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REVIEW OF THE ARTIFICIAL INTELLIGENCE METHODS USED FOR PERMANENT WAY DIAGNOSTICS

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Abstract

The article discusses the implementation potential of the Artificial Intelligence methods in monitoring and analysis of permanent way condition monitoring. Regular inspection of railway track conditions is crucial for maintaining safe and reliable train operations. The diagnostic track recording vehicles and trolleys collect voluminous accurate information on track and turnouts' safety and functional parameters. The traditional analysis of this data made by human experts only turns out to be less efficient and prone to human error than automated analyses. Research into artificial intelligence yielded methods to carry out tasks previously considered too complex to be done without human intervention. Most inspection data can be analysed automatically, be it track and turnout geometry readings and video inspection information. If required, unique annotation overlays and reporting procedures can be applied to provide instantaneous results. Information collected by the test vehicles provides diagnostic data, which the diagnostic software can analyse on the intelligent platform. This intelligent platform can use various Artificial Intelligence tools like expert systems, intelligent agents continuously browsing the diagnostic results database, Genetic Algorithms, Neural Networks, or Bayesian framework as a self-learning system. The automated and unbiased analysis results make sound maintenance decisions possible. Such an approach makes allocating the limited budgets and resources possible with various priorities to optimise the amount of investment required to keep the assets in good health. Efficient maintenance planning has become possible with maintenance work schedules, work order generation, work maintenance support and others, categorising the track and turnout quality based on the collected information.

Keywords: track and turnout maintenance planning, artificial neural networks, Bayesian networks, genetic algorithms, optical track and turnout inspection

1 Introduction

The use of computer support in track diagnostics and maintenance keeps getting more and more sophisticated and efficient nowadays, with tasks ranging from, formerly, exploiting their sheer calculating power, up to now, when lots of effort is being put to embed human expertise and intelligence in the current computer systems. These include both the control and data acquisition tasks and reasoning based on this data.
The Artificial Intelligence research field was first defined in 1956. Projects in this area were awarded millions of dollars for making this vision a reality before it turned out that the project's complexity was significantly underestimated. Investment and interest in AI skyrocketed in the early 21st century when its novel methods were successfully applied to many problems

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in scientific research and industrial applications, using contemporary computing hardware and collecting voluminous datasets.
Artificial Intelligence (AI) techniques, especially machine learning (ML), reinforcement learning, and deep learning, are particularly well suited to data types and looming diagnostics challenges. In addition to knowledge-based KBS (KA) and machine learning (ML), Artificial Intelligence implements other methods, like fuzzy systems, neural networks (NN), genetic algorithms (GA), image processing, big data analysis (BDA), and case-based reasoning (CBR).
Human experts are perishable, reluctant to move where needed, unpredictable, unreliable, and costly. On the other hand, the Artificial Intelligence expertise remains permanent, transferable where needed, with consistent characteristics, has a lower cost per user, accessible anytime, almost anywhere. The response time of the Artificial Intelligence tools is faster than human experts; moreover, it is free from distraction or fatigue, and some of them can explain why and how a particular conclusion has been reached.
For expert knowledge elicitation, one needs to find engineers with in-depth knowledge of track assessment and quality control, experience in track inspection and maintenance actions, a deep understanding of the causes of track failure, and who are involved in planning maintenance actions throughout the network. Their experience with recorded data and measurement systems was also of great value, as was their clear understanding of variables and tracking behaviour over time. In this process, it is less justified to increase the knowledge of people involved in the administrative management of the railway or scientists who are not actively involved in the daily maintenance of the tracks.
To give an example, based on the Polish experience, the first applications should be mentioned of this approach, like the modelling of structural and technological issues in the railway surface, applied computer science in the pavement maintenance system, research into and development of expert systems for the railway roads applications in railway roads. Following works included the system supporting track classifications and distribution of expenditures on surface maintenance (KLAN), a system supporting railway organisations of modernisation enterprises (ORMOD), expert diagnostic systems UNIP and DONG, and an advisory system for diagnosing the CWR (DIAGNOS). Much work was also exerted into an expert system for the selection of kinematic values (WARKIN) support systems for interpretation of the track condition (UNIP, JAKON, DIMO, SOHRON, DOSZ, SOKON) [1-4]). Next, the application of artificial neural networks in railway surface issues followed [5-6].

