Optimal Design of Fuzzy Image Noise Reduction Technique for Visual Inspection of Pre-Amplifier

Anakkapon Saenthon and Somyot Kaitwanidvilai

Abstract—**In this paper, the optimal design of fuzzy image filtering is adopted for inspecting the perfection of pre-amplifier circuits, an important part of a hard disk drive. A high resolution X-ray camera is applied for capturing the image. Then the proposed automatic visual inspection which mainly consists of the image processing algorithms is applied to find the interesting features. The technique used in this paper enhances the ability to reduce noise by investigating the design of optimal fuzzy filtering. Particle Swarm Optimization (PSO) is adopted to find the optimal fuzzy filter. As our results indicate, our technique is superior to conventional methods such as the mean filter, the median filter, and the Adaptive Wiener filter.**

Index Terms— **Automatic Visual, Inspection, Fuzzy Image Processing, Fuzzy Filtering, Image Processing**

1. INTRODUCTION

This paper presents the design of an optimal fuzzy image noise reduction technique applied to the inspection of a pre-amplifier in an HDD. This method is adopted in the developed visual inspection and used in an HDD company. Pre-amplifier circuit is an important invisible part in HDD component; however, this part can be inspected by using an X-ray camera. Normally, the X-ray image is inspected by a human who probably introduces some human errors into the inspection process. To overcome this problem, an automatic visual inspection can be applied. All image processing used in the CCD camera can be applied to the X-ray image. Much image noise occurs in the X-ray image; thus, image noise reduction is a strongly needed in this inspection. There are many noise reduction filters used in conventional image processing. This paper proposes a method that can enhance the ability to reduce filter noise, that is, fuzzy image noise filtering for an X-ray camera.

In fuzzy image processing (FIP), expert knowledge can be incorporated to overcome the problems which are difficult to solve by conventional image processing. FIP is a powerful set of tools to represent and process human knowledge in form of fuzzy if-then rules. In addition, many difficulties in image processing, which are not always due to randomness but rather to ambiguity and vagueness, can be managed by FIP. Examples of FIP are shown in [1-3]. Ali, M.A. [1] proposed a new shape-based algorithm, called fuzzy image segmentation using shape information (FISS), by incorporating general shape information. The new FISS algorithm was compared to other well-established shape-based fuzzy clustering algorithms in their paper. Marino, P. et al. [2] applied the FIP to a visual inspection for a quality control process. They showed that fuzzy image processing is able to inspect each end efficiently. Van De Ville, D. [3] introduced a new fuzzy filter which has two stages. The first stage computes a fuzzy derivative and the second stage uses these fuzzy derivatives to perform fuzzy smoothing. In this paper, fuzzy filtering and conventional filtering are investigated for a Flip-Chip visual inspection machine. To find the optimal fuzzy filter, PSO is applied to find the optimal amplification factor in the FIP. Results show that our proposed technique can reduce noise better than the conventional filter. The remainder of this paper is organized as follows. Section 2 addresses the concept of fuzzy filtering. Section 3 illustrates the proposed PSO based FIP filter. Section 4 describes the experimental setup and results. Section 5 concludes the paper.

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2. FUZZY FILTERING METHOD

In this paper, the X-ray image from an X-ray camera is a raw image for visual inspection. Fig.1. shows the diagram of the experimental setup in this research work. The image from the X-ray camera is captured by the image processing unit and developed on a PC. First, image noise reduction is adopted to remove the noise and then image feature extraction is applied to find the interesting features. However, this paper only focuses on the role of the noise reduction filter.

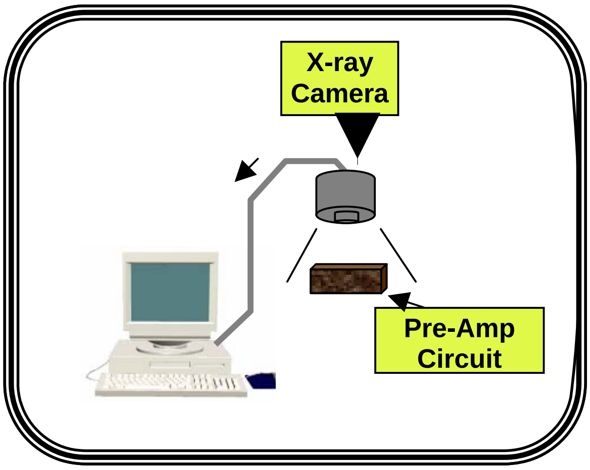

Fig. 1: The experimental setup for Automatic Visual Inspection Machine

2.1 Fuzzy Filtering (Fuzzy Noise Reduction) [3]

In this paper, the fuzzy image processing in [3] is adopted. This section illustrates the concept of fuzzy filtering for noise reduction. Fig. 2 shows the neighbourhood of the central pixel (x,y) defined in this paper. The fuzzy derivative of each direction can be computed using some of the neighbourhood pixels.

