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RESEARCH INTO DETECTING DEFECTS OF MIRROR SURFACE PRODUCTS (OPTIMIZING PARAMETERS FOR AN INSPECTION SYSTEM BY GENETIC ALGORITHM)

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Abstract. *Mirror surface inspection is a difficult problem met frequently. In order to improve this problem, an automatic vision defect inspection system for mirror surfaces has been developed and its effectiveness has been confirmed. However, setting optimal parameters is very important for this system although they are currently set by human judgment. In this paper, in order to set optimal parameters, an optimization method by using a Parameter-free Genetic Algorithm (PfGA) is first proposed. And then its effectiveness is confirmed by simulation using the defect detection methods and an encouraging result is obtained.*
Keywords: Mirror surfaces inspection, Specular reflection, Optimization method, Parameter-free Genetic Algorithm

1. **Introduction.** Mirror surfaces of industrial parts, such as machined surfaces, painted surfaces and plated surfaces are highly reflective, so their inspection is a difficult problem met frequently. Visual inspection of the appearance of metal parts in most manufacturing processes mainly depends on human inspectors, whose performance is generally subjective, variable, and therefore inadequate. An automatic vision inspection system offers objectivity, better reliability and repeatability and is able to carry out defect measurement to evaluate industrial parts' quality. However, methods enabling an automated inspection of mirror surfaces are still lacking. Few papers of mirror surface inspection have been published. A typical kind of vision system has been built to inspect defects on mirror surfaces by analyzing the deformation of lighted stripes [1]. And a vision system to detect bump defects (e.g., dust and hair) on mirror surfaces has been presented [2]. However, it was incapable of curved surface inspection because highlights from the curve surfaces, which cannot always be avoided in one image, may mask the true location of the objects and lead to incorrect measurements.

In recent years, for chrome-plated part, the authors [3-5] developed an automatic vision defect inspection system for mirror surfaces. The primary significance and novelty of this work were in achieving defect inspection of mirror surfaces. The objects in this research were not only surfaces with highly specular reflection but also circumscribed curved surfaces. This is a significant advancement over the previous method. The experiments showed that this system could reliably detect defects on mirror surfaces and that the system was robust to the shape and location of the defect which was extracted in the synthetic image reconstructed from a set of images. Moreover, the inspection system was cost-efficient because of the low algorithmic complexity and was suitable for use in industrial applications. However, setting optimal parameters is very important for this system.

In this paper, in order to set optimal parameters, an optimization method by using a Parameter-free Genetic Algorithm (PfGA) is proposed, and its effectiveness is confirmed by simulation using a previous defect detection method [4] and a new Canny method explained in Section 2. The remainder of the paper is organized as follows. In the next section, the automatic vision inspection system [5] is introduced and defect detection processing strategies are reviewed. Parameter optimization by using the PfGA is presented in Section 3. And then, Section 4 demonstrates some experimental results and discussion. Finally, in Section 5, we state the conclusions of this paper.

2. **The Defect Detection Method of Mirror Surfaces with Highly Specular Reflection.** A schematic of the automatic surface inspection system prototype is presented in Figure 1. The inspection system consists of an acquisition system having a light-source system and a CCD camera. For the camera we chose the most popular sensor, the charge coupled device. In our application, the inspection system is in a dark room. The object is fixed properly on the work piece. Under certain illumination conditions, the location of the object mainly depends on its surface shape. In the current research, we placed the object to ensure few highlights and distinct highlight regions from different images.

