

The work described in this document was performed by Transportation Technology Center, Inc.,  
a wholly owned subsidiary of the Association of American Railroads.

# Rail Defect Detection Using Accelerometers

Tariq Abuhamdia (Virginia Tech), Brad Hopkins (Amsted Rail),  
Mehdi Ahmadian (Virginia Tech), Saied Taheri (Virginia Tech), and David Davis (TTCI)

## Summary

As part of Transportation Technology Center, Inc.'s (TTCI) Affiliated Laboratory Program, Virginia Tech has developed methods capable of detecting broken rails and locating the type of impending rail breaks that show up as small surface fractures on the head of the rail. During the first stage of the project, an algorithm was developed that utilizes the vertical acceleration measured by a truck-side mounted accelerometer.<sup>1</sup> The second stage incorporated the longitudinal and the lateral acceleration components, which resulted in improvements over the first stage developed algorithm, thus an improvement in the detection capabilities.<sup>1</sup>

Testing was conducted on the High Tonnage Loop (HTL) at the Facility for Accelerated Service Testing (FAST) in Pueblo, Colorado. TTCI's instrumented freight car (IFC) was used to collect data for algorithm development and validation. The sensors used were accelerometers mounted on top of the side frames on the IFC, which included a GPS (global positioning sensor) unit on the car. During normal train operations at FAST, which include having the IFC in the consist, the train was stopped whenever a broken rail was found by currently used detection methods; i.e., visual inspection and signal system detection. The exact location of the rail break was noted. The IFC vertical acceleration data for train laps, with and without broken rails, was then processed to determine if the algorithm could find the broken rails. The algorithm was also evaluated for the ability to find impending rail breaks by observing the acceleration signatures generated at the same location of the broken rail for previous train passes. The track was also inspected visually to note the locations of special track components.<sup>1</sup>

The tuned algorithm was shown to successfully locate track defects like broken rails, as well as track features and track ride quality exceptions such as impending rail breaks, chipping joints, a low battered weld, and broken concrete ties on the HTL from the accelerometer data without issuing any false positives.

The first stage succeeded in identifying fully developed breaks along the rail. However, it was less successful in detecting finer defects and irregularities on the rail surface. The improvement, through adding the other acceleration components, raised the method's capabilities, enabling detection of track ride quality exceptions, such as a chipped rail joint, and distinguishing track features, such as switches, frogs, and large-gap joints. The refined analysis was done by selecting broken rail events and previous laps to develop the algorithms.

At the heart of the algorithm is a multiple-resolution technique called the wavelet transform.<sup>1</sup> In recent years, the wavelet transform has gained popularity in event detection and health monitoring applications.<sup>1</sup> The power of the wavelet transform is its ability to represent a signal in different scales (or frequency bands). This allows for a simultaneous time-scale representation of the signal. The wavelet transform is therefore able to detect specific events that occur within a signal and give their location in time.



**INTRODUCTION**

In 2012, the Federal Railroad Administration reported that 33.12 percent of train accidents were caused by track failures.<sup>1</sup> This was a 13.75 percent decrease in failures from 2011 and a 32.75 decrease from 2008.<sup>1</sup> Rail service failures were the leading cause of track caused accidents. Rail quality continues to increase as cleaner and harder steels are produced, as well as implementation of more effective grinding practices and improved welds. However, the limitations of rail flaw inspection technologies suggest that rail service failures are likely to occur. Thus, the addition of more effective broken rail detection is likely to be beneficial.<sup>1</sup>

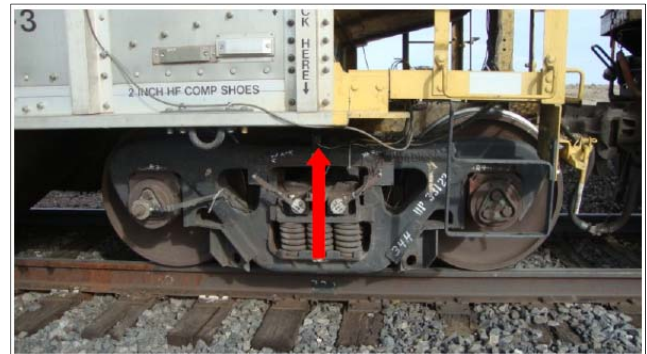
Defect detection based on vibrations measurement is standard in mechanical structures. Some researchers investigate utilizing different acceleration components such as the three Cartesian components and the yaw, pitch, and roll rotations.<sup>1</sup> TTCI has conducted extensive testing at FAST using an IFC equipped with various sensors, including carbody accelerometers, side frame accelerometers, top chord strain gages, bolster strain gages, spring nest displacement transducers, and GPS speed and position measurements. TTCI has also developed software that uses the data collected from these sensors to detect track irregularities. Results from this work show that top chord strain gages, vertical carbody accelerometers, and suspension displacement transducers adequately capture vehicle pitch and bounce motion, which can be related to long wavelength track irregularities. The study also found that vertical accelerometers on the side frames are good for detecting short wavelength irregularities, such as broken rails.<sup>1</sup>

