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AUTONOMOUS BROKEN RAIL DETECTION TECHNOLOGY FOR USE ON REVENUE SERVICE TRAINS

SUMMARY

ENSCO Inc. in collaboration with Virginia Tech (VT) has developed, tested, and integrated a wavelet-based broken rail detection algorithm. This algorithm utilized acceleration data that was recorded by the Vehicle/Track Interaction (V/TI) Monitor, an autonomous measurement system that proved promising during an experimental blind test. To compliment the V/TI Monitor, a geo-fencing technology identified single axle impacts that occur at locations away from known track features.

Both of these methods were evaluated using historical data collected in 2011 and data recorded as part of this study (between December 2012 and April 2013). Difficulties in establishing ground truth data led the researchers to perform dynamic simulations with LS-DYNA and arrange a controlled test over known rail breaks at the Transportation Technology Center (TTCI). For all data sets analyzed, the algorithms were unable to identify broken rails with a high degree of accuracy while minimizing the number of false-positive alerts. This report will focus on the results produced by the rail-detection algorithm from the 2011 historical data and a controlled test at TTCI.

BACKGROUND

Broken rails are a major cause of derailments. An 2008 investigation showed that between 2003 and 2006, there were 335 derailments caused by broken rails and 14 of them resulted

in a hazardous material release. The average estimated cost of a broken rail derailment in 2008 was \$525,400 (Schafer).

The current practice used to detect broken rail relies on the signaling system (where wayside signal and train control systems are in place), which monitors rail for an open circuit that indicates the presence of broken rail. Monitoring an electrified track circuit is not 100% reliable and can lead to missed opportunities for detection, especially when a rail break occurs and electrical conductivity remains uninterrupted (most commonly, when rail breaks happen at a tie plate or joint bar). If secondary rail break detection systems are on board revenue service trains, derailment risk would likely decrease and operations such as high speed and intercity rail transportation could be safer.

OBJECTIVES

Provide real-time rail break monitoring/detection by developing, testing, and implementing a broken rail detection algorithm for an autonomous monitoring system currently used in industry wide operation.

METHODS

This research included an analysis of historical data, a field evaluation with a railroad, dynamic simulations, and a controlled test to produce data for refining and evaluating the feasibility of proposed break detection approaches.



Wavelet Based Detection Algorithm

Wavelet transform analysis was selected as a viable technique to detect broken rail because it is able to identify a discontinuity (or sudden change) in a signal indication. It is believed that a broken rail would appear as an anomaly in a transient signal.

If wavelet-based detection analysis is used to find a rail break, the following steps would occur:

- Acceleration signal analyzed by a continuous wavelet transform
- Fault detection identified by a singularity in the measured signal and quantified via the Lipschitz's Exponent
- A threshold is applied against the scaled magnitude of the Lipschitz's Exponent (here on referred to as Intensity Factor (IF))

The steps above outlines the rail break detection approach illustrated in Figure 1.

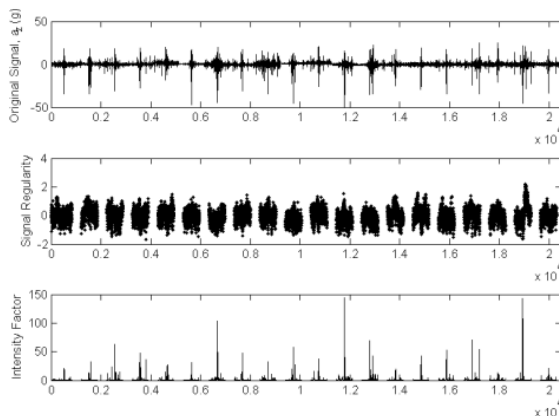


Figure 1. Wavelet Based Algorithm Process

Geo-Fence Method

ENSCO also pursued an alternate approach for the detection of broken rail, one which would identify singled out axle impacts that may indicate a rail failure.

The strategy behind this approach would not count any areas with repeated low level axle impacts over the past year that are probably associated special track work (e.g. switches, diamonds, joints).



Figure 2. Geo-Fence Example

However, a single axle impact with no surrounding hits within the area and no historical repeat of impacts may suggest a potential broken rail.



Figure 3. Singled Out Axle Impact



RESULTS

The researchers were unable to thoroughly assess the various approaches to detecting broken rail, due to difficulties with establishing the ground truth in the historical and revenue service tests. For example, the Receiver Operating Characteristic (ROC) curve generated by varying a single metric when analyzing data collected in 2011 resulted in only a slightly better performance than a random guess.

