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Separating coal and gangue using three-dimensional laser scanning

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ABSTRACT

The underground separation of gangue from coal is an important part of the process of reducing transportation costs and improving production efficiency. A new method is proposed in this paper to separate gangue from coal on the basis of density, calculated from volume using three-dimensional (3D) laser scanning technology. This approach is based on the laser triangulation method and weight. Taking into account the weigh-in-motion technology that is currently widely applied, the main objective of this approach is to determine the volume of the object being measured. Thus, the principles of 3D laser scanning and laser triangulation were studied in detail and a relative formula was deduced. The reasons and solutions for possible errors are also analyzed in this paper, depending on the method applied to measure volumes of gangue and coal. Physical relationships of objects to be measured, as well as laser and measuring data planes are also presented, depending on principles of 3D laser scanning. A parameter selection method is presented to determine the appropriate photoelectric recognition device to use for coal or gangue, while error due to voids between objects was measured, and transportation belts analyzed. The assumption put forward in this study is that the ratios of voids between objects, transportation belt, and the exact volume of objects all conform to a normal distribution; this was shown to be the case by both experiments and statistical theory. A mathematical model was therefore constructed that is suitable for the recognition of coal and gangue based on this theory, while algorithms of recognition threshold values and identification rate are presented.

1. Introduction

Gangue minerals accounts for between 15% and 20% of raw coal in China (Qian et al., 2007). Indeed, as coal production has increased, so has gangue generation; by the end of 2009, the total amount of gangue produced added up to 5.0×10^9 t, encompassing 40% of the total Chinese solid waste (Miao and Qian, 2009). The accumulation of coal gangue not only takes up a great volume of soil, but also pollutes air, soils, and water sources (Pan et al., 2005). Since the utilization rate of coal gangue is about 40% in China at present, the accumulated volume of this mineral continues to grow at a rate between 0.15 billion tonnes and 0.2 billion tonnes per year (Yang and Lou, 2003). Therefore, the issue of how to deal with gangue has become urgent and needs to be solved. At present, three methods are available to deal with gangue: ground accumulation, comprehensive utilization, and underground backfill. Of these, the latter is presently the fastest, involving the least people. Determining an appropriate underground method to separate gangue from coal is nevertheless a promising approach to decrease transportation costs and improve production efficiency.

At present, several well-developed separation methods are available to extract gangue from goal: screen-jigging (Tao, 2003; Yang and Lou, 2003), heavy medium (Sun, 2009), winnowing (Chen and Yang, 1997), selective fragmentized, inclined-trough, and γ-ray with double energy (Han et al., 1997; Zhong et al., 2000). At the same time, while new methods being researched include pattern (Liu et al., 2000; Ma, 2003; Li et al., 2001; Ma and Jiang, 2004; Cheng and Wang, 2006; Song and Wang, 2007; Lan and Zheng, 2008; He et al., 2012; Yu et al., 2012) and optical-recognition based techniques(Zhang et al., 2011), manual processing is still carried out in some places. All technologies are mechanical in their basis, with the exception of γ-ray with double energy separation and the use of manual approaches. Manual selection, however, is both labor-intensive and inefficient, while under general conditions, mechanical devices can process larger volumes at higher energy and have a much larger effect on the environment. The γ-ray with double energy separation approach is based on the use of an electron selection device, and is advantageous because it can process small volumes at high efficiency, consuming less energy. At the same time, however, this method requires a radiation source, so users must comply with specialized safety regulations. In addition, the γ-ray method also requires a high-tension power supply, which makes it hard to use underground. While both the pattern- and optical-recognition methods recognize gangue by observing surface features, in real situations the surfaces of this mineral and coal can often be wrapped in pulverized coal, rendering surface features invisible. As a result, a number of factors need to be taken into account when applying these methods in real

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situations. Electronic selection devices should be the focus of future development of gangue separation methods. In this paper, the physical properties of coal and gangue are compared and a separation method based on three-dimensional (3D) laser scanning is presented. The method presented here is based on measuring the volume of an object using 3D laser scanning, determining its weight via weigh-in-motion technology, and then calculating density. This enables the recognition of gangue. The main objective of this study is not to discuss weigh-in-motion technology, as this is widely applied, rather to investigate the question of how to measure the volume of an object.

2. Experiment

2.1. Experimental equipment

The coal gangue photoelectric separation system that was used in this study is shown in Fig. 1. In order to improve recognition speed and rate, this system incorporates two sets of photoelectric recognition systems. Basler Cameras are embedded in this system (daA1600-60 type) and can reach a shooting rate of 60 fps/s with an array size of 1600×1200. Data is output in RGB555 format, while common red lasers with a wavelength of 650 nm are also used (YD-L650-P30-12-50 model). The control system utilizes a S3C2440A core circuit board with ARM11, with four Keli weighing sensors (HSX50KG model) that complete the weigh-in-motion system.

