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Laser-based on-line machine vision detection for longitudinal rip of conveyor belt

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ABSTRACT

Conveyor belts are widely used in mines, power plants, ports to transfer lump materials or products. They are prone to longitudinal rip in operation, which generally results in a stoppage of production, even causes belt break or longitudinal rip accidents for lacking the detection and treatment in time. It has long been recognized that a conveyor belt monitoring system for early detection of longitudinal rip is desirable. Based on the line laser detection technology, an on-line detection method is investigated to accomplish conveyor belt longitudinal rip detection rapidly and accurately, and the monitoring system utilizing machine vision technology is designed in this paper. A red line laser stripe projects on the surface of conveyor belt, and the image obtained by the corresponding CMOS camera is processed and analyzed to judge whether there is a rip on the belt surface or not. Firstly, the red stripe region of interest is segmented. Then, the skeleton representation of the stripe center and the binary image are obtained by maximum pixel value method. And the abnormal pixels, which correspond to the rip position, are detected by the neighborhood search method using the difference algorithm and the curvature method. Finally, the fault region is marked. Experimental results show that the proposed method is fast and high precise. This on-line detection method and system can effectively resolve the problem of conveyor belt longitudinal rip detection, and can be used during production hours with a full conveyor load.

1. Introduction

Conveyor belts are widely used in mines, power plants, ports and warehouses to transfer lump materials or products [1,2]. They are prone to longitudinal rip in operation, which generally results in a stoppage of production, even causes belt break or longitudinal rip accidents for lacking the detection and treatment in time. It has long been recognized that a monitoring system for early detection of longitudinal rip in conveyor belts is desirable [3].

At present, a variety of conveyor belt monitoring systems are developed, such as the mechanical system [4], electromagnetic sensor detection system [5–7], ultrasonic belt detection system [8–10], and radio frequency identification-based detection system [11,12]. Among them, the old and popular system is hanging a wire under the belt. If a foreign body penetrates the belt and moves that wire in the running direction of the belt, a stop of the motor is induced. Indeed, the penetrating

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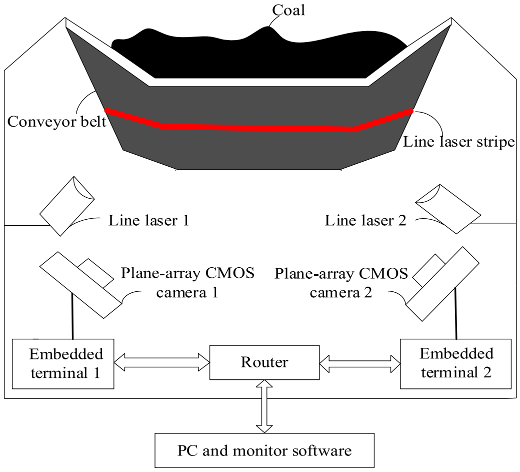


Fig. 1. Sketch map of laser-based longitudinal rip machine vision monitoring system.

body has to emerge long enough to contact and move the string. If the penetrating body is stuck somewhere and continuing to rip the belt, which is usually happening, the system cannot react[4,10]. The typical electromagnetic sensor belt rip detection system is induction loops/coils in combination with external transmitters and receivers. The loops are vulcanized into the belt or attached to the conveyor belt [6]. If a sensor loop is cut by a foreign body, no signal is transferred by the loop anymore - the receiver sensor does not get a signal and shuts off the conveyor drive. Sensor loops/coils are sensitive parts, which may trigger off false alarm. Also if high grade iron ore like magnetite, with very strong ferromagnetic properties, is being conveyed, the rip detection system may not work properly [5–7]. The ultrasonic belt detection system is generally used to transmit ultrasonic signals directly by conveyor belt, but the signal coupling is very difficult, and the vibration or impact of the conveyor belt will produce misjudgment [8–10]. Furthermore, this system does not work equally well to all types of belting, for this reason it require sample of the target belting for evaluation [8].The radio frequency identification-based rip detection system utilizes UHF RFID tags. And the UHF RFID tags incorporate the use of electromagnetic or electrostatic coupling in the radio frequency portion of the spectrum to communicate to and from the tag. So it also has the disadvantages of the electromagnetic sensor detection systems [11].