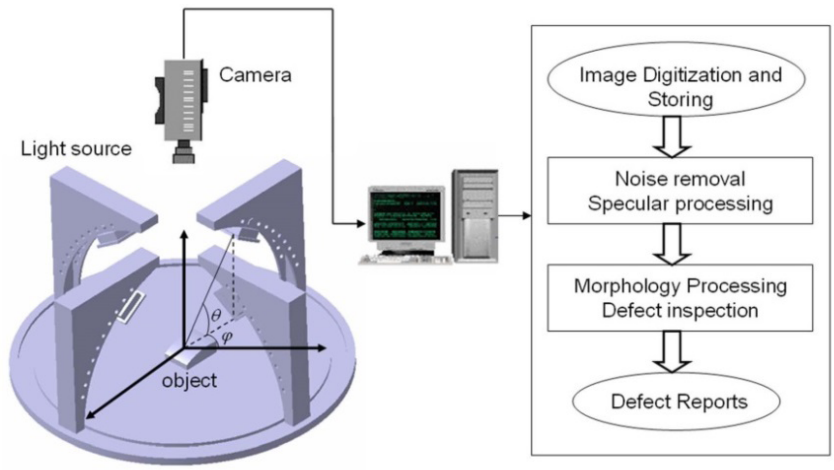


FIGURE 1. The schematic representation of the automatic vision inspection system

As shown in Figure 1, the defect inspection procedure is performed as follows. First, in the image acquisition stage, four (or more) images are generally captured from the object illuminated by four different incidence directions in turn. Second, a specular processing procedure is performed to remove any specular reflections and emphasize defects. After this processing, all defects are successfully gathered in a synthetic image reconstructed from the input images by using a multi-image reconstruction method [3]. Third, the synthetic image is submitted to the noise removal stage and all defects are extracted by using the defect detection method [4]. Finally, the system outputs the detection results and provides information on whether there are any defects on the surface and other analyses [5].

Figure 2 shows the flowchart of the defect detecting method shown in Figure 1 (which will henceforth be called the previous method). In this case, the synthetic image is first input as the target image. For the target image, Top-hat processing is carried out, which calculates the difference between the input image and its image of implementing the opening. To extract the inspection area, then, after binary processing, mask processing is carried out by using the dilated image of the template. In addition, the template image for this research is colored white outside the inspection area. Finally, noise is removed and the defects are extracted by using threshold processing.

The method shown in Figure 2 has five parameters as follows:

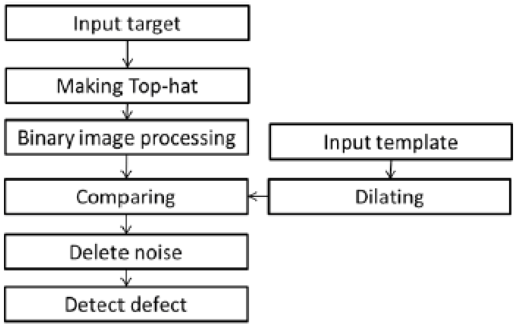


Figure 2. Previous method

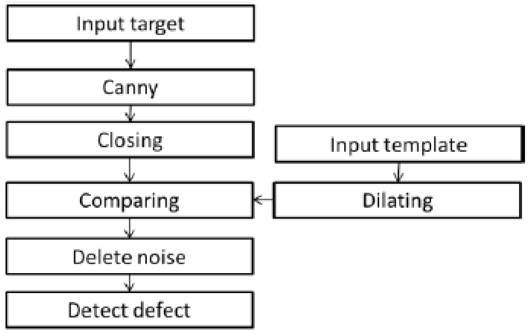


Figure 3. Canny method

Parameter 1: the size of dilation for the template,
Parameter 2: the value of the threshold to binarize the template,
Parameter 3: the size of opening processing for the target image,
Parameter 4: the number of times for the opening processing of the target,
Parameter 5: the value of the threshold to binarize the Top-hat of the target.

These parameters have conventionally been determined empirically from the inspection object, and optimization is not confirmed. Therefore, how to optimize the parameters is a problem. In order to improve this problem, an optimization method by using a genetic algorithm is proposed in Section 3.

Furthermore, to confirm the effectiveness of the proposed optimization method, a new defect detecting method is proposed which is called the Canny method, and the flowchart is shown in Figure 3. By comparing Figure 2 and Figure 3, it can be seen that the Canny method uses Canny processing and Closing processing, instead of the Top-hat processing and binary processing of the previous method. And the Canny method also has five parameters as follows:

Parameter 1: the size of dilation for the template,
Parameter 2: 1st parameter for Canny processing,
Parameter 3: 2nd parameter for Canny processing,
Parameter 4: the size of closing for the target,
Parameter 5: the number of times for the closing processing of the target.

