Low Cost Alternative of High Speed Visible Light Camera for Tokamak Experiments

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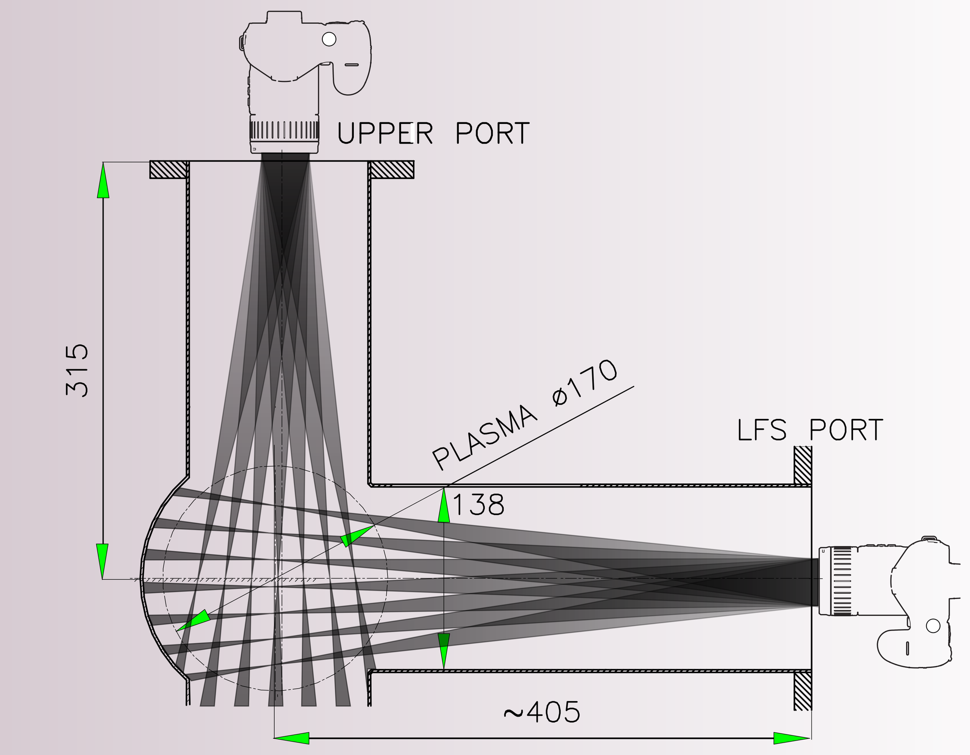
Tomography experimental setup

Experimental setup for tomographic reconstruction. Camera orientation is set for the horizontal rows of the CMOS chip to be perpendicular to the plasma column in order to use the rolling shutter effect.



Minimum Fisher Regularization

Plasma emissivity g_j is retrieved from the line integral $f_i \in 1,\dots,L$

$$f_i = \sum_j^N T_{ij} g_j + \epsilon_i$$

f_i is the plasma emissivity projection (chord), T_{ij} is the geometric factor, L is the number of chords, N is the number of pixels and ϵ_i is the statistical error with a known random distribution.

Minimum Fisher Reconstruction (MFR)

- widely used method
- stable, reliable results, decent speed reconstruction time
- very flexible method

The solution is obtained by minimizing the Fisher information constrained by the observed data

$$\min_g \left(\|Tg - f\|^2 + \lambda O(g)\right)$$

where the χ^2 distribution is defined as

$$\chi^2 = \sum_i^L \left(\frac{\sum_j^N T_{ij} g_j - f_i}{\sigma_i}\right) \approx L$$

Fisher information is

$$I_F = \int \sum_{i,j=1}^2 \left| \frac{\partial g(x,y)}{\partial x_i} \frac{\partial g(x,y)}{\partial x_j} \frac{1}{g(x,y)} \right| \mathrm{d}x\mathrm{d}y$$

α_R is a regularization constant and σ_i is the expected variance of the i-th chord.

$$H^{(k)} = \sum_l B_l^T W^{(k)} B_l$$

W is the weighting matrix $W_{ij}^{(k)} = \delta_{ij}/g_j^{(k-1)}$ and B_i are matrices of the discrete derivatives.

Magnetic surfaces were determined self-consistently from the center of emissivity (magnetic reconstruction is unreliable at the GOLEM tokamak)

Summary

The results are optimistic and suggest that this camera could be considered a low cost, versatile diagnostic for small tokamak experiments.

