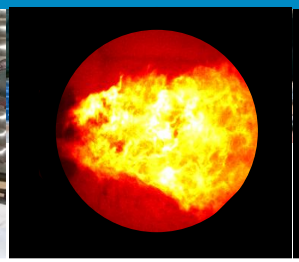
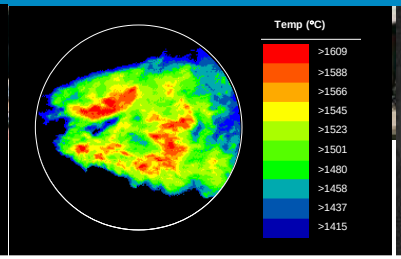
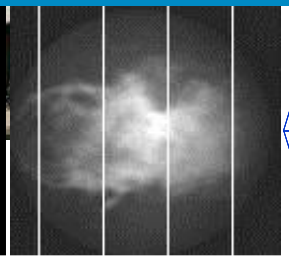
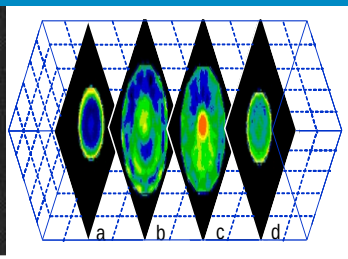
University of Kent | School of Engineering and Digital Arts

BF2RA Project:

Intelligent Flame Detection Incorporating Burner Condition Monitoring and On-Line Fuel Tracking



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Industrial Supervisor: Kelly Walker, E.ON

Outline

- Aim and Objectives
- Current Progress
  - System Design & Implementation
  - System Initial Tests
    - Test on a 660MW_{th} Boiler
    - Test on a 9MW_{th} Oil CTF
  - Intelligent Burner Condition Monitoring
  - Intelligent On-line Fuel Tracking
- Future Work

Aim and Objectives

- **Aim**

  to develop a cutting edge flame monitoring technology that can indicate burner conditions and track the type of fuels (coal and/or biomass) in a power plant.

- **Objectives**
  - To develop a technology for flame stability measurement, burner condition monitoring and on-line fuel tracking through digital imaging and flame signature analysis;
  - To evaluate the technology under a range of biomass firing, coal/biomass co-firing, and oxy-fuel fired conditions on a combustion test facility and on a full scale multi-burner furnace;
  - To make recommendations for improvements of existing furnaces through the use of the new technology.

Why Monitor Flame?

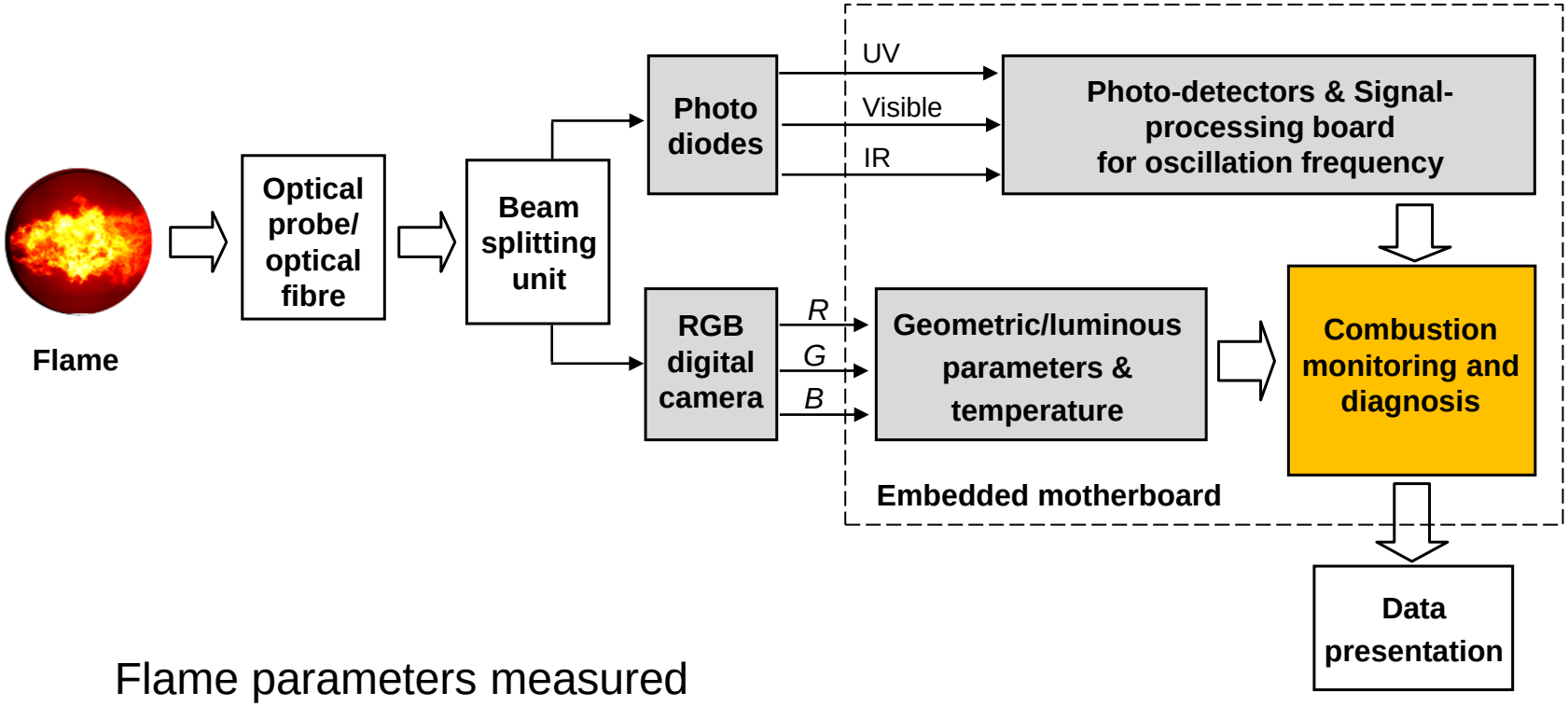
- The characteristics of a flame, such as size, shape, brightness, colour, oscillation frequency and temperature, provide instantaneous information on the performance of the combustion process.
- Existing flame monitoring instruments can only measure global variables (input/output of boiler), which provide very limited description about the flame (inside of boiler).

Power plant

Flames inside a boiler

Current Progress - Flame Monitoring System

- **System Strategy**



Flame parameters measured

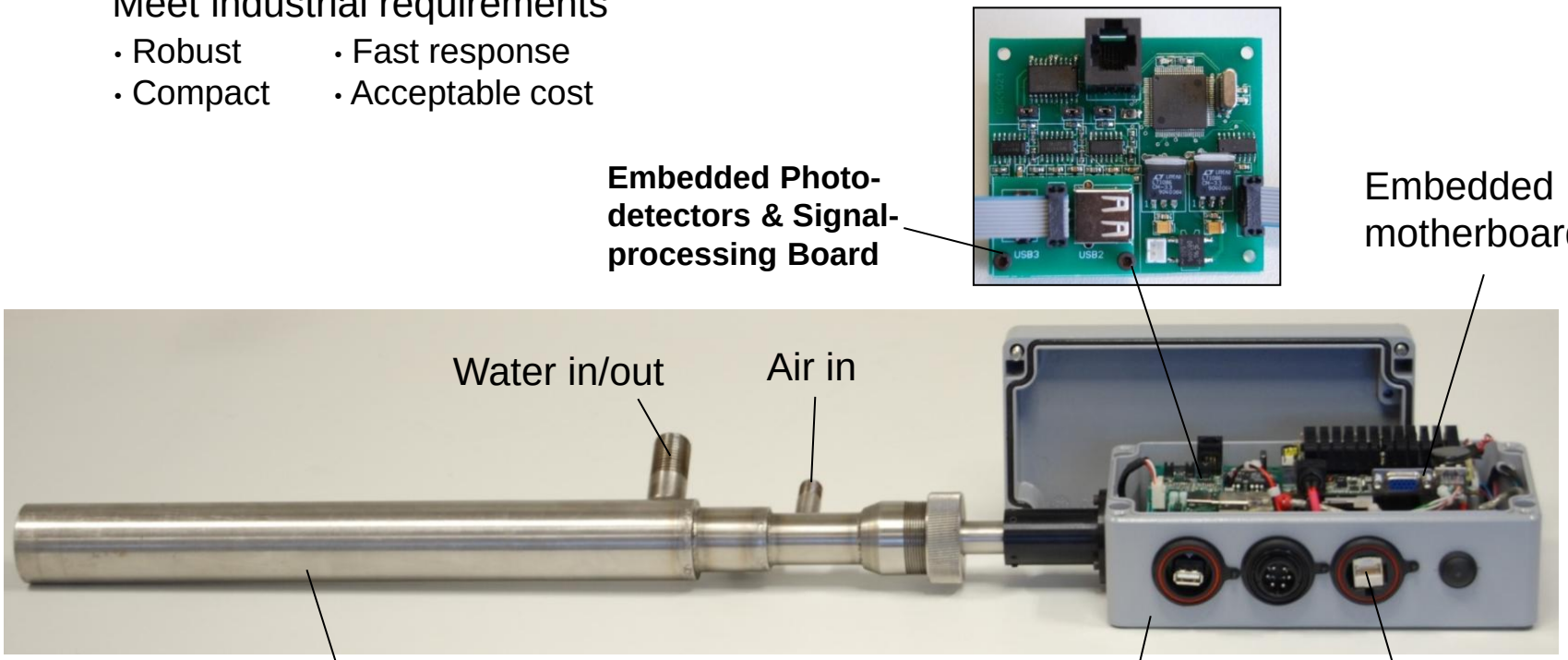
- *Geometric (Ignition point, size and shape)*
- *Luminous (brightness, non-uniformity)*
- *Oscillation frequency , temperature distribution*

