Abstract

This doctoral dissertation concerns the development, construction, and operational evaluation of a diagnostic system for visual inspection of railway rails and sleepers, based on a multi-sensor camera setup and artificial intelligence algorithms. The system enables automatic detection of surface defects and assessment of the degradation level of rails and sleepers, providing objective and repeatable diagnostics as an alternative to manual track patrols. The solution has been designed as modular and suitable for installation on various types of rail vehicles, allowing track inspections to be carried out during standard railway operations without negatively affecting the capacity of the monitored track sections.

The aim of the dissertation was to develop a system that increases defect detection effectiveness by 15–30%, reduces inspection time by 40–50%, and lowers infrastructure maintenance costs by 20–30%. These goals were verified through laboratory and field studies, including tests of the diagnostic system on railway line no. 250. The research hypothesis assumed that integrating visual inspection systems with artificial intelligence algorithms would improve diagnostic accuracy compared to traditional methods used by infrastructure managers.

The research methodology included designing the system architecture, building the multi-sensor setup, developing defect-detection algorithms, and creating an original imperative algorithm for assessing the degradation level of rails and sleepers. The latter represents one of the key contributions of this dissertation, enabling quantitative wear analysis based on images without the need to identify specific defect types. System calibration and an analysis of the influence of driving parameters and environmental conditions on data quality were carried out. The study also included a comparative experiment contrasting the performance of the developed system with the results of a traditional track patrol.

A particularly important element of the dissertation is the author's contribution, which includes the development of an original method for assessing the degradation of rails and sleepers, as well as the preparation and execution of comparative studies between visual inspection and traditional track patrols. The author defined the key functional requirements of the system, participated in prototype construction, acquired and expertly evaluated the data, and developed diagnostic indicators. The author was also responsible for the comprehensive organization and execution of operational tests, including preparation of the measurement setup, integration of the system with a rail

vehicle, and analysis of the results. The research demonstrated that the developed system identifies more defects than manual inspection, including early-stage degradation that is difficult to detect during traditional patrols. This enables better maintenance planning and earlier intervention in response to progressing wear of track components. The system increases repeatability and objectivity of infrastructure condition assessment, reduces inspection time, and minimizes the risk of human error. Automation also improves personnel safety by reducing the need to work directly on the track and contributes to lowering maintenance costs.

The conclusions indicate that visual inspection supported by artificial intelligence can serve as a reliable diagnostic tool in the railway sector and can effectively complement traditional diagnostics. The developed system was positively verified under real operating conditions and represents a significant step toward the digitisation and automation of maintenance processes. At the same time, the dissertation identifies limitations of such solutions, resulting from environmental conditions, vehicle-movement parameters, and the variability of defect characteristics. These limitations open a space for further discussion and for developing methods that enhance the robustness, stability, and applicability of visual systems in infrastructure diagnostics. The results provide a solid foundation for continued research, functional expansion of the system, and its integration with infrastructure management platforms. The dissertation constitutes an original contribution to the development of new diagnostic technologies and has significant implementation potential in the field of railway track maintenance.