Effective Conveyor Belt Inspection for Improved Mining Productivity

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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 low-cost prototype hardware, acquisition of infrared thermal data, and initial design of a Smart-Camera based system.

Contents

1	Introduction	5
2	Executive Summary	5
3	Experimental Apparatus	6
4	Experimental and Operating Data	7
5	Data Reduction	10
6	Hypothesis and Conclusions	11

List of Figures

1	The low-cost Prototype BeltVision system includes two fluorescent lightbars and a modular computing unit with a touchscreen display.	7
2	A full-sized test rig has been built and installed at NREC for testing and algorithm development.	8
3	Low-cost smart-camera system overview.	8
4	Several different line-scan sensing elements were evaluated: (a) shows an image from a Dalsa CCD-based line-scan element; (b) shows a similar image from a Perkin-Elmer CCD-based line-scan element which is significantly less expensive; and (c) shows an image from a CMOS line-scan element which was even less expensive, but which was found to have inadequate image quality.	9
5	(a) Shows a section of raw belt image containing a vulcanized splice. (b) Shows the same image following initial image processing to highlight the splice contours. . .	11

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, 5, and 6.

Patent protection for the belt inspection system has been granted by the US Patent Office
The Belt Inspection System patent has issued under patent number 6,988,610. The majority of the claims, 70 in all, were approved.

Test conveyor delivered and installed at NREC Facility A test conveyor has been constructed to allow above-ground testing of belt-inspection hardware and software. The test conveyor has been delivered to NREC, and is in active use.

Low-cost BeltVision prototype fabricated and installed on test conveyor The low-cost BeltVision prototype design and fabrication is completed, and a low-cost unit is installed on the NREC test conveyor. This permits rapid testing and refinement of computer vision algorithms.

Resolution study for vulcanized splice detection A study was conducted to analyze the impact of camera resolution on image clarity and vulcanized splice detection. This study was used to identify the appropriate tradeoff between sensor cost and image resolution.

Full-resolution belt images recorded and reviewed for use in developing vulcanized splice detection algorithms In the past 6 months, additional full-resolution belt images have been recorded and brought to the surface. Images of several belts have been reviewed, and initial algorithms for vulcanized splice detection are being evaluated.

Initial design of the low-cost smart-camera system for mechanical splice detection is complete
A set of required features has been defined, based on feedback from potential end users balanced against the need to lower system cost, and an initial design has been created.

Evaluation of low-cost camera imaging elements is complete A study comparing available line scan imaging elements has been completed, and an appropriate element has been selected for the low-cost system.

Infrared camera systems have been installed and tested at CONSOL's Blacksville bunker belt, and interface software is being written to permit continuous recording Full-resolution IR images of the belt will be recorded and will be used to evaluate the use of thermal imaging in vulcanized splice failure prediction.

10 Development and pre-production low cost 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 3/4 million miles of belt.

Beitzel Corp is currently producing and selling a very low volume of the preproduction low cost systems The logistics of deploying and supporting a system in mines dictate a cautious approach. In addition, Beitzel Corp is surveying belt managers for input into desired system features and potential new target markets.

3 Experimental Apparatus

The majority of proposed effort towards experimental effort falls under Task 4 of the proposal document. We describe the relevant portions of Task 4 here, along with statements of technical progress, which are **bolded** and inset for easy reference.

Task 4.1 Upgrade NREC Prototype System Computing Capability The current imaging system prototype at the NREC will be upgraded to support the objectives described in this document. The NREC will make the needed upgrades and repairs.

The low-cost (PC-based) prototype BeltVision unit design is complete, and a low-cost prototype has been installed on a test conveyor at NREC. This system is in use for algorithm development and system testing. In addition, two low-cost prototype BeltVision units have been installed in CONSOL mines and are being used to gather data and conduct operating tests. The completed low-cost prototype can be seen in figure 1.

Task 4.3 Design and Fabricate Bench top Mechanical Splice Simulator

The Beitzel Corporation will design and fabricate a bench top mechanical splice simulator for use in developing the low cost vision system.

Beitzel developed and fabricated a full size mechanical splice simulator for developing the low cost inspection system. The system includes a working conveyor belt and several mechanical splices. In addition, the belt contains two vulcanized

Figure 1: The low-cost Prototype BeltVision system includes two fluorescent lightbars and a modular computing unit with a touchscreen display.

splices for use in vulcanized splice detection algorithm development. The simulator is installed at NREC and is shown in figure 2, along with a low-cost BeltVision prototype.

Task 4.4 Assemble lab prototype of Low Cost Belt Vision System Cameras, lenses, and digitizers, as needed, will be assembled for the development and testing of imaging for low cost vision system. The NREC and CONSOL Energy will be responsible for this task

The pre-production low cost BeltVision system has been built and is currently under test. The initial design for a smart-camera based mechanical splice detection system has been completed. The design is based on feedback from potential users and mining experts, and strikes a good balance of functionality and overall system cost. The design includes sensing element, communications hardware, and an on-board FPGA for image processing. All of these components are contained in one low-cost, easily replaceable housing as illustrated in figure 3.

4 Experimental and Operating Data

Feasibility studies and experimental data are addressed in Tasks 1 and 2 of the proposal document. We describe the relevant portions of Tasks 1 and 2 here, along with statements of technical progress, which are **bolded** and inset for easy reference.

