A review of automatic coal volume measuring technologies

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Keywords. Automatic coal volume measuring technology, Laser, UAV.

Abstract. In coal-fired power plants, how to timely inventory coal storage, in order to optimize the coal stock, and improve coal blending operation, and then carry out economic dispatch scientifically and reasonably, has always been an important topic. The traditional way of artificial method has big error, high cost and serious waste of resources. Ultrasonic measurement technology is greatly affected by time difference and dust. Measurement technology based on computer vision requires interpolation to fit the correction model. The above methods all have large measurement errors and have been eliminated by the market. This paper mainly introduces coal measuring technologies based on laser and uav tilt photography which have been researched and applied more recently. Their respective installation methods, characteristics and applicable working occasions are analyzed. They have the common characteristic that the 3d coordinate point cloud data of coal yard surface needs to be solved before the 3d model of coal yard can be generated and the coal storage amount can be calculated. In the case that the 3d coordinate point cloud data of coal yard of power plant cannot be obtained directly, 3d reconstruction can be carried out by using 2d images of coal yard in coal report, or by using neural network model, and then the coal volume can be checked. This research idea is of great significance to realize effective and accurate supervision of coal storage in power plants.

Nowadays, Electric Power Industry is dominated by thermal power generation, and the most important raw material for thermal coal-fired power plants is coal. According to statistics, fuel accounts for the largest share of the cost of power generation in coal-fired power plants, accounting for about 70-80% of the production cost of the whole plant [1].

In the current situation of rising coal prices and declining profits of power generation enterprises, coal-fired power plants generally adopt economic coal blending in order to reduce fuel costs and improve economic efficiency. Timely inventory of coal stocks of each coal type in coal yards can provide data support for accurate coal blending operations. At present, the statistical reporting of coal supply, consumption and storage in power plants has become the norm, but the coal information of each power plant in the dispatcher's
possession is completely dependent on the power plant's independent reporting, and the credibility of the data is doubtful and the automation level is not high, especially for the vital coal storage data of each plant, the dispatcher lacks effective supervision means. The purpose of this paper is to investigate the measurement technology of coal storage in power plants in order to provide further research ideas for the automated monitoring and verification of the coal stockpile reported by the centralized power plants.

According to the different measurement principles, the published coal inventory technologies applied to thermal power plants include ultrasonic measurement technology [2-3], computer vision-based measurement technology [4-5], laser scanning measurement technology [6-8], and unmanned aircraft tilt photography measurement technology [9-10].

Since the time accuracy of ultrasound cannot be well controlled in the measurement process, it will inevitably cause measurement errors, especially when accurate measurement of points over a large area is required, ultrasonic measurement cannot meet the application requirements. In addition, the propagation speed of ultrasonic waves will change because of different transmission media, so the uncertainty caused will be even greater. Also, the presence of dust in the coal field can have a great impact on the measurement [2-3].

As for the measurement technology based on computer vision, due to too few effective coordinate points, the 3D model of the coal field obtained by this technique will be seriously distorted, and naturally there is a large measurement error [4-5].

With the rise of two-dimensional laser measurement technology, it has rapidly replaced the original measurement techniques and methods and gradually occupied the market. At present, it has been rarely seen in thermal power plants to use coal inventory instrument based on ultrasonic and computer vision measurement technology, and more and more mature are the coal inventory instrument based on laser scanning measurement technology and coal inventory instrument based on UAV tilt photography measurement technology, so this paper will focus on these two coal inventory technologies.

1 Laser coal inventory technology

When scanner working, the 2D laser scanner scans the surface of coal field in cross-section and obtains 2D coordinate data of coal field cross-section profile, which is matched with the position information obtained by displacement sensor or angle sensor, and finally obtains the surface form and 3D coordinate data of the measured target through software processing, and then carries out coal field storage calculation and 3D model establishment and display. According to different mounting platforms, the laser coal inventory instrument can be divided into portable laser coal inventory instrument, fixed laser coal inventory instrument and laser coal inventory instrument based on walking robot.

