

Optical Method for Automatic Slider Misalignment Detection

Songpol Ongwattanakul¹, Paknipa Koonapinan²,
Rudeerat Dee-sawad³, and Sakol Nakthammaporn⁴, Non-members

ABSTRACT

Mounting a slider to the suspension arm typically requires the use of epoxy as adhesive. The process of attaching the two parts begins with placing a droplet of epoxy on the suspension arm at the designated location. A robot arm places a slider on top of the adhesive with accurate position and orientation. While waiting for the epoxy to cure, the slider may be drifted along the x- and y-axes, or rotated above the z-axis causing slider misalignment. This leads to defective parts in the production of the hard disk. Therefore, we propose an automatic slider misalignment detection system by using computer vision technique. The system must accurately perform the misalignment detection at a sufficiently fast rate to meet the real-time requirements from the production line.

Keywords: slider assembly, HGA, misalignment

1. INTRODUCTION

Hard disk read/write heads are too small to be used without attaching them to a larger unit. Each hard disk head may be called a head slider or just slider for short. In modern hard disk, the density of binary information stored on the surface may exceed 100 Gbit/in². Therefore, the slider assembly requires extreme precision in engineering to function correctly.

The read/write heads are fabricated on a silicon wafer by photolithography process similar to the making of semiconductor chips. The wafer is then diced into small pieces before being engineered to have a special wedge shape. Therefore, the aerodynamic pressure produced by spinning of the disk can create a lift by an extremely small gap (5-20 nm in height).

In the slider assembly line, the read/write head also known as slider and the suspension are mounted together. The process requires the use of epoxy adhesive to hold them in place. This epoxy must be cured under ultraviolet light. A droplet of epoxy is administrated at the center of the mounting location on the suspension. A robot arm precisely places the

head on the epoxy with accurate position and orientation. The assembly is then cured under ultraviolet light. This process may take a few minutes for the epoxy to cure.

While the epoxy remains in liquid form, slider misalignment may occur right after the robot releases the slider. This misalignment composes of three parameters which are the displacement in x- and y-axes, and the rotation above z-axis. These three parameters are crucial in determining defective parts.

In typical production, all sliders are measured to determine the amount of misalignment by using a model. This model is defined by the hard drive manufacturer. The model comes with standard marks on the suspension. The reference marks may be created by using photolithography for achieving the highest accuracy. Therefore, high precision measurements of misalignment can be done accordingly from the image of a slider assembly.

2. LITERATURE REVIEW

Automatic visual inspection systems are currently being used in various industries. Several studies [1-3] demonstrate the inability of humans to perform monotonous and endless routine jobs. Therefore, the hard disk industries are no exception. An inspection system must satisfy four basic criteria: detection performance, speed of inspection, cost, and flexibility as mention in [4]. Most of the inspection systems employ image processing for image preprocessing and feature extraction.

2.1 Related Image Processing Issues

The system is heavily relied on image processing technique for the automated visual inspection process. Therefore, it is necessary to emphasis on some image processing issues that are used in the implementation of the proposed system.

2.1.1 Thresholding

Thresholding is an image segmentation method where individual pixels in a grayscale image are marked as 'object' pixels if their value is greater than some threshold value and as 'background' pixels otherwise. Typically, an object pixel is given a value of one while a background pixel is given a value of zero as follow,

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^{1,2,3,4} The authors are with the Department of Computer Engineering Faculty of Engineering, Mahidol University 25/25 Buddhamonthon Sai 4, Salaya, Buddhamonthon, Nakornpathom 73170, Thailand, Email: songpol33@hotmail.com

$$I_B(x, y) = \begin{cases} 1, & I_A(x, y) \geq T \\ 0, & \text{Otherwise} \end{cases} \quad (1)$$

where $I_B(x, y)$ is the thresholded output of $I_A(x, y)$ pixel and T is a threshold value. The key parameter in thresholding is the choice of the threshold. Several different methods for choosing a threshold exist. The simplest method is to choose the mean or median value, the rationale being that if the object pixels are brighter than the background, they should also be brighter than the average.

