3D Visualisation and Quantitative Characterisation of Fossil Fuel Flames Using Digital Imaging Techniques

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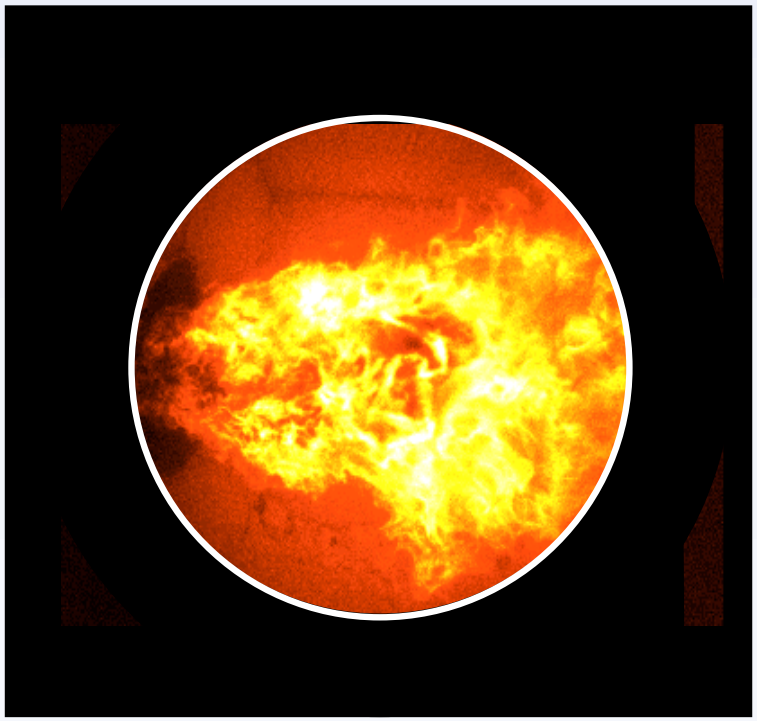
Outline

- Introduction
- System Description
- 3D Geometric Model
- 3D Temperature Measurement
- Experimental Results
- Conclusions and Future Work

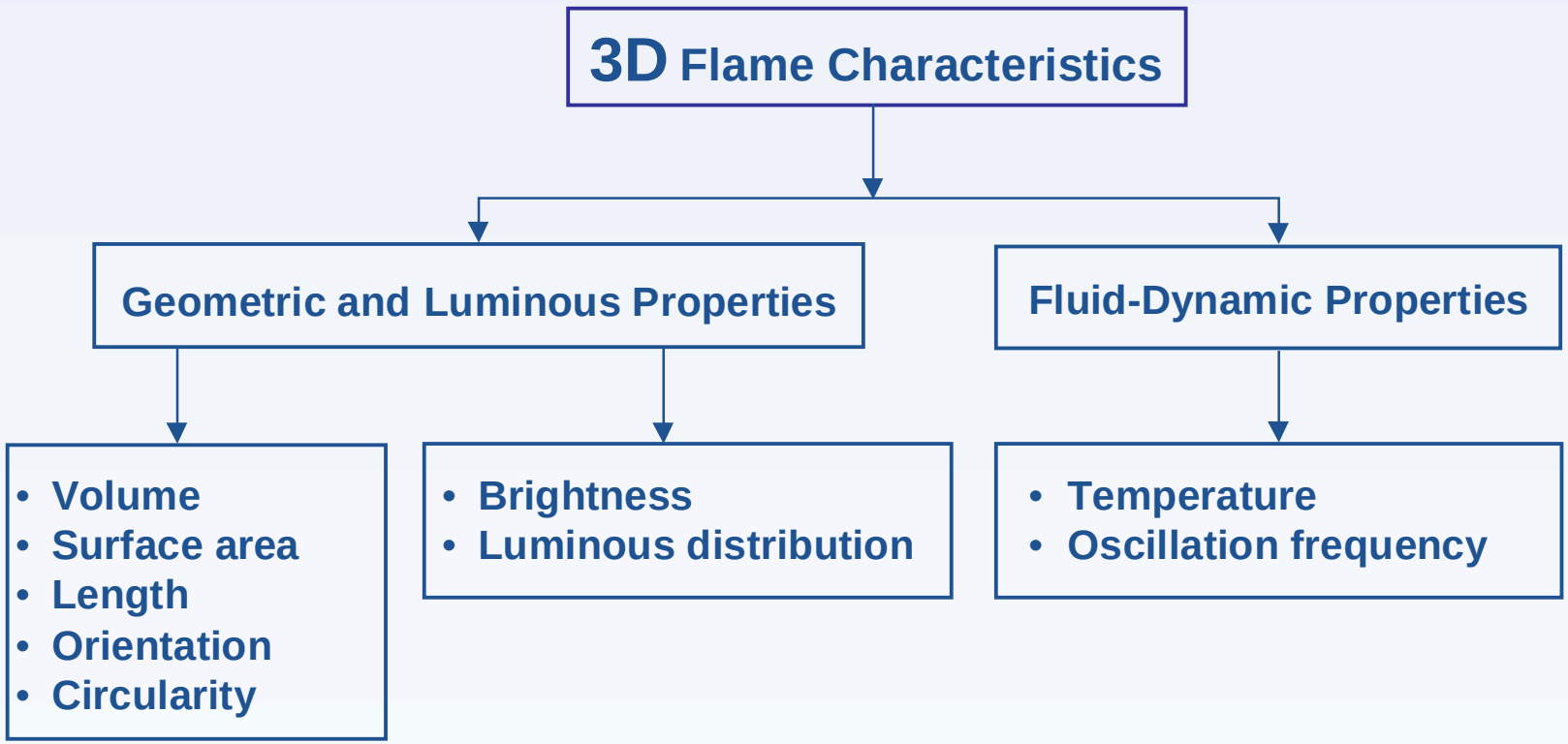
Introduction

- Flame characteristics are closely related to combustion efficiency, pollutant emissions and plant safety.
- Existing flame imaging systems provide superior data although limited to two dimensions.
- To fully reveal the dynamic nature of a flame, 3D visualisation and characterisation techniques are required.



