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VISUAL DIMENSIONAL INSPECTION OF OIL SEAL BASED ON LABVIEW

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Abstract. *The market in oil seal trimming machine (OSTM) is professional and small, but most of it have only trimming function and lack on-line dimensional inspection. Besides, 100% test is a trend of market since unstable quality of oil seal will lead to huge loss in benefit for the manufacturer. Therefore, the main purpose of this paper is to develop a LabVIEW-based visual dimensional inspection system for the oil seal and to integrate it with OSTM together such that the OSTM can execute on-line visual dimensional inspection. In practice, a platform based on industrial control computer, peripheral component interconnect (PCI) vision frame grabber and programmable logic controller (PLC) is built and several application software modules by using LabVIEW and NI Vision Development Module are developed. The experimental results show that such well integrated OSTM can carry out productivity of 3000 pieces per hour and has accuracy of less than 0.04mm in measuring error.*
Keywords: Oil seal, Trimming machine, LabVIEW, Visual dimensional inspection

1. **Introduction.** Variety of oil seals have been widely used in industrial equipment, automobile parts and variety of transmission devices. In several systems of an automobile vehicle such as engine and brake system all need to use oil seal. Although oil seal is just a small part, it would significantly influence the safety of vehicles and people and lead to huge loss in benefit for the manufacturer once the oil seal malfunctions and has the phenomenon of leakage. Besides, the customer always strictly demands the dimensional error after trimming edge of oil seal, especially in inner diameter. Both domestic and foreign markets in OSTM are professional and small, and most of trimming machines made by several companies [1-3] only have trimming function and lack on-line dimension measurement, for example, measurement of inner diameter, outer diameter and concentricity. If only the sampling test is executed for some oil seals, the chance of leakage will be significantly increased and caused accident or disaster will lead to huge loss of the manufacturers. If 100% test is required to be made for every seal on an independent test instrument, it can only be executed by manually one by one testing. In such situation, not only the test speed is slow but also the benefit cost ratio cannot be promoted. Therefore, the manufacturers of OSTM have expected to on-line test the dimension of oil seal immediately after completing the trimming process. This strategy has the merits of immediate analysis of pass rate, and then the machining process can be immediately well adjusted and the loss due to manufacturing of large amount of defective products can also be successfully prevented. Therefore, to integrate the trimming machine with noncontact on-line visual inspection system is an effective way to solve aforementioned problem.

In recent years, several manufacturers of OSTM have employed intelligent camera [4,5] to realize the visual dimension inspection. The intelligent camera has features of built-in CPU, libraries, easy operation interface, multiple interfaces (e.g., RS-232, Ethernet, and Modbus) and easy integration. When it is employed to test the dimension of oil seal, the testing results show that it is required to teach the charge-coupled device (CCD) camera for three times in daily test to achieve the demand precision. The reasons might be the built-in libraries, environmental light inference, CCD camera resolution and so on. On the other hand, for the purpose of inspecting the contact gap and contact malposition of automotive relay, a LabVIEW-based machine vision approach was proposed to realize 100% on-line detection [6]. Based on computer vision method, Wu et al. [7] and Jiang and Jiang [8] proposed an oil seal dimension measuring system to carry out the noncontact, on-line and 100% detection. The main purpose of this work is to develop a visual dimensional inspection system with the merit of easily integrating with the OSTM which is controlled by PLC. In contrast to the investigation of them, based on LabVIEW, this work not only develops a method to implement the visual dimensional inspection, i.e., inner diameter, outer diameter and concentricity, of oil seal but also develops a method to integrate the visual dimensional inspection with the OSTM which is controlled by PLC. Therefore, this work aims at proposing an easy-implemented and LabVIEW-based visual dimensional inspection, i.e., inner diameter, outer diameter and concentricity, system to integrate with OSTM for achieving on-line 100% detection of oil seal such that the market's demand is satisfied. A brief description of the architecture of an automated OSTM is given in Section 2. In Section 3, the software modules developed by using LabVIEW are described. Experimental results and discussion are given in Section 4. Finally, Section 5 offers some conclusions.

