Burner Flame Image Analysis Techniques

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Abstract — Digitalised image is used to derive information or the signatures of the flames in the flame image analysis. Thus, visual and numerical analysis methods based on the intensity levels have been implemented in this project following several stages. The digital processing of these images by digitised video can significantly extend the way in which visual images of flames can be assessed and hence quantity correlation between flame characteristics derived from flame image digital analyses and coal properties based on small-scale bench tests could be performed. This digital image analysis of pulverised fuel (PF) flame is a promising technique to describe the strong turbulent flow flames as series of frames are needed to represent a flame's property. Therefore, it is able to provide information for modelling and optimistic operation, etc.

INTRODUCTION

Flame image analysis means a method to describe a flame by assessing the digitalised flame video images. To derive information from captured flame images or the signatures of the flames, a number of analysis methods based on the intensity levels have been implemented in different stages of this project. Here is the summary of some analysis methods applied. The methods can be divided into two kinds, i.e. visual and numerical methods. Visual methods provided an efficient way to observe the differences between the flames directly and basics for the following numerical analyses.

Unstable combustion in pulverized coal boilers require additional expenditure for continuous oil or gas support firing. It is important from both economic and safety considerations that there is not a loss of ignitions. Loss of flame is not necessarily a problem if it is detected and appropriate action is taken. However, if it is not detected or inappropriate action is taken, re-ignition can cause serious damage to the furnace. This will cost a large amount of money to repair the damages and will take the unit out of service for many months. A partly stabilised flame will also lead to poor combustion efficiency and high NO_x generation.

Conventionally, a coal's susceptibility to stability has been assessed by reducing swirl number at a given primary/secondary stream momentum ratio or change primary/secondary ratio at a given swirl number until the flame lifts off the burner [1]. However this relies on visual observation and also of necessity to compare the performance of coals under different firing conditions. The feasibility of making quantitative instability measurements using video camera images of flames at comparable burning settings has therefore been investigated.

The rapid development of computer technology has made video capture and processing on a routine basis viable. Digital processing of video images can significantly extend the way in which visual images of flames can be assessed and hence quantity correlation between flame characteristics derived from flame image digital analyses and coal properties based on small-scale bench tests could be performed.

The flame stability tests started with the tests done on a 500 KW pilot-scale coal Combustion Test Facility (CTF) which is not only to avoid unnecessary risks of testing on utility boilers but also the operating parameters are easy to control and the tests are cheaper compared to the tests on utility boilers. The flame images were recorded on videotapes and then captured and digitized on a personal computer. The partial success from this project has leaded to the tests on the full-scale burners.

Different ignition patterns were observed by using image analysis, which suggested that the ignition mechanism is different for different coals. For high rank coals, the ignition of volatile and carbon sometimes happen separately

FLAME IMAGE

Pulverised Fuel (PF) flames were traditionally monitored primarily for safety reasons using a flame detector. When a flame failure is detected, the fuel valve automatically closes to prevent an explosion. However, a flame detector is not capable of providing reliable information for optimising operation parameters. More advanced systems may even use a combination of detectors to monitor flame flicker, a basic indication of flame stability and measurement [2]. Still, the information generated by such systems rarely influenced the control and optimization of combustion [3]. New systems are programmed to break down and analyse a wide array of flame characteristic data from which boiler operators can glean valuable information about combustion.

Digital flame analysis is an advanced flame monitoring and analysis technique and has already entered marketplace. While cine camera recordings of flames for scientific purposes have been made for at least 30 years, and video cameras have been in use for over a decade, only recently have personal computer processor, RAM and disk price/performance ratios become low enough to enable video capture and processing on a routine basis. Video signal is converted to digital value by the color image card and before being used to calculate the temperature distribution which is according to the brightness value of the flame image pixels. The combustion characteristic parameters are picked up from this flame image [4].

Digital process of video images can significantly extend the ways in which 'visual' images of flames can be assessed. As in an image processing technique, it requires automatic real time fire detection produce by the video images. By using a video camera, coupled with an optical filter, it is possible to capture images of the flame in a burner and then acquire sequences of images of the near-infrared emission during the combustion process [5]. The full image sequences are then analyzed to select a candidate flame region. Characteristic fire features are extracted from the candidate region and combined to determine the presence of fire or non-fire patterns. The underlying algorithm is based on the temporal variation of fire intensity captured by the visual image sensor [6].

