# Calibration of Diagnostic Image Data in Fusion Experiments

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**UCL Data Intensive Science CDT & UKAEA Culham Centre for Fusion Energy - Industry Partner Group Project.**

## INTRODUCTION

Nuclear fusion occurs when two nuclei combine together to make a heavier nucleus. The sum of the masses of light nuclei is greater than the mass of the new larger nucleus. Thanks to mess-energy equivalence, this mass difference is released as energy.

Fusion reactors on Earth:

- Fuse nuclei from heavy isotopes of hydrogen.
- Operate at temperatures exceeding 100 million degrees Celsius.
- Would power steam turbines to generate electricity.
- Might one day provide clean and safe renewable energy.

The Joint European Torus (JET) and Mega Amp Spherical Tokamak (MAST) are two nuclear fusion reactors housed at the Culham Centre for Fusion Energy (CCFE). JET is the flagship device for EUROfusion, the EU-wide programme for developing fusion power.

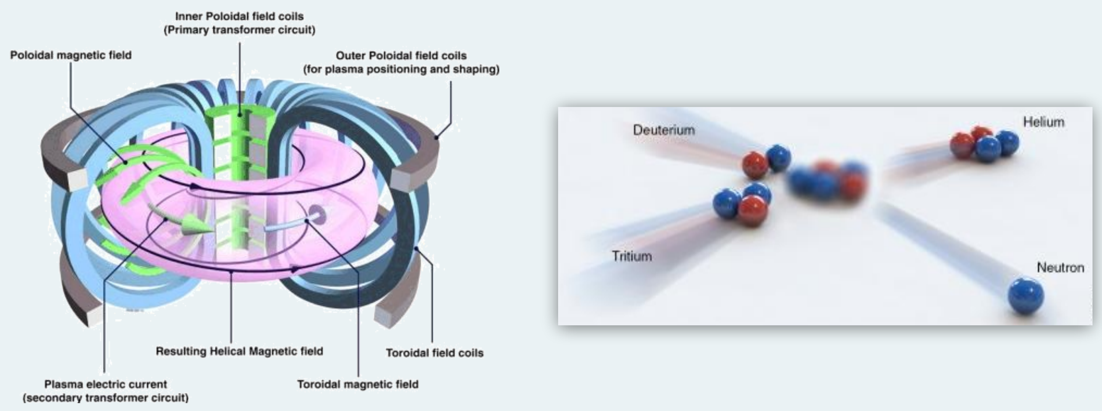


Figure 1: (Left) Schematic of a tokamak, showing the magnetic fields used to contain the plasma. (Right) Deuterium-tritium (both heavy isotopes of hydrogen) fusing to form a helium nucleus and a neutron. The neutron leaves the plasma and is used to heat water, driving steam turbines and generating electricity.

## CAMERAS & DIAGNOSTICS

The cameras inside fusion reactors (Figure 2 & 3) are essential tools for understanding the the dynamics of the confined plasma. This project investigates the feasibility of automatically aligning images.

- High speed cameras sensitive to various wavelengths of light are used.
- Tokamaks shake during operation, causing the cameras and optics to move.
- Analysing the plasma requires aligned images.
- Manually aligning images is extremely time intensive.