2. **Architecture of the Automated OSTM.** The processes of an automated OSTM which has been integrated with visual dimensional inspection process are shown in Figure 1. The control flow includes feed of non-trimmed oil seal, pick and place, trimming of both the edge of inner circle and the edge of outer circle, visual dimensional inspection and classification of go/no-go oil seal. Both a non-trimmed and a trimmed oil seals are shown as Figure 2. Figure 3 shows an OSTM which has been equipped with a visual dimensional inspection system. Figure 4 shows the block diagram of the system with visual dimensional inspection function. It mainly comprises a personal computer, an NI PCI image acquisition card, a CCD camera, and a PLC (programmable logic controller). The PLC (i.e., Mitsubishi FX2N series) is responsible for controlling the processes of feed, pick and place, trimming and classification of go/no-go oil seal. And the PC is mainly responsible for performing the visual dimensional inspection. The hardware connection between the PC and the PLC is RS232 interface. The OSTM is demanded to produce 3000 pieces in one hour, namely it has only 0.833 second to complete the whole processes.

To incorporate the visual inspection system into the existing automated trimming machine, the mechanisms to mount the vision device, i.e., a set of CCD camera and a set of light source, are designed and shown in Figure 3. In Figure 3, the shot of CCD camera is installed downward and is responsible for acquiring oil seal image in vertical (z) direction. Besides, there is a set of back-lighted light source installed in the visual inspection area

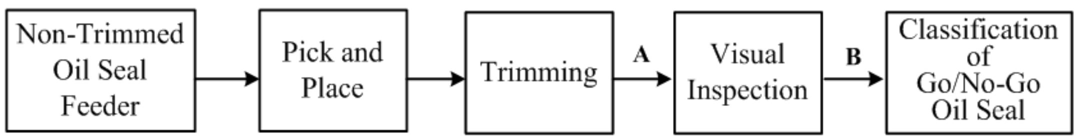

FIGURE 1. Processes of trimming oil seal

Figure 2. The appearance of oil seals (left one is non-trimmed)

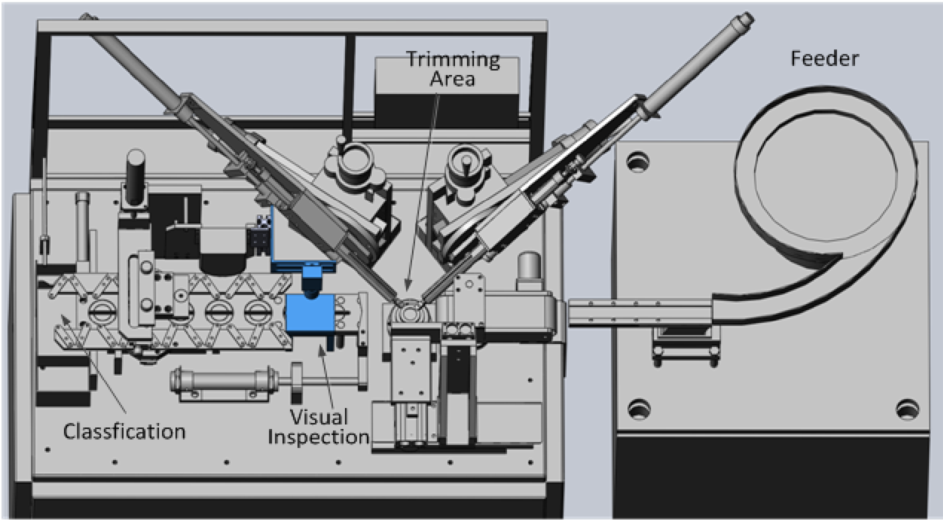

Figure 3. Layout of the proposed visual inspection system

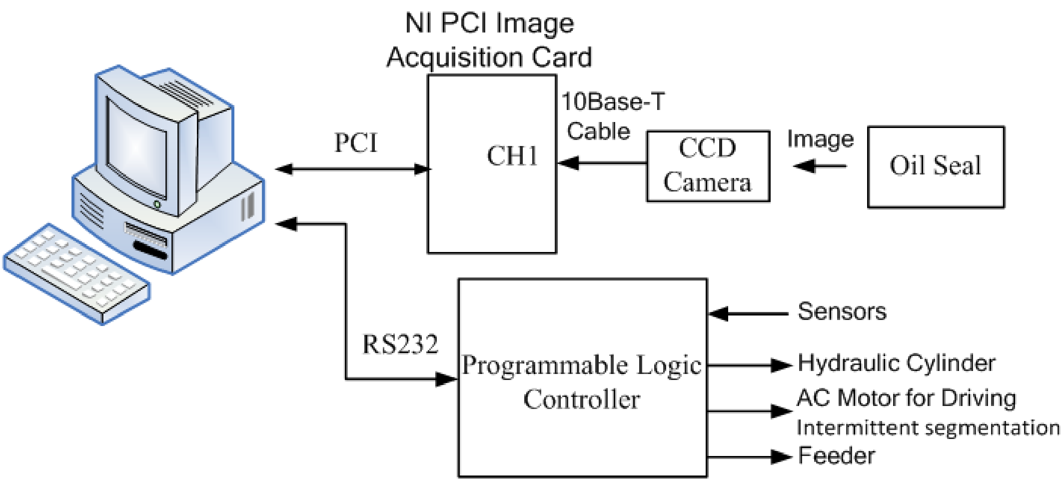

Figure 4. Block diagram of the system

to steadily provide the trimmed oil seal with back light such that the acquired image is suitable for latter image processing.

