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To Improve the Accuracy of Laser Pulse Range Finding by Time Scale-Up

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Abstract: A method of improving the accuracy of laser pulse range finding from ±10 m to ±1 m inexpensively by means of time scale-up is described. Time scale-up can stretch the entire flight time by a factor of 1 000 and then the stretched result is counted to calculate the distance. The use of this technique decreases the resolution of counting from nanosecond to microsecond, therefore a separate counting oscillator followed by an interpolation operation is unnecessary. This technique can improve the accuracy of laser pulse range finding inexpensively and effectively.

Key words: time scale-up; range finding; capacitor; charging and discharging
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Laser based distance and range measuring equipments have been used for a number of years to provide extremely accurate distance measurements for a remote target or object. For a highly accurate and reliable device, its great distance ranging capability and inherent complexity are translated into a cost and form factor most suitable only for certain specific applications. Perhaps there is a need for a laser based range finder of more limited range, which can be economically manufactured as a rugged, compact unit to provide accurate distance measurement capabilities in other less stringent types of applications.

Laser pulse range finding systems measure the distance by counting the flight time of laser pulse, i.e.

$$d = \frac{1}{2}ct = \frac{1}{2}cn\frac{1}{f}, \qquad (1)$$

where d is the distance that is measured, c is the velocity of light, t is the flight time, n is the number of timing signals counted by timer during the flight time and f is the frequency of the oscillator.

Normal timer and oscillator with a 30 MHz frequency can be used when the resolution of measurement is not high (±5 m or ±10 m). However, if the resolution is ±1 m, it is concluded from Eq. (1) that

$$\Delta d = \frac{1}{2}c\Delta t = \frac{1}{2}c\frac{1}{f}\Delta n. \qquad (2)$$

If the counting error Δn is ±1, the resolution of the timer must not be less than 6.67 ns and the frequency of the oscillator must not be less than 150 MHz[1]. Not only is it difficult to design such a reliable oscillator and timer with so high an operating frequency, but also the cost is too high to design them. A method therefore is described herein to resolve the problem disclosed above.

1 Time Scale-Up

1.1 Principle of Time Scale-Up

Time scale-up is to amplify the flight time proportionally, we have

$$d = \frac{1}{2}ct = \frac{1}{2}c\frac{T}{M} = \frac{1}{2}c\frac{1}{Mf}n, \qquad (3)$$

where M is the amplification of the flight time, i.e. $M = T/t$. As stated above,

$$\Delta d = \frac{1}{2}c\frac{1}{Mf}\Delta n, \qquad (4)$$

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if Δn is ± 1, and Δd is ± 1 m, the operating frequencies f are reduced to $150/M$ MHz. If the amplification M is 1 000, f equals 150 kHz. Normal timers and oscillators can meet it.

As a component used to store energy (Fig. 1), the capacitor C is charged when the K_1 is on and the K_2 is off. The longer the capacitor is charged, the higher the voltage on its positive plate. And the capacitor is discharged when the K_1 is off and the K_2 is on. The discharging time is the time T counted by the timer.

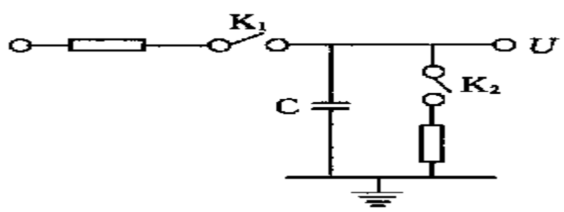

Fig. 1 The principle of time scale-up

Shown in Fig. 2 are three curves of the capacitor at different charging times. Corresponding to these charging times, t_1, t_2 and t_3, the discharging times are T_1, T_2 and T_3 respectively. The capacitor is charged with a relatively large current, and then discharged with a small current applied over the entire flight time. The entire flight time is essentially stretched by a factor of 1 000 and then the stretched result is counted. By charging the capacitor at a fast rate and discharging at a slow rate, the flight time is expanded so that a slower timer can count it accurately[2].

