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Sub-pixel Image Registration Techniques for High Precision Micro Motor Runout Measurement

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Abstract *–The purpose of this paper is to demonstrate a method for runout measurement of hard disk drive spindle motor. This paper first reviews different technologies used for obtaining high precision micro motor runout measurement, and compares the limitation of several existed nanometer level measurement instruments that are used to measure spindle motor runout.*

An instrument based on optical vision sub-pixel image registration technology is thus developed for realizing high measuring accuracy, easy operation and low cost micro motor test. The experimental studies on different type micro motor are also presented.

I. INTRODUCTION

In recent years, the hard disk drive tend to high storage capacity, high areal record density which will above 100 Gb/in^2 and small component size which reach to 0.85 inch[1] and high data access rate .

The spindle motor is the key component in the hard disk drive, the runout and eccentricity is the critical dimension on hard disk spindle motor, and they are very concerned in the micro motor design and quality control [2]. In order to reach high speed data read and write, the spin speed of spindle motor gradually increases to 15000 rpm and will reach to 25000 rpm near further [1], With areal density increasing at a rate of 60 percent annually and track density doubling every two years, the NRRO requirement is reaching the nanometer level.

There are some technologies are used to measure spindle motor runout. There are:

Capacitance-based instrumentation is designed primarily to take non-contact measurements of position, displacement, vibration, and run out. These sensors can be used on conductive and nonconductive target materials, but can be sensitive to environmental parameters that change the dielectric constant of the medium between the sensor and the target. The system measuring accuracy is related to the distance between the probe and measurement object.

Eddy current sensor non contact measuring system, these linear position sensors usually contain two coils, one active coil that is influenced by the presence of a conducting target, and a second coil that completes a bridge circuit and provides temperature compensation. As the target comes closer to the probe, the eddy currents become stronger, which changes the impedance of the active coil and causes a bridge unbalance related to the target position.

Inductive position sensors are non-contact devices that determine an object's coordinates (linear or angular) with respect to a reference. Displacement is measured when the object moves from one position to another at a specified distance (or angle).

A fiber optic displacement transducer uses an adjacent pair of fiber optic elements, one to carry light from a remote source to an object or target whose displacement or motion is to be measured, and the other to receive the light reflected from the object and carry it back to a remote photo sensitive detector.

The accuracy of these measuring systems is influenced by the environment and measurement spindle motor specification. The system resolution is dependent on the distance between the spindle motor and sensor. The sensor size limits the system to measure the micro motor.

The LDV (Laser Doppler Vibrometer) can be used to measure the spindle motor axial runout, but it is limited to measure radial runout due to the small measurement area.

There are some nano resolution measuring systems were developed. There are

Atomic force microscopy (AFM)
Scanning tunneling microscopy (STM)
Transmission electron microscopy (TEM)
Interferometry
Video microscopy

The measuring range of first four measuring systems is narrow; it is only a few micrometers. And the measuring time is long, it need a few minute to finish measuring a part.

According to the requirement of measurement hard disk spindle motor runout, the measuring system must be able to measure sub-micrometer to a few hundred micrometers. To allow us to observe system dynamics, they must be capable of time-resolved measurement. Time-resolved measurement techniques can be subdivided into two categories: 1) real time methods that allow measurements of arbitrary motions and 2) time-averaged techniques that rely on assumed property of the motion.

If the motion to be measured is repeatable, the optic microscopic based on pattern analysis, which the minimum resolvable time integral can be governed by the light pulse width rather than by the detector integration time can be used. Here the detector need not be fast compared to the motion being analyzed. Allowing standard CCD cameras to be used to measure motions at frequencies much higher than camera frame rate.

A high precision micro motor runout measurement system based on sub-pixel image registration techniques has been developed. It can be used to measure 3.5 inch to 0.85 inch and even for the MEMS micro motor, and its measurement range is from 100 micrometer to 0.005 micrometer.

II. SUB-PIXEL IMAGE REGISTRATION TECHNIQUES

Image registration refers to the problem of spatially aligning two or more images. Its goals are to establish the correspondence between two images and determine a geometric transformation that aligns one with the other.

The image registration algorithm must adapt to the variations due to the differences in acquisition, which cause the images to be misaligned, lighting, spatial distortions and spindle motor movement.

The image registration techniques are the different combinations of the effect choice of image feature space, similarity measure, and search space and search strategy.

Registration methods can be viewed as two catalogs: 1) Minimum sum of error difference registration, the sum of square difference is given by Eq. (1) and 2) Maximum sum of cross registration variance between real time image and reference pattern image, the correlation coefficient is given by Eq. (2) .

$$SSD = \sum_{n=1}^{N} \sum_{m=1}^{M} [P_{t1}(n,m) - P_{t2}(n,m)]^2 \qquad (1)$$

$$C = \frac{\sum_{n=1}^{N} \sum_{m=1}^{M} P_{t1}(n,m) P_{t2}(n,m)}{[(\sum_{n=1}^{N} \sum_{m=1}^{M} P_{t1}(n,m)^2)(\sum_{n=1}^{N} \sum_{m=1}^{M} P_{t2}(n,m)^2)]^{1/2}} \qquad (2)$$

In the micro motor run out measuring system, there is only one sensor, one view point and fixed the magnification during the measurement. The illuminator can be adjusted using the serial communication to ensure the best contrast. Figure1 illustrates the reference pattern image and real image registration.