Coal-Fired Flame

Introduction

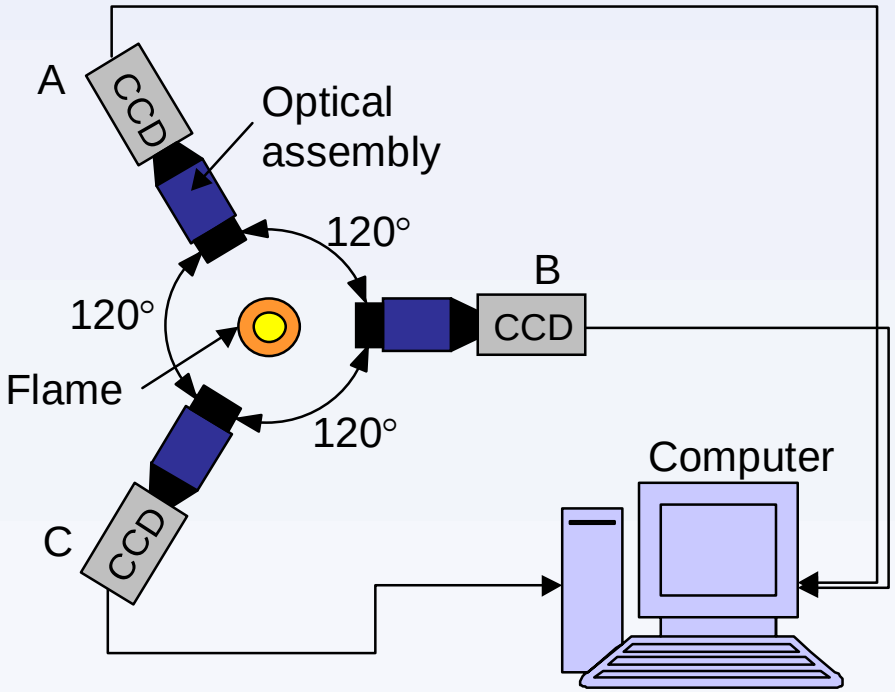


System Description

Multi-camera system

Features:

- 3 identical CCD cameras
- 360° sensing
- Simultaneous capture



3D Geometric Model

3D Reconstruction of a flame geometric model using the multi-camera system

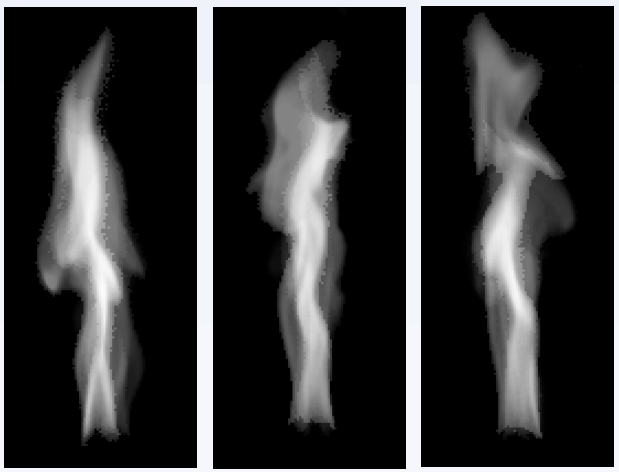
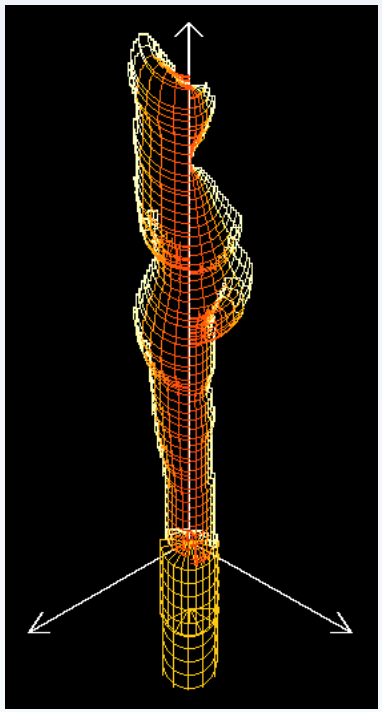
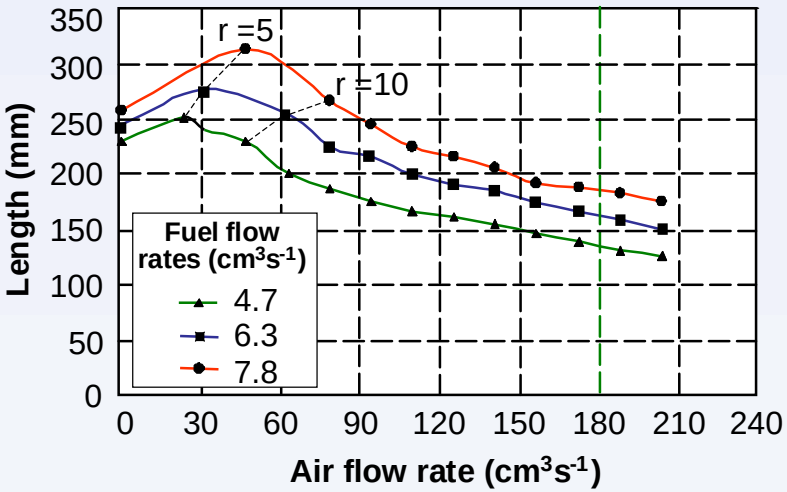


