DECIMATION OF SAMPLING POINTS TO CONSTRUCT METROLOGICAL FRAME

RYOSHU FURUTANI

Tokyo Denki University, Department of Precision Engineering
E-mail: ryo@cck.dendai.ac.jp

Abstract - In general, the profile measuring machine uses the displacement sensor attached on movable mechanism in order to measure the object. It could measure the object profile by the amount of movement of the displacement sensor and output of the displacement sensor. When measuring the object, metrological frame is important as a reference. The movable mechanism as the linear stage is used as the metrological frame. However, the linear stage has a profile error according to the movement. We proposed a new method to distinguish the profile error of the metrological frame from the output of the displacement sensor. This method requires two linear stages and a displacement sensor. The object profile and profile error of the movable mechanism are determined by calculation using output of the displacement sensor. The validity of the new method was confirmed by the simulation and experiment. Due to the movement of two stages, the sampling points and the experiment equation are dramatically increasing. So it is necessary to decimate the sampling points is necessary keeping the separation of the profile errors from the sensor information accurate. In this paper, some decimation method are proposed and the validities of them are examined by simulation.

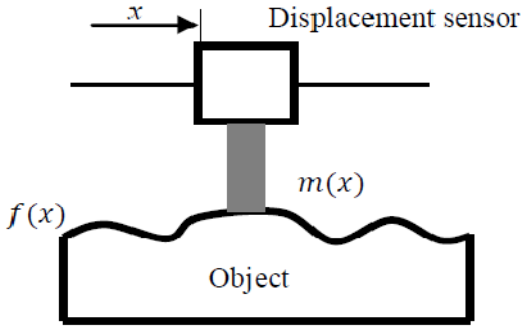
Index Terms - Form Measurement, Metrology Frame, Error Separation, Two Parallel Stages, Decimation of Sampling Points.

I. INTRODUCTION

Profile measuring machine can measure the profile of the object with high accuracy and widely used in industry. In general, the profile measuring machine uses the displacement sensor attached on movable mechanism in order to measure the object. It could measure the object profile by the amount of movement of the displacement sensor and output of the displacement sensor. When measuring the object, metrological frame as a reference is important. If the metrological frame does not have any profile errors as shown in Figure 1, where the amount of movement of the displacement sensor is expressed as x, the relationship between the object profile f(x) and output of the displacement sensor m(x) is expressed as (1).

$$m(x)=f(x)+ax+c \quad (1)$$

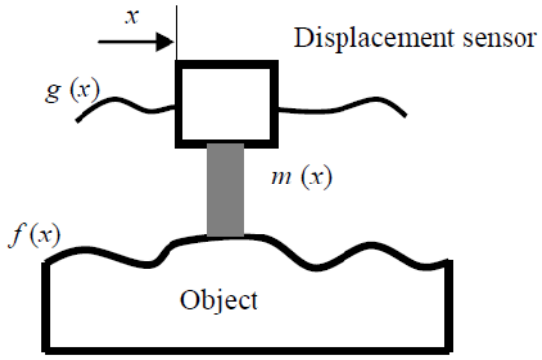
where ax+c is the slope and offset of the movable mechanism to the object. It is possible to measure the object profile because the output of the displacement sensor agrees with the object profile. However, as shown in Figure 2, metrological frame has some profile errors. When the metrological frame has some errors, the output of the displacement sensor includes both of the profile of the object and the profile error of the metrological frame. The relationship between the profile of the object f(x) and output of the displacement sensor m(x) is expressed as (2).



$m(x)$:Output of the displacement sensor

$f(x)$: Object profile

Fig.1: Profile measuring machine consists of a displacement sensor and movable mechanism in case of movable mechanism without profile error.



$m(x)$:Output of the displacement sensor

$f(x)$: Object profile

$g(x)$: Profile error of the displacement sensor axis

Fig.2: Profile measuring machine consists of displacement sensor and movable mechanism in case of movable mechanism with profile errors

$$m(x)=f(x)+g(x)+ax+c \quad (2)$$

where g(x) is the profile error of the metrological frame. So, it is necessary to distinguish the profile error of the movable mechanism from object profile to measure the object profile more accurately[1-3]. The new method to distinguish the object profile from the profile error of the movable mechanism isproposed, which is not dependent on the issues of the reversal method and multi-point method as shown in Figure 3[4].

