Application of High-Precision Scene Perception Technology in Mining Material Transportation

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ABSTRACT

By innovatively applying high-precision scene perception technology, a digital elevation model (DEM) is established to simulate real-time 3D digital twin scenes of mining material transportation. Based on 5G low latency data transmission technology, timely response is made. Through the establishment of an integrated control system for precise positioning of mining cranes, anti sway of hoppers, safety protection, and intelligent scheduling and management of mining storage areas, unmanned, efficient, standardized, and safe operations at the mining yard site are achieved.

Keywords: Crane; High precision scene perception; 3D digital twin; Intelligent scheduling

1. SYSTEM OVERALL DESIGN PLANNING

System research and development includes laser scanning and positioning system, automatic positioning system for crane operation, remote control platform for central control, wireless control system for industrial interconnection, remote video monitoring system, precision grab control system, security protection system, and upper hangar management system.

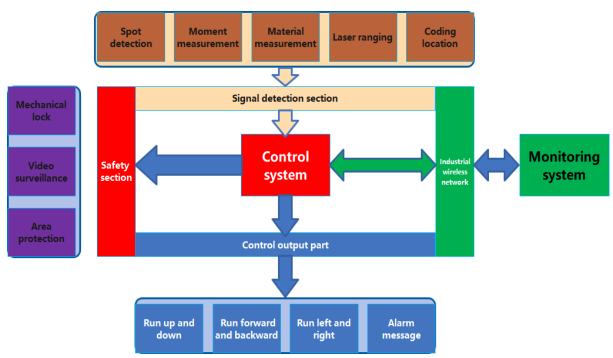

Figure 1 Overall framework for crane remote monitoring

2. RAW MATERIAL POOL LASER SCANNING POSITIONING SYSTEM

The scanning and acquisition principle of laser scanning and positioning system is that the laser pulse wave is emitted by the Alarm messagelaser transmitter and mixed with a large amount of industrial field noise. Through the analysis of the acquisition waveform, it can be seen that the amplitude modulation signal is generated by the scanning laser strapping to the raw material excitation. Through the algorithm of extracting signal envelope from extreme value points, the time domain signal is maximized and then the arithmetic average is obtained to obtain a relatively smooth time domain signal curve, which can effectively extract signal information and filter out high-frequency noise, and then analyze the location information of raw material warehouse to achieve real-time and efficient monitoring by laser scanning. The maximum value of the signal is to take out the peripheral contour of the sampled data, but the obtained signal pattern mostly presents the shape of a broken line. In order to reduce the influence of interference and improve the smoothness of the curve, it is

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necessary to smooth the sampled data, which can not only reduce the interference components, but also maintain the change characteristics of the original curve[1].

The calculation formula of average method：

$$y(t) = \frac{1}{2^N + 1} \sum_{n=-N}^{N} \hbar(n)x(t-n) (1)$$

Formula (3) is also known as the simple average of $2^N + 1$ points. When $N - 1$ is a 3-point simple average, when $N = 2$ is a 5-point simple average.If equation (3) is regarded as a mole wave formula, the filter factor：

$$\hbar(t) = [\hbar(-N), \ldots, \hbar(0), \ldots, \hbar(N)]$$

$$= \left[\frac{1}{2^N + 1}, \ldots, \frac{1}{2^N + 1}, \ldots, \frac{1}{2^B + 1}\right]$$

$$= \frac{1}{2^N + 1}(1, \ldots, 1, \ldots, 1) (2)$$

After processing by the above algorithm, the signal curve is shown in Figure 2：

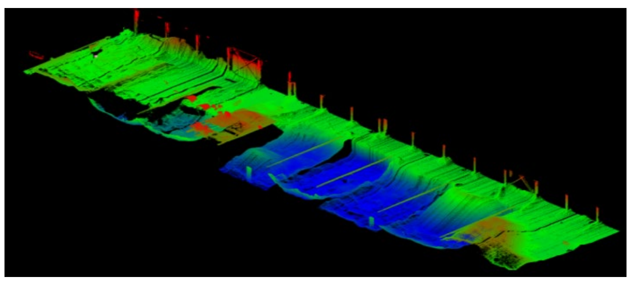

Figure 2 Warehouse level scanning profile

3. CRANE AUTOMATIC POSITIONING SYSTEM

The automatic positioning system of the crane in the raw material warehouse is divided into the automatic positioning of the truck, the car and the grab bucket. The positioning method of the truck, the car and the grab lifting mechanism adopts the absolute encoder and the calibration switch. The lifting mechanism uses the rotary absolute encoder, which is installed coaxial with the drum, and can directly detect the height of the grab bucket. The encoder of the big car and the small car of the crane is installed on the driven wheel, and the accumulated error is eliminated by calibrating the switch[7]. The purpose of this design is: the absolute encoder is mainly used for precise control, protection of the operating terminal, and protection of the operating area[8]. The calibration switch is used to eliminate the accumulated error of the installation encoder, protection of the operating terminal, protection of the operating area, and boundary setting of the operating area[2].

