High-speed rail inspection by non-contact sensing and advanced processing

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Introduction

Undetected rail flaws continue to cause several train accidents worldwide. Common ultrasonic rail inspections use Rolling Search Units (RSUs) that run at a maximum speed of ~35 mph. There is a need to complement existing ultrasonic rail inspections by techniques that allow to test at revenue speed (e.g., 60 mph or above) and can reliably detect critical flaws including defects under shelling. The University of California San Diego (UCSD) has been working on this topic for several years with the Federal Railroad Administration (FRA) and in-kind support from the Burlington Northern Santa Fe (BNSF) and other railroads. The objective of this research is to develop and demonstrate such high-speed rail inspection technology. The potential outcome is a new "smart train" capability where trains can perform their own inspection during normal operations. This testing mode would not require traffic disruptions or complicated inspection scheduling while significantly improving the reliability of flaw detection by exploiting the redundancy offered by multiple train passes over the same segment of rail.

Experimental work

The system under development utilizes two arrays of air-coupled non-contact sensors with stand-off distance from the top of the rail running surface of more than 3 in. (hence fully noncontact) (see Figure 1). The excitation ultrasonic signal is provided by a controlled acoustic source (comprised of two air-coupled transducers) as well as by the wheel-rail interaction. An effective signal processing technique based on segmental-averaged Normalized Cross-Power Spectrum (NCPS) (Huang et al., 2024) is utilized to extract the Impulse Response Function (IRF) between two points of the rail. A statistical analysis is then performed on the reconstructed IRFs to flag true outlier indications (corresponding to internal flaws) and separate them from false positive indications.

Results

Results are shown from tests conducted at TTC (Pueblo, CO) with an FRA research car at different speeds. Two features are used to extract the damage index: inverse of variance (feature F_1) and variance ratio (feature F_2). Figure 2 shows DI for a sample test run at 40 mph using F_1. Test redundancy (repeated passes over the same test track) is also leveraged. The performance of the system is assessed by computing Receiver Operating Characteristic (ROC) curves that best determine the achievable tradeoff between the Probability of Detection (POD) and the Probability of False Alarms (PFAs). Results shown in Figures 3 and 4 reveals the constructive effects of redundancy concept in obtaining perfect detection rate. Also, the positive effect of using feature F_2 (as a more localized feature) in improving the performance of the method is emphasized.

Conclusions

A new version of high-speed rail inspection technology developed by UCSD was briefly presented. The system consists of twelve non-contact receivers that collect signals leaked from the interaction of waves with the rail. The excitation source includes train wheel interaction along with a controlled acoustic source. The defect detection results obtained from field tests at MxV Rail (formerly TTC) confirm the applicability of this technology at revenue speeds, without interrupting the train's regular serviceability.

References

Huang, C., Hosseinzadeh A.Z., Lanza di Scalea, F. 2024. *Ultrasparse ultrasonic synthetic aperture focus imaging by passive sensing.* IEEE Trans. Ultrason. Ferroelectr. Freq. Contr., 71 (5): 518-535.