The new method requires two linear stages and the displacement sensor. Two linear stages are mounted in parallel, the displacement sensor and the object are mounted on each stage. Two stages can move and locate independently. The relationship between positions of object and displacement sensor on the each of movable stages, the object profile f(u) can be expressed as (3).

$$m(v,w)=f(u)+g(v)+h(w)+av+bw+c \quad (3)$$

where g(v) is the profile error of the displacement sensor axis. h(w) is the profile error of object axis. m(v,w) is the output of displacement sensor. a and b is slope of the movable mechanism from the object. c is offset of the movable mechanism from the object. In this state, the relationship between the displacement sensor and the object is u=v-w. The several different outputs of the displacement sensor are obtained by any positions of the displacement sensor and the object. Equation (3) are solved as linear equation of (4).

$$Ax = b \quad (4)$$

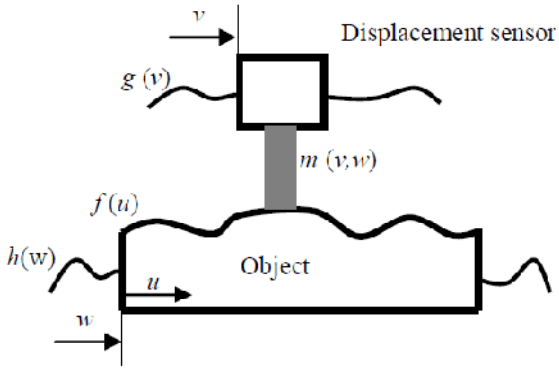
where matrix A is Jacobian of f (u), vector x is vector of unknown parameters, and vector b is output of the displacement sensor. However, Equation (4) cannot be solved because the rank of matrix A is less than the number of unknown parameters. Therefore, the unknown parameters are reduced by the constraints in the next step.

The object profile, the movement axis of the displacement sensor and the movement axis of the object can take any posture with regard to coordinate system. So even if both ends of the movement axis and object profile cut off (for example: they are set to zero), the profile of the movement axis and the object profile can keep the own profile. As the result, it is possible to solve linear equation as (5) because the rank of matrix A is consistent with the number of unknown parameters.

$$x = (A^t \cdot A)^{-1}A^t b \quad (5)$$

So, the object profile, the profile error of the object axis and the profile error of the displacement sensor axis can be calculated by (5). It was confirmed to be possible to construct metrological frame. In this method, two stages are positioning at a lot of points. So, it spends a lot of time to detect the data at a lot of measuring points and to calculate the form of the metrological frame using the least squares method. In order to reduce the time of measurement and calculation, it is useful to reduce the number of measuring points. However, if the number of measuring points of the metrological frame is reduced, the form of the metrological frame is estimated insufficiently[8].

In this paper, the method that the number of the measuring points of the metrological frame is remained



$m(v,w)$:Output of the displacement sensor

$f(u)$: Object profile

$g(v)$: Profile error of the displacement sensor axis

$h(w)$: Profile error of the object axis

Fig.3: The new method composed of two linear stages.

and the number of the positioning points of the stage of moving object is reduced, is discussed at the point of viewto keep the separation of the profile error of the stage of the displacement sensor accurate.

II. SIMULATION OF DECIMATION

A. Condition of Simulation

In order to explain the simulation condition, the following term is defined.

Stage A: the linear stage with the displacement sensor

Stage B: the linear stage with the object.

After separation of profile error, the stage A is used as the metrological frame.

The both profile errors of stage A and stage B are defined as random profile according of normal distribution with the average of 0 and standard deviation of 1. The profile error of object is defined as random profile according of normal distribution with the average of 0 and standard deviation of 2.

The number of sampling points are shown in Table 1.

Table 1: Parameters of profiles

		Stage A	Stage B	Object
Random profile	average	0	0	0
	Standard deviation	1	1	2
Number of sampling points		257	257	513

Any sampling points has random noisewith average of 0 and standard deviation with 0.01.

At first, all points, i.e., 257x257=66 049 points are sampled.

B. Decimation Method

As the stage A is used as a metrological frame, the stage A is fully sampled in any decimation method.

(1)The separation method using all sampling points are executed as a reference.

(2) The stage B moves at the point w=0 and the point w = 1. This decimation method is the case of minimum number of sampling.

