MVA2009 IAPR Conference on Machine Vision Applications, May 20-22, 2009, Yokohama, JAPAN

Machine Vision for Excess Gluing Inspection in Spindle Motor Assembly

Varunyou Buddhachan
Department of Control Systems
and Instrumentation Engineering
Faculty of Engineering, King Mongkut's
University of Technology Thonburi
126 Prachautid, Bangmod, Toongkru, Bangkok,
10140, Thailand.
s9403515@st.kmutt.ac.th

Pakorn Kaewtrakulpong
Department of Control Systems
and Instrumentation Engineering
Faculty of Engineering, King Mongkut's
University of Technology Thonburi
126 Prachautid, Bangmod, Toongkru, Bangkok, 10140, Thailand.
pakorn.kae@kmutt.ac.th

Abstract

Quality inspection of gluing quality in inner threads of bearing sleeve of harddisk-drive is an important step in spindle motor assembly. This paper presents an automated inspection system based on machine vision for quality control of gluing quality. At present, the inspection process is performed by human inspectors. However, they have low throughput and cannot identify all defects. To increase the quality and productivity, an automated visual inspection system is needed. The approach is based on detecting reflected light from the defects under oblique lighting. The defects generate highlights along the threads in the image of the inner sleeve. To reduce spurious reflections from thread roofs, input image of threads is enhanced by a Gabor filtering and the 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 algorithm.

1. Introduction

Automated inspection system is becoming an essential tool for quality control in modern manufacturers. One of the most widely used systems is machine vision thanks to its high flexibility. In harddisk assembly manufacturing, inspection of excess glue is an important topic in the spindle motor assembly as misclassification in the inspection could lead to a substantial loss. In the spindle motor assembly, adhesive material is used to join the bearing sleeve to its cap. After the joining, the assembly 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.

Like other inspection processes, gluing quality inspection is dependent of experience of the inspectors. A proper microscope and lighting setting is also required. This inspection not only takes long time but also engages the inspector to this tedious and error-prone task. Hence, an automated visual inspection system is implied for solving this problem.

Similar work to our problem is the thread inspection system based on Wavelets transform proposed by Laligent et al [1]. 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 comprehensible by the inspector when a misclassification occurs.

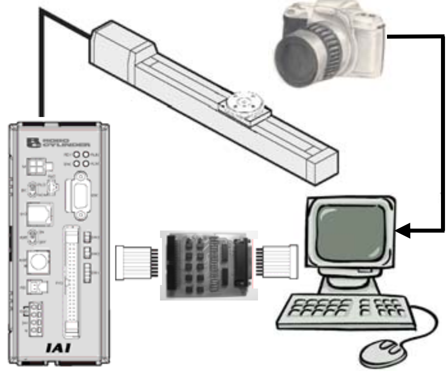


Figure 1. Inspection station for examining excess gluing

2. System Configuration

The overall architecture of inspection station is presented in Figure 1. It consists of image processing system and an inspection table. Image processing system includes a Canon 400D Single-Lens Reflex (SLR) camera with build-in flash and electronic shuttering, and a macro lens 100 mm., f/2.8 attached on a structured platform. A Pentium 4 (3 GHz) PC with 1.5 GB of RAM is used for processing and controlling. The camera and the PC are synchronized through a USB port for parameter adjustment, remote shuttering and image transferring. The inspection table is an RCS (RoboCylinderServo) series made by IAI Inc. It is an electric actuator with ball screw, linear guide and AC servo motor. It is able to move on multiple points up to 16 positions controlled by RCS controller. This programmable single-axis positioner is integrated with driver for RCS actuators and can be assigned position, speed and acceleration/deceleration. Movement is executed by operations via digital I/O with an isolated circuit to separate 5VDC components from 24VDC components.

After a spindle motor specimen is loaded into the gripper in the inspection table. The table is moved to the inspection position according to a processing system command. When it stops at the inspection position, it sends a "Position Complete" command to the processing unit. Camera will take a photo of the spindle motor by remote shutter command. Captured image is then transferred to the processing unit for analysis. The processing unit will send a new position command to inspection table and display the result of inspection at the same time. Then the table moves to the unloading position for disposing the motor and returning a position complete command to the processing unit. Finally, it moves to the loading position again and waits for a new command. The cycle of system is shown in Figure 2.

