Project no. 012440

EUROPAC

European Optimised Pantograph Catenary Interface

Specific Targeted Research Project (STREP)

Thematic Priority 6: Sustainable Development, Global Change and Ecosystems Sustainable Surface Transport

Publishable Final Activity Report

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Project coordinator organisation name: SNCF

R2.0

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1. Abstract

The EUROPAC (EURopean Optimised PAntograph Catenary interface) project, which took place from 1 January 2005 to 31 December 2007, gathered major European railway stakeholders around a research project on vehicle-infrastructure interaction through the pantograph-catenary contact.

The project, coordinated by SNCF, aimed at enhancing interoperability between pantographs and catenaries all over Europe, decreasing the number of incidents related to this system and reducing maintenance costs by switching from preventive maintenance to corrective maintenance.

It resulted in three major outcomes: a joint simulation software, a track-side monitoring station and an on-board monitoring system.

Participants:

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2. Project Execution

2.1 Introduction

Two rolling-stock / infrastructure mechanical interfaces are present in the railways. The first consists in the wheel / rail contact, which has been a topic of research for many years, concerning safety and comfort, from the modelling and experimental point of views. The second consists in the pantograph / catenary contact, in which much less research has been performed. However, the pantograph-catenary interface represents one of the most critical interfaces.

From a scientific point of view, the pantograph-catenary interaction generally constitutes the first blocking point when increasing the train speed, due to the phenomenon known as the “catenary barrier” – in reference to the sound barrier – which refers to the fact that when the train speed reaches the propagation speed of the flexural waves in the contact wire a singularity emerges, creating particularly high level of fluctuations in the contact wire. When operating in a multiple unit configuration, the pantograph-catenary system is even more critical, since the second pantograph experiences a catenary that is already perturbed by the passage of the first pantograph.

From a more practical point of view, this interface implies interoperability issues, contrary to the wheel / rail contact. Finally, defects in the catenary or in the pantograph often lead to the rupture of the contact wire and consequently to the interruption of service on the line and to perturbation on the adjacent lines. Statistics consolidated over Europe show an average number of approximately one million minutes of delay related to current collection, generating tremendous costs to the railway stakeholders in particular and to the society in general.

The Europac project, co-funded by the European Commission, addressed this problematic through three main topics: simulation, track-side and on-board monitoring.

The first result of EUROPAC is a joint interoperable software, which simulates the pantograph-catenary dynamic interaction. It is made of two independent softwares which are based on the most up-to-date scientific knowledge. The first module, OSCAR[1,2,3] (Outil de Simulation du CAptage pour la Reconnaissance des défauts, developed by SNCF), simulates the catenary and the second one, DAP[4,5,6] (Dynamic Analysis Program, developed by IST), simulates the pantograph. The resulting tool, named EUROPACAS, allows simulating any type of pantographs and catenaries in three dimensions, and allows taking into account up to now unaddressed effects such as the action of wind, temperature, switches, road bridges, etc.

The second main outcome of EUROPAC is a track-side monitoring station, which is in operation along a high-speed line in Germany. It is based on already existing sensors such as uplift and acceleration sensors, mounted on the contact wire. Coupled with a real-time diagnosis tool, which analyses the measured signals in an automatic way, it allows detecting and identifying defects in the pantographs passing on the line.

Last but not least, EUROPAC resulted in an on-board monitoring system which automatically inspects, at high-speed, the state of the catenary. Based on “classical” sensors such as accelerometers and force sensors mounted on a pantograph, it is completed with an expert system combining human-like expertise and automation, named the Real-Time Data Analyser (RTDA). This RTDA analyses the signals in real-time, and consequently detects, localises and identifies the defects present in the catenary system.