Acknowledgments

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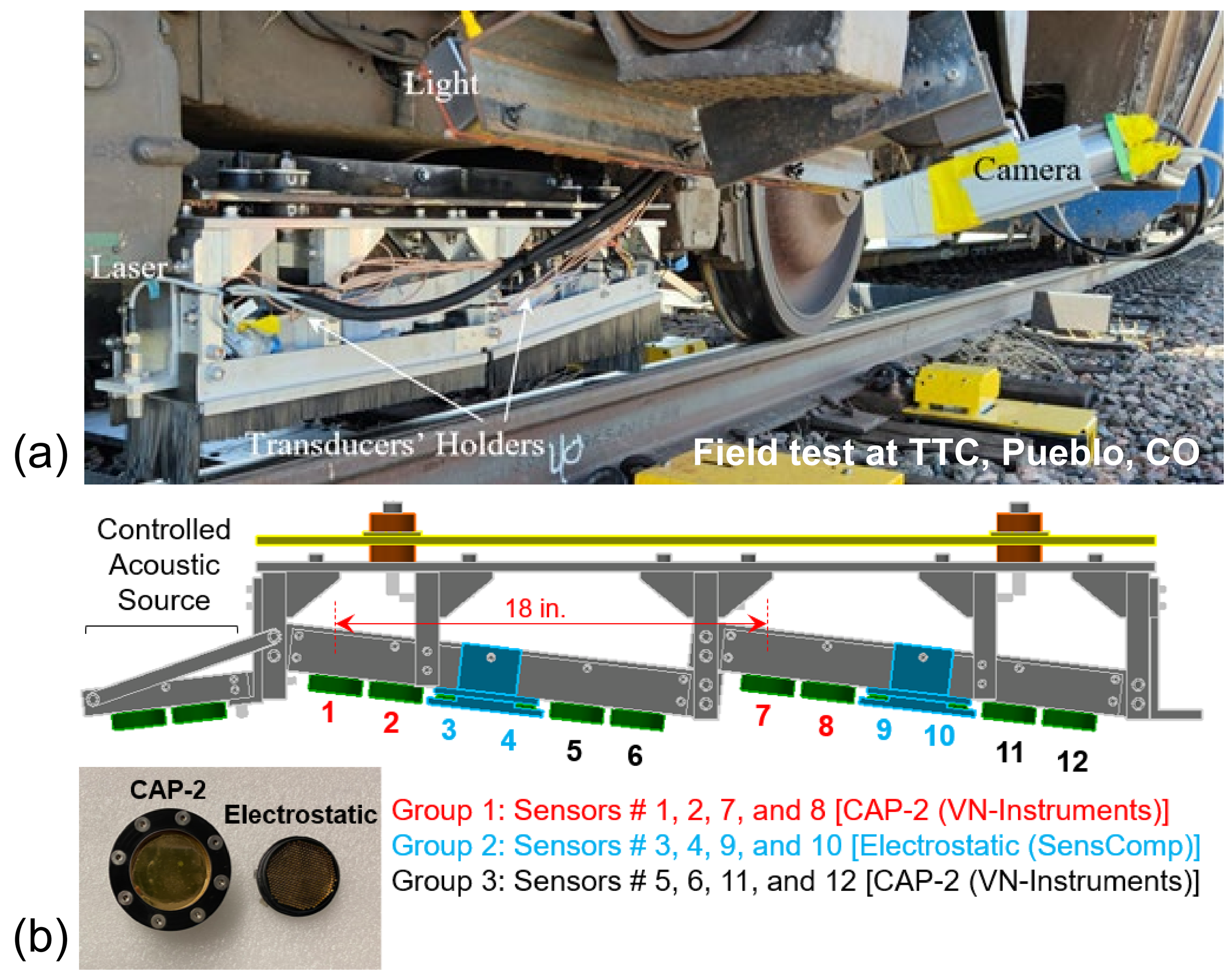