Because these systems listed above are imbedded into or attached to the conveyor belt, all of them have a limited fault detection capability. And none of the system has been used successfully in practice to detect longitudinal rip in conveyor belts. However monitoring conveyor belts by the machine vision technique can improve the detection efficiency and precision, so it has attracted much attention.

Ponsa et al. developed a computer vision detection system to detect defect of belts at a speed rate up to 2 m/s by using plane array camera to capture images [13]. Qi Junyan et al. [14] developed a machine vision detection system of conveyor belt longitudinal rip based on LabVIEW, using the multiple channel Planar Array CCD camera to capture the image, and using USB or 1394 interface for data transfer. Zhang Xi et al. [15] proposed a detection method on longitudinal rip based on USB plane array camera and ARM, and proposed image differential method for detecting the position of longitudinal rip whether there is the light transmission or not. Yang Yanli, Zhang Wei, Yang Yang, Li Jie, Qiao Tiezhu et al. separately proposed the machine vision method or algorithm for detecting longitudinal rip based on line array or planar array camera [3,16–19]. CBM, an international organization based in Australia, developed a longitudinal rip machine vision detection system [20].

For the above methods or systems based on the machine vision technique, the processed image is the whole collected image, and the image information of the conveyor belt is rich but the conveyor belt longitudinal rip characteristics information is unobvious, which directly affects the extraction of fault information and will finally lead to misjudge. So both the accuracy and speed of the longitudinal rip fault diagnosis of the conveyor belt can't be guaranteed.

In order to improve the real-time ability and accuracy, a new on-line machine vision detection method for conveyor belt longitudinal rip based on line laser is proposed, and the monitoring system is designed in this paper.

2. Laser-based machine vision monitoring for longitudinal rip

The sketch map of the laser-based on-line machine vision monitoring system for longitudinal rip as show in Fig. 1. The system mainly includes plane-array CMOS cameras, line laser sources, embedded terminals, PC and monitoring software and so on. The line laser sources and plane-array CMOS cameras are arranged between the upper and lower belts. The red laser stripe generated by line laser projects on the back of the upper conveyor belt, and it is vertical to the conveyor belt running direction. Because of the short imaging distance (about 35 cm), wide belt width (more than 100 cm) and vaulted shape of conveyor belt, several pairs of plane-array CMOS cameras and line laser soures along the width direction of conveyor belt can be placed side by side to cover the whole width of conveyor belt. For the 1.2 m wide(i.e. the width of the conveyor

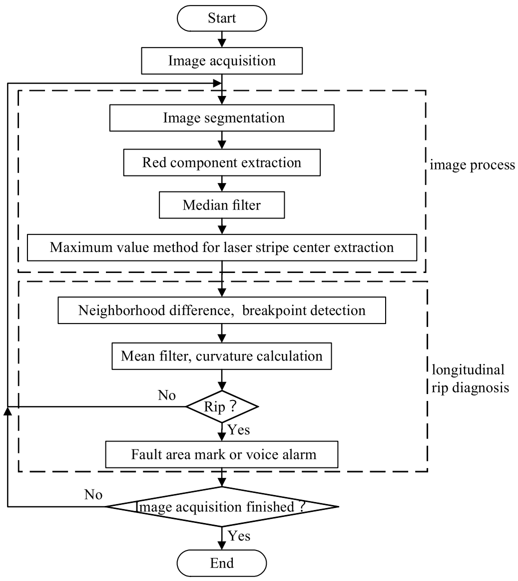


Fig. 2. The flow diagram of conveyor belt longitudinal rip detection.

belt) conveyor belt, we use two pairs of CMOS cameras and laser soures. The conveyor belt images which contained the laser stripe are captured by cameras. And the embedded processing terminals are used to collect, process and analyze the conveyor belt images. When the longitudinal rip is detected, the voice alarm is performed, and the longitudinal rip images and alarm signals are sent to the PC through Ethernet for the monitoring software displaying the images and verifying the fault.

In view of the fact that the long-term harsh environments of conveyor belts, uneven illumination, dust, coal cinder will have a greater effect on image quality. The sealed cowling has been installed below the upper belt, which is used to protect the cameras and laser sources are not affected by dust and water. At the same time the sealed space also effectively suppress the image noise caused by dust and cinder. And two belt cleaning equipment are installed ahead and behind the sealed cowling, thus we can clear the coal and coal slime adhered to the surface of the upper belt in order to avoid the misidentification of longitudinal rip fault.

