Defect inspection in semiconductor images using pattern recognition and neural network

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Abstract
We first present a method for detecting defects in an image with a flat background. To estimate inlier distribution, we use the fast Minimum Covariance Determinant (MCD) method with 68% of pixels. From the standard deviation (σ) estimated by the Fast MCD method, the region greater than 6σ is determined as a defect. For othrer images, using the cosine similarity map, we can classify the structure of image as 'Flat', 'Linear', 'Patterned', and 'Complex'. We also present two ways for converting an image with linear or patterned structure to an image with a flat background. Complex images that are neither linear nor pattern are inspected by neural network.

1 Introduction

- A variety of structures appear in semiconductor images.
- We classify the structures and present a defect inspection method suitable for each structure.

2 The fast MCD algorithm

The fast MCD algorithm, proposed by Rousseeuw et al. [1], is a inlier distribution estimator. The main idea of the fast MCD method is to use only a part of the data and update the part using Mahalanobis distance.

Algorithm 1: Fast MCD algorithm

Let H_1 be the initial subset of size nA_α.
while $\det(\Sigma_k) \neq 0$ *and* $\det(\Sigma_k) \neq \det(\Sigma_{k-1})$ **do**
  Compute mean vector μ_k and covariance matrix Σ_k for H_k.
  Compute Mahalanobis distance $d_M(x_i,\mu_k) = \sqrt{(x_i-\mu_k)^T\Sigma_k^{-1}(x_i-\mu_k)}$ for $i = 1 \ldots n$.
  H_{k+1}: the subset of size nA_α with the smallest Mahalanobis distance.
end

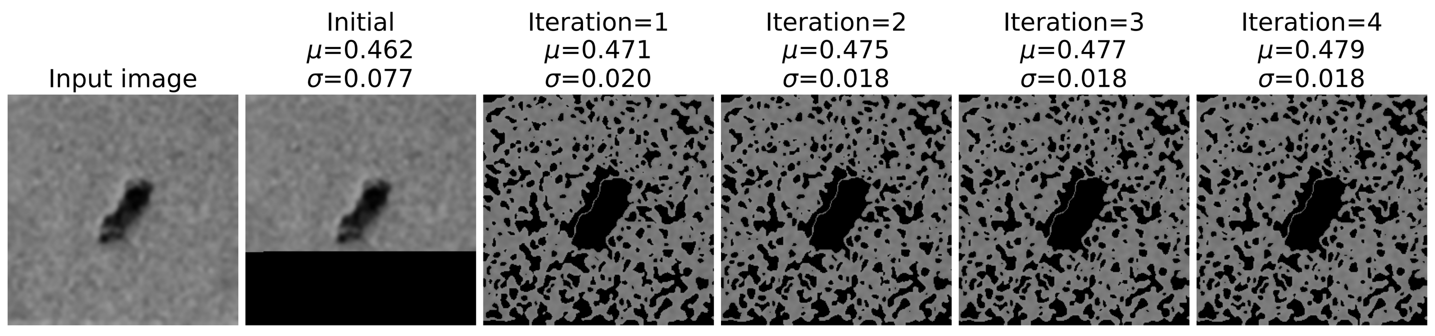

Figure 1: H_k subset for the fast MCD method when $A_\alpha = 0.68$.

Under the assumption of Gaussian noise, a histogram of the image follows a normal distribution. Let $A_\alpha \in [0,1]$ be the area of the normal distribution in the interval $\mu \pm \alpha\sigma$ and σ_α be the standard deviation of the normal distribution on the same interval. Then, the standard deviation σ of the original distribution can be obtained by multiplying r_α as

$$A_\alpha = \frac{1}{\sqrt{2\pi}\sigma}\int_{\mu-\alpha\sigma}^{\mu+\alpha\sigma} e^{-\frac{(x-\mu)^2}{2\sigma^2}}dx, \quad \sigma_\alpha^2 = \frac{1}{\sqrt{2\pi}\sigma A_\alpha}\int_{\mu-\alpha\sigma}^{\mu+\alpha\sigma}(x-\mu)^2 e^{-\frac{(x-\mu)^2}{2\sigma^2}}dx,$$

$$r_\alpha\sigma_\alpha = \sigma, \text{ where } r_\alpha = \frac{1}{\sqrt{1-\frac{2\alpha e^{-\frac{\alpha^2}{2}}}{\sqrt{2\pi}A_\alpha}}}.$$

3 structure classification and removing the structure

3.1 Cosine similarity map

We divide an image into 2×2 subimages and compute the cosine similarity maps. From the cosine similarity map, we obtain repeated regions by threshold. Using the repeated regions, we classify the pattern in the image.