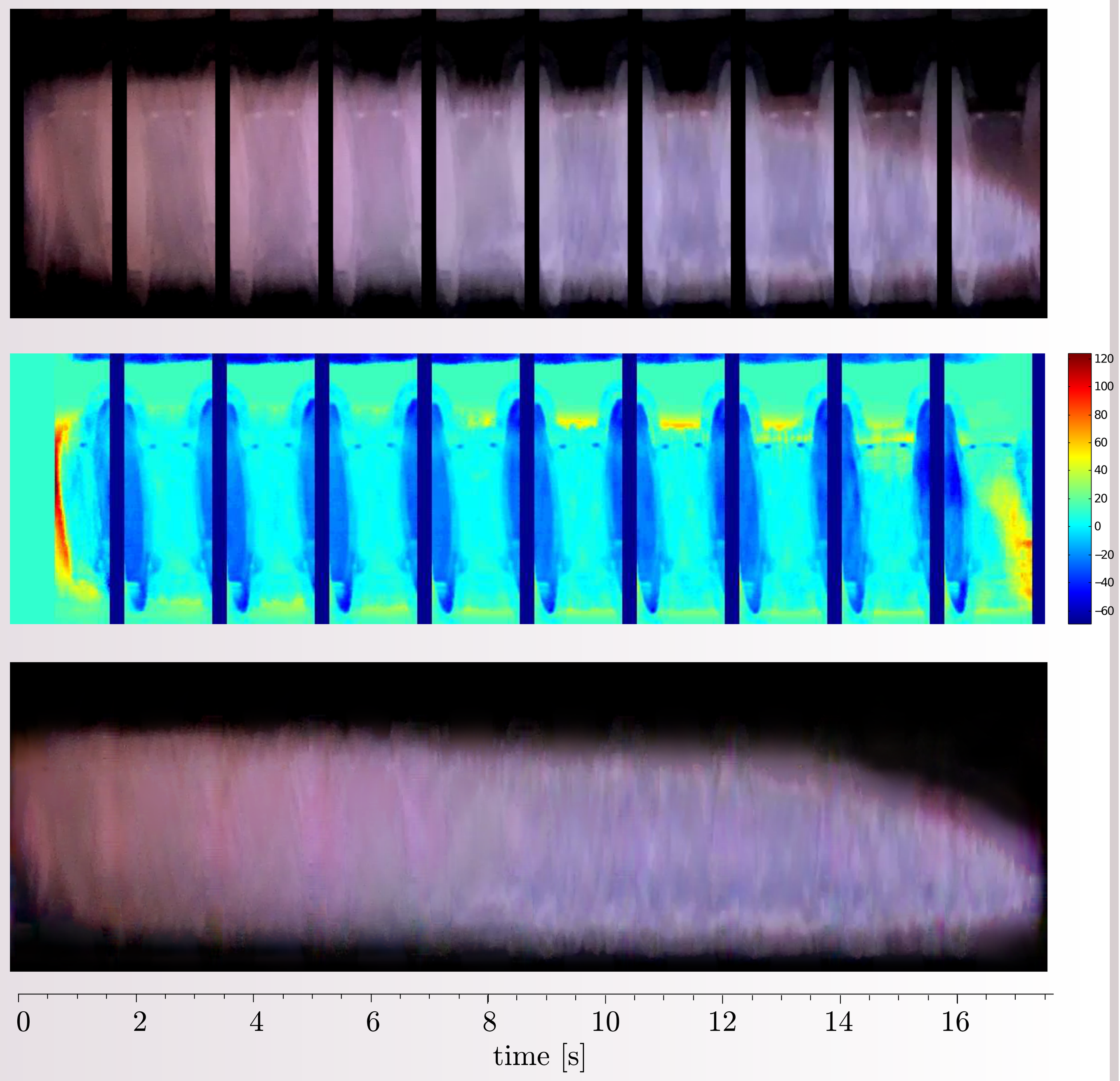
Image preprocessing

Preprocessing must compensate for

- Reflections from the background
- Gaps in the time evolution during the image readout (16% in one processed frame)
- Missing time synchronization with the global trigger

SVD decomposition and FFT was used for correction and gaps filling ("impainting") of the incomplete data.

The subtraction was done using SVD and filtering of the main "topos" vectors. The impainting was done in order to maximize the reconstruction length when more cameras were used.