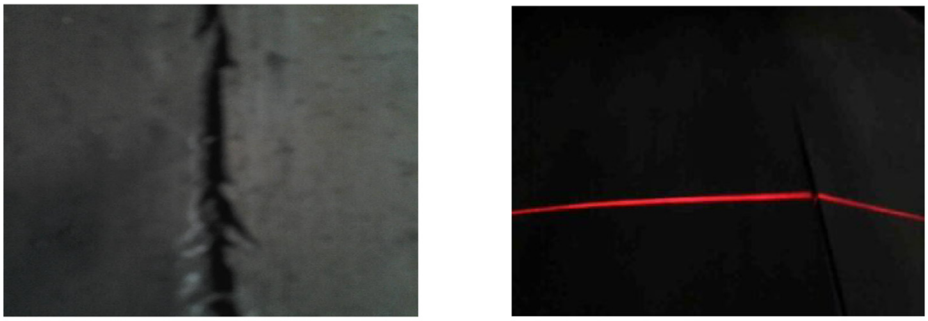
The flow diagram of conveyor belt longitudinal rip detection is presented in Fig. 2. The conveyor belt longitudinal rip detection can be divided into two processes: conveyor belt image process and longitudinal rip diagnosis. In the conveyor belt image process, firstly, the red stripe region image is segmented from the original image; secondly, the red component is extracted as the gray-scale image. Then the median filter is applied. Lastly, the skeleton representation of the stripe center and the binary image are obtained by maximum pixel value method. In the longitudinal rip diagnosis process, the abnormal pixels, which correspond to the rip position, are detected by the neighborhood search method using the difference algorithm and the curvature method. When the fluctuation (hide in neighborhood difference values and curvature values) of laser stripe at a position is greater than a threshold, it means that there is a jump distortion region of the line laser stripe image, and it can be considered as suspicious rip. In order to reduce the error rate, the final result is obtained using the two continuous image's judgments, i.e. if there are two rip judgments then determine it as rip fault. Then the fault area is marked or voice alarm when rip is detected.

3. Conveyor belt image process

As for the long term harsh environments of conveyor belts, load capacity, scratches from the iron and steel scrap or coal gangue and other obstacles, all of those may cause longitudinal rip fault, which will lead to production halts, transporting materials losses, equipment damage, some casualties, and tremendous economic losses. Through analyzing the conveyor belt longitudinal rip characteristics information, which compared with the intact conveyor belt image, the surface features have obvious differences. For fast and accurate extraction of characteristics information, the method of image analysis is proposed. The introduction of line laser, all kinds of the conveyor belt longitudinal rip characteristics extraction is transformed into the image of laser stripe center extraction. This will enhance both the accuracy and effective of detection.

Fig. 3 shows two conveyor belt longitudinal rip original images captured by cameras. They are respectively based on the white light irradiation and red line-laser irradiation.

From the Fig. 3, we can see that the image based on line-laser is much easier for longitudinal rip detection by machine. Because the image information of the image based on white light is rich, which directly affects the extraction of fault information and will finally lead to misjudge, and the whole image should be processed for the longitudinal rip detection.



(a) image based on white light (b) image based on line-laser

Fig. 3. Original images captured by cameras.

Fig. 4. Gray-scale image.

Fig. 5. Median filter result.

The introduction of line laser, all kinds of the conveyor belt longitudinal rip characteristics extraction is transformed into the image of laser stripe center extraction. This will enhance both the accuracy and effective of detection. So we use the laser-based machine vision method in this paper.

In view of the fact that the complexity environment of coal mine conveyor belt uneven illumination, the interference of coal dust and so on, it is necessary to preprocess the conveyor belt image for the sake of noise suppression. In order to improve the real-time of the system, a simple and efficient image processing algorithm was proposed in this paper.

3.1. Image segmentation, red component extraction and median filter

Firstly, the red stripe region of interest is cropped to 800×80 pixels image from the original image of 800×600 pixels, which aims to eliminate the redundancy areas of image so that reduce the amount of data processing and improve the speed of image processing.

The original image is the RGB colour image, and it is composed of three components: red, blue and green. Meanwhile, the laser stripe is red. So the red component of the image is extracted as the grayscale using the expression

$$f(x, y) = R(x, y) \tag{1}$$

where $f(x, y)$ represents a gray-scale image, $R(x, y)$ is the red component image of the original image. Fig. 4 shows the gray-scale image extracted from the Fig. 3(b).