2.2 EUROPACAS, a universal simulation tool

The EUROPACAS software (cf. Figure 1) aims at simulating the pantograph-catenary dynamics. Thanks to its three-dimensional feature, it allows to

- Model the wide variety of catenaries (AC catenaries, with or without stitch wire, with a fixed or suspended registration tube, DC catenaries, etc.),
- Model any pantograph type (telescopic, diamond, single arm, servo-controlled, etc.),
- Take into account the effects of lateral wind or of extreme temperatures (longitudinal dilatation of the wires),
- Study the effects of singularities (road bridges, switches, overlaps) or defects (wear, missing or shorten dropper, splicer, bad regulation of the equipments, blocked pantograph suspension).

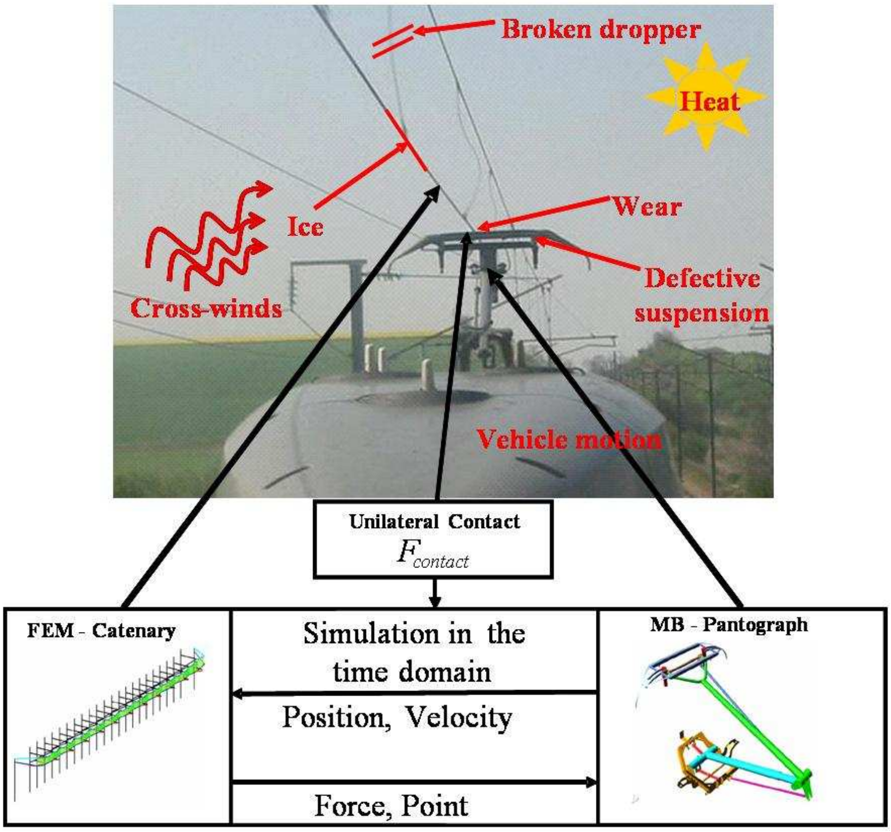


Figure 1: Principles of the EUROPACAS software. Pictures courtesy from SNCF.

In order to improve interoperability, EUROPACAS must necessarily be able to represent all catenary or pantograph types (examples of EUROPACAS catenary models are presented in Figure 2). Thanks to this feature, EUROPACAS can be used in the preliminary phase to adapt the settings of a pantograph to a new network, for instance when a type of train has to travel from one national network to another. In some networks where catenaries are relatively “soft”, it can be preferable to apply a relatively low mean contact force to reduce the maximum uplift at supports, whereas in other networks, where catenaries are more “rigid”, a higher mean contact force is used to reduce contact force fluctuations. By using this type of simulations, the period necessary for the homologation tests can in some cases be reduced, as well as the associated costs.