3. **Parameter Optimization by Using a Genetic Algorithm.** Generally, in order to find the optimal values of the five parameters, it would need more than 200 years to calculate the scores of all the patterns, which are the combinations of the five parameters, using an ordinary computer. In this study, therefore, an optimization method is used which features a Parameter-free Genetic Algorithm (PfGA) which can mark high scores without a huge amount of calculation [6,7]. The PfGA is one kind of genetic algorithm and has the following desirable characteristics: 1) it does not need the user to set parameters, such as the mutation rate, and 2) it convergences earlier than the simple genetic algorithm.

Figure 4 shows the flowchart of the PfGA and Figure 5 shows a conceptual diagram of the [Choice method] for the PfGA. It can be seen from Figure 4 that the PfGA can be implemented by the following six steps.

(1) Select one individual at random from the "All searching area" and put it into the "Specific area".
(2) Repeat step (1) again.
(3) Select the two individuals as parents at random and make two individuals as offspring through "N-point crossover" of the parents.

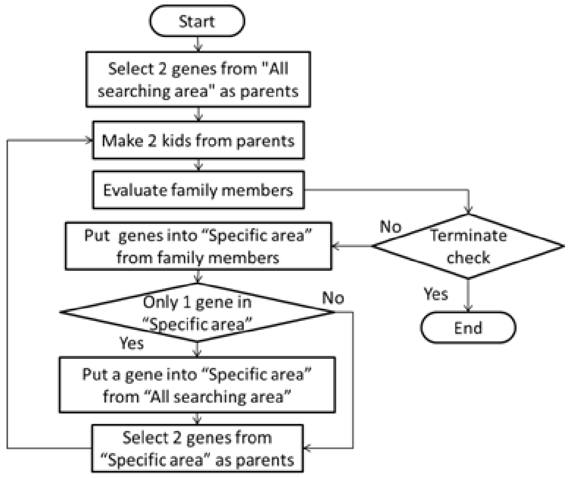


FIGURE 4. Flowchart of PfGA

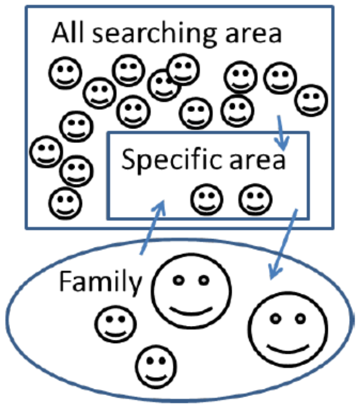


FIGURE 5. Concept diagram of the PfGA

(4) Select one individual among the two offsprings and mutate it in a random number and position.
(5) Evaluate four individuals (parents and two offsprings) and return 1 to 3 individuals into the "Specific area" by following the [Choice method] (it will be shown below).
(6) Return to step (3) when number of individuals in the "Specific area" is more than two, but if it is not, return to step (2).

Furthermore, the [Choice method] can be shown as follows.

(1) If both offsprings are better than both parents, then both offsprings and the better parent (total 3 individuals) return to the "Specific area".
(2) If both offsprings are worse than both parents, then the better parent (1 individual) returns to the "Specific area".
(3) If only one parent is better than both offsprings, then the better parent and the better offspring (total 2 individuals) return to the "Specific area".
(4) If only one offspring is better than both parents, then the better offspring (1 individual) returns to the "Specific area".

4. Experiment and Result Consideration.

4.1. Definition of the score for the results of the inspection. In order to evaluate the optimization result of the parameters, an evaluation sample is created that has defects on the whole surface of the inspection part. And the size of defects is based on the evaluation criteria for the defect.

Figure 6 shows a picture of the evaluation sample, which is combined by pictures from four aspects that correspond to the four surfaces of the evaluation sample, and the specular reflection in each picture has been removed by the specular processing procedure shown in Section 2. By using this picture, the defects are identified using the defect detection methods mentioned in Section 2, and the score based on the rate of detection is calculated. The values of the parameters which make the score a maximum are defined as the best values of the parameters.

