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Integrative binocular vision detection method based on infrared and visible light fusion for conveyor belts longitudinal tear

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ABSTRACT

Real-time and reliable detection of conveyor belt longitudinal tear is an important task in mining operations. This paper presents a novel method of Integrative Binocular Vision Detection (IBVD) to detect the longitudinal tears of conveyor belts. Based on infrared and visible fusion, the IBVD sensor device collects the fusion images of the belt. After extracting the tear features by projection method, the progress of potential tears can be evaluated and the tears can be identified. The IBVD method is verified by an experiment platform fulfilling the acquisition, pro-processing and analysis of fusion images for tear detection. The fusion image processing time is less than 18 ms, which satisfies the requirement of real-time online monitoring. Compared to the individual measurement technique of either infrared detection or visible light detection, the average accuracy of the IBVD method reaches up to 96%, the IBVD method is more reliable in tear detection.

1. Introduction

Belt conveyor is an important transport equipment in coal mining. There are many various kinds of belt conveyors to transport the coal, such as pipe belt conveyor [1], conventional through belt conveyor [2] and so on. Pipe belt conveyor is emerging in recent years, which can meet the requirement of environment protection. Conventional through belt conveyor is usually used in the underground coal mining to transport coal. Among the belt conveyor, conveyor belt is the most crucial part to undertake the material. Conveyor belt longitudinal tear may happen at the loading point of belt conveyor, such as the outlet of a loading chute or hopper, the discharge port of a belt conveyor. In mining operations, the hard impurities [3] often mixed in coal, like coal gangue and metal materials, may damage the conveyor belt in the mode of longitudinal tears. Namely, longitudinal tear may be caused instantaneously at the loading point and discharge point by the penetration or puncture of the hard impurities into the belt, or the progress of the scratch on the surface of the belt. Compared with other problems in conveyor belt transportation process such as transversal tear of conveyor belt, longitudinal tear needs a wider repair range and can cause catastrophic damage, which may lead to the shutdown of the overall mining process. That is very expensive, not only for the maintenance of the equipment but also for production. Hence, the longitudinal tear of conveyor belt can lead to very expensive downtime of mining equipment and production, can cause a huge economic loss for industrial companies, and measurement technique of conveyor belt longitudinal tear is an important issue. We need to detect the longitudinal tear in real-time when the tear occurs so that the operation of belt conveyor can be stopped as soon as the tear is detected to avoid losses. For the past few years, computer vision measurement technology is widely used in many fields, such as fire detection [4,5], intelligent transportation [6–8], food processing industry [9] and military field [10]. It has the characteristics of automation, accuracy and intelligence. It aims to duplicate the effect of human vision by electronically perceiving and understanding an image. The image acquisition is real-time, reliable and can work online through computer vision. In this paper, therefore, the belt measurement technology based on computer vision is investigated to detect longitudinal tear of conveyor belts.

Currently, computer vision measurement technology has become an important direction in belt fault detection because it can improve the detection efficiency and precision. For example, Tessier [11] proposed an online visual inspection method for

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conveying belt by using plane array camera to capture images. Miao [12] proposed an On-line conveyor belts inspection method by using several Charge Coupled Device (CCD) cameras to collect conveyor belt images. Additionally, Zeng [13] proposed a method to detect the coal belt tearing based on digital signal processing. In this method, the CCD area array camera is used to collect the conveyor belt images and the image signal is processed by programming with C++ and MATLAB. In Ref. [14], a conveyor belt detection system is developed by Carnegie Mellon University for quality monitoring of belt splices. However, the detection technique based on machine vision is still at its preliminary stage, and it is limited in practical application due to harsh environment in coal mine. Because of the harsh environment in coal mine, the visible light CCD is difficult to identify the tear of conveyor belts. Furthermore, taking into account the working conditions of conveyor belts and the processing of the longitudinal tear detection, there are some key technical issues have not yet to be resolved, such as the technology of high-quality image acquisition, high-speed image processing, interested area extracting, reliable tear identification, and so on. These issues will affect the accuracy and reliability of the tear detection. Therefore, a new longitudinal tear detection method is required for conveyor belt that is real-time, highly accuracy, reliable and can work in the harsh environment.