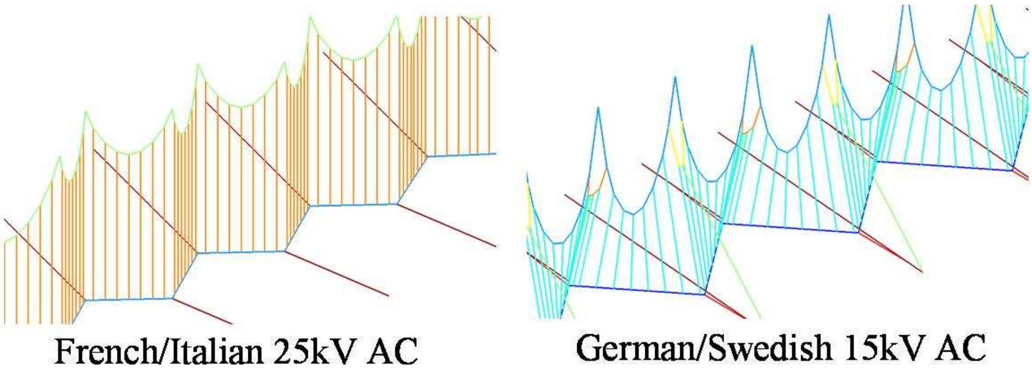


Figure 2: Examples of catenary types present in Europe. In France or Italy, contact and messenger wires have stagger, whereas in Germany or Sweden, only the contact wire is staggering. In Germany or Sweden, the registration tube is suspended. In France or Italy, the registration tube is fixed and there is no stitch wire.

EUROPACAS is not only able to simulate the nominal behaviour of the system, but also perturbed conditions (a simulation including defects and singularities is presented in Figure 3). This enables to:

- Improve the design of catenaries not only in plain-track spans, but also in section overlaps, road bridges,
- Gain knowledge about the effect of defects on the dynamics. This knowledge can be used to build defect signatures in order to teach the defect detection expert systems.

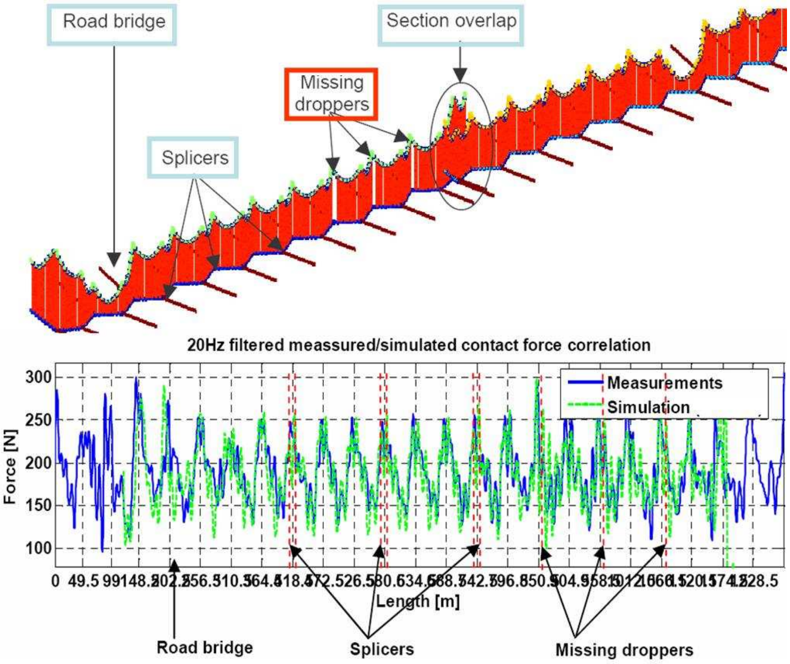


Figure 3: Model and corresponding result (contact force) for different singularities/defects.

Finally, a high level of effort was spent on studying the effects of extreme climatic conditions. The first application concerns the effect of wind on current collection, which constitutes a critical phenomenon and a challenge for researchers. Indeed, cross-winds are deflected by the train roof and the resulting pressure field on the pantograph is particularly complex. To gain knowledge on this phenomenon, both wind tunnel tests and computational fluid dynamics simulations (cf. Figure 4) were carried out.

