AUTOMATED JOINT BAR INSPECTION USING HIGH SPEED CAMERAS

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ABSTRACT

Current techniques for inspection of joint bars are either not adequate or very labor intensive. ENSCO, Inc. has developed a novel video system for automated joint bar inspection from a moving vehicle. The system is based on high-speed digital line-scan cameras, mounted under the vehicle. The cameras capture high resolution images of joint bars located on the field and gage sides of both rails. The powerful on-board computer system uses an adaptive image processing algorithm to analyze the images and notify the vehicle operator when a crack in a joint bar is detected.

A fully functioning prototype of the system has been installed on a Hi-railer. Several field tests and demonstrations of the system have successfully been conducted. The field tests and demonstrations have proven the feasibility and effectiveness of this technology for detection of visible cracks in joint bars.

INTRODUCTION

Broken joint bars have been identified as one of the significant causes of main line derailments in the United States. Currently, joint bars are inspected visually by railroad maintenance personnel during regular track inspection. The quality of this inspection, which is usually performed from a Hi-Railer, is questionable. Realistically, an inspector cannot see small defects in joint bars while driving a
Hi-Railer. Visual inspection of joint bars on foot provides good results; however, inspection on foot is a very slow and labor intensive process.

This paper presents the results of the development and testing of a novel automated video inspection system of joint bars, which operates from a moving vehicle. The system provides significant improvement in inspection quality and objectivity compared with visual inspection from a Hi-railer and significant improvement in productivity compared with on foot inspection.

**DESCRIPTION OF THE SYSTEM**

**System Concept**

The system utilizes high-resolution line scan cameras inspecting joint bars on both field and gage sides of each rail. The cameras are triggered at a fixed distance rate of 0.5mm by a signal from an optical encoder (tachometer) mechanically connected to a measuring wheel (Figure 1). A lighting subsystem provides consistent uniform illumination for the cameras. All these components are mounted outside the Hi-railer, either on an instrumentation beam suspended from the hi-railer body (cameras, lights) or on hi-railer gear (laser sensors, encoder).

In addition to the imaging components under the vehicle, the system includes a signal conditioning unit, a power distribution unit, a GPS receiver, and a hand-held terminal for manually marking mileposts and other ground features. The
system utilizes two computers: an Image Acquisition and Analysis Computer with specialized image acquisition and counter timer boards and a Laptop computer that provides image storage and an operator interface.

![Figure 1. Main System Components](image)

**Mechanical Design**

The prototype system is designed to be mounted on a high rail vehicle. A beam containing all the cameras and lights is mounted on the rear bumper of a high rail vehicle (Figure 2). The beam is installed using existing bolt patterns on a Hi-railer in order to minimize mechanical modifications to the vehicle. The beam provides a rigid frame for securing light and camera positions. These positions
are adjustable. The tachometer (encoder) is connected to a separate high rail wheel suspended from the frame.

Figure 2. Joint Bar Inspection System Mounted to the Rear of the Hi-railer

For transportation purposes, the frame is designed such that the two field side cameras can be folded in to stay within the profile of the Hi-railer while the vehicle is driving on the road (Figure 3).
During inspection it is important to provide consistent high quality images of joint bars under various environmental conditions (i.e., bright sun, partial shade, night time, rain). To achieve this goal, the system relies on artificial illumination. A light shield protects the inspected area from sunlight. The shield is designed to snap to a frame over the instrumented beam when the system is deployed (Figure 4).
Electrical and Computer Design

The system includes two custom designed electrical enclosures providing power distribution and signal conditioning (Figure 5). The system also includes two computers. The Laptop computer located in front of an inspector provides an operator interface. It also stores images of joint bars with suspected cracks and generates reports at the end of the survey. The Image Acquisition and Processing computer is a dual Pentium high speed computer that captures and analyzes images of joint bars. It interfaces with the laser sensors providing joint bar detection. It also interfaces with DGPS and Termiflex units used for determining the location of the inspected joint bars.
Software

The system includes custom written software that provides the following main functionality:

Image acquisition. Images are acquired by the image acquisition cards (one for each rail) based on a trigger signal from the lasers. When a trigger is received, the corresponding acquisition card captures 3,000 line scans spaced at 0.5mm that are used by the computer to build images of gage side and field side joint bars.
Image tagging with location information. The system counts the distance from the latest milepost entered by the operator and also receives continual GPS updates. All captured images are tagged with both MP/feet and Lat/Long location reference.

Image analysis. The computer checks images for the presence of cracks. If a crack is suspected, the system passes a message and a corresponding image to the laptop computer.

