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Machine learning approach for automated coal characterization using scanned electron microscopic images

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ABSTRACT

Increased coal utilization has accelerated the need of understanding the basic knowledge of coal quality. Coal is highly heterogeneous in nature and because of its heterogeneity, numerous analytical techniques are needed for its characterization so as to predict its behavior and characteristics. Conventional analysis had been a basic technique long since for coal characterization performed by petrologists. Such conventional characterization of coal samples is time consuming and are limited by the high degree of subjectivity in the results. This paper come up with an automated image analysis approach towards the characterization of given different grades of coal samples. The objective of this work is to improve the characterization of coal samples by analyzing the textural and color features of coal using image processing techniques and to assist in the development of a preliminary screening of the coal samples. Automated characterization of coal is accomplished using image acquisition, features extraction, feature selection and classification over scanned electron microscopic images of coal samples. Hence, authentic and accurate subtyping of coal is obtained with the use of improved prominent features and a standard neural network classifier.

1. Introduction

Coal is a composite and a heterogeneous combination of inorganic mineral matter and organic matter formed over aeon from successive layers of decomposed vegetation. It comprises of various constituents called macerals, exclusively classified by its own particular arrangement of physical properties, compound structure and morphology. Coal can be categorized as coking and non-coking coal based upon the presence of ash value and volatile matter. The coal that contains low ash values and volatile matter with high carbon content are generally comes under coking coal. The non-coking are those which have high ash and volatile value with low carbon content. Coking coal is mainly used in manufacturing industries like steel, on the other side, non-coking coal is used in the power generation. Due to the abundant availability of coking coal in Jharkhand region of India, the characterization of coking coal has been chosen as the subject of research. About 5800 million tons of coal is annually consumed, out of which about 75% is used for power generation. By the year 2030, it is estimated that the utilization of coal is going to be approximately doubled in order to meet the unending human need for energy riches. The countries like United States (27%), China (13%), India (10%) and Australia (8.7%) constitute more than 58% of the world's restorable reserves of coal. It has been predicted by the International Energy Agency (IEA) that the world's demand for energy will increase around 60% over the next 30 years, especially in developing countries. Eventually, this will lead to more coal consumption to meet this world's demand for energy. Hence, less time consuming and more efficient technique is required for coal characterization for the efficient use of coal.

Currently, in coal industries, chemical analysis using conventional analyzers is a standard procedure for a confirmative screening and characterization of coal quality. Although, the conventional techniques for coal characterization like proximate analysis, ultimate analysis, ash content analysis, etc. involves using of modern and scientific method, still, these techniques require highly experienced and skilled petrologists to discriminate the different grades of coal samples. The existing analysis is a time consuming process and provide less accuracy in results having a high degree of subjectivity. These conventional techniques are subject to variation as they involve different machines observation which results in non-uniformity of the results in subtyping. There is always a chance of variability in inter and intra observing characteristics of coal done by petrologists in the screen analysis of

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coal. Due to non-reliability and differences in the results of conventional characterization techniques, these leads to conflictness between the industries on the decision of coal quality. Hence, the conventional characterization is required to be improved by introducing the computer-aided screening method using image processing techniques.

Image-processing method empower us to achieve a quantitatively valid measures of petrographic data on the qualities of coal constituents. From such an investigation, the significant amount of petrographic information along with the identification and quantification of textural and color feature concerning the coal beneficiation, can be determined.

The purpose of this paper is to devise an automated image analysis approach useful for the coal characterization with the help of image processing techniques, pattern recognition, machine learning and neural networks. Automated coal characterization accomplished with the procedure like image acquisition, preprocessing and sub-imaging, feature extraction, feature selection and classification that are briefly discussed in Section 2. The motivation behind this work is to remove the conflictness of quality decision between the industries by introducing a computer based technique. The proposed method improves the results that can be obtained by analyzing the textural and color features of coal samples. Such automated procedures ensure uniformity in result, reliability, accuracy, cost effective, efficiency and is less time consuming. Moreover, the proposed technique is not dependent on the involvement of expert petrologists and hence, not leaving any chance of variability in results.

Till date, a large number of researchers have investigated in order to find the characteristics of coal involving image-processing procedures. According to literature, it has been reported that, all across the world, numerous research groups are working on image-based automated and semi automated characterization techniques. A significant amount of work has been done to reveal the overall basic characteristics of coal, to be particular, textural feature, maceral characterization, crack analysis, color feature, porosity, etc. Some papers deals with the image based analysis that have been briefly discussed below.