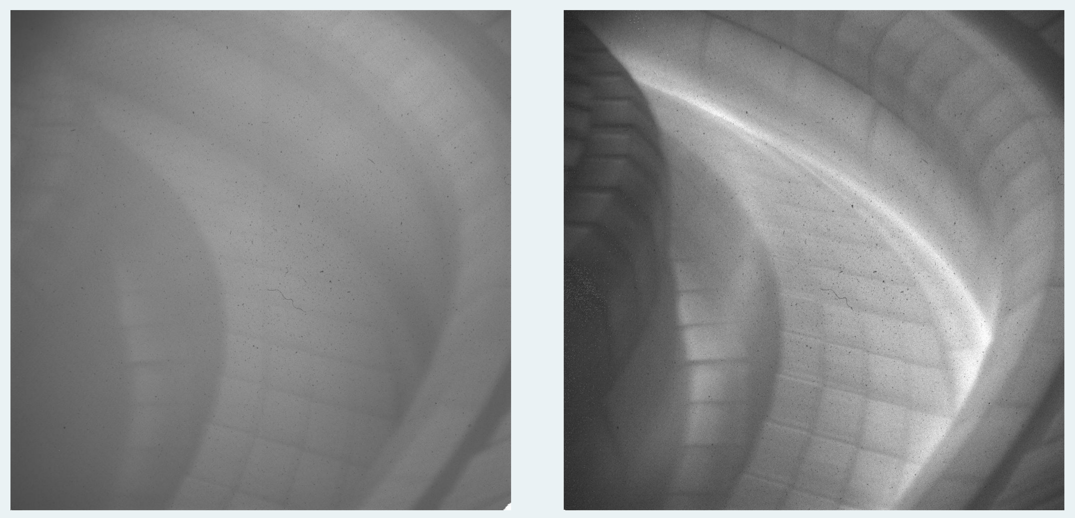

Figure 2: Two grayscale images taken from the KL11 viewport. Common features are low signal-to-noise ratios, exposure problems, and motion blur.

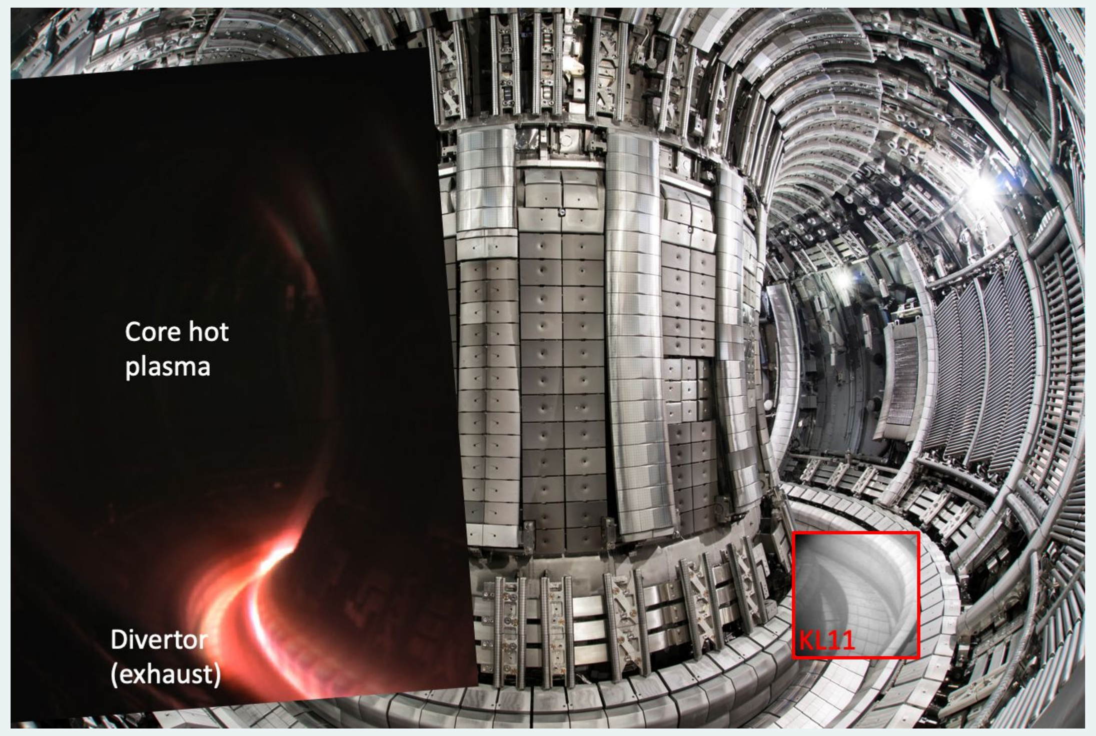


Figure 3: Image showing the inside of JET. In the bottom right, the field of view of camera KL11 is shown, which is used extensively in this project and featured in other figures in this poster.

