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Design of A Gaussian Filter based on Particle Swarm Optimization for Automatic Visual Inspection System

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***Abstract*—This paper proposes a development of image processing technique for inspecting the printed circuit board (PCB) of hard disk drive (HDD), which is an important part. Normally, PCB inspection is carried out by using high–resolution line scan camera. The visual inspection system of PCB is usually corrupted by image processing noise. Measuring system is significantly affected by noise because the size of the PCB is very small. To overcome this problem, this paper proposes an effective filter which uses Particle swarm optimization to design the optimal standard deviation parameter in the Gaussian filter. Experimental results demonstrate the effectiveness of the proposed filtering technique.**

***Index Terms*—Image processing, Gaussian filter, Particle swarm optimization.**

I. Introduction

Thailand is one of the largest exporter country of hard disk products with an export value of more than 400 million baths. In Thailand, HDD industry has a relatively short but fascinating history. In the past decades, the HDD storage capacity is increased from only 5 MB of data to be more than 100 GB. This enormous growth was made possible by developments in diverse fields of knowledge including materials, mechatronics, tribology, signal processing and electronics. HDD is composed of many components such as flip-chip, HDD arm, spindle motor, and etc. The quality of HDD components influences the overall hard disk drive quality. To ensure the quality of such components, many inspections and testing are performed. Visual inspection is one of the most important inspections in quality assurance of HDD industry. It ensures that all components are produced in standard size good quality for hard disk settings. Normally, this inspection is carried out by a skilled inspector; however, there are some drawbacks with the human inspector such as human error, time consuming, and etc.

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In the past decades, many immense developments in automatic visual inspection machines have been done and the results of those are used extensively in today's industrial process inspection. To inspect the physical shape of the component in HDD, mostly, a high resolution camera is used as a video capture device and the inspection is carried out by human. The effectiveness of such inspection is mainly depends on the skill of inspector. Unfortunately, there are many problems caused by human inspection such as the unskilled inspectors, human errors, time consuming, and etc. To overcome these problems, this research aims to study and provide solutions to the primary problems in visual inspection.

Several approaches for enhancing the ability of visual inspection and image processing were proposed in [1-2]. In [1], the image processing is enhanced by radiographs utilizing filtering, gray scale transformation and Sobel gradient operator. They applied the Gaussian filter for removing noise and then applied the Sobel gradient operator for determining edge image. The proposed technique was implemented on the x-ray film. Heath, M. et al., [2] used the Gaussian Filter to reduce noise and applied the double threshold method to achieve the better results of image classification.

In this paper, we developed an automatic visual inspection technique for inspecting printed circuit board (PCB) in a HDD component. The developed technique enhances the visual inspection system and solves the significant problems caused by human inspection. The accuracy of the proposed technique is investigated in comparison with the measured value from the destructive inspection. As shown in experimental results, the proposed technique has good accuracy for inspecting PCB in a HDD. The remainder of this paper is organized as follows. Automatic visual inspection and proposed image processing is described in section II. The experimental results are shown in section III. And, finally, in section IV the paper is summarized with some final remarks.

II. Automatic Visual Inspection Machine

A. Developed Visual Inspection Machine [1-3]

The developed inspection technique is shown in Fig. 1. In this system, a line scan camera is used as a video capture device and our proposed image processing is developed for inspecting the completeness of PCB. Fig. 1 shows the diagram of experimental setup in this research work. The image from line scan camera is sent to the image processing unit which developed on personal computer. Theory and concepts of image processing used in this paper are described next.

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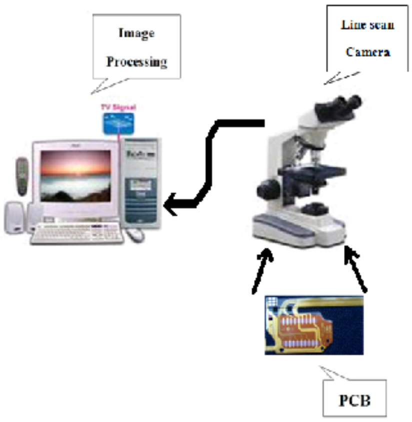

Fig. 1 Diagram of the developed system.