1.1 The portable laser coal inventory instrument

The measurement principle of the portable laser coal inventory instrument is shown in Figure 1, where the surveyor walks around the coal pile with the instrument in hand, the laser scanner dynamically measures the geometric information on the surface of the pile, the attitude measurement system simultaneously measures the spatial attitude data of the laser scanner, the GPS measures the spatial position of the laser scanner during the measurement process, and the 3D point cloud of the pile is formed through data fusion, and then the 3D model reconstruction and volume calculation are carried out. The GPS measures the spatial position of the laser scanner during the measurement process, and the data is fused to form a 3D point cloud, which in turn performs 3D model reconstruction and volume calculation.
Fig. 1. Schematic diagram of measurement principle of the portable coal inventory instrument.

The Portable laser coal inventory instrument can be operated only by personnel handheld, with the advantages of easy and fast to use, but there are also the following problems.

1. It is greatly affected by the environment. The yard environment is complex, and there are often large reclaimers running back and forth on both sides of the yard, so the point cloud data collected will inevitably have foreign matter point clouds and noise point clouds, which will cause errors to the final measurement results.

2. There is an obvious scanning blind area. As can be seen from Figure 1, the laser scanner cannot scan the top of the coal pile during the measurement process, and the data can only be processed assuming that the top of the coal pile is a flat surface, which will certainly cause measurement errors.

3. Not conducive to the health of the surveyor. Large power plant coal yard and covers an area of large, uneven coal pile edge is difficult to walk, low efficiency and easy to inhale coal dust and toxic gases.

Therefore, the portable coal inventory instrument can only be used as a temporary or verification coal inventory device, not as a permanent coal inventory device.

1.2 The fixed laser coal inventory instrument

The fixed laser coal inventory instrument mounted on the coal yard traveling car or stacker reclaimer is used more often at home and abroad. The two-dimensional laser scanner and travel sensor are mounted on the coal yard traveling car or stacker reclaimer and follow its movement, the laser scanner obtains the two-dimensional coordinate information of the surface of the measured coal pile, and the travel sensor obtains the position information of the laser scanner, then three-dimensional coordinates of the coal yard surface are solved, and then the three-dimensional model of the coal yard is established and the coal storage quantity of the coal yard is calculated. there are various installation methods according to the different forms of coal field [6].

1.2.1 Single strip coal yard - bucket wheel machine large arm side mounting

Fig. 2. Diagram of the installation of the coal inventory instrument on the side of the big arm of the bucket wheel.

As shown in Figure 2, the laser coal inventory instrument is installed on the side of the bucket wheel's big arm, which is a kind of installation method suitable for single strip coal
field only. During the measurement, the bucket wheel's big arm is parallel to the track and lifted to the highest position; while the bucket wheel is walking forward, the laser scanner is activated to scan the coal field in section and get the coal field outline; at the same time, the bucket wheel's walking position is recorded to get the outline position. After the scanning, the 3D coordinates of the coal field surface are obtained, and then the 3D model of the coal field and the storage data are obtained. This way the coal inventory instrument is easy to install, but there are the following problems:

1. If the coal yard is stacked too high, the top of the coal yard cannot be scanned due to the limited height of the bucket wheel machine's large arm.
2. It can only scan the outline of the coal pile on one side of the coal pile near the bucket wheel, so it can only predict the outline of the other side of the coal pile based on the data scanned on one side, which will inevitably cause measurement errors.
3. Restricted to walking limit. Generally, a large amount of coal will be piled up outside the traveling limit of the bucket wheel, which cannot be scanned in this way and can only be estimated manually, which will inevitably lead to measurement errors.

1.2.2 Installation on single strip coal yard-door pickup bucket wheel

![Fig. 3. Installation on single strip coal yard-door pickup bucket wheel.](https://example.com/fig3.png)

Some power plants with a single strip coal yard are equipped with a portal pickup bucket wheel. Figure 3 shows a schematic diagram of the laser coal discograph installed on the portal pickup bucket wheel. The laser scanner and control box are mounted on the bucket wheel carriage, and a travel encoder is installed at the wheels underneath the bucket wheel to measure the travel distance of the bucket wheel. When the bucket wheel runs along the rails laid on both sides of the coal field at a uniform speed, the laser scanner scans the coal field to get a two-dimensional outline of the coal field, and the travel encoder gets the position of this outline. When the bucket wheel runs from one end of the coal field to the other end, the scanning of the whole coal field is completed, and the three-dimensional model of the coal field is obtained after data processing.