Current Progress - Flame Monitoring System

- **Optical probe based system**

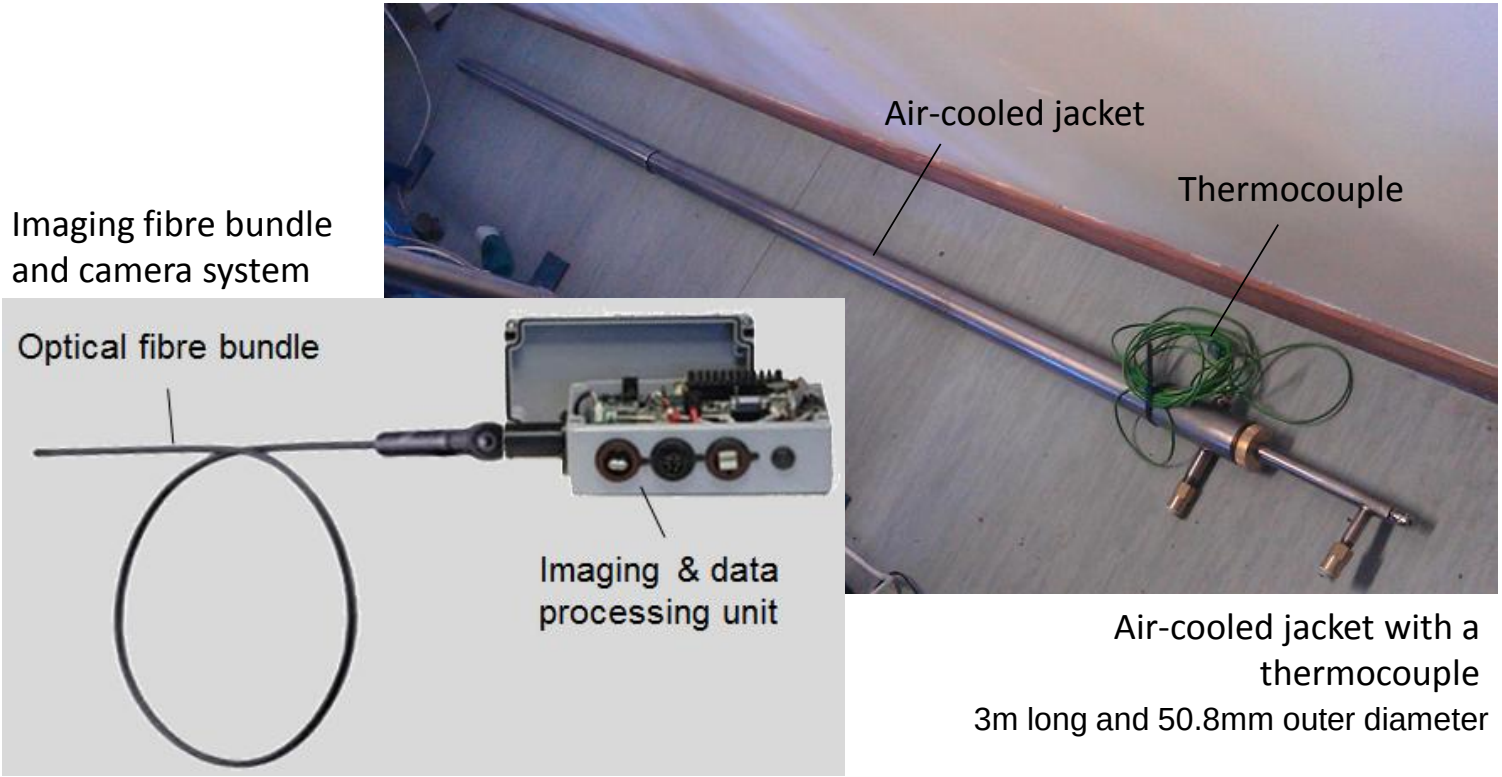
Meet industrial requirements

- Robust
- Fast response
- Compact
- Acceptable cost



Current Progress - Flame Monitoring System

- **Optical fibre based system**

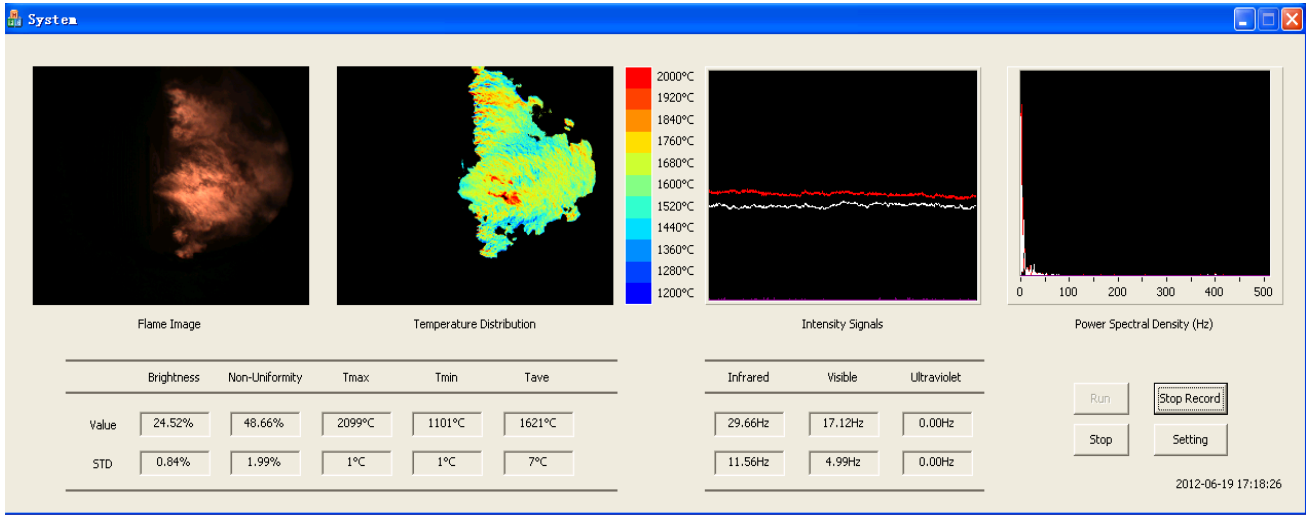


Air-cooled jacket with a thermocouple

3m long and 50.8mm outer diameter

Current Progress - Flame Monitoring System

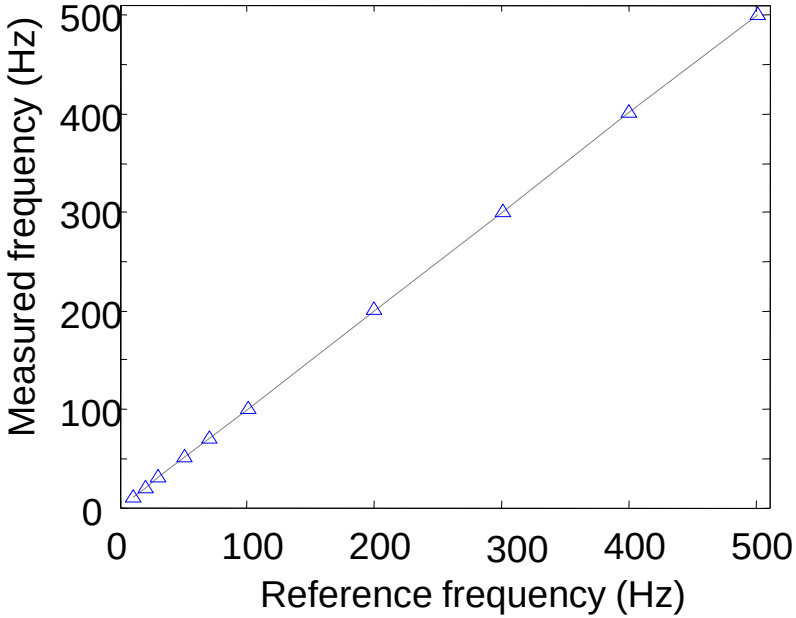
- **System Software**
  - Compute and display on-line flame sensorial information (flame image, 2-D temperature distribution, flame radiation signals, power spectral densities, etc.)
  - Setup system (camera exposure time, gain control, etc.)
  - Record data (raw images/signals, processed results)



Graphical user interface

Current Progress - System Evaluation