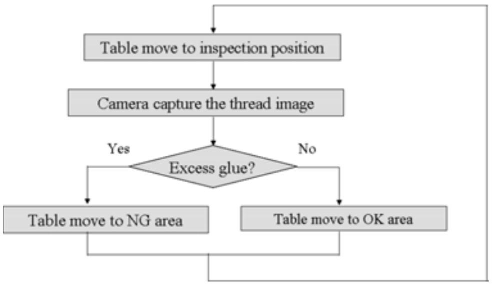


Figure 2. Cycle of glue quality inspection system

3. Inspection Algorithm

The excess 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. In other words, the problem of detecting excess glue defect by machine vision may be formed as a task to detect reflected light rays at different angles. Figure 3, shows a part of cut-in profile image of a bearing sleeve with some excess glue. 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. As spurious reflections are normally present at shoulders of thread roofs, they can be identified and removed from further consideration if the pattern of shoulders can be recognized. This can be done by fitting geometric primitives to the image data. By removing highlight spots around the shoulder of threads, we form areas of interest where defect should be visible.

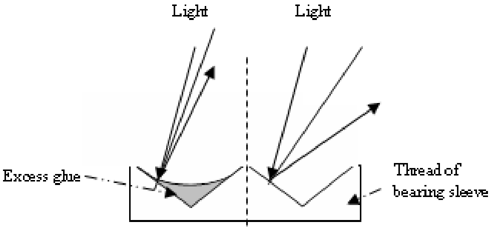
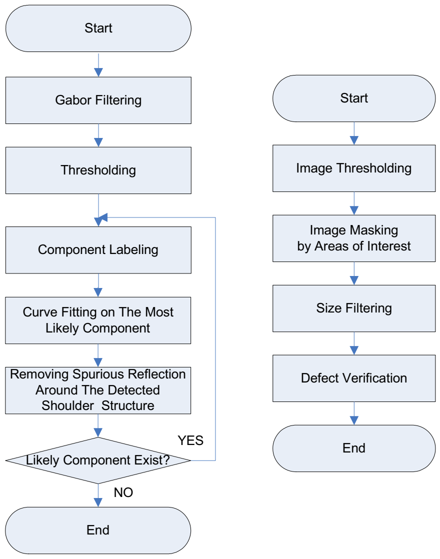


Figure 3. Cut-in profile image of a bearing sleeve with some excess glue.

The outline of our proposed method is shown in Figure 4. The technique can be divided into two processes: thread localization and defect identification. The main purpose of the thread localization is to obtain areas of interest where defect may be present. Figure 4a, shows a 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 4b.



a) b)

Figure 4. Block diagram of our proposed method

a) Thread localization b) Defect identification

3.1. Thread Localization

After, the inspection table moves to the inspection position and a command is sent to the processing unit to capture and download the image of workpiece sitting in a fixture under an oblique lighting. A Region Of Interest (ROI), overlaid by a rectangle in Figure 5, is selected to accelerate the processing. Figure 6, shows 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 characteristic of this distinctive pattern is selected as a target in our method. The pattern of thread shoulder is located by Gabor Filtering [3] with its period compatible to cycles of thread pattern as shown in Figure 7. Only high intensity pixels passing a threshold are selected for further processing as shown in Figure 8.

A two-dimensional Gabor function is used to enhance texture of threads within the ROI and can be written as

$$\mathbf{G}(\mathbf{X},\mathbf{Y};\lambda,\theta,\psi,\sigma,\gamma)=\exp\left(-\frac{\mathbf{X}'^2+\gamma^2\mathbf{Y}'^2}{2\sigma^2}\right)\cos\left(2\pi\frac{\mathbf{X}'}{\lambda}+\psi\right)$$

where $\mathbf{X}'=\mathbf{X}\cos\theta+\mathbf{Y}\sin\theta$

And $\mathbf{Y}'=-\mathbf{X}\sin\theta+\mathbf{Y}\cos\theta$

λ represents the wavelength of cosine factor, θ represents the orientation of the normal to the parallel stripes of a Gabor function, ψ is the phase offset, σ is the sigma of the Gaussian envelope and γ is the spatial aspect ratio.