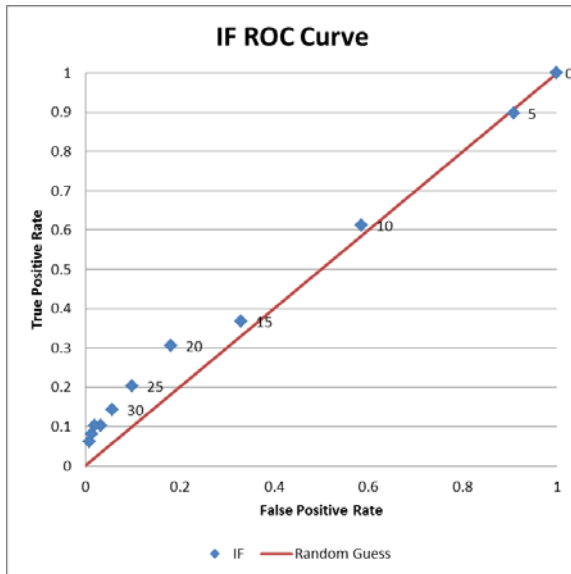


Figure 4. NS 2011 Data - IF ROC Curve

To address the original evaluation approach's deficiencies, dynamic simulations were performed to model conditions for a controlled rail break test. Rail break placement, test speeds, and break sizes were varied. An example of an unsupported break (in-between ties) of 25mm can be seen in Figure 5.

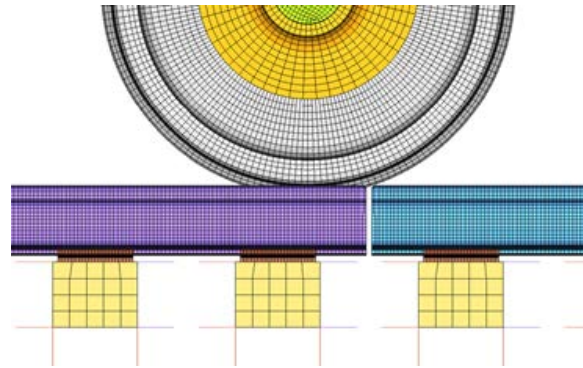


Figure 5. LS-DYNA Rail Break Model

Both the dynamic simulations and controlled tests carried out at TTC resulted in an IF values below 50. Significantly lower than an IF value above 75 for revenue breaks seen in Figure 1. The IF values shown in Figure 6 were calculated at various test speeds within the area of a known break.

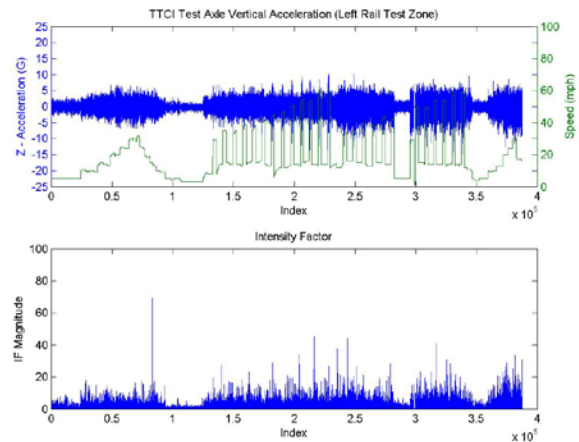


Figure 6. TTCI Test – IF Results



CONCLUSIONS

A wavelet-based algorithm and geo-fence technique that detects broken rail were evaluated against multiple data sets collected as part of this research. A reliable industry ready candidate for detecting broken rail was not produced by this study, because the algorithm was unable to successfully identify a high percentage of true rail breaks while maintaining a low overall false positive rate. The geo-fence technique showed promise for reducing false alarms due to special track work and has the potential to improve any vibration-based detection system, regardless of sensor configuration. The outcome of this study may have been affected by uncertainty in true conditions of the rail in the case of historical data and a revenue test and/or variance in the severity and types of rail breaks reported and tested.

FUTURE ACTION

It is suggested that any future research efforts focus on extracting features from various break sizes and types. Research may also benefit from the use of support vector machines (SVM) to include additional features for classification such as intensity factor, tri-axial accelerations, short-chord measurements (which showed promise), and peak-to-peak measurements. Any future tests to be performed on broken rail may benefit from the following:

- Tri-axial acceleration measurements (lateral, longitudinal, and vertical).
- Increased sampling rate.
- Higher processing power

REFERENCES

Schafer, II, D.H., Barkan, C.P.L., "A Prediction Model for Broken Rails and an Analysis of Their Economic Impact." *Proceedings of the AREMA 2008 Annual Conference*. Salt Lake City, UT.

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CONTACT

Rafael Maldonado

Research Manager
ENSCO, Inc.
2211 Hydraulic Rd., Suite 301
Charlottesville, VA
(703) 321-4603
maldonado.rafael@ensco.com

Jared Withers

FRA Task Manager
Federal Railroad Administration
Office of Research and Development
1200 New Jersey Avenue, SE
Washington, DC 20590
(202) 493-6362
jared.withers@dot.gov

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