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A Machine Vision-Based Edge Detection Method for Belt Lap of Pipe Belt Conveyor

Nini HAO[a], Xingyu WANG[a1], Yuan ZHANG[a, b], Mengchao ZHANG[a], Changzheng SUN[b], Chengquan HU[b]
[a] *College of Mechanical and Electronic Engineering, Shandong University of Science and Technology, Qingdao 266590, China*
[b] *Libo Heavy Industries Science and Technology Co., Ltd, Taian 271000, China*

Abstract. The extraction of positional features from the longitudinal lap edge straight line of the conveyor belt in a pipe belt conveyor holds significant importance in the detection of conveyor belt torsion faults. This study presents a proposed algorithm for detecting the longitudinal lap edge on a conveyor belt using machine vision. The algorithm involves several steps, including extracting regions of interest (ROI) from conveyor belt images and converting them to grayscale. Local enhancement is achieved through image stretching, and edge features are extracted using the Prewitt operator. Morphological methods are then applied to address impurities, and the lap edge is detected through straight line detection using the Hough transform. The conducted experiments involving the utilization of OpenCV on authentic images of a cylindrical pipe belt conveyor within an industrial setting demonstrate the algorithm's proficient ability to accurately recognize the longitudinal lap edges of conveyor belts.

Keywords. Pipe belt conveyor, Torsion detection, Edge detection, Machine vision

1. Introduction

The pipe belt conveyor is a highly efficient and environmentally sustainable method of transporting bulk materials [1-2]. It finds extensive application in various industries, such as mining and harbor operations. During the extended duration of operation, the conveyor belt is susceptible to torsion caused by uneven forces, leading to substantial reductions in productivity [3]. Hence, it is of utmost significance to diligently monitor the torsion phenomenon during the functioning of a pipe belt conveyor.

Conveyor belt torsion is commonly characterized by the rotation of the belt's lap position, exceeding an angle of 20° in either the clockwise or counterclockwise direction in relation to the structural frame of the conveyor [4]. At present, the detection of conveyor belt torsion may be categorized into two distinct approaches: the conventional method and the utilization of video-based artificial intelligence (AI) recognition technology [5-6].

The conventional method typically involves manual inspection or the utilization of mechanical integrated protection systems, and the non-contact approach is employed for monitoring the position of the lap point situated at the uppermost section of the conveyor

[1] Corresponding Author: Xingyu WANG, College of Mechanical and Electronic Engineering, Shandong University of Science and Technology, Qingdao 266590, China; E-mail: Singyoo@163.com.

belt. While continuous real-time monitoring offers certain benefits, it presents challenges in effectively monitoring torsion angles and expanding the spatial arrangement of the body, hence leading to increased costs associated with operation and maintenance [7-9].

The utilization of video-based artificial intelligence (AI) recognition technology is increasingly prevalent in the identification of abnormal states in pipe belt conveyors. This study presents a novel lap edge detection technique, which is then validated through experimental analysis. The primary objective is to investigate the correlation between the properties of lap edge lines and torsion, hence offering technical assistance for the identification of belt torsion in pipe belt conveyors.

2. Experimental Setup

The capture and processing of image data were conducted using a camera configuration, as depicted in Figure 1a. The experimental setup comprises a pipe belt conveyor, a camera, and a computer running the Windows operating system, which facilitates the creation of a Python-based OpenCV development environment. The camera was positioned in a vertical orientation, precisely in front of the intersection of the conveyor and belt. The lens of the camera was directed towards the central axis of the pipe molding part of the load-bearing area in order to take images. The acquired images underwent offline and real-time processing utilizing the OpenCV framework. Figure 1b depicts the physical diagram of the pipe belt conveyor within the experimental platform.

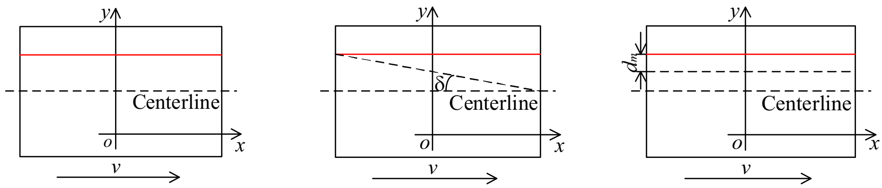
(a) experimental model (b) pipe belt conveyor

Figure 1. Experimental setup.