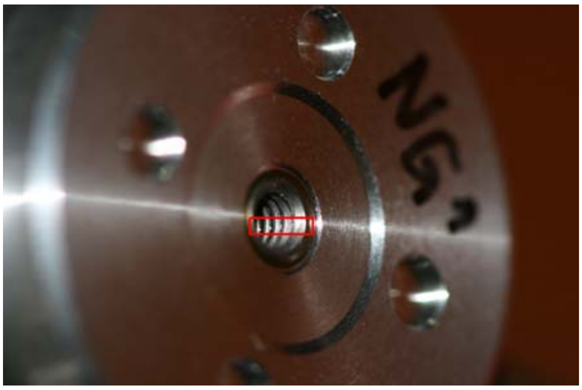


Figure 5. Image obtained from acquisition system.

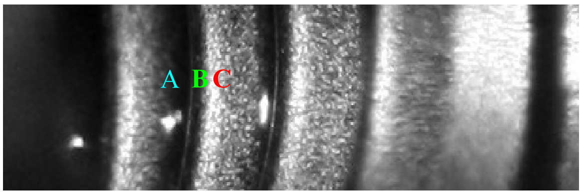


Figure 6. Thread characteristics.

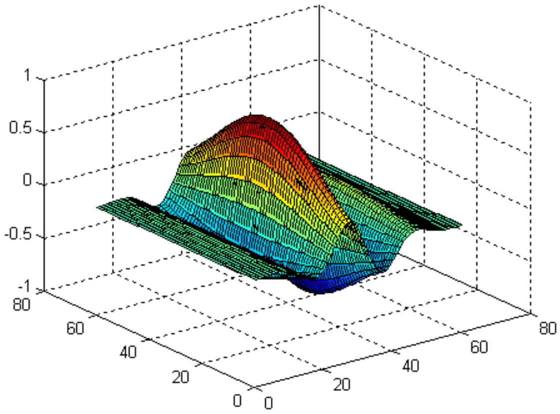


Figure 7. Gabor filter that is used to enhance the thread shoulder.

Figure 8. Result from thresholding.

After potential thread shoulders are enhanced, sequential thread shoulder 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 step. The process is then repeated until no longest connected object satisfies the condition.

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

$$\mathbf{A}\hat{\theta} = \mathbf{b}$$

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

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

Solution to this can be found using pseudo inverse,

$$\hat{\theta} = \left(\mathbf{A}^T\mathbf{A}\right)^{-1}\mathbf{A}^T\mathbf{b}$$

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

The result of the complete thread localization is shown in Figure 9.

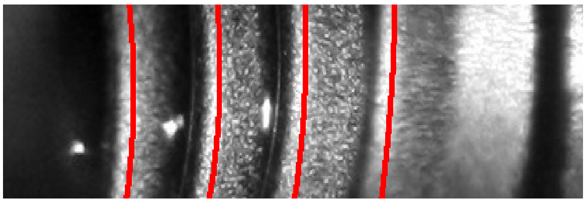


Figure 9. Threads of bearing sleeve formed by parabola curve.

3.2. Defect Identification

The excess glue defect is normally shown as compact highlight spots in thread groove areas within the acquired image. These high intensity spots can be detected by image binarization with a threshold. Nevertheless, highlight spots not only come from the defect but also from other surface interactions with the incident light. By considering highlight spots only within the thread grooves, the defect is effectively identified. Figure 10 and 11 show the results from binarization and image masking, respectively.

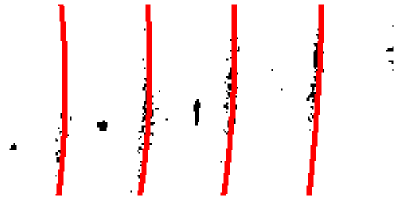


Figure 10. Result from binarization.

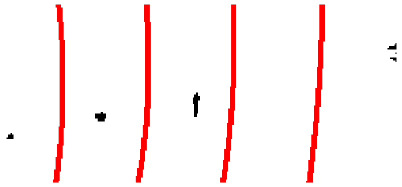


Figure 11. Result from image masking.

An example of an accepted part is shown in Figure 12. It can be seen that highlight spots along the thread shoulders are not detected by our method.

