



## Combined use of sensor data and structural knowledge processed by Bayesian network: Application to a railway diagnosis aid scheme

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### ABSTRACT

This article describes a hybrid diagnosis system based on the combined use of sensor data (local information) and structural knowledge (global information). The approach is illustrated on an application that involves the detection of broken rail for railway infrastructure. Recently, there have been a large number of attempts to solve diagnosis problems by mixing low-level and high-level data. The inherent difficulty of combining different levels of data is offset by the benefits that accrue from additional knowledge: prior information can improve the understanding of sensor data. To introduce the application context, the paper describes first the importance of rail diagnosis. The technological solutions for broken rail detection are then listed. Since the used sensor is able to detect other kind of rail defects or singularities, the defect classification phase also involves the problem of distinguishing between real (broken rail) and false defects (rail singularities). With the help of prior information extracted from an infrastructure database, a Bayesian network is designed to infer the probabilities of membership of real or false defect classes on the basis of previous decisions. The performance of the combined use of these probabilities and sensor processing are finally presented. They demonstrate the advantage of the approach based on both a local description of the defect and a description of its environment.

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### 1. Introduction

In the field of railways, the increase in axle loads and the speed and the frequency of traffics are responsible for ever increasing contact forces which may damage rails or vehicles. Optimum use must be made of all resources in order to provide the shorter cycle times and better safety and reliability that are required. For this reason, infrastructure maintenance is an important area of interest for railway operators. In particular, rail inspection is an essential part of the maintenance process and is vital for preserving the safety and availability of railway infrastructure.

Rail defects are of several types (cf. Fig. 1), ranging from internal cracks to surface defects (UIC, 2001; Zerbst et al., 2005). Each kind has a specific damage fatigue process, and a specific lifetime and safety impact. Operators obviously aim to develop preventive maintenance procedures. Thus, long-term policies can optimize maintenance operations with regard to financial cost and reliability objectives. But from a probabilistic point of view, some major defects such as broken rails cannot be totally avoided, even with good maintenance practices. In the network of Paris, rail breakages were estimated to 3–4 per year per line. They correspond to the last step of a complex fatigue scheme that could have two main origins (Scutti et al., 1984; Jablonski and Pelloux, 1992): (1) the evolution of internal flaw starting at a metallurgical inhomogeneity and growing with

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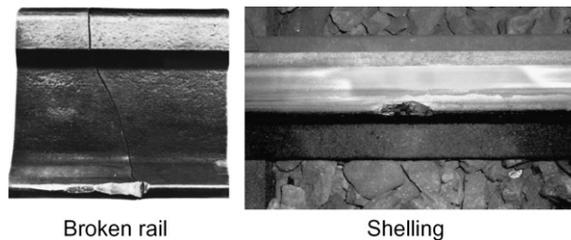


Fig. 1. Classes of surface rail defect.

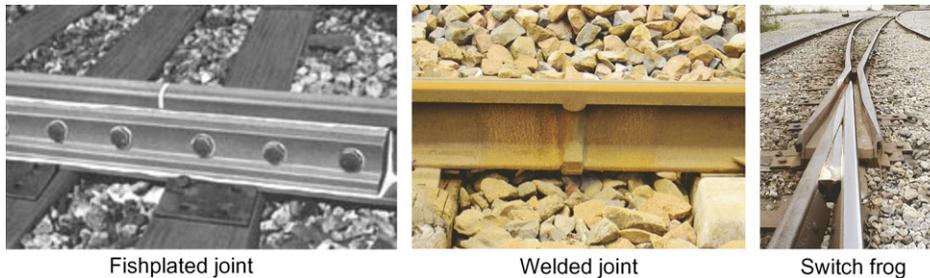


Fig. 2. Classes of singular points in the rail.

the mechanical cycling of wheel/rail contact stresses, (2) the degradation process of welded joints which have not been properly achieved.

In the following, we also denote broken rails, all the surface transversal cracks that become real broken rail after few train runs (Sih and Jeong, 1992). In a broken rail situation, for safety reasons, a detection procedure is required. This solution must be considered independently from the specific inspection vehicles that travel along the tracks following a maintenance schedule. In fact, the railway operators need to locate each broken rail with real time requirements during the whole operational service. The widespread used system is called track circuit (cf. Section 2.2). Railway networks mostly equip their tracks with this kind of device whose first function is the train localization. Nevertheless, they have several technical and economical drawbacks that drive the operators to develop alternative solutions, especially into driverless metro context.

This paper deals with a global diagnosis system for broken rail detection that combines two information sources: local and global. The local data is provided by a dedicated sensor that detects any modification in the geometry and/or electromagnetic characteristics of the rail. Obviously, broken rails are detected, but so are singular points such as the welded joints, fishplated joints and switch joints that join together rail lengths (cf. Fig. 2). The global data is provided by track setting rules that constrain the position of singular points of the track while real defect are not spatially dependant. The global statistical model uses a Bayesian network to take account of these spatial dependencies and independencies. This study investigates the possibility of combining these two approaches in order to distinguish real defects from singular points under difficult operating conditions.

The paper is organized as follows: Section 2 describes the importance of rail diagnosis and, with regard to the local approach, presents the dedicated eddy current sensor and its signal processing. The problem of confusion between real defects and singular points is also highlighted at the end of this section. Section 3 will detail the different technological solutions which exist for distinguishing between real and false defects. A software solution for this distinction is proposed in Section 4 that introduces the probabilistic graphical models and Bayesian networks and Section 5 details the practical implementation. Some results for the broken rail application are given in Section 6. Finally, Section 7 summarizes the conclusions and outlines future topics for research in this area.

## 2. The nondestructive testing of rails

### 2.1. Rail flaw inspection techniques

The nondestructive testing of rails is an important subject of investigation and development for railway operators. Its objective is to develop flaw detection systems in order to obtain optimum performance, safety and service life from rail assets. Rail defects can be classified according to their shape and position in the rail section. They include transverse or longitudinal cracks, broken rail, large head spalls, internal corrosion, surface wear, corrugation, etc.

The aim of any non destructive technique is to detect a defect before it reaches a critical size and leads to a rail break. Most networks have their own inspection cars equipped with dedicated sensors. An inspection technique is selected on

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