- Linear image: Axis ratio of a connected component > 3.
- Patterned image: The number of connected components > 3.
- Homogeneous background: JSD between histogram and the Gaussian distribution < 0.1.

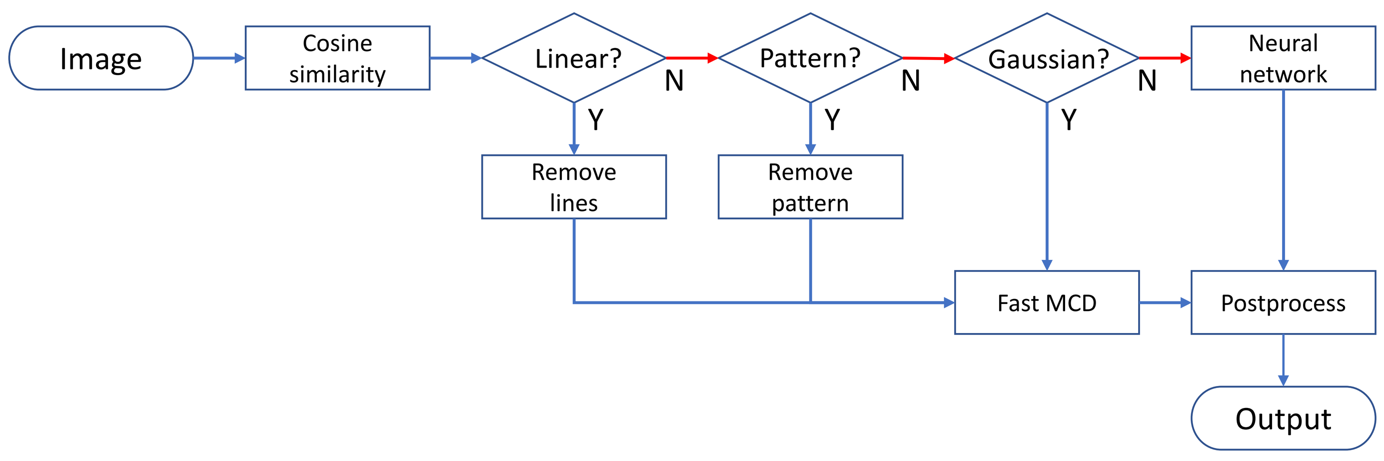

Figure 2: Flowchart for defect insepction.

3.2 Flat images

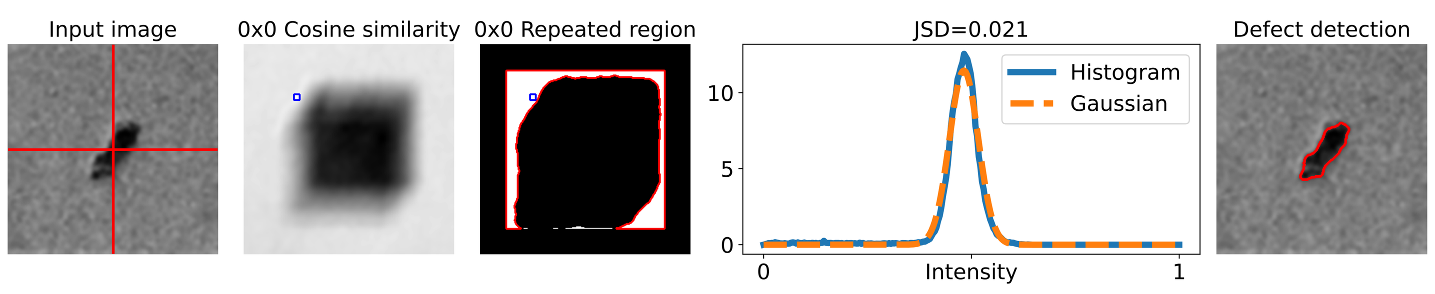

Figure 3: If the axis ratio is smaller than 3 and the number of connected components is also smaller than 3, then we compute the JSD between the histogram and the estimated Gaussian distribution. If JSD/ln(2) is smaller than 0.1, then the image is classified as a flat image and the fast MCD method is applied to detect defects.