An example of x-ray image used as a raw image of our proposed algorithm is shown in Fig. 2. In our developed algorithm, positions and specified properties of PCB are automatically detected.

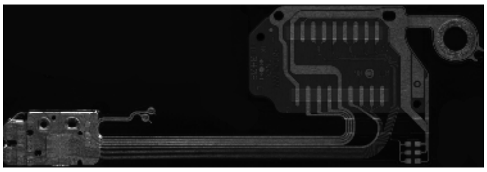

Fig. 2. An example of PCB image.

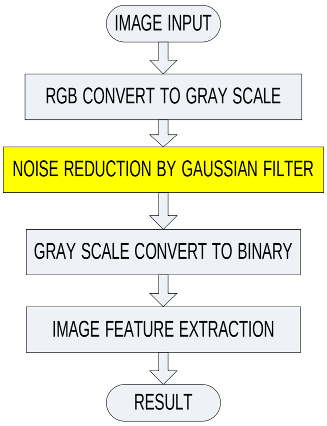

Fig. 3. Block diagram of the proposed algorithm.

Detail of the proposed image processing is described by following steps. [4]

1. Capture the picture from x-ray camera and then convert the mode of picture from RGB to gray. One formula that can be used for this purpose is.

$$G_{gray}(x,y)=\left[\frac{G_R(x,y)+G_G(x,y)+G_B(x,y)}{3}\right] \quad (1)$$

where,

$G_R\ (x, y)$ is the red intensity value at position (x, y),
$G_G\ (x, y)$ is the green intensity value at position (x, y),
$G_B\ (x, y)$ is the blue intensity value at position (x, y),
$G_{gray}\ (x, y)$ is the gray intensity value at position (x, y).

2. Adjust the intensity by the normalized intensity method. This process will change the intensity of image to the standard boundary using (2).

$$G_{nor}(x,y) = Re \times \frac{[G(x,y) - \min(G(x,y))]}{[\max(G(x,y))-\min(G(x,y))]} \quad (2)$$

where $G\ (x, y)$ is the intensity value at the position (x, y),
$G_{nor}\ (x, y)$ is the adjusted intensity value at the position (x, y),
Re is standard intensity range.

In this paper, Re is selected as 255 to make the highest and lowest of intensity values in image are 255 and 0, respectively.

3. Gaussian filters are designed to give no overshoot to a step function input while minimizing the rise and fall time. This behavior is closely connected to the fact that the Gaussian filter has the minimum possible group delay. From these properties, Gaussian filter's benefit can be used as noise reducer in printed circuit board (PCB) image.

4. Convert the gray image to binary image by thresholding method.

B. Gaussian filter [6]

The Gaussian distribution in 1-D has the form:

$$G(x)=\frac{1}{\sqrt{2\pi}\sigma}e^{\frac{-x^2}{2\sigma^2}} \quad (3)$$

where σ is the standard deviation of the distribution. We have also assumed that the distribution has a mean of zero (*i.e.* it is centered on the line x=0). The distribution is illustrated in Fig. 4.

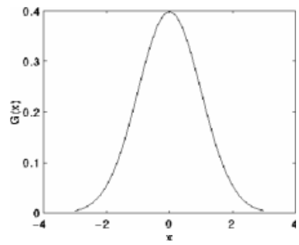

Fig. 4 1-D Gaussian distribution with zero mean and σ =1

In 2-D, an isotropic (*i.e.* circularly symmetric) Gaussian has the form:

$$G(x,y)=\frac{1}{2\pi\sigma^2}e^{\frac{-(x^2+y^2)}{2\sigma^2}} \quad (4)$$

This distribution is shown in Fig. 5.

