§17. Numerical Simulation of 3D Image Reconstruction of LHD Plasma with IR Imaging Video Bolometers

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The arrangement of software for image reconstruction is in progress in order to realize the 3D tomography of radiation from LHD. Using the observation ports 6.5-U, 6.5-L, 6-T and 10-O, the system of four imaging bolometers was carefully improved in sightline positioning design [1] and installed on LHD for the 17th cycle of experiments. Assuming the toroidal periodicity and symmetry of the plasma, one half period of toroidal angle 18° was taken as the region of interest.

Numerical simulations were carried out on the improved layout of the four-camera system. With the geometry of the layout and on the basis of the physics of radiation detection, the projection matrix H that relates the unknown 3D plasma image $\boldsymbol{f}$ to its projection $\boldsymbol{g}$ in camera system was theoretically calculated with the aid of the CAD software. The 3D radiation distributions obtained with the EMC3-EIRENE code of impurity behavior were used as phantoms. By omitting the non-radiation voxels from image reconstruction, the size of the matrix H was decreased to 2,528x13,161 so that the singular value decomposition could be accomplished with a personal computer.

Figs. 1 and 2 show the result of applying the Tikhonov (unit matrix) regularization to the under-determined linear equation $H\boldsymbol{f}=\boldsymbol{g}$. Changing the value of the regularization parameter γ lead to the changes of the reconstructed image $\hat{\boldsymbol{f}}$ and its projection $H\hat{\boldsymbol{f}}$ as in Fig. 1. Uniform random numbers, whose upper limit of interval was 10% of the mean of the true projection values, were added to produce the data vector $\boldsymbol{g}$, and the Lagrange function to be minimized was defined as $\Lambda(\boldsymbol{f}) = \gamma\|\boldsymbol{f}\|^2+\|H\boldsymbol{f}-\boldsymbol{g}\|^2/M$ with M=2,528. While the mean of the squared residuals ε^2 monotonically decreased with γ, the generalized cross validation GCV was minimized and well reflected the minimum of the reconstruction error δ^2. The value of $\varepsilon = 2.17\text{x}10^{-6}$ at the minimum of GCV was much smaller than the root mean square $5.08\text{x}10^{-5}$ of the added random numbers. If we had taken the Morozov condition, we would have got a smoothed reconstruction similar to (C) in Fig. 1. This result shows the validity of computation and reconfirms the usefulness of GCV [2, 3] for the tomography in which the angular loss of projection data is very large. The condition number of the matrix H was evaluated as $7.71\text{x}10^{34}$ using the software IDL.

For a better regularization according to the non-negativity constraint, additional study has been made to build fast iterative algorithms.

Finally, we obtained the first result of image reconstruction from experimental data of LHD.

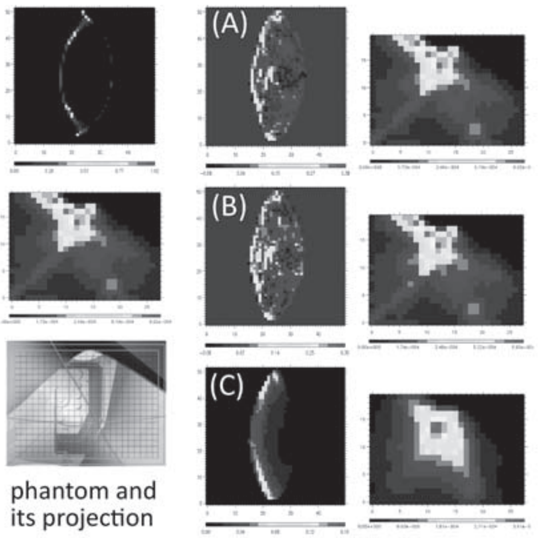

Fig. 1. Result of a numerical simulation: (left) a 3D phantom $\boldsymbol{f}_\text{o}$ and its projection $H\boldsymbol{f}_\text{o}$, which are displayed in one poloidal section and in the 6.5-L port camera, respectively; (right) reconstructed images $\hat{\boldsymbol{f}}$ and their projections $H\hat{\boldsymbol{f}}$ displayed in the same section and camera for γ values of (A) $4.0\text{x}10^{-16}$, (B) $1.9\text{x}10^{-13}$ (min. GCV), and (C) $2.7\text{x}10^{-9}$.

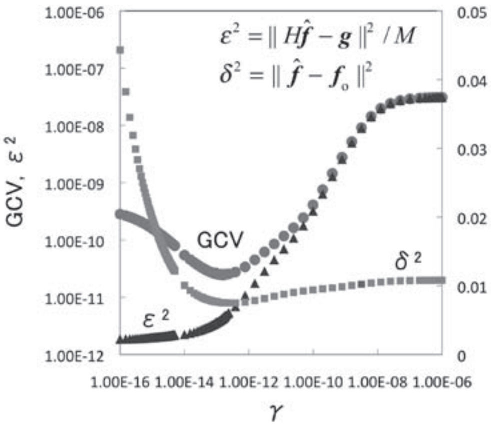

Fig. 2. Changes of GCV, ε^2 and δ^2 with the regularization parameter γ; while ε^2 changed monotonically with γ, both GCV and δ^2 were minimized for the same discrete value of $\gamma=1.9\text{x}10^{-13}$ in this case.

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1) Sano, R. et al.: Plasma Fusion Res. **8** (2013) 2402138.
2) Iwama, N. , Hosoda, Y. et al.: Bulletin of the Daido Inst. of Tech. **41** (2005) 105.
3) Iwama, N. et al.: J. Plasma Fusion Res. SERIES **8** (2009) 691.