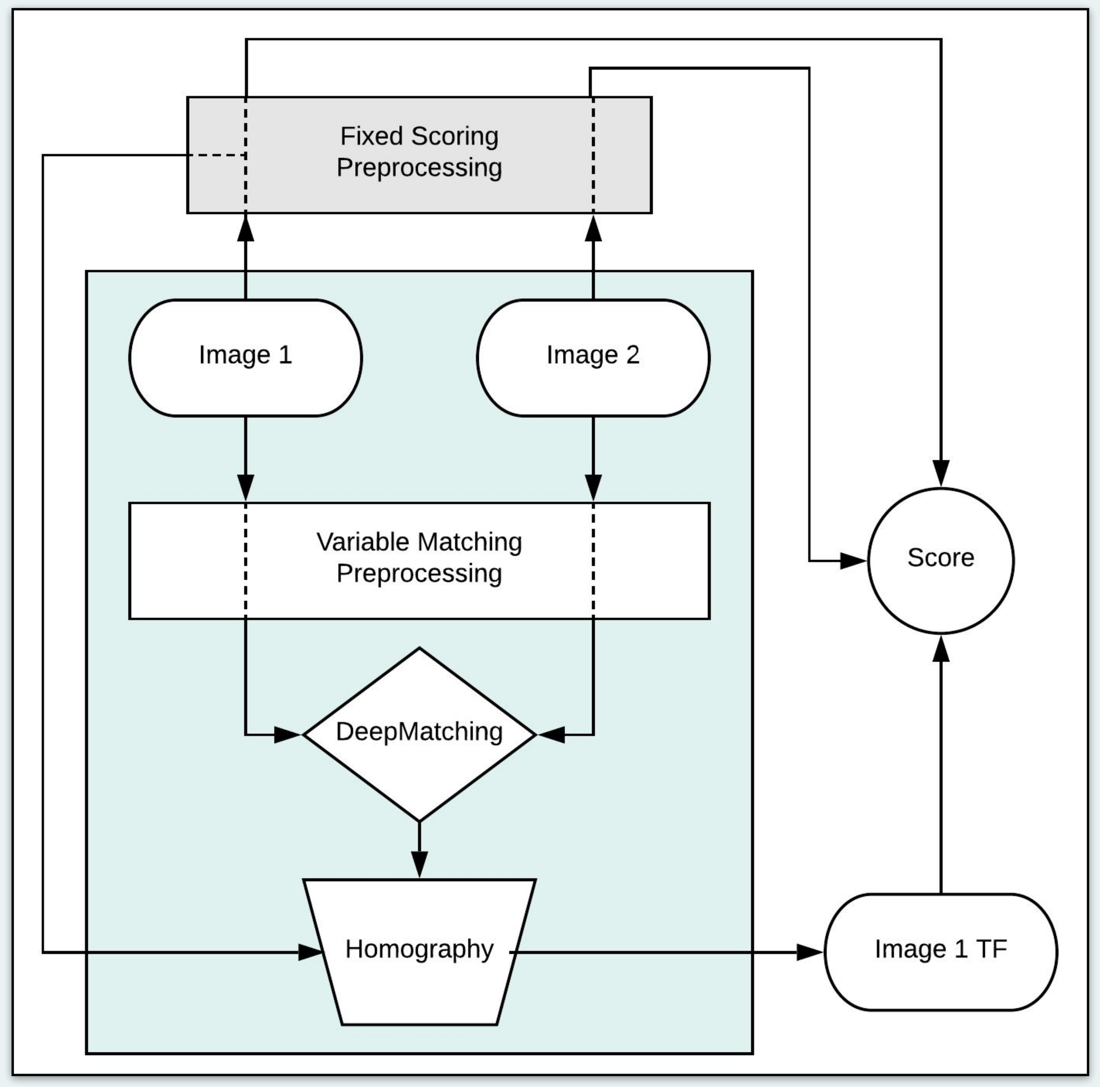


Figure 4: Schematic of the framework used to align images. Matching and scoring preprocessing steps are independent. Alignment takes place within the green shaded area and is optimised by the scoring procedure.

## PREPROCESSING

Preprocessing is an important first step in the process of image calibration.

- Feature matching does not perform well on low quality images.
- Harsh operating conditions inside the reactors means images are mostly of low quality (Figure 6 & Figure 2).
- Preprocessing is used to normalise and improve the levels of noise and contrast in the images (Figure 6).

Preprocessing is automatically performed by successively applying image manipulations. The parameters of these operations are optimised based on analysis of the image content, such that each image receives optimised preprocessing.