Specifically, a csv file is first made beforehand, in which the coordinates of the center of all the defects in the sample for the scoring are written as the correct answer. Then all the detected defects are labeled one by one and the center coordinate and radius of the circumscribed circle of each label are obtained. Finally, the numbers of "correct" and "incorrect" are counted by the following rules.

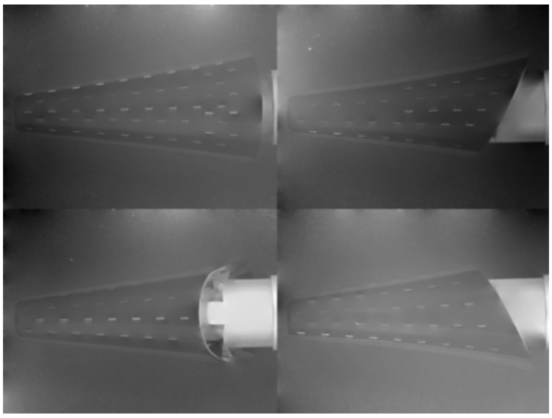


FIGURE 6. Evaluation sample (covering all surfaces)

(1) If the coordinate is in the circumscribed circle of the detected defect, then "correct" is increased by 1.
(2) If the coordinate is not in the circumscribed circle of the detected defect, "incorrect" is increased 1.
(3) All the coordinates are prevented to be "correct" more than two times.

After all the detected defects are classified as "correct" or "incorrect", the score is defined the below formula.

$$score = 10000 \times \frac{correct - incorrect}{number\ of\ defects\ in\ evaluation\ sample}$$

4.2. **Evaluation results and discussion.** The programs of the previous method and the Canny method, and the parameters optimization using the genetic algorithm have been created in C# and the free image processing source OpenCV Sharp [8]. As a result of searching the best values of parameters by the PfGA, there are many value patterns of maximum score 10000 obtained by both the previous method and the Canny method. Figure 7 shows a sample, which includes a defect of $\Phi = 0.4$, and Figure 8 shows a defect detection result obtained by using a pattern of the best values of the parameters, where Figure 8(a) shows the result obtained by using the previous method, and Figure 8(b) shows the result obtained by using the Canny method. It can be seen from Figure 8 that both methods detected defects successfully. However, it was found that some normal points are detected as defects by using some patterns of the best values of the parameters.

To compare the defect detection effectiveness between the optimal parameters obtained by the PfGA and the previous parameters obtained by human judgment, defect detection was carried out by the previous method using the values of parameters which were decided

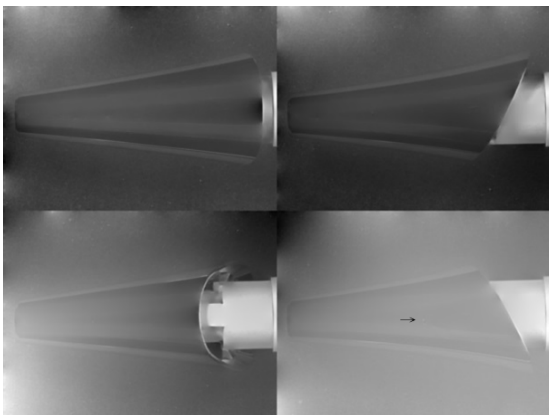
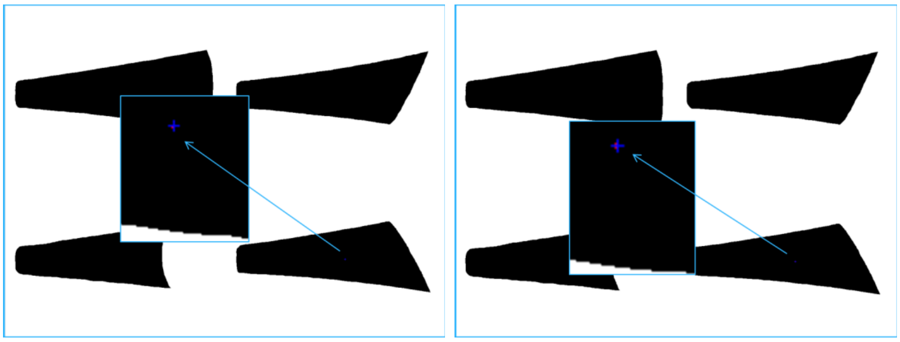
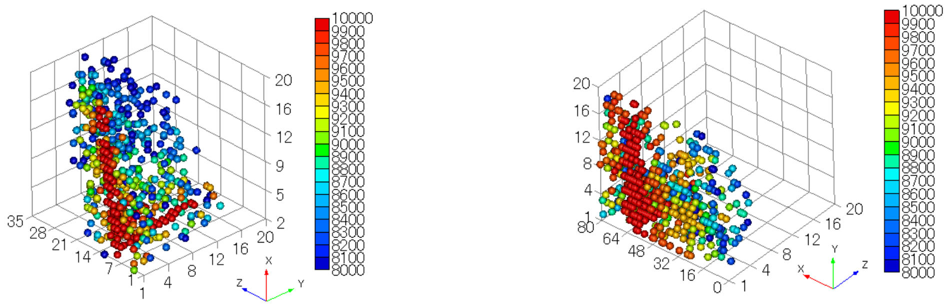