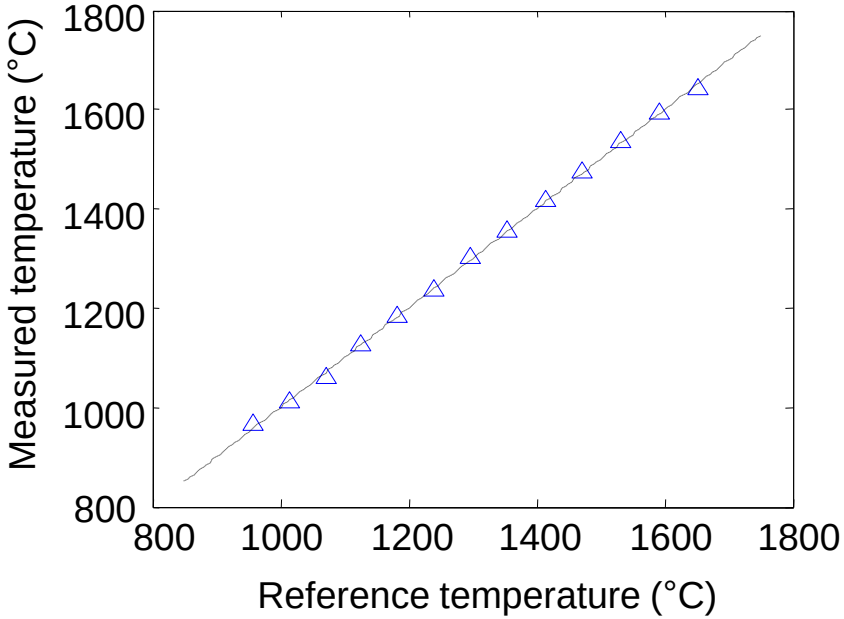
- The oscillation frequency measurement was evaluated using a standard frequency-varying light source.
- The relative error is no greater than 2% (0 to 500Hz).



Comparison between the measured and reference frequencies

Current Progress - System Evaluation

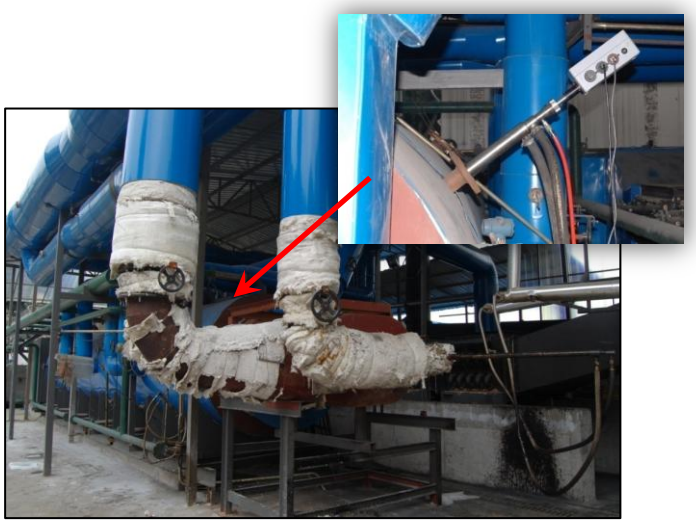
- The system was calibrated using a blackbody furnace, and verified by measuring the true temperature of a standard tungsten lamp.
- The max error of 14.8°C occurs at 1650°C (equivalent to the relative error of 0.9%.



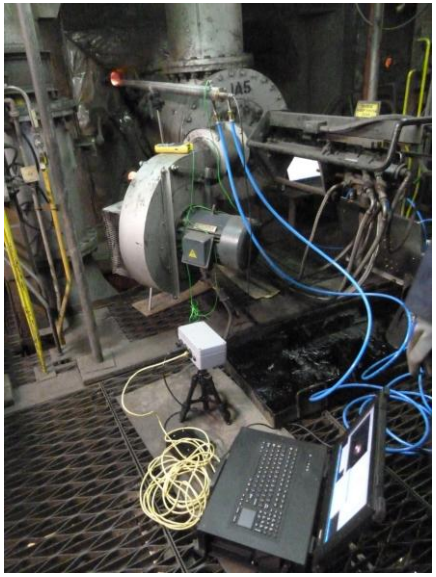
Comparison between the measured and reference temperatures

Field Trials

- The system has been tested on
  - a 660MW_{th} coal/biomass-fired boiler at a power station in UK
  - a 9MW_{th} heavy-oil-fired CTF at Zhejiang University, Hangzhou, China

