

Research on Shape and Density Value Compensation Algorithm for Deeply Overlapping Ore X-ray Transmission Images Based on Region Growing

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Abstract

The use of X-ray transmission sorting technology for mineral sorting can increase the content of target minerals, thereby optimizing resource utilization and improving production efficiency. However, the ore images obtained during the sorting process often exhibit target adhesion and overlapping, leading to sorting disorder and resource waste. To improve mineral resource utilization and sorting efficiency, this paper proposes an ore image shape and density value compensation algorithm for deeply overlapping ore images with significant overlapping shadows.

This algorithm is used to restore the shape of individual ore images and compensate for the density values in their overlapping regions. The binary image of the overlapping region is extracted using a region growing algorithm, and an “OR” operation is performed between the overlapping region binary map and the individual ore binary map to restore the shape of the individual ore image. Density value compensation for the overlapping regions of the individual ore image is achieved through contour lines with different circumscribed circle radii.

Experimental results show that the individual ore images processed by the algorithm possess shapes and density values closer to actual conditions. Compared with standard control data, the accuracy of the center coordinates improved by 73.58% compared to the un-restored images, the average density value compensation efficiency for the overlapping regions reached as high as 91.35%, and the similarity between the compensated regions and the actual conditions increased by 82.71% compared to the uncompensated images. The method in this paper demonstrates strong effectiveness in shape restoration and density value compensation for deeply overlapping ore images with significant overlapping shadows, which can significantly enhance mineral sorting efficiency.

Full Text

Preamble

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Research on Shape and Density Value Compensation Algorithms for Deeply Overlapping Ore X-ray Transmission Images Based on Region Growing

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Abstract

Utilizing X-ray transmission (XRT) sorting technology for mineral processing can effectively increase the concentration of target minerals, thereby optimizing resource utilization and improving production efficiency. However, ore images obtained during the sorting process often exhibit target adhesion and overlapping, which leads to sorting disorder and resource waste. To improve mineral resource utilization and sorting efficiency, this paper proposes a shape and density value compensation algorithm for deeply overlapping ore images characterized by distinct overlapping shadows. This method is designed to restore the shape of individual ore images and compensate for the density values within their overlapping regions.

The algorithm extracts the binary image of the overlapping area using a region-growing technique. A logical “OR” operation is then performed between this overlapping area binary map and the individual ore binary map to restore the shape of the independent ore. Density value compensation for the overlapping regions of the individual ore images is achieved through contour lines with varying circumscribed circle radii. Experimental results demonstrate that the processed individual ore images possess shapes and density values that more closely approximate actual conditions. Compared to standard reference data, the accuracy of the center coordinates improved by 73.58% relative to un-restored images. The average density value compensation efficiency for overlapping regions reached 91.35%, and the similarity between the compensated regions and actual conditions increased by 82.71% compared to uncompensated images. The method presented in this paper demonstrates strong effectiveness in shape restoration and density value compensation for deeply overlapping ore images with significant shadows, thereby substantially enhancing mineral sorting efficiency.

Keywords: Deeply overlapping ore images; X-ray transmission; Shape restoration; Density value compensation; Region growing;

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1. Introduction

X-ray transmission (XRT) sorting has emerged as a critical technology in the mining industry, offering a non-destructive means to pre-concentrate ores based on their atomic number and density. By identifying and removing waste rock before secondary crushing and grinding, XRT systems can significantly reduce energy consumption and chemical usage. Despite these advantages, the performance of XRT sorting is often hindered by the physical arrangement of the ore on the conveyor belt. In high-throughput environments, ore particles frequently collide, adhere, or overlap.

Deeply overlapping ores present a particular challenge for traditional image processing algorithms. When two or more particles overlap, the resulting X-ray image displays a “shadow region” where the detected intensity is a cumulative function of the thickness and attenuation coefficients of all overlapping layers. This phenomenon leads to two primary issues: shape distortion, where multiple particles are perceived as a single large entity, and density miscalculation, where the overlapping region appears denser than the constituent materials. These inaccuracies often result in the misclassification of ore as waste or vice versa, leading to diminished sorting efficiency.

