§41. A Noise Removal of the Penumbral Images by the Kernel Principal Component Analysis and its Evaluation

Nozaki, S. (Univ. Ryukyus),
Fujioka, S. (Osaka Univ.),
Azuma, R. (Aoyama Gakuin Univ.)

In inertial confinement fusion research, the neutron imaging is a key technique because the neutron images can provide direct information about the burn region; penumbral imaging[1-3] is a powerful technique for neutron imaging or other penetrating radiations. The aperture in the penumbral imaging is larger than the size of the source image. On the detector, the coded image of the source image is recorded as a penumbral image. The reconstructed image can be obtained by deconvolution of the penumbral image. Usually, the Wiener filter is used for the deconvolution. A limitation of the penumbral imaging is that the reconstruction process is sensitive to the noise of the penumbral image. Some methods like the heuristic method[4] or uniformly redundant penumbral array method can obtain the clear image from noisy the observed penumbral image. However, in the use of the fast ignition[5], a lot of γ-rays are produced by interaction between the heating laser and the compressed fuel. As a result, the S/N on the detector becomes extremely low and the noise distribution is nonlinear. If the we obtain the reconstructed image from the penumbral image by using the Wiener filter, there are many artifact in the reconstructed image. It will prevents the diagnostic of the plasma. Therefore a new method for the reconstruction of the extremely noisy penumbral image is needed.

The basic concept of the proposed method is shown in Fig. 1. At first, the reconstructed image is calculated by the Wiener filter. We apply the kernel principal component analysis method to the reconstructed image to remove the artifact. After the use of the calculation, we finally obtain the clear reconstructed image. The kernel PCA[6] is developed method of the traditional principal component analysis method. The kernel PCA is very well suited to extract interesting nonlinear structures in the data. The kernel PCA first maps the data in some feature space **F** via function **Φ** and then performs linear PCA on the mapped data. Let a data set as $\mathbf{X}_k$, $k=1,...,N$, where N is the number of the training samples. So the covariance matrix **K** in the feature space can be expressed as:

$$\mathbf{K} = \frac{1}{N}\sum_{1}^{N} \Phi(X_i), \Phi(X_i)^T = \langle \Phi(X_i), \Phi(X_i) \rangle \tag{1}$$

If we use a Mercer kernel k which satisfies with $k(X_i, X_j) = \langle \Phi(X_i), \Phi(X_j) \rangle$, the eq. (1) can be written as:

$$\mathbf{K} = \frac{1}{N}\sum_{1}^{N} k(X_i, X_j). \tag{2}$$

In this study, we used a Gaussian kernel $k(x,x')=\exp(-\|x-x'\|^2/c)$, where c is a constant. We obtain the eigenvectors and eigenvalues. We reconstruct the image from the several eigenvectors. The reconstructed image **Z** can be expressed as:

$$\mathbf{Z} = \frac{\sum_{i=1}^{l} \gamma_i \exp(-\|\mathbf{Z} - \mathbf{X}_i\|^2 / c)\mathbf{X}_i}{\sum_{i=1}^{l} \gamma_i \exp(-\|\mathbf{Z} - \mathbf{X}_i\|^2 / c)}, \tag{3}$$

where, $\gamma_i = \sum_{k=1}^{n} \beta_k \alpha_i^k$ and $\beta_k = \sum_{i=1}^{l} \alpha_i^k k(x,x_i)$, recpectively. When we actually obtain the reconstruction, We use eq. (4) of division of eq.(3).

$$\mathbf{Z}_{t+1} = \frac{\sum_{i=1}^{l} \gamma_i \exp(-\|\mathbf{Z}_t - \mathbf{X}_i\|^2 / c)\mathbf{X}_i}{\sum_{i=1}^{l} \gamma_i \exp(-\|\mathbf{Z}_t - \mathbf{X}_i\|^2 / c)}. \tag{4}$$

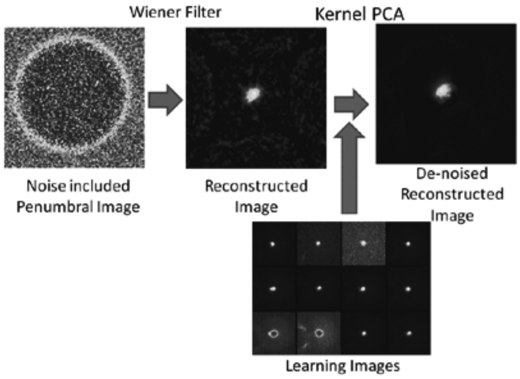

Fig. 1. The basic concept of the proposed method by use of the kernel PCA.

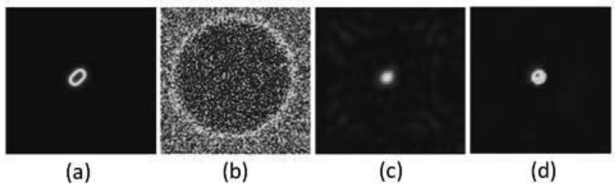

Fig. 2. Computer simulation results. (a) Source phantom, (b) Penumbral image of the source phantom., (c) Reconstructed image by the conventional method, (d) Reconstructed image by the proposed method.

We carried out the computer simulation to validate the our proposed method. The number of the learning image is 480. The results are shown in Fig. 2. The source phantom (Fig. 2(a)) is generated from two Gaussian image. The signal-to-noise ratio of the penumbral image(Fig. 2(b)) from the source phantom is 3.5 [dB]. The reconstructed image by the proposed method(Fig. 2(c)) is more clearer than the one by the conventional method(Fig. 2(d)). We also calculated image errors. The image error between the source phantom and the reconstructed image by the proposed method is 1809. The image error between the source phantom and the reconstructed image by the conventional method is 3143. The results show that the our method is useful to reconstruct the image from the noisy penumbral images.

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