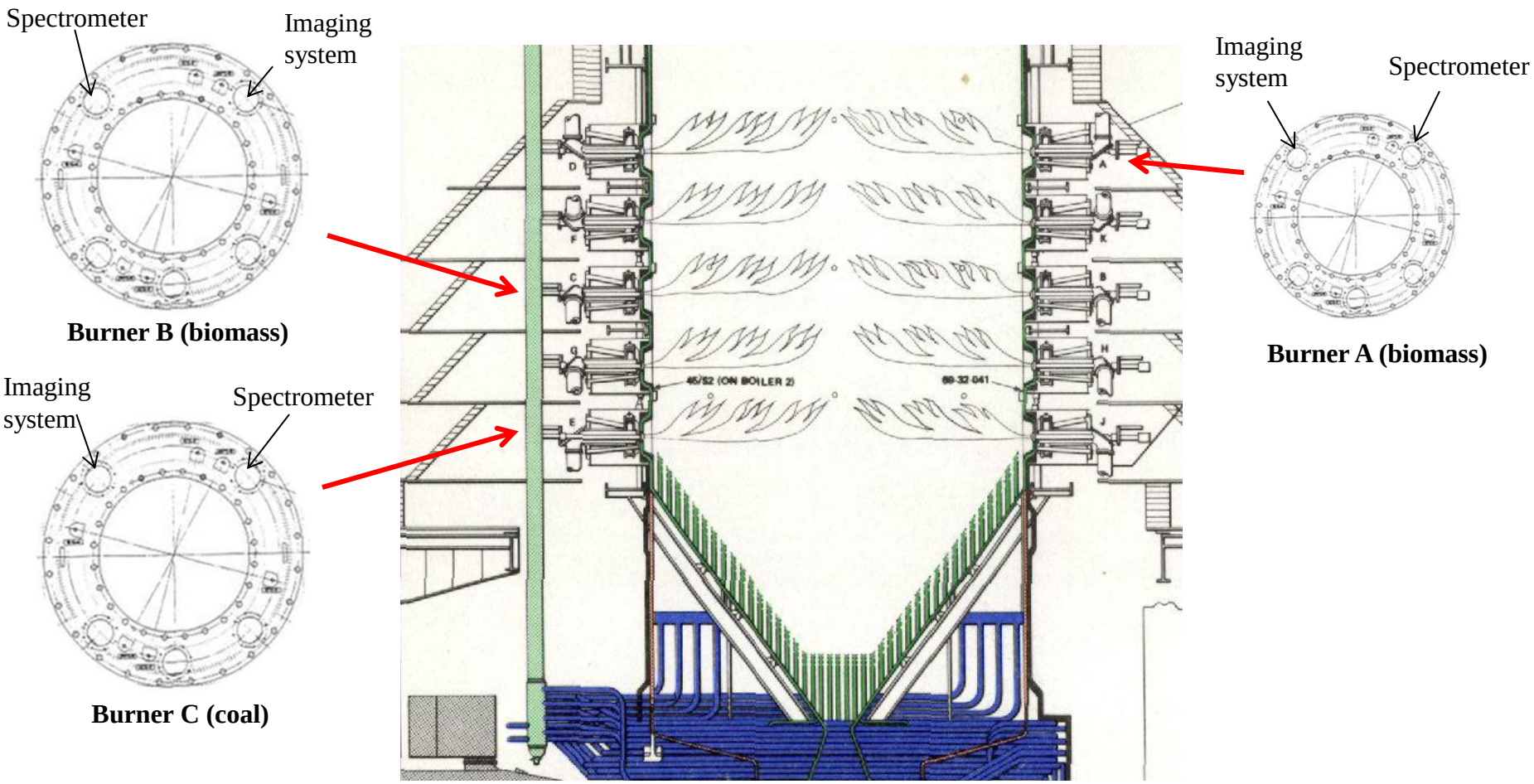


9MW_{th} CTF at Zhejiang University



A power station in UK

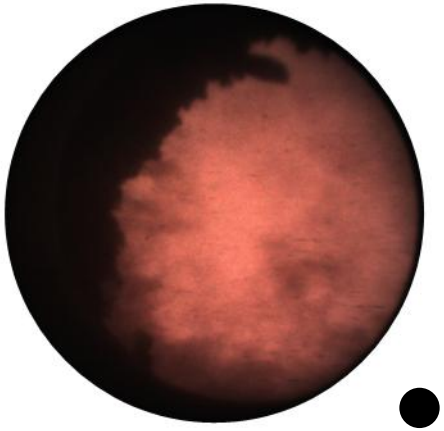
Test on a 660MW$_{th}$ Boiler



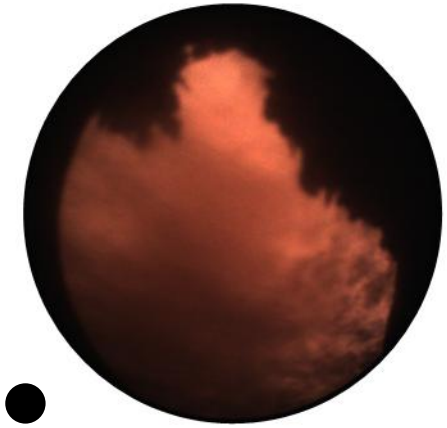
Boiler cross-section and system installation

Images of Biomass & Coal flames

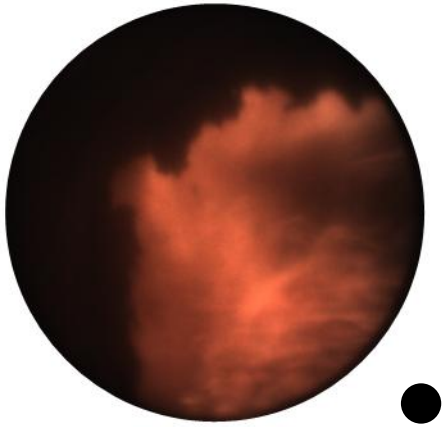
Burner A (100% biomass)



Burner A (feeder off,
burner firing supported by oil)



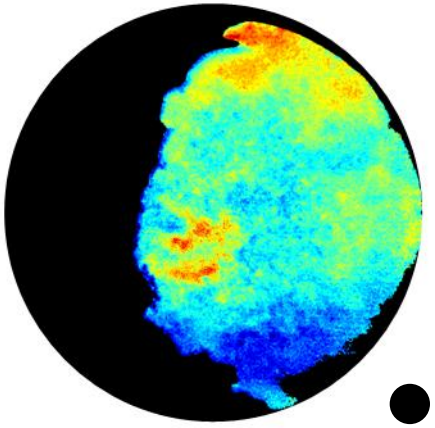
Burner B (100% biomass)



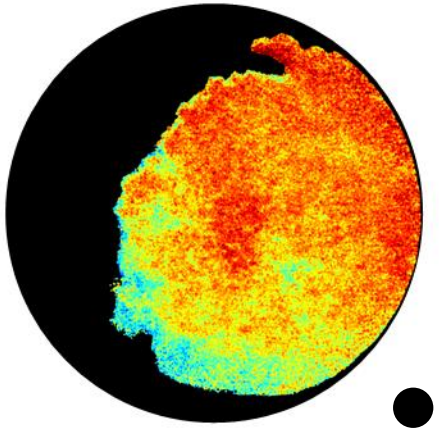
Burner C (100% coal)

Note: ●- Location of the burner.

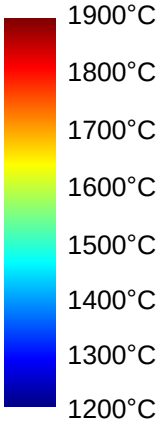
Flame Temperature Distribution

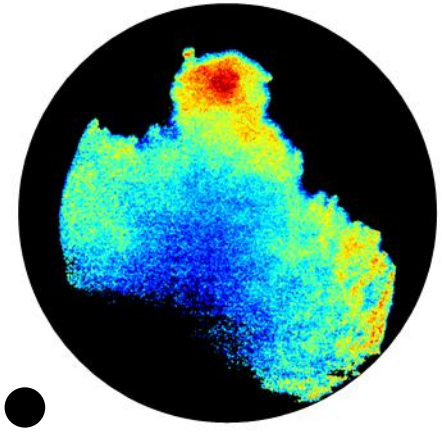


Burner A (100% biomass)

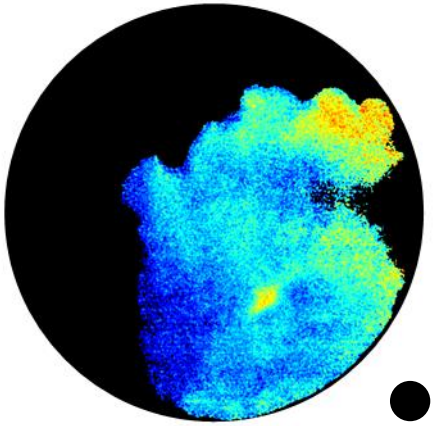


Burner A (feeder off,
burner firing supported by oil)





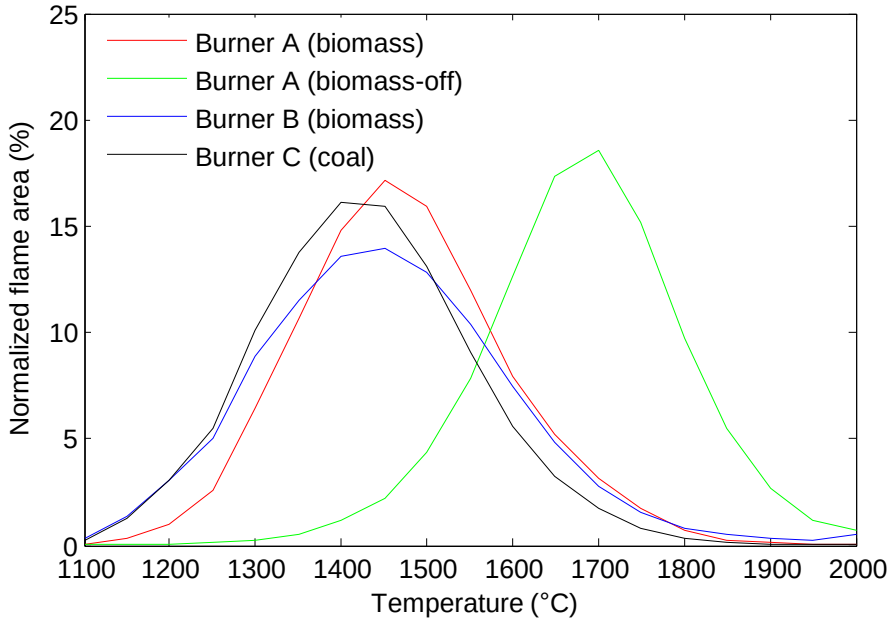
Burner B (100% biomass)