The positioning error can be divided into two types, namely relative error and absolute error. Absolute error is the deviation between the detected coordinates and the real coordinates, which is generally expressed by the length unit of measurement. The following formula is shown.

$$\text{Error} = \sum_{i=1}^{n} \sqrt{(x_i - \hat{x}_i)^2 + (y_i - \hat{y}_i)^2 + (z_i - \hat{z}_i)^2} (3)$$

The formula indicates the number of monitoring cameras used to locate the material. (x,y,z) represents the real coordinates of the material center, and $(\hat{x}_i, \hat{y}_i, \hat{z}_i)$ is the estimated coordinates of the material center. The relative error is generally expressed by the ratio of the absolute error value to the measured range radius. The smaller the relative error of positioning, the higher the positioning accuracy. The Relative error (RE) is as follows, where R indicates the monitoring radius of the surveillance camera.

$$RE = \frac{\sum_{i=1}^{n}\sqrt{(x_i - \hat{x}_i)^2 + (y_i - \hat{y}_i)^2 + (z_i - \hat{z}_i)^2}}{n \times R} (4)$$

At the same time, in order to reflect whether the positioning coordinate result falls on the material (not necessarily the material center), the Relative shift rate (RS) is used to indicate that the positioning coordinate result falls on the material, and any material grasping device can grasp the material. In the formula, r represents the equivalent radius of the material (if the radius of the material is not equal in multiple directions, take the average value).

$$RS = \frac{\sum_{i=1}^{n}\sqrt{(x_i - \hat{x}_i)^2 + (y_i - \hat{y}_i)^2 + (z_i - \hat{z}_i)^2}}{n \times r} (5)$$

The theoretical basis is that there are many optical channel engraving on the absolute encoder disc. By reading the pass and dark of each engraving line, a set of unique binary codes from 2 to the zero power to 2 to the n-1 power are obtained. The interrupt signal pulse is sent from the receiving device to the encoder, and the absolute position value is synchronized by the encoder and the clock pulse to the receiving device[8]. The timing diagram shows that the receiving device sends a clock signal to trigger, the encoder starts to output and synchronize with the clock signal from the high position, the clock signal starts to store the signal at the first falling edge, after the t2 delay time, the encoder data signal begins to transmit, and t3 is the recovery signal, waiting for the next transmission.

In order to better compare the similarity degree between the detector and the tracker, and optimize the measurement method, DeepSort uses cosine distance to measure the similarity matrix of all feature vectors in each target box, and uses Mahalanobis distance to judge the proximity of the Kalman filter prediction box information and the motion information of the target detection result box. The Mahalanobis distance is calculated as follows:

$$d^{(1)}(i,j) = \left(d_j - y_i\right)^T S_i^{-1}\left(d_j - y_i\right) (6)$$

In the formula, Si represents the covariance matrix between the tracking prediction box and the target detection box at the current time, dj represents the position of the j th detection box, and yi represents the position of the i th tracking prediction box. Only when the value of the Mahalanobis distance is less than the specified threshold, the motion state correlation matching can be trusted, and the threshold function is shown in the equation.

$$b_{i,j}^{(1)} = \| \left[d^{(1)}(i,j) \leq t^{(1)}\right] \quad (7)$$

The value of t(1) is 9.4877. The cosine similarity measurement formula for apparent features is as follows:

$$d^{(2)}(i,j) = \min\left\{1 - r_j^T r_k^{(i)} | r_k^{(i)} \in R_i\right\} (8)$$

The extraction of apparent features requires the use of Cosine depth feature network mentioned in 4.1.1 to extract the feature vector. Similarly, only when the cosine distance is less than the specified threshold is desirable, and the threshold function is shown as follows:

$$b_{i,j}^{(2)} = \| \left[d^{(2)}(i,j) \leq t^{(2)}\right] (9)$$

Therefore, in order to make the advantages of the two measures complementary, that is, reliable location information can be obtained by using the Mahalanobis distance, and the ID of the re-emerging target can be recovered by using the cosine measure, the cost formula of the combined Mahalanobis distance and apparent cosine measure is as follows:

$$c_{i,j} = \lambda d^{(1)}(i,j) + \left(1 - \lambda\right) d^{(2)}(i,j) (10)$$

The influence of each association measure on the combined association can be adjusted with the λ parameter. All gating thresholds can be expressed as follows:

$$b_{i,j} = \prod_{m=1}^{2} b_{i,j}^{(m)} \quad (11)$$

In the process of starting and stopping the crane after grabbing materials, the acceleration and deceleration of the truck and the car will cause the swing of the crane. A specific anti-roll control algorithm is used to calculate the optimal speed of the crane, clarify the relationship between the swing of the crane and the acceleration and deceleration of the truck, and collect the real-time detection of the Angle meter value of the anti-swing module, so that there is no swing speed model during production[3]. The model data mechanism is as follows:

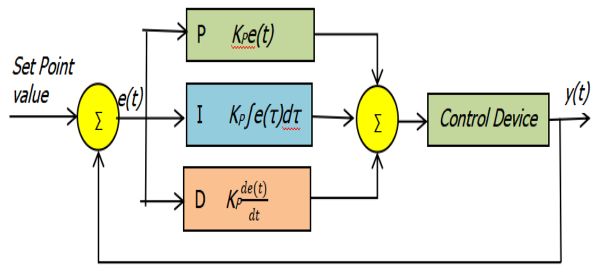

Figure 3 anti-swing control model

4. SUMMARY

The storage crane remote centralized control system is designed around the four goals of ensuring safety, improving material grab efficiency, reducing cost and improving intelligence. Through the research and development of the crane positioning system, hopper anti-roll system, safety protection system, field data acquisition system, raw material reservoir management system, host computer control system and other contents, as well as optimizing the storage yard planning, Reasonable material stacking and other measures will eventually achieve unmanned, efficient and safe operation on the crane site of the raw material warehouse, and improve the intelligent and scientific level of crane control.

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