3. Methodology

3.1. Analysis of the Torsion in Conveyor Belt

The phenomenon of conveyor belt torsion in pipe belt conveyors can be classified into two distinct categories: deflection and overall offset. In the absence of considering the elastic-plastic deformation of the conveyor belt and the alteration of pipe diameter, it is possible to perceive the existence of an angle δ between the longitudinal lap edge of the conveyor belt and the centerline of the polygonal roller group (typically hexagonal), as depicted in Figure 2b. It is worth noting that the magnitude of this angle in the actual working condition is considerably small. The term "offset" in the context of a conveyor belt pertains to the longitudinal overlap between the conveyor belt's edge and the center line of the polygonal roller group, often hexagonal, aligned in a parallel manner in the horizontal direction. This offset is represented by a distance denoted as "d_m," as seen in Figure 2c.



(a) normal condition (b) deflection condition (c) overall offset condition

Figure 2. Schematic diagram of torsion.

3.2. The Process of Algorithms

To effectively identify the aforementioned types of conveyor belt torsion, it is crucial to possess the capability to precisely and expeditiously detect the boundary of the conveyor belt overlap. Subsequently, the inclination of the straight line formed by the overlap boundary and the longitudinal coordinates of the intersection between said straight line and the y-axis need to be extracted. These parameters, denoted as δ and d_m in Figures Figure **2**a and Figure **2**c, respectively, are of utmost importance in this context. Hence, this study presents a novel approach utilizing machine vision technology to identify the overlapping edge of the conveyor belt efficiently. The implementation steps of the program are illustrated in Figure 3.

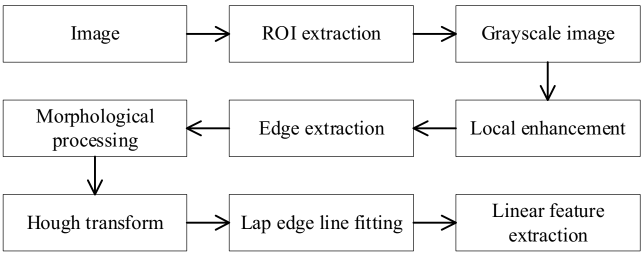


Figure 3. Flow of conveyor belt lap edge detection.

Digital image processing encompasses several operators that are employed for edge detection. Some often utilized operators include Canny, Prewitt, Sobel, and Robert, among others. While the Canny operator is known for its ability to produce high signal-to-noise output and accurately extract various edge information, the focus of this paper is specifically on extracting horizontal edges. In this context, the Prewitt operator is deemed suitable for identifying noise and grayscale gradient in the image [10]. Therefore, the Prewitt operator is employed in this paper to extract the edges of the image obtained through the region of interest (ROI).

Once the Prewitt operator has been applied to extract the edges, the subsequent step involves utilizing the Hough transform to identify straight lines. This method involves mapping the pixels in the picture onto a parameter space by means of developing a mathematical analytic formula for shape detection. The transformation process is then applied to the formula in the following manner:

$$y = kx + b\,,\ \ \rho = x\cos\theta + y\sin\theta \tag{1}$$

Where (x, y), k, b are the coordinates, slope, and intercept of points on a straight line within the Cartesian coordinate system, ρ , θ are used to respectively denote the distance from the line to the origin and the angle between the vertical line from the origin to the line and the positive direction of the polar axis in the parameter space, respectively.

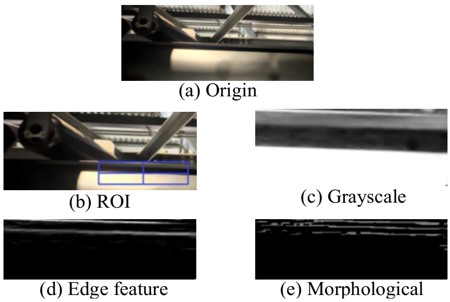
4. Result

The experimental technique outlined in Section 2 is implemented in this study by configuring the Python 3.11 environment in PyCharm and validating the algorithm using OpenCV 4.8.0.

4.1. Image Preprocessing

Figure 4a depicts the original image with a resolution of 1920×1080. The extraction of the ROI from the original image is necessary in order to address issues encountered during the operation of the conveyor belt, such as wear and tear and missing edges. This extraction method aims to enhance recognition accuracy and minimize the overall processing time. The region of interest (ROI) corresponds to the blue rectangular box depicted in Figure 4a. This same ROI is also illustrated in Figure 4b. Furthermore, Figure 4c displays the outcome of applying graying to the ROI region. The grayscale image can be subjected to image stretching in order to enhance the local contrast and accentuate the local characteristics.

Figure 4d displays the outcome of the Prewitt operator's edge detection. A series of image morphological processing techniques are employed to enhance the visibility of edge line contours and eliminate imperfections such as edge burrs and small bumps in Figure 4d. Specifically, an erosion operation is applied to the image.