One type of flame digital monitoring and analysis systems has been successfully applied by Imatran Voima Oy (IVO), Vantaa, Finland, at different Finnish power plants on two types of boilers firing a variety of fuels, i.e., wall-fired units and tangentially fired units [3]. In this system, air cooled semiconductor-type cameras monitor individual burns. Each camera is mounted within a protective housing and protrudes into the furnace at a 90^o angle to the burner being monitored. The cameras generate analogue video signals that are converted to digital form in the system's image analyzing boards. The intensity of flame images is represented by a number from 1-256. These digital values are then processed to measure combustion-related parameters and the images are also displayed on monitors in the boiler control room. For wall fired boilers, the position of the ignition point relative to the burner mouth, the average flame intensity and the stability at the ignition point were used as the indicators. These indicators were correlated to burner specific combustion parameters, which were then manipulated to raise efficiency, lower emission and improve overall combustion control. Such a system, Digital Monitoring and Analysis of Combustion (DIMAC), was further introduced by Nihtinen [7]. He reported that the DIMAC system, which was installed in seven power plants in Finland, could improve boiler efficiency by between 0.2-0.5 per cent unit as a result of more efficient control of the burning process, reduce NO_x formation by 10-20 per cent. This system analyzed each image 25 times a second and, after averaging, produced flame parameters every 0.5 seconds, providing truly continuos monitoring of the combustion quality.

A flame digital processing system, aimed at predicting unburnt carbon, was installed in Sendai Power Station of Tohoku Electric Co., Japan [8]. The luminance of combustion flame was converted to digital images with 512∗480 points and 128 gray levels. A time-averaged image was created within 60 seconds and then converted to a temperature distribution image by correlating it with the temperature measurement data using two-colour pyrometry. SaskPower's 300 MW Shand station in Canada also installed flame scanners to optimize combustion and minimize emissions [9]. Each scanner consists of a 6.5-ft-long steel pipe with an air-cooled sapphire lens at one end. Behind the lens, fiberoptic wave-guides transmit the flame radiation to photo-sensitive detectors. Sensor outputs are fed to electronic circuitry mounted outside the boiler, which convert the data to digital form. The pattern recognition software was used afterwards to drive relay and analog outputs monitored by the burner management system. Based on these signals the burner management system controls the fuel flow to the burners. Although the primary function of the scanner is to initiate the rapid shutoff of fuel and air when a burner flame is lost, analysis of the flame signatures also permits operator to adjust fuel and air parameters to maintain maximum combustion efficiency and minimum emissions, especially NO_x.

While the research on the flame image processing techniques is still at the early stage in China but it is attracting more attention and some papers have been published. Sun *et al* [10] reported a computing method estimating the combustion status in PF boilers and that a newly developed flame monitoring system based on this method had been installed in a 200 MW power plant in JinZhou. They divided the flame image into three zones, unburnt zone, combustion zone and post-combustion zone and arranged a minimum intensity value based on grey scalar levels for each zone to estimate the flame performance. Zhou *et al* [11] developed another similar system and reported that it had been tested in two 200 MW power station, XinHai Power Station and QieYie Power Station. They used the grey scale intensity value and flame area to detect the flames and analysis the accident courses. Quantification of this physical of fossil fired flames is also becoming increasingly important to achieve in-depth understanding and subsequent optimization of the combustion process by using an advanced flame monitoring system. The system combines optical sensing, digital image processing and computing techniques and is designed to measure most physical parameters of a flame with some investigation into the geometrical and luminous properties of the pulverized coal flames [12]. A range of physical parameters of the flame can also be determined by processing the flame images using the appropriate digital image processing techniques. The parameters characterizing a flame can vary, depending upon the type of furnace and the nature of the viewing field available. The parameters of pulverized coal flame are then classified into two main categories, i.e. geometrical and luminous parameters [13].

Flame image digital analysis seems to be a new promising technique in monitoring, improving and understanding PF coal fired flames. Its application at this early stage has proven its efficiency in improving boiler operation, control system and safety, raising boiler efficiency and reducing NO_x release. The research on the estimation for the NO_x emissive concentration of the pulverized coal boiler was conducted by using the flame image processing technique [4].

Most of the applications of digital image analysis in PF combustion described here are aimed to develop an optimistic control system, which is obviously irrelevant to the objective of this project. However, a reasonable understanding of PF flame is essential to all the objectives. Digital image analysis is a promising technique to describe flames and therefore is able to provide information for modelling and optimistic operation, etc.