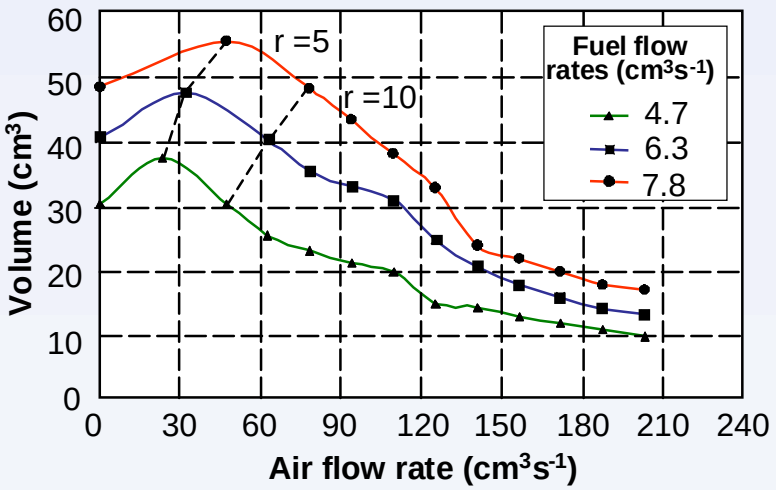
Image A Image B Image C

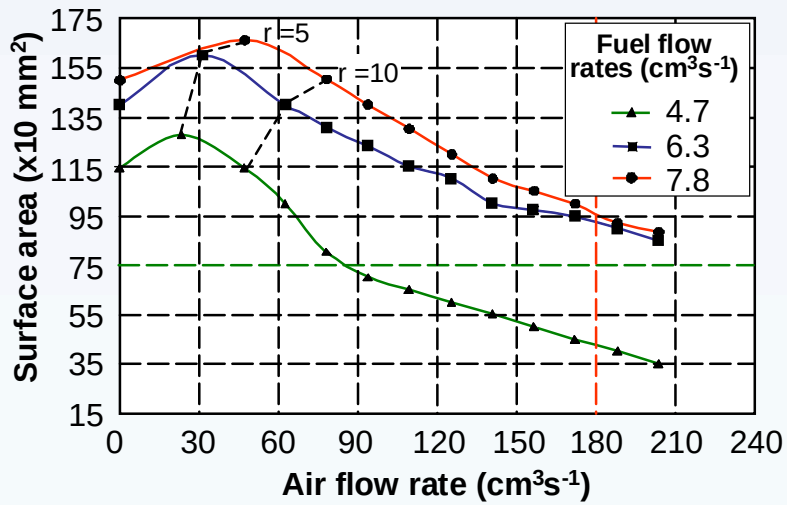
- Contour extraction
- Mesh generation
- Pseudo-colouring