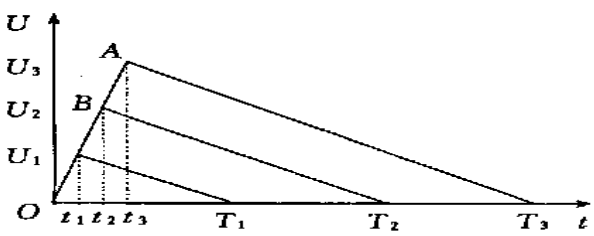

Fig. 2 Curves of charging and discharging

1.2 Linearity of Charging and Discharging

In order to keep a constant amplification corresponding to different charging times, the capacitor must be charged and discharged linearly or approximately linearly. But the capacitor in Fig. 1 is charged and discharged according to exponential law, therefore, we can only cope with the charging and discharging as linear ones under a certain condition.

The charging voltage and the discharging voltage on the positive plate of the capacitor are given by

$$U_c = \frac{1}{C}\int I \mathrm{d} t, \tag{5}$$

$$U_c' = U_c - \frac{1}{C}\int I' \mathrm{d} T, \tag{6}$$

where I and I' are the charging current and the discharging current respectively. If I and I' are constants, Eqs. (5) (6) can be simplified to $U_c = It/C$ and $U_c' = U_c - I'T/C$. Two transistors working in the amplification region can be used as these two constant current sources[3].

1.3 Calculation of the Amplification of Discharging Time

It is obvious that the slope of charging curve is $k = U_c/t = I/C$; and the slope of discharging curve is $k' = (U_c' - U_c)/T = -I'/C$. On the assumption that the original voltage on the positive plate of the capacitor is equal to the terminal discharging voltage and both are zero volts, we conclude from Eqs. (5) (6) that

$$\frac{T}{t} = \frac{0 - U_c}{U_c}\frac{k}{k'} = \frac{I}{I'}.$$

Thus, the amplification of the charging time is equal to the ratio between the charging current and discharging current actually. If I/I' is 1 000, then t is expanded 1 000 times and the resolution of the instrument is shrunk 1 000 times. The timer has a 1.5 ms resolution and, because the flight time has been expanded by a factor of 1 000 on the input side to the timing section, it is the equivalent of a 1.5 ns resolution, which corresponds to a measurement resolution 1 m for the laser range finding system.

1.4 Calculate the Distance

The curve of charging and discharging is OT_2B when the distance measured is d_1 and is OT_3A when the distance measured is d_2 (shown in Fig. 2). It is easy to demonstrate that

$$\frac{Ot_2}{Ot_3} = \frac{t_2T_2}{t_3T_3} \text{ and } d_2 = d_1\frac{t_3T_3}{t_2T_2}. \tag{7}$$

Then we can get d_2 according to Eq. (7) by calibrating d_1, t_2T_2 and measuring t_3T_3.

2 Actual Feasibility

All of the fixed errors can be deleted from the measurements, and only the random factors can affect the accuracy of the measurements. Therefore, we must choose the constant current sources with high stability during the designation. The parameters of the capacitor should keep stable, too. And it should have a good ability of charging and discharging and a small insulation current[4].

2.1 The Beginning of Charging Voltage and the End of Discharging Voltage

In fact, neither the original voltage nor the terminal voltage on the positive plate of the capacitor is zero. It can degrade the uncertain factors around the zero point. In addition, the original voltage of charging is not equal to the terminal voltage of discharging.

The capacitor has its negative plate grounded and its positive plate connected to the charging circuit and the discharging circuit as well as to the " + " terminal of a comparator. Under the reset condition the voltage at the top plate of the capacitor is clamped to a voltage V_1 equal to 1.0 V. A voltage V_2 equal to 0.9 V is defined as the voltage at the " - " input of the comparator. The capacitor is unclamped while the laser pulse is emitted, and the timer begins to count when the capacitor is charged. As the echo pulse is detected by the laser receiving diode, the charging circuit is off and the capacitor begins to discharge, because the discharging circuit is always on. When V_1 is discharged below V_2 and the comparator output changes state to turn off the timer.

2.2 Modification to the Formula for Calculating the Distance

Equation (7) is available only when the original voltage of charging equals the terminal voltage of discharging and both of them equal zero. But neither of these two conditions can be satisfied actually. Therefore, we must modify Eq. (7) as follows:

① There is still a discharging time T_0, when the measured distance is zero, i.e. the time it takes for capacitor to discharge from 1.0 V to 0.9 V.

