time is needed to avoid settling time of the stepping motor. As seen from Fig.10 the standard deviation of multi Z values is small and reduces rapidly with increase of the number of averaging times when the delay times is programed less than 140ms. Therefore, the settling time is assumed about 140ms. The standard deviation approaches to $1.2\times10^{-3}$m when the n is increased to more than several tens. This is a final value, which is probably caused by the target that is not held completely perpendicular to primary light axis. If measurements need sufficient accuracy, the delay time and the number of averaging times should be chosen 140ms and 10 times, respectively.

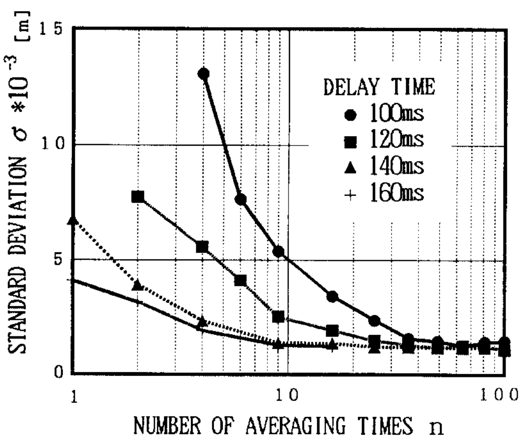


Fig.10 Experimental results of standard deviation of Z values vs. number of averaging times.

## 5. CONCLUSION

The sensitivity of the self-mixing type laser range finder has been greatly improved by employing a new differentiator circuit. The improved range finder enables one to measure precisely a distance to a plane target which is tilted against the beam axis about 80 degrees. By cooperating the improved range finder with the laser scanner using two plane mirrors, measurement in 25 seconds of a range-image of an object under the condition of standstill is successfully performed.

In case of employing the stepping motor at present, the upper limit velocity of the moving target will be a few mm/s. However, if we adopt a continuously driven laser scanner and adaptive signal processing method the time required to measure a range-image will be greatly reduced.

## REFERENCES

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(2) S.Shinohara et al.: "Compact and High-Precision Range Finder with Wide Dynamic Range and Its Application", IEEE Trans. on Instrumentation and Measurement, 41, 1,pp.40-44, Feb., 1992.