(a) Origin (b) ROI (c) Grayscale (d) Edge feature (e) Morphological

Figure 4. Pretreatment results of conveyor belt image.

4.2. The Hough Line Detection

Following the aforementioned processing steps, a significant portion of irregular interference data, such as blocks present in the conveyor belt image, is effectively eliminated. Subsequently, the edge detection outcome undergoes the Hough transform, resulting in the extraction of a straight line, as visually depicted in Figure 5.

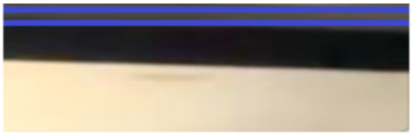


Figure 5. Process effect of Hough transform.

4.3. Data Collection and Collation

The methodology outlined in this scholarly article was employed to conduct a field test on the operational image of a pipe belt conveyor. The findings of this test are presented in Figure 6, where the upper and lower sides are depicted by red line segments representing the detected margins of the conveyor belt overlap. This paper calculates the positional characteristics (k, b) of the detected conveyor belt lap edge straight line in order to visualize its positional information. Table 1 presents these characteristics, with the coordinate system's origin located in the upper-left corner of the image. The x-axis extends to the right, while the y-axis extends downward.

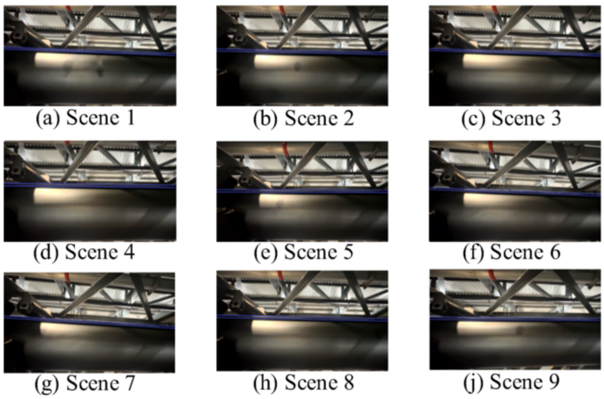


Figure 6. Actual operating effect diagram.

Table 1. Straight line position characteristics of conveyor belt lap edge.

Scene	k(Upper)	b(Upper)	k(Lower)	b(Lower)
1	0.038461537	498.3461834	0.038461537	521.3461834
2	0.020000001	515.7399693	0.020000001	541.7399693
3	0.032258064	519.6613401	0.032258064	543.6613401
4	0.010810810	481.2784105	0.010810810	510.2784105
5	0.016666667	557.1833435	0.016666667	583.1833435
6	0.037735852	591.7925177	0.037735852	617.7925177
7	0.062500002	549.9374827	0.062500002	575.9374827
8	0.020134229	548.5234433	0.020134229	578.5234433
9	0.008207934	608.8071126	0.008207934	638.8071126

Given the inherent instability of the field environment, characterized by factors such as fluctuating light intensity and vibrations during conveyor belt operation, it is postulated that the disparity between the detected pixel value and the manually calibrated actual value does not exceed a threshold of 3. This threshold is deemed to represent accurate detection. According to the data presented in Table 2, the disparity between the detected value and the true value falls within the margin of error. This finding suggests that the algorithm proposed in this study demonstrates a high level of precision in identifying the edges of the conveyor belt lap.

Table 2. Pixel-value difference of conveyor belt lap edge detection.

Scene	Pixel-value difference		Scene	Pixel-value difference	
	Upper sides	Lower sides		Upper sides	Lower sides
1	0	0	6	0	0
2	0	0	7	1	1
3	0	0	8	1	2
4	1	0	9	2	0
5	0	0			

5. Conclusions

This work examines the issue of conveyor belt torsion in pipe belt conveyors. It analyzes the correlation between the longitudinal lap edge and conveyor belt torsion and introduces a novel technique for detecting the lap edge of the conveyor belt using machine vision. The technique utilized in this study is founded upon the principles of Prewitt edge detection and Hough straight-line identification. This approach enables the direct extraction of positional characteristics of straight lines, hence streamlining the analytical methodology.

Empirical evidence demonstrates that the algorithm in question exhibits a notable degree of reliability and stability. The visualization of lap edge data on conveyor belts holds significant importance in the investigation of conveyor belt torsion law and detection. Furthermore, it provides valuable guidance for ensuring the safe and efficient operation of pipe belt conveyors. Furthermore, the subsequent stage involves the determination of the conveyor belt torsion angle by utilizing the longitudinal lap edge straight line characteristic, followed by the assessment of the extent of torsion in the conveyor belt.

Acknowledgement

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