To mitigate these issues, this research introduces a novel compensation framework. By integrating region-growing techniques with density-based modeling, we aim to reconstruct the individual profiles of overlapping ores. This approach not only improves the precision of shape recognition but also restores the integrity of density data, providing a robust foundation for subsequent machine learning classification and mechanical separation.

2. Methodology

The proposed algorithm focuses on the segmentation and reconstruction of overlapping ore regions through a multi-stage process. The core of the method lies in identifying the boundaries of the overlapping sections and applying compensation factors derived from the physical principles of X-ray attenuation.

2.1 Overlap Detection and Region Growing

The first stage involves the identification of potential overlap zones. Given an XRT image, we utilize a region-growing algorithm to isolate the binary masks of overlapping areas. The algorithm starts from seed points identified by local intensity maxima—which typically correspond to the thickest parts of the overlap—and expands until it reaches the boundaries defined by the gradient of the X-ray attenuation.

Machine vision has been widely applied in mineral separation. In industrial settings, X-ray-based ore sorting devices perform mineral classification [FIGURE:1]. Target minerals are crushed into particles of uniform size and identified

by dual-energy X-ray equipment on a conveyor belt. The system distinguishes between ores based on variations in X-ray attenuation intensity.

[FIGURE:1] Mineral sorting process by dual-energy X-ray

Based on imaging results, the system identifies the mineral type and calibrates the blowing center of each independent ore. The blowing center is defined as the centroid position of the independent ore image, calculated from the restored binary image, serving as the control target for the pneumatic blowing system. Finally, the valve controller adjusts the airflow based on these coordinates to direct minerals into corresponding bins [?].

However, target adhesion and overlapping frequently occur on conveyor belts. This causes multiple independent ores to be treated as a single target, interfering with the determination of the blowing center. In industrial applications, deeply overlapping ores are typically discarded, leading to resource waste [?]. Therefore, adhered ore images must be segmented. For deeply overlapping images, it is necessary to compensate for the actual shape and density values to ensure precise classification and coordinate calibration.

2.2 Existing Methodologies and Limitations

Existing methods include thresholding, edge detection [?], concave point detection [?], region growing [?], and deep learning [?]. While effective in specific scenarios, most lack specificity for ore images due to irregular shapes, non-uniform thickness, and blurred edges. Concave point detection and matching have achieved success for lightly adhered ores but suffer from shape loss and density distortion in deep overlap scenarios [?].

Traditional region growing algorithms rely on fixed thresholds and struggle with grayscale superposition. Deep learning requires large-scale labeled data and has high computational costs. Consequently, there is an urgent need for specialized processing for deep overlap by integrating imaging mechanisms with image statistical features.

2.3 Image Preprocessing

For deeply overlapping ore images, overlapping regions are located within segmented areas defined by segmentation lines [FIGURE:2]. The algorithm crops the segmented regions based on these lines to reduce noise interference.

[FIGURE:2] Acquisition Process of Segmented Region Images (a: Segmented region with the segmentation line; b: Segmented region mask; c: Original image of the segmented region; d: Filtered image of the segmented region)

The acquisition process for segmented regions is shown in [FIGURE:3]. Let the length of the segmentation line be L , representing the span of the contact area. The coordinates of the concave points P_1 and P_2 define L as the Euclidean distance between them.

[FIGURE:3] Methods for Acquiring Segmented Regions

To ensure overlapping shadows are fully contained, the segmented region scale parameters are set based on L . Median and Gaussian filtering are applied to the segmented regions to filter salt-and-pepper noise and smooth the image, enhancing pixel features for the overlapping areas.

2.4 Adaptive Region Growing Optimization

The algorithm extracts a binary map of overlapping regions using region growing. The midpoint of the segmentation line serves as the initial seed point. To address the stochastic nature of fixed thresholds, this paper proposes an adaptive thresholding method based on grayscale distribution peak analysis.

[FIGURE:4] Binary image of overlapping regions obtained by region growing

Overlapping regions possess the lowest grayscale values in the segmented image, forming a distinct peak in the grayscale distribution curve [FIGURE:5]. The grayscale value corresponding to this peak is used as the “overlapping region peak grayscale value.” During growth, the seed point’s grayscale is replaced by this peak value. The allowable upper limit for grayscale variation is set as $\omega/2$, where ω is the width of the peak.

