Sparse Image Representation for JET Neutron and Gamma Tomography

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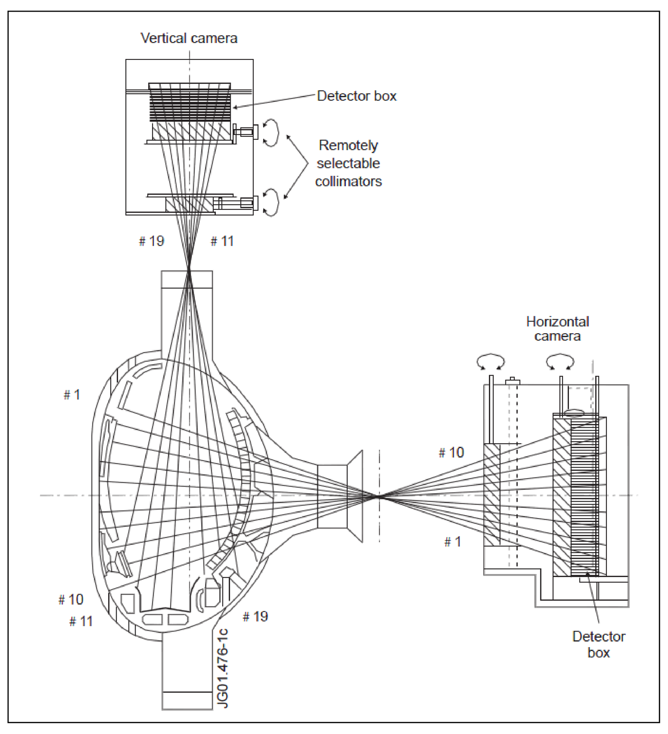
ABSTRACT

The JET neutron/gamma profile monitor plasma coverage of the emissive region enables tomographic reconstruction. However, due to the availability of only two projection angles and to the coarse sampling, tomography is a highly limited data set problem. A new reconstruction method, based on the sparse representation of the reconstructed image in an over-complete dictionary, has been developed and applied to JET neutron/gamma tomography. The method has been tested on JET experimental data and significant results are presented. The proposed method provides good reconstructions in terms of shapes and resolution and produces artefact free images.

JET NEUTRON/GAMMA PROFILE MONITOR



Schematic view of the JET neutron emission profile monitor

- Two fan shaped multi-collimator cameras, with 10 channels in the horizontal camera and 9 channels in the vertical camera.
- Adjacent channels are 15-20 cm apart and have a 7 cm width as they pass near the plasma centre.
- Set of detectors and associate electronics for simultaneous measurements of the 2.5 MeV D-D neutrons, 14 MeV D-T neutrons and γ –rays
- Time resolution : ~10 ms
- Plasma coverage determined by the 19 lines of sight can be used for neutron or γ-ray tomography.
- The 2D tomographic reconstruction is located in the plane defined by the major torus radius (R) and the major torus axis (Z). The thickness along the toroidal direction: ~ 75 mm.

THE TOMOGRAPHIC PROBLEM

In 2-D tomography systems, the measurements *p* are taken along lines of sight, and can essentially be represented by line integrals; i.e. the measurement is given by straight line integrals of the emissivity *f(x,y)*:

$$f = argmin_f \|Wf - p\|_2^2 \quad (1)$$

where *W* is the projection matrix The projection matrix element represents the proportion of the emission from pixel , accumulated in detector .

SPARSE IMAGE REPRESENTATION (SIR)

The sparse image representation technique led, in the last years, to significantly improved results in signal, image, and video processing [1-2]. The signal sparse representation problem consists of finding the optimal over-complete dictionary *D* that leads to the lowest reconstruction error given a fixed sparsity factor *L* (number of coefficients in the representation).

$$\{\alpha, D, f\} = argmin_{\alpha,D,g}\left\{\underbrace{\sum_{j=1}^{M}\left\|g_j - D\alpha_j\right\|_2}_{image\ reconstruction} + \lambda\underbrace{\sum_{l=1}^{L}\|\alpha_l\|_0}_{sparsity}\right\} \quad (2)$$

signal reconstruction error — signal sparsity

The dictionary *D* contains prototype atom-signals. The signals are described by sparse linear combinations of these atoms – α are the coefficients of the decomposition; λ is a regularisation parameter. Since images are usually large, the decomposition is implemented on overlapping image patches instead of the whole image.

The dictionary can be a fixed, general one (DCT, wavelet, curvelets, etc), or it can be adapted to suit the application domain.

THE RECONSTRUCTION METHOD

The unknown image can be retrieved by minimising the following objective function:

$$\{\alpha, D, f\} = argmin_{\alpha,D,f}\left\{\underbrace{\gamma\|Wf - p\|_2^2}_{tomographic\ reconstruction} + \lambda\underbrace{\sum_{j=1}^{J}\left\|\alpha_j\right\|_0}_{sparsity} + \underbrace{\sum_{j=1}^{J}\left\|g_j - D\alpha_j\right\|_2}_{image\ reconstruction} + \Omega_{smoothing}\times f\right\} \quad (3)$$

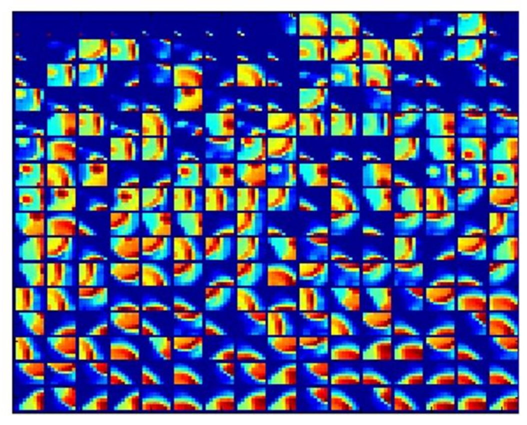
where γ is a regularisation term which controls the balance between the tomographic reconstruction and the image reconstruction from the over-complete dictionary.