2 Areas of use

AI tools can process real-time data. Using sensors, digital data or remote inputs, they combine information from many different sources, instantly analyse the material and act on the conclusions drawn from this data. With considerable improvements in storage systems, processing speed, and analytical methods, AI algorithms can provide complex analyses and decision-making. The ever-expanding application of artificial intelligence methods and tools has potential in almost every aspect of permanent way diagnostics decision making [7-8].
The main factors stimulating progress in the effective use of the AI tools are:
- Revealing the technical degradation of the permanent way, which are the critical reasons for derailments
- Legal requirements
- Customer needs in projects, requiring digitalisation, and automatic assessment of the inspection results

To that end the various data collection methods and tools are required:
- Sensors (contact-based, contactless, optical, acoustic; eddy current, ultrasonic)
- Data fusion methods

The data may be collected by:
• Manned systems
• Robotic units

To begin with, however, in systems taking advantage of human expertise and statistics of defects in the track, knowledge elicitation is required. To this end, maintenance and geometry decision questionnaires can be prepared for different infrastructures and operating conditions.

Railway assets can include a wide range of subsystem components such as railway tracks, special tracks (turnouts, switches and crossings, slipways, siding, rings), signals, control and communication systems, aerial cable structures, tracks and stations, bridges and viaducts, tunnels, airspace arrangements (e.g. shopping malls, buses, hotels, etc.)

Machine learning algorithms, for instance, are used to optimise the performance of a given object using examples and/or past experience with it. It can be used, for instance, to monitor rail condition and summarise trends over time. The monitoring of the condition of all railway assets has led to the emergence of “big data”, which was obtained and recorded as a result of onboard monitoring and inspections on the way of fixed and mobile assets [9-11].

Automated Switch Inspection Vehicles (ASIV) are also available for automated railway inspections. The turnout section includes turnouts, rails and joint rails on the open and closed sides of the turnout. All of them can be analysed automatically, even using the virtual templates as equivalents of the formerly used physical ones - which the pertinent regulations may require.

As turnouts represent a structural “discontinuity” in a railway track, featuring a change of its geometry and rigidity, a vehicle moving in a turnout generates a big load. This force leads to rapid degradation of the turnout and its major components and derailment in the worst case. Derailment at turnouts is one of the main categories of derailment, accounting for more than 20 % of derailments caused by the inadequate track condition caused by insufficiently detailed inspections, poor maintenance, inspection errors, and wrong maintenance plans [17-19].

Railway track detection adopts non-destructive methods, divided into vision-based methods such as laser scanners and video image processing, and motion-based methods such as acceleration measurements, which measure the vertical motion of the vehicle to detect damage to rails and other track elements.

As regards the machine vision systems, computer vision research is carried out to inspect turnouts and other railroad components. Such machine vision systems include a video capture system for recording digital images of binary files and custom algorithms for detecting image defects. Machine vision systems are currently used or developed for railroad inspections, including railroad and mobile equipment, including inspection of sleepers, railroad surface defects, railroad profiles, railroad profile ballast, or gauge.

A machine vision system’s task is to collect images and videos of track components. The critical task in their development is to understand where these components are located concerning the system and how many unique views are required to carry out the desired inspections. Views of the components must show them in all their possible positions, let the component(s) be distinguished from the background objects, and be adequately oriented for obtaining necessary measurements.

Moreover, the cameras must be placed to provide views that permit the machine vision algorithms to consistently and reliably detect the track components of interest under various conditions. Assuring stable lighting conditions requires providing lighting systems and light curtains, all of which work reliably in the demanding track conditions.

Based on the analysis of derailment statistics and information from experts in the field, research efforts are exerted to validate track fasteners and switch components. Risk monitor-

ing for rail infrastructure management is based on accurate condition monitoring and due diligence of the track. Because a system trained to inspect products or manage a manufacturing asset can analyse thousands of products or processes per minute, detecting subtle defects or problems can quickly surpass human capabilities [12-16].
It may not be sufficient for an inexperienced diagnostician to obtain the probability of a component defect. This person may need explicit advice on which components should be repaired. To provide this type of support, extending the diagnostic advisory system is necessary so that each diagnosed track or turnout component would have two additional test results: a cost and the relevant decision.