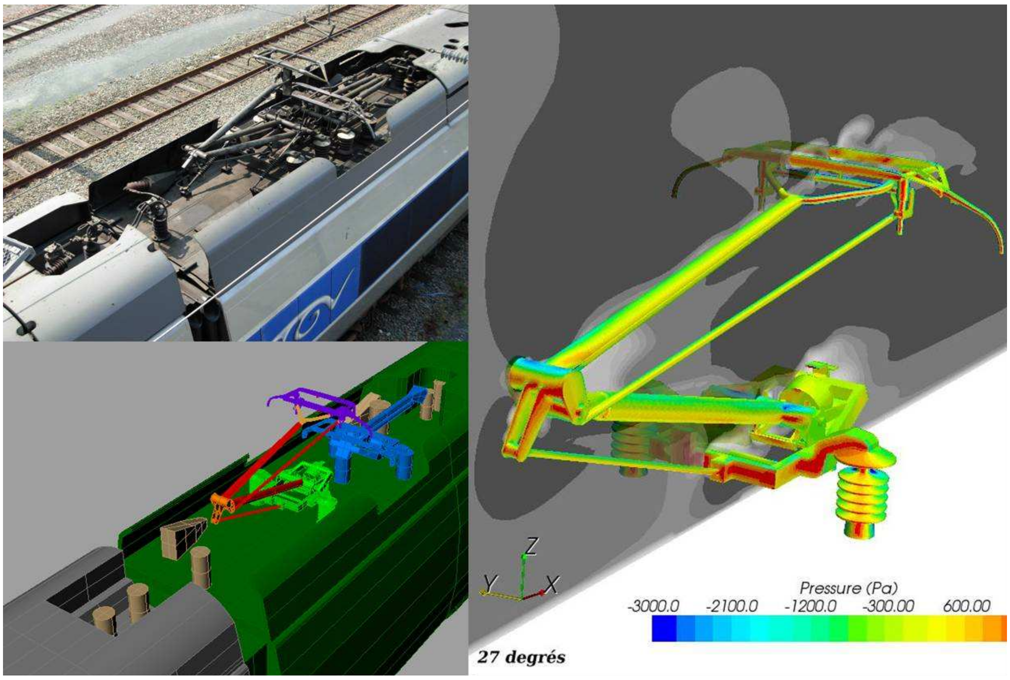


Figure 4: Left: Real roof and pantograph of a TGV Atlantic, and the corresponding model. Right: Simulated pressure distribution for a cross-wind with an angle of 27°. Pictures courtesy from Alstom and SNCF.

Thanks to these studies, the aerodynamic coefficients for the different pantograph components were determined. Combined with the catenary aerodynamic characteristics, this allowed assessing the effect of wind on current collection (cf. Figure 5, Left), which can be used to specify maximum acceptable wind speeds on a particular line, for what concerns current collection, or to design a line subjected to extreme winds.

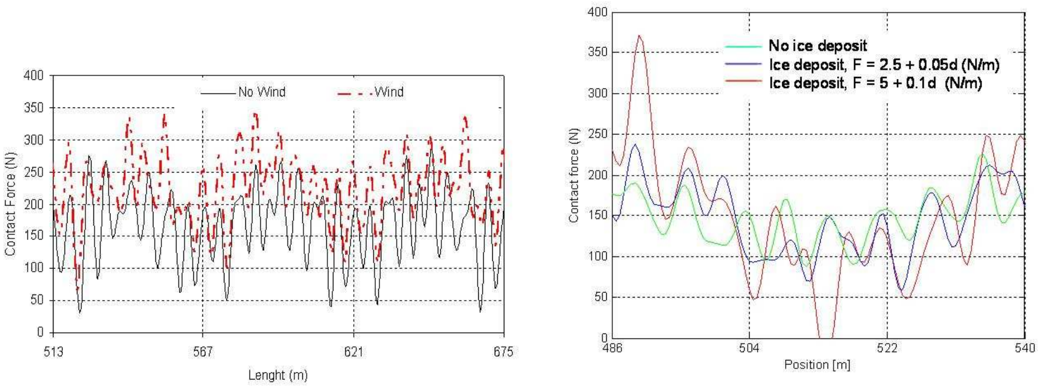


Figure 5: Effect of wind (Left) or temperature (Right) on the contact force.

