High Speed Joint Bar Inspection Using Advanced Image Collection and Processing Techniques

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ABSTRACT

Joint bar failures continue to be a leading cause of derailments in the railroad industry, even in Continuously Welded Rail (CWR) where joints are infrequent. Visually detecting cracks before they break completely through often requires a time consuming, on-foot inspection. Cooperative efforts by Federal Railroad Administration and ENSCO, Inc. have led to the production of new automated techniques capable of performing such detailed inspections at speeds up to 65 mph. The research takes advantage of advancements in technology for high speed cameras, data acquisition and high speed intelligent image processing. The systems will accurately inventory and inspect joint bars at high speed (up to 65 mph) and are expected to help railroads meet new requirements for inventoring and inspecting joint bars in CWR territory which have been issued by the FRA in response to new laws passed by Congress in August of 2006.
INTRODUCTION

Broken joint bars have been identified as one of the major causes of main line derailments in the US. Currently, joint bars are inspected visually by railroad maintenance personnel during regular track inspection. The quality of this inspection, when done from a hy-railer, is questionable. Realistically, an inspector cannot see small defects in joint bars while driving a hy-railer. Even large cracks and broken bars can be missed by this method of inspection. Visual inspection on foot can provide better results, but this is a very slow, tedious and labor-intensive process. Normal rail traffic and revenue services are often interrupted when an on-foot inspection is performed.

With new federal mandates enacted which in many cases increase the required inspection frequency, it has become evident that the industry is in need of more effective and efficient inspection procedures. In 2004, National Transportation Safety Board (NTSB) investigated a series of derailments caused by joint bar defects and concluded that current hy-rail inspection processes were inadequate. In response to these findings, Federal Railroad Administration (FRA) set forth a Final Rule which requires the railroads to perform frequent walking inspections based on the track speed and line density. In response to this challenge, an image-based system for joint bar inspection was developed and tested with the goal of capturing high quality digital video images of joint bars from a moving vehicle. The system consists of high speed, high resolution line scan cameras which capture images of the joint bars, a lighting system, and computers which process images taken of the rail and report defects to the operator. The computers employ a series of advanced image processing algorithms to detect joint bar defects. Joint bars are tagged with milepost and footage information as well as precise GPS coordinates. All significant track features are inventoried and stored in a permanent database.

The video inspection solution presented here greatly increases the speed of the inspection process. The system operates up to speeds of 65 mile per hour and can be mounted to either a hy-rail or rail-bound vehicle. In addition to the defect detection
features, the system also gives the operator the ability to record all significant track features and their locations, such as joints, bridges, switches and frogs in a comprehensive database.

**DESIGN CONCEPT**

The system is designed to acquire high resolution images of the rail and process these images using advanced computer algorithms. The system capitalizes on the capabilities of computational image analysis in order to detect the presence of joints and their defects. The entire system has been designed with optimization of image quality in mind. A lighting subsystem provides optimal lighting conditions for the selected cameras. A mechanical mounting structure positions the cameras and lights for the most effective view of the rail web.

A user interface provides the operator with a platform to easily evaluate and interpret data.

![System Concept Diagram](image)

*Figure 1: System Concept*
SYSTEM DESCRIPTION

The Automated Optical Joint Bar Inspection System (JBIS) consists of several major subsystems: a lighting subsystem, an image acquisition system, image processing algorithms to detect joint locations and defects, and a user interface that allows the user to manage and review the data.

System Installation and Implementation

The lights and cameras are mounted on a mechanical beam. The beam can be designed for installation on both rail-bound and hy-rail vehicles. The system is designed to fit within Plate C Clearance when fully deployed. When installed on a hy-railer, the beam is designed to be folded for highway passage. All components installed exterior to the car body are shock mounted and weather proofed (Figure 2).
Most of the interior system components are rack-mounted to optimize storage space and cable routing. Rack mounted chassis provide conditioned power to all of the electrical components. Image acquisition computers, data storage devices and networking components are also rack mounted (Figure 3).

![Figure 3: Rack Mounted Components](image)

**Lighting Subsystem**

The lighting system provides even and consistent illumination of the rail with high-powered Xenon lights. The lighting system is designed to temper variations in illumination caused by ambient light while also providing sufficient shadowing properties. The intensity of the light emitted is great enough to eliminate the need for light shields (Figure 4), and the wavelength of the light is optimized to operate within the threshold of the camera. The lights are mounted on a beam exterior to the car and are in line with the line scan cameras.
Image Acquisition System

The line scan cameras are positioned on the beam in a manner that optimizes the view of the rail web while still falling within Plate C requirements. The system is composed of four cameras, one each for both field and gage sides of left and right rail. The cameras continuously image the rail as it is traversed. A high resolution encoder supplies the cameras with a 0.5mm fixed distance trigger. The cameras then send the images to a data collection computer for assembly and analysis.