PROCESSING TECHNIQUES

The rapid development of computing makes it possible to process flame image on an ordinary PC without too much time consuming and cost and thus provides a novelty mean to assess PF flame. The advantage of this technique is that the complicated flame can be visualised and further processed in digital form for various objectives. Therefore, the information, which is hardly available by other existing techniques, can be derived both is visual and digital form. The basics relevant to the forthcoming PF flame image processing are introduced in this chapter.

Basics

Some most likely used terms in this analysis are summarised here.

Digitalisation: digitalisation is the conversion of an analogue signal or code into a digital signal or code [14]. Most of our everyday life is spent in the analogue world, receiving natural signals through our eyes and ears, delivered to them in waveforms. The digital world can not deal with these continually changing patterns and needs to get the information into a medium which computers can handle. It does this by sampling the analogue patterns and converting them to simple numerical values, in this case ones and zeros, or bits as they are often called. So the terms used in digital world like '**conversion' or 'capture'** mean that the analogue signal is converted to a digital one or the analogue is captured into digital form.

Pixel: the name is derived from the term Picture Element. Pixels are dots arranged on grids that combine to form an image. Computer images are created as an array of such dots, each having a specific colour.

Grayscale: An 8-bit colour mode that stores and displays images using 256 shades of grey from black to white. Each colour is defined as a single value between 0 and 255, where 0 is darkest (black) and 255 is lightest (white).

A greyscale value can also be thought of in terms of the other colour models: in RGB, a greyscale value corresponds to equal amounts of all RGB colours; in CMYK, a greyscale value corresponds to zero C, M, and Y values with a positive K value; in HSB, a greyscale value corresponds to zero H and S values with a positive B value.

AVI Files: AVI is the filename extension (Audio Video Interleave) for a Windows video file. AVI files include video and animation.

BMP Files: The filename extension for Windows bitmap files.

RGB: RGB is an additive set of colours based on the light primaries red green and blue, refers to a colour mode, and to a colour model.

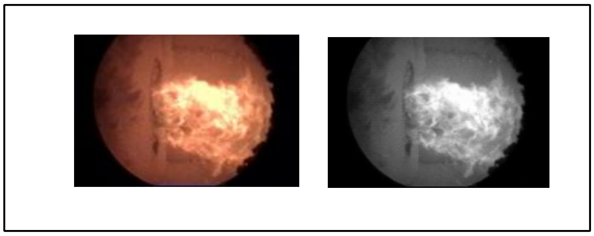
The RGB colour mode is a 24-bit method of processing image, which uses 16 million colours to store and display images.

The RGB colour model is a colour model, which defines colours using light primaries. Because of this, it is the model used for monitor display.

Flame Capture and Digitalization

PF coal-fired flames were acquired using an ordinary colour CCD camera attached to the endoscope from a Combustion Test Facility (CTF) and recorded on videotapes in the standard format of PAL (25 frames per second).

Flame images recorded on tapes were then captured on a computer using a Video logic PCI Capture card as shown in Figure 1(a) (30 frames). The captured images are in the format of half frame (380 × 270 pixels) or quarter frame (210 × 150 pixels) 24-bit RGB and stored as an AVI file on hard disk. Digitalisation of flame images was finished simultaneously during this capturing process.



(a) RGB AVI file (b) Grayscale AVI file

Figure 1: Flame Image in AVI File

Typically, about 500 frames (about 20 seconds at 25 frames per second) were captured. These 24-bit RGB images were then converted to 8-bit grey scale quarter frame (210×150 pixels) as shown in Figure 1(b) (30 frames) to reduce the size of the files and speed up the further analysis process and separated into individual frames as shown in Figure 2 and saved as bitmap format using Corel Photo paint 7.0 [15]. During the process of separating a video image into individual frames, the frames were 'cropped' to further reduce the file size and cut out unwanted background captured due to the location of the endoscope. The final size of the individual frames is 128×108 pixels (changeable) and the elements (intensity) in the data matrices is in the range of 0-255.

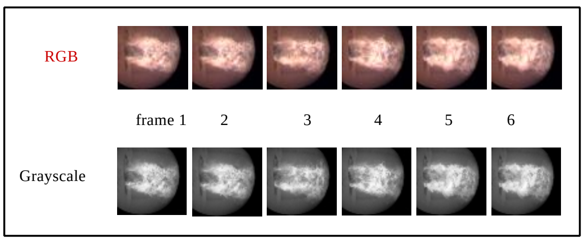


Figure 2: Frame Sequence Example

VISUAL OBSERVATION ANALYSIS

The image brightness was adjusted during capture by changing the settings of capture card to reduce saturation both in greyscale and three colour channels (red, green and blue channels) and to simplify the calibration process. After some experiments, the brightness for 1/2000 flames was set up as 110 and 70 for 1/1000 flames. The captured AVI files from video were separated into individual frames in BMP format and cropped to 79 ×60 pixels.