2.1.2 Edge Detection

The Canny edge detection algorithm is known to be the optimal edge detector. The first and most obvious criterion is low error rate. It is important that edges occurring in images should not be missed and that there be no responses to non-edges. The second criterion is that the edge points be well localized. In other words, the distance between the edge pixels as found by the detector and the actual edge is to be at a minimum. A third criterion is to have only one response to a single edge.

Based on these criteria, the canny edge detector first smooths the image to eliminate and noise. It then finds the image gradient to highlight regions with high spatial derivatives. The algorithm then tracks along these regions and suppresses any pixel that is not at the maximum (nonmaximum suppression). The gradient array is now further reduced by hysteresis. Hysteresis is used to track along the remaining pixels that have not been suppressed. Hysteresis uses two thresholds and if the magnitude is below the first threshold, it is set to zero (made a nonedge). If the magnitude is above the high threshold, it is made an edge. And if the magnitude is between the 2 thresholds, then it is set to zero unless there is a path from this pixel to a pixel with a gradient above the upper threshold.

2.1.3 Ellipse Fitting

The literature on ellipse fitting divides into two broad techniques: clustering (such as Hough-based methods [5, 6]) and least-squares fitting. Least-squares techniques center on finding the set of parameters that minimize some distance measure between the data points and the ellipse.

In 1999, Fitzgibbon, M. Pilu, and R.Fisher introduce a highly robust and efficient ellipse fitting method called direct least square fitting of ellipses [7]. The new fitting method combines the following advantages:

- Ellipse-specificity, providing useful results under all noise and occlusion conditions;
- Invariance to Euclidean transformation of the data;
- High robustness to noise;
- High computational efficiency.

This ellipse fitting algorithm is later implemented as part of the OpenCV library package. The OpenCV is an open source computer vision library from Intel®.

2.2 Automated Misalignment Detection System

The system aims to detect misalignment of the slider on the assembly arm with minimum human interference. Therefore, the graphic user interface (GUI) of the system is considered optional and used for debugging purpose only.

The structure of the system requires a computer and an imaging device with proper illumination. The actual implementation requires the installation of misalignment detection system to the slider attachment production line to acquire the slider-arm attachment images. The imaging device must be installed perpendicular to the slider-arm attachment plane. Sufficient light must also be provided for optimal brightness and contrast of the scene. A key factor that is the main contribution to the accuracy of the system is the imaging resolution. Higher resolution leads to higher accuracy in measurement.

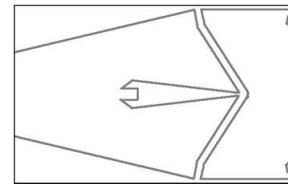


Fig.1: A slider from the top view

The slider is rectangular in shape from the top view as shown in Fig. 1. The entire assembly arm is relatively huge compared to the slider. Therefore, the focus is on the attachment area shown in Fig. 2 where there are two circles on the left side of the attachment area. These two circles are created by photolithography process as a precision mark that can be use as a reference in measuring the attachment misalignment.

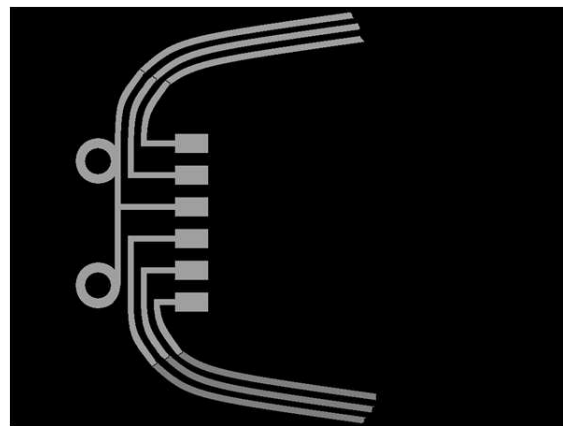


Fig.2: The attachment area on the assembly arm with the two-circle precision mark on the left

For the measurement model, to determine the translation (x, y) and rotation misalignment (θ) , the two-circle mark is used to create a vertical reference, V , line that connects the center of both circles. A horizontal reference line, H , is constructed from the middle point of line V with the direction perpendicular to V and away from the two-circle mark. The length of H determines where the designated center of slider should be located as shown in Fig. 3.