The laser stripe image has the false contour and noise caused by the uneven illumination and CMOS detector. Median filter is a kind of neighborhood operation, the output of the median filter is determined by the intermediate value of the neighborhood image. For the limit value (a large difference between the pixels with the surrounding gray value) it is not nearly as sensitive as the average value. Through compare and contrast analysis, the 3×3 median filter is applied in this paper. The isolated noise points can be eliminated, and less fuzzy can be generated in the image. And this filter may not only effectively suppress in image noise, but also preferably maintain image characteristic information. Fig. 5 shows the median filter result for the Fig. 4.

Fig. 6. The skeleton of the stripe center.

3.2. Extracting the laser stripe center image based on maximum pixel value

Take a gray-scale image of size $M \times N$ as an example, which is expressed as

$$f(x,y)=\begin{pmatrix} f(1,1) & f(1,2) & \dots & f(1,N) \\ f(2,1) & f(2,2) & \dots & f(2,N) \\ \vdots & \vdots & \vdots & \vdots \\ f(M-1,1) & f(M-1,2) & \cdots & f(M-1,N) \\ f(M,1) & f(M,2) & \dots & f(M,N) \end{pmatrix} \tag{2}$$

where $f(x, y)$ represents the gray-scale image. Firstly, the maximum pixel value f_{ym} of each column (y = 1,. . ., N) is calculated, so the maximum value matrix MV is obtained, which is expressed as

$$MV = \left(f_{1m}f_{2m}f_{3m}\cdot\cdot\cdot f_{(N-1)m}f_{Nm}\right) \tag{3}$$

Secondly, finding the pixel value of the ordinate of each column which equal to the maximum pixel value f_{ym}. ①If a column has two pixel values equal to the maximum pixel value f_{ym}, for example: $f(x_1, y) = f(x_2, y) = f_{ym}$, where $0 \le x_1 < x_2 \le M$, then compared $f(x_1 - 1, y)$ with $f(x_1 + 1, y)$. If $f(x_1 - 1, y) \ge f(x_1 + 1, y)$, the ordinate of the maximum value $xm = x_1$; if $f(x_1 - 1, y) < f(x_1 + 1, y)$, $xm = x_2$. ②When the pixel values of a column n pixels (n>2) are equal to the maximum value f_{ym}, then the ordinate of the maximum value xm is calculated by

$$xm = \text{round}\left(\frac{\sum_{i=1}^{n} x_i}{n}\right) \quad (i = 1, 2, 3, \ldots.n; n > 2) \tag{4}$$

where round represents round towards nearest integer.

Lastly, using the pixel value $f(xm, y) = 255$ to get the skeleton of the stripe center. The image of stripe center skeleton is presented in Fig. 6.

4. Longitudinal rip diagnosis

4.1. Neighborhood difference

According to the method of maximum pixel value, the trend of the laser stripe center is obtained, and then we can use the method of neighborhood difference to judge the conveyor belt longitudinal rip region. The skeleton image obtained by the method of maximum pixel value can be represented as

$$h(x,y)=\begin{pmatrix} h(1,1) & h(1,2) & \dots & h(1,N) \\ h(2,1) & h(2,2) & \dots & h(2,N) \\ \vdots & \vdots & \vdots & \vdots \\ h(M-1,1) & h(M-1,2) & \cdots & h(M-1,N) \\ h(M,1) & h(M,2) & \dots & h(M,N) \end{pmatrix} \tag{5}$$

Firstly,extracting the ordinate of each column pixel value $h(xm, y) = 255$ in the skeleton image to make up an one-dimensional array $LP = (xm_1, xm_2, xm_3, \ldots\ldots., xm_N)$ whose elements represent the ordinate of the maximum pixel values. Secondly, the neighborhood difference is caculated at one pixel interval, the difference value is calculated by

$$d = xm_{y+2} - xm_y \tag{6}$$

If at a position $\left|d\right| \ge T1$ (e.g. $T1 = 2$), it is considered as the suspicious fault region. The distribution of the neighborhood difference values as shown in Fig.7.