The automated joint bar crack detection algorithm uses multiple image processing techniques to reliably detect cracks. First, the algorithm uses an adaptive approach to find the location of the rail head in the image (Figure 6). Then, the rail head is analyzed to find the location of the gap between two consecutive segments of rail. This gap provides the location of the center of the joint bar. After this step, the image is analyzed to extract the edges of the joint bar and segment the joint bar into different regions (Figure 6).
Once the joint bar is detected and segmented, a match filter is applied within different segments to get a map of locations where there are likely cracks. In order to differentiate cracks from regular scratches, every crack candidate is analyzed, and its attributes such as length, width, aspect ratio of the bounding rectangle, orientation and distance to edge are estimated (Figure 7). These parameters are used to remove obvious false detections and to assign a score to every joint bar corresponding to the likelihood of the crack detection. Joint bars with detected cracks will be presented to the user.
Operator interface. When a crack is detected, the laptop computer beeps and information about the exception appears on the screen (Figure 8). The operator can then review the image of the cracked joint bar, zoom in and out and scroll the image. If necessary, the operator can use the presented location information to find and verify the crack on the ground. After verification, the operator can confirm or reject the exception or input additional comments.
Figure 8. Operator Interface

Report generator. After completion of the survey, the operator can generate an exception report that will list all detected cracks and their location.

FIELD TESTS AND DEMONSTRATIONS

ENSCO conducted two daily field tests at a railroad yard near Washington, D.C. for verification of system functionality and two field demonstrations, one at a small railroad and another at a class 1 railroad. The conditions and results of these field demonstrations are summarized below.
Field Demonstration 1: Small Eastern Railroad

This field demonstration was performed on April 7 and 8, 2005. The goal of this test was to verify the system operation in real survey conditions and to collect images for developing a crack detection algorithm. The first day was used to set up and calibrate the system, and then to test 15 miles of track. The second day 50 miles of track were tested. All tested track was class 2 (25 mph). Out of 35,000 inspected joint bars, the software detected 60 joint bars (or 0.2%) as potential cracks. Based on visual analysis of the images, three cracked joint bars were confirmed and reported to the railroad.

Since the false detection rate was considered too high (only 1 out of 20 detected cracks was confirmed), additional efforts were undertaken to improve the algorithm and to decrease the false detection rate. Analysis of the images demonstrated that the main causes of false detections were scratches, grease, and mud on joint bars. The algorithm was modified to better filter out these triggers and the number of false detection significantly decreased. However, due to the insufficient number of actual cracks, the statistical evaluation of the algorithm performance was not possible.
Field Demonstration 2: Class 1 Railroad

This field demonstration was performed from September 19 to September 22, 2005. The first two days were spent calibrating and verifying that the system was operating correctly. Over the next 2 days, an 18-mile long subdivision was tested several times. Some of the detected cracks were verified by looking at the image of the joint bars and some were verified on the ground. A hand-held GPS receiver was used to find joint bars during on-the-ground verification. The GPS system provided accurate location information for the cracked joints.

The following statistics summarize the results of this test:

• 18 mile test on class 1 (10 mph) track
• 9,750 joint bars inspected
• 251 suspected cracks detected
• 98 cracks confirmed (40% of suspected cracks)
• 6 of the confirmed 98 cracks were center cracks

Some examples of the detected cracks and falsely detected cracks are provided below (Figures 9-13).
Figure 9. Small Center Crack Detected by the System

Figure 10. Medium Sized Hair Line Center Crack Detected by the System
Figure 11. Large Center Crack Detected by the System

Figure 12. Large Quarter Crack Detected by the System
In order to determine the percentage of missed cracks, 1,700 random joint bar images were looked at by an analyst. Out of these joint bars, the system correctly detected 17 cracks and missed 3 diagonal quarter cracks (no missed center cracks). The reason for missing several diagonal quarter cracks is well understood and is being corrected. This was the first time that the system captured images of these types of cracks, and the algorithm was not trained to recognize them. Another example of a joint bar defect that is currently not automatically recognized by the system is provided in Figure 14. The collected archive of more than 45,000 joint bar images is currently being used to include
these types of defects and further enhance the detection and reporting capabilities of the system.

Figure 14. An Image of a Joint Bar with Two Missing Bolts Captured by the System

CONCLUSION

The developed prototype system is fully functional and provides inspection of joint bars on field and gage sides of both rails at Hi-railer speed. The system detects and reports visible cracks in joint bars and their location in near real time during a survey. Field demonstration of the system has proven that the visible cracks are detected with acceptably low false alarm rates (40% of detected cracks were confirmed and 60% were rejected by the system operators). The algorithm is being refined to decrease the probability of false detections and missed exceptions.

Future plans include:
• Testing of the developed prototype system under different conditions, including Continuously Welded Rail.

• Further tuning of the crack detection algorithm to decrease the probability of missing cracks.

• Development of an algorithm for automated detection of missing bolts and nuts.

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