NW	N	NE
W	(x,y)	E
SW	S	SE

Fig. 2 Neighbourhood of pixel position (x,y)

The fuzzy noise reduction steps described in [3] can be briefly shown as follows:

A. Fuzzification

The derivation denoted by $\nabla_D(x,y)$ is defined as illustrated in the following. Examples of derivations in directions *N* and *NW* are shown as follows:

$$\nabla_N(x,y) = I(x,y-1) - I(x,y)$$

$$\nabla_{NW}(x,y) = I(x-1,y-1) - I(x,y) \quad (1)$$

As shown in Fig. 3, the membership function of the degree of gradient is defined where *K* is the adaptive parameter [3].

$$K = \sigma\alpha \quad (2)$$

where α is the final amplification factor that can be selected, and σ is the noise variance [3].

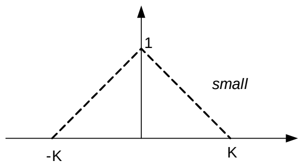

Fig. 3: Membership function for the property "small"

The membership function for the property "small" is defined as

$$m_K(u) = 1 - \frac{|u|}{K}, \quad 0 \le |u| \le K$$
$$= 0 \quad , \quad |u| > K \quad (3)$$

The value of fuzzy derivative for the pixel (x,y), $\nabla^F_D(x,y)$, in every direction can be calculated by applying the fuzzy rule. For example, in the *NW* direction:

If ($\nabla_{NW}(x,y)$ is small) and ($\nabla_{NW}(x-1,y+1)$ is small) or ($\nabla_{NW}(x,y)$ is small) and ($\nabla_{NW}(x+1,y-1)$ is small) or ($\nabla_{NW}(x-1,y+1)$ is small) and ($\nabla_{NW}(x+1,y-1)$ is small)

Then ($\nabla^F_{NW}(x,y)$ is small)

B. Fuzzy Smoothing

To compute the correction term Δ for any pixels, the pair of fuzzy rules for each direction is applied [3]. An example for the direction in NW is shown in the following.

λ^+_{NW} : if $\nabla^F_{NW}(x,y)$ is small and $\nabla_{NW}(x,y)$ is positive then *c* is positive

λ^+_{NW} : if $\nabla^F_{NW}(x,y)$ is small and $\nabla_{NW}(x,y)$ is negative then *c* is negative

where the terms "positive" and "negative" are defined by the membership functions in Fig. 4 (a) and 4 (b), respectively. The value *L* is the number of the gray level of the images. In this paper, *L* = 255. The correction term Δ for this fuzzy noise reduction technique for the direction *D* can be computed by [3].

$$\Delta = \frac{L}{8}\sum_{D \in dir}(\lambda^+_D - \lambda^-_D) \quad (4)$$

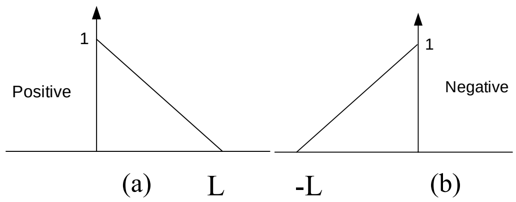

Fig. 4 Membership functions for the properties (a) positive (b) negative

3. PSO BASED FIP FILTERING

Optimal FIP filter can be designed by using PSO. In this paper, PSO is adopted to find the optimal amplification factor which is one of the most important factors in designing FIP. The cost function used for evaluating the optimal filter is shown in follow.

$$MSE = \frac{\sum_{i}^{M}\sum_{j}^{N}(O(i,j) - I(i,j))^2}{MN} \quad (5)$$

Where *O* is the output image, *I* is the original image, *i* and *j* are the position of pixel in axis *x* and *y*, respectively, *M* and *N* are the width and height of the image. In this paper, the pixel values in the image *O* are obtained by applying the FIP smoothing filter to the original image plus additive Gaussian noise. The proposed technique can be summarized as follows:

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Step 1 Specify the boundary α and define the PSO parameters such as population size, maximum and minimum velocities and momentum, etc. In this case, p is the candidate α which are referred to as 'particle'.

Step 2 Generate the swarm of the first iteration randomly.

Step 3 Find the fitness of each particle. The inverse of the cost function in (5) is adopted as the fitness.

