A Machine Vision Method for Inspecting Excess Glue in Spindle Motor Assembly

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Varunyou Buddhachan[1] and Pakorn Kaewtrakulpong[2]

Abstract

In this paper, we propose a method to automatically detect excess glue in inner threads of bearing sleeve of harddisk-drive spindle motor by machine vision techniques. The glue is used to join the bearing sleeve to the cap of the motor. After the joining, the assembly then undergoes a hardening process. Excess glue from the process may be present and will reside rigidly in the inner threads of the bearing sleeve. This prevents the motor from securely fit into the harddisk-drive body resulting in scraping the workpiece. Oblique lighting is employed to form reflected light back from surfaces of the excess glue. The defects generate highlights along the threads in the image of the inner sleeve. To reduce spurious reflections from thread roofs, threads are located by a geometric primitive fitting. By properly detecting those highlight spots within regions between adjacent thread roofs, the defect is accurately identified. Experimental result showed a good performance of our proposed method.

Keywords: Spindle motor, bearing sleeve, inner threads, excess glue

Introduction

Spindle motor is an important part in a harddisk-drive. It is composed of three parts: stator, bearing, and hub. In spindle motor assembly, adhesive material is used to join the bearing sleeve to its cap. A hardening process is also applied to ensure secured fitting. Excess glue from the process may occur and will reside rigidly in the inner threads of the bearing sleeve. This prevents the motor from securely fit into the harddisk-drive body resulting in scraping the workpiece.

At present, the excess glue defect is normally inspected by human operator under a proper microscope and lighting setting. During the process, the operator needs to turn and tilt the specimen around to get a view that shows the defect. This process not only takes long time but also engages the operator to this tedious and error-prone task. Therefore this work initiates an attempt towards automating the process by investigating a machine vision technique together with its image acquisition setting to detect the defect.

Department of Control Systems and Instrumentation Engineering
Faculty of Engineering, King Mongkut's University of Technology Thonburi
126 Prachautid, Bangmod, Toongkru, Bangkok, 10140, Thailand.
**corresponding author; e-mail: s9403515@st.kmutt.ac.th, pakorn.kae@kmutt.ac.th*

Similar work to the problem is the thread inspection method based on Wavelets transform proposed by Laligent et al (Laligent et al., 1993). It is used to detect defects including wrenching, crushing and absence of inner threads of cosmetic product cap. However, the method is not transparent and may lead to a generalization problem when applied to defect with great variations such as the excess glue in our case. In other words, misclassification of the defect may lead to retraining the system with more defect cases. The method proposed in our work is, however, based on thread modeling which makes the system more understandable by the inspector when a misclassification occurs.

Proposed Method

The problem of detecting excess glue defect by machine vision may be formed as a problem of detecting reflected light rays at different angles. Figure 1, shows a cut-in profile image of a bearing sleeve with some excess glue. The glue normally covers few threads starting from the deepest thread. By applying appropriate oblique lighting to the threads, the defect can be identified by reflecting highlight spots. Since exact alignment of the threads at different placement cannot be assumed, locating the reflected light at the same locations is not possible. Moreover, due to complex surface geometry, reflections can occur in several different areas along the threads.

Since spurious reflections are normally present at shoulders of thread roofs, they can be identified and removed from further consideration if the thread roofs can be accurately recognized. This can be done by fitting geometric primitives to the image data. By removing highlight spots around the detected thread roofs, we form areas of interest where defect should be visible.

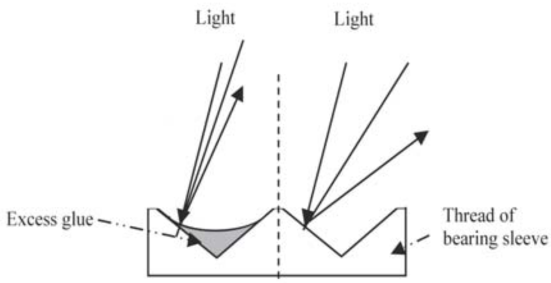

Figure 1. Cut-in profile image of a bearing sleeve with some excess glue.