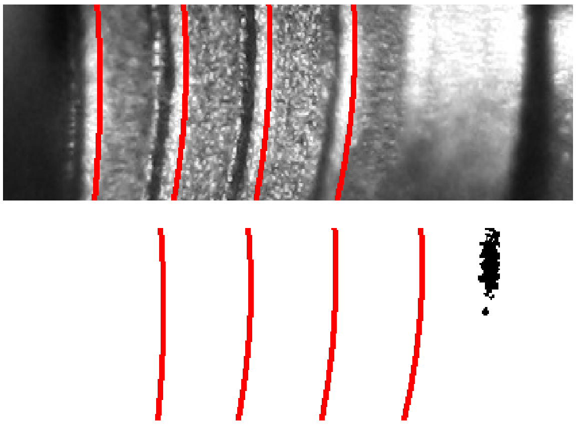
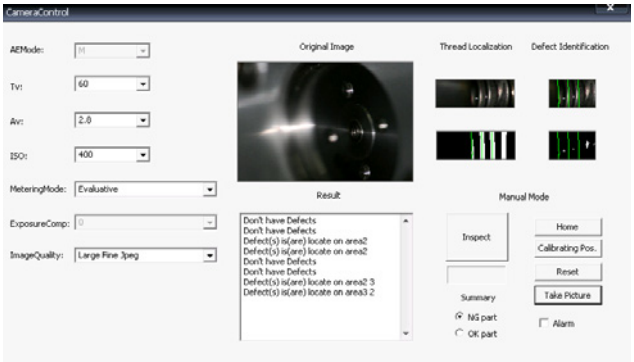


Figure 12. Example of accepted part.

Results from each step are integrated on the right hand side of Graphic User Interface (GUI) shown in Figure 13. It helps the operator to understand the inspection result when misclassification occurs. In addition, the pictures show results of part analysis and manual mode for control inspection table and camera. In the middle column, pictures show the acquired image and stack of intermediate results. It shows the defect areas when there are significant highlight spots between the threads. The left zone is used for camera's parameter adjustment.



AEMode: M

Tv: 60

Av: 2.0

ISO: 400

MeteringMode: Evaluative

ExposureComp: 0

ImageQuality: Large Fine Jpeg

```
Don't have Defects
Don't have Defects
Defect(s) is(are) locate on area2
Defect(s) is(are) locate on area2
Don't have Defects
Don't have Defects
Defect(s) is(are) locate on area2 3
Defect(s) is(are) locate on area3 2
```

Figure 13. Graphic User Interface of system

4. Experimental Result

The proposed inspection system was tested on 25 labeled samples from an assembly line of spindle motors. The samples were verified by an intrusive test. In the set, four samples are accepted whereas 21 samples are rejected parts.

Experimental results are shown as a confusion matrix in Table 2. It can be seen that most of the specimens are correctly classified. However, one rejected specimen was misclassified since the reflected light was not sufficient as displayed in Figure 14. If only thread localization process is considered, all specimens can be correctly located as shown in Table 1.

Table 1. Thread Localization Result

Decision	Ground truth (25)	
	Accepted parts (4)	Rejected parts (21)
Accepted parts	4	0
Rejected parts	0	20
Overall accuracy	100 %	

Table 2. Experimental Result

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

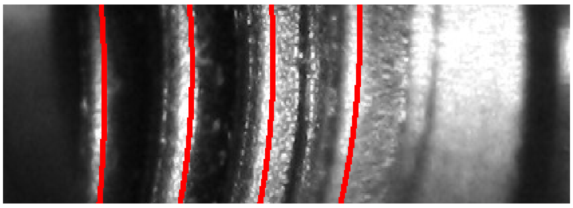


Figure 14. The misclassified sample.

5. Conclusion and Future Work

An automated inspection system for inspecting excess glue in inner threads of bearing sleeve of harddisk-drive spindle motor is presented. 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% accuracy). However, some problems still occur probably due to complex interaction with the lighting.

Acknowledgment

This research has been funded by Hard Disk Drive Institute (HDDI) under National Electronics and Computer Technology Center (NECTEC). The authors would like to thank NIDEC Electronics (Thailand) Co.,Ltd., Rojana factory for their comments and supports on process knowledge, equipment and test specimens.

References

[1] O. Laligent, F. Truchetet, and E. Fauvet, "Wavelets transform in artificial vision inspection of threading," *in Proc. IECON'93 Industrial Elec. Control and Instr.*, vol. 1, pp. 513-518, Nov. 1993.

[2] Russ, J. C., The Image Processing Handbook, 5th ed., CRC press, 2005.

[3] S.E. Grigorescu, N. Petkov and P. Kruizinga, "Comparison of texture features based on Gabor filters", *in Proc. 10th Int. Conf. Image Analysis and Processing,* Vennice, Italy, Sep. 1999, pp 142-147