Zhang et al. [1] proposed the technique of predicting ash content of coarse coal by means of image analysis and GA-SVM. In this investigation, coal particles were arbitrarily chosen to calculate the ash content, and a semi-automatic local-segmentation calculation had been proposed to recognize the corresponding coal particle regions. Thirty-eight color and texture features were extracted from every coal particle image, and Genetic Algorithm was utilized to choose the features. Results showed GA was helpful to diminish the excess features and enhanced the prediction impact of ash content of coal particles. Support Vector Machine (SVM) was utilized to build up the prediction model of ash content. The prediction lists of RMSE and *R*-square were utilized to calculate the prediction impacts of ash content. This paper concluded that the prediction impacts of narrow size divisions was superior to wide size portion, and bigger size fraction was more accurate than smaller size division in ash content prediction.

Kistner et al. [2] discussed the monitoring of mineral processing systems by using textural image analysis. In this paper, the utilization of diverse texture feature representations in two critical areas of mineral processing was explored, specifically grade control in froth flotation circuits and classification of aggregate material based on the relative constituents of fine particles. It was exhibited that the utilization of a multiscale wavelet representation enhanced the execution of the recognition systems for an automated grade control of a PGM froth flotation circuit. On the contrary, the texton representation showed the best performance for the recognition system in the grouping of coal particles on the premise of fines content. This demonstrated that both feature sets conceivably given the magnificent minimal representations of surface properties. This paper concluded that the more progressed texton and steerable pyramid texture analysis investigation should be considered in the configuration of vision-based procedure control plans.

Rafael et al. [3] discussed the automated coal petrography for macerals characterization using histograms technique. This research considered a coal reflectogram (histogram) gave the reflectance distribution of coal sample in the mode of frequency histogram. This work revealed the macerals histogram keeping in mind the end goal to devise this mechanism in petrographic analysis and coal characterization. This procedure has been produced which permits liptinite, vitrinite and inertinite to be classified from the resin background. The approach implemented the color as in images processing, that offered effective descriptor which improved the identification and extraction of the maceral sample.

Mao et al. [4] discussed on porosity analysis based on computer tomography (CT) images of coal. This paper described that there were diverse scale pores in coal samples. The resoluteness of CT was restricted, that recognized the pore greater than one pixel. The CT image reflected the thickness variety of a cut with thickness, and the grey value demonstrated the porosity fluctuation inside of one voxel. The surface porosity was characterized for analyzing the damage which was greater than a pixel, while voxel porosity were utilized for examining the pore changed in internal scanning layer thickness, that represented the qualities of CT images. The destruction in the coal examples under uniaxial loading was assessed by surface porosity in pixel scale, furthermore be computed by voxel porosity. With the load developing, the difference of two sorts porosity were separated into three stages: compression phase, elastic phase and damage stage. These porosities showed the damage advancement from distinctive scale. In this paper quantitative count strategy for porosity for coal sample under diverse scales was given.

Yang et al. [5] reported about an improved estimation of coal particle mass using image analysis. They proposed an enhanced mass model for the estimation of coarse coal particles utilizing image analysis, which was just comprised of two variables, i.e., projected region and thickness of coal particles. A progression of analysis was intended to build up and test the enhanced mass model. Backlit system was dispensed with the shadows cast by coal particles and the inside surface. No-touching coal particles image handled by two-peak method with the ideal threshold decided manually were fragmented the coal particles precisely. The thickness model was more appropriate for the coarse coal particles that likewise demonstrated the particles from diverse sources needed distinctive thickness models. The target of this model was to permit the coarse coal particles to be optically "sieved" precisely, simply and fast.

Asa [6] proposed the machine learning characterization of a two-seam coal deposit. In this investigation, geostatistical modeling and simulation calculations were utilized to characterize the coal deposit. The output of such method were then encouraged to a machine learning algorithm – generalized regression neural network. The subsequent intelligent model had been utilized to anticipate values as needed in a genuine mine operation in real time. This guaranteed the operational adaptability and upgraded the mining and mixing of coal to meet power plant or contract necessities. The GRNN model block values predicted from neuro-genetic optimizer with significant accuracy.

Over the last few years, various image analysis techniques have been developed for the characterization of coal. Image segmentation and gray level analysis have been the most preferred techniques among the other methods used for the characterization. All of above methods have been shown to generate significant