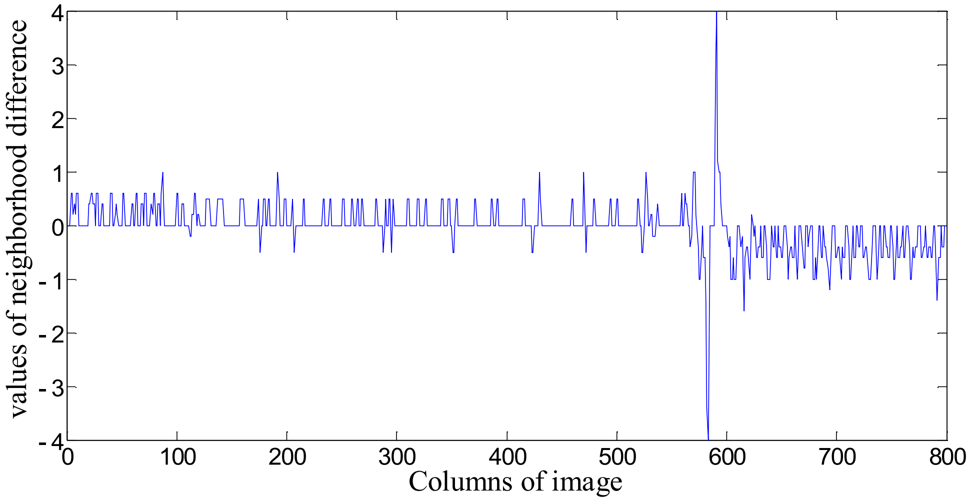


Fig. 7. The distribution of the neighborhood difference values.

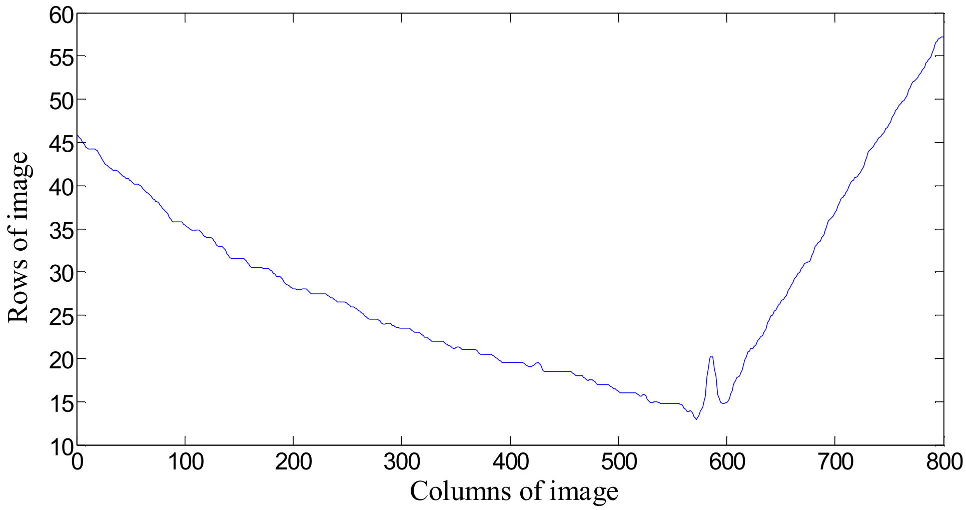


Fig. 8. The filtered curve.

4.2. Mean filter

Arithmetic mean filter is the simplest filter of the mean filter. Let S_{xy} represents the set of coordinates in a rectangular window (neighbornhood) of size $m\times n$, centered at point (x, y). The value of the restored image $\hat{f}$ at point (x, y) is simply the arithmetic mean computed using the pixels in the region defined by S_{xy}. In other words,

$$\hat{f}(x, y) = \frac{1}{mn} \sum_{(s,t)\in S_{xy}} f(s, t) \tag{7}$$

The arithmetic mean filter simply smoothes the local variations in an image, and noise is reduced as a result of blurring.

In this paper, the mean filter of 1×5 is adopted to the one-dimensional array *LP*. The result is much more convenient for calculating difference and curvature. The filtered curve is shown as Fig. 8.

4.3. Curvature calculation

When the conveyor belt rips, most of the time, it has no significant cracks. But because of the tension, the belt is severely deformed and twisted. So extracting the line laser characteristics information and analyzing the skeleton image curvature trends can detect the rip fault.