3.3 Linear images

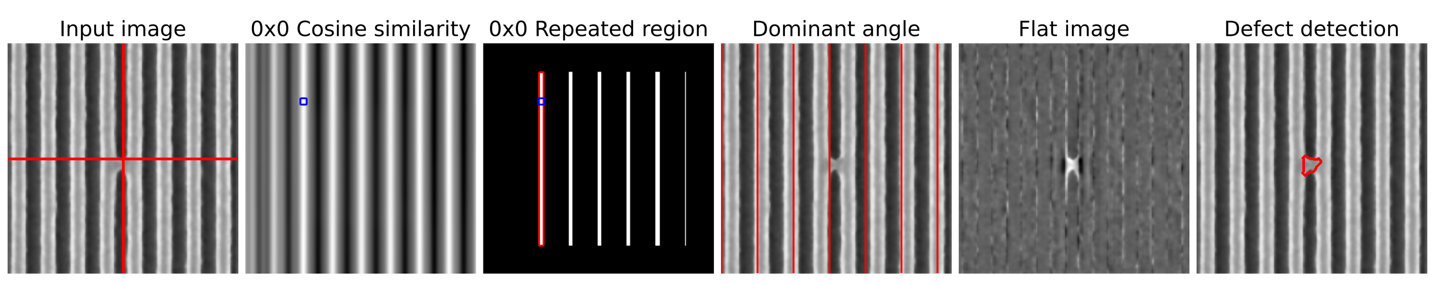

Figure 4: Since the axis ratio of a connected component in the repeated regions is bigger than 3, the image is classified as a linear image. Also from the repeated regions, we can get the dominant angle. Along the angle the linear structure is removed to obtain a flat image. Then, the fast MCD method is applied to detect defects.

3.4 Patterned images

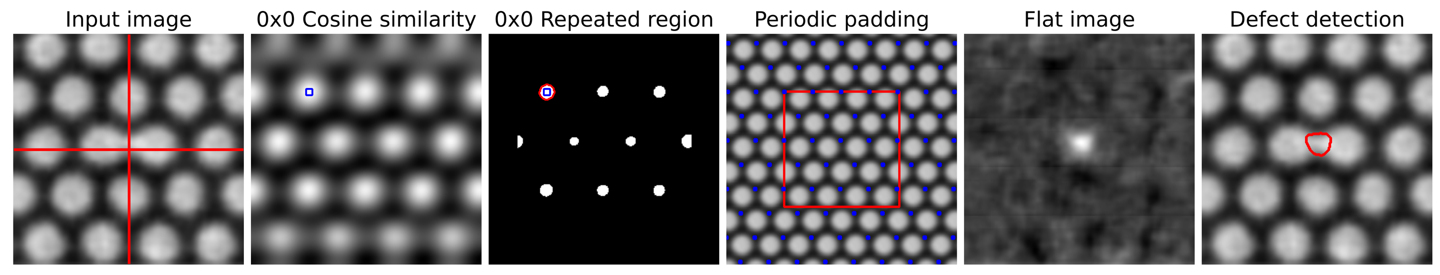

Figure 5: Since the axis ratio is smaller than 3 and the number of connected components is greater than 3, the image is classified as a patterned image. Also from the repeated regions, we can get basis vectors. We construct lattice points and a periodic padding image. Then, the fast MCD method is applied to detect defects.

