§38. An Improvement of Reconstruction of Noise-included Penumbral Images by Kernel Principal Component Analysis and its Evaluation

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Penumbral imaging[1] is a powerful imaging technique to 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. In the use of the fast ignition, a lot of γ-rays following a Gaussian distribution are produced by interaction between the heating laser and the compressed fuel. Furthermore, there are some errors of the observed image on the detector following the Poisson distribution. As a result, the S/N on the detector becomes extremely low and the noise distribution is complicated. Two-directional and two-dimensional principal component analysis ($(2D)^2$PCA) [2] method can effectively remove the noise and its reconstruction is improved. However, there remain still many artifacts in the reconstructed image even when the noise is efficiently removed. It will prevent the diagnosis of the plasma. Therefore a new method to remove the artifacts from the reconstructed image is needed. We proposed a use of kernel principal component analysis to remove the artifact in the reconstructed image. 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 a clear reconstructed image. In the calculation of the kernel principal component analysis, the experimentally obtained pinhole images are used as "training samples". By use of the training samples, we can obtain of the feature vector of the plasma images. The feature vector can extract the feature of the reconstructed image, that is, the artifact can be removed[3]. The methods can also combine the noise reduction method by $(2D)^2$PCA method.

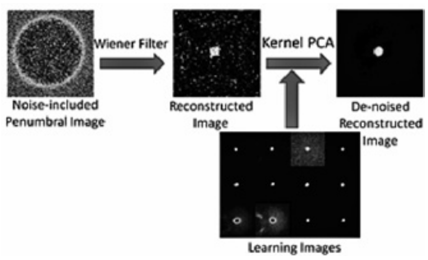
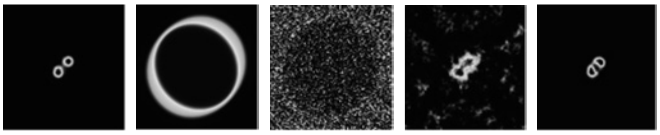


Fig. 1. Basic concept of the removal of the artifact in the reconstructed image by the use of the kernel principal component analysis.

The results of the computer simulation are shown in Fig. 2.

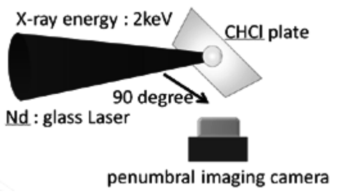


(a) (b) (c) (d) (e)

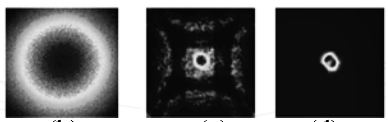
Fig. 2. Computer simulation and its result. (a): Source phantom (b): Penumbral image from the source phantom (c): Noise added penumbral image (d) The reconstructed image by the Wiener filter only (e): The reconstructed image by the proposed method.

The source phantom consists of two Gaussian distribution. The two Gaussians simulate the two cores of the high-temperature plasmas. The Gaussian noise and Poisson noise are included in the penumbral image. Its signal-to-noise ratio (S/N) is 3.5 [dB]. The range of the phantom is 0 to 65565, which simulates the range of an x-ray CCD used in inertial confinement fusion experiments. There are few artifacts in the reconstructed image by the proposed method (Fig. 2(e)) compared with the one by the conventional method (Fig. 2(d)).

We also applied the method to the experimentally obtained penumbral image. The experimental setup, obtained penumbral image and reconstructed image are shown in Fig. 3. The obtained penumbral image(Fig. 3(b)) is extremely polluted by the noise. There are a lot of artifacts in the reconstructed image by the Wiener filter only (Fig. 3(c)) due to the noise. On the other hand, The reconstructed image by the proposed method (Fig. 3 (d)) is clearer than the one by the Wiener filter only (Fig. 3 (c)) and it can also observe shape of the core of the plasma.



(a)



(b) (c) (d)

Fig. 3. Experimental setup for real laser-plasma experiments(a), obtained penumbral image(b), reconstructed image by the conventional method (c), and reconstructed image by the proposed method(d)

1) Nugent, K.A. and Davis, L.: Opt. Commun. **49** (1984) 393.
2) Nozaki, S., el al., : Plasma and Fusion Research, **7** (2012) 2404120-1.
3) Nozaki, S., et al., : The 6th International Conf. on Soft Comp. and Intel. Sys. (2012) W2-45-4.