Whitepaper

Optical Measurement Systems for Monitoring Railway Infrastructure

In a Whitepaper published in the international "Applied Sciences" scientific journal, the authors give a detailed overview of the available monitoring systems for all key components of railway infrastructure.

Review

Optical Measurement Systems for Monitoring Railway Infrastructure – A Review

Kira Zschiesche and Alexander Reiterer

Predictive Maintenance

A wide range of measurement methods and systems are in use worldwide.

An ever-increasing number of passengers and goods, high speeds, heavy vehicles, and, not least, extreme weather conditions are taking their toll on rail infrastructure. Optical measurement systems are suitable for detecting damage to the track infrastructure at an early stage, enabling predictive maintenance.

Numerous such systems are in operation worldwide for railway condition monitoring. Installed on mobile or stationary platforms, they capture different parts of railway infrastructure, from overhead contact wire systems, rail tracks, or clearance profiles to poles or vegetation. The systems must measure precisely, quickly, and reliably despite harsh environmental conditions, a wide temperature range, varying light conditions or different degrees of reflection.

While systems based on tactile methods or visual inspection by humans are still widely used for railway monitoring, non-contact optical sensors are on the rise in this sector. Photogrammetry, laser scanning, and fiber optics are light-based measurement methods mostly used for railway infrastructure monitoring. The spectrum of available optical measuring systems ranges from manually operated systems such as trolleys to fully automated mobile systems that operate from measurement trains or self-driven platforms. Many of the systems can carry out inspections at high speeds without impairing regular railroad traffic.

> "There is a clear trend towards optical inspection technologies, automation and digitization."

Technological trends

In recent years, there has been a clear trend towards automation and digitization in railway monitoring. Multi-sensor systems provide increasingly detailed data and will evolve into collaborative robots that can be used autonomously. Compact, lightweight systems will in future be deployed on small carrier platforms such as UAV. Such systems will increasingly be used in regular train service, which will shorten inspection intervals and improve predictive maintenance. Finally, thermographic cameras or specialized laser setups will be extending non-destructive optical methods beyond surface-level analysis to detect hidden damage.

Novel data processing and interpretation strategies

Optical measuring systems generate large amounts of data, such as point clouds or digital images. Post-processing is often still carried out manually or semi-automatically, but there are approaches to reduce measurement data in real time. However, there is a lack of standardization in data processing, and solutions are often tailored only to specific requirements.

Extracting as much information as possible from the measurement data acquired and making it easily accessible for railway operators will be one of the hot topics of the future. Artificial intelligence and big data analysis can be used to solve clearly defined evaluation tasks and will play an important role in this context. Using AI-based approaches to data analysis, objects and defects can be automatically identified and classified.
In recent years, more and more research has been done on AI-based data evaluation in the rail sector and some railroad operators have been investigating the benefits of AI for specific data interpretation tasks.

Optical measurement methods for railway inspection

Camera systems

mostly used for surface defect detection

- \+ High-speed
- \+ Low-cost
- – Dependent on ambient lighting
- – Focusing

Laser scanners

mostly used for clearance measurement

- \+ High-speed
- \+ Unequalled resolution
- \+ Independent of ambient lighting
- \+ Automated matching with digital model
- \+ Eye-safe
- – Reflectivity of measurement objects
- – Sensitivity to environmental conditions
- – Large data volumes

Fiber optic sensors

mostly used for monitoring strain, temperature, vibration in civil structures

- \+ Highly sensitive
- \+ Robust
- \+ Autonomous long-term monitoring
- – Installation challenging
- – Fibers prone to breakage

Monitoring objects

Individual railway infrastructure components require different measuring technology. Which systems are available on the market and how do these systems perform? A Whitepaper published in the international "Applied Sciences" scientific journal gives a detailed overview of state-of-the art monitoring systems for all key components of railway infrastructure. Here is a brief overview:

Sleepers

- **Main causes of failure** Tamping damage, cracking from center binding, cracking from environmental or chemical degradation, cracking due to dynamic loads, and wear or fatigue of the shoulder/fastening system
- **Measuring technology** Cameras, various sensors
- **Performance** Detection of a variety of typical flaws in sleepers, ballast, and fastenings with resolutions into the millimeter range at speeds of up to 100 km/h. Data analysis using algorithms and model-based approaches
- **Challenges** Limitation of visible area, no information on crack depth, no long-term analyses due to lack of localization
- **Opportunities** Smart sleepers with built-in sensors