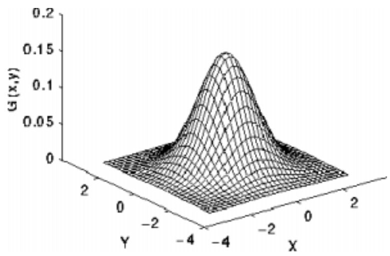

Fig. 5 2-D Gaussian distribution with mean (0,0) and σ =1

The idea of Gaussian smoothing is to use this 2-D distribution as a `point-spread' function, and this is achieved by convolution. Since the image is stored as a collection of discrete pixels we need to produce a discrete approximation to the Gaussian function before the convolution is performed. In theory, Gaussian distribution is non-zero everywhere, which would require an infinitely large convolution kernel, but in practice it is effectively zero more than about three standard deviations from the mean, and so

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we can truncate the kernel at this point. Fig. 6 shows a suitable integer-valued convolution kernel that approximates a Gaussian with σ of 1.0.

$\frac{1}{273}$

1	4	7	4	1
4	16	26	16	4
7	26	41	26	7
4	16	26	16	4
1	4	7	4	1

Fig. 6 Convolution kernel on Gaussian filter with σ =1.0

Once a suitable kernel has been calculated, then the Gaussian smoothing can be performed using standard convolution method. The convolution can in fact be performed fairly quickly since the equation for the 2-D isotropic Gaussian shown previously is separable into *x* and *y* components. Thus the 2-D convolution can be performed by first convolving with a 1-D Gaussian in the *x* direction, and then convolving with another 1-D Gaussian in the *y* direction. (The Gaussian is in fact the *only* completely circularly symmetric operator which can be decomposed in such a way.)

C. Mean Squared Error (MSE)

MSE is one of many approaches to measure difference between an estimator and true value of the quantity. MSE corresponds to the value of the squared error loss or the quadratic loss and measures the average of the square of the "error" that differs from the quantity to be estimated. Difference occurs by randomness or the estimator does not account for information that could produce a more accurate estimate.

Measuring efficiency of Gaussian filter in reducing of noise in PCB is used by MSE method as Follows. [5]

$$MSE = \frac{1}{MN}\sum_{y=1}^{M}\sum_{x=1}^{N}\left[I(x,y) - I'(x,y)\right]^2 \quad (5)$$

where *I(x,y)* is the original image, *I'(x,y)* is the approximated version (which is actually the decompressed image) and *M,N* are the dimensions of the images.

D. Particle Swarm Optimization (PSO)

In the proposed technique, PSO is adopted to design a filter. PSO was first proposed by Eberhart and Kennedy [6]. This technique is a population-based optimization problem-solving algorithm.

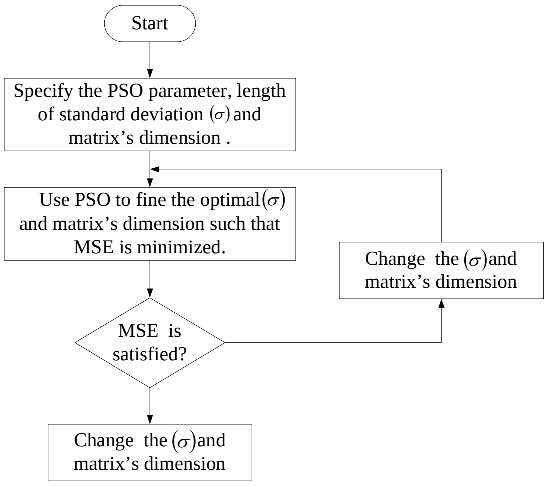

Fig. 7. Flow chart of the proposed design procedure.

Our proposed algorithm is summarized as follows.

Step 1 Specify the PSO parameters , length of standard deviation and matrix' s dimension

Step 2 Specify the PSO parameter ranges.

Step 3 Initialize several sets of parameters σ and matrix' s dimension as swarm in the 1st iteration. In this case, each [σ and matrix' s dimension] is a particle.

Step 4 Use the PSO to find the optimal PSO parameter .

Step 5 Check performances in both frequency and time domains. If the performance is not satisfied such as too low *MSE* (too low fitness function), then go to step 2 to find the optimal filter parameter.

Standard PSO algorithm used in step 4 of the proposed technique is briefly described as follows.