The vision devices employed in this study include a PCIe-8236 GigE vision frame grabber with power over Ethernet, a CCD camera (Basler ace camera, acA2040-25gm, 2048×2048, 25 fps, monochrome), a back-lighted light source (Red light, BANNER LED RB70×70M) and a shot (Computar M3520-MPV, Ultra Low Distortion, 35mm, F2.0, 2/3 inch). The image data being acquired from the CCD camera is transmitted to the vision frame grabber through the Ethernet cable (10Base-T Cable), and the interface between the PC and the vision frame grabber is PCI.

3. **Description of Software Modules Developed by Using LabVIEW.** Using module design method, the software modules based on LabVIEW are developed. The architecture of the developed software modules includes main operation module, visual dimensional inspection module, record module of classification and measured data, communication module between PC and PLC and display module. The programs in PC and PLC are alternatively executed to control the processes required for the OSTM and several auxiliary registers M in PLC act as communication flag between them. When the process proceeds to symbol A in Figure 1, the register M10 is set by the PLC program. The state of M10 is read through the communication module and is used to start the visual inspection module. When the visual inspection is completed (symbol B in Figure 1), the register M10 is reset by the communication module. The state of M10 is recognized by the PLC program and the classification process is proceeded. Besides, the visual inspection result, i.e., go/no-go, will set/reset the register M11 in the PLC through the communication module, and the operation of classification process depends on the state of M11. The visual dimensional inspection module to detect dimensions, i.e., inner diameter, outer diameter and concentricity, of oil seal is developed by using LabVIEW 2013 and NI Vision Development Module (VDM) [9]. The main operation module is shown in Figure 5. A detailed description of the proposed visual dimensional inspection method in this work is shown as follows.

All the image processing functions which are employed in the following steps are included in the vision assistant of VDM.

Step 1. Layout of light source

A back-lighted light source is selected to project light from the back of oil seal.

Step 2. Nonlinear image calibration

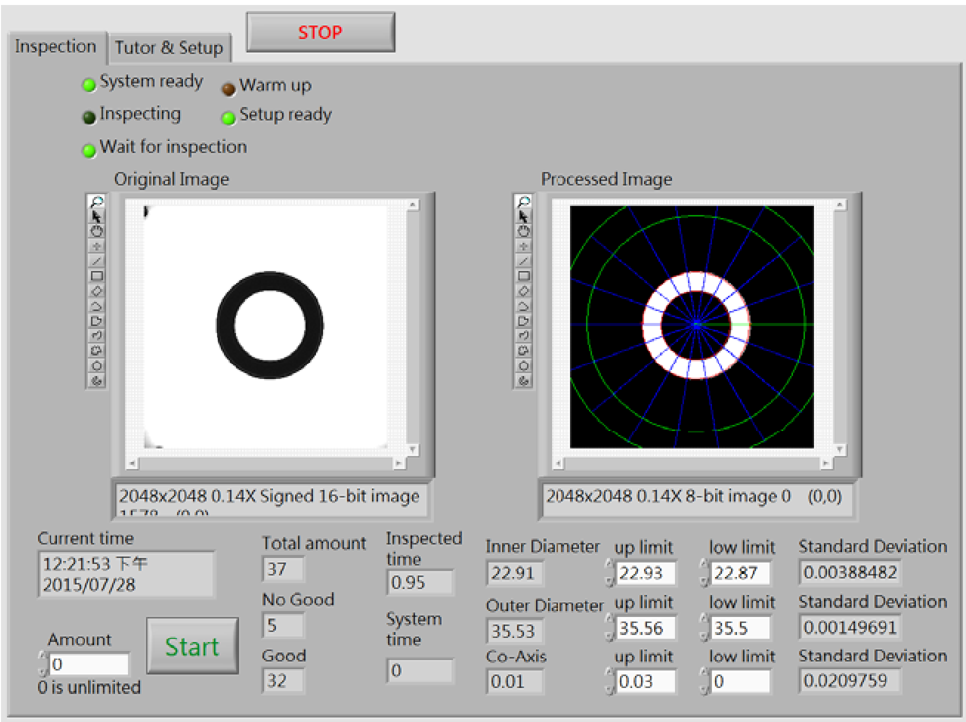

FIGURE 5. Main operation module

Many reasons may cause the deformation of the acquired image, such as distortion of shot, and angle deviation of acquisition image. By using the image calibration function and a nonlinear calibration pattern, the deformation of acquired image has been calibrated.