3.5 Complex images

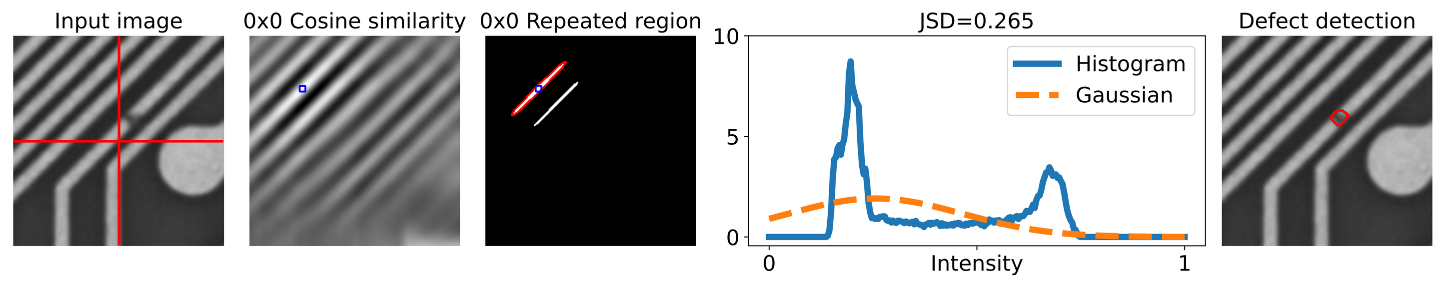

Figure 6: If the axis ratio is smaller than 3 and the number of connected components is also smaller than 3, then we compute the JSD between the histogram and the estimated Gaussian distribution. If JSD/ln(2) is bigger than 0.1, then the image is classified as a complex image and the segmentation network is used to detect defects.

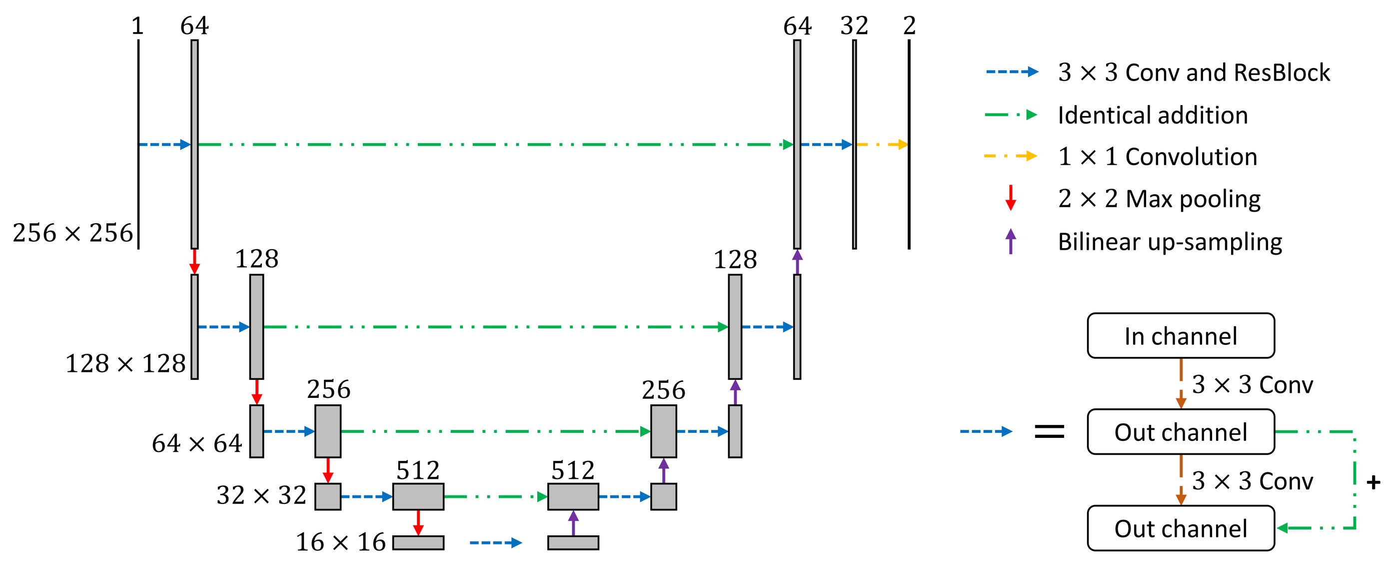

Figure 7: Segmentation network architecture; it has a U-Net structure with a ResBlock [2] form in a skip connection.