Step 4 Update the inertia weight (*Q*), position and velocity of each particle using the following equations.

$$Q = Q_{\max} - \left(\frac{Q_{\max} - Q_{\min}}{i_{\max}} \right) i \tag{6}$$

$$v_{i+1} = Qv_i + a_1[\gamma_{1i}(P_b - p_i)] + a_2[\gamma_{2i}(U_b - p_i)] \tag{7}$$

$$p_{i+1} = p_i + v_{i+1} \tag{8}$$

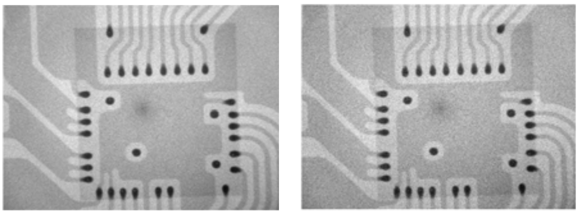
where a_1, a_2 are acceleration coefficients.

γ_{1i}, γ_{2i} are any random number in (0→1) range.

Step 5 While the current iteration is less than the maximum iteration, go to step 3. If the current iteration is the maximum iteration, then stop. The particle which has the maximum fitness is the answer of this optimization.

4. EXPERIMENTAL RESULTS

To reduce image noise, image filtering is firstly performed. The image feature extraction algorithms are next applied to inspect the bump shape. To evaluate the performance of fuzzy filtering and conventional methods, all filtering methods discussed in this paper are implemented for filtering the image with Gaussian noise. Mean square error (MSE) between the original and filtered image is used as the performance index for evaluating the ability of the filter. Fig. 5 shows the original image and image with additive Gaussian noise level (noise variance $\sigma = 0.015$).



(a) (b)

Fig. 5: (a) Original image from X-Ray camera, (b) Image with additive Gaussian white noise variance σ =0.015

In the proposed technique, boundary of α is set as [0, 10]. The PSO parameters are selected as: population size = 20, minimum and maximum velocities are 0 and 1.5, acceleration coefficient = 2.0, minimum and maximum inertia weights are 0.5 and 1.0. When running the PSO for 20 iterations, an optimal solution is obtained as shown in Fig. 6. Optimal α obtained by the proposed technique is 2.13 which results in the MSE = 72.34. The comparison of MSE between overall filters is shown in Table 1. As shown in this table, the fuzzy filtering with optimal parameters gains the lowest *MSE* compared to overall filters. This means that the output image when applying this filter is closer to the original image than others. Fig. 7 shows the experimental results of applying fuzzy filtering.

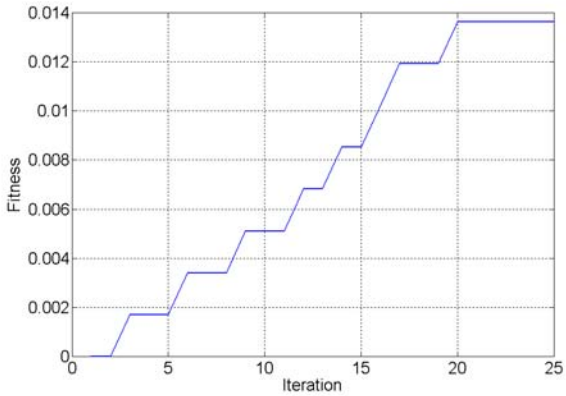
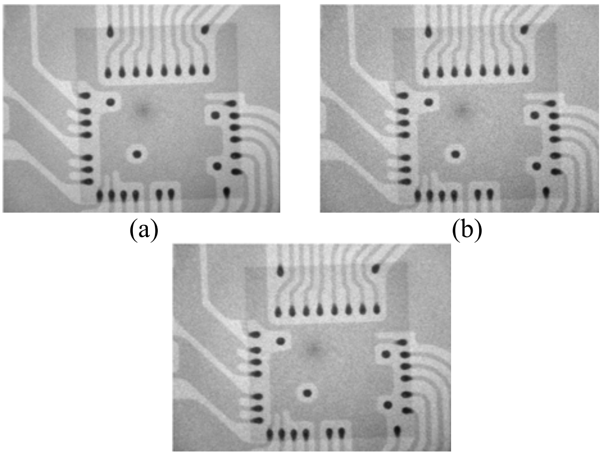


Fig.6 Convergence of solution of the proposed technique.



(a) (b)

(c)

Fig. 7 (a) Original image from X-Ray camera, (b) Image with additive Gaussian white noise σ = 0.015, (c) 2nd iteration of applying Fuzzy filter with α =2.13.

5. CONCLUSIONS

Conventional image processing can be applied for inspecting the pre-amplifier circuit. The fuzzy image processing used in this paper is optimal fuzzy filtering, which is superior to conventional filters. PSO can be adopted for enhancing the ability of the proposed filter. The experimental results prove the ability of the proposed technique in practical work.

Table 1 MSE values of overall filters used in this paper

Type of Image	MSE
Image with Noise	325.57
Mean filter	112.23
Median filter [3x3]	120.97
Adaptive Wiener filter [3x3]	91.15
2nd order Fuzzy Filter [3x3], α = 2.13	72.34

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