(3.1) The decimation interval is set to 4. The number of sampling points on the stage B is 65. In this case, rank of the Jacobian is insufficient to solve. So additional sampling points between intervals are necessary. The number of additional sampling points are 3.
(3.2)The decimation interval is set to 8. The number of sampling points on the stage B is 33. In this case, rank of the Jacobian is insufficient to solve. So additional sampling points between intervals are necessary. The number of additional sampling points are 7.
(3.3)The decimation interval is set to 16. The number of sampling points on the stage B is 17. In this case, rank of the Jacobian is insufficient to solve. So additional sampling points between intervals are necessary. The number of additional sampling points are 15.
(4) The decimation intervals are changed and the sampling points are as 0,1,2,4,8,16,32,64,128, 256. The number of sampling points is 10.
The decimation strategy is shown in Table 2.

Table 2: Decimation Strategy

	No. of sampling points on stage A	No. of sampling points on Stage B	number of sampling points
Case 1	257	257	66 049
Case 2	257	2	514
Case3.1	257	68	17 476
Case3.2	257	40	10 280
Case3.3	257	32	8 224
Case 4	257	10	2 570

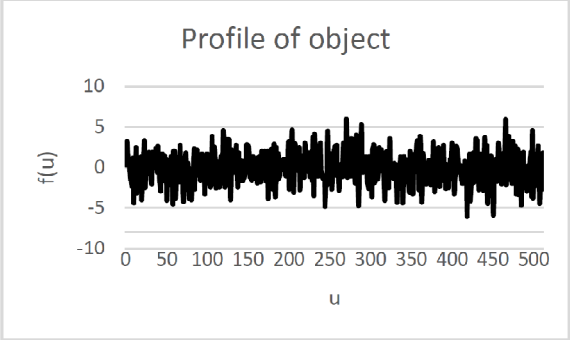
C. Decimation Result

The true profiles of the stages and object are known as Fig.4. The decimation results are evaluated based on the difference of the calculated profile of the stage A. The items of the evaluation are the peak-to-valley and the standard deviation of the differences.
The evaluation results are shown in Table 3.

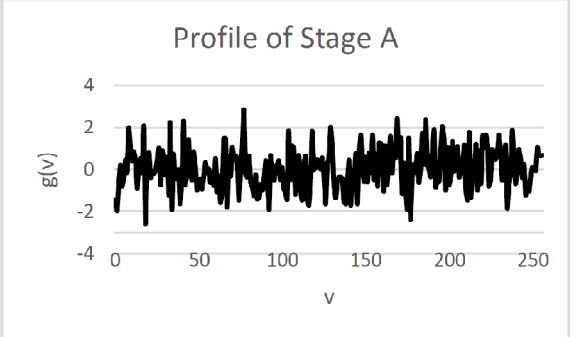
Table 3: The evaluation result of the decimation

	peak-to-valley	standard deviation
Case 1	0,0042	0,0006
Case 2	0,2425	0,0527
Case 3.1	0,0085	0,0014
Case 3.2	0,0093	0,0017
Case 3.3	0,0120	0,0019
Case 3.4	0,0174	0,0034

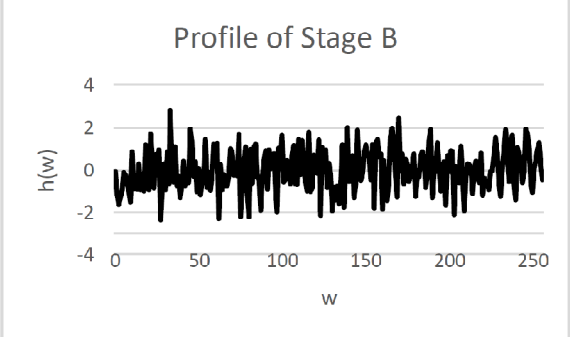
In Table 3, it is proved that if the number of sampling points is larger, the profile of the stage is estimated more accurate. The number of sampling points should be determined due to the accuracy and the measuring time. In this simulation, the case 3.2 would be best sampling strategy.



(a) Profile of object



(b) Profile of stage A



(c) Profile of Stage B

Fig.4: The profiles of stage A, stage B and the object are generated randomly.

CONCLUSION

In the case that the movable stage has the unknown profile error, the profile of the movable stage and the profile of object can be separated from the output of the displacement sensor. As this method requires the positioning of two stages, a lot of sampling points and experiments equation are required. In this paper, some decimation methods are proposed and are examined in simulation. It is proved that the case 3.2 is best sampling strategy in simulation.
The decimation strategy will apply to the actual measuring system and the results should be compared with the simulation result.

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