One-page summary: Next-gen Smart Sensors Turn Every Train into an Inspector

The objective of this project is to demonstrate the viability of novel technologies to detect rails in unacceptable condition at full track speeds.

We estimate that rail operators in the US pay at least $1B per year to inspect rail, logging 10 million inspection-miles per year at a cost of $100 per inspection-mile. Even using today's fastest platforms for continuous testing, it takes over 19 train-days to inspect a transcontinental corridor, which a revenue service train can travel in less than half that time.

We propose to deliver a system to significantly reduce the cost and increase the speed of performing visual inspections of rail. The system is an autonomous, non-contact inspection system based on light and millimeter waves to detect unacceptable wear and external flaws in rail. The system can be mounted to revenue service equipment and operated at track speeds, allowing inspections twice as fast as currently possible and without any disruption to rail operations. We estimate that our system could reduce the cost per inspection-mile by up to 99%.

By providing near-continuous monitoring of any track in revenue service, our system of small, low-cost train-mounted sensors could support remote and AI-enabled rail inspections, the development of digital twins, and robust preventative maintenance programs. The system would also neatly complement traditional ultrasonic inspections for internal defects. It would outperform expensive laser monitoring systems and data-heavy digital imagery systems on cost, capability, ease of implementation, and upside for further innovation.

The system uses two subsystems in tandem, one based on millimeter waves (mm-waves) and the other on visible light waves, to detect rail wear and defects in real time at full track speeds. The mm-wave subsystem launches a mm-wave towards the rail to monitor its transverse profile. It captures the reflected waves and converts them into a digital "barcode" that is characteristic of the rail transverse profile. A string of "barcodes" thus generated in real time as the train travels is much less "data-heavy" than other formats, such as high-resolution digital images. This allows for instantaneous diagnosis of the segment of rail in view by a simple comparison between the generated barcode with the one that corresponds to an acceptable rail transverse profile.

The mm-wave subsystem is synchronized to GPS to log the exact location of a defect or excessive wear. A fault detection event immediately switches on the optical subsystem further back on the train, which operates as a depth imager to produce an accurate 3D reconstruction of the worn or defective section of the rail. The identified fault can then be verified and classified by a remote observer, either human or AI.

The project team includes Nanfang Yu, a Columbia University professor and a leading inventor of nanophotonic technologies, and Adam Jaffe, a Senior Engineer at Arup with a background in nanoscience and a focus on commercializing nanotechnologies with applications in the built environment.