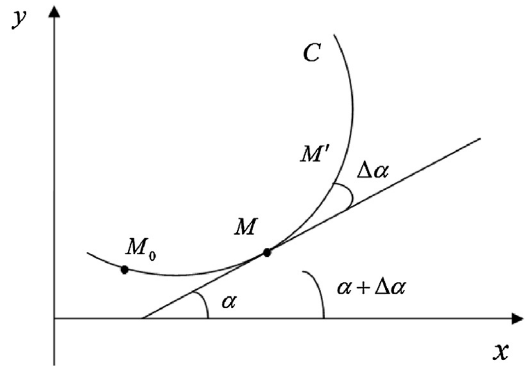


Fig. 9. Curvature calculation.

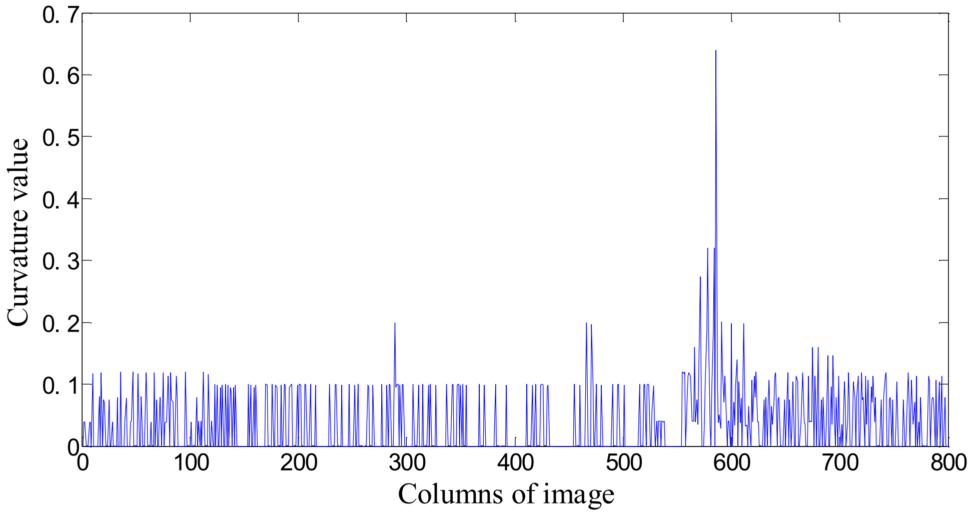


Fig. 10. The distribution of the curvature value.

The curvature is the rotation rate which angle is divided by the arc length along the tangent direction of a certain point on the curve, and defined by differential. The degree of the curve deviates from the straight line, the greater the curvature, the greater the degree of the curve. By calculating the curvature of fitting curve of the line laser skeleton image, we can realize the jumping distortion position detection.

4.3.1. *Definition and calculation of curvature*

As shown in Fig. 9, supposing that the curve C is smooth, Δs is the arc length from point M to M' on the curve C, and the angle of tangent is $\Delta\alpha$.

$\bar{K} = \left|\frac{\Delta\alpha}{\Delta s}\right|$ is described as the mean curvature of the arc segment $MM\prime$, and $K = \lim_{\Delta t \to 0}\left|\frac{\Delta\alpha}{\Delta s}\right|$ is called the curvature of the point M on the curve C, under the condition of $\lim_{\Delta t \to 0}\frac{\Delta\alpha}{\Delta s} = \frac{d\alpha}{ds}$.

4.3.2. *Calculation the curvature of the laser stripe center skeleton*

The curve curvature through the curvature calculation formula is simple and feasible when the curve equation is known. But for the curve which is composed of the discrete points in the digital image, the curvature formula is complex and difficult to be realized. In this paper, the curvature of the fitting curve of the skeleton image is calculated as

$$K = \lim_{\Delta s \to 0}\left|\frac{\Delta\alpha}{\Delta s}\right| = \left|\frac{d\alpha}{ds}\right| = \frac{\left|y''\right|}{\sqrt{\left(1+y'^2\right)^3}} \tag{8}$$

where y' is the first derivative, and y'' is the second derivative.

The curvature distribution of the filtered curve in Fig. 8 is shown in Fig. 10. If the threshold of curvature is $T2$ (e.g. $T2 = 0.5$), when the curvature K at a position is greater than $T2$, it means that there is a jump distortion region of the line laser stripe image, and it can be considered as the suspicious region of longitudinal rip.

