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Thermal Vision Analysis of Wheel-Rail Interaction: Application of Convolutional Neural Networks

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Abstract

This paper focused on the application of a Convolutional Neural Network in the analysis of the thermal images of the wheel-rail interface. The first part is centered on the primary motivations behind conducting thermal imaging measurements in the wheel-rail contact area and the analysis of the thermograms using Convolutional Neural Networks. It was emphasized that automatic classification of the wheel-rail contact types can provide valuable insights, especially considering the spatial data and statistical metrics, which can be useful in the case of wear intensity analysis. Subsequently, the methodology of thermal imaging measurement and the design of a classifier utilizing Convolutional Neural Network technology were presented. In the context of result analysis, the very promising capabilities of detecting various contact types using Convolutional Neural Network s were highlighted. The paper concluded by summarizing the key benefits arising from the proposed technology and its potential impact on wheel-rail interaction studies.

Keywords: wheel-rail interface, thermal imaging, convolutional neural networks, image classification, frictional heating, creepages.

1 Introduction

Creepage between the wheel and the rail leads to the dissipation of frictional energy into heat [1]. This phenomenon, in turn, increases the temperature of both the wheel and rail materials, potentially causing phase transformations and consequently various wear types of wheel and rails. Furthermore, the heating of the wheel and rail may induce fluctuations in the tangential force values, contributing to the dynamic instability of the vehicle on the track. This results in a deterioration of driving comfort and safety, the generation of intensified vibroacoustic phenomena, as well as accelerated wear of infrastructure elements and rolling stock.

Frequently, the assessment of wear levels relies solely on interval measurements, lacking comprehensive information on the interaction within the relevant context, encompassing infrastructure, rolling stock, and dynamic factors. Due to the nature of wheel-rail contact mechanics and the adverse impacts of temperature increases, there is a significant need to identify scenarios where substantial heat generation occurs in real operational contexts. To address this, Infrared (IR) and CNN technologies are proposed as valuable tools for conducting a comprehensive analysis.

Thermal imaging of the wheel-rail interface enables the detection of local temperature rises at the interface, resulting from the dissipation of frictional energy into heat, in real time and taking into account the entire spectrum of operating conditions [2]. It thus represents an extremely valuable research tool. Each type of wheel-rail contact naturally exhibits a distinctive temperature distribution, making it detectable through the arrangement of temperature rises. CNNs are an essential Deep Learning tool in the issue of image classification, proving their efficiency and effectiveness in many areas of the application. Thus, the combination of these techniques opens up the possibility for an analysis of the vehicle-track wear intensity, which would include the classification of contact types, the generation of statistics, or the spatial visualization of specific contact situations.

2 Methods

The thermal imaging measurement was carried out on a typical low-floor tram vehicle exploited in the Poznan tram system. The analysed vehicle was a three-bogie vehicle with a rigid bogies configuration and classic (rigid) wheelsets.

The FLIR A700 thermal imaging cameras were placed behind the attacking wheelset of the middle bogie (non-driven) and aimed at both wheels. To avoid the direct observation of the contact through the camera lens, which could lead to lens damage by third bodies, a mirror dedicated to IR measurements was used. By appropriately aligning the mirror, it was possible to achieve an optical axis adapted to the camera's placement along the transverse beam of the bogie frame (Fig. 1).

Figure 1: Measurement setup.

The classification of thermal images was conducted using CNN technology. A pre-trained MobileNetV2 [3] architecture was employed, onto which a classification layer suitable for the specific types of contact between wheel and rail was applied (Fig. 2).

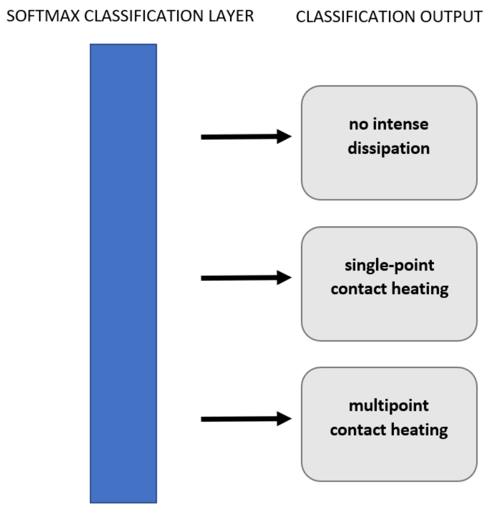

Figure 2: Classification layer and the output.