The current method for detecting broken rails from a vertical acceleration signal typically monitors the amplitude of the waveform and flags an event as a defect if the amplitude exceeds a threshold level previously determined by statistical analysis. This method may identify a broken rail when the rail gap reaches a predetermined width. This gap threshold is set high enough to avoid false positives from passing over special track components, such as a turnout frog. As a result, broken rails are often missed, and impending breaks are rarely detected when using this technology. Therefore, Virginia Tech has focused its efforts on improving the methods for signature identification of rail surface irregularities

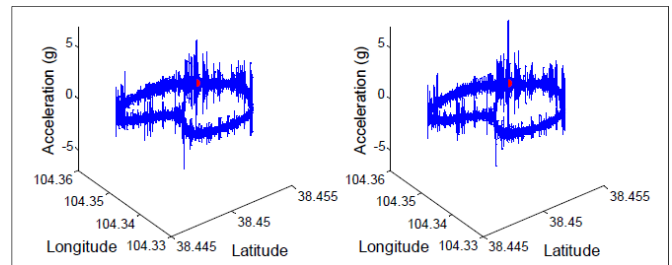
**Test Setup and Data Collection**

Figure 1 shows a side frame on the IFC with an arrow indicating the location of the accelerometer. As the IFC travels around the HTL, data is collected and stamped with GPS coordinates. Figure 2 shows the vertical acceleration signal for two consecutive laps around the HTL. The red dot marks the location of a broken rail. Note the large increase in acceleration amplitude from lap 1 to lap 2.

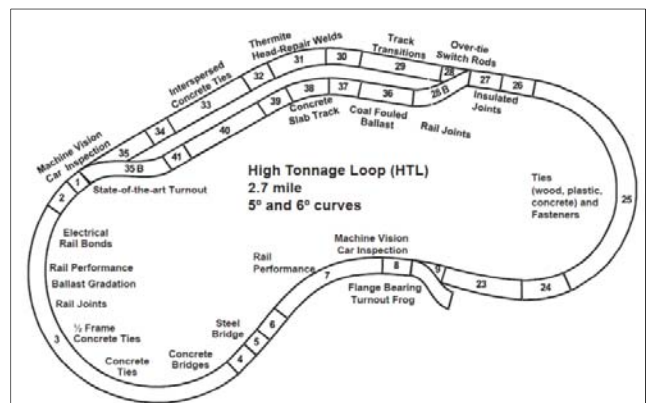
Figure 3 shows a layout of the track sections on the HTL with the different track components in test. Figure 4 shows photographs of track features and rail surface irregularities that caused high vehicle vertical accelerations at various sections of the HTL, which include a No. 11 switch at the end of Section 8, a moveable point frog at the end of Section 35, a fixed point frog at the end of Section 27, a steel bridge from Section 5, a rail joint from Section 29, and a broken rail in Section 34.



**Figure 1. IFC Side Frame with Arrow showing Location of Accelerometer**



**Figure 2. Side Frame Vertical Acceleration Signatures for Two Consecutive Laps around the HTL (the red dot marks the location of a broken rail)**



**Figure 3. Diagram of HTL showing Sections Labeled with Track Components Tested in Those Sections**

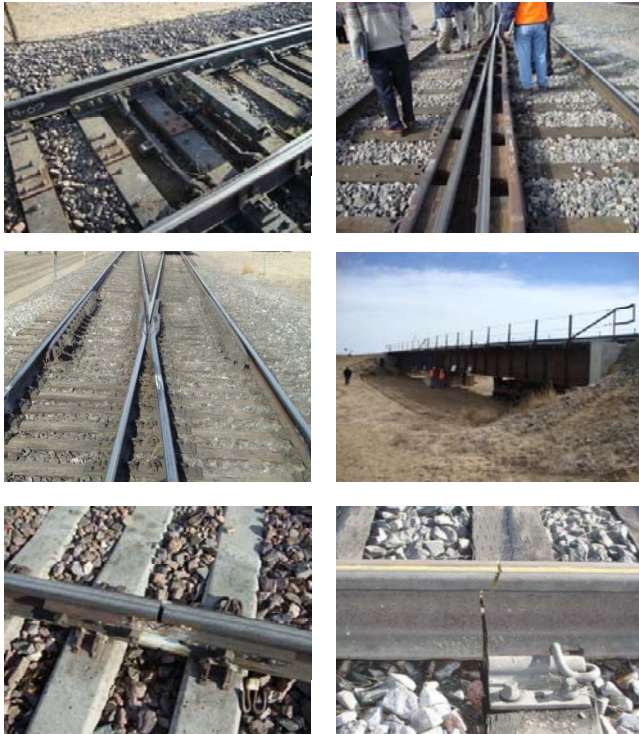


Figure 4. Various Rail Surface Irregularities on the HTL: (clockwise, begin top left) No. 11 Switch, Moveable Point Frog, Steel Bridge, Broken Rail, Rail Joint, and Fixed Point Frog