High speed, multiprocessor computers assemble the images from the cameras line by line. Frame grabbers housed within the computers receive the images from the camera. The images are assembled and tagged with synchronization information supplied by a counter timer board.

Image Processing Algorithms

After the images are assembled, the first image processing algorithm evaluates the images for the presence of a joint bar. The joint bar is detected by comparing changes in pixilation within an image (Figure 5).
Joint bar images are extracted from the rest of the data. GPS coordinates and milepost/footage location are received through a serial port on the computer and the images get tagged with this information.

Once a joint bar is detected, a second algorithm scans the image for cracks in the joint bar. The rail head and gap are identified by the algorithm and a region for evaluation is established. The algorithm identifies areas on the bar where a crack is more likely to be present (Figure 6). Anomalies in the pixilation of the image are acknowledged and rated on their likeness to the characteristic pattern of a crack. The length, width, defining shape, and coloration of the suspected defect are all considered by the algorithm (Figure 7). Based on these criteria, the algorithm prescribes a probability rating to the defect. Images tagged with a high defect probability are flagged and sent to the operator for consideration.

All image processing occurs in real time. A compression board compresses the images and sends them to the user interface computer for evaluation and inventory reporting.
Figure 6: Crack Detection Region

Figure 7: Crack Detection Filter
Operator Interface and Software

All joint bar images, whether deemed defective or not, are sent to a database with corresponding milepost and footage data as well as GPS coordinates. Detected defects are sent to the operator interface and are accompanied by an on-board alarm. The image of the defect is presented to the operator with the defect highlighted for easier consideration. The resolution of this image is very high, enabling the operator to easily evaluate the defect. The image can be panned, zoomed and scrolled, and the operator can add comments to the image, delete an image, or accept it as a defect.

An automated report of the data may be generated. The operator can choose to generate defect reports of confirmed cracks. Inventory reports of all joints present on a line may also be generated. The inventory reports include GPS coordinates of each event as well as milepost and footage location.

Track features such as switch points, frogs, bridges, and road crossings may also be entered into the database via a Termiflex in order to create a complete inventory of all significant track elements. The database can be accessed at any time in the future, allowing for evaluation of track wear over time.

Figure 8: Operator Interface
SYSTEM PERFORMANCE

The prototype system was tested on several major railroads through the course of development. Once the system was deemed fully functional, it was tested on three major railroads across the United States. The purpose of these tests was to acquire data to train the algorithm with. After completion of each test, the crack detection algorithm was reviewed and modified based on the real-time performance of the system during the test. Defects in the dataset were used to refine the algorithm in order to decrease the false detection rate and increase the number of true defects detected.

Mileage

The fully functional prototype system has inspected 173 miles of track to date on three major railroads. Track inspected during system development will not be considered for the purposes of this study. Of the 173 miles inspected by the finalized prototype, 122 miles were on Jointed Rail and 51 miles were on Continuously Welded Rail (CWR).

Joint Count

The system inventories all joints present on a line, and this information is stored in a comprehensive database complete with GPS coordinates and milepost and footage information. From the three field tests performed, a total of 29,382 joints were inventoried by the system (58,764 joint bars). This averages to 170 joints per mile. Preliminary evaluation of the reliability of the joint detection mechanism has been performed, with a more comprehensive evaluation pending. Results to date indicate that the joint detection accuracy of the system is 98% typical. Therefore, the actual joint count over the sections surveyed is estimated to be between 28,795 – 29,970 joints, or 57,590 – 59,940 joint bars.
Automated Crack Detection Statistics

Of the 58,764 joint bars inventoried, 2306 joint bars were flagged for review, or 3.9%. Of these detected defects, 151, or 6.5%, were confirmed by visual inspection of the image. Many of these defects were field verified as well. After a visual review of all images collected, it was found that the algorithm missed approximately 17% of the defects present in the data set.

The sensitivity level of the crack detection threshold can be adjusted to increase the detection rate of defects; however, adjusting this variable also reduces the filter for false positives. Therefore, as the true detection rate is increased, the false detection rate will increase as well. At some point, the value of an increase in the true positive detection rate is significantly compromised by the corresponding increase in the false detection rate. This concept is best presented by a Receiver Operating Characteristic, or ROC Curve. The Crack Detection ROC Curve (Figure 9) shows that for a true positive detection rate of 80% or less, the false detection rate is reduced to around 3%. However, for a 10% increase in the positive detection rate, to 90%, the false detection rate increases by 20%.

