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Systematic Mapping of Research on Railway Track Superstructure Condition Monitoring 2016-2021

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Abstract

A systematic mapping on the research within railway track condition monitoring has been performed for the years 2016 to 2021. The method of literature review is repeatable and systematic; allowing for more papers to be assessed compared to a systematic literature review. 166 papers were analysed, where information regarding sensors as well as method of data collection was collected. Sensor methods have predominantly been accelerometer based and vision based. Track-following methods, especially vehicle borne sensors have been more popular than specific trackside measurements.

Although in-service vehicles were more popular than specific track geometry vehicles, many authors did not present the type of vehicle used, indicating that this was not an important point to make for those authors. The use of in-service vehicles has the potential to increase the amount of data collected and maximize track availability even during measurement campaigns. Regarding accelerometers on track following vehicles, both the car-body and axle-box were popular locations of the sensors. The suspension systems between axle-box and car-body filters high frequency input, perhaps making the car-body position more suitable for long wavelength irregularities, and the axle-box better for short wavelength irregularities. The fact that there is no clear preference toward either location indicates that there is no method that is best practice for all types of track superstructure irregularities.

In future work, one may evaluate the monitoring system's ability to assess degradation of the track superstructure over time, as well as investigating the use of measurement results as support for maintenance decisions. The first topic would aid in the assessment of the severity of the degradation and risk of failure. The latter topic would increase insight into the value of information for track monitoring measurements in structural health monitoring.

Keywords: systematic mapping, review, railway track, monitoring

1 Introduction

Track condition monitoring results in better economy and safety due to more efficient, condition-based maintenance. The track can be monitored through several methodologies, including track following systems, such as trolleys and railway vehicles, as well as sensors placed at discrete locations along the track. Railway track monitoring is not a new idea, with the first track monitoring vehicle appearing in literature as early as 1928 [1].

As a field of knowledge with a long history both in industry and research, there have been a few literature reviews prior to this one. In his state-of-the art review from 2019, Farkas [2] performs a review of measurement of railway track geometry, with comprehensive review of common sensors and their limitations and possibilities. Weston et.al in 2015 [3] observe specifically the use of instrumented in-service vehicles to monitor the condition of the track. In 2020, a systematic literature review by Xie et.al [4] reviews different data-driven models for predicting track maintenance needs.

These three reviews show clearly that the research field is broad, spanning from sensor choice, sensor location and data analysis models. Even beyond the scope of these papers, condition monitoring also may cover maintenance strategies based on the measured or model derived status of the track. The organization of topics within the research field is visualized in Figure 1. First, the observed phenomenon can vary, most generally between long wavelength track irregularities and short wavelength, as well as other obstacles on the track. The method for data collection, including the sensor choice and position needs to be decided. From the measured data, information about the status of the track can either be correlated to a multibody physics model or to known evidence about the track. Finally, an algorithm must be built for damage detection. How this is finally used for maintenance decisions, is the maintenance optimization.

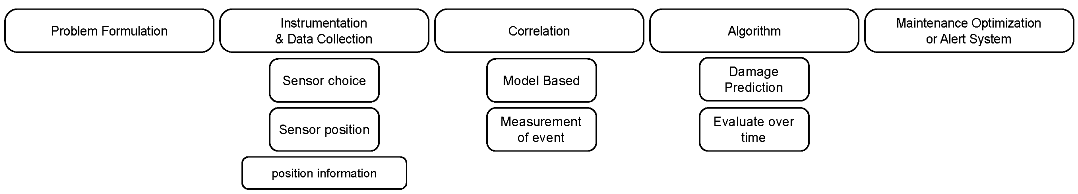

Figure 1: Topics within the research field of track condition monitoring

This paper presents a systematic mapping of railway track condition monitoring research in the period 2016-2021 to provide an overview of the current sensor technology, the latest advances in the field and find prospects within railway track condition monitoring.

2 Methods

The method is inspired by guidelines by Petersen, Vakkalanka and Kuzniarz [5]. Although the guideline is intended for software engineering, the procedure is suitable for the transport engineering domain. The method consists of research questions, search terms, literature search, inclusion criteria, data extraction, and analysis. Validity and repeatability evaluation was not performed in this review, deviating from the method in [5].

The research questions set the focus of the systematic mapping. The goal of this paper is to understand the trends and research gaps in track condition monitoring; the research questions reflect these goals.

- What are popular methods of track condition monitoring – including sensor choice and position?
- What trends within railway track condition monitoring are there?
- What are the research gaps in the field?

From the research questions, the search was designed using the PICO process [5], shown in Table 1. The search string used was **"railway track" AND (condition OR status OR quality OR health) AND (monitoring OR detection OR measurements).**

Population	**Intervention**	**Control/Compare**	**Outcome**
Railway Track	measurement	n/a	Condition, status, track health

Table 1: PICO terms used for creation of search query

The databases chosen aimed to find a varied sample, rather than to achieve an exhaustive search of existing literature. The databases selected were Engineering Village, IEEExplore, ProQuest, ScienceDirect and Scopus. These were considered a good variation of credited science and engineering databases. The keyword search was applied to the title, abstract, and keywords, when allowed by the search function on the website and all results until and including 2021 were included. The number of papers per database is found in Table 2. After removing duplicates, a total of 725 papers were exported to the software EndNote 20.