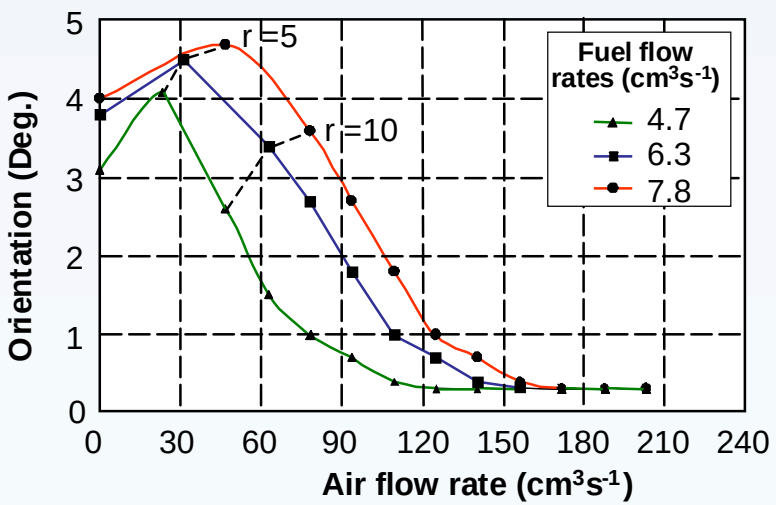


3D Parameters

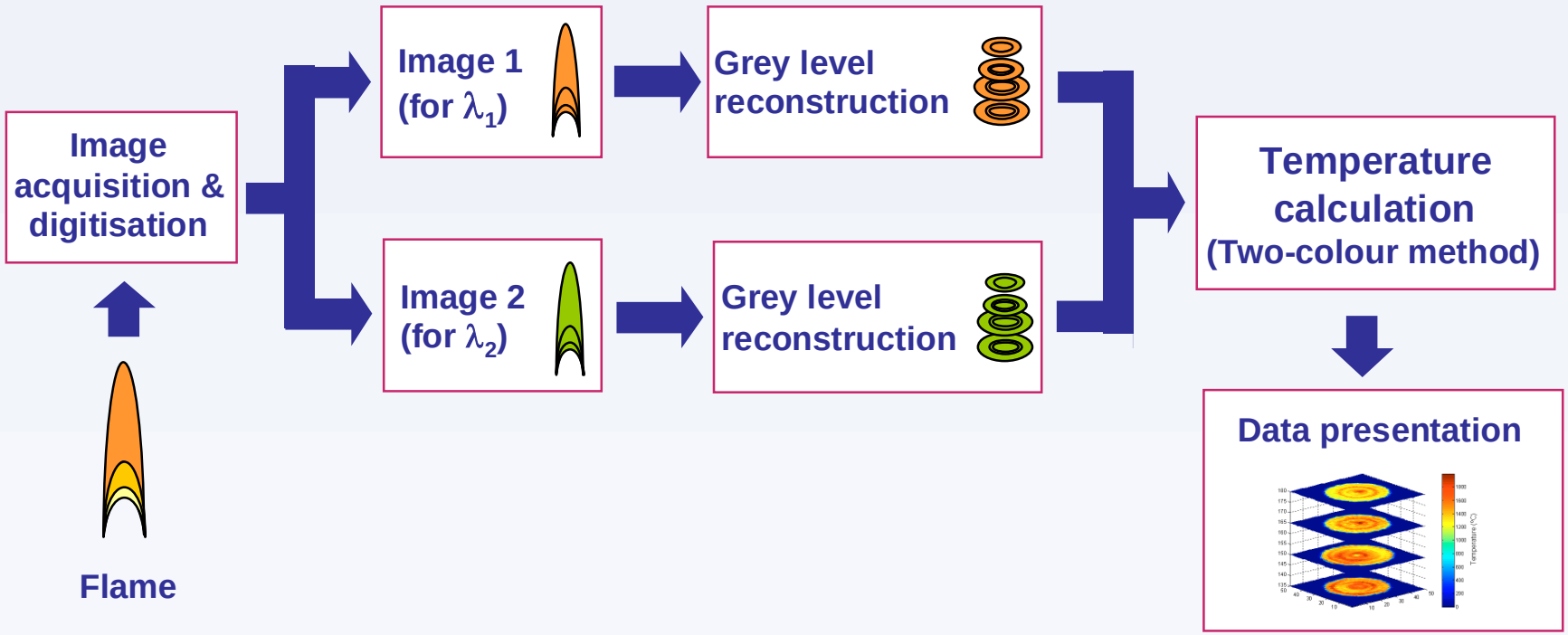






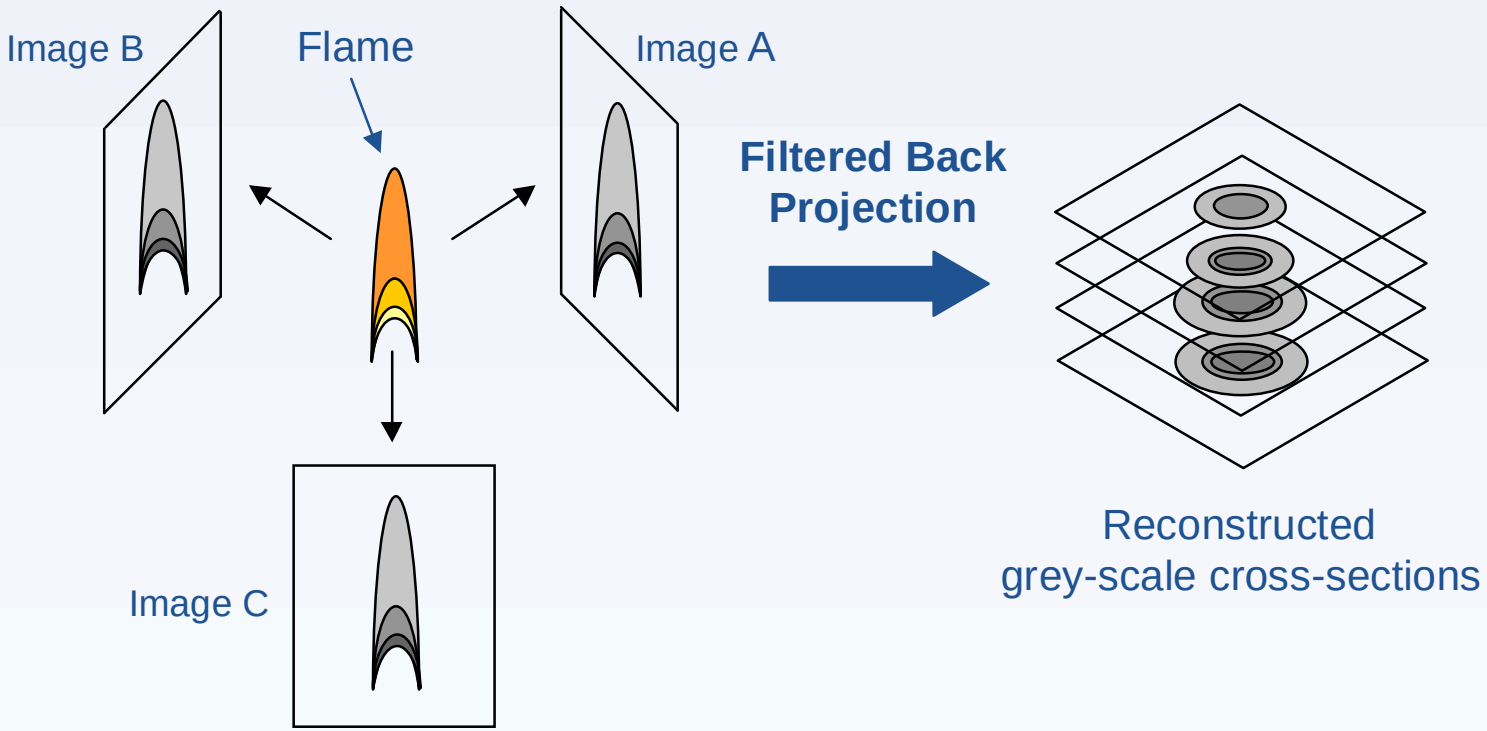


3D Temperature Measurement



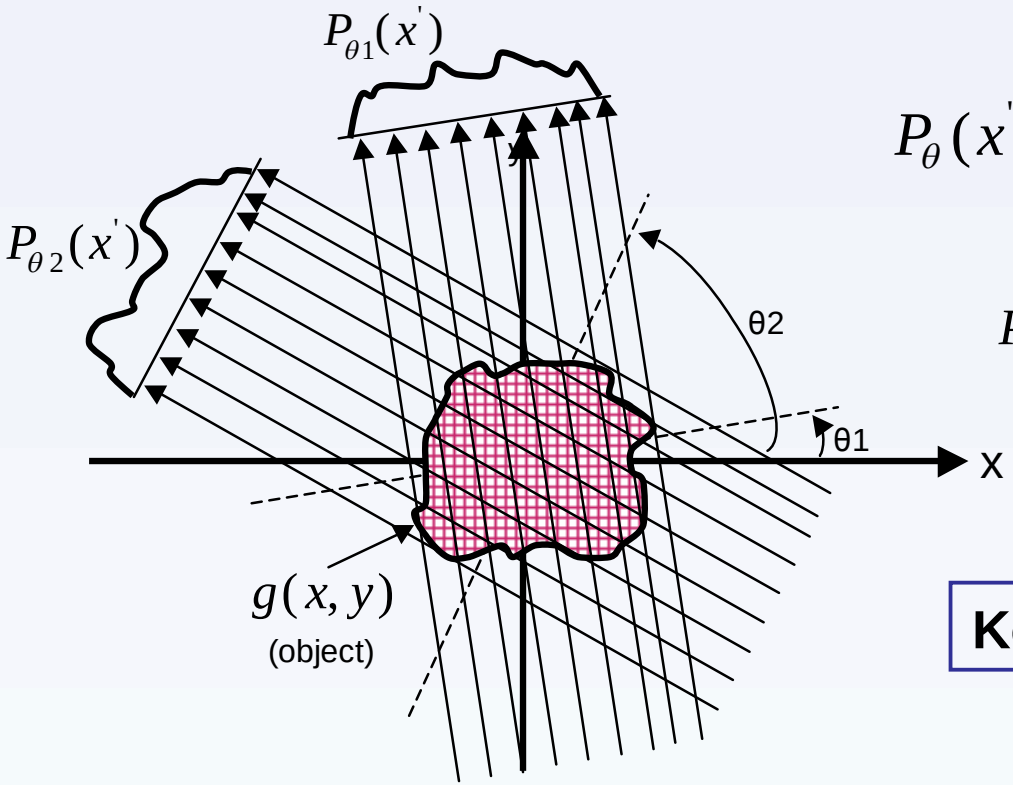
Reconstruction of Cross-Sections

2D images captured by the multi-camera system are used to reconstruct flame cross-sections through a de-convolution process.



Reconstruction of Cross-Sections

Parallel projections from different angles:



$$P_\theta(x') = \int_{-\infty}^{\infty} g(\bar{x})\delta(\bar{x}\cdot\bar{n} - x')d^2\bar{x}$$

$P_\theta(t)$ *known as the Radom Transform*

Key: Central Slice Theorem

Reconstruction of Cross-Sections

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Filtering & Back-projecting

- The Central Slice Theorem states that the 2D Fourier transform of a 2D function yields the same result as the successive execution of a Radom and a 1D Fourier transform in radial direction.

- The object can be reconstructed by back-projecting and adding successively the filtered projections:

