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Computational Method on the Shearer Position

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Abstract

According to problems such as low accuracy, high error in the shearer body position, this paper proposes a new computational method combining with the information of shearer, scraper conveyor and hydraulic support in order to realize three machine positioning. Using the sensor information and static-dynamic fusion, this paper solves positioning problem of the three-dimensional in the process of the shearer movement, and derive the relevant formula. Through the laboratory simulation experiment and industrial field experiments of Xi'an Coal Mining Machinery Co., Ltd show that this system can effectively improve the precision and stability of the fuselage orientation, so as to provide security for realizing the memory of shearer cutting and remote control.

Keywords*: shearer, scraper conveyor, hydraulic support*

1. Introduction

The shearer automation and remote control is the key to realize the automation of fully mechanized working face, which is also an important factor to ensure the safety production in coal mine. Though the existing coal mining automation programs mentioned in Reference [1-5], it can come to the conclusion that memory cutting is one of the most simple and effective solution. And the premise of Memory cutting is to get the shearer position information. A little deviation of position will directly affect the accuracy of shearer memory cutting. As the face of the plate may be tilted or undulating, and therefore need establish a shearer body positioning system to obtain the correct location. As the face of mine exist harsh environment, it is difficult to obtain using a single sensor directly shearer body three-dimensional location information. Some scholars have proposed the use shaft encoder to calculate the distance of coal mining traveled to locate in the Reference [6], but only getting distance in one direction, not coordinates. Another scholar raised by onboard gyroscopes and accelerometers measure movement in the coal mining operation posture and position, but measurement accuracy is low, the cumulative error and other issues. There are two main reasons. (1) Only receive for its own sensor data, neglecting the role of the scraper conveyor and hydraulic support of the relevant data. (2) As mentioned in Reference [7-9] shearer severe vibration during exercise is easy to interfere with or even damage the on-board sensors, so only the dynamic data collected is not enough, it must be combined with the scraper conveyor, hydraulic support of the relevant sensor data to complete the positioning of the shearer. To solve the above problem, this paper proposes method of combining data of dynamic data and Shearer scraper conveyor, hydraulic static to obtain location information of shearer body in three directions, so as to provide security for realizing the automation of shearer and remote control.

2. Analysis of Shearer Working Path

The coal mining machine in underground work is not independent finish, but need to stand with the scraper conveyor and hydraulic support, which is commonly referred to as the "three-machine interaction". As shown in Figure 1, hydraulic support lined up along the direction of the coal wall, covering coal mining and scraper conveyor, shearer run on the orbit of scraper conveyor. This article will shearer along the transport direction of the scraper movement is defined as "horizontal movement". In the coal mining machine cutting coal wall process, the scraper conveyor will be pushed towards the coal wall by the hydraulic support as mentioned in

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Reference [10, 11]. So when the shearer cutting finishes one knife, the whole scraper conveyor moving toward the coal wall for some distance, to achieve the movement of shearer body wall toward the direction the coal wall. Shearer be perpendicular to this direction of movement of the coal wall is defined as "vertical movement".

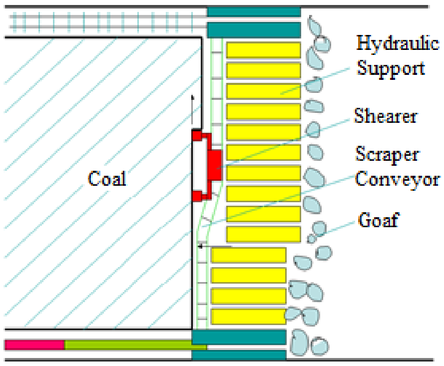

Figure 1. Schematic Diagram of Shearer Working Path

3. Establishment of Positioning Coordinates

The positioning of shearer is to determine the coordinates in its three-dimensional coordinate system coordinates. Shearer's body is too large to not be treated as a particle. Therefore we need to select a feature point on shearer, which use the three-dimensional coordinates of feature point to uniquely determine the location of coal mining. In this paper, running gear of shearer and scraper conveyor with rail contact points are selected as the position to calculate, and can be converted to other points.