$\Omega_{smoothing}$

- introduces a smoothness assumption in order to compensate for the lack of experimental information.
- the tomographic reconstruction searches for the emissivity distribution that is constant on magnetic flux surfaces.
- implemented as one-dimensional median filtering, using a sliding window which moves on the magnetic contour lines

Deriving of the dictionary D:

- Set of 50 already existent tomographic reconstructions which encompass most of shapes existent in this kind of tomography, obtained using the maximum likelihood (ML) tomographic method [3].
- ML reconstructions represented as 38 x 70 pixels images.
- 250 random patches of the size of 8 x 8 pixels were randomly chosen for minimising the objective function (2).
- Dictionary size *K=256* , Sparsity factor *L=6*.



The learned dictionary.

- ➢ This dictionary was used as an initial guess for solving Eq. 3.
- ➢ After deriving the dictionary, an iterative procedure is followed. It allows, at each stage, the alternative minimisation of tomographic reconstruction term, smoothing and sparse representation.

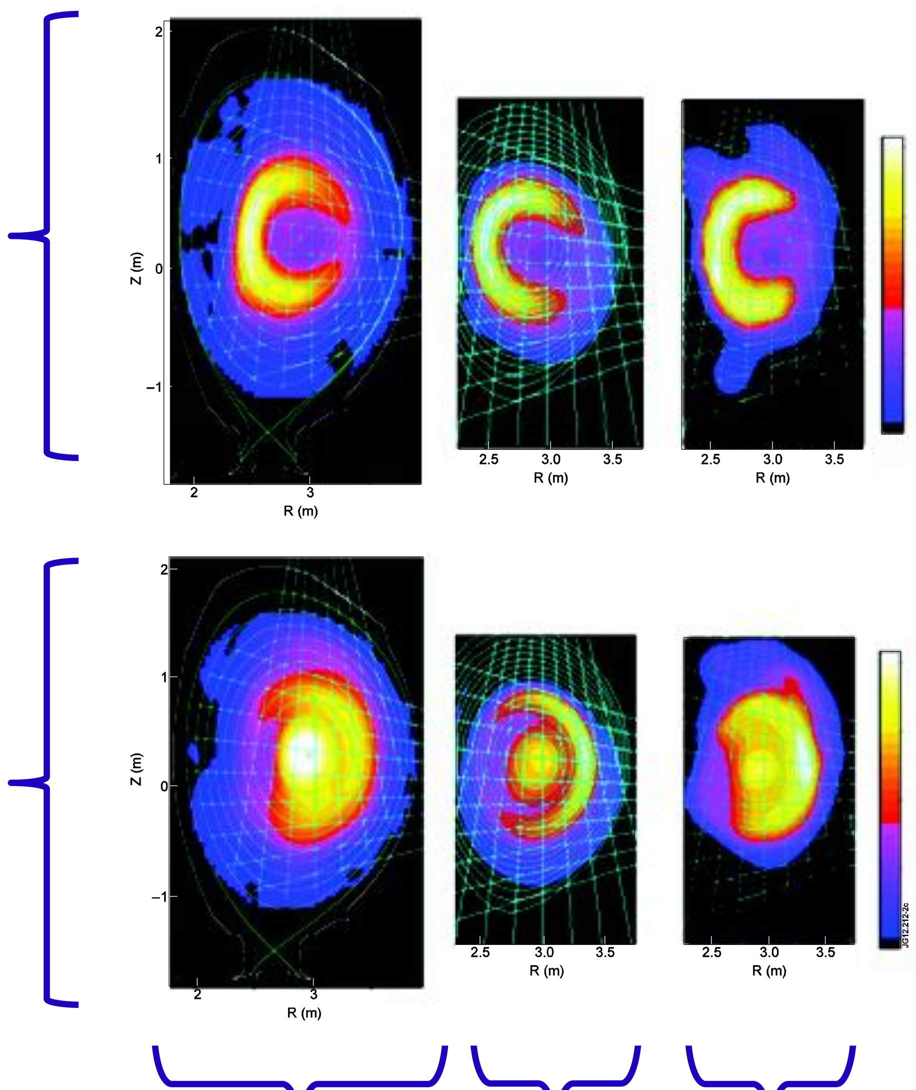
RESULTS

The results have been obtained for the application of the method to JET experimental data corresponding to in an experiment with T-puff in the deuterium plasma.

In order to evaluate the performance of the method, the results are presented together with those provided by Ingesson et al. method [4], which is used here as a reference method and by the ML method.

'Banana' profile distribution corresponding to an experiment where the DT-neutron emission was measured in the ohmic deuterium discharge during the off-axis injection of the T neutral beam—shot 61237 at 46.22–46.27 s

'Peak plus banana' profile distribution recorded just after the T-puff, when tritons partly penetrated into the plasma core from the periphery—shot 61132 at 62.67 s



Reference method — ML method — SIR method

CONCLUSIONS

Sparse image representation principle can be successfully used for retrieving emissivity distributions in case of JET neutron/gamma tomography. A priori information is used in order to solve the highly underdetermined tomographic problem. An over-complete dictionary for the sparse representation is derived from a set of already existent tomographic reconstructions which encompass most of the possible shapes existent in this kind of tomography. Smoothing along magnetic contour lines is also used for additional regularisation.

The proposed method provides good reconstructions in terms of shapes and resolution. Further work will be dedicated to investigating the possibility of an implementation compatible with the inter-shot analysis.

ACKNOWLEDGEMENTS

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