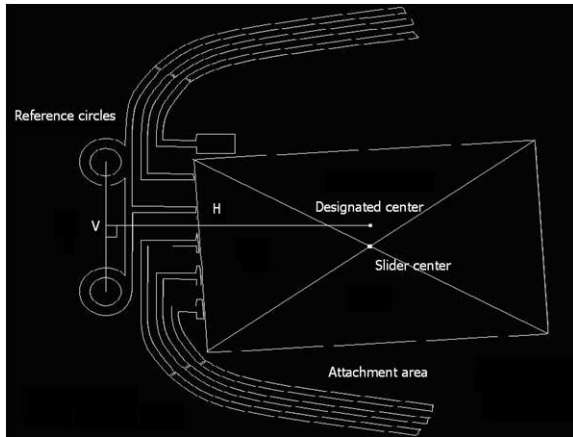


Fig.3: The measurement model

3. EXPERIMENTAL METHOD

The image processing algorithm inside the automated misalignment detection system, for this experiment, is as follow,

```

A <= CameraCapture();
B <= MedianFilter(A);
C <= Threshold(B, Th);
D <= CannyEdge(C);
E <= FitEllipse(D);

j <= 0;
For all  $E_i$ , if Radius( $E_i$ ) is close to  $4.5 \mu m$ 
{
     $P_j$  <= Center( $E_i$ );
    j++;
}

MidPoint <= ( $P_1 + P_2$ )/2;
DesPoint <= CalCoor( $P_1, P_2, Dist$ )

For all  $E_i$ , if Area( $E_i$ ) is maximum
{
    Maj <= MajorAxis( $E_i$ );
    Min <= MinorAxis( $E_i$ );
    Loc <= Center( $E_i$ );
}

ErrTran <= ||DesPoint - Loc||;
H <= Vector(MidPoint, DesPoint);
ErrRot <= Angle(Maj, H);

```

where Th and $Dist$ are an appropriate threshold and the given length of reference line H , respectively. The program written for this experiment employs OpenCV library to perform most image processing functions.

4. RESULTS AND DISCUSSIONS

In the experiment, the misalignment detection system operates in an offline mode. The input images are synthesized from the actual images of slider and arm. An individual slider image and a single assembly arm image are provided by the courtesy of Seagate Technology. These two pictures are combined to simulate the slider-arm attachment process. As a result, one thousand synthesis images are generated with random misalignment of ± 2.25 microns (10 pixels) in the attachment plane (both directions) and ± 5 degrees in above the normal vector of the attachment plane as shown in Fig. 4. These test images will be used to determine the accuracy of the proposed automated misalignment detection system.

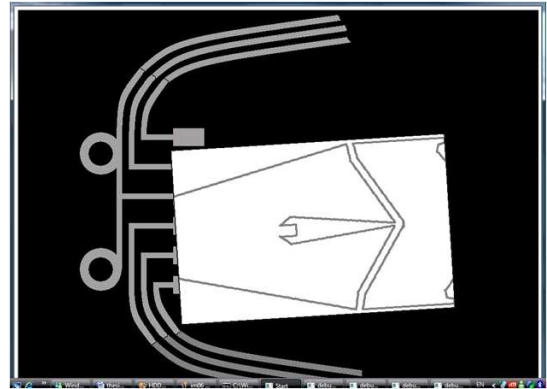


Fig.4: A sample of the synthesized images

The experiment is conducted to assess the accuracy and performance of the proposed automated misalignment system. The assessment processes one thousand synthesized images. Some examples of intermediate step during the image processing process are shown in Fig. 5 and 6.

