Effective Conveyor Belt Inspection for Improved Mining Productivity Semi-Annual Technical Progress Report

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Abstract

This document details progress on the project entitled “Effective Conveyor Belt Inspection for Improved Mining Productivity” during the period from November 15, 2004 to May 14, 2004. Highlights include fabrication of an improved LED lightbar, fabrication of a line-scan sensor head for the Smart-Camera based prototype, and development of prototype vulcanized splice detection algorithms.

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1 Introduction

This report presents technical progress on the Effective Conveyor Belt Inspection for Improved Mining Productivity project, funded under U.S. Department of Energy award number DE-FC26-04NT42086.

The project proposal describes the first-year objective as follows:

Phase I (Year 1) Objective

Expand the capability of the belt inspection system to detect vulcanized splices. The Phase I objective will be to identify and test sensors capable of surviving the mining environment and the detection hardware to precisely locate the sensor. In addition, we will develop a prototype version of the image capture and lighting hardware that will form the heart of the low cost automated belt inspection system.

The following sections describe progress toward this objective.

2 Executive Summary

This 6-month period includes several noteworthy achievements, which are summarized here. More detailed discussion of these accomplishments is presented in sections 3, 4, and 5.

Prototype vulcanized splice detection algorithms running Two prototype algorithms for vulcanized splice detection have been developed, and are currently under test.

LED light bar research and manufacture evaluation completed Significant effort has gone into designing an LED light bar which improves both light quality and system ruggedness.

Full-resolution infrared belt images acquired at two mine sites Software for acquisition of continuous full-resolution thermal images has been completed, and belt scans have been acquired at two mine sites.

Analysis of infrared belt images for applicability to splice detection and integrity testing has been completed The infrared image scans have been carefully analyzed for thermal patterns indicating the presence and/or condition of vulcanized splices.

Additional full-resolution conventional image recordings have been acquired CONSOL Energy's Robinson Run mine, and at a 2nd belt in the Blacksville mine. Full resolution scans of additional belts have been acquired to provide a wider and more varied dataset for vulcanized splice detection algorithm development.

Printed circuit board design and fabrication for a CCD line scan camera using Perkin Elmer sensor head completed Hardware design for the low-cost smart-camera based BeltVision system is progressing apace.

Imaging in continuous mode with the newly fabricated camera has been demonstrated over 1394 This not only highlights the correct functioning of the newly developed hardware, but also illustrates that the no cumbersome, high-dollar, frame-grabber card is required.

12 Developmental systems currently deployed An additional 2 pre-production (PC-based) low cost systems have been deployed underground. The deployed development and pre-production systems have cumulatively inspected more than 1.5 million miles of belt.

Beitzel Corp is continues to produce and sell a very low volume of the preproduction low cost systems The logistics of deploying and supporting a system in mines dictate a cautious approach. Beitzel Corp is also continuing to survey belt managers for input into desired system features and potential new target markets.

3 Infrared Detection of Vulcanized Splices

Vulcanized splices are formed by fusing disjoint sections of belt together under heat and pressure. The layers of fabric which make up the conveyor belt core are not continuous through the splice. Vulcanized splice failure typically begins with delamination of the joined sections of the belt. The delamination worsens with use, eventually leading to splice failure. This progression suggests that the extreme variations in belt tension as the belt moves from a loaded section of its run to an unloaded section (or vice versa) may be repeatedly stretching the vulcanized rubber, eventually leading to fatigue and failure.

NREC worked with CONSOL Energy to evaluate the extent to which this stretching, and concomitant heating, affect the surface temperature of the belt. This investigation was conducted on the grounds that significant heating would provide an easily detectable marker for vulcanized splices, particularly those splices which are beginning to fail.

3.1 Experimental Apparatus

An infrared thermographic camera (Thermovision A series, manufactured by FLIR Systems) was temporarily obtained. The camera was mounted in two active mines: the Loveridge mine in Fairview, West Virginia; and the Blacksville mine in Blacksville, West Virginia. In each case, the camera was positioned so as to image the belt as it passed over a main driver roller, since this is a point of transition between high and low tension sections of the belt. In the Loveridge mine, particular attention was made to be sure that a length of belt was visible downstream of the transition area. In both mines, the camera output was connected to a laptop computer so that temperature measurements could be recorded to hard drive.

3.2 Experimental and Operating Data

Full resolution thermographic images were acquired for several revolutions of each belt. The field-of-view and placement of the camera were such that the portions of belt visible in subsequent frames overlapped by roughly 20%. Figure 1 illustrates the thermographic imaging interface during acquisition of the Blacksville belt scan. Note that the colormap of the image has been adjusted to highlight small temperature variations.

Figure 1: The thermographic imaging interface during acquisition of footage from the Blacksville mine.

3.3 Data Reduction

Data reduction was minimal: the range of temperature variation was computed for each belt, and the acquired images were analyzed to identify regions noticeably outside the norm.