Pre-labeled thermograms depicting the contact situation were used for training, according to the supervised learning paradigm. Initially, transfer learning was conducted, and subsequently, through the unfreezing of individual layers and the determination of training parameters based on experiments, network fine-tuning was achieved.

3 Results

As a result of thermal imaging measurements, thermograms were obtained capturing typical contact situations with local temperature rises between the wheel and the rail. An exemplary thermogram is presented in Fig. 3. Within the quantitative analysis of the images, temperature increases reaching a value even of 40°C were recorded.

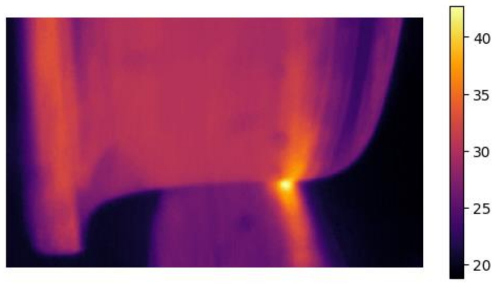

Figure 3: Sample thermogram with temperature colorbar.

During feature engineering three main contact situations classes were distinguished: no intense dissipation, single-point heating, and multipoint contact heating (Fig. 4). Each of these contact situations has its thermal signature resulting from the nature of the wheel-rail interaction.

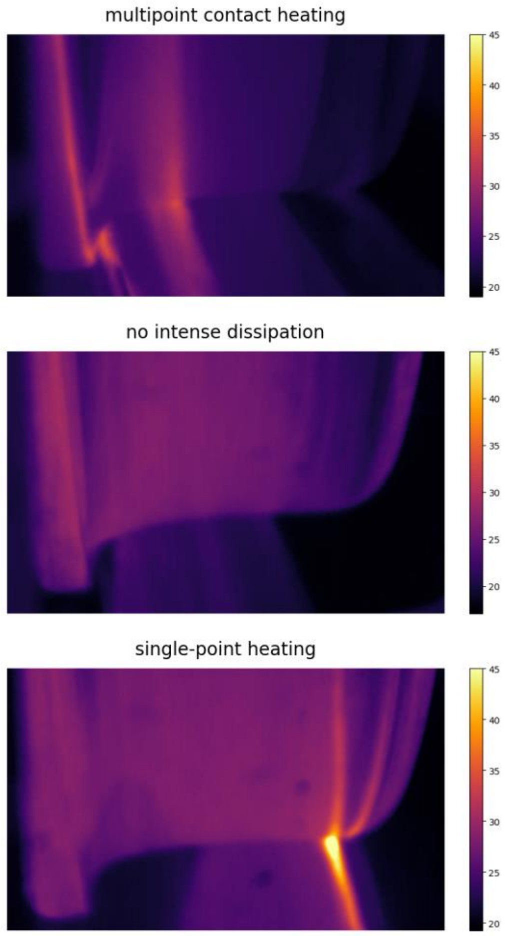

Figure 4: Predicted contact situations.

After fine-tuning, the designed classifier demonstrated the capability to identify contact types with an accuracy of approximately 98%, accompanied by respective F_1 values of 1.00, 0.98, and 0.97, for no intense dissipation, single-point contact heating and multipoint contact heating respectively. Such classification metric values indicate the effectiveness of the designed classifier in classifying types of contact.

4 Conclusions and Contributions

Detecting and subsequently limiting localised increases in temperature at the wheel-rail interface is essential for improving the performance of a rail transport system. Experiments carried out have shown that quantitative thermal imaging measurement is feasible under real operating conditions. Moreover, the use of CNNs provides a basis for the automation of data processing and further development of the algorithm, thus providing a framework for a comprehensive contact situations analysis. On this basis, it is proposed to use the measurement system to identify the relevant wheel and rail wear for the specific operation conditions including:

- rolling stock configuration,
- infrastructure context,
- dynamic conditions,
- weather conditions.

Insights into wheel-rail contact situations under these conditions will enable operators to characterize rolling stock configurations and infrastructure sections in terms of wheel and rail wear, thereby enhancing the informational value.

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