Step 3. Calculation of the pixel length

In order to calculate the pixel length (mm/pixel), firstly, the image of a circular calibration template with 20 ± 0.001mm diameter is acquired and the preprocessing in Step 5 to Step 7 is performed on this original image. Thus, its represented number of pixels in diameter is computed by using the processing function *Machine vision -> find circular edge*. After multiple operations, the average value is taken and the pixel length is found to be 0.0544549mm/pixel.

Step 4. Acquisition of oil seal image

The NI vision acquisition software is used to acquire the oil seal image here.

Step 5. Binary thresholding

The processing function *Greyscale -> Threshold* is used to preprocess the image and to obtain a binary image. The threshold type is set to "Manual threshold" and the threshold value is set as 3000. All the greyscale values of pixels which are greater than the threshold value are set as the biggest greyscale value, i.e., 4095, and all the greyscale values of pixels which are smaller than the threshold value are set as the smallest greyscale value, i.e., 0.

Step 6. Removing of small particle in the binary image

By using the processing function *Binary -> Advanced Morphology* (Remove small objects), the redundant small particle in the binary image can be detected and removed.

Step 7. Improvement of contrast and brightness

By using the processing function *Greyscale -> Lookup Table (Equalize)*, both the contrast and brightness in the image obtained in Step 6 can be improved.

Step 8. Search of central location of oil seal in the whole image

When the image processing function *Clamp* is used to search the oil seal, the whole image is set as the inspection area and two edge points which lie on the vertical tangent of outer circle of the oil seal are found. And then, the *Caliper* function is further used to calculate the central point of this two edge points. Namely, this central point is the central point CP of the oil seal which is not necessarily the central point of the whole image. Next, by using the *Set Coordinate System* function, the coordinate data of this central point is found and is set as the starting searching point of the next image processing step.

Step 9. Edge detection and calculation of diameter

(1) Edge detection of circle and calculation of diameter

The *Machine vision -> find circular edge* function is employed to search the edges, the centers and the diameters of both the inner circle and the outer circle. While the *find circular edge* function is applied to searching the edge of the inner circle, the detection of edge is completed by the way of radiated search from the central point CP to the nearest edge points. These edge points are the edge of inner circle and are further used to estimate the center $CT_i(x_i, y_i)$ and the diameter of the inner circle. Besides, while the *find circular edge* function is applied to searching the edge of the outer circle, the detection of edge is completed by the way of radiated searching from four boundaries of the whole image to the central point CP and the nearest edge points in every direction are identified as the edge points of the outer circle. These edge points are further used to estimate the center $CT_o(x_o, y_o)$ and the diameter of the outer circle.

(2) Calculation of concentricity

By using the processing function *Caliper* in Vision Assistant, the concentricity d is calculated as follows:

$$d = \sqrt{(x_o - x_i)^2 + (y_o - y_i)^2}. \tag{1}$$

4. **Experimental Results and Discussion.** The image of the to-be-measured oil seal being back-lighted is shown in Figure 6(a). Figure 6(b) shows the image Figure 6(a) after