② The time counted by the timer is $(T_0 + T)$ when the measured distance is not zero. The T can be used to calculate the measured distance through Eq. (7).

Consequently, we used the three discharging times as the original data to calculate the distance in the design.

T_0: The discharging time corresponding to the zero distance, or the zero calibration time.

T_c: The discharging time corresponding to the fixed distance, or the fixed pulse width calibration time.

T: The discharging time corresponding to the measured distance.

Hence, Eq. (7) can be modified as

$$D = d\,\frac{T - T_0}{T_c - T_0}, \tag{8}$$

where d is the distance when T equals T_c and D is the measured distance.

3 Results and Discussion

There are four charging and discharging curves in Fig. 3. It is apparent that the charging time is so short relative to the discharging time that it can be ignored. And the discharging curves are almost parallel. In addition, the higher the voltage, the longer the discharging time. Therefore, it is concluded that the time scale-up is available.

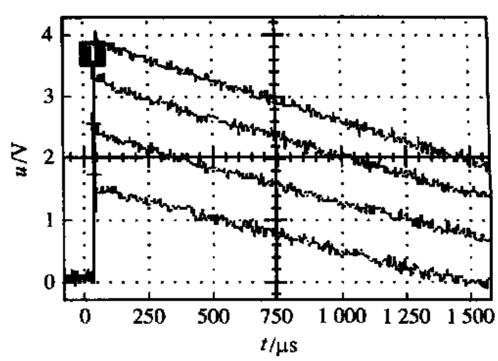

Fig. 3 Waveform of charging and discharging

In order to simulate the disturbance from the elements, we check the discharging time by using three transistors of the same model as discharging constant current sources. The results are shown in Tab. 1.

Tab. 1 Estimation for transistors of the same model in the discharging circuit

t/μs	T/μs		
	transistor 1	transistor 2	transistor 3
0	30.0	30.0	30.0
0.25	241.5	241.5	240.0
0.75	615.0	607.5	615.0
1.00	804.0	807.0	813.0
2.00	1 441.0	1 447.5	1 468.5
3.00	1 990.5	1 993.5	2 005.5
4.00	2 457.0	2 466.0	2 479.5
5.00	2 860.5	2 868.0	2 890.5
6.00	3 214.5	3 241.5	3 247.5
6.60	3 418.5	3 430.5	3 457.5

It is demonstrated that, firstly, as the charging time increases, the amplification of the discharging time decreases monotonically; secondly, the discharging time is almost stable corresponding to a certain transistors. Moreover, we also get the same conclusion when we use other kinds of transistors. Thus it can be seen that the amplification should be maintained by modifying the discharging time based on the zero calibration time T_0 and the fixed width pulse calibration time T_c. We also conclude from the experiment that the discharging times corresponding to the same kind of transistor differed not much. This is the prerequisite for modifying the discharging time.

4 Conclusion

Maintain the charging current at milliamp level and the discharging current at microamp level to make their ratio near 1 000. Choose a capacitor with good ability of charging and discharging. It may not be saturated when charged for 6.6 ms. Thus the resolution of the timer is reduced to microsecond level from nanosecond level. Thus we can transform a high resolution measurement into a low resolution measurement without changing the accuracy of the result. Therefore the resolution of instrument is reduced 1 000 times.

In the laser pulse range finding system, because of the unavoidable affection from the elements, it is necessary and accessible to build up a lookup table to modify the measured results.

As stated above, it may be inexpensively produced and provides highly accurate range measurements of up to 1 000 m or more with a resolution of less than 1 m.

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用时间比例放大技术提高脉冲激光测距的精度

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摘 要: 介绍了利用时间比例放大技术以低成本把脉冲激光测距精度提高到 ±1 m 的方法. 利用时间比例放大法可以把激光脉冲往返于测程之间的时间按比例放大 1 000 倍, 放大后的结果用于计算被测距离. 这种方法把测距系统的计时精度从纳秒级降低到微秒级, 从而降低了对系统时钟分辨率的要求. 采用时间比例放大技术可以有效地提高激光脉冲测距的精度, 而且使测距系统成本低, 工艺简单.

关键词: 时间比例放大; 测距; 电容; 充放电