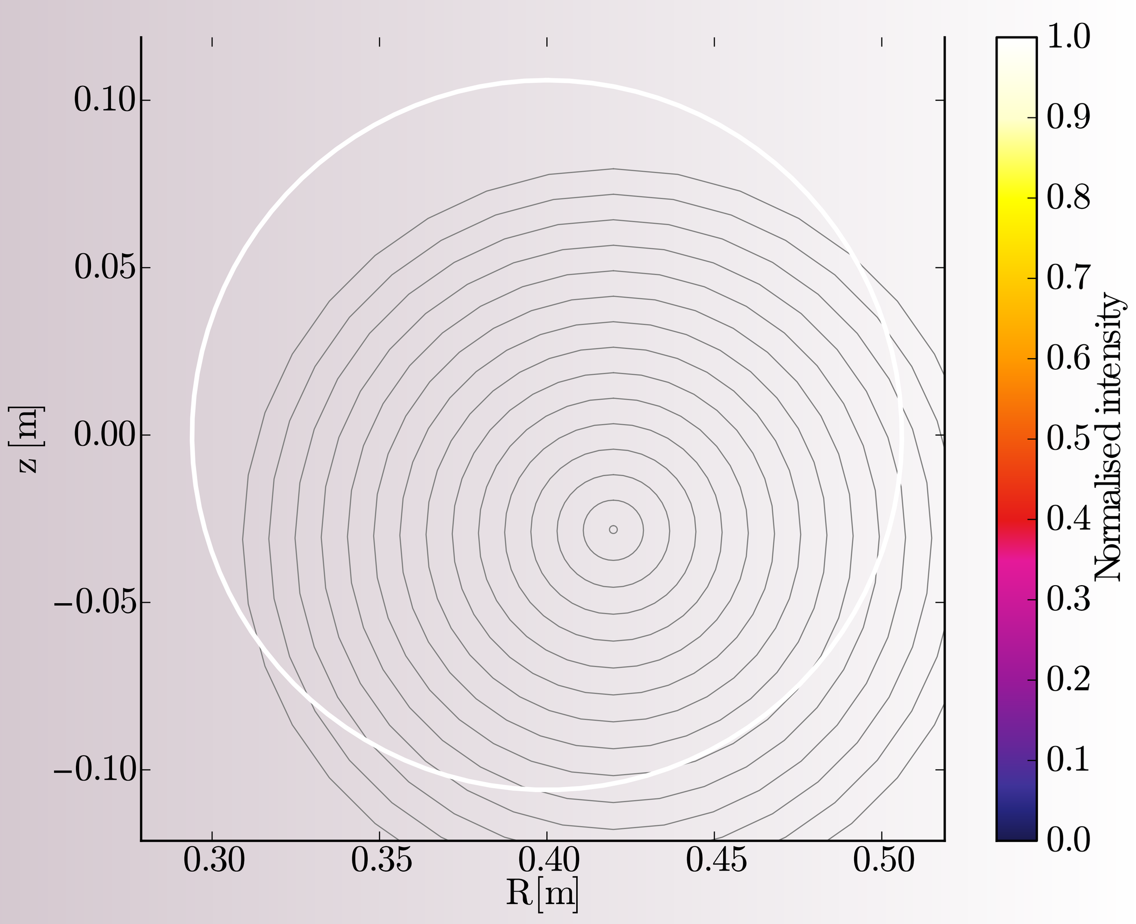
Original (top) and fixed image (bottom) and subtracted reflections (middle) from discharge #7251, side camera. The image is in real color. The filling gas was He.

Tomographic reconstruction

Assumptions for the applied pixel tomographic algorithm [1]:

- **Smooth emissivity profile** – optimal solution is found by minimizing the Fisher information with the measurements as constraints [2]
- **Boundary conditions** – zero emissivity out of the Scrape-Of-Layer (SOL) and only positive emissivity inside is assumed
- **Smoothing along flux surfaces** – divergence of the real chords (lines-of-sight) is approximated by a set of "virtual" line chords

An example of tomographic reconstruction for discharge #7251 at 11.1 ms. Only the red light component is plotted. Gray lines correspond to the assumed magnetic field and the white line is the limiter ring determined boundary.



The hollow profile is caused by an influx of neutral particles from the tokamak wall. The flux surfaces were estimated using an iterative self-consistent approach which was applied in order to find the center of emissivity.