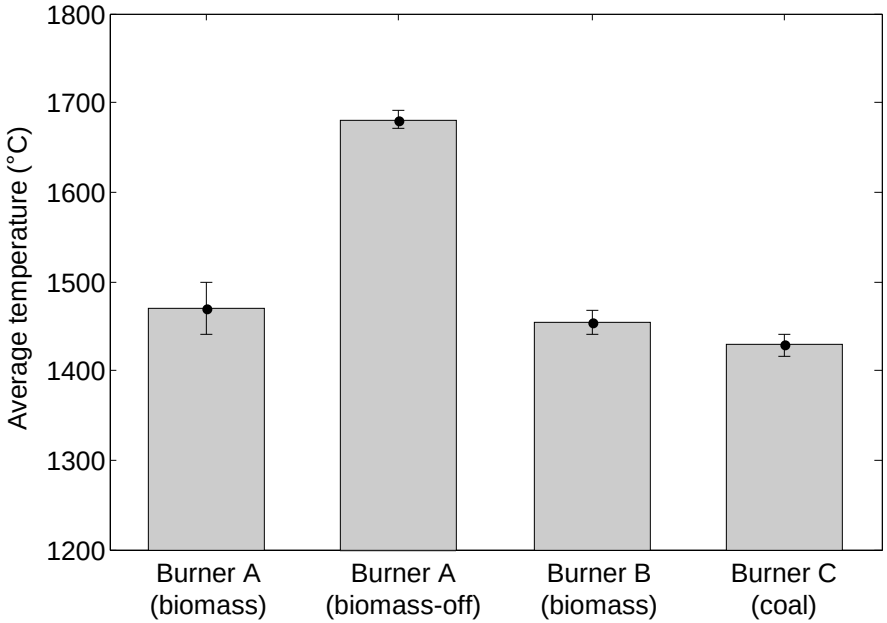
Burner C (100% coal)

Note: ●- Location of the burner.

Temperature Variation



Temperature histogram

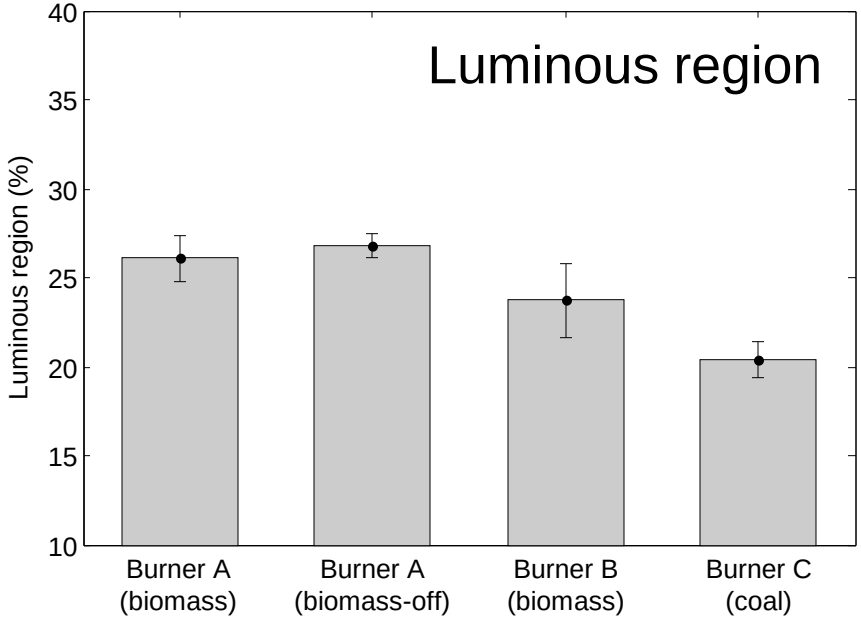


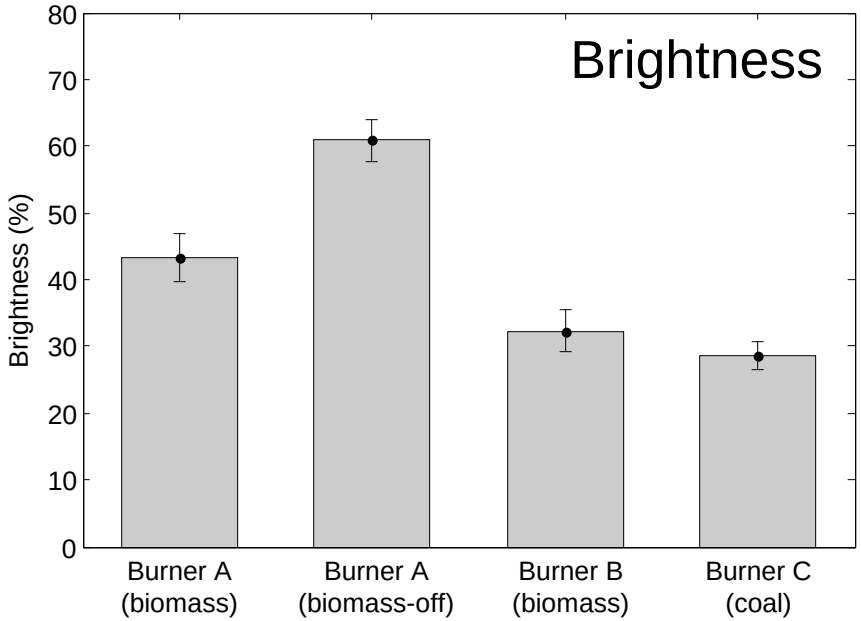
Average temperature

Remarks:

- The biomass flame has a substantial delay in ignition and fluctuates significantly.
- Increased standard deviations of the flame temperature and luminous region were found under all the biomass conditions, indicating greater instability of the biomass flames.

