Research on direction recognizing and subdividing method for moiré (interference) fringes

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A new direction recognizing and subdividing method for moiré (interference) fringes is presented. By setting two certain thresholds, counting errors caused by direct voltage excursion are avoided. Counting and direction recognizing are discussed in detail. Experimental results are given. The better adaptability and large subdivision number are the good quality of this method.

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As a way to transform displacement signal to photoelectric one, technology of moiré (interference) fringes has been widely used in digital displacement measurement[1,2]. In order to improve resolution of fringes measurement, many fringes subdividing methods have been presented. But many of them only take zero-point or peak-value point as counting and subdividing bases for moiré (interference) fringes. The counting result inevitably contains error caused by direct voltage excursion. Furthermore, more attention has been paid to subdividing but less to direction recognizing.

Aiming at above problems, a two thresholds method for direction recognizing and subdividing is presented. Two thresholds equal to amplitude of normalized fringes signal in $\pi/4$ phase are set. When signal jumps upward or downward the threshold, a number is added or subtracted reversibly. Direct voltage excursion or high-frequency noises can no longer result in counting error. A full signal period is again divided into 8 segments for subdividing. Direction recognizing is easy when fringes signal moves less than a signal period because the amplitude change is monotonous.

When moiré (interference) fringes are incident on the surface of photo-detector, the output of detector can be expressed as

$$V = V_0(t) + V_1(t)\sin\frac{2\pi x(t)}{d} + N(t), \qquad (1)$$

where t is time, $x(t)$ is displacement, $V_0(t)$ is direct voltage, $V_1(t)$ is signal's amplitude, and $N(t)$ is random noise.

Equation (1) shows the output of detector contains factors affecting counting and subdividing of moiré (interference) fringes, such as direct voltage excursion, amplitude fluctuation and random noise etc. And direct subdividing method cannot be employed because of the nonlinear relation between the output and corresponding displacement.

Two thresholds, Th and Tl, are adopted for subdividing the two orthogonal signals, as shown in Fig. 1. Th equals to the amplitude of normalized signal in the $\pi/4$ phase and Tl is the negative of Th. One signal period is then divided into four segments indicated by I, II, III and IV.

If sine jumps upward of Th and cosine is positive at the same time, displacement direction is positive and one number is added. If sine jumps upward of Th and cosine is negative, displacement direction is negative and one number is subtracted. Similarly, the displacement direction can be determined when sine jumps downward Tl and correspondingly adding or subtracting is executed. So twice countings are achieved for one signal period.

Excessive numbers may be counted when fringes move less than one signal period width. For example, one

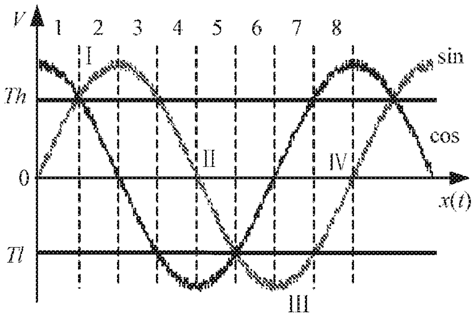

Fig. 1. Direction recognizing and subdividing diagram for moiré (interference) fringes.

Table 1. Correction for Positive Movement of Fringes

Ori. \ Stp.		I 2	I 3	II 4	II 5	III 6	III 7	IV 8	IV 1
I	2	0	—	—	—	1	1	1	1
	3	2	0	—	—	1	1	1	1
II	4	2	2	0	—	1	1	1	1
	5	2	2	2	0	1	1	1	1
III	6	1	1	1	1	0	—	—	—
	7	1	1	1	1	2	0	—	—
IV	8	1	1	1	1	2	2	0	—
	1	1	1	1	1	2	2	2	0

Note: (1) "0" represents that 2 is subtracted from counting numbers when the amplitude of start point is lager than that of stop point; (2) "1" represents that 1 is subtracted from counting numbers and "2" represents 2 is subtracted from counting numbers; (3) "—" represents no modification.

excessive number will be counted if the start point locates in section IV and the stop point locates in section I; two excessive numbers will be counted if the start point locates in section IV and the stop point locates in section III. Thus, data correction is necessary. Table 1 shows every correction case when displacement direction is positive.

One signal period is again divided into 8 segments according to Table 2. And each segment covers $\pi/4$ phase. Two adjacent sample points can only vary in sequential segment if system's sample speed is high enough. Suppose the start segment and stop segment are same, direction can be judged because the function is monotonic[3,4]. If the start segment and stop segment are different, direction can be judged as stated positive direction. The magnitude of fraction displacement can be worked out by looking up subdividing data table.

Figure 2 shows block diagram of a high-speed sample and processing system. Two digital signal processors (DSP) are used. DSP1 first samples the orthogonal signals and compares the sine data with threshold, then recognizes the displacement direction and counting. DSP2 gets the subdividing function, looks up subdividing data table, corrects the counting error and controls display of displacement. The hardware design can assure high system processing speed. Experiment results prove that the frequency the system can deal is as high as 500 kHz.

An orthogonal signal source was used to simulate fringes signals. Sine and cosine signals are generated simultaneously. Signal's amplitude can be varied. Direct voltage excursion can be changed according to preset data. The amplitude of random noise can be adjusted in a certain range. Experimental results acquired under difference conditions are show as follows.

Figure 3 was the subdividing displacement curve when the inputs were increased from 0 to 1/4 period by step of 1/1024 period. The measurement condition was that: the peak-to-peak values of two inputs were set to 2 V, the direct voltage was adjusted to zero, the amplitude of random noise was less than 5 mV. We can see that the system resolution reaches 1/1000 period from Fig. 3(b).