There is no scanning dead space in this installation, and the measurement process of coal inventory instrument scans vertically downward, thus high measurement accuracy can be achieved. Unfortunately, in order to improve the efficiency of the coal yard and the efficiency of coal stacking and pickup, most power plants adopt the way of arranging a strip coal yard on each side of the track, and few power plants adopt a single strip coal yard.

1.2.3 Installation on single strip coal yard-door pickup bucket wheel

For double strip coal field, if the coal field is not large and the coal pile is not high, coal inventory instrument can be installed in the centre of the front end of the bucket wheel machine's big arm, as shown in Figure 4. When measuring, the bucket wheel machine arm...
first swings to the left coal pile directly above and lifts to the highest position and scans the left coal field during the bucket wheel machine walking forward to get the section profile of the coal field, and records the bucket wheel machine walking position at the same time to get the profile position. After scanning, the three-dimensional coordinates of the coal field surface are obtained through data processing, and then the three-dimensional model of the left coal field and the volume data are obtained. Then, the bucket wheel rotates to the top of the right coal pile, and the right coal field 3D model and storage data are obtained in the same way.

![Diagram of the installation of the coal inventory instrument in the middle of the big arm of the bucket wheel.](image)

**Fig. 4.** Diagram of the installation of the coal inventory instrument in the middle of the big arm of the bucket wheel.

There are some problems with this type of installation of laser coal inventory instrument.  
1. It is only suitable for smaller scale strip coal yards.  
2. There is a large scanning blind area. The top contour of the coal pile cannot be scanned completely.  
3. It is not possible to scan the coal piled up outside the traveling limit of the bucket wheel, so it can only be estimated manually, which is another source of measurement error.

1.2.4 Double strip coal yard - bucket wheel middle crossbeam mounted

![Diagram of the installation of the coal inventory instrument on the middle crossbeam of the bucket wheel.](image)

**Fig. 5.** Diagram of the installation of the coal inventory instrument on the middle crossbeam of the bucket wheel.

For double strip coal yards, in the case of larger coal yards and higher coal piles, the bucket wheel machine middle crossbeam installation method is mostly used, as shown in Figure 5, where coal inventory instrument is installed at the highest point position of the coal yard, which is the bucket wheel machine middle cross beam or middle tower base. In this way, the entire contour of the left and right coal yards from the side near the bucket wheel to the outside of the top of the coal pile can be scanned within the bucket wheel's travel range.
For the coal pile outside the front and rear walking limit position of the bucket wheel, the angle between the laser beam plane of the laser scanner and the vertical plane is changed by a rotating head, so that the laser beam is projected further away to complete the scanning of the coal pile outside the limit position of the bucket wheel, as shown in Figs. 6 and 7, so that the problem of scanning blind areas at the front and rear ends of the coal field, which exists in the middle installation method of the bucket wheel's arm, can be solved [6]. Figure 8 shows the three-dimensional model of a coal field obtained from the omnidirectional scanning. However, when the coal pile exceeds a certain height, this method still cannot scan the outermost contour of the coal pile, and can only rely on the contour shape of the inner side of the coal pile to deduce the outer contour shape, which is the main source of measurement error of this type of the coal inventory instrument.

1.2.5 Circular coal yard - bucket wheel middle crossbeam mounted

Circular coal yards are increasingly favored by coal-fired power plants because of their advantages of relatively small land area, large memory storage capacity per unit area, and resistance to harsh environments [11], as shown in Figure 9, a laser scanner is usually installed on the stacker-reclaimer's stacker arm or reclaimer arm for full-range scanning of the coal yard during stacking or rotation; a rotary encoder is installed at the rotation gear of the stacker-reclaimer's stacker arm or reclaimer arm to measure the rotation angle of the stacker-reclaimer arm [12].