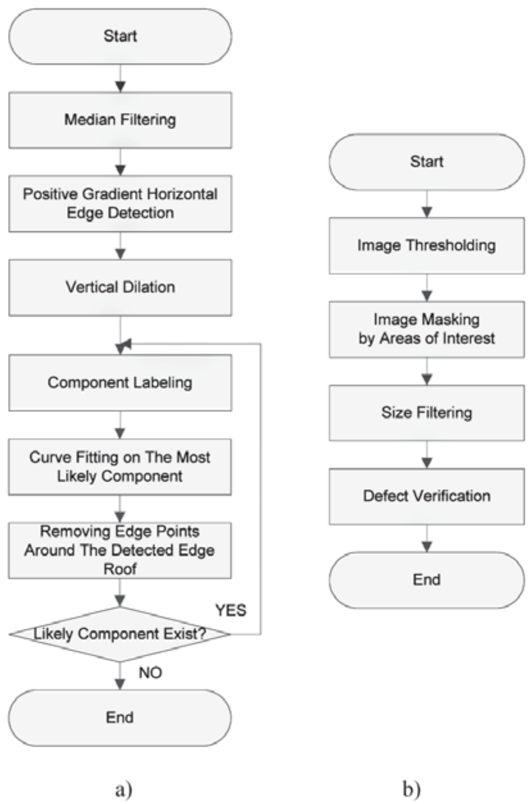

Figure 2. Block diagram of our proposed method
a) Thread localization
b) Defect identification

The outline of our proposed method is shown in Figure 2. The technique can be divided into two processes: thread localization and defect identification. Main purpose of the thread localization is to obtain areas of interest where defect may be present. Figure 2a, shows block diagram of this part. In defect identification, the highlight spots within the areas of interest are identified and verified if they are likely to come from the excess glue reflections. An overview of steps employed in this part is shown in Figure 2b.

A. Thread Localization

The process starts by capturing an image of the threads sitting in a fixture under an oblique lighting. A Region Of Interest (ROI), overlaid by a rectangle in Figure 3, is selected to accelerate the processing. Since a high intensity light source is employed, noises and reflections can be seen over the thread surface areas. A median filtering is then applied to smooth out non-uniform brightness in thread surface terrains. Result from the smoothing is shown in Figure 4. A closer look around a thread roof reveals intensity changes from dark region A at the thread groove to brighter strip B at the thread rooftop and brightest region C at the shoulder of the thread. To locate the thread region, the interface between rooftop (B) and shoulder (C) regions is selected as a target in our method. Horizontal Sobel gradient operator is applied to the smoothed image. Only positive gradient pixels passing a threshold are selected for further processing as shown in Figure 5. A vertical dilation (Russ,2005) is introduced to link missing vertical edges and form long vertical lines along the threads as displayed in Figure 6.

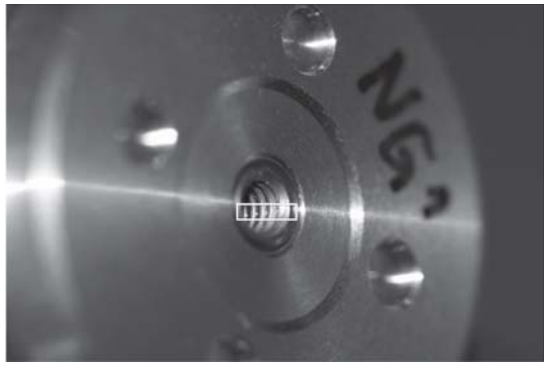

Figure 3. Image obtained from acquisition system.

Figure 4. Result from median smoothing.

Figure 5. Result from horizontal Sobel edge detection.

Figure 6. Result from vertical dilation.