4 Numerical results

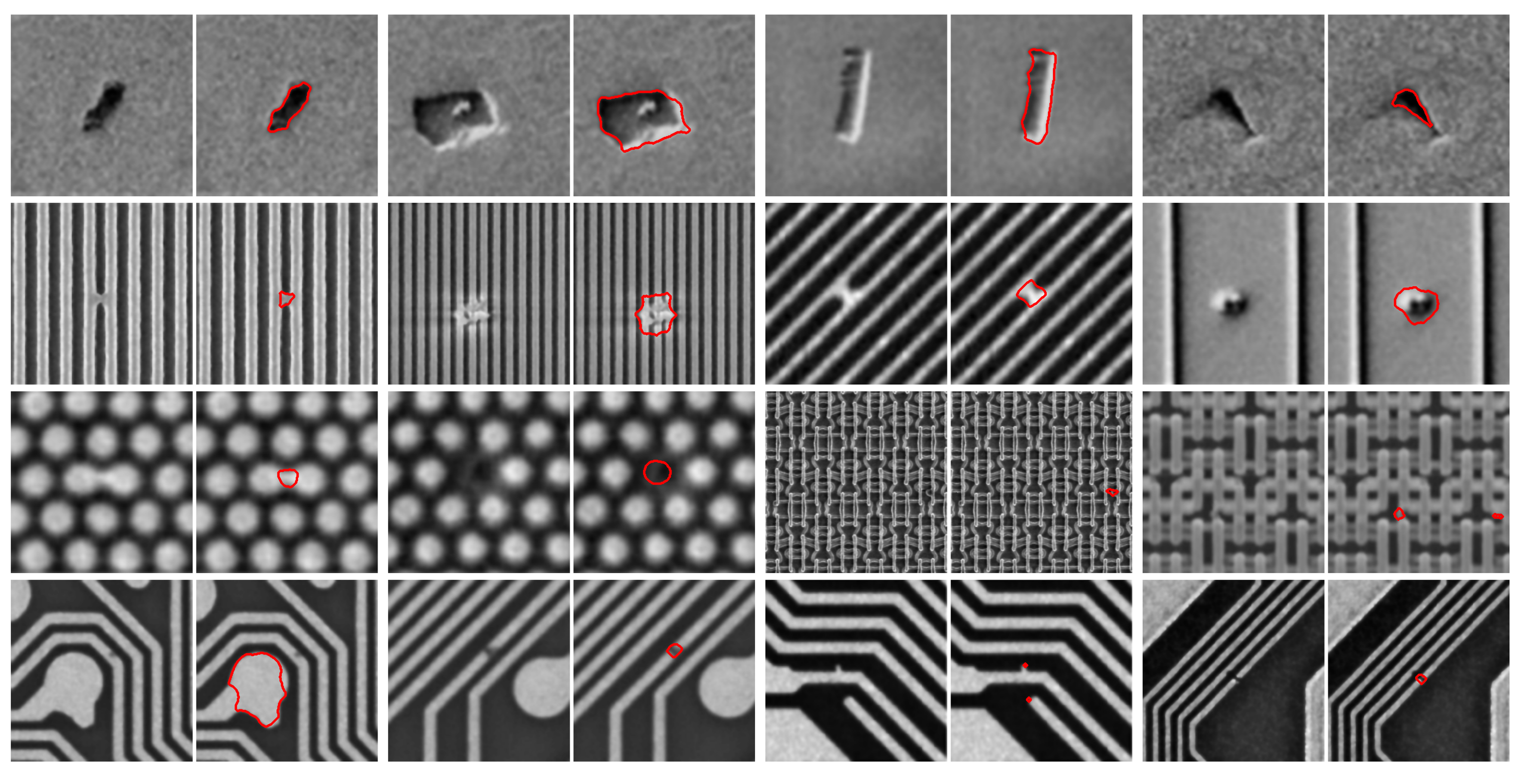

Figure 8: Defect inspection results for defective images.