Due to the limitations of the mechanical structure of the stacking arm and the retrieval arm of the circular coal yard, and the presence of concrete support columns inside the
circular coal yard, the stacking arm and the retrieval arm of the stacking and retrieval machine cannot rotate 360 degrees individually, resulting in a blind scanning area.

Fig. 9. Installation diagram of single probe the coal inventory instrument in round coal yard.

1.2.6 Circular coal yard - double probe stacking arm and pick-up arm mounted on

In order to eliminate the scanning blindness of the single probe coal inventory instrument, one solution is to install a laser scanner on each of the stacker arm and the reclaimer arm of the stacker reclaimer, and a set of rotary encoders at the rotating gears of the stacker arm and the reclaimer arm, as shown in Figure 10. The stacker arm and the reclaimer arm are rotated separately, and the data from both sets are finally integrated, then the full range measurement of a circular coal yard can be realized. Figure 11 shows the three-dimensional model.

Fig. 10. Installation diagram of double probe the coal inventory instrument in round coal yard.

Fig. 11. Round coal yard 3D model

1.3 Walking robot-based laser coal inventory instrument

In recent years, more and more thermal power plants have started to adopt fully enclosed or semi-enclosed coal storage yards.

Under the dome of the closed coal yard, there exists a maintenance roadway, which runs through the whole coal yard and is usually used for maintenance. A sliding track is installed underneath the roadway, and a railcar or walking robot (containing a laser scanner, positioning encoder, wireless communication device, power charging device, cart drive device, etc.) is mounted on the track as shown in Figure 12.
During the measurement, the walking robot slowly walks, and the laser scanner scans the coal field to obtain the surface contour of the coal field, while the position of the contour is obtained by the positioning encoder. After the measurement is completed, the scanned data is processed by the software to obtain a 3D coordinate point cloud of the coal field surface, and then the volume of the coal pile is calculated, and the data can be used to build a real-time 3D model of the coal pile.

**Fig. 12.** Schematic diagram of the laser disk coal meter based on walking robot.

The coal inventory instrument based on walking robot can effectively solve various problems of measuring equipment installed on the bucket wheel, especially the scanning blind area problem, and the scanning degree is fast, no blind area in the scanning process, and high accuracy of the coal inventory instrument [13].

### 2 UAV tilt photography coal inventory technology

In recent years, with the development of UAV technology and 3D reconstruction technology, the difficulties of inventorying coal by manual measurement method and laser measurement method can be better solved by acquiring orthorectified image sequence of open coal storage site through UAV and then generating 3D realistic model of open coal storage site through 3D reconstruction algorithm.

The coal inventory system based on UAV tilt photography generally takes high-definition images of coal field by UAV sailing according to the planned trajectory first, then processes the images through motion recovery structure algorithm to get 3D coordinate point cloud of coal field surface, and then builds 3D realistic model of coal field and calculates coal storage volume.

#### 2.1 UAV aerial photography to collect image data

UAV aerial photography acquisition of image data is done by relying on UAVs, HD cameras, and portable ground stations. Before the UAV collects data, the ground station is used to pre-plan the UAV's trajectory, flight altitude, flight speed, overlap between sampled images and the attitude angle of the camera during the sampling process. While the UAV carries HD cameras for data acquisition work, the ground station software monitors the UAV flight status in real time to ensure the safety of the sampling work [9].

A reasonable planning of the UAV sampling route is required after the flight area is determined. Figure 13 shows a UAV flight area trajectory planning map, where the blue area is the data acquisition area and the green line is the UAV flight route.
The drone parameters mainly include the flight altitude, flight speed, vehicle yaw angle and drone movement after the completion of the task at the time of drone sampling. The camera parameters include camera orientation, photo mode, camera head pitch angle, image overlap and exposure at the sampling moment. Generally the vertical overlap and horizontal overlap should reach 70% and 50% or more respectively to meet the requirements of 3D real-world model reconstruction.