After potential thread lines are enhanced, sequential thread detection is applied. It starts by performing a component labeling algorithm to the image and computing object properties including length, number of pixels and aspect ratio. The longest connected objects with appropriate number of pixels and aspect ratio is selected and fitted to a parabola curve by Least Squares (LS) curve fitting. Bands of equal perpendicular distance from the detected curve are established and any horizontal edges within the bands are removed. This resultant image is used as an input for the next iteration. The process is then repeated until no longest connected object satisfied the condition.

The LS parabola fitting problem of the inner thread can be written as

$$A\hat{\theta} = b \qquad (1)$$

where $\mathbf{A} = \begin{bmatrix} y_1^2 & y_1 & 1 \\ y_2^2 & y_2 & 1 \\ \vdots & \vdots & \vdots \\ y_n^2 & y_n & 1 \end{bmatrix}$, $\mathbf{b} = \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{bmatrix}$, and

$\hat{\theta} = \begin{bmatrix} a \\ b \\ c \end{bmatrix}$.

$(x_1,y_1),...,(x_n,y_n)$ are horizontal edges of the longest connected object.

Solution to this can be found from

$$\hat{\theta} = (A^T A)^{-1} A^T b \qquad (2)$$

where $\hat{\theta}$ is the least square estimate of the equation.

The result of the thread localization complete is shown in Figure 7.

B. Defect Identification

The excess glue defect is normally shown as compact highlight spots in thread groove areas in the acquired image. These high intensity spots can be detected by image binarization with a threshold. Nevertheless, these detected spots not only come from the defect but also from other surface interactions with the incident light. By considering highlight spots in the thread grooves 2, 3 and 4, the defect is effectively identified. Figure 8 and 9 show the results from binarization and image masking, respectively.

Figure 8. Result from binarization.

Figure 9. Result from image masking.

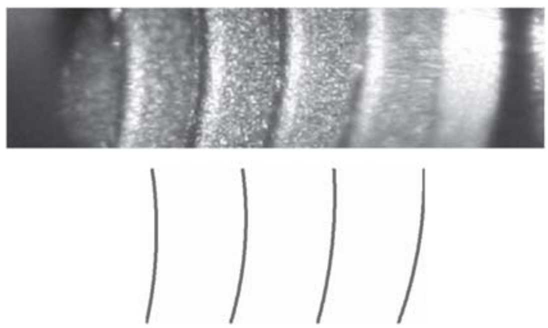

Figure 10. Example of accepted part.

Experimental Result

Our image acquisition system includes a Canon 400D Single-Lens Reflex (SLR) camera with built-in flash and electronic shuttering, and a macro lens 100 mm., f/2.8 attached on a structured platform. 25 samples labeled by human experts from an assembly line of spindle motors were used to investigate performance of our approach. In the set, four samples are accepted whereas 21 samples are rejected parts.

Experimental results are shown as a confusion matrix in Table 1. It can be seen that most of the specimens are correctly classified. However, one rejected specimen was misclassified since the reflected light was not strong. The algorithm was implemented in MATLAB and took 1.65-2.91 seconds per sample on a PC with Pentium 4, 3GHz. and 1.5 GB of RAM.

Table 1. Experimental Result

Decision	Ground truth (25)	
	Accepted parts (4)	Rejected parts (21)
Accepted parts	4	1
Rejected parts	0	20
Overall accuracy	96 %	

Conclusion and Future Work

An effective method for inspecting excess glue in inner threads of bearing sleeve of harddisk-drive spindle motor is presented. It is intended to be a part of an automated inspection system. The approach consists of two processes: thread localization and defect identification. The thread localization is used to locate areas of interest, and defect identification is used to verify highlight spots resulted from the defect. Experimental result shows a good performance of the technique (96% of success) and its efficiency. However, some problems still occur probably due to the direction of light source and inappropriate focus. Future work will be on implementing the algorithm for real-time processing and on integrating it into a fully automated system.

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