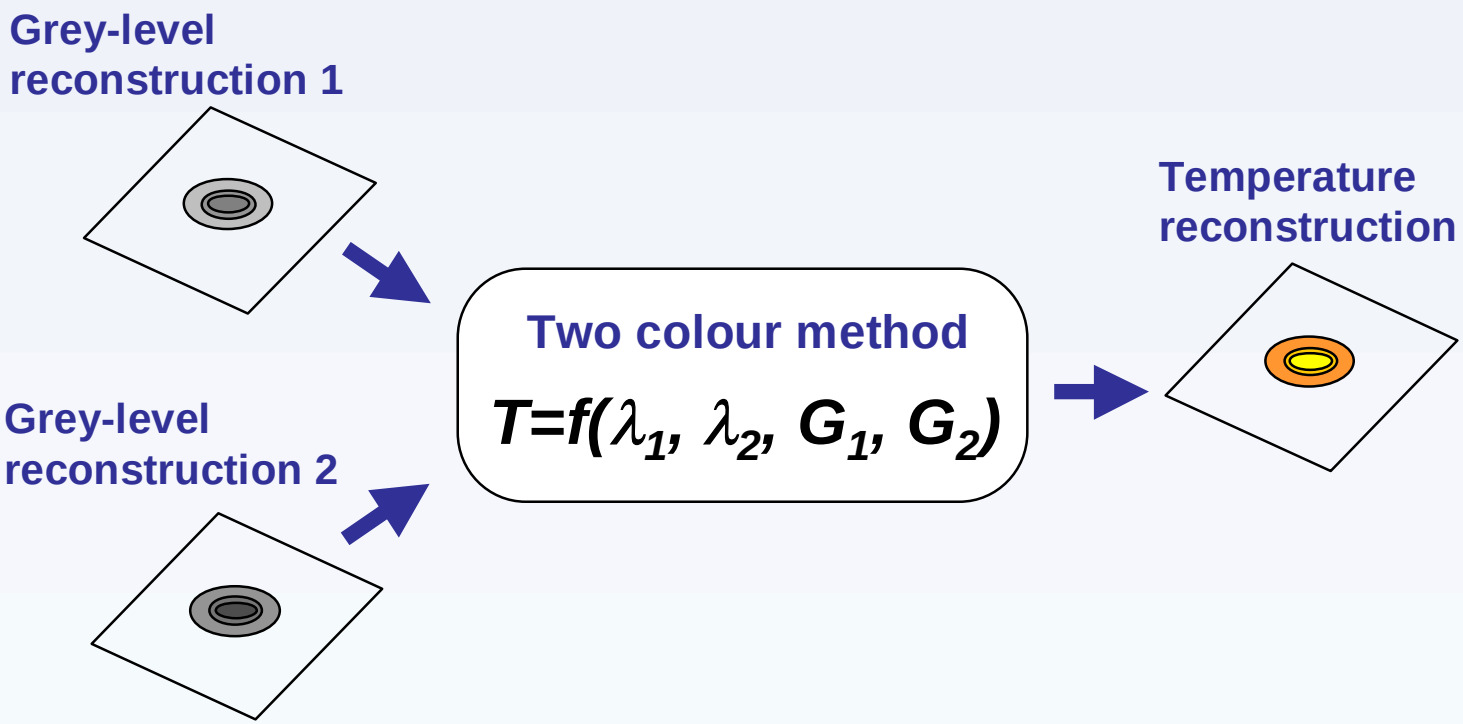
$$g(\bar{x}) = \int_0^{\pi} Q_\theta(\bar{x} \cdot \bar{n}) d\theta$$

where

$$Q_\theta(\bar{x} \cdot \bar{n}) = (h * P_\theta)(x')$$

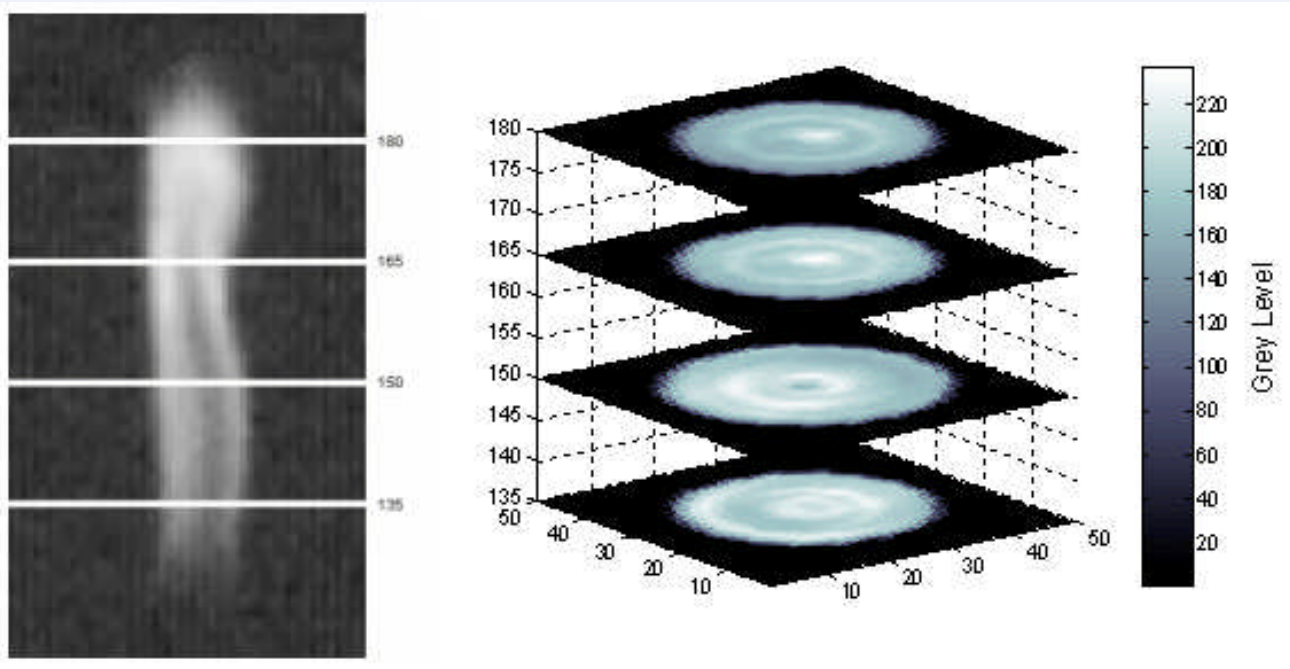
Temperature Calculation

Temperature is determined from flame radiation intensities at two wavelengths based on the Planck's radiation law.