The most common cause of a false detection is the presence of a frayed bond wire. Other common causes of false positives are rust and grease spots, weeds, and debris.
Images of Detected Defects

Figure 10: Tiny Hairline Center Crack Detected by Automated System

Figure 11: Broken Bar Detected by Automated System
Figure 12: Hairline Center Crack Detected by Automated System

Figure 13: Grease on Bar Detected as Crack by Automated System

CONCLUSION

Advanced image processing techniques can greatly impact the speed and effectiveness of joint bar inspection. The system presented in the paper demonstrates the ability to capture high resolution images of rail at speeds up to 65 miles per hour. The system can also operate under certain adverse weather conditions such as rain and light snow.

Through the course of development of this system, many capabilities and limitations of line scan and image processing technologies have been discovered by the development team. Establishing a lighting system which would provide optimal lighting conditions for the railroad environment was a large part of the developmental process. Detailed image analysis pointed to further areas of improvement as the system approaches maturity.

Further work is being done to improve the detection algorithms. Different classifiers are being introduced to increase the likelihood of detecting a crack without impacting the false detection rate. A filter specifically designed to detect the shape and location
of bond wires will eliminate many of the false detections. Improvements to the user interface will also speed the review process.

We are planning to expand the capabilities of this system to include missing bolt detection, rail gap, and rail batter. The technology can also be applied to inspect other track features such as switch points and frogs.

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Andie Berry is a Senior Engineer and Project Manager at Ensco, Inc., Applied Technology and Engineering Division in Springfield, VA. Ms. Berry works on the design and implementation of systems for track inspection and asset management. She has worked to develop technology for visually based inspection systems including the joint bar inspection system. She also manages both commercial product development as well as governmentally funded technology research. Her areas of expertise include electrical system design, circuit board design, semiconductors, and project management.

Ms. Berry received dual Bachelor of Science Degrees in Electrical Engineering and Biomedical Engineering from Duke University in 2001. Her concentrated studies were in VLSI design, biomedical instrumentation, and semiconductor physics.

Xavier Gibert-Serra received the B.S. degree in telecommunications engineering in 2001 from Universitat Politecnica de Catalunya (UPC), Barcelona, Spain, and the M.S. degree in electrical engineering in 2003 from the University of Maryland, College Park, in the area of communications and signal processing.

He is a senior scientist at Ensco, Inc., Applied Technology and Engineering division, Springfield, VA. For three years he has designed and implemented data processing algorithms for rail products such as the optical rail profile system, the joint bar inspection system and the track geometry measurement system among others. He has also been part of the Team ENSCO at the 2005 DARPA Grand Challenge, working in vision-based obstacle detection and road following. His main areas of expertise are computer vision, pattern recognition and dynamic systems.
Boris Nejikovsky is a Chief Engineer of ENNSCO, Inc. Applied Technology and Engineering Division. He holds advanced degrees in electrical and civil engineering. His career has been dedicated to advancing state of the art in railroad and civil engineering instrumentation, measurement techniques, and inspection technologies. Mr. Nejikovsky has been with ENSCO, Inc. for 15 years. While at ENSCO, he managed development of multiple track and vehicle inspection systems based on various technologies. He has broad expertise in the areas of track geometry, ride quality, track strength, rail profile, and rail corrugation measurements. He is also an expert in automated track video inspection, vehicle track interaction monitoring, and vehicle testing and evaluation. Mr. Nejikovsky is a member of the American Railway Engineering and Maintenance of Way Association Committee 2 for Track Inspection Systems. He has authored numerous papers and technical reports on track inspection and vehicle testing and holds several patents in the area of instrumentation and railroad inspection technology.

Ali Tajaddini is a program manager in office of research and development of Federal railroad Administration. He got his B.S. in Civil and Environmental Engineering in 1980 and M.S. in Structural Engineering and M.S. in Engineering Mechanics in 1984 from University of Wisconsin-Madison. He is resisted as Professional Engineer in states Maryland and Wisconsin. He has been working in FRA since 1999. Prior to working at FRA he worked as structural engineer and analyst for Auto industry and he worked for 10 years at research and test Department of Association of American railroads in Chicago Technical Center and Transportation Technology Center and two years at Ensco, Inc doing research in area of vehicle track interactions, Track geometry and wheel Impact loads.
FIGURE REFERENCES

Figure 1: System Concept

Figure 2: Beam Components

Figure 3: Rack Mounted Components

Figure 4: Xenon Lights

Figure 5: Joint Bar Detection Algorithm

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Figure 9: Crack Detection ROC Curve

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