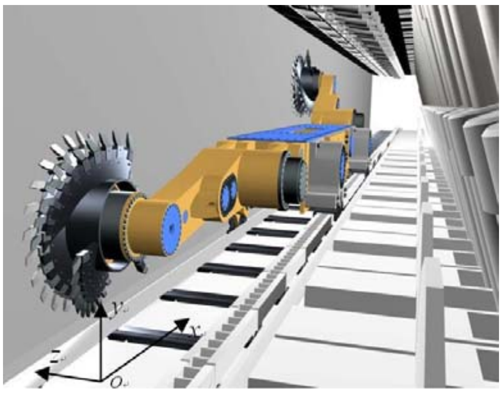

Figure 2. Coordinate System of Shearer Positioning

As shown in Figure 2, this positioning of the body coordinate system makes the following provisions. (1) The initial state in the starting position of characteristic points of shearer is the origin of the system. (2) The opposite direction of acceleration of gravity is the y-axis direction; the direction of gravity is the y-axis negative direction. (3) Parallel to the scraper conveyor and perpendicular to the y axis the direction is the x-axis; facing the coal wall, the right of the x-axis is positive direction, the left of the x-axis is negative direction. (4) Perpendicular to X-Y plane the direction and point to the coal wall positive direction is the z-axis, contrary to is the negative z-axis direction. Note that the origin is set fixed point in the system of the initial state, not along with the vertical movement and horizontal movement of the shearer to change, and the connection point of the origin and the point slide by pushing of the corresponding slip scraper conveyor must be parallel to the Y-Z plane.

In this 3-dimensional coordinate system, the running track of the shearer can be projected onto X-Y, Y-Z, and X-Z three-plane to format three curves. Combination of the above discussion we can see: Shearer trajectory in the X-Y plane of projection is "horizontal movement" track; in the Y-Z plane of projection is "vertical movement" track. Figure 2 shows the body positioning coordinate system when be exploited by the level, usually the face was not certain level but layout angle, this time Shearer trajectory is inclined curve in the X-Y plane and Y-Z plane of projection, this is of the significance on the shearer body positioning.

4. Body Positioning Strategy

The shearer, scraper conveyor and hydraulic support in the coal face are mutual cooperation, coordination, and therefore the shearer body positioning must include the relevant information of scraper conveyor and hydraulic support. And it is not reliable only relying on the sensor data in the process of airborne sensor data for positioning to locate the sensor, because the body will affect the impact of airborne sensor signal output during exercise shearer vibration, coal and other factors, resulting in data distortion and seriously affect the positioning accuracy. Therefore, this article using the "three-machine orientation" and "convergence movement" strategy to achieve the shearer body positioning.

4.1. 3-machine Positioning Strategy

In the shearer body positioning, we can control access to the hardware parameters and sensor the data of coal mining, scraper conveyor, hydraulic support to locate operations, so it is called "3-machine positioning". Specific organizational structure is as shown below.

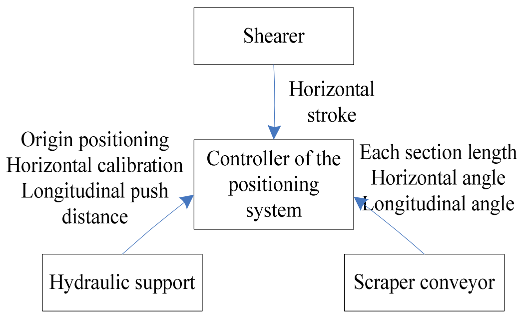

Figure 3. Structure Diagram of 3-machine Positioning Strategy

1. Airborne sensors of shearer include dynamic tilt sensors, vibration sensors, shaft encoders, infrared receivers, etc. One shaft encoder is used to get the itinerary of shearer on the scraper conveyor, and sends the data to the body positioning controller.
2. Length of each section of the scraper conveyor can be set through the body of the positioning controller. The horizontal and vertical angle of scraper conveyor can get through the tilt sensor on each the slot section of the scraper conveyor. None of these scraper conveyors use tilt sensor which requires the necessary automation to its transformation, specific rehabilitation programs is not discussed in this article by the limited space.
3. Hydraulic support locates the origin of a shearer and horizontal alignment through it's on board infrared launcher. Through its hydraulic cylinder, we can obtain the vertical slip distance, and sent to the body positioning controller.