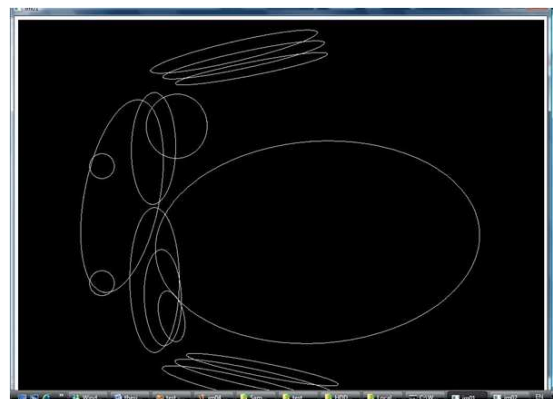


Fig.5: The sample image after the FitEllipse Step

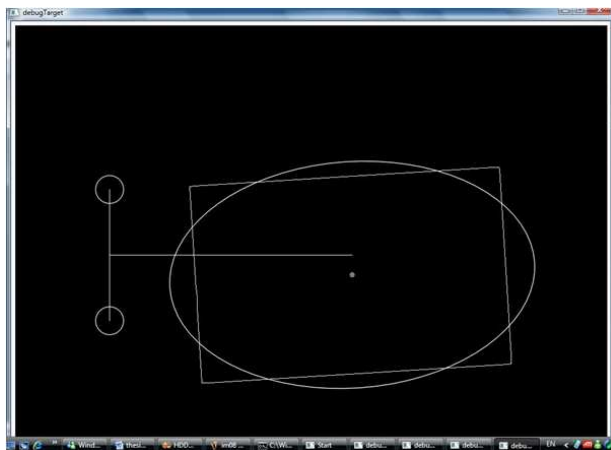


Fig. 6: The sample image after adding measurement model



Fig. 7: The report shows misalignment in x - y plane and the rotation above z axis.

Finally, the program shows misalignment parameters which are (x, y) and θ as shown in Fig. 7. The accuracy of the misalignment detection system is shown in Table 1.

Table 1: The error of the slider-arm attachment misalignment detection system

Error	$x(\mu\text{m})$	$y(\mu\text{m})$	$\theta(\text{deg})$
Average	0.287	0.273	0.447
SD	0.176	0.109	0.494
Max	1.575	1.125	3.904

The system takes 29.64 milliseconds by average to process an individual picture. Therefore, it is capable of detecting slider-arm misalignment 121,457 pieces per hour.

5. CONCLUSION

The proposed system can accurately measure the misalignment with the average error and standard deviation in x - y plane of 0.287 micrometers and 0.176 micrometers respectively. The average rotation error and standard deviation above the z -axis are 0.447 degrees and 0.494 degree. The average execution time is 29.64 milliseconds on an AMD Turion 64 computer

running at 1.8 GHz with 2 GB of memory. Therefore, the proposed slider misalignment system is competent to be deployed in the assembly line.

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Songpol Ongwattanakul received his PhD in Computer Engineering from the University of Alabama in 2003. At present, he is the head of department at the Department of Computer Engineering, Mahidol University, Thailand. His interests are in the areas of image processing, medical imaging, and high performance computing.

Not
Available



Redeerut Deesawat Born in 1985, Ms. Redeerut Deesawat is currently pursuing her Bachelor's Degree in Computer Engineering at Mahidol University. Her areas of interest are image processing and its applications. Her education is partially supported by the HDD cluster scholarship program under NECTEC.



Piya Kovintavewat Born in 1985, Mr. Sakol Nakdhamabhorn is currently pursuing his Bachelor's Degree in Computer Engineering at Mahidol University. His areas of interest are image processing and its applications. His education is partially supported by the HDD cluster scholarship program under NECTEC.