Due to the micro motor is rigid and rotation, and the image geometric deformation can be calibrated in advance [2]. The image features are extracted, that will be used for matching have scale, rotation and shift invariance.

The images are registered using the translation that optimizes the similarity criterion. To compute the translation parameter maximum cross correlation techniques are used. Assume that two image $P_1(m,n)$ is a motor reference pattern and $P_2(m,n)$ is motor rotation image, and P_2 is a shifted of P_1,Then we compute cross correlation functions of the projections of the two images in the x and y directions. This features detection method can decrease the system computational time.

The Eq. (3) and Eq. (4) give translation parameter matching on horizontal axis and vertical axis separately.

$$C_{x1x2}(n) = \frac{1}{N} \sum_{i=1}^{N} P_{x1}(i) P_{x2}(i+n) \qquad n=1...N \qquad (3)$$

$$C_{y1y2}(m) = \frac{1}{M} \sum_{i=1}^{M} P_{y1}(i) P_{y2}(i+m) \qquad m=1...M \qquad (4)$$

Where P_{x1} and P_{x2} are the image P_1 and P_2 projections onto the horizontal axis, P_{y1} and P_{x2} are the image P_1 and P_2 projections onto the vertical axis . And C_{x1x2} is the correlation function along the horizontal direction and C_{y1y2} is the correlation function along the vertical direction. The search space is C_{x1x2} and C_{y1y2} that is capable of aligning the images.

The maximum value of the correlation mapping function means the current spindle motor position. The position parameters can be computed as follows:

$$t_x = \max_n [C_{x1x2}(n)] \qquad (5)$$

$$t_y = \max_m [C_{y1y2}(m)] \qquad (6)$$

Where t_x is the maximum translation parameter that along horizontal direction, and t_y is the translation parameter along vertical direction.

The correlation mapping function values are influenced by measuring noise. The noise is random and frequency is changing caused by different measuring spindle motor. An adaptive low pass filter was designed for the correlation mapping function to increase measurement accuracy. This method is less sensitive to the intensity differences between the reference and real spindle motor images.

The search strategy will decide how to choose the next features from the search space, to be tested in the search for the optimal features. Search continues according to the search strategy until a feature is found whose similarity measurement is satisfactory.

EXPERIMENTS

The figure 2 illustrates a total of 7200 measurement points every one degree one measurement point and 20 rotations cycle runout measurement polar distribution for the 1.8-inch spindle motor. Figure 3 and figure 4 illustrate the maximum, average, minimum value of 20 times measurement value at same spindle motor location for 3.5 inch and 1.8 inch hard disk drive.

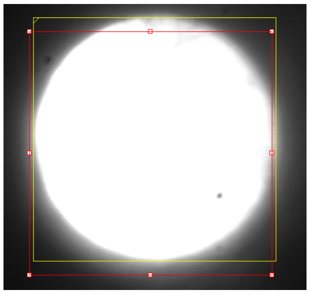

Fig. 1 Reference pattern and real image registration

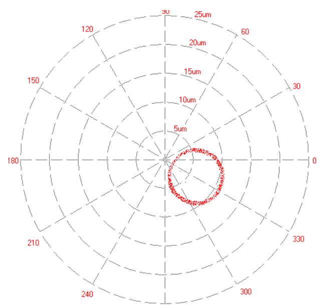

Fig 2. Micro motor runout measurement result

CONCLUSION

A effective and low-cost spindle motor runout measuring system has been developed based on micro vision techniques. The experiment results demonstrate the new spindle motor runout measuring system has 1) wide dynamic measurement range, 2) the ability to provide high precision results of spindle motor rotation speed from 100rpm to 15000rpm, 3) the ability to measure different motor size, 4) the ability to measure all type of motors.

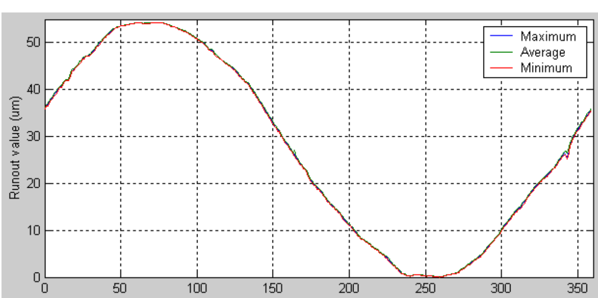

Fig 3. The spindle motor runout measurement In the 3.5 inch HDD

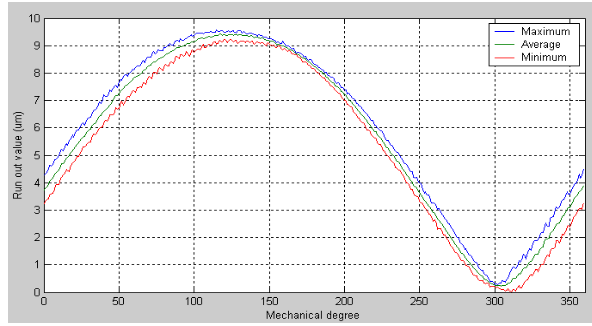

Fig 4. The spindle motor runout measurement In the 3.5 inch HDD

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