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Support vector machine based online coal identification through advanced flame monitoring

Hao Zhou [a,*], Qi Tang [a], Linbin Yang [a], Yong Yan [b], Gang Lu [b], Kefa Cen [a]

[a] *State Key Laboratory of Clean Energy Utilization, Institute for Thermal Power Engineering, Zhejiang University, Hangzhou 310027, People's Republic of China*
[b] *Instrumentation, Control and Embedded Systems Research Group, School of Engineering and Digital Arts, University of Kent, Canterbury, Kent CT2 7NT, UK*

HIGHLIGHTS

- A new coal identification system based on support vector machine (SVM) was proposed.
- Coal identification was achieved under various combustion conditions. The averaged prediction accuracy was up to 99.1%.
- The prediction accuracy of the coal identification system was up to 94.7% under "unstudied" operation cases.
- Influence of the number of samples and the number of operation cases on prediction accuracy was analyzed.

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ABSTRACT

This paper presents a new on-line coal identification system based on support vector machine (SVM) to achieve on-line coal identification under variable combustion conditions. Four different coals were burnt in a 0.3 MW coal combustion furnace with different coal feed rates, total air flow rates and flow rate ratios of primary air and secondary air. The flame monitoring system was installed at the exit of the burner to acquire the coal flame images and light intensity signals. Spatial and temporal flame features were extracted for coal identification. The averaged prediction accuracy is 99.1%. The mean value of the infrared signal has the most significant influence on prediction accuracy. For "unstudied" operation cases, the prediction accuracy is 94.7%.

1. Introduction

Power stations often use combustion optimization packages to optimize combustion processes and meet the increasingly stringent environmental regulations [1]. However, many types of coal are available in stocks and the type of coal being fired is often unknown and even unpredictable. This limits the application of the optimization packages. Traditional coal analysis methods are expensive and time-consuming. Therefore, an on-line coal identification technology is desirable for continuous optimization of power stations.

On-line coal identification is often based on flame measurement technologies and many studies have been reported. Huang et al. [2] used a two-color method to obtain the temperature distribution in a 500 kw model furnace. The temperature distribution was calculated by the ratio of grey levels of two images captured at two different wavelengths. Jiang et al. [3] proposed a simplified two-color method, in which the structure of the temperature measurement system was simpler than that of the conventional method. Huang et al. [4] developed a novel instrumentation system for on-line continuous flame flicker measurement. The flicker was obtained after processing the radiation intensity of the flame images through power spectral density analysis. Lu et al. [5] built a multifunctional flame measurement system based on digital image processing. Geometric, luminous and thermodynamic parameters of the flame were obtained on a 1 MW model coal-fired furnace under different loads. González-Cencerrado et al. [6] used an advanced vision based system to study flame characteristics on a swirl burner. Luminous and spectral parameters were obtained and analyzed with each individual pixel. Identification of areas with different luminous and oscillating patterns was achieved. Flame measurement technologies have also been applied in many fields, such as studying flame characteristics on oxy-fuel combustion [7], researching characterizations of biomass and coal co-firing [8], predicting NOx emissions from a pulverized coal boiler [9] and optimizing combustion process [10].

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* Corresponding author. Tel.: +86 571 87952598; fax: +86 571 87951616.
E-mail address: zhouhao@zju.edu.cn (H. Zhou).

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With the extraction of flame features, flame monitoring could be used for on-line coal identification. Xu et al. [11] established an on-line coal identification system using digital signal processing and fuzzy inference techniques. Multiple signals covering a wide spectrum of coal flames from infrared to ultraviolet through visible band and flame flickers were input to the fuzzy inference system for coal identification. With some improvements, Xu et al. [12] proposed a neural network based approach to on-line coal tracking. The approach used principal component analysis to reduce correlations between the input data and hence the complexity of the neural network. It was claimed that the performance of new approach was better than that of the fuzzy inference system. Most recently, independent component analysis has also been applied to coal identification [13].

For the earlier work as outlined above, on-line coal identification was achieved at nearly fixed coal feed rate and air flow rate, which meant coal identification was only achieved under steady combustion conditions. In this paper, a new approach based on support vector machine (SVM) is proposed to achieve on-line coal identification under variable combustion conditions.