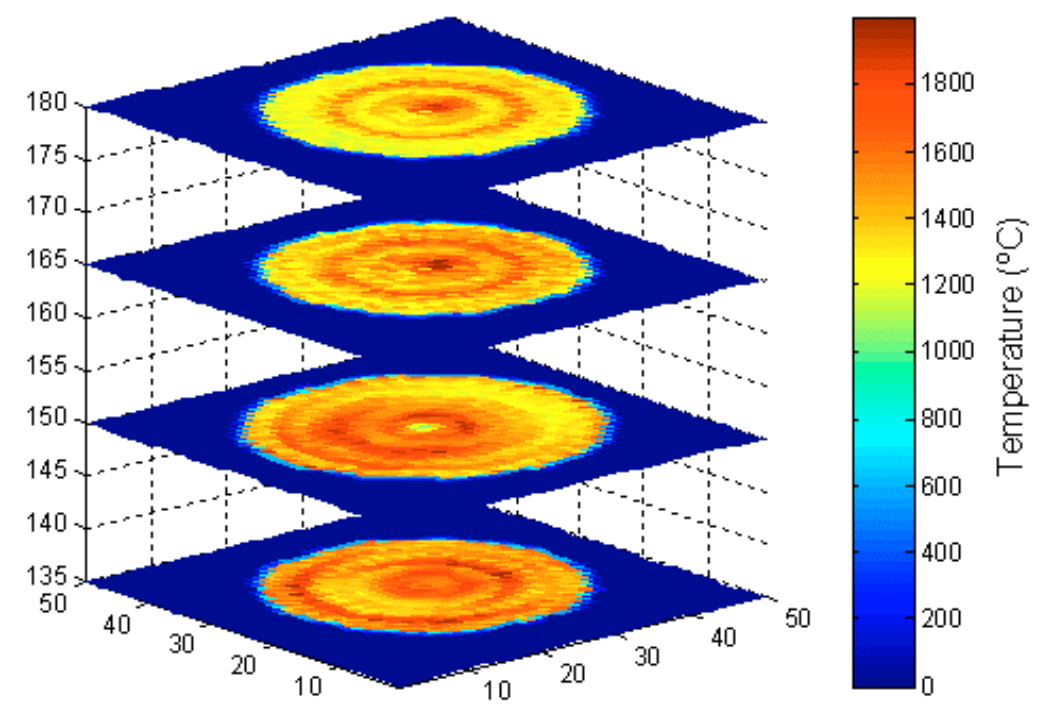
Experimental Results

Grey-level reconstruction using a single 2D image



Experimental Results

Temperature distributions of cross-sections

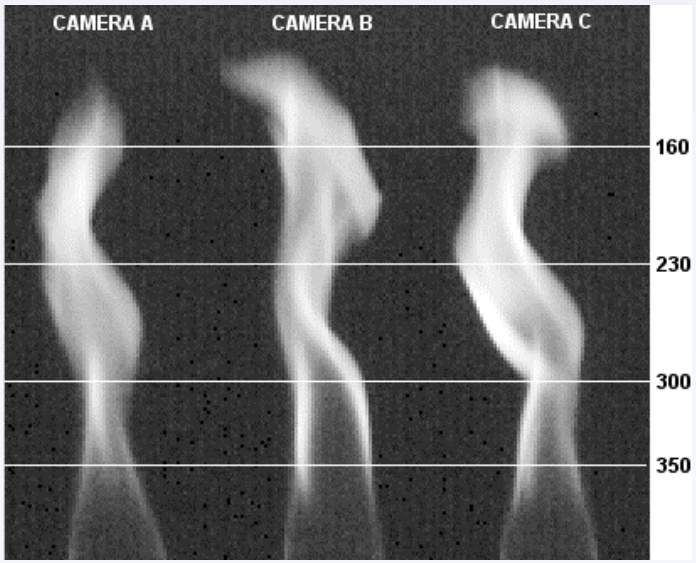


Single Camera or Multiple Cameras?

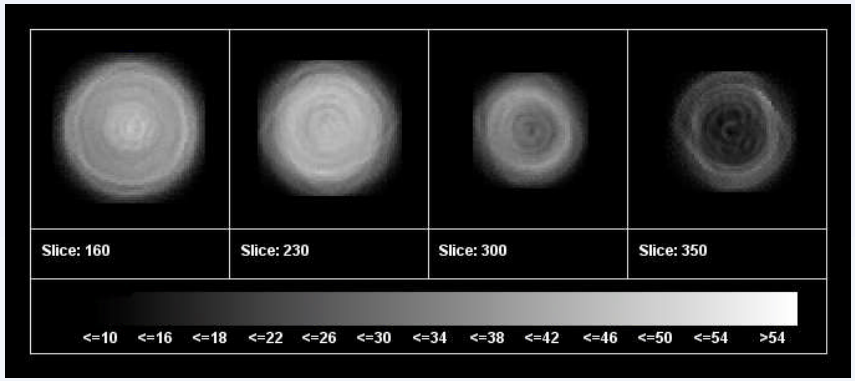
- **Single camera imaging:**
  - ✓ Simplicity
  - ✓ Easy implementation
  - ✓ Low cost
  - ✓ Assumption of rotational symmetry
  - ✓ Applicable to an ideal case
- **Multi-camera imaging:**
  - ✓ No rotational symmetry assumption made
  - ✓ Increased accuracy
  - ✓ Higher number of projections (up to 6 with 3 cameras)
  - ✓ Complex system set-up