To further highlight the difference between these flame images, thresholds from 110 to 190 were used to produce false colour images. The results are given in Figure 3. The false colour images shown in Figure 3 look effective to highlight the difference in flames. The main difference seems to be at flame root areas. This provides the basic clues for further quantity analyses.

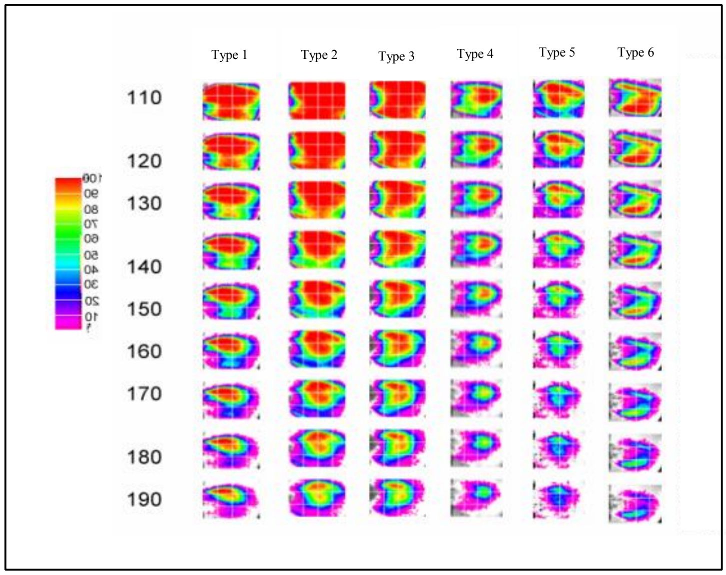


Figure 3: False Colour Threshold Images

Figure 4 gives random selected single RGB frame images from some flames to further observer the shape of these flames. The clear background makes it easier to look at the flame shapes. The comparison between different type of coal images at 110 and at 70 makes it clear to see the difference in the setting of camera expose speed. The Green/Red ratio false colour images and their standard deviation images are given in Figure 5.