Database	**Search Results**
Engineering Village	525
IEEExplore	114
ProQuest	132
ScienceDirect	72
Scopus	308

Table 2: Number of papers per database

To ensure that only relevant papers to the systematic mapping were included, inclusion and exclusion criteria were formulated. Only papers specifically on the monitoring of railway track superstructure using measurements published between 2016 and 2021 were included, excluding foreign objects and electric components. Literature reviews on the topic were also included for reference of previous publications but were excluded from analysis. Publications observing ballast subgrade, wheel, and vehicle damage were excluded since they were outside of the defined scope.

After exclusion, 166 articles were included, of which 7 were literature reviews. Data analysis was performed by reading each abstract and writing keywords related to the paper. Some papers required additional reading of the introduction or conclusion chapter to obtain correct keywords. The gathered data was analysed using the text analytics toolbox in MATLAB.

3 Results

The number of publications per year is shown in Figure 2. There is a small increase in publications per year in the past 6 years. Note that a superficial search of the articles from the period 1986-2015 resulted in only 104 publications compared to the 166 publications between 2016-2021. This indicates that a strong increase in publications may have occurred in the 2010s.

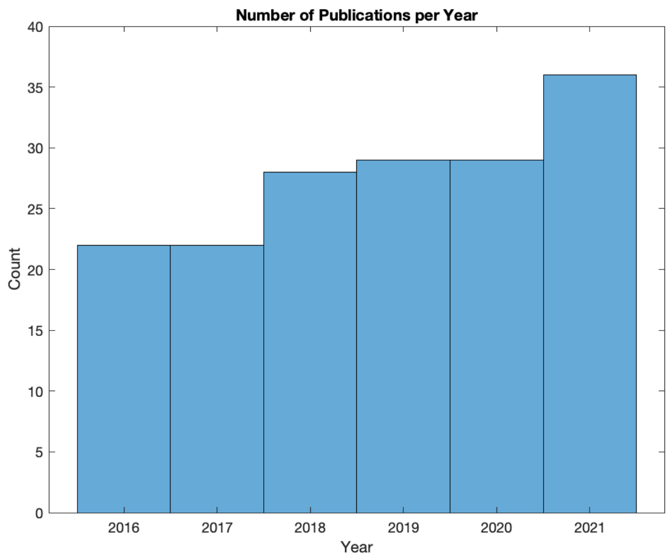

Figure 2: Number of publications per year

The most popular sensors are presented in Figure 3. If more than one method was covered in a paper, all were included in the statistic. The most popular method was accelerometers, followed by vision-based measurement devices such as cameras or 3D scanners. Although the distribution of sensor choice heavily favours accelerations and vision-based methods, there is a large variation in total number of sensor types. This may correspond to the large variety in track anomalies that need observation, such as surface defects, misalignment, and subsurface cracks.

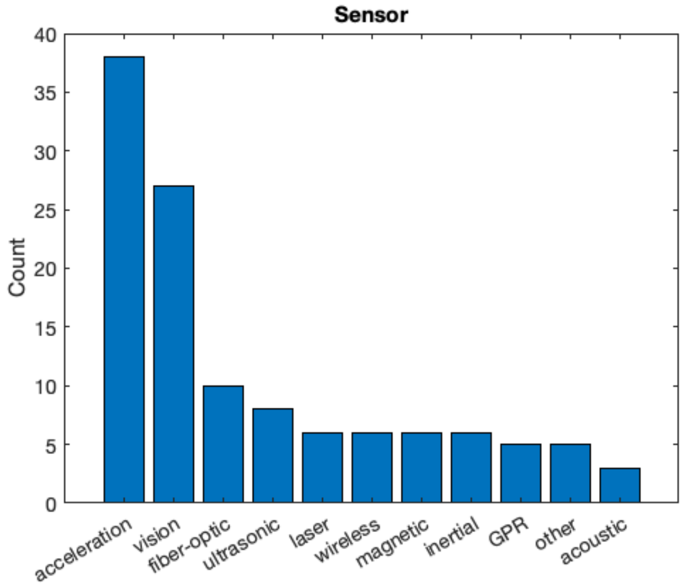

Figure 3: Popular sensor choices

The positioning of the sensor categories and distribution is shown in Figure 4. The vehicle-based method is outstandingly popular, although trackside sensors occurred relatively frequently as well. Other track-following methods, which included UAVs, trolleys, and multi-robot systems, were less common. Track-following methods have the advantage that they cover large distances of the track. However, localization issues arise, and depending on the method of instrumentation, the availability of the track may decrease resulting in revenue loss. Trackside methods may be more suitable for measuring specific components, such as bridges, switches, and crossings.