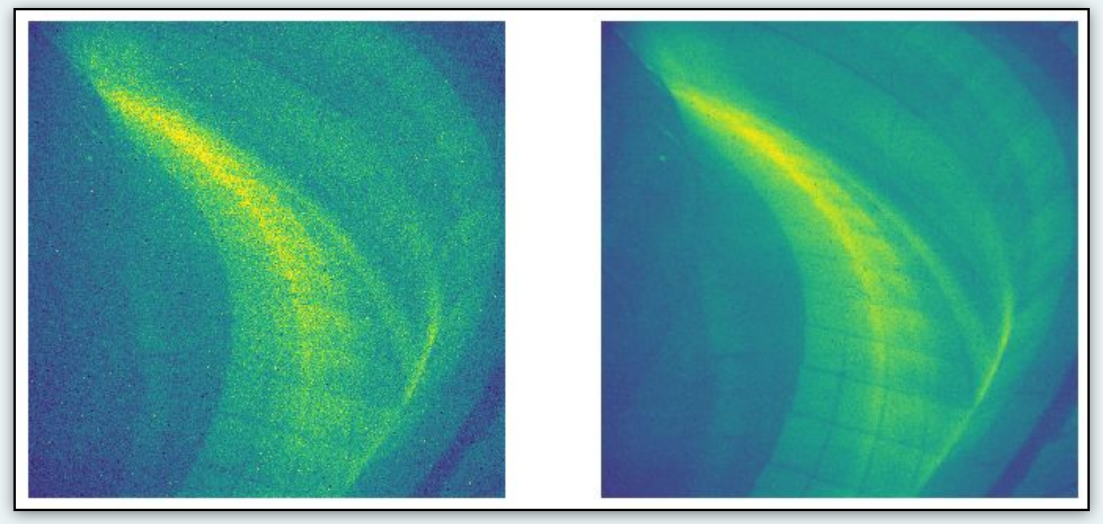

Figure 6: (Left) A noisy raw KL11 image. (Right) Denoised image using Gaussian subsampling. The plasma and other features of the image are more clear. Images are in false colour.

## FEATURE MATCHING

- Algorithms work by finding common points in two input images
- A transformation that aligns the images is derived from the coordinates of common points.
- A homography is used, assuming rigid transformations that are not depth dependent.
- Feature matching was performed by DeepMatching [1].


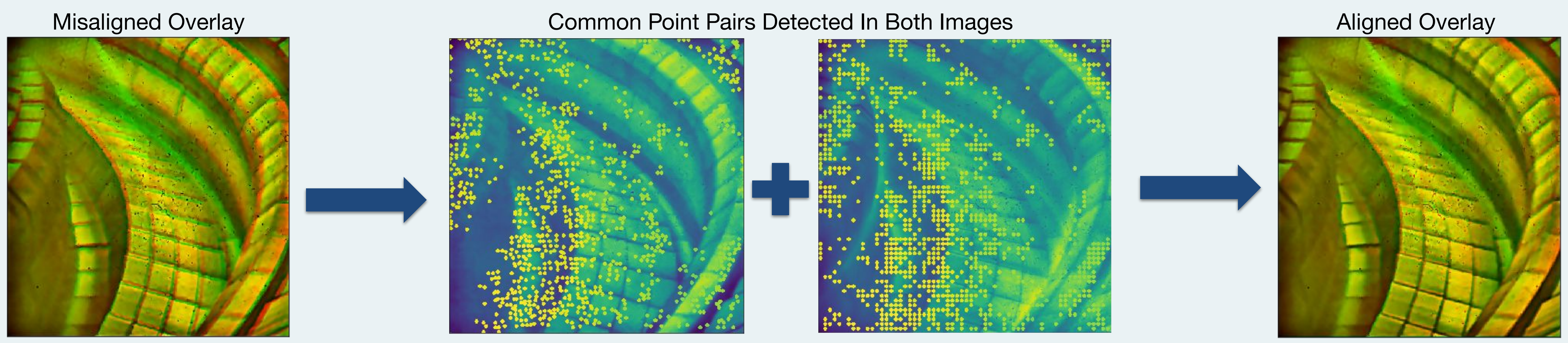


Figure 5: (Left) Two misaligned input images showed as an overlay. One image is displayed in red and the other in green. Red and green fringes show clearly that the images are misaligned. (Middle) The common point pairs that are detected in both images using DeepMatching [1]. (Right) The aligned images after applying a transformation, generated using the detected point pairs, that aligns the images.

## DEEPMATCHING

- DeepMatching [1] is a state-of-the-art dense feature matching algorithm.
- It is loosely inspired by deep convolutional networks.
- Performs well for images with repetitive textures (Figure 5).

