CETRA2024 15-17 May 2024, Cavtat, Croatia
8th International Conferenceon Road and Rail Infrastructure

THE POSSIBILITY OF USING MACHINE LEARNING FOR NETWORK-WIDE PREDICTIVE MAINTENANCE ON URBAN RAILWAY TRACKS – URITMIS PROJECT OVERVIEW

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Abstract

Track measurement and evaluation using hand-held measuring equipment, although resulting with valuable data on the infrastructure has proven ineffective due to operator safety concerns, time consumption and disruption of the regular operation schedule. In recent years, new measuring methods have been established, using specialized or in-service vehicles to collect data on condition rail track infrastructure. However, accessing large datasets requires an extensive amount of time to process and evaluate the data before providing valuable information on track infrastructure condition to the operator. Effective large dataset analysis method could simplify the maintenance and intervention plan for the tramway infrastructure and improve the quality of track monitoring system. Several researchers and authors have investigated the possibility of implementing various machine learning approaches to speed up and automate the evaluation of track condition data. Based on historic and real-time data from in-service vehicles, using machine learning it is possible to detect irregularities and update digital twin model of the track for predictive maintenance. As part of the project URITMIS - Urban railway infrastructure predictive maintenance system based on monitoring of vibroacoustic track properties, machine learning techniques and digital twin models of the tramway track will be investigated to improve maintenance efficiency and track reliability and resilience of tramway networks. This paper presents current state of art as well as case-study of weld detection and evaluation from in-service vehicle bogie acceleration signals.

Keywords: track maintenance, machine learning, urban railway systems, vibroacoustic measurements

1 Introduction

As a part of the project URITMIS, an interdisciplinary research team is developing a system for predictive maintenance of tram track infrastructure based on monitoring of vibro-acoustic properties with its final goal to improve the efficiency of rail and tram traffic and increase safety and comfort of the commuters. Different vibro-acoustic measurement and analysis techniques together with machine learning and numerical modelling are foreseen to process a large amount of data collected from in service vehicles vibration monitoring, to describe and evaluate the condition of the railhead running surface (irregularities, faults). The data analysis will be automated, and the track maintenance plan will be optimized based on historical and real-time data, all to assess the tram track's current and future condition.

1.1 Novel measuring methods using in-service vehicles

Tramway and light rail systems are crucial for modern urban transportation in European cities. Their unique track structure, including grooved rails, solid monolithic concrete base, and shallow grooves, prevents the efficient use of standard measuring vehicles for track condition monitoring. Additionally, the length of urban rail networks often doesn't justify specialized measurement vehicles. The condition of the track is one of the most important factors for ensuring the safe movement of rail vehicles, therefore, it is crucial to work on the maintenance of these tracks to satisfy the requirements set by the standard.
Current methods for measuring individual track geometry parameters, directly measuring rail unevenness and wear with handheld devices, and visual inspection offer potentially very detailed insights into the state of the rail infrastructure [1]. However, these methods come with some drawbacks, including the inability to collect data frequently and the dependence on weather, the low speed at which data is acquired (up to 4 km/h), the disruption of regular service, and the inability to collect data about the track in its loaded state [2]. Using the measurement of the vehicle's noise and vibration levels, it is possible to detect "squat" irregularities [3], corrugation [4–6], and other damages on the track [7–9].
While railway vehicle acceleration data has been a useful tool for identifying track irregularities in recent years, there weren't many applications for light rail and tram systems. With a focus on reactive maintenance and historical data, some researchers have investigated the use of vehicle-recorded vibration signals for tram track damage identification [10]. To reduce workforce and financial limitations, low-cost monitoring systems equipped with GNSS sensors have been used, which reduces data collection efforts [11]. In [12], the idea of monitoring track conditions using indirect measurements of the railhead running surface (via accelerometers mounted on an in-service vehicle) was studied. The aforementioned research is closely linked to the project's concept, however, it focuses on monitoring vibrations on standard railway (ballast) tracks, whereas the URITMIS project aims to develop a predictive model for maintaining tramway tracks.