Luminous Region and Brightness

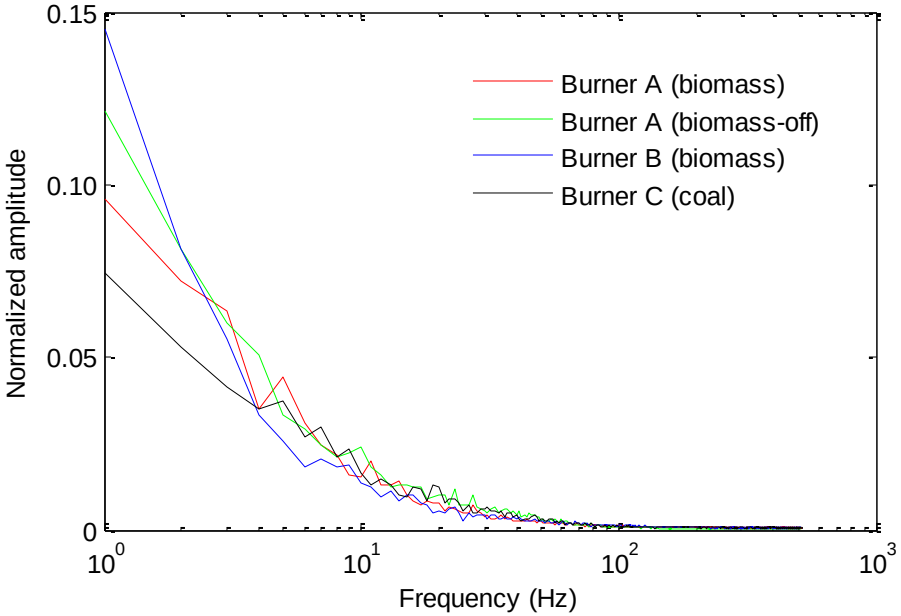




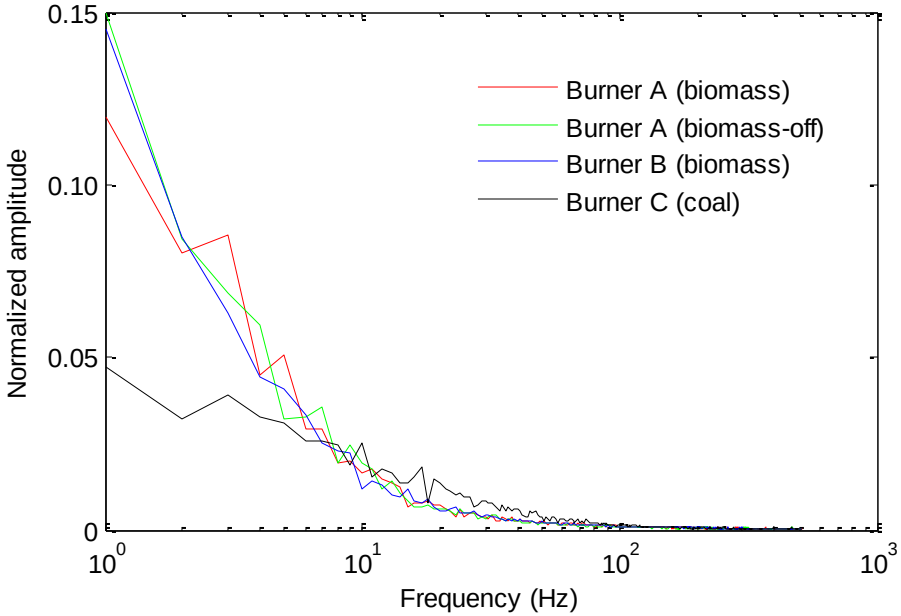
Remarks:

- The biomass flame has relatively unstable ignition in nature, compared with coal flame.
- The significant fluctuation in the ignition of the biomass flames may affect the reliable operation of the flame eye. This is due the fact that the field of view of the existing flame-eye is very narrow,

Frequency Spectrum



In visible band

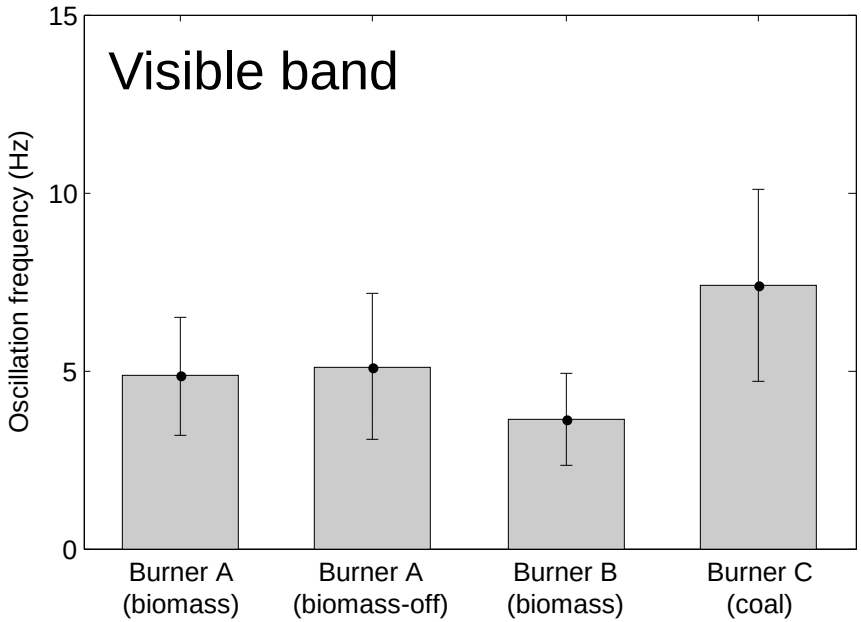


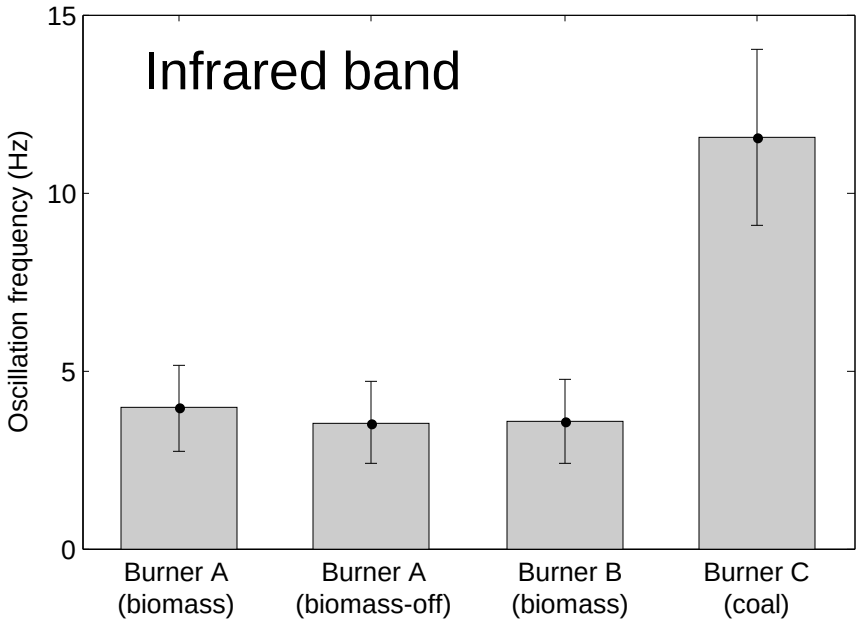
In infrared band

Remarks:

The biomass flames exhibit very different profiles of frequency spectrum from that of the coal flame.

Oscillation Frequency

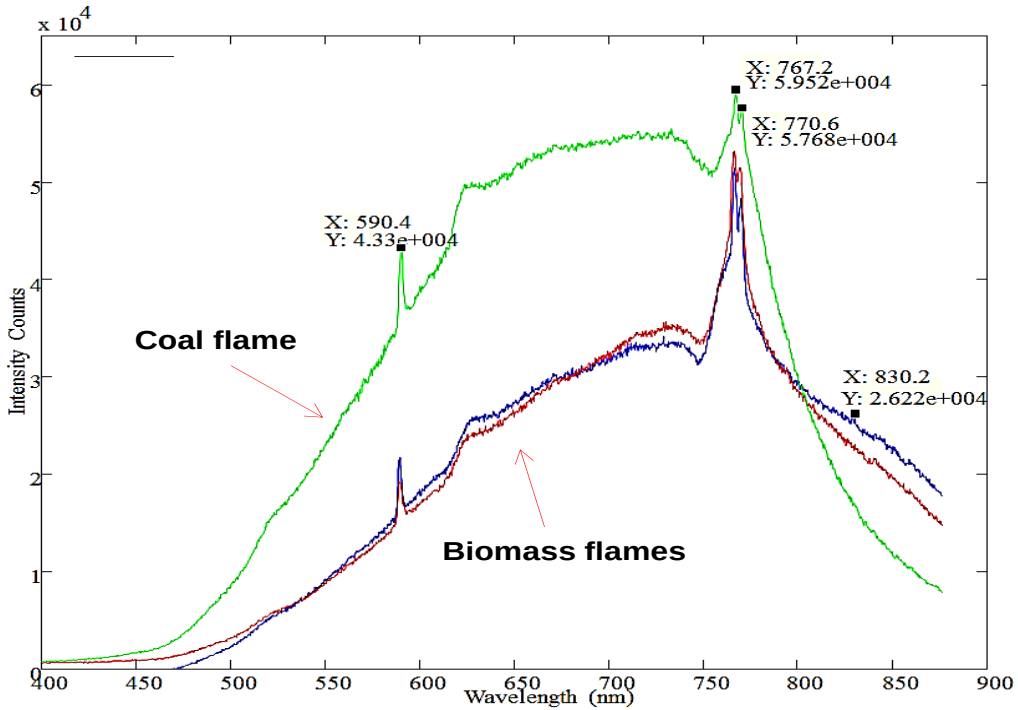




Remarks:

- The amplitude of the low-frequency components for the biomass flame is much higher than that of the coal flame in both visible and infrared bands, resulting in much lower oscillation frequencies.
- The different frequency spectral characteristics of the biomass flame may explain why the exiting flame eye, which is specially designed for coal flames, fails when it is applied to a biomass flame.