As mentioned in the first paragraph, the longitudinal tear may happen at the loading or discharge point. In the process of tear, the belt is scratched and punctured along with temperature increasing, and the belt is penetrated along with the temperature rise and light transmission. Therefore, visible light and infrared can be applied together. Visible light CCD [15,16] and infrared CCD [17,18] are two kinds of visual sensors that can both realize non-destructive testing. Visible light sensor can provide an image signal with the characteristics of abundant detailed object information and clear texture feature, and the visible light image is more consistent with human visual characteristics. Nevertheless, the visible light can only response to a very narrow visible light band. In the faint light, the visible light sensor cannot obtain a clear image. Additionally, just when the conveyor belt is penetrated and the longitudinal tear is formed, the visible light tearing image can be collected by the visible light sensor, which is mounted between the upper and lower belts. Therefore, the visible light image can only show the eventual tear but cannot show the scratch process. Infrared sensor can capture infrared radiation of the target. Any substance which temperature above absolute zero can produce infrared radiation. Infrared radiation can through dust and fog. Therefore, the infrared sensor can well utilized in the low-light level (even in the dark) and other harsh environment. Moreover, when the belt is scratched by the sharp edge or the belt is penetrated by the metal anchor, an amount of heat is generated at the scratched and penetrated place of the belt. The belt place of higher temperature can radiate more infrared light which is sensitive to an infrared sensor, then the infrared tear image can be collected. Therefore, the infrared image can show the whole process of the longitudinal tear and progress of potential tears can be evaluated. Due to the infrared image acquisition is based on temperature by infrared sensor, the infrared image cannot show the detail information of conveyor belt longitudinal tear, and the resolution of infrared image is not high. The reliability of infrared detection needs to be improved.

Based on the above imaging characteristics of visible light sensor and infrared sensor, the individual technology of visible light only detect the tear without knowing the progress, and the individual technology of infrared can only detect either scratch or tear based on temperature. In order to compensate the deficiency of both individual technology, the two technology can be integrated. Integrating the complementary characteristics of infrared and visible light, we propose a novel longitudinal tear detection method based on infrared and visible light fusion for conveyor belts. In this paper, the proposed detection method is named Integrative Binocular Vision Detection (IBVD) method. It is a new method to detect the longitudinal tear of conveyor belts in this area. In the IBVD method, the fusion image of conveyor belt is collected by the proposed IBVD sensor device, which based on the infrared and visible fusion. In the IBVD sensor device, the beam splitter prism is used to project the coaxial light incident from the same lens to the infrared CCD (Charge Coupled Device) and visible light CCD, the infrared and visible light of the same point is received by the infrared CCD and visible light CCD simultaneously. The use of the proposed IBVD method makes detection results more accurate and can decrease the influence on accuracy by the complex underground environment. The remainder of the paper is organized as follows: the Section 2 presents the detection method. Then, both the experiment and analysis are provided to verify the accuracy and efficiency of the proposed method in Section 3. Finally, the overall conclusions are given in Section 4.

2. The description of the IBVD method

The IBVD method consists of three major parts, fusion image acquisition, image processing and tear detection. First, IBVD sensor device is used to collect fusion image. Second, the image enhancement algorithm and image segmentation algorithm are used to process the image in order to extract tear feature better. Finally, the tear feature is extracted by the detection algorithm and the progress of potential tears can be evaluated and tears can be identified. Every part is introduction in detail in the following section.

2.1. Fusion image acquisition

The acquisition of belt image is the key part of longitudinal tear detection of conveyor belts. High-quality images help to increase the efficiency and reliability of the tear detection. Taking into account the harsh environment in coal mine, the IBVD sensor device for infrared and visible fusion is proposed to collect the fusion image of belt. In the sensor device, there are two parts: signal acquisition unit and signal fusion unit. The beam splitter prism is selected as the light splitting element, which is made up of transparent material. Through the single lens and beam splitter prism, the visible light and infrared are transmitted into two sensitive element, one is the visible CCD, another is the infrared CCD. Then the infrared and visible signal are fed to the signal fusion unit, and the fusion image will be obtained. The overall block diagram of image acquisition is schematically shown in Fig. 1.

As shown in the diagram of the image acquisition, the infrared radiation of object and the visible light are focused on the prism through a single lens. Then, through the beam splitter prism, the visible light and infrared are transmitted into two sensing elements, visible light imaging chips and the infrared imaging chips. In the proposed sensor device, the beam splitter prism is used to realize the beam splitting by coating "a" and "b" surfaces with the beam-splitting film, which working in two wide spectral ranges (high-transmissivity at 400–700 nm, high-reflectance at 8–12 um). With the beam-splitting film, the two rectangle surface "a" and "b" can transmit the visible bands and reflect the infrared bands. The surface "a" can transmit the visible and reflect the infrared, afterwards, the infrared is reflected once more by the surface "b". Finally, the infrared is received by the infrared sensing element, at the same time, the visible light is received by the visible light sensing element. After reflection or transmission into the sensing element by the beam splitter prism, the infrared and visible light are converted to corresponding electric signal respectively