§20. Feasibility Study of 3D Plasma Image Reconstruction with IR Imaging Video Bolometers

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This research aims to implement a new three-dimensional (3D) tomography system by using the infrared imaging video bolometers (IRVB) that are operating on LHD. The biggest progress in this year was the achievement of calculating the projection matrix, which was the most challenging problem of this work [1]. The calculated matrix, which is a geometrical matrix that relates the objective plasma image to the camera signals, has enabled computational tests of 3D tomography.

Under the assumption of toroidal symmetry of LHD plasma, three IRVB cameras (Fig. 1) effectively view the LHD plasma in its one half period (toroidal angle interval $0^o<\phi<18^o$), which is the region of interest (ROI) of 3D tomography. By considering the spatial resolution of camera, the ROI is divided to 46,800 voxels, each of which is 50mm long in both major radius R and vertical coordinate Z, having an angle of 1° in ϕ. When the region with no plasma is removed out of image reconstruction, the number of objective voxels is decreased to 13,161. On the other hand, the number of channels in cameras is 1,986 in total. As a result, in the linear equation $H\boldsymbol{f}=\boldsymbol{g}$ for the image vector $\boldsymbol{f}$ and with a data vector $\boldsymbol{g}$, the projection matrix H has a size of 1,986x13,161 and sparse with the nonzero element density 1.6%. Adopting a data structure for omitting the zero elements in computing, one can save the necessary memory size to about 3 MB.

On this underdetermined equation, the normal equation for a least-squares solution is given as $(H^TH)\boldsymbol{f}=H^T\boldsymbol{g}$, where $H^T\boldsymbol{g}$ is an image obtained by the procedure of back projection. When the projection data $\boldsymbol{g}$ is acquired by omnidirectional observation as in medical X-ray CT, $H^T\boldsymbol{g}$ is a blurred image (an approximate solution) that requires a sharpening operation $(H^TH)^{-1}$ with an aid of regularization. When the projection observation is missed at view angles, $H^T\boldsymbol{g}$ gives an image that is distorted in accordance with the limited angle. One finds an example in the missing wedge problem of electron tomography [2]. So, in general, the back projection gives useful information on the expected performance of the imaging system.

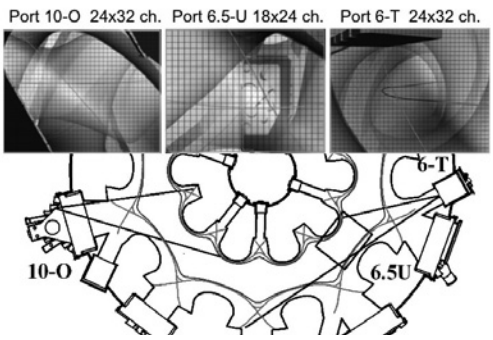

Fig. 1: Fields of view of the IRVB cameras that were installed on three ports of LHD, and CAD images of three cameras with channel numbers.

With respect to the IRVB system, a result of back projection is illustrated in Fig. 2. The software EMC3-EIRENE, which has been constructed for the impurity behavior simulation in LHD, was used to produce a numerical phantom of emissivity distribution. For the convenience of comparison, the phantom $\boldsymbol{f}_0$ and the back projection $H^T\boldsymbol{g}$ of a simulated data $\boldsymbol{g}=H\boldsymbol{f}_0$ are displayed graphically in a series of 2D poloidal slice images. It is to be noted that the brief procedure of back projection gives a rough imaging of plasma corresponding to the current geometry of three cameras. Inspection of the artifacts might be useful for optimizing the camera location. A reliable inversion from $H^T\boldsymbol{g}$ to $\boldsymbol{f}$ is the next target of image processing.

With an upgrade of the 2D tomography software of Hopfield neural network, contribution to an experimental study of the impurity radiation loss in LHD was an additional work of this year. The research was supported by the budget NIFS10KLEH005.

1) Peterson, B.J. et al.: ITC21, P2-37, Nov.28-Dec.1 (2011).
2) Iwama, N. et al.: Ann. Rep. NIFS 2011, p. 134.

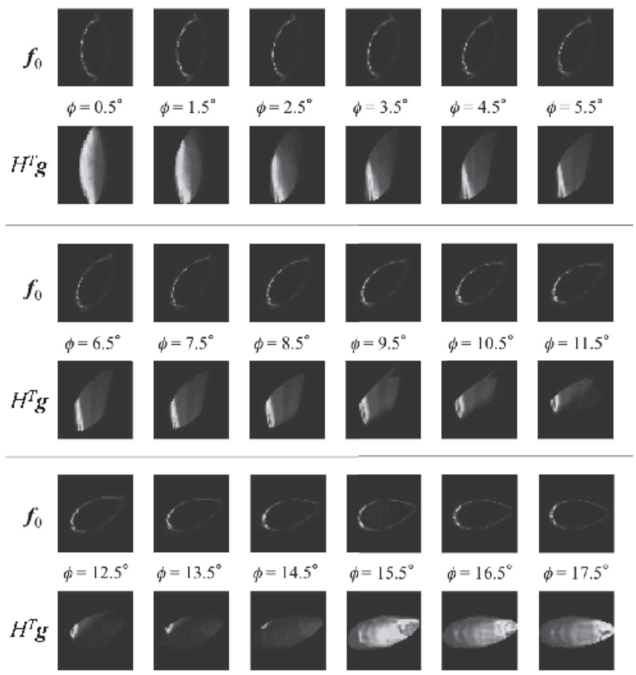

Fig. 2: 3D phantom $\boldsymbol{f}_0$ calculated by EMC3-EIRENE (upper rows), and 3D back-projection image $H^T\boldsymbol{g}$ (lower rows); both are displayed in poloidal R-Z planes with 32x32 pixellation and at every toroidal angle ϕ=1°, sequentially.