Figure 1. (a) Prototype, and (b) sensing layout

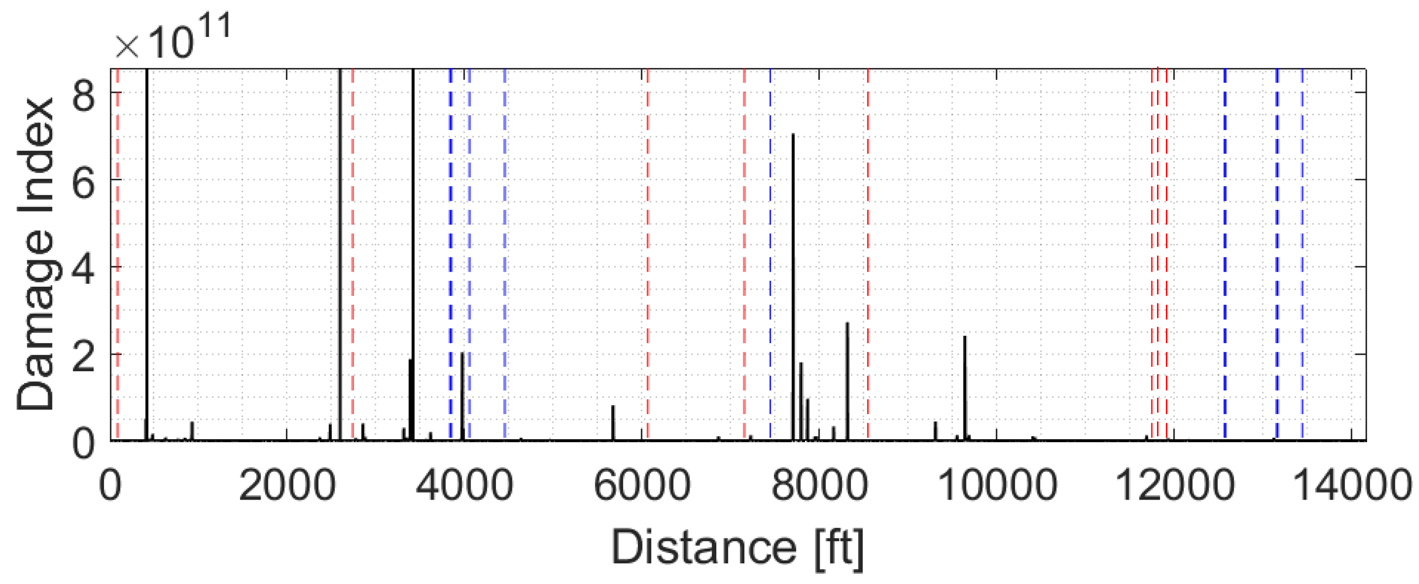

Figure 2: Damage index plot for feature F_1 (i.e., 1/var) for 40 mph

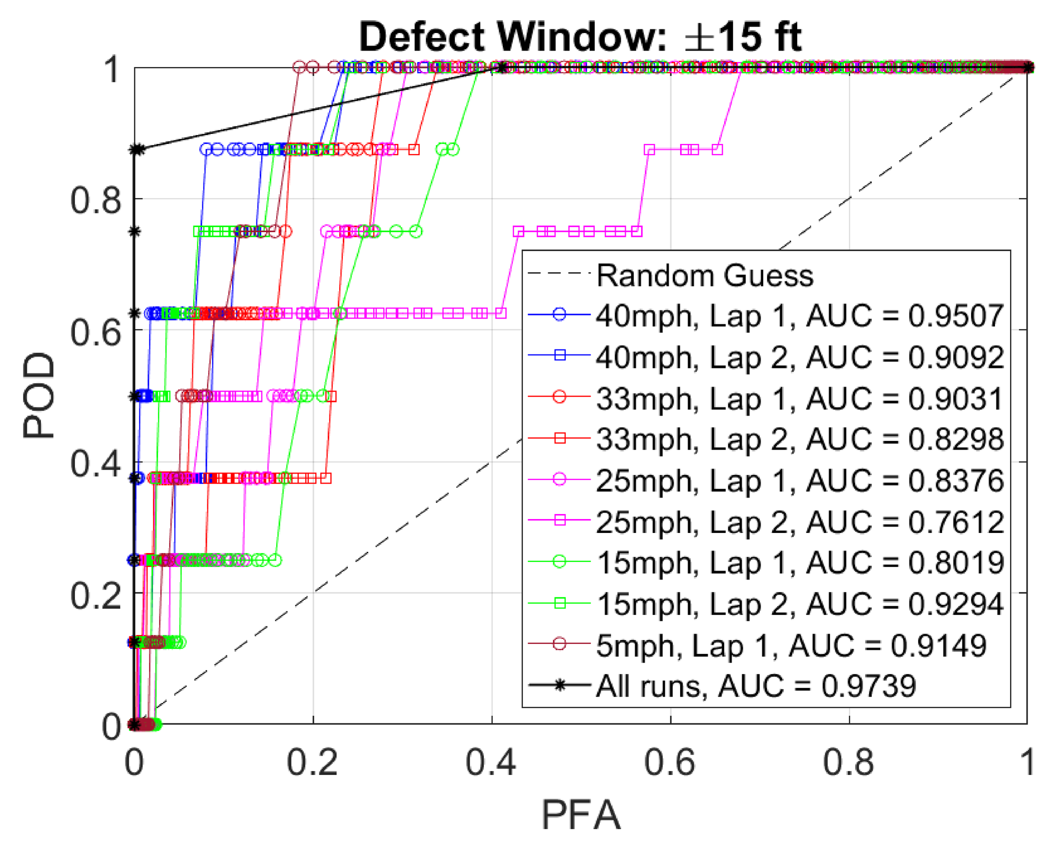

Figure 3: ROC curves for TDs using feature F_1. AUC: Area under curve.