**Algorithm Development**

The method developed in the first stage of development consisted of a two-step process. The first step computes the wavelets transform coefficients of the vertical acceleration. The wavelet transform is an operation that convolves the raw (or filtered) signal with a wavelet. A wavelet is a short waveform with finite amplitude and duration. The wavelet is dilated and compressed to achieve different scales. The wavelet and scales were specifically selected to extract features from the signal that best represented the signatures of interest.

The second step computes the Lipschitz exponent or intensity factor, a severity metric that can be used to determine whether or not the signature is representative of a defect. If the intensity factor exceeds predetermined threshold, then a break event exists at that location.<sup>1</sup>

The algorithm was “tuned” with vertical acceleration signatures generated from 17 locations of special track components, two locations of surface fractures or impending breaks, and four locations of broken rails. The algorithm was tuned to treat special track components as no-interest events.

The second stage method augments another step before the previous two steps. The augmented step computes the cross-correlation between every two of the three acceleration components. Then, each of the cross-correlation results is fed to the wavelet transform step followed by the intensity factor step. Figure 5 shows the three steps involved in the improved process.

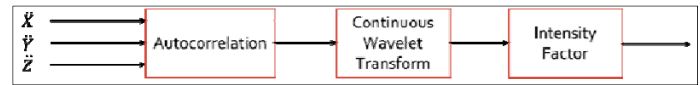


Figure 5. Processing stages

**Break Detection Based On Vertical Acceleration Intensity Factor**

The tuned algorithm of the first stage was validated with vertical acceleration signatures generated from five locations of special track components, one location of a surface fracture or impending break, and one location of a broken rail. Figure 6 shows results from this validation set for one lap around the HTL. The top plot shows the raw vertical acceleration signature, and the bottom plot shows the relative severity, which is used as a determiner of whether or not the signature was generated from a rail defect.

The impending break and broken rail are distinguished from the other signatures in the dataset after the data has been processed with the algorithm. It should also be noted that by simply observing the amplitude of the raw acceleration signal, the impending break and broken rail are not distinguished from the signatures generated from special track components.

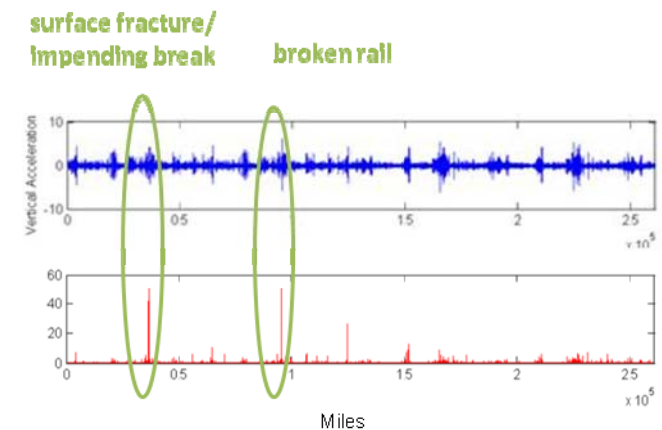
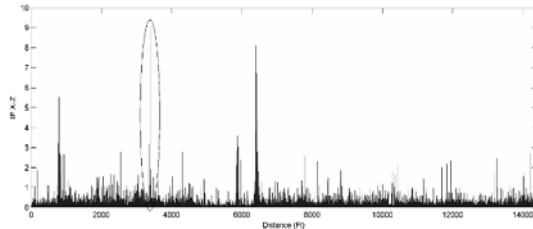


Figure 6. (top) Original Vertical Acceleration Signal, (bottom) Algorithm Output: Relative Defect Severity

**Defect Detection Based on Acceleration Cross-Correlation Intensity Factor**

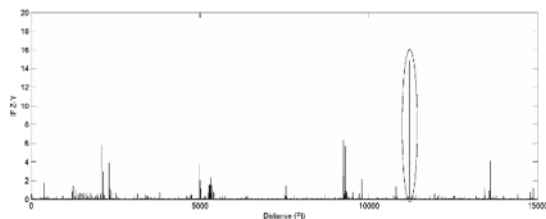
Three types of defects — chipping joint, low battered weld and broken concrete ties — were detected by the method developed in the second stage. The tuned algorithm succeeded in finding the defects in all the data files supplied.