4.2. Static-dynamic Fusion Strategy

Various hardware and sensor information used by shearer body position is not all operated during the process of collection of the shearer, some are set in the on-board controller, some are run before the shearer acquisition, so called "integration movement". This strategy avoids high signal errors, distortion and other issues only in the dynamic acquisition.

1. Static collection data: the length of each section of the scraper conveyor, horizontal angle and vertical angle; hydraulic support the slide distance.
2. Dynamic collection data: Shearer horizontal stroke, data of hydraulic support for located the origin and horizontal calibration.

5. Theoretical Model of Body Positioning

Shearer runs along the scraper conveyor in the coordinate system of positioning the body, so scraper conveyor determines the shearer only running track. If the scraper conveyor is known the arrangement of the situation in three-dimensional coordinate system, combined with the current trip of shearer, system coordinates of shearer can be found in the 3-dimensional coordinate. Among them, the scraper conveyor layout affects the horizontal x-axis and y-axis coordinates of shearer; the situation of hydraulic support for the longitudinal slip scraper conveyor affects the y-axis and z-axis coordinates of shearer. From the above analysis, we can see that the y-axis coordinate of shearer is special, which impacted by the horizontal movement and vertical movement. Design of shearer body positioning processes include: lateral positioning, vertical positioning and three-dimensional positioning.

5.1. Lateral Positioning

Lateral movement of shearer occurs in the X-Y plane, so the horizontal positioning of the shearer is to determine the characteristic points of the x-coordinate and y-coordinate. Figure 4 is a schematic of horizontal positioning of shearer, starting point of scraper conveyor is coordinate origin o, thick solid line represents scraper conveyor the projection in the X-Y plane, the small dots on each section is hinge point between the scraper conveyors. Let scraper conveyor total have n nodes, each section length is *h*, the *k* hinge point of the coordinates is (x_k, y_k), and angle between k nodes and the x-axis is α_k, among $n \in Z$ and $n > 0$, $k \in n$.

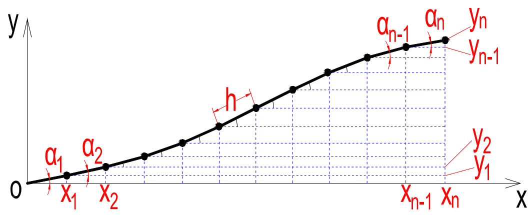

Figure 4. Schematic Diagram of Shearer Lateral Positioning

Steps of the lateral positioning are as follows:

•Seek projection of scraper conveyor in the X-Y plane. The length of each section of the scraper conveyor is *h*, and the angle between *n* tilt sensors with the x-axis is $[\alpha_1, \alpha_2, \cdots, \alpha_{n-1}, \alpha_n]$. It can be obtained the following piecewise function of scraper conveyor the projection in X-Y plane:

$$\begin{cases} f_1(x) = x \tan\alpha_1 & 0 \le x \le x_1 \\ f_2(x) = f_1(x_1) + (x - x_1)\tan\alpha_2 & x_1 < x \le x_2 \\ \vdots & \\ f_{n-1}(x) = f_{n-2}(x_{n-2}) + (x - x_{n-2})\tan\alpha_{n-1} & x_{n-2} < x \le x_{n-} \\ f_n(x) = f_{n-1}(x_{n-1}) + (x - x_{n-1})\tan\alpha_n & x_{n-1} < x \le x_n \end{cases} \quad (1)$$

•Seek position of shearer on the scraper conveyor. Current trip of shearer is set 2. Among them, $k \in n$ is the quotient, $0 \le p < h$ is remainder. It can be seen that the feature points of shearer scraper conveyor locate p on the section *k*.