3.4 Hypothesis and Conclusions

The working hypothesis that vulcanized splices show significant heating as they transition between loaded and unloaded portions of the belt was not borne out by the data. In both mines, no discernible temperature difference between vulcanized splices and other regions of the belt was detected.

4 Vulcanized Splice Detection Software

When sections of conveyor belt are joined using vulcanized splices, the ends are cut at an angle. For the mines involved in this study, the cut angle is nominally 22° , and the junction between the belt sections produces a characteristic diagonal line across the surface of the belt. A vulcanized splice detection algorithm has been developed which operate on 2D visual images of the conveyor belt by searching for these lines. This line detection and classification is challenging because of several factors: the apparent line angle in the belt images depends on the speed of the belt and the line-scan frequency; splice lines are often very faint; and typical belt images include spurious lines caused by water, pulley lagging, and other artifacts.

The vulcanized splice detection algorithms begins by processing the input image using an *interest operator*. In the initial prototype, this interest operator is a simple horizontal edge detector. Optionally, this output of the interest operator may be thresholded to zero out low-interest pixels. Figure 2 illustrates a section of an image of a conveyor belt containing a vulcanized splice, and a corresponding image of interest values after thresholding.

Following application of the interest operator, the resulting values further processed to isolate potential splices, and the resulting values are sent to a classified as splice or non-splice.

Figure 2: (a) A portion of an input image. (b) A corresponding image after application of the interest operator and thresholding. (c) The original image with the detected splice overlayed.

Figure 3: Individual scanlines are assembled to make a coherent image of the belt, then saved as individual image files.

4.1 Experimental Apparatus

Twelve low cost prototype systems for belt inspection and image acquisition have been installed in mines throughout western Pennsylvania and West Virginia. Each prototype system includes a pair of synchronized high-speed high-resolution line-scan cameras mounted side-by-side so that the output from the two cameras can be concatenated to approximate a single scan-line. The prototype is positioned in such a way that the direction of belt travel is perpendicular to the camera scan-line. As the belt moves under the cameras, successive scan lines are assembled to make a 2D image as shown in figure 3. These images are saved to hard disk and provide a high-resolution surface image of the belt. The approximate resolution of the surface image is 50 pixels/inch.

Robinson Run Belt (58 Splices)

Threshold	Missed Detects	False Positives
1.5	0	127
1.6	0	42
1.7	4	22
1.8	11	12
1.9	13	10
2.0	16	7
2.1	22	6

Table 1: Splice detection results for the first vulcanized splice detection algorithm applied to the Robinson Run belt. The column labeled “Missed Detects” indicates how many images were manually determined to contain vulcanized splices, but were not identified by the detection algorithm. The column labeled False Positives indicates how many images were manually determined not to contain vulcanized splices, but *were* identified by the detection algorithm.

4.2 Experimental and Operating Data

Full resolution recordings were acquired at seven installation sites. These recordings include images of the entire belt. Footage from each site was grouped into a series of 2D images, each containing 4096 scan lines and representing approximately 82 inches of belt surface. Images from two of the installation sites were manually inspected to identify vulcanized splices. The two sites were located in the Robinson Run Mine and the Blacksville Mine. Among the two image sequences, 80 vulcanized splices were identified, and the name of the image containing each splice was recorded in a spreadsheet.

4.3 Data Reduction

The vulcanized splice detection algorithm was applied to each image, and those images for which the algorithm indicated a splice were noted in a spreadsheet. This spreadsheet was compared with the manually scored spreadsheet to generate counts of the number of correct and incorrect classifications. The classification was performed repeatedly using a range of tunable parameters. Results are presented in tables 1 and 2.

4.4 Hypothesis and Conclusions

The purpose of this effort was to demonstrate feasibility of vulcanized splice detection using image processing techniques. The preliminary results for both belts were wholly satisfactory. In both cases, it was possible to detect all of the known vulcanized splices without an excessive number of false-positives.

Although detection performance was good, the accuracy of this algorithm was quite sensitive to the choice of detection parameters. The difference in detection performance between the two mines

Blacksville Belt (22 Splices)

Threshold	Missed Detects	False Positives
1.5	0	0

Table 2: Simple algorithm splice detection results for the Blacksville belt. Column labels are as described in table 1.

is attributable to variation in lighting conditions and to differences in the surface condition of the two belts. Images from the Robinson Run mine were considerably more challenging, and led to many more false-positives. To address these limitations, an advanced algorithm is currently being developed.

5 Additional Efforts

A comparative evaluation of LED vs. fluorescent lighting systems has been performed. LED lighting design has been greatly refined at Beitzel Corporation to minimize the number of required LEDs through active cooling and overdriven feed voltages. The optimized LED light bars show significant advantages over fluorescent lights both in terms of image quality and in terms of mechanical robustness.

Additional efforts are underway at Beitzel Corporation to evaluate RFID tags as solution for uniquely identifying splices. Challenges for the RFID tags include method of embedding in the belt and hardware longevity. This work will continue in the coming months.