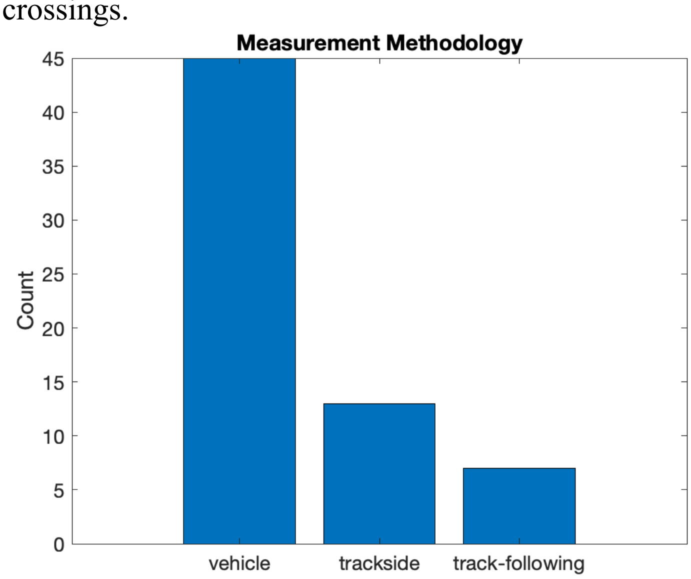

Figure 4: Measurement methodology, i.e., the attachment of the sensor to a position on the track or a moving body

Regarding the vehicle-based methods, the distribution of sensor position on the vehicle, as well as the type of vehicle assessed, is shown in Figure 5. Car-body placement and axle-box positions were equally common, although in ten of the analyzed abstracts, the authors did not clearly state the positioning of the sensor. The primary suspension between axle-box and bogie acts as a lowpass filter, resulting in the bogie and car-body position obtaining less high-frequency content [3]. These positions may be more suitable for monitoring long-wavelength irregularities.

On the right-hand side of Figure 5, the vehicle type is shown. The use of in-service vehicles was more popular than track monitoring vehicles. Noticeably, it was common to not clearly state the vehicle type in the abstract. A possible explanation could be that the track monitoring vehicle is status quo in industry in many countries now; a vehicle of that type does not need further explanation in research papers using them.

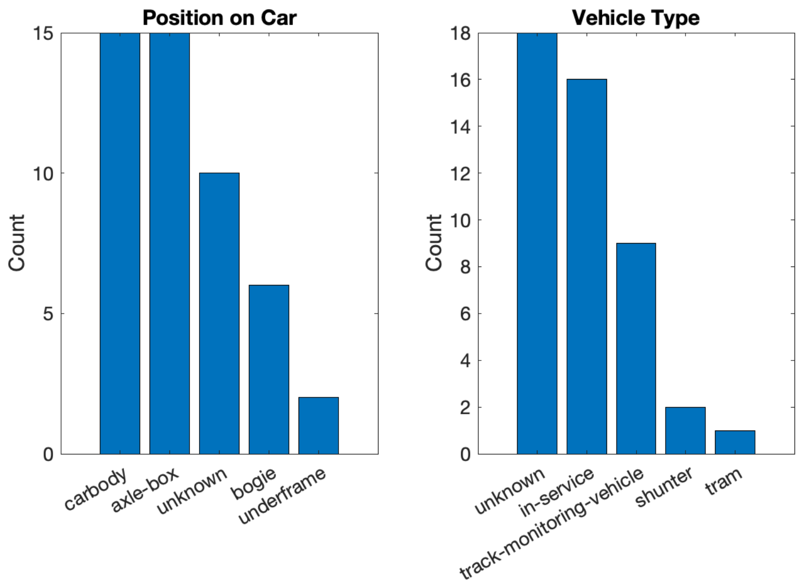

Figure 5: left: position of sensor on a vehicle car, right: type of vehicle used for measurement

4 Conclusions and Contributions

This paper presents a systematic mapping of research on railway track condition monitoring between the years 2016 and 2021. Railway track monitoring is not a new feat, and research on the topic has been increasing in intensity. Only in the past six years have many different sensor mechanisms, measurement positions, and vehicle types been studied for their potential in contributing to the detection of irregularities on the track and track misalignment. This systematic mapping shows the trends in methodology in research history for railway track superstructure health monitoring, illustrating that accelerometers and vision-based methods are popular sensor choices, and that the use of instrumented vehicles has dominated the track-following methodology compared to for example UAVs, trolleys and multi-robot systems.

The position of sensors on the vehicle is equally popular within the carbody as on the axle-boxes, although the primary and secondary suspension of the vehicle often filters out much of the high-frequency content. This find solidifies the theory that no single measurement position is most suited for detecting all types of track irregularities, as this would have resulted in one clear dominating measurement position.

Although the in-service vehicle is more popular than the specific track monitoring vehicle, there is a large portion of the evaluated research that does not state the vehicle type in the abstract. As such, we cannot draw clear conclusions on the popularity of in-service vehicles for the use of measuring track condition. This trend is valuable, because the use of in-service vehicles has the potential to drastically increase the amount of data collected and maximize track availability even during measurement campaigns.

In future work, one may evaluate the monitoring system's ability to assess degradation of the track superstructure over time, as well as investigating the use of measurement results as support for maintenance decisions. The first topic would aid in the assessment of the severity of the degradation and risk of failure. The latter topic would increase insight into the value of information for track monitoring measurements in structural health monitoring.

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