$$\frac{s}{h} = k \cdots p \quad (2)$$

•Seek x-coordinate and the y-coordinate of feature points of shearer. Feature points is located at the *k* section of the scraper conveyor, we can find the coordinates of the *k* hinge points is (x_k, y_k).

$$\begin{cases} x_k = h\sum_{i=1}^{k}\cos\alpha_i \\ y_k = h\sum_{i=1}^{k}\sin\alpha_i \end{cases} \quad (3)$$

And then find p on the section k of scraper conveyor. Being relative to the coordinate offset data of point (x_k, y_k) is (x_p, y_p):

$$\begin{cases} x_p = p\cos\alpha_{k+1} \\ y_p = p\sin\alpha_{k+1} \end{cases} \quad (4)$$

When trip of the shearer is s, component of the lateral movement in the x-axis is x_s and in the y-axis is y_s:

$$\begin{cases} x_s = x_k + x_p = h\sum_{i=1}^{k}\cos\alpha_i + p\cos\alpha_{k+1} \\ y_s = y_k + y_p = h\sum_{i=1}^{k}\sin\alpha_i + p\sin\alpha_{k+1} \end{cases} \quad (5)$$

5.2. Vertical Positioning

Hydraulic support for slip scraper conveyor makes the starting point shift relative to the coordinate origin, thus forming a shearer the longitudinal motion in the Y-Z plane. Therefore, as long as we can calculate offset which shearer is relative to the origin of coordinates, you can get the offset which points of the scraper conveyor relative to the origin of coordinates, then getting feature points of shearer offset relative to the origin of coordinates under the action of the vertical movement s. Origin point of shearer makes 2 times slide, the distances of slip are: $[d_1, d_2, \cdots, d_{m-1}, d_m]$, the angles between direction of the slip and the z-axis are: $[\beta_1, \beta_2, \cdots, \beta_{m-1}, \beta_m]$, under the longitudinal movement, offsets which the origin point of scraper conveyor is relative to the origin of coordinates are as follows:

$$\begin{cases} y_d = \sum_{i=1}^{m} d_i \sin\beta_i \\ z_d = \sum_{i=1}^{m} d_i \cos\beta_i \end{cases} \quad (6)$$

5.3. 3-dimensional Positioning

As we can be seen from the above derivation, horizontal movement affects the x-coordinate and the y-coordinate of feature points; vertical movement affects the y-coordinate of feature points and the z-axis coordinates. We can calculate component of feature points in the X-Y plane and Y-Z plane coordinate, the feature points of the shearer can be got in three-dimensional coordinate system coordinates of body positioning. The definition of each variable and ranges consistent are consistent with the previous text.

$$\begin{cases} x = x_s = h\sum_{i=1}^{k}\cos\alpha_i + p\cos\alpha_{k+1} \\ y = y_s + y_d = h\sum_{i=1}^{k}\sin\alpha_i + p\sin\alpha_{k+1} + \sum_{i=1}^{m} d_i \sin\beta_i \\ z = z_d = \sum_{i=1}^{m} d_i \cos\beta_i \end{cases} \quad (7)$$

6. Test Results and Analysis

In order to verify the correctness of theoretical models and system positioning accuracy, the authors makes an experiment at the platform through prototype model in the 1:6 composition, Measure lateral positioning accuracy of shearer in the situation of scraper tilt 5°, 10°, 15°, as shown in Figure 5. In this study, platform have 20 scrapers, length of each has

240mm; there are 100 sampling points at the experiment, sampled one time at the average interval of 48mm.