2. Experimental setup and flame monitoring system

2.1. Coal combustion furnace

Fig. 1 is a schematic diagram of the pulverized coal combustion furnace where experimental work was carried out. The experimental setup mainly consists of a 0.3 MW vertical furnace, coal feeder, swirl burner and flame monitoring system. The inner diameter and length of the vertical furnace are 350 and 3950 mm, respectively. Refractory material was installed in the furnace to prevent heat loss. The feed rate of the coal feeder could be varied from 10 to 45 kg/h by adjusting the rotational speed of the electromotor. The swirling number of the burner is 0.6. The temperature of preheated primary air and swirl secondary air was about 40 °C and the air flow rates were adjustable by controlling the valves. During the experiments, pulverized coal with an average particle size of 60 μm was burnt in the furnace. The temperature in the furnace during the experiments was about 1360 °C. The flame monitoring system was installed 244 mm under the exit of the swirl burner. The flame monitoring system has a 90° viewing angle and is able to capture the flame images in a $189 \times 151\ \mathrm{mm}^2$ section in the center of the furnace.

2.2. Flame monitoring system

Fig. 2 shows the flame monitoring system that was used in this study. Technical details of the system are reported elsewhere [14], only a brief description is given for the reader's convenience. The system consists of a water cooling tube, camera lens, beam splitter, signal-processing board with three photo-detectors (for infrared (IR), visible (VI) and ultraviolet (UV) signals, separately), digital camera and embedded motherboard. The camera lens, protected by cooling water and central air flow, is used to guide the light of the flame from the furnace to the beam splitter. The beam splitter divides the light into two beams. One beam is captured by the digital camera to obtain flame images. The other beam is transmitted to the photo-detectors on the signal-processing board to obtain light intensity signals. The digital camera is an industrial RGB (red, green, blue) camera with a resolution up to 1280 × 1024 pixels and the signal-processing board has a maximum sampling frequency of 1024 Hz. The flame images and light intensity signals are received by the embedded motherboard. Application software on the embedded motherboard processes the flame images and light intensity signals and extract spatial and temporal features of the flame.

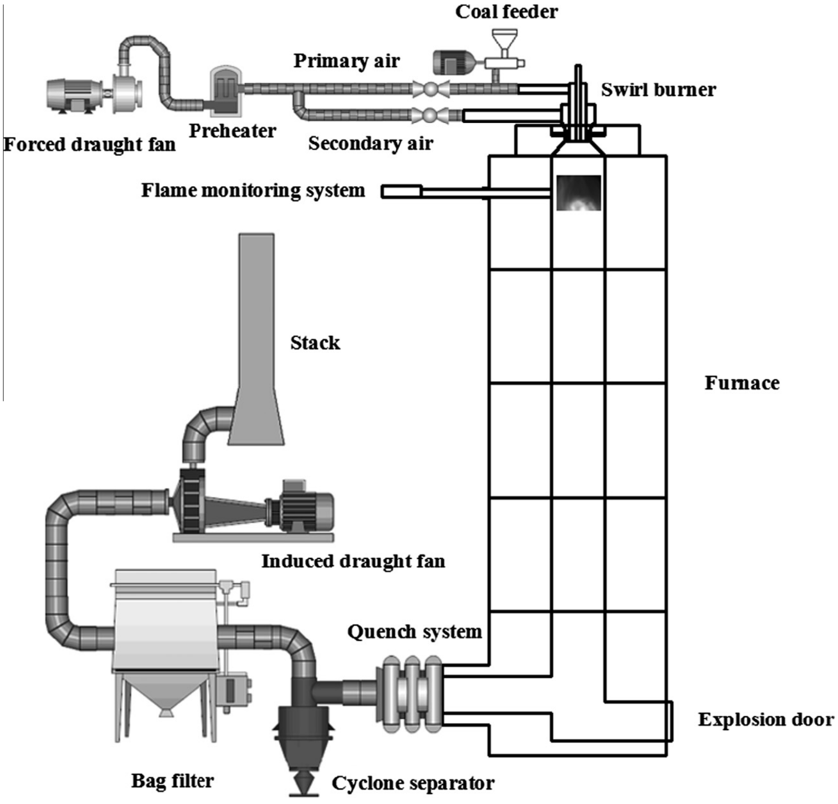

Fig. 1. Schematic diagram of the pulverized coal combustion furnace.