Specify the parameters in PSO such as population size (*n*), upper and lower bound values of problem space, fitness function (*J*), maximum and minimum velocity of particles (V_{max} and V_{min}, respectively), maximum and minimum inertia weights (Q_{max} and Q_{min}, respectively).

1. Initialize *n* particles with random positions within upper and lower bound values of the problem space. Set iteration count as *iter* =1.
2. Evaluate the fitness function (*J*) of each particle.

$$Fitness\,function\,(J) = MSE = \frac{1}{MN}\sum_{y=1}^{M}\sum_{x=1}^{N}\left[I(x,y) - I'(x,y)\right]^2 \quad (6)$$

3. For each particle, find the best position found by particle *i* call it X_{pi} and let the fitness value associated with it be J_{pbesti}. At first iteration, position of each particle and its fitness value of i^{th} particle are set to X_{pi} and J_{pbesti}, respectively.
4. Find a best position found by swarm call it *G* which is the position that maximum fitness value is obtained. Let the fitness value associated with it be J_{Gbest}. To find *G* the following algorithm described by pseudo code is adopted.

```
(At first iteration set J_gbest,=0)
  For i = 1 to n do
      If J_pbesti > J_gbest, then
  G = X_pi, J_Gbest= J_pbesti
  end;
```

5. Update the inertia weight by following equation

$$Q = Q_{\max} - \frac{Q_{\max} - Q_{\min}}{iter_{\max}}\,iter \quad (7)$$

where *Q* is inertia weight, *iter* and $iter_{max}$ are the iteration count and maximum iteration, respectively.

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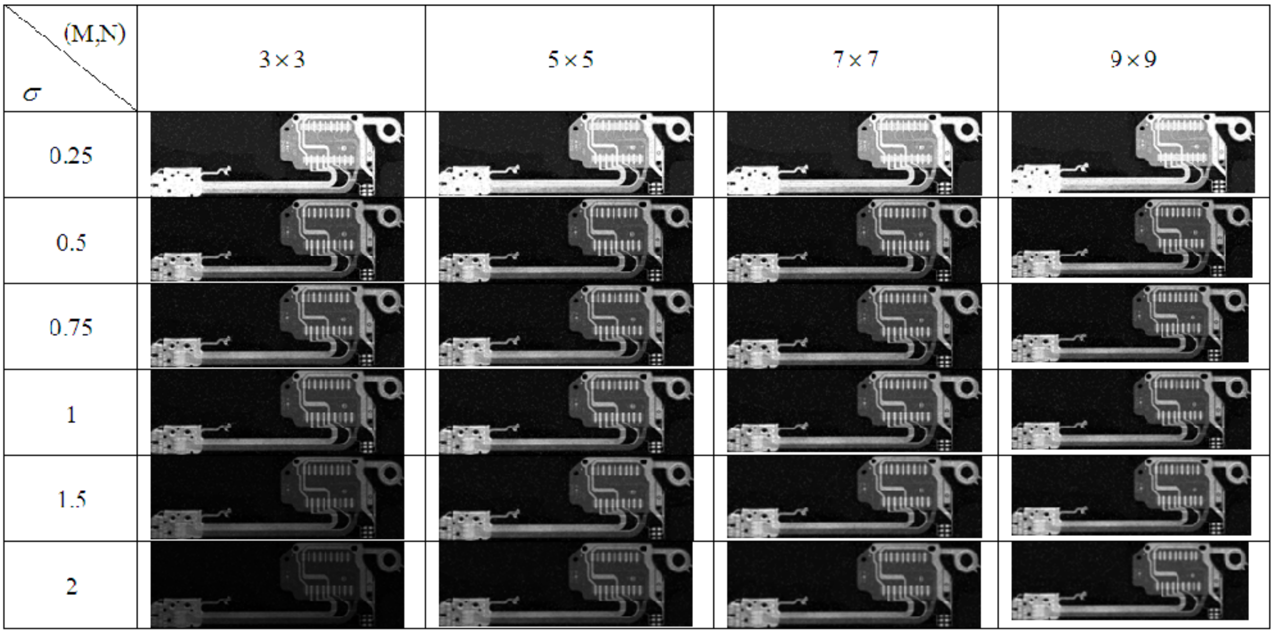