1.2 Track maintenance models

Models used for track maintenance can be divided into three main categories according to [13]: statistical models, mechanical models, and artificial intelligence (AI) models.
Artificial intelligence models have been developed to predict and track condition degradation using human-like intelligence and computer programs. These models process data using fuzzy logic, neural communication networks, decision support systems, and machine learning, using historical and real-time data for future predictions [14].
The possibility of employing machine learning and digital twin models in railway maintenance is presented in the following chapters. Also, an overview of the URITMIS project and a new predictive maintenance model, as well as discussions of the challenges that come with employing machine learning in such systems is presented.

2 Machine learning approaches in railway maintenance

Machine learning models are used in tasks where the development of explicit algorithms is impractical due to unpredictability. Such models were used in research [15], where the approach of predicting deviations of predefined levels of track quality index (TQI) for the purpose of track maintenance planning, was used. The authors in [16] developed a machine learning model for predicting future damage and warnings of critical parts of railway vehicles based on historical data, while in [17] the possibility of using the standard deviation or deviation rate of track geometry data was investigated using a random forest model (RF)

for predicting the future state of the track. Main observed parameter has been track gauge. In addition to the TQI quality index, the Track Degradation Index (TDI), which is determined based on the amount and volume of irregularities and damage on the track, was developed to assess the condition of the track.
Using the measurement of vibration accelerations of vehicles, it is possible to detect "squat" irregularities [3], corrugations [4,5] and other faults on the track [7]. The aforementioned methods of detection of various irregularities and faults mostly rely on mechanical and mechanical-empirical models that can be implemented for preventive and reactive maintenance but are not applicable for the creation of predictive track maintenance models. The research paper [18] represents a step forward in this field, as a predictive model of the degradation of track geometry elements was created using machine learning, specifically for monitoring track twist and track cant change over a period of time, based on vibration acceleration data. Although this model represents a step forward in this area, it does not rely on irregularities and damage on the running surface of the rail head, which is the idea on which this project would be based.

3 Numerical models for track condition monitoring

Carrying out a classic railway track inspection is usually a financial and time-consuming procedure, so it is performed periodically. The maintenance of the tracks is often carried out as a reaction model that attempts to avoid by monitoring and monitoring the status of the tracks in real time. With the rapid development of computer technology, research is being conducted to develop numerical models for real-time monitoring of the status of railway tracks using machine learning methods.
The monitoring system with numerical models is very useful to detect the source of vibrations caused by high-intensity forces. These forces are generally the result of the passage of the wheels of the tram due to the local defects of the track. The relatively simple railway numerical models allow static and dynamic analysis. These models are usually composed of discrete bodies connected by springs and dampers, which are defined as linear or non-linear mechanical models. However, in order to ensure the reliability of these numerical models and obtain the most accurate results possible in real time, it is necessary to verify the initial data obtained from field measurements and parameter updates of numerical models. Such validated model can then further be used to test extreme scenarios related to different monitored parameters that cannot be achieved on in-service network, such as very serious fault development (rail breaks, bearing failures) as well as operating conditions (i.e. excessive speed, derailment).
The aim of the development of digital twin models within the framework of the URITMIS project is to develop and improve existing numerical models to monitor the current state of a tram line in real time, to detect and determine the type of damage to the individual components of the track structure. The confirmation and continuous update of the numerical models will be carried out by machine learning and artificial intelligence using data obtained from measurements.

4 Overview of URITMIS project

Recent advances in sensors alongside data technology have made it possible and affordable to monitor railway and tramway infrastructure using sensors mounted on vehicles or tracks, enabling measurements of the track in a loaded state. Data obtained from these sensors is processed and evaluated to plan track maintenance using a variety of models, including preventive, reactive, and predictive. The transition to predictive maintenance based on track condition prediction and diagnosis promises to optimize urban railway operations by improving safety, reliability, and efficiency through real-time track condition monitoring and database analysis for decision-making.

The new model of predictive maintenance – URITMIS, implies the development of a system for continuous monitoring of vibrations on the tram track with simple measuring equipment mounted on a conventional tramway vehicle with the purpose of automatic detection, classification, and gradation of irregularities on the track structure. By correlating data with conventional measurement methods and machine learning methods, predictive track maintenance will be ensured.
The data collection will be carried out at several test locations that have been determined based on research conducted by the research team on the tram networks in Zagreb and Osijek. Using machine learning, the detection of infrastructure damage such as rail cracks, rail corrugation, and fastening system degradation can be improved and applied to the operating conditions of conventional tram vehicles. Models will be calibrated with the help of directly collected track parameters such as track geometry, local defects and defects along the route, and vehicle defects such as flat spots on the wheels. A predictive maintenance system will be developed as a final goal of the URITMIS project, with the automation of the collection and processing of data on the state of the track, information on which locations an intervention is needed, in what time period, and to what extent.