Fig. 11. Belt conveyor for test in laboratory.

Fig. 12. The monitoring system.

5. Experiment and results

5.1. Experimental steps and parameters

The steps of conveyor belt longitudinal rip detection algorithm are showed in Fig2. The size of the laser stripe image of conveyor belt which collected through the plane array camera, is 800 × 600.Then the red stripe region of interest is cropped to 800 × 80 pixels image, and the red component is selected as the gray-scale image. After the 3 × 3 median filter, the stripe center is determined by the maximum value of each column pixel value. When the value of neighborhood difference is greater than the threshold $T1$ ($T1 = 2$ in this paper), it can be considered as the breakpoint. In the Mean filter and curvature calculation processing, the 1 × 5 mean filter is performed, an $T2 = 0.5$.

The belt conveyor for test in laboratory is shown in Fig. 11. And the monitoring system system for test is shown in Fig. 12. Lenovo Z485 notebook with AMD A8-4500M APU, 6GB memory and Windows 7 operating system was used. And the program software is MATLAB2012 and Visual Studio 2012. The embedded processing terminal uses S3C2440 microprocessor.

5.2. Experimental results

Fig. 13 shows the experimental illustration of conveyor belt longitudinal rip detection algorithm.

Simulation by using Matlab software and C# programming language showed that the algorithm is effective. The processing time (image process and longitudinal rip diagnosis time in the Fig. 2) for the image that contains the longitudinal rip is 51.736 ms using C#. And the time of embedded processing terminal is about 300 ms. Considering we use the two continuous images to obtain the final judgment, when the conveyor belt is running at 5 m/s, the 3.0 m length longitudinal rip of the conveyor belt at the monitoring point can be successfully detected as using this embedded processing terminal. It is fast and good enough for the conveyor belt longitudinal rip safety monitoring. So the proposed method can be used in either the PC software for the displaying the images and verifying the fault conveniently or the embedded processing terminal to facilitate multi-point integration and reduce the system price.

In order to better judge whether there is a rip on the surface of conveyor belt or not, by analyzing the trend of the skeleton representation of the stripe center, this paper unites two methods to judge the position of longitudinal rip, that are neighborhood difference and the curvature method.

For testing the effectiveness of the conveyor belt longitudinal rip detection algorithm that we proposed, the skeleton method is also used in the process of extracting the stripe center to compare with the maximum value method. The comparison results are shown in Fig. 14.

From Fig. 14, we can see that the method proposed in this paper is better than the skeleton method. A large number of experiments show that the maximum pixel value method extracting the skeleton of the stripe center consistent with the original image, but the change tend between the skeleton method and the original image is very different, so it is difficult to judge the position of conveyor belt longitudinal rip using the skeleton method. Furthermore, the computational complexity of the algorithm proposed in this paper is smaller than that of the other method.

As we know, all systems using visions are very sensitive to environmental conditions, particularly water and dust conveyors at work. Fig. 15 shows the environmental experiment result of the monitoring system.