2.2 Reconstruction of 3D realistic model of coal field

The reconstruction of 3D real-world model of coal field is usually realized based on the Structure from Motion algorithm, which refers to the process of recovering the 3D structure of the scene by solving the camera parameters from the image sequences acquired from different angles. It is usually based on the pair-polar geometric relationship of feature matching points between two-view or multi-view images, and the 3D structure recovery of the scene is achieved by mapping a certain number of 2D image feature points onto the 3D spatial coordinate system to form a 3D point cloud [14]. The mapping relationship from the 2D plane to the 3D space is represented by a projection matrix composed of the internal camera parameters and the external camera parameters. The flow of the motion recovery structure algorithm is shown in Figure 14.

2.2.1 Camera internal parameters acquisition

The internal parameters of the camera are determined by the internal structure of the camera, including camera focal length, image principal point coordinates, pixel size, etc. Camera calibration is usually used to obtain the internal parameters of the camera. Through the camera calibration process, the mapping relationship between the two-dimensional coordinates of the image and the three-dimensional spatial coordinates is found, and the camera parameters corresponding to each image are calculated.

With the development of camera calibration technology, many practical calibration methods have been proposed. Such as the planar template calibration method proposed by Zhengyou Zhang [15] takes multiple calibration plate images at different locations and solves the internal parameters of the camera according to the mapping relationship, which is highly accurate, robust, convenient and flexible, and has been widely adopted.
2.2.2 Camera external parameters acquisition

The camera motion can be decomposed into rotational motion and translational motion. The motion of the camera during shooting can be described based on the motion of the points between images, provided that there is a certain degree of overlap in the image content. That is, if the camera rotates and moves during shooting, the contents of the captured images will have the same rotation, translation, and other changes. Therefore, the motion trajectory of the captured contents between images can be found during camera shooting and the position pose at the moment of camera sampling can be recovered.

First, the image is pre-processed to eliminate the influence of interference on the image. Then, feature point extraction is performed, and the feature points are the points in the image with sharp changes in brightness (usually corner points, line intersections) or the extreme value points of curvature on the image edge curve. Then feature point matching is performed to identify the feature points corresponding to the same spatial object points in two or more images, find the relationship between images according to the feature points, and solve the external parameter matrix of the camera[16].

2.2.3 Coalfield 3D structure restoration

Based on the camera internal parameters and camera external parameters obtained above, the camera projection matrix can be recovered, the mapping relationship between 2D pixel coordinate points and 3D spatial coordinate points can be found, the 3D spatial coordinates corresponding to the image pixel points can be solved, and a 3D point cloud can be generated, and then the 3D structure of the coal field can be recovered. Figure 15 shows the 3D realistic model of a coal field obtained according to the above method.

Fig. 15. A three-dimensional realistic model of a coal field obtained by a drone coal inventory system.

3 Summary

This review mainly studies laser coal inventory technology and UAV tilt photography coal inventory technology, and summarizes the characteristics of portable laser coal inventory instrument, fixed laser coal inventory instrument, walking robot-based laser coal inventory instrument and UAV tilt photography-based coal inventory system, and their respective applicable operating occasions.

No matter which type of coal inventory instrument is used, the 3D coordinate point cloud data of coal field surface is finally solved, and then the 3D model of coal field can be generated and the storage capacity can be calculated. The most ideal way to monitor and check the coal stock reported by the centralized power plant is to directly obtain the 3D coordinate point cloud data of the coal inventory system of each power plant, and then re-establish the 3D model of the coal field of the power plant and perform the storage calculation. However, in practice, for various reasons, power plants are unwilling to provide, or the coal tray system does not disclose its coordinate point cloud data and thus
the power plant is unable to provide, so the method of calibrating through the 3D coordinate point cloud data of the power plant coal field is almost impossible to achieve.

However, all coal inventory systems will eventually generate an inventory report for the user, which will record a two-dimensional image of the coal yard and storage data at the time of inventory. Therefore a feasible idea is to use the 2-D image of coal yard for 3-D reconstruction, or use the coal yard inventory image and stock quantity data to build a neural network model to calibrate the coal stock data of the power plant, which is important for establishing the optimal fuel blending model and storage model to realize the effective and accurate supervision of coal stock data of the power plant.

References