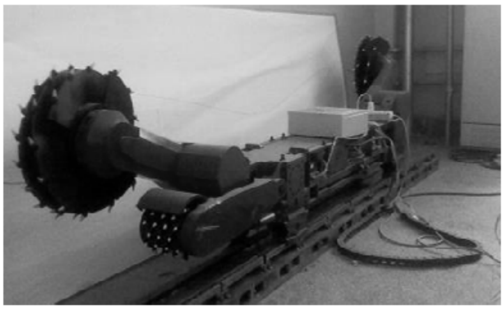

Figure 5. Experimental Platform of Shearer Position

The results are shown in Figure 6. We can see that positioning system have a clear cumulative error, and the error increases when angles of the scraper and the tilt increase. When the angle is 5°, the maximum error is about 4%; When the angle is 10°, the maximum error is about 5%; When the angle is15°, the maximum error is about 7%. For example, as 200m long mechanized mining face, 7% margin of error is equivalent to about 3.6m the amount of error on the y-direction, apparently unable to meet the on-site production. This is mainly because the system uses incremental shaft encoder to measure the lateral displacement, so inevitably there will be error accumulation problem as mentioned in the Reference [12-13]; other shearers usually work in the low state, will lead the output shaft encoder pulse generator positive and negative to jitter frequently, resulting in pulse counting error.

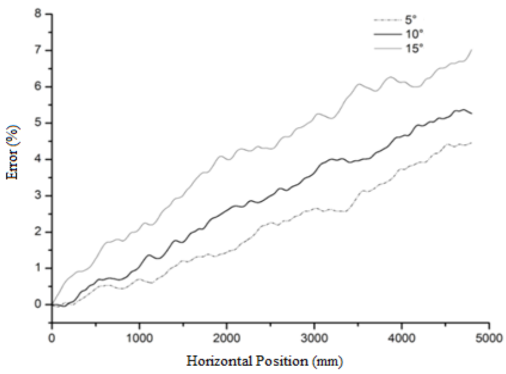

Figure 6. Positioning Accuracy with Accumulated Error

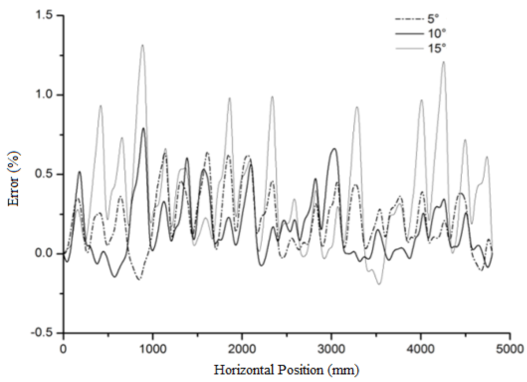

Figure 7. Positioning Accuracy without Accumulated Error

In order to reduce the shaft encoder cumulative error which also exist in Reference [14], this paper uses hall proximity switches in each section of the scraper, shearer uses the switch signals to calibrate horizontal displacement in each section scraper, which will control accumulate error in a limited range. The results are shown in Figure 6, accumulated error can be seen has been inhibited. When the angle is 5°, the error is less than 0.7%; When the angle is 10°, the error is less than 0.9%; When the angle is 15°, the error is less than 1.4%. For example, as 200m long mechanized mining face, 1.4% margin of error is equivalent to about 37m the amount of error on the y-direction, apparently unable to meet the on-site production. If necessary, accumulation of system error can be reduced by the method of reducing calibration spacing further.

7. Conclusion

Based on the "three-machine orientation" and "static and dynamic integration" strategy of body positioning system of shearer, which can effectively improve body positioning accuracy and stability for the realization the memory cutting and remote control of shearer, and ultimately provide protection for shearer automation. In the laboratory we can make the simulation experiment through the 1:6 prototype models, primarily validate the correctness and feasibility of the scheme, and show that the precision positioning of system can meet control requirements in actual production process. In Xi'an Coal Mining Machinery Co., Ltd. Type of MG900/2210-WD electric traction shearer in the industrial field experiments further verifies the feasibility and the positioning accuracy of the system. Currently, the system has passed the mid-term assessment of China 863 Program, and has been acknowledged and recognized by experts. Next experiments of mechanized mining face will be carried out in cooperation with China Pingmei Shenma Group, and the system will be further improved and perfected resulting according to the result of experimental.

Acknowledgments

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