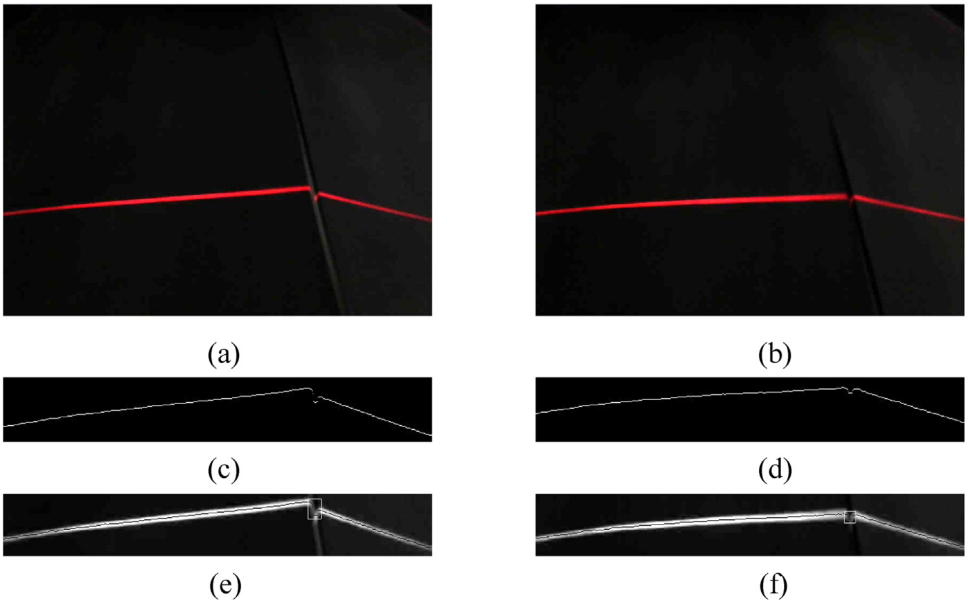


Fig. 13. Illustration of conveyor belt longitudinal rip detection algorithm.(a)(b)are the original image.(c)(d) are the skeleton representation of the stripe center and the binary images are obtained by maximum pixel value method.(e)(f) are the final result image in which fault region is marked.

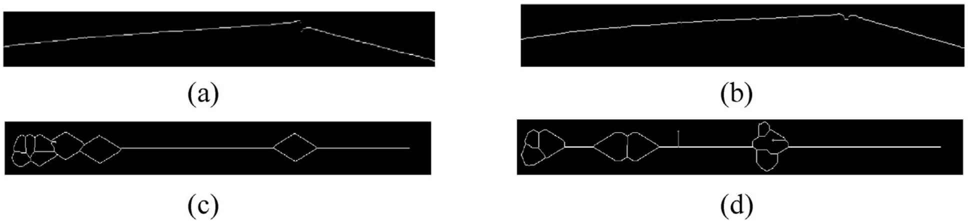


Fig. 14. The comparison results of extracting the stripe center. (a)(b) are the skeleton representation of the stripe center by the maximum value method.(c)(d) are the skeleton representation by the skeleton method.

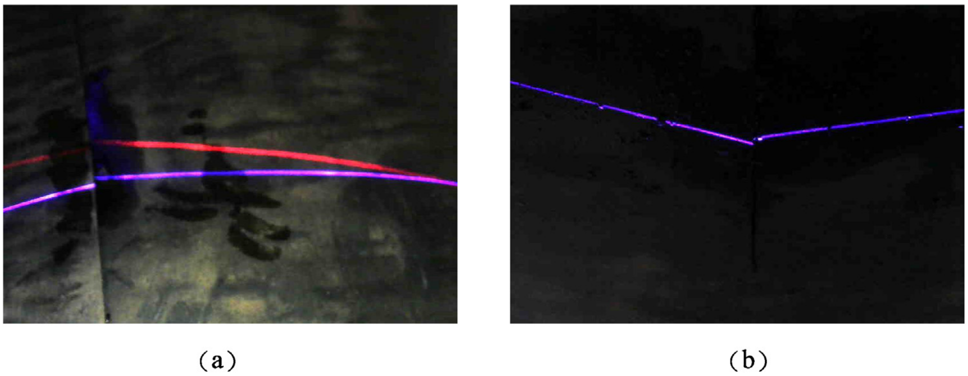


Fig. 15. Environmental experiment result of the monitoring system. (a) There is water on the conveyor belt (the above line is the red laser light while another is blue- violet laser light). (b) Cinder and coal slime adhered to the surface of conveyor belt (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

From Fig. 15(a), we can see that the water can affect the brightness of the laser line, and the red laser is more easily absorbed by water than the blue-violet laser. So it is better to use the blue- violet or blue laser in the case of water. Fig. 15(b) shows that cinder and coal slime will cause the laser line to break, so that the longitudinal rip detection is misjudged. In practice, therefore, the conveyor belt cleaning equipment should be installed ahead the monitoring system to remove the cinder and coal slime on the conveyor belt surface, and the comprehensive judgment is carried out by the two continuous images, in order to avoid misjudgment.

6. Conclusion

In this paper, based on the line laser detection technology, an on-line detection method is investigated to accomplish conveyor belt longitudinal rip detection rapidly and accurately, and the monitoring system utilizing machine vision technology is designed. Experimental results show that the proposed method is fast and high precise, and the processing speed is millisecond. This on-line detection method and system can effectively resolve the problem of conveyor belt longitudinal rip detection, and has broad application prospects in the field of coal and many other fields.

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