Fig. 8. Images of PBC after reducing noise with different values of σ , *M* and *N*

6. Update the velocity and position of each particle. For the particle *i*, the updated velocity and position can be determined by following equations.

$$v_i(iter+1)=Qv_i(iter)+\alpha_1[\gamma_{1i}(X_{pi}-X_i(iter))]+\alpha_2[\gamma_{2i}(G-X_i(iter))] \quad (8)$$

$$X_i(iter+1)=X_i(iter)+v_i(iter+1)$$

7. Increment iteration for a step. (*iter* = *iter*+1)
8. Stop if the convergence or stopping criteria are met, otherwise go to step 2.

III. Experimental Results

Fig. 8 shows the results of noise reducing in PCB after applying Gaussian filter. Matrix's dimension were set up at 3×3, 5×5, 7×7 and 9×9 (size) and standard deviation (σ) were set up at 0.25, 0.5, 0.75, 1, 1.5 and 2, respectively. Considering Fig. 8, it is seen that all images are alike and not easy to decide the best image. To help deciding the best image systematically, MSE was used as a measure to evaluate the efficiency of noise reduction. The results from applying MSE to determine the suitability of filtering image for different cases are given in Fig. 9.

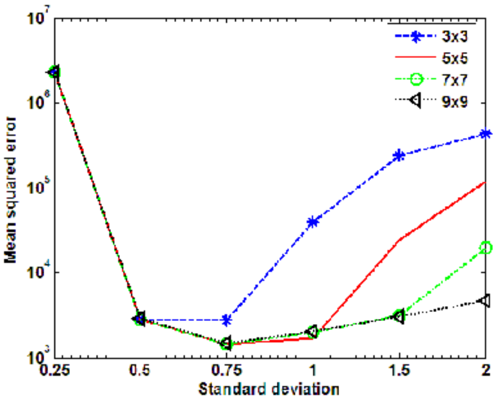

Fig. 9. MSE value of PCB image in experiment with salt & pepper noise value at 0.02.

Fig. 9 shows MSE and standard deviation value for comparison of noise reduction in PCB by Gaussian filter with salt & pepper noise at 0.02. Filter's parameter of matrix's dimension was 3×3, 5×5, 7×7 and 9×9 and standard deviation (σ) at 0.25, 0.5, 0.75, 1, 1.5 and 2, respectively. At low value of σ, it is seen that for all dimensions the achieved MSEs are identical. However as σ increases, the achieved MSE decreases and become distinguishable. From this Fig., it is found that σ of 0.75 and the dimension of 5×5 give the best (lowest) MSE. Additionally, as σ further increases, all achieved MSEs from different dimensions increases with the lower MSE from the case of 9×9 dimension.

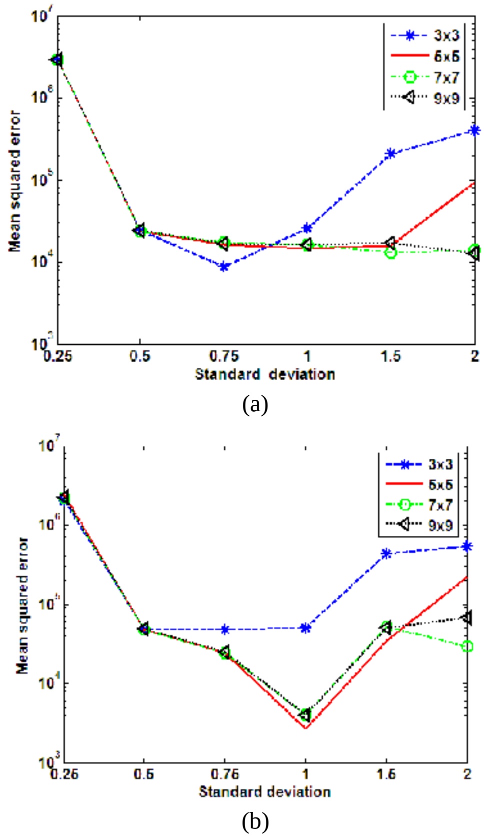

Fig. 10. MSE value after treated with salt & pepper noise.