When finding the correlation between the vertical and longitudinal acceleration first, and then feeding the result to multiple-resolution analysis and computing the intensity factor, the location of the low battered weld is better distinguishable. Figure 7 shows the result for the correlation-intensity factor analysis. The highest peak corresponds to the exact defect location.

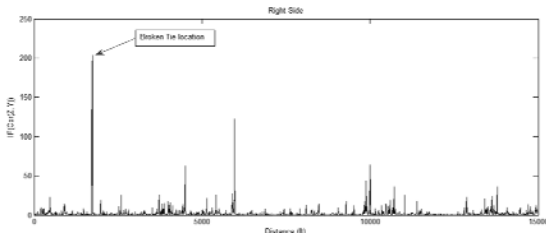


**Figure 7. Intensity Factor of Vertical and Longitudinal Acceleration Autocorrelation of Low Battered Weld Defect. The defect location is circled by ellipse.**

In the chipped rail case, the intensity factor of the correlation between the vertical and the lateral accelerations revealed the location of the defect. The result in Figure 8 shows the location of the defect exactly at the position of the highest peak circled by the ellipse. The same applies to the broken concrete ties case. The intensity factor of the correlation between the vertical and the lateral accelerations yielded the exact location of the defect. Figure 9 shows the distinct intensity factor peak that corresponds to the exact location of the broken concrete ties.

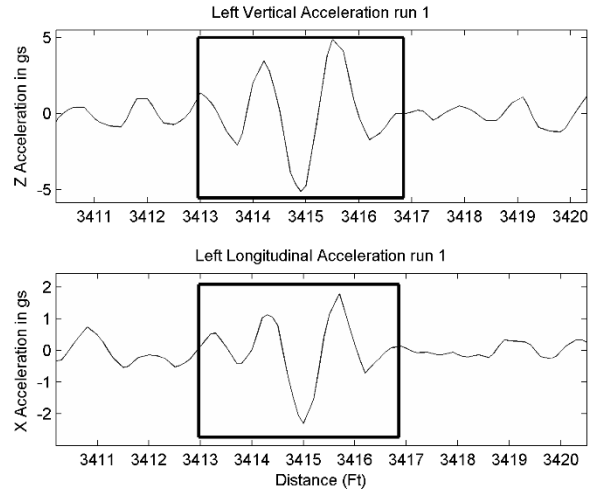


**Figure 8. Intensity Factor of Vertical and Lateral Acceleration Autocorrelation of Chipped Rail Defect. The defect location is circled by ellipse.**



**Figure 9. Intensity Factor of the Autocorrelation between the Vertical and Lateral Acceleration for Signal Containing Broken Concrete Tie Signature**

The detection threshold depends on the defect effective wavelength. Figure 10 shows an example of wavelength for the low battered weld defect. The algorithm determines the wavelength and assigns a detection threshold based on it. The algorithm catches track features like frogs and switches when the detection threshold is set small. To avoid false positives, these events can be ignored based on prior knowledge of the GPS data of the elements or other location data or by raising the detection threshold.



**Figure 10. Vertical (top) and Longitudinal (bottom) Acceleration Signatures of Low Battered Weld Defect**

**CONCLUSION AND FUTURE WORK**

Two methods have been developed that are capable of detecting and locating ride quality exceptions, impending rail breaks, and broken rails from the vertical, longitudinal, and lateral acceleration components measured using accelerometers placed on a unsprung mass of a railcar. The first method successfully distinguished the fully developed rail breaks from special track components without issuing false positives.

The second method detected ride quality and maintenance defects and distinguished them from track features. This indicates that the three acceleration components may be used in identifying rail defects. The ability to track smaller defects encourages the shift from reactive maintenance to preventive maintenance and preventive health monitoring.

Future work includes testing the algorithm at different speeds. All the data used to develop the algorithm was collected with the IFC operating at a constant speed of 40 mph and at a sampling frequency of 256 Hz. However, the algorithm should be validated with data collected at different operating speeds and different sampling frequencies. This validation will allow for the fine tuning of the algorithm and a more practical study of its potential success rate.

**Acknowledgements**

The investigators appreciate the support of Rail Transportation Technologies at Virginia Tech during this project and the financial support under the AAR’s Strategic Research Initiatives Program. Special thanks also to Abe Meddah and the rest of the technical team at TTCI for performing the tests and providing the data.

**References**

1. Abuhamdia, T., S. Taheri, A. Meddah, and D. Davis. 2014. “Rail Defect Detection Using Data from Tri-axial Accelerometers.” *Proc. of ASME Joint Rail Conference*, Colorado Springs, CO.