4.1 Preliminary measurements and data acquisition

Preliminary measurements are currently carried out through the monitoring of instrumented tram vehicle vibrations on the entire network of ZET tram tracks in Zagreb (116 km), along with other vibro-acoustic and track condition measurements, as a part of professional and research activities on the Chair for Railways of Faculty of Civil Engineering in Zagreb.
Preliminary measurements include the measurement and analysis of the acoustic level of railhead running surface roughness [19], determination of track decay rate of standard railway and tram tracks [20,21], pass – by noise measurements of a railway vehicle [22].Special emphasis is placed on the vibro-acoustic properties of tram tracks, where the design and testing of new fastening systems and the complete tram track are included [23,24]. Research was also carried out in the field of track geometry and determination of degradation parameters of tram track networks [25], determination of the geometry of rail welds and their mechanical characteristics, and the influence of switches and crossings on the increase of vibrations in structures [26,27]. In the research [28], the impact of vibrations from tram traffic on buildings previously damaged in the earthquake was also analysed, as well as the influence of the track distance on the surrounding buildings through the monitoring of vibrations on buildings [29].
Analysis of ride comfort based on vibration signals recorded using accelerometers installed on a tram vehicle [30] and in [31] an overview of methods of testing track conditions and the impact of vibrations on buildings using instrumented (accelerometers) tram vehicles, was made. A detailed analysis of the appearance of corrugations and general roughness of the railhead running surface by indirect (using an instrumented vehicle on which accelerometers are mounted) and direct methods (handheld devices) is presented in papers [6] (Fig.1.). Additionally, the influence of various parameters (curves, micro-location of detected corrugation of running surface), on the appearance and growth of corrugation of the railhead running surface. The wheel wear of tram vehicles was analysed as well [29]. Railhead running surface roughness and wheel roughness are important in determining combined railhead running surface roughness (which can be determined using vehicle vibration acceleration data) (Fig. 1.). From vibration acceleration signals recorded on vehicles, it is possible to detect and identify various irregularities and damages on the track using this data and certain transfer functions (with signal processing) (Fig.1.) and finally create a database that would serve as a basis for creating a predictive model for track.

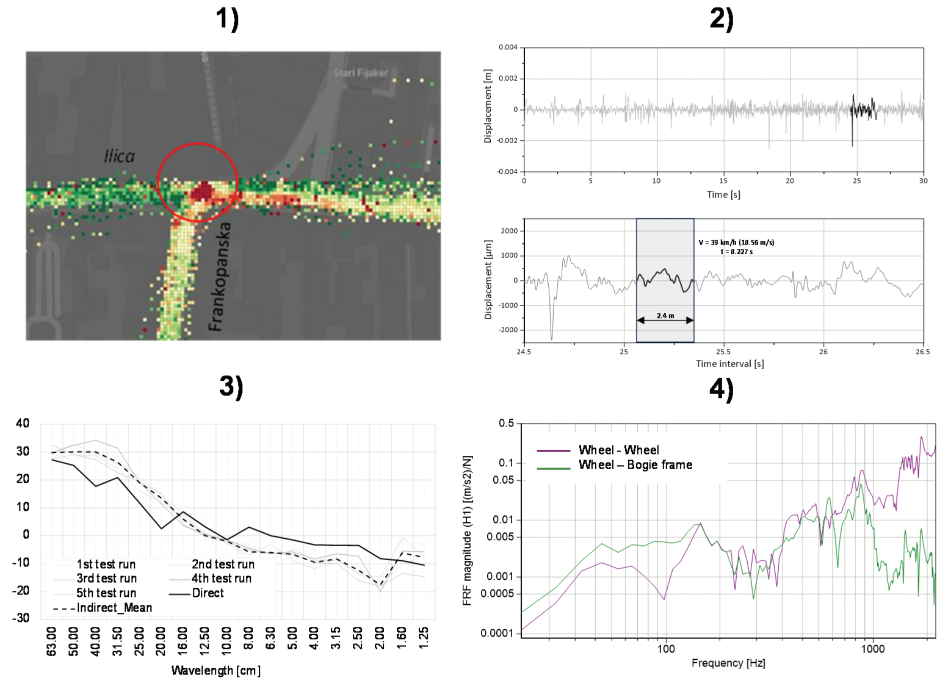

Figure 1 1) Detection of locations with increased vibrations; 2) connection of irregularities with the acceleration signal (displacement); 3) frequency response of rail corrugation; 4) wheel-wheel and wheel-bogie frame transfer functions

