

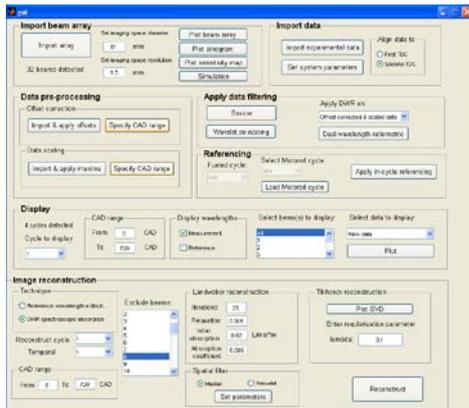
# TIPOD – A User-Friendly Software Base for Chemical Species Tomography Systems

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**Introduction:** The user-friendly MATLAB-based TIPOD package provides fast, flexible analysis and image reconstruction of large volumes of chemical species tomography data. The new version, TIPOD-2013, provides options for: data pre-processing (e.g. filtering, denoising); data referencing; quality-based data selection; image reconstruction (e.g. Landweber with median or wavelet filters, Tikhonov); off-line still-frame display; export to industry-standard video; and flexible simulation for development or validation of optimal sensor arrays. The principal application areas to date have been in auto and aero engines.

## TIPOD framework

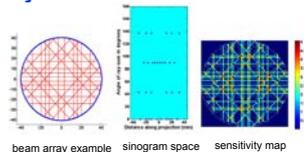


### Main TIPOD data processing stages:

- (i) Import beam geometry;
- (ii) data simulation;
- (iii) data import;
- (iv) data pre-processing and filtering;
- (v) referencing;
- (vi) data display;
- (vii) image reconstruction.

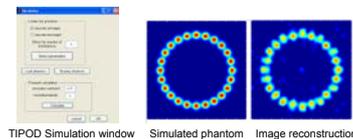
## Import beam array geometry

- Import of a beam array with  $n$  beams
- Set the number of pixels by defining the diameter of the imaging space and imaging space resolution in mm
- Calculate sensitivity matrix



## Simulation

- Selection of simulation phantom: standard Gaussian soft-edged or hard-edged phantoms or user-defined phantom.
- Visualization of the phantom
- Forward calculation based on Beer-Lambert law
- Image reconstruction (using TIPOD main menu) with all or subset of beams



## Data import, pre-processing and filtering

### Data Import:

The data represent transmission measurements at two optical wavelengths for each in-cylinder beam path first stored in the Labview environment as (.BIN); exported in ASCII format (.txt) and then imported by TIPOD into the MATLAB environment. After that the following parameters need to be set:

- Frame acquisition rate in frames per second (FPS)
- Engine rotational speed in revolutions per minute (RPM)

### Data Alignment:

TIPOD automatically locates Top Dead Centre (TDC) from extinction of the beams due to blocking by the piston and 'crosses' preceding captured data. The user specifies which of the two TDC regions is the beginning of the power stroke. Data are then stored as a function of crankshaft angular position (CA degrees).

### Data pre-processing stage consists of two main sequential steps:

- Offset correction – In this step TIPOD provides a user choice of either automatic or manual offset correction.
- Scaling – This step offers a choice of semi-automatic or manual scaling of the data to their full-scale values.

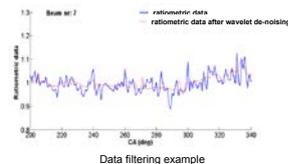
### Data filtering:

TIPOD uses the following data filters to remove noise from the data:

- Boxcar moving average
- Wavelet de-noising

### Dual wavelength ratiometric (DWR) approach:

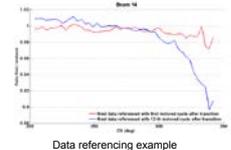
In this step the ratio of measurement and reference wavelength intensities has been taken either on raw data, pre-processed data or filtered data.



## Referencing

Applied to suppress data artefacts that are unrelated to the target species distribution.

- "Manual reference selection", where the user analyses the measured data in some detail and then selects an appropriate motored (i.e. non-fuelled) cycle, shortly after the fired cycles of interest, to serve as the reference cycle;
- "Load reference", where the user has previously selected and saved a motored cycle that can be used as a reference.



## Data display

- Selected dataset: raw data, pre-processed, filtered or DWR data
- Selected cycle within the file
- Choice of measurement, reference or both wavelengths
- Display of each beam separately or display of all beams
- Data to be displayed in specific CA range or full CA range by default

## Aero application

- Exploiting its simulation and image reconstruction facilities, TIPOD has been used to optimise the geometrical array design of a 128-beam system for the EPSRC FLITES project to image emissions from a Rolls-Royce jet engine.
- The optimisation approach has been adapted from the work of the Waterloo group.

## Conclusions

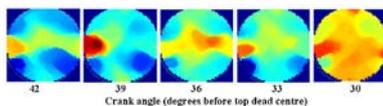
- The TIPOD software package is now established for a variety of applications
- TIPOD provides advanced functionality for process engineers and for tomographers
- TIPOD can be provided on request

## Acknowledgement

- Colleagues Kyle Daun and Mathew Twynstra from University of Waterloo, Canada for supporting the development of the TIPOD software package

## Image reconstruction

- TIPOD offers the option to perform image reconstruction either on DWR data or reference wavelength data
- Prior to image reconstruction the user can also perform a qualification test that is applied to the DWR transmission data from each beam, to reject poorly behaved beams
- This qualification test prevents the resulting image being impaired by the inclusion of poor quality data, e.g. those with unacceptably low signal-to-noise ratio (SNR) due to heavily contaminated lenses
- Image reconstruction can be performed only on one cycle at a time using two standard algorithms:
  - Iterative Landweber image algorithm with two smoothing filters: median filter and wavelet filter. The parameters of both filters can be set separately.
  - Tikhonov algorithm
- TIPOD provides a variety of means to display and export the reconstructed images.



Example of tomographic image sequences showing the hydrocarbon fuel distribution in one cylinder of a 4-cylinder gasoline engine

## References

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