Acknowledgment

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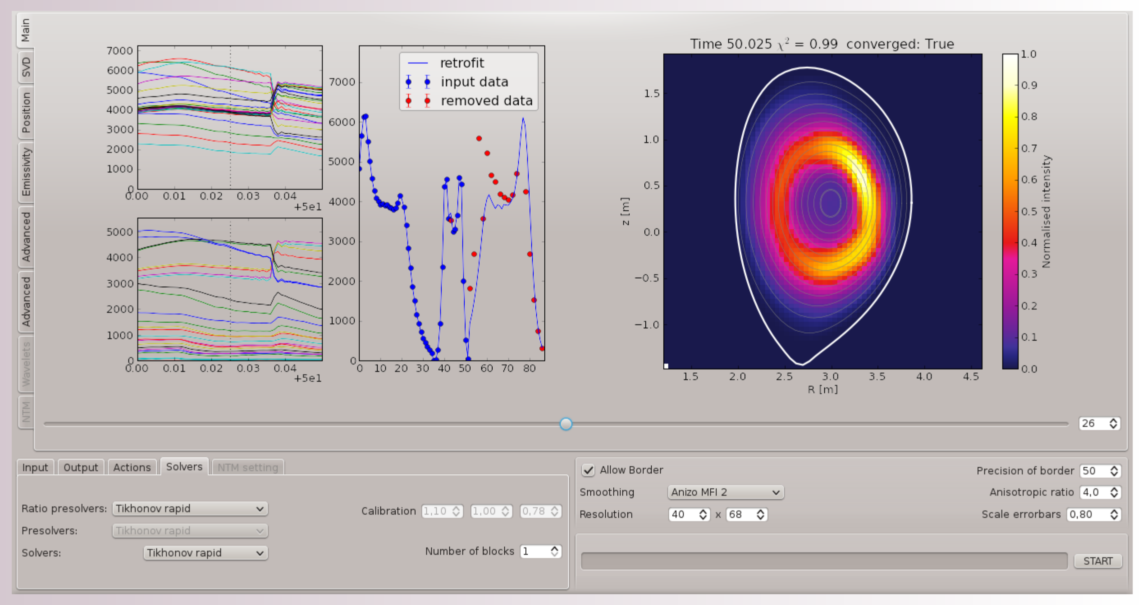
Reconstruction tool

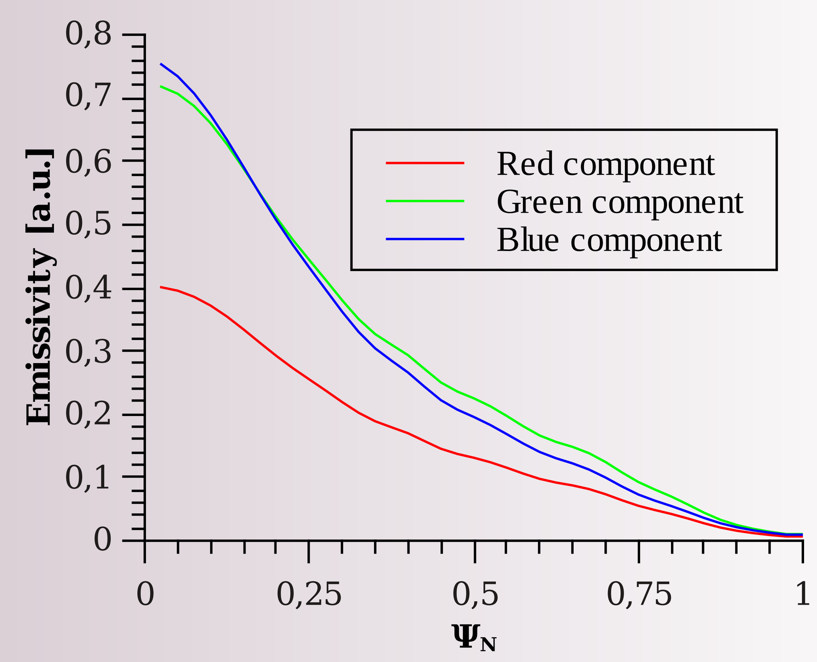


Features of the developed reconstruction tool:

- Universal interface – applied on 4 tokamaks
- Open-source based – Python, Qt4
- Native parallelization
- Advanced "linear" solvers (QR,SVD,GEV)
- Wavelet reconstruction of islands

Contact us for more information.

Emissivity profiles – colors



An estimation of the emissivity profile in shot #7251 at 1.8 ms. The emissivity is renormalized, Ψ_N is an estimation of the normalized poloidal flux.

References

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[3] V. Svoboda, B. Huang, J. Mlynar, G.I. Pokol, J. Stockel, and G Vondrasek. Multi-mode Remote Participation on the GOLEM Tokamak. *Fusion Engineering and Design*, (), 2011.