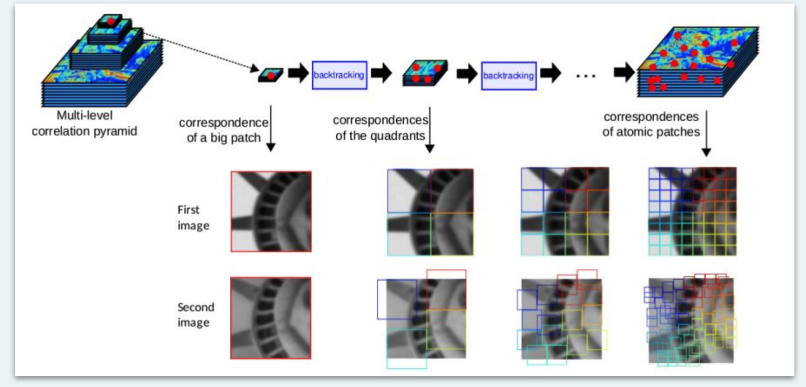


Figure 7: The final step of DeepMatching [1], showing that common point pairs (or atomic patches in the figure) are obtained from a set of image correlations derived at different scales.

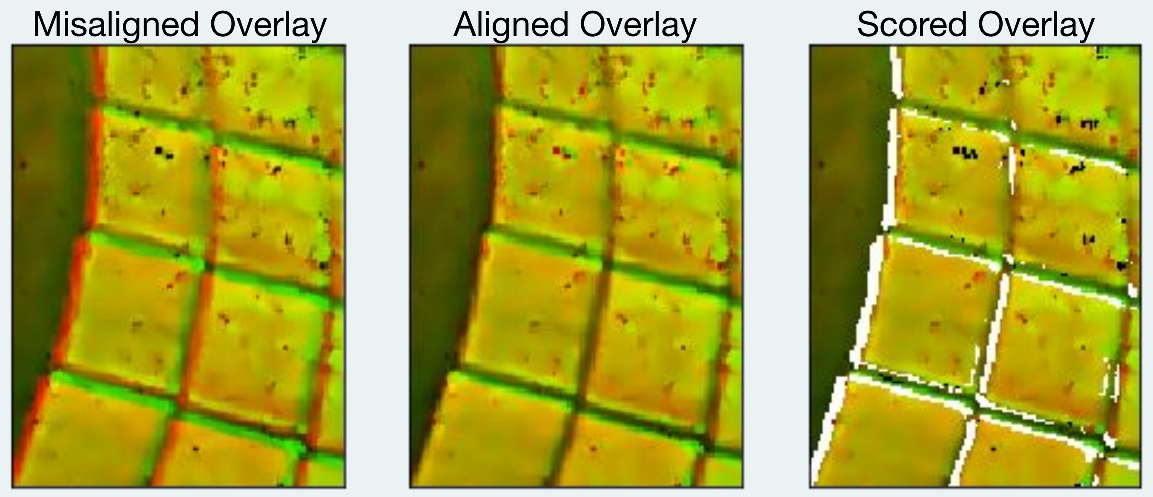


Figure 8: (Left) Two zoomed KL11 images are overlaid in different colour channels of the image (red and green). Where red and green fringes appear, the images are misaligned. (Middle) Aligned overlay obtained using DeepMatching. (Right) A scored alignment where points that are labelled as improved (worsened) are coloured in white (black).

## SCORING

A major difficulty in automatically aligning images was the necessity of manual validation of alignments. A scoring algorithm was developed to quantitatively assess different preprocessing and feature matching stratergies.

- Scoring uses a pair of images ($l_1$, $l_2$) and the aligned version of one ($l'_1$). For each pixel $ij$, the improvement in agreement of pixel intensity is calculated as

$$d^{ij} = |l_1^{ij} - l_2^{ij}| - |l_1'^{ij} - l_2^{ij}|$$

- Scoring depends on preprocessing applied to the images.
- For consistency when comparing different preprocessing techniques, separate preprocessing is used when scoring (Figure 4).
- Figure 8 demonstrates visually the performance of the scoring algorithm. The algorithm detects points which were initially unaligned, but became aligned after transformation.

Results from the scoring algorithm are shown in the following table. The results demonstrate that DeepMatching performs best with heavy preprocessing applied to input images.

| | Successful Count | Failed Count | Unscored Count |
|---|---|---|---|
| Unpreprocessed | 15 | 37 | 448 |
| Downsampled | 19 | 17 | 464 |
| Sequential Light | 79 | 22 | 399 |
| Sequential Heavy | 105 | 19 | 376 |
| Sequential Superheavy | 142 | 24 | 334 |

[1] Jerome Revaud et al. “DeepMatching: Hierarchical Deformable Dense Matching”. June 2015. arXiv:1506.07656.