Fig. 10 shows MSE value after applying salt & pepper noise of 0.05 and 0.075 for Fig. 10(a) and (b), respectively. The best (lowest) MSE for the case of 0.05 noise value in Fig.

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10(a) is from the standard deviation of 0.75 and the size of 3×3 while the best MSE for the case of 0.075 noise value in Fig. 10(b) is from the standard deviation of 1.0 and the size of 5×5. It is seen from these three Fig.s (Fig. 9, Fig. 10(a) and (b)) the best achievable MSE is not from the same condition; that is, not from the same value of standard deviation and the matrix dimension. To get the best MSE for different value of noise, PSO technique is adopted. That is, the optimum value of standard deviation and matrix dimension are determined using PSO technique. The following are the result after running PSO in order to find the optimum parameters in Gaussian filtering.

PSO parameter:

In this paper, the following PSO parameters are used; that is, population size = 30, maximum iteration = 10, standard deviation (σ) $\in$ [0.25 2], acceleration coefficients = 2.1, minimum inertia weights = 0.6 and maximum inertia weights = 0.9.

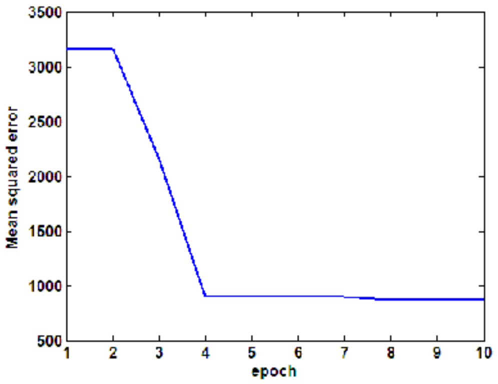
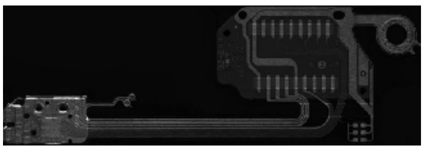
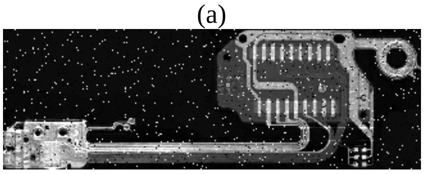


Fig. 11. Convergence of the fitness value.

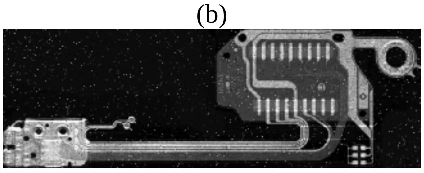
From Fig. 11, the achieved MSE starts to converge at the 4th iteration and slightly decreases after that. The optimal value of MSE is 875.0843 as given in the Fig. 11.



(a)



(b)



(c)

Fig. 12. (a) Original image (b) Corrupted image with noise of 0.02 (c) Image after applying the proposed technique

To verify the effectiveness of noise reduction by PSO Technique, experiments were performed as given in Fig. 11. The images for different stages are shown in Fig. 12. It is clearly seen that after applying the proposed technique to the corrupted image, the achieved image (in Fig. 12(c)) is improved. This is just an example for showing the efficiency of the proposed technique in designing filtering parameters in order to reduce the noise in the image.

IV. Conclusion

In this paper, two parameters in the Gaussian filter namely the standard deviation and the matrix dimension are designed using PSO technique. The optimum values of standard deviation and matrix dimension for reducing the noise in an image are achieved by considering the resulting MSE with PSO technique. For example, as shown in Fig. 12 with the noise of 0.02, the achieved optimum standard deviation and matrix dimension from PSO technique are 0.65 and 5×5, respectively. It is quite clear that applying PSO technique to design the Gaussian filter's parameters is a promising approach which can be applied in practice.

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