3 Current customer's needs

The end-user – customer's – awareness of the capability of the contemporary inspection technology has resulted in the often sophisticated requirements concerning the new diagnostic systems, also of the autonomous nature [20-21]. They are usually procured to ensure the track and rolling stock safety, increase productivity and efficiency, and reduce operating costs with the automated measurement technologies, modular and scalable, built into either the new customised vehicles or retrofitted into existing vehicles. Such needs may, as an example, refer to:

- Track Measurement Systems
- Track Geometry Measurement System
- Turnout Geometry Measurement System
- Rail Profile Measurement System
- Rail Corrugation Measurement System
- Power Rail Measurement System
- Overhead Wire Measurement System
- Ride Quality Measurement System

Track Imaging Systems with high-resolution camera systems and advanced image processing algorithms that can operate day or night deliver comprehensive track inspection and evaluation, including:

- Imaging System for Diagnostics of Sleepers' condition
- Track Component Imaging System
- Driver View Imaging System
- Rail Surface Imaging System
- Joint Bar Inspection System
- Overhead Wire (Catenary) Imaging System
- Tunnel Wall Imaging System
- Thermal Imaging System

Autonomous Inspection Systems that can operate uninterrupted, more frequently, and without onboard operators on passenger and freight cars in revenue service for cost-effective maintenance planning and railway standards compliance:

- Vehicle / Track Interaction Monitor: real-time monitoring of track and vehicle conditions without impacting the revenue service. Risk alerts should be transmitted via the cellular network, received as email alerts, and viewed in a web application.
- Autonomous Track Geometry Measurement System should measure and create reports with track geometry exceptions, including gauge, cant, twist, unevenness, and alignment checking their values with the relevant safety standards.
- Overhead Wire (Catenary) Measurement System

Track Inspector Tools should accurately know the location and condition of track assets from the condition of the track to the location of a train for efficient maintenance, safer operations, and cost savings through reliable data management.
All exemplary systems should provide easy, authorised access to the inspections and diagnostic analysis results. This can be described as an application for web-based management of inspection schedules, maintenance, defect identification, and follow-up records in performance reports to ensure regulatory compliance.

4 Conclusions

The AI tools mentioned above make use of a wide range of techniques. As of now, in several areas, the reasoning based on measurement data is well understood and formulated in a straightforward procedure. Many of them still need more research, e.g., analysis of the railhead and turnout wear [22]. Such research may lead to novel maintenance data sheets based on the 3D measurements, sometimes making also use of colour images rather than the monochrome ones only, point clouds representing the turnout surface rather than a set of images of transverse sections of the turnout.
Note that various aspects of the track and turnout degradation may be described sometimes best in a set of rules, frames, or scenarios, including heuristics acquired from human experts in the knowledge elicitation process, while others can be presented as a set of formulae, plots, or tables with the numerical data. However, developing diagnostic systems that could propose well-justified decisions in a wide range of track maintenance tasks remains a challenge, calling for development of tools with the ability to:

- coordinate monitoring, diagnosis and supervisory control,
- integrate data driven, analytical and knowledge-based systems,
- emply various knowledge representations, like rules, frames, models, scenarios, and cases,
- employ a flexible structure of controllers, actuators, sensors, and process models, capable to adapt to the actual conditions.

The development of such integrated systems is the future. These systems will be capable of integrating data from ultrasonic and acoustic sensors with video cameras, accelerometers, inertial systems, and location systems. The maintenance planning systems will use the results - often processed by the autonomous software agents.
Thus, many devices on board in-service vehicles automatically provide valuable diagnostic data that can be analysed by diagnostic software agents that constantly scan a database of diagnostic results. Developing agents for each activity/device starts with understanding the ongoing maintenance and repair requirements. This can be done by interviewing operators to understand what aspects were essential to their work and check its quality. Developing a list of requirements with their degree of importance allows for refining the proposed solutions. Only now functions can be assigned to agents in the system.
The next step is to change the agents' behaviour so that the overall behaviour of the entire system matches the expectations. At an early stage of implementation of agent systems, it is recommended that they do not directly control any devices but recommend specific actions to the human operator. This approach minimises the risk of potential equipment damage and should be used for general safety reasons. We limit our considerations to the maintenance and repair of a permanent route only here. Standard static maintenance scheduling can solve the problem and provide sub-optimal but impractical scheduling due to unrealistic assumptions.

This is because real-world systems are complex and dynamic, with many events and processes, with many levels of the organisation, and are subject to random disturbances. Some of these violations may be referred to as new events and may come in based on ongoing checks on the itinerary the night before, and those already in the queue may be cancelled; over time, some tasks may become more or less critical. Also, some resources may be temporarily unavailable as deliveries may be delayed, raw materials may be out of stock, tools may be unavailable for some reason, to name a few: personnel may be unavailable, equipment life may be affected by quality. Therefore, real-time control is required, as all decisions must be based on the current state of available resources.

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