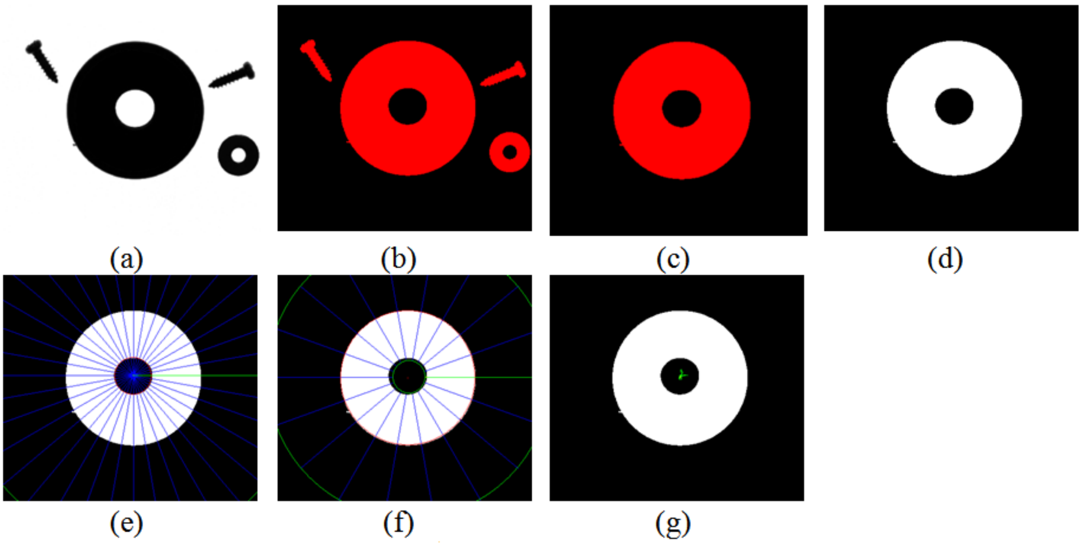

FIGURE 6. (a) Acquired original image; (b) binary image; (c) image after removing small particle; (d) image after improving contrast and brightness; (e) edge detection of inner circle; (f) edge detection of outer circle; (g) calculation of concentricity

binary image processing. The image in Figure 6(c) shows the image in Figure 6(b) has already removed the redundant images which are two screws and one washer. The image shown in Figure 6(d) shows the effect of improving contrast and brightness. The result of detecting the edge of the inner circle is shown in Figure 6(e) and the result of detecting the edge of the outer circle is shown in Figure 6(f). Figure 6(g) shows the result of using *Caliper* function to calculate the concentricity of the circles of both the inner circle and outer circle.

In order to verify repeatability and accuracy of the proposed visual dimensional inspection system, several oil seals whose practical inner diameter and outer diameter are, respectively, 7.537mm and 25.782mm are sampled to inspect its inner diameter, outer diameter and concentricity by using a precision measuring instrument (VML300 3D optical image measuring instrument, accuracy: 3um) and these data will be viewed as reference data denoted by M_2. On the other hand, each of the same oil seals is inspected by using the proposed visual inspection system for 10 times, and these datum will be used to calculate average value and standard deviation and to make statistical analysis. Let C_i be the inspected data taken on the same oil seal by using the proposed visual dimensional inspection system, where $i = 1 \sim 10$. By taking average on C_i, $i = 1 \sim 10$, the average value is obtained and denoted by M_1. Then, according to C_i, $i = 1 \sim 10$ and M_1, standard deviation S can be calculated by using Equation (2)

$$S = \sqrt{\sum_{i=1}^{n} \frac{(C_i - M_1)^2}{n-1}}, \tag{2}$$

where $n = 10$. It is well known that standard deviation can be used to represent repeatability of a measuring instrument. The smaller the standard deviation is, the more the measured data concentrated in the neighborhood of M_1 are. That is, the smaller standard deviation value denotes the measuring system has higher repeatability.

The statistical analysis of the inspection data is shown in Table 1. Observe that the S values in Table 1 all are very small. It demonstrates that the proposed visual inspection has good repeatability in both diameter and concentricity inspection. In addition, the absolute errors between M_1 and M_2 in inner diameter, outer diameter and concentricity

Table 1. Statistical analysis of inspection data

Unit: [mm]

Statistical / Item	Average value M_1	Reference value M_2	Standard deviation S	Error $\lvert M_1 - M_2 \rvert$
Inner diameter	7.543	7.537	0.00092	0.006
Outer diameter	25.770	25.782	0.00141	0.012
Concentricity	0.006	0.030	0.00121	0.024

are all under the required specification, i.e., 0.04mm. It demonstrates that the proposed visual dimensional detection approach has good enough accuracy and has the superiority to integrate with the trimming machine for on-line inspection.

Double describe that this work aims at developing a visual dimensional inspection system with the merit of easily integrating with the OSTM which is controlled by PLC. Thus, in contrast to the investigation of the previous work [7,8], this work proposes an easy-implemented and LabVIEW-based method which not only can implement the visual dimensional inspection of oil seal but also can integrate the visual dimensional inspection with the OSTM which is controlled by PLC.

5. **Conclusions.** A LabVIEW-based visual dimensional inspection system for the OSTM has been successfully developed and integrated with it such that it can execute on-line visual dimensional inspection. The experimental results show that the visual inspection time can satisfy productivity demand (3000 pieces/hour) and has enough accuracy in OSTM measurement. Therefore, the work provides satisfactory results and thus helps the manufacturer promote its technology and competitiveness. Further study will be focused on the detection of surface defects of oil seal to promote the performance of the OSTM.

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