[FIGURE:5] Grayscale distribution curves of segmented region images

2.5 Shape Restoration and Density Value Compensation

Shape restoration is performed on the binary image. An “OR” operation is performed between the segmented independent ore image and the overlapping region binary map [FIGURE:6]. To fill internal gaps, a convex hull operation is applied, followed by subtraction of the original segmented image to isolate the compensation area.

[FIGURE:6] Shape restoration process of deeply overlapping ore images

Using the shape-restored binary images as masks, grayscale images are extracted [FIGURE:7]. To correct distorted density values in overlapping regions, the algorithm utilizes the contours of the shape-repaired images. Centered on the contour moment, contours with varying circumscribed circle radii are drawn [FIGURE:8].

[FIGURE:7] Shape restoration effect

[FIGURE:8] Density value compensation process for grayscale images of independent ores

For pixels on the contour falling within the background (overlapping) region, grayscale values are reassigned based on the mean grayscale value of the foreground pixels on that same contour [FIGURE:9]. This reconstructs the density gradient from the center to the periphery.

Figure 10

Figure 1: Figure 10

[FIGURE:9] The compensation process for density values in independent ore images

Overall flow chart of the algorithm operation

3. Test Results and Analysis

3.1 Data Acquisition Platform

Tungsten ore samples (40-100 mm) were imaged using the X1400 intelligent ore sorter [FIGURE:11]. High-energy images (140 kV) were used to reflect density distribution and adhesion states.

[FIGURE:11] X1400 intelligent ore sorter

3.2 Dataset Preparation

A dataset of 304 sets was prepared, consisting of “standard independent ore images” and their “corresponding deeply overlapping images” [FIGURE:12].

[FIGURE:12] Dataset preparation (a: Independent ore; b: Deeply overlapping; c: Segmentation line)

3.3 Performance Evaluation of Region Growing

The proposed method was compared with other region-growing algorithms [FIGURE:13]. The shape extraction ratio (EX) was used for evaluation.

[FIGURE:13] Shape extraction effects of various algorithms

Comparison of Average Shape Extraction Ratios Across Various Algorithms

Method	Running Time (ms)	Average Shape Extraction Ratio
Proposed Method	12.4	0.91
Region Growing-Merging	15.2	0.72
Watershed-Enhanced RG	18.5	0.68
Inward Region Growing	14.1	0.75

The proposed method achieved a significantly higher extraction ratio (up to 26.3% improvement) with comparable execution time.

3.4 Shape Restoration and Density Compensation Effects

Centroid coordinate deviation (d) was used to evaluate shape restoration. The average center deviation of shape-repaired images (\bar{d}_{repair}) was 2.56, a 73.58% improvement over unrestored images [FIGURE:14].

[FIGURE:14] Scatter plot of center coordinate deviations

Density compensation was verified by comparing compensated regions with control images [FIGURE:15]. The average similarity reached 91.35%, an 82.71% improvement over uncompensated images.

[FIGURE:15] Density compensation effects

3.5 Practical Sorting Performance

Actual sorting tests were conducted. Traditional strategies result in 0% resource utilization for deep overlap as they discard all such ores. The proposed method increased resource utilization to 88%.

Resource Utilization Comparison

Experimental Group	Condition	Total Number	Misclassified	Resource Utilization
Baseline	No Overlap	50	2	96%
Traditional	Deep Overlap	50	50	0%
Proposed Method	Deep Overlap	50	6	88%

4. Conclusion

This paper proposes a shape and density compensation algorithm for deeply overlapping ore images. By using adaptive region growing and contour-based compensation, the method restores ore shapes and reconstructs density distributions. Experimental results show a 73.58% improvement in centroid accuracy and a 91.35% density compensation efficiency. This approach significantly enhances mineral sorting efficiency and resource utilization in industrial XRT systems. Future work will focus on improving compensation accuracy and extending the algorithm to more complex overlapping patterns.

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