Task 1.2 Perform an Engineering Design and Feasibility Study for a Low Cost Belt Vision System CONSOL, Beitzel and NREC will establish specifications and design goals. Preliminary sketches and designs will be generated to guide us in the next tasks. Beitzel will lead the redesign of the mechanical packaging and the NREC will perform redesign on image capture and computing hardware. Embedded computer designs will be strongly considered. The focus in Phase I will be on imaging but an evaluation of imaging computing will also be considered.

A low cost imaging specification document has been generated. We considered many alternative imaging and computing hardware technologies (ex. CCD

Figure 2: A full-sized test rig has been built and installed at NREC for testing and algorithm development.

Figure 3: Low-cost smart-camera system overview.

Figure 4: Several different line-scan sensing elements were evaluated: (a) shows an image from a Dalsa CCD-based line-scan element; (b) shows a similar image from a Perkin-Elmer CCD-based line-scan element which is significantly less expensive; and (c) shows an image from a CMOS line-scan element which was even less expensive, but which was found to have inadequate image quality.

vs. CMOS). Figure 4 shows sample images from several available line-scan sensing elements. Evaluation was made for the required image resolution to enable detection and evaluation of mechanical and vulcanized splices. A final down select was made to a smart-camera based on CCD linescan element manufactured by Perkin-Elmer, an Altera FPGA and a Motorola Coldfire CPU incorporated into a single unit. The overall architecture of the smart camera is shown in figure 3.

Task 1.4 Evaluate Alternative Technologies for Measuring Stretch and/or Distortion across Vulcanized Splices on Ply Belt Technologies to be considered as a minimum include RF tags, flexible strain gauges and the use of vision for detection of splice distortion. For RF tags consideration will be given to utilizing the Doppler Effect to detect the signal of an RF tag or triangulation to measure distances between RF tags. The NREC will be responsible for this task.

Infrared cameras were installed and tested to acquire thermal images of operating belts. The theory is that loading and unloading of the belt will stretch the vulcanized splice, resulting in local heating. The degree of heating may correlate with splice condition, as stretching may be increased in a failing splice. Software is being written to acquire continuous full-resolution thermal images of the belt, and analysis of these images will continue in the upcoming months.

Task 2.1 Fabricate Mechanical Splice Inspection Systems and Install In this task CONSOL Energy will fabricate several of the existing belt inspection systems and install the systems on problematic belts. In addition to providing coverage of mechanical splice defects, these systems will be made available to NREC personnel for full resolution image data collection and future testing of enhanced functionality. CONSOL Energy will have main responsibility for this task.

Two portable pre-production low cost data collection units have been fabricated and installed at CONSOL mines. Additional full-resolution scans have been

acquired using these units, and will be used for software algorithm development and verification.

Task 2.2 Design and Fabricate a Portable Belt Inspection System Beitzel will design and fabricate a lightweight and portable Belt Inspection System based on the existing belt Inspection System design. The Portable Belt Inspection System will be made available to NREC personnel for data collection on various processing plant and hard rock mining conveyor belts. Beitzel will lead this task.

The two data collection units described under Task 2.1 are highly modular and easily portable by hand. The units are being utilized for both data collection and on-site mechanical splice detection.

Task 2.3 Deploy Portable Belt Inspection System for Data Collection Beitzel personnel with assistance from CONSOL Energy personnel will deploy the Portable Belt Inspection System on a minimum of two different hard rock mine belts to collect full-length high-resolution images of belts with known surface defects. Each deployment will last between two and five days. In addition to the data collection task, project personnel will meet with the appropriate mine personnel to discuss the unique needs and conditions that we may expect to encounter at their particular operation.

Data has not been collected from hard rock mines. The data collection units have not been available for deployment at hard rock mines due to data collection activities and continued use for mechanical splice inspection at the coal mines.

5 Data Reduction

Data reduction and image processing are addressed in Task 3 of the proposal document. We describe the relevant portions of Task 3 here, along with statements of technical progress, which are **bolded** and inset for easy reference.

Task 3.4 Develop Software to Measure Stretch and/or Distortion across Vulcanized Splices NREC will develop software to acquire data from sensors and develop quantitative indicators of stretch, distortion, or any other indicators deemed appropriate for signaling the state of integrity of a vulcanized splice on ply belt.

Work is underway to identify thermal patterns due to stretching of vulcanized splices as the belt is loaded and unloaded. Data processing algorithms will be used to detect and quantify any such thermal patterns. In addition, initial algorithm descriptions have been drawn up for identification of vulcanized splices in the conventional images returned by the installed data collection units.

Figure 5: (a) Shows a section of raw belt image containing a vulcanized splice. (b) Shows the same image following initial image processing to highlight the splice contours.

6 Hypothesis and Conclusions

Both below-ground performance of the installed unit and above-ground processing of the full-resolution belt images indicate excellent performance on mechanical splice detection. Preliminary analysis of the thermal images from the installed IR cameras suggests that identification of vulcanized splices from thermal patterns will be quite challenging, however no concrete conclusion has been drawn yet. In full-resolution conventional images from the Blacksville site, simple image processing renders many of the vulcanized splices clearly visible, as shown in figure 5. Several of the newer and less worn splices are difficult to see, however we still have high hopes for consistently detecting these splices and assessing their condition.