Tracks

- **Main causes of failure** Manufacturing defects, improper handling, installation, exhaustion
- **Measuring technology** Cameras, LiDAR (line scanners), various sensors
- **Performance** Detection of all critical track parameters (track gauge, cross level/cant, twist, alignment and longitudinal level, mid-chord offset; varying specifications ranging from measuring speeds of up to 400 km/h and measurement accuracies in the submillimeter range depending on technology and measuring object
- **Challenges** Detection limited to superficial defects and geometrical deviations; no information on damage inside rail material; need for automatic cleaning due to soiling of the sensors

Contact wire

- **Main causes of failure** Wear and tear, excessive sag, corrosion, incorrect alignment, harsh environmental conditions, soiling
- **Measuring technology** (Line-scan) cameras, LiDAR
- **Performance** Detection of height and stagger, position, residual thickness of up to 8 wires; millimeter accuracy at speeds of up to over 300 km/h depending on system
- **Challenges** Need to adjust camera focus due to varying heights of the wire; overexposure of camera images due to varying lighting conditions; wire contamination can lead to incorrect measurement results

Poles

- **Measuring technology** LiDAR
- **Performance** Enables localization / georeferencing during maintenance, even in areas with no GNSS signal
- **Opportunities** Straightforward evaluation due to direct localization instead of indirect localization in point clouds or images

Clearance

- **Risks** Objects (e. g. vegetation) protruding into the track's clearance profile
- **Measuring technology** LiDAR, cameras
- **Performance** Clearance detection without interrupting regular traffic
- **Opportunities** Use of 3D data for Building Information Modeling (BIM) approaches in the railway construction sector

Tunnels

- **Risks** Infringement of tunnel gauge, cracks, delaminations
- **Measuring technology** LiDAR, camera technology
- **Performance** 3D detection of clearance and tunnel surface texture from mobile platforms by using laser scanners, sometimes in combination with cameras; measurements at speeds ranging from 100 to over 300 km/h, resolutions in the centimeter to millimeter range; moisture detection by means of multispectral measurements
- **Opportunities** Detecting hidden delamination without contact, using a pulsed laser (optical hammer impact test)

Panthographs

- **Main causes of failure** Abnormal wear and cracking, material melting due to arcing
- **Measuring technology** Cameras, LiDAR, thermal cameras
- **Performance** Detection of wear, tension, temperature and/or electrical arc discharges; accuracies vary according to distance between system and panthograph and sensor technology
- **Challenges** Dependent on ambient light and weather conditions, soiling of the sensors; varying positions of the carrier vehicle requires sophisticated alignment, calibration and focusing

Wheels

- **Main causes of failure** Cracks, fatigue, scaling, spalling, flat spots, cavities, indentations
- **Measuring technology** Cameras, LiDAR, various sensors
- **Performance** Defect detection by laser profile measurement in combination with cameras, measurement on moving trains at speeds of up to 150 km/h
- **Challenges** Changing light conditions, reflections, shadows, motion blur
- **Opportunities** AI-based evaluation of measurement data for higher degree of automation

Rolling stock

- **Risks** Slipped loads, inclination of wagons, open hatches, defective trains infringing the clearance
- **Measuring technology** Cameras, LiDAR (stationary portal systems)
- **Performance** Detection of train profile in motion; accuracies of about 10 mm achieved at driving speeds of more than 300 km/h
- **Challenges** No detection of bottom side of the train, reflectivity of objects, need for power supply in remote locations/areas

Vegetation

- **Risks** Loss of buffer function of the ballast bed due to ingrown weed roots
- **Measuring technology** Line cameras or multispectral cameras
- **Performance** Speeds of up to 100 km/h, linking with spraying systems feasible
- **Challenges** Dependent on artificial lighting
- **Opportunities** Selective application of pesticides, long-term documentation of vegetation growth

Railroad measurement systems by Fraunhofer IPM

Fraunhofer IPM develops optical measuring systems for monitoring the condition of rail infrastructure. Experts in measuring techniques and optics, designers, electrical and software engineers work together on supplying turnkey solutions for the special requirements of infrastructure operators and providers of surveying services.

Our high-resolution laser scanners and ultra-fast camera systems combined with fast image processing provide high-quality measurement data for predictive maintenance of railroad infrastructure. The robust measuring systems are deployed throughout the world and are characterized by their speed, precision and reliability.

www.ipm.fraunhofer.de/railway

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Contact

Prof. Dr. Alexander Reiterer
Head of Department
Object and Shape Detection
Phone +49 761 8857-183
alexander.reiterer@ipm.fraunhofer.de

Dr. Kira Zschiesche
Group Manager
Mobile Railway Measurement Techniques
Phone +49 761 8857-172
kira.zschiesche@ipm.fraunhofer.de

Fraunhofer Institute for Physical Measurement Techniques IPM
Georges-Köhler-Allee 301
79110 Freiburg, Germany
www.ipm.fraunhofer.de/en