Spectroscopic Characteristics

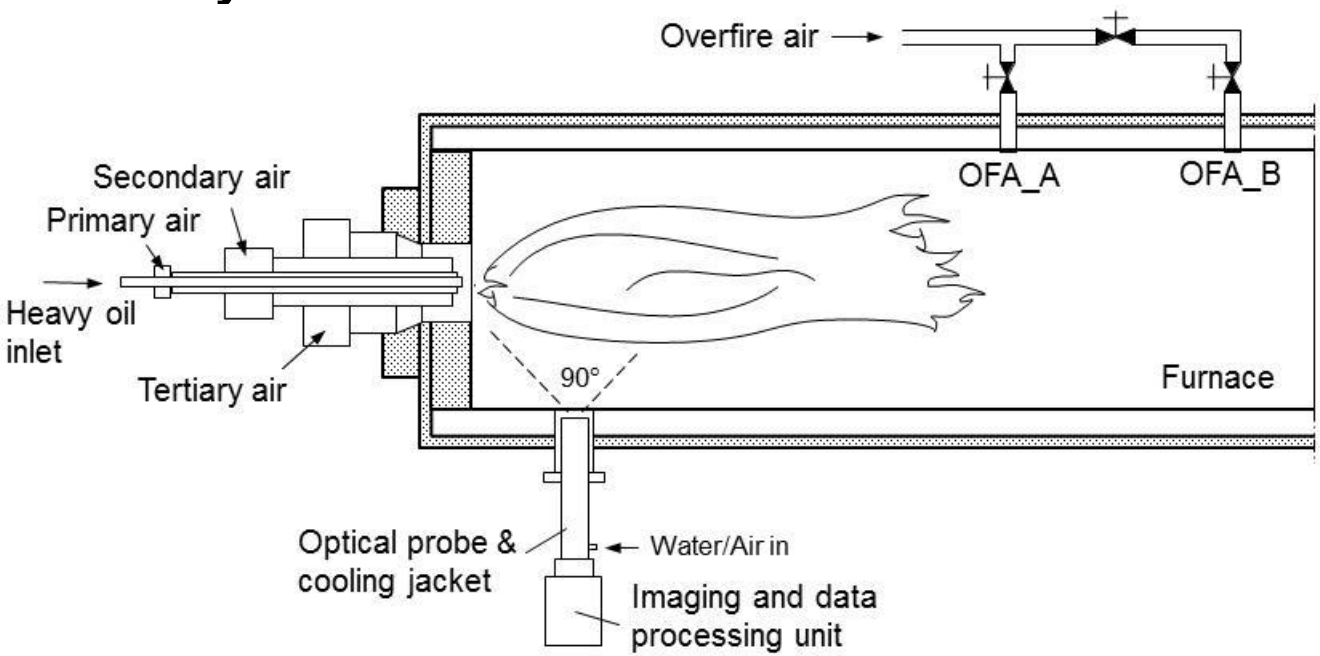


Remarks:

Flames from all biomass-fired burners tested have shown very similar spectroscopic profiles, which are significantly different from that of a pulverised coal flame. However, the spectroscopic intensity of the biomass flame vary significantly even under the same condition

Tests on the 9MWth Heavy-Oil-Fired CTF

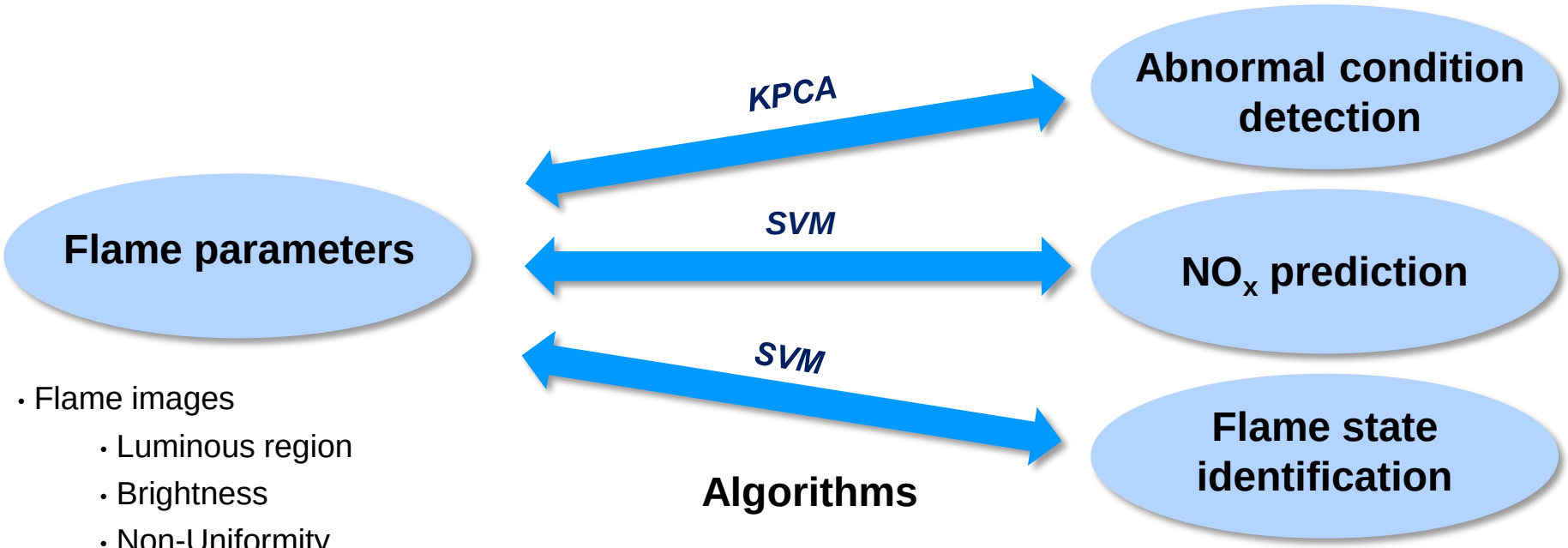
- **Test facility**



- **Test conditions**
  - Variations in the swirl vane angle of tertiary air
  - Variations in the swirl vane position of secondary air
  - Variations in the ratio of primary air to total air
  - Variations in the ration of overfire air to total air and its nozzle position

Intelligent Burner Condition Monitoring

- **Use flame parameters as the "signature" of a particular combustion condition**



- Flame images
  - Luminous region
  - Brightness
  - Non-Uniformity
- Flame radiation signals
  - Oscillation frequency
  - DC, AC, skewness and kurtosis
  - Energy distribution

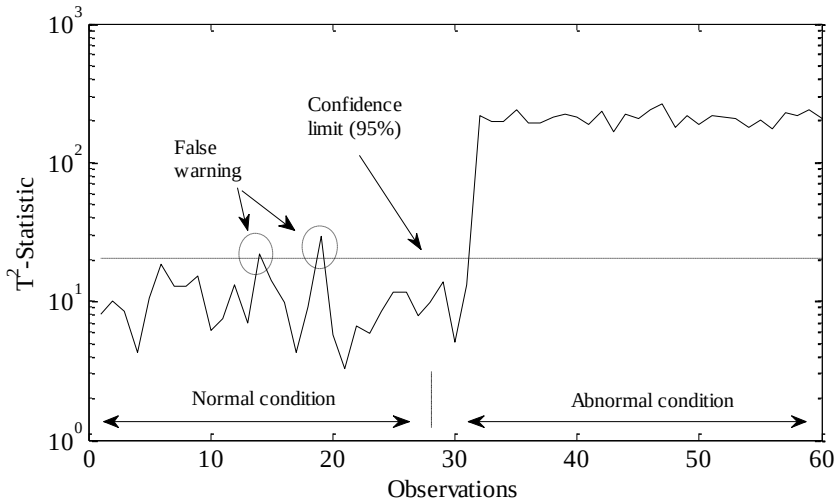
KPCA: kernel principal components analysis

SVM: support vector machine (classification/regression)