Using this system, coal gangue photoelectric separation encompasses a number of steps as an object is moved forward along a conveyor belt. Weight is first determined using the weigh-in-motion system; thus, when controller 1 receives a signal from positional sensor 1, camera 1 begins to shoot continuously and start timing. Images from this process are transferred to memory via a USB bus, and camera 1 stops shooting when it receives the signal from positional sensor 2. Camera 2 then starts to shoot continuously as controller 2 receives a signal from positional sensor 3, only stopping when it receives a signal from positional sensor 4. Incoming images are then processed, laser lines are extracted, and the optical section area is calculated by two microprocessors. The forward speed of the object can be calculated using the distance between two positional sensors and the time taken for the object to pass. At the same time, the volume of the object is calculated using the integral of optical section area against time. Finally, coal and gangue can be identified based on the recognition algorithm of calculated density versus volume and weight.

2.2. Light triangulation distance measurement

The 3D laser scanning method is an extension of laser triangulation distance measurement, which can be subdivided into the straight beam and angle beam method depending on differences in camera installation. Thus, taking the surface roughness of coal and gangue into account, the straight beam method was selected for use in this study. In order to improve the utilization rate of image sensors, the focus between the camera normal and laser lines was located above the conveyor belt surface, as shown in Fig. 2.

In this application, the intersection between the camera lens normal *OA* and laser line is located above the surface of the conveyor belt, while the thickness of the object to be measured was lower than the target, and the imaging laser point was in the upper half of the image sensor. Otherwise, the imaging point is located in the lower half of the image sensor. The formulae used to calculate the thickness of the material being tested are listed below.

In the $ME > AM$ case:

$$h = ME = AM + \frac{XD \times AO}{DO \times \sin\beta + XD \times \cos\beta} \tag{1}$$

In the $ME < AM$:

$$h = ME = AM - \frac{XD \times AO}{DO \times \sin\beta - XD \times \cos\beta} \tag{2}$$

In these expressions, A denotes to the intersection between the lens normal and the laser line, while AM and βrefer to the distance between the intersection and the measurement target and the angle between the laser line and the lens normals, respectively, determined by system installation, and DO refers to the distance between the camera lens and the imaging sensor, while AO refers to the distance between A and the camera lens along the lens normal, and XD refers to the offset distance on an imaging sensor relative to a situation when no object is tested.

Thus, if XD in Eqs. (1) and (2) equals $p \cdot y(n)$, and $y(n)$ is the pixel offset of the n^{th} laser spot in the X direction, then p is the physical size of each pixel. Thus, when system installation is set, AO, DO, β, and p all remain constant, while the unit of p is normally μm/point, and the scope of AO and DO is at the centimeter level. Thus, $p \cdot y(n) \cdot \cos\beta$ will be very small compared to $p \cdot y(n) \cdot AO$ and $DO \cdot \sin\beta$ can be neglected. Thus, sectional area can be calculated as outlined below.

In the $ME > AM$ case:

$$S = (N-1)AM + k\sum_{n=0}^{N-1} y(n) \tag{3}$$

In the $ME < AM$ case:

$$S = (N-1)AM - k\sum_{n=0}^{N-1} y(n) \tag{4}$$

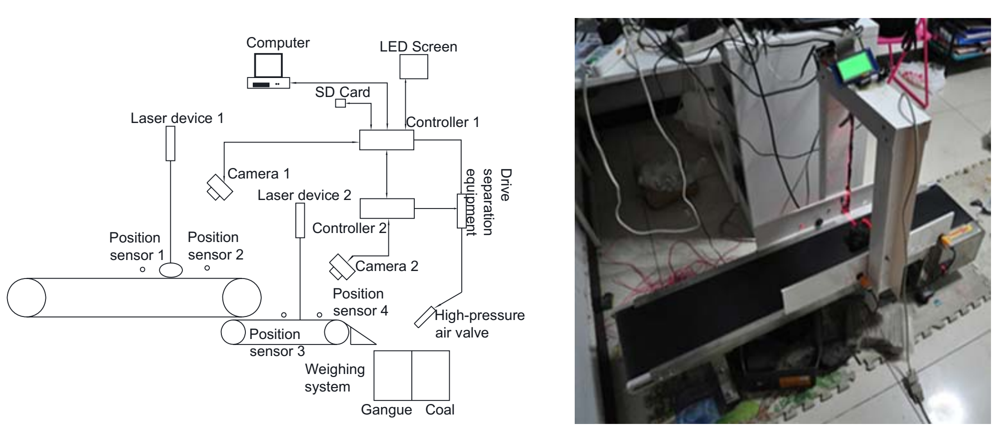

Fig. 1. Diagram and photograph of the coal-gangue separation system used in this study. a. Schematic diagram, b. Experimental equipment.