Figure 4 was twice measurement results under different conditions. Output 1 was acquired under the case that: the peak-to-peak values of two inputs were set to 2 V, the maximum excursion of direct voltage was 0.2 V and it fluctuated around zero voltage at frequency of 1 Hz, the amplitude of random noise was less than 5 mV. But output 2 was measured under difference condition that: the peak-to-peak values were lowered from 2 to 1.5 V, the maximum excursion of direct voltage was 0.5 V and it fluctuated around zero voltage at frequency of 5 Hz,

Table 2. The Judging Criterion for Subdividing

Seg	Sin Sign	Cos Sign	|Sin| − |Cos|	Func
1	+	+	< 0	tg
2	+	+	> 0	ctg
3	+	−	> 0	ctg
4	+	−	< 0	tg
5	−	−	< 0	tg
6	−	−	> 0	ctg
7	−	+	> 0	ctg
8	−	+	< 0	tg

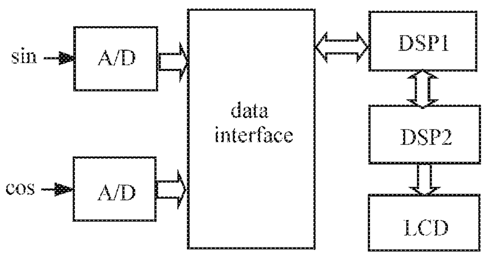

Fig. 2. The block diagram of high-speed sampling and processing system.

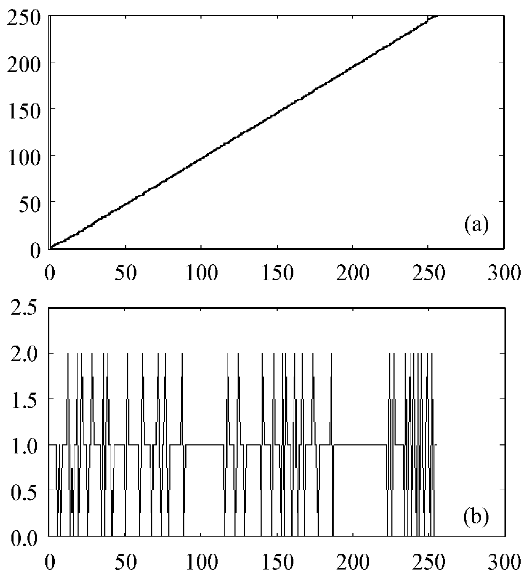

Fig. 3. Subdividing displacement curve when inputs are increased from 0 to 1/4 period by step of 1/1024 period. (a) Cumulate displacement curve; (b) error between two adjacent outputs data.

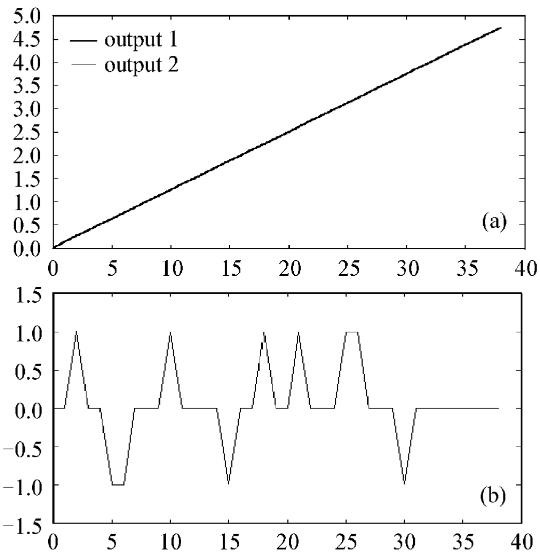

Fig. 4. (a) Two output displacement curves when inputs are increased by step of 1/8 period under different conditions. (b) Error curve between the two curves in (a).

the amplitude of random noise was increased up to 10 mV. For each measurement, the total input was 4.75 period and input step was 1/8 period. The measurement results show that output 1 and output 2 are almost superposed entirely. The error between corresponding data of output 1 and output 2 is not larger than 1/1000.

All of the above experimental results show taking threshold as counting and subdividing criterion can really improve the anti-jamming capability, eliminate the counting error caused by direct voltage excursion. Even if the amplitude variation of input signals is relatively large and random noise increases to a certain degree, this method can still work well. The system subdivision multiple exceeds 1000.

This paper presents a new direction recognizing and subdividing method for moiré (interference) fringes. By setting two thresholds, which are equal to the magnitude of signal in the $\pi/4$ phase, this method can exactly recognize the direction, count and subdivide moiré (interference) fringes. Experimental results show the influence of direct voltage excursion, amplitude fluctuation and random noise on counting and subdividing can be avoided simultaneously. The application of this method enhances the veracity of measurement and improves the adaptability and anti-jamming capability of measuring system.

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References

1. H. B. Lü, J. L. Cao, S. J. Su, and G. L. Tang, Proc. SPIE, **4077**, 40 (2000).
2. J. Cui, H. Q. Li, and Q. Chen, Opt. Technique (in Chinese) **26**, 294 (2000).
3. W. X. Yu, Z. Q. Zou, and X. T. Hu, Aviation Precision Manufacturing Technology **37** (4), 35 (2002).
4. X. P. Jing, S. P. Li, Y. S. Liu, and Y. L. Qiu, J. Shenyang Polytechnic University **16** (2), 18 (1994).