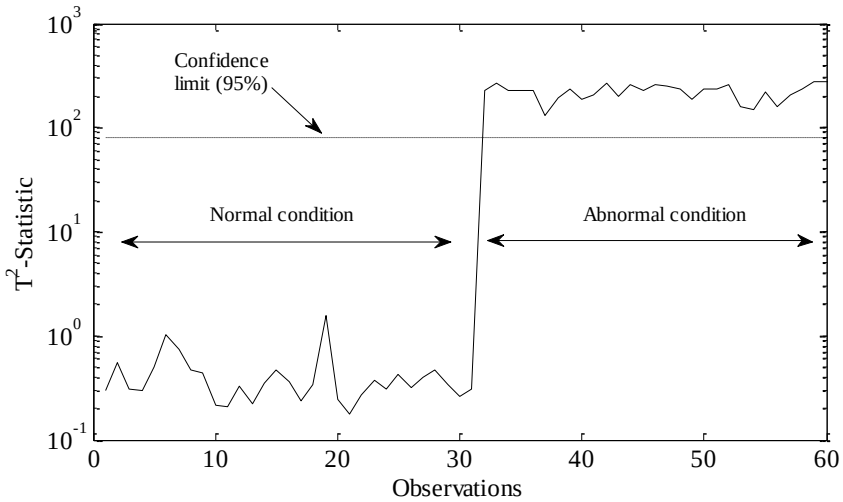
Intelligent Burner Condition Monitoring

Example - Abnormal Condition Detection

- **An abnormal condition was generated by setting the SA swirl vane position deviated from its baseline configuration.**



(a) PCA



(b) KPCA

Monitoring charts of combustion process by KPCA

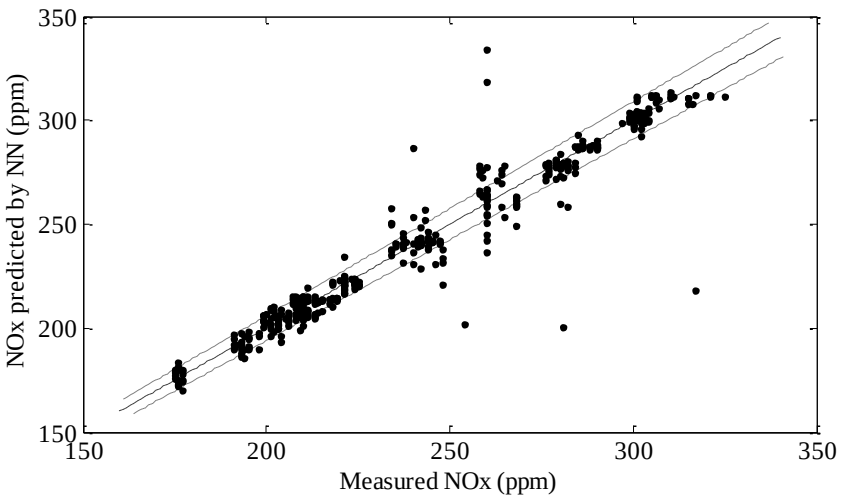
Remarks:

- Compared with PCA, KPCA model performed better in illustrating the discrepancy between the normal and abnormal conditions, and showed no false warnings at all.

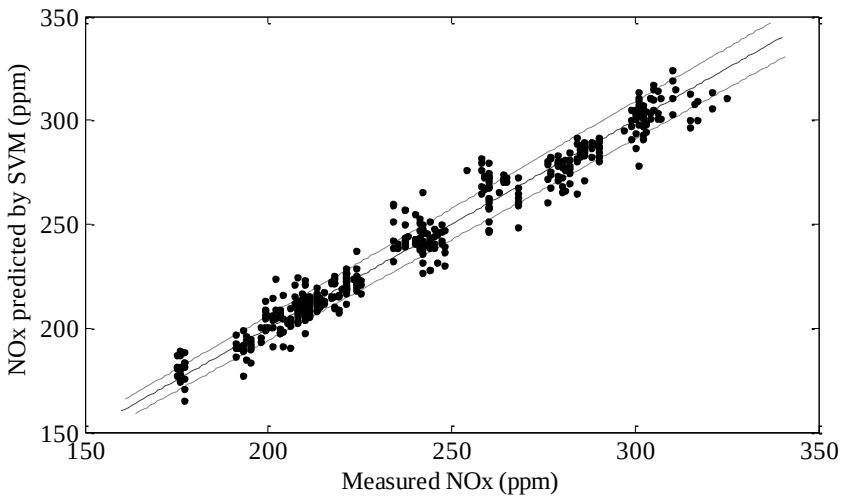
Intelligent Burner Condition Monitoring

Example - NO_x Predication

- **Comparison between predicted and measured NO_x emissions**



Neural Network (NN)



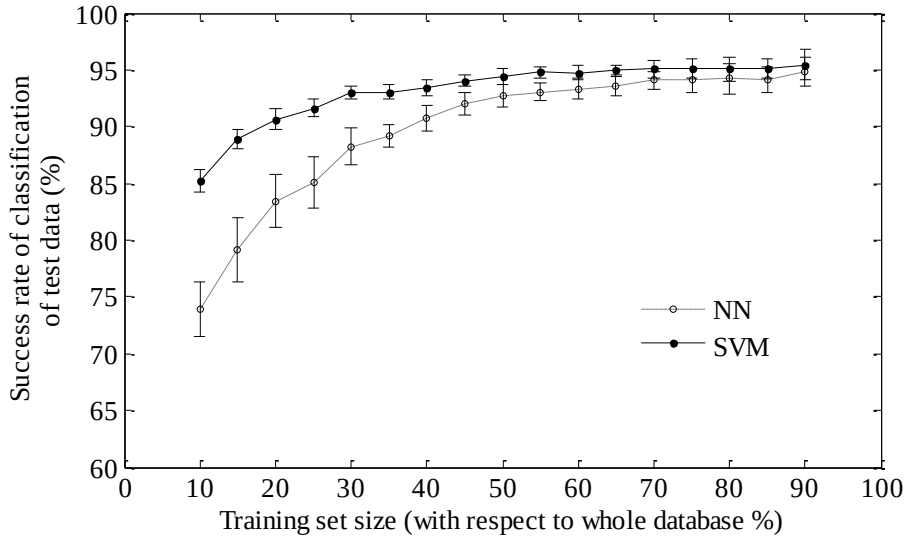
Support Vector Machine (SVM)

Remarks:

- For NO_x prediction, SVM model exhibits better performance than the tested conventional NN model, which is due to SVM's better generalization ability.
- The maximum relative error of the SVM is about 10.22%, much smaller than that of the NN 23.15%.

Intelligent Burner Condition Monitoring

Example - Flame State Identification



Variations of the success rate of classification of testing data with training set size

Remarks:

- For flame state identification, SVM model exhibits not only better but also stable performance than the tested conventional NN model.
- The increase of success rate with training data size suggests that adequate data should be collected to represent all the possible patterns of a dynamic process so as to achieve a more reliable flame state identification.

Intelligent On-line Fuel Tracking

- **Use flame parameters as the "signature" of a particular fuel fired flame**

Flame parameters

Pattern Recognition & Machine Learning algorithms

Fuel tracking

- Flame images
  - Luminous region
  - Brightness
  - Non-Uniformity
- Flame radiation signals
  - Oscillation frequency
  - DC, AC, skewness and kurtosis
  - Energy distribution

- Neural network
- K-nearest neighbor
- Decision trees
- Bayes classifier
- Hidden Markov model
- …

Coal, biomass, oil

Fuel from different sources

Challenges in on-line fuel tracking

- Extraction and selection of flame features
- Classifier design and learning for fuel recognition
- Performance evaluation
- It can only be done with field trials

Future Work

- **Field Trials**

  It is hoped the field trials are to be undertaken on

  - Ironbridge Power Station (biomass/oil fired),
  - Cottam Power Station (biomass/coal fired),
  - Wilton Power Station (coal fired), or
  - CTF run by Leeds University (oxycoal flames)

Concluding Remarks

- An imaging based instrumentation system has been developed for intelligent flame monitoring, burner condition monitoring and fuel tracking.
- A statistical process control method (KPCA) and pattern recognition method (SVM) have been applied for intelligent burner condition monitoring.
- The system has been evaluated using a blackbody furnace and a standard frequency-varying source.
  -- The relative error of oscillation frequency measurement is no greater than 2% (0-500Hz).
  -- The relative error of temperature measurement is about 0.9% (1000 ^{o}C -1650°C).
- The system has been tested on a full-scale coal/biomass fired boiler and an industrial-scale heavy oil fired combustion test facility.
- The test results have demonstrated the effectiveness and the potential of the techniques developed for flame characterization and burner condition monitoring.

Acknowledgments

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