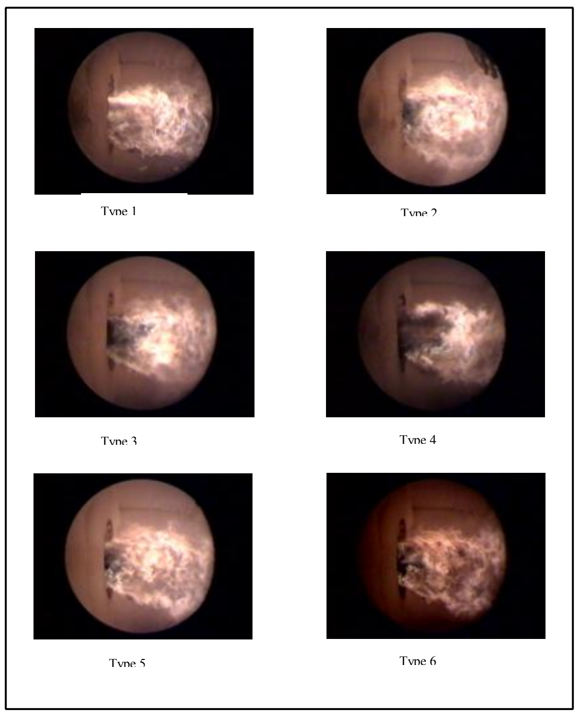


Figure 4: Single RGB Frame Images

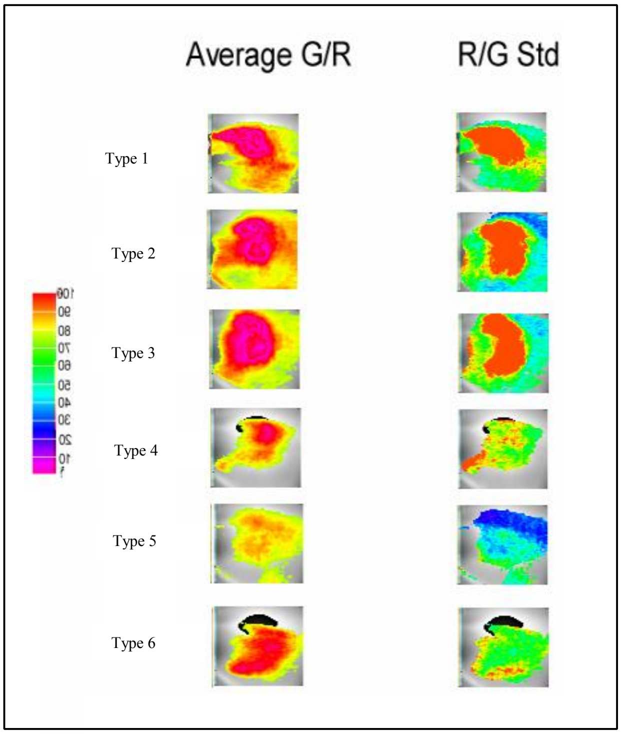


Figure 5: False Colour G/R ratio and standard deviation images

SUMMARY

There are plenty of ways to show the difference between flames but it is extremely important to keep all the conditions the same through the test to find the correlation between flame properties and coal characteristics. It can be seen from this project that the test facility's settings, cameras, image capture card, computer monitors and even videotapes have to be all taken into account when doing image analysis.

Pulverized coal flame is a strong turbulent flow so the individual frames are not sufficient to represent a flame's property. It is very possible to find the same or very similar frames from different coal flames. However, despite of the highly fluctuant turbulence flow, the flame features can still be derived by averaging frames but sufficient number of frames are needed to derive the representative information. A sequence of about 100 frames corresponding to four seconds was confirmed to be sufficient to implement analyses.

REFERENCES

[1] F. C. Lockwood and T. Mahmud, "On the Prediction of Pulverised Coal Flame Stability", *22nd Symposium (International) on Combustion*, The Combustion Institute, Pittsburgh, 1988

[2] Y. P. Huang, Y. Yan and G. Riley, "Vision-based measurement of temperature distribution in a 500 kW model furnace using the two colour method", *Measurement,* vol. 28, pp 175-183, 2000.

[3] Steven Collins, "Advanced Flame Monitors Take on Combustion Control", *Power*, vol/ 137, 75-76, 1993.

[4] F. Wang , X. J. Wang, Z. Y. Ma, J. H. Yan, Y. Chi, C. Y. Wei, M. J. Ni and K. F. Cen, "The research on the estimation for the NO_x emissive concentration of the pulverized coal boiler by the flame image processing technique", *Fuel,* 81(16), pp 2113-2120, 2002

[5] M. Chimenti, C. Di Natali, G. Mariotti, E. Paganini, G. Pieri and O. Salvetti, "An IR image processing approach for characterising combustion instability", *Infrared Physics & Technolog,* vol. 46, pp. 41–47, 2004

[6] G. Marbach., M. Loepfe. and T. Brupbacher, "An image processing technique for fire detection in video images", *Fire Safety Journal,* vol. 41, pp 285–289, 2006

[7] J. J. Nihtinen, "Flame image monitoring and analysis in combustion management", in *11st Annual Pittsburgh Coal Conference,* (1994); 518-523

[8] M. Shimoda, A. Sugano and Y. Watanabe, "Prediction method of unburnt carbon for coal fired utility boiler using image processing technique of combustion flame", *IEEE Transaction on Energy Conversion*, vol. 5 (5), pp 640-645, 1990

[9] SaskPower's Shard Station. Process Integration a Hallmark of Shard Station Design. *Power* (1993); 45-50

[10] J Sun, W. Y Xu, Y. F Yu and J. S. Wu, "The computing method of estimating combustion performance using flame image processing technique", *Thermal Power,* vol. 1 (38), 14-18, 1997

[11] N. Zhou, Z. Z. Lu and S. M. Wang, "Application of digital image processing technique in boiler furnace flame detecting", *Boiler Technique* , 8-13, 1997

[12] Y. Yan, G. Lu and M. Colechin, "Monitoring and charaterisation of pulverized coal flame using digital techniques", *Fuel*, 81, pp 647-656, 2002

[13] G. Lu, Y. Yan and D. D., "Ward Advanced monitoring, characterization and evaluation of gases fired flames in utility boiler", *Journal of the Institute of Energ,* vol. 73 (494), pp 43-49, 2000

[14] D. L. Stuart, *Digital Image*, A Practical handbook, Library Association Publishing. 2001

[15] D. Huss, *Corel PHOTO-PAINT 7 Plus the Official Guide;* McGraw-Hill, 1997