FIGURE 7. Target image ($\Phi = 0.4$)



(a) Previous method (b) Canny method

FIGURE 8. Result of inspecting Figure 7



(a) Previous method (b) Canny method

FIGURE 9. Distribution and evaluation values of parameters

based on human judgment. As a result, the score was 9779, although the maximum was 10000. The same parameter was also used to detect the defect in Figure 7 by using the previous method. The result shows that defect was detected, but there are 5 normal points were also detected as defects.

As shown above, many patterns with the best values of the parameters can be found by the PfGA, so, the problem is how to select between them. Here, 700 patterns of parameters were searched, in which 500 patterns of parameters had scores over 8000 and the remaining 200 patterns of parameters had scores over 10000. In order to simplify the problem, the values of parameters 1 and 2 were chosen from the best values and fixed, because these parameters do not vary widely. Figure 9 shows the distribution of the values of parameters 3, 4 and 5, where Figure 9(a) is obtained by the previous method, and Figure 9(b) is obtained by the Canny method. In addition, the x-axis, y-axis, and z-axis are related with each value of parameter 3, parameter 4 and parameter 5, respectively. The color shows the score level. In the case of the previous method, the maximum score can be obtained according to the following condition:

$$\mathrm{p3} \geqq 3, \quad \mathrm{p4} \leqq 24/\mathrm{p3} + 1, \quad 11 \leqq \mathrm{p5} \leqq 14,$$

where p1 = 9, and p2 = 254 are fixed. In this case, there are only 14 out of 164 patterns whose score is not a maximum. In the case of the Canny method, the maximum score can be obtained according to the following condition:

$$57 \leqq \mathrm{p3} \leqq 63, \quad \mathrm{p4} \leqq 10/\mathrm{p5} + 2,$$

where p1 = 9 and p2 = 80 are fixed. In this case, there are only 7 out of 136 patterns whose score is not a maximum.

Therefore, it is better to choose the best values of the parameters from the area shown above in which many best parameter values are gathered for inspecting.

5. **Conclusions.** In this paper, in order to set optimal parameters, an optimization method using the Parameter-free Genetic Algorithm (PfGA) was proposed, and its effectiveness was confirmed by simulation using a previous defect detection method and a new Canny method. The results obtained can be shown as follows.

(1) The parameter optimization method proposed by using the PfGA is able to find suitable values even after only a few calculation processes. And it was confirmed that the best values of parameters which were obtained by the proposed method were effective with a real defect image. At the same time, the algorithm was able to optimize parameters even if the defect detection method is different.
(2) It was confirmed that the new defect detection method called the Canny method was effective in detecting defects.
(3) By comparison with the previous parameters decided by human judgment, it was confirmed that the parameters which were obtained by the PfGA were superior.
(4) It was confirmed that the distribution of best values of parameters existed in a limited range and a selection guideline of parameters values was obtained.

In future research, the rule for scoring to reduce the misdetection rate using the best values of parameters will be reconsidered. The quality of images whose specular reflection is deleted is not stable in some cases. Therefore, the specular reflection removing process will be improved.

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