4.2 Predictive maintenance system development

Using vibration signal characteristics, the URITMIS project aims to identify locations on tram lines where higher vibration levels exist, due to defects or irregularities on the track (Fig.1.). By combining wheel roughness measurements with combined roughness data, it attempts to find recurrent patterns in the frequency response of irregularities/defect and calculate rail surface roughness (Fig.1.). The methodology also attempts to identify the frequency responses for different irregularities/defects. In addition, it develops numerical models of tram tracks with particular vibro-acoustic characteristics, verifies results through direct surface measurement, and uses machine learning techniques to create a predictive maintenance system. A schematic overview of URITMIS predictive maintenance system development is shown in Fig. 2.

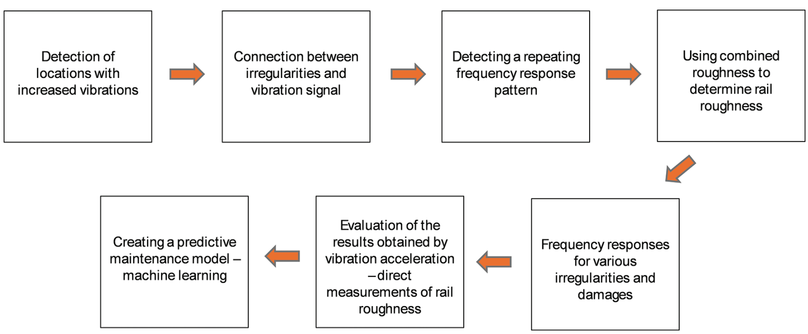

Figure 2 URITMIS system development process

The innovative URITMIS approach will be implemented by acquiring and processing data, analysing noise and vibration from tramway vehicles coming from the wheel-rail interface, identifying track defects in various tram operating conditions using machine learning, and determining track and wheel transfer functions to indirectly compute rail and wheel roughness.is innovation of the URITMIS approach will be implemented through data collection and processing involving analysis of tramway vehicle noise and vibration coming from the wheel-rail interface, utilizing machine learning to detect track defects across various tram operating conditions, and determining track and wheel transfer functions to indirectly calculate rail and wheel roughness.

5 Discussion and conclusions

Identification and classification of faults on tramway infrastructure such as corrugation, bad welds, etc can be a challenging task using limited on-board sensing equipment such as accelerometers or microphones. On the other hand such sensors are optimal for long term monitoring applications given their robustness, reliability and availability. Advanced signal processing techniques and additional parameter determination (such as transfer functions) have to be implemented in order to reliably determine actual condition on rail running surface because data collection is performed away from the actual wheel-rail interface (i.e. axel box, or wheel frame). Large datasets of recorded signals using in-service vehicles together with directly identified faults on the infrastructure give a basis to implement machine learning algorithms to improve detection and classification of faults on rail running surface.
Identified faults on infrastructure will be monitored in a 3-year period giving the opportunity to model the behaviour of different faults in time and generate predictive maintenance model for urban railways. Faults will also be introduced in advanced numerical model of the track structure and updated according to actual monitoring results. Advanced numerical model will give opportunity to test the development of faults beyond the monitoring period and test certain critical scenarios not reproducible in in-service conditions, to further improve the reliability of tram infrastructure maintenance models.
Finally, a reliable and robust predictive maintenance model can serve as a tool for infrastructure managers to assess the state of infrastructure, identify critical sections and prioritize and plan needed maintenance work based on actual filed collected data.

Acknowledgments

This paper was written as a part of the “URITMIS – Urban railway infrastructure predictive maintenance system based on monitoring of vibroacoustic track properties” project NPOO. C3.2.R2-I1.06.0001 that is funded as a part of Development and research grants from National plan of recovery and resilience, financed by EU Commission.

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