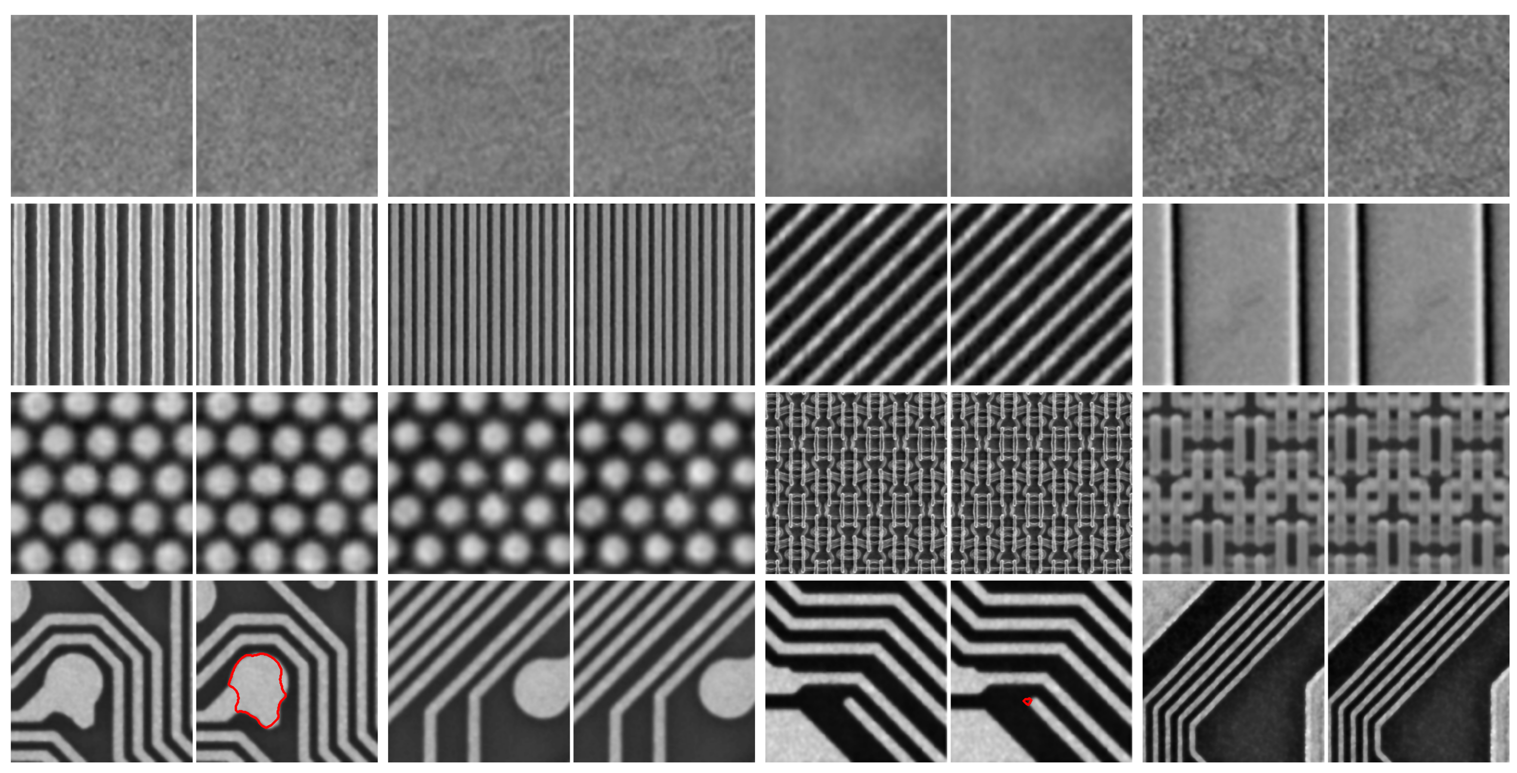

Figure 9: Defect inspection results for defect free images.

References

[1] P. J. Rousseeuw and K. Van Driessen: *A Fast Algorithm for the Minimum Covariance Determinant Estimator*, Technometrics, 41, pp. 212-223 (1999)

[2] K. He, X. Zhang, S. Ren, and J. Sun: *Deep residual learning for image recognition*, IEEE Conference on Computer Vision and Pattern Recognition (CVPR), pp. 770-778 (2016)

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