Experimental Results for Multi-Camera system

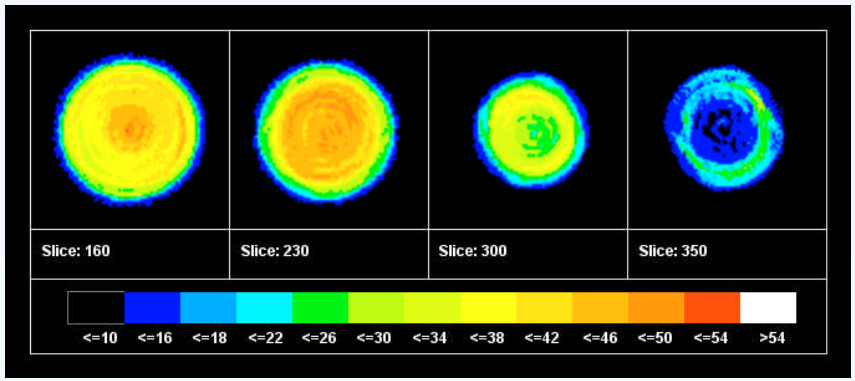
Flame images captured from positions A, B and C



Reconstructed grey-scale cross-sections



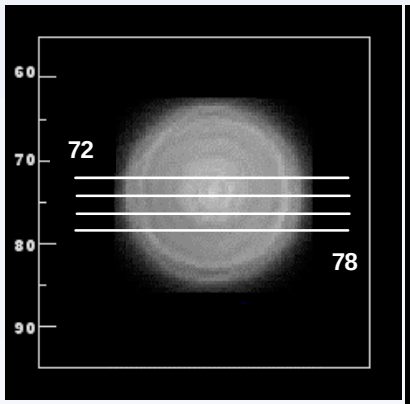
(Grey-scale)



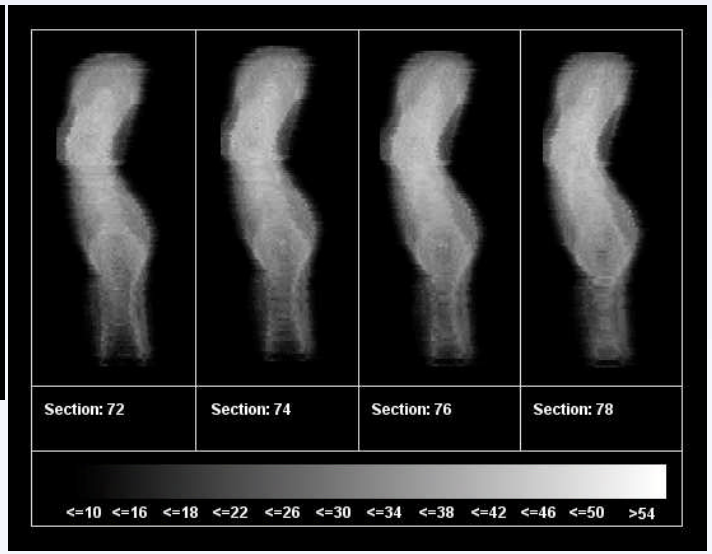
(Colour-scale)

Experimental Results for Multi-Camera system

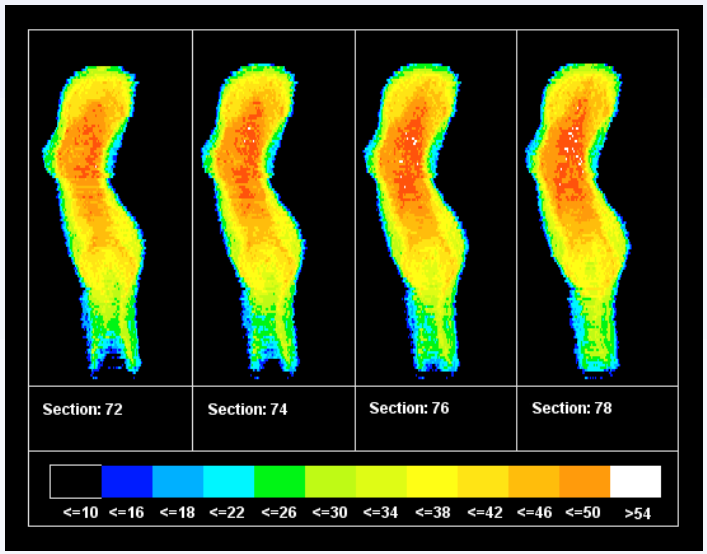
Reconstructed longitudinal sections viewed from ‘position A’



Location of sections



(Grey-scale)



(Colour-scale)

Conclusions

- Vision based techniques for 3D visualisation and characterisation of combustion flames have been proposed.
- A multi-camera instrumentation system has been successfully designed and constructed for flame geometric reconstruction and characterisation.
- The concept of using a single camera for 3D flame temperature monitoring has proven effective in simple combustion cases.
- Algorithms for the 3D visualisation and reconstruction of a combustion flame based on multi-projections have been proposed for an improved accuracy.

Future Work

- Optimisation between the suitable number of projections and the reliability of the reconstructed flame model.
- Study of different algorithms for more accurate reconstruction of flame cross-sections.
- 3D temperature determination using the two colour technique.