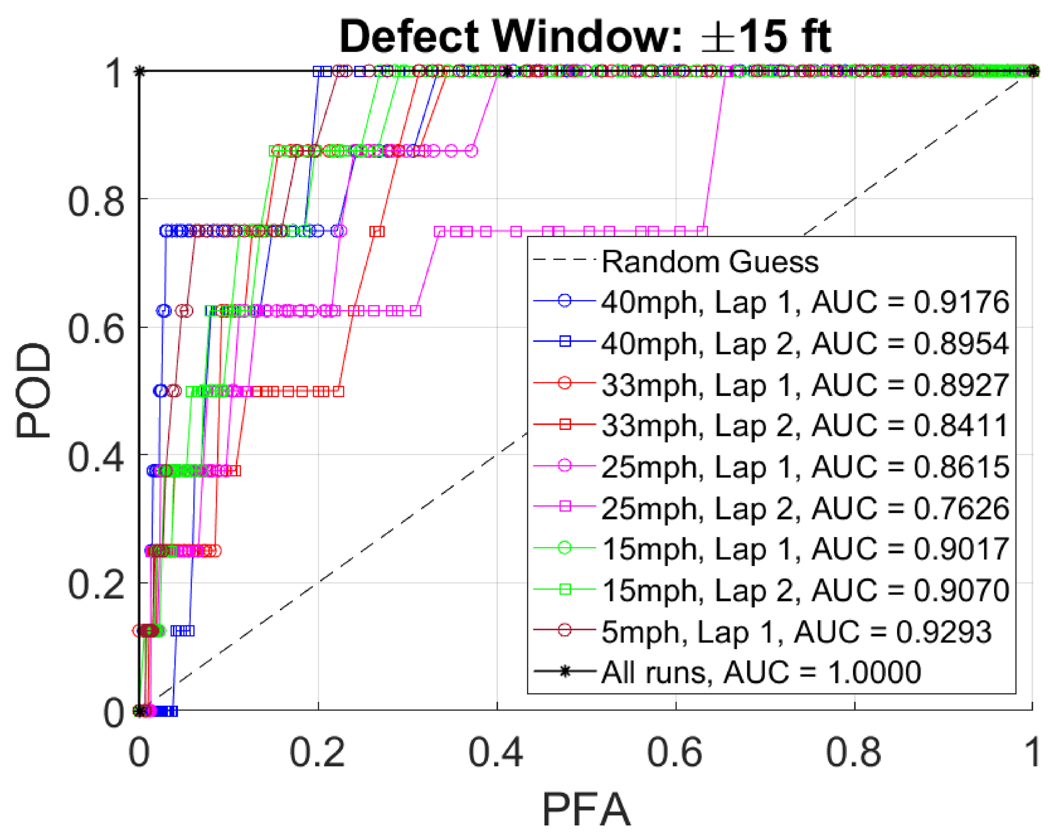

Figure 4: ROC curves for TDs using feature F_2 . AUC: Area under curve. "Defect Window" is the spatial size of detection window flagging as true.

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