Another application of the software concerns the study of extreme temperatures. When subjected to temperature changes, the wires constituting the catenary elongate or retract, resulting in changes in the mechanical tensions, even for regulated catenaries. An additional effect is the deposit of ice on the wires, which drastically modifies its geometry and consequently the current collection quality. As described on the right of Figure 5, the presence of ice can strongly increase the contact force fluctuation, thus deteriorating the dynamic behaviour of the system.

2.3 The track-side monitoring station

The second main outcome of the EUROPAC project is the implementation of a track-side monitoring station. Contrary to the existing systems, it is fully automated while including human-like expertise. To achieve these features, the track-side monitoring station is made of already existing sensors:

- Uplift sensor made of a draw wire with incremental encoder,
- Accelerometer clamped to the contact wire,
- Axle counting sensors and light barriers,
- Weather station to remove weather dependence,

and includes a Real-Time Data Analyser (RTDA), which is connected to the acquisition unit, and a Decision Support System (DSS), as described in Figure 6.

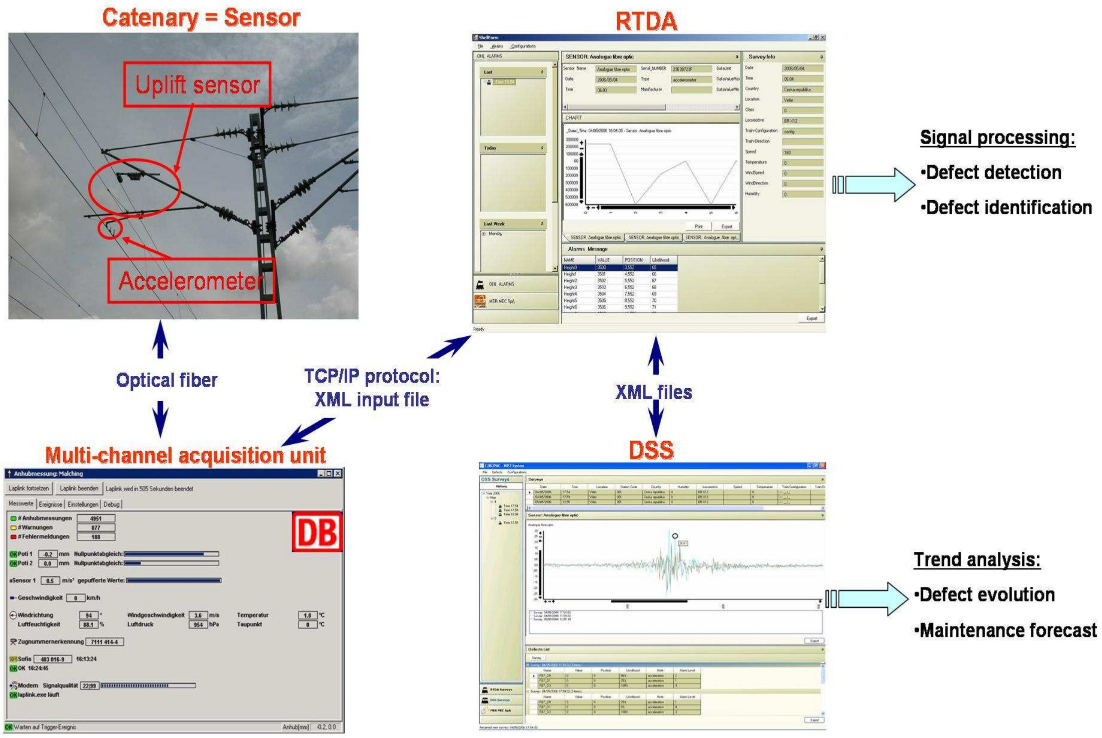


Figure 6: Principles of the track-side monitoring station. Pictures courtesy from DB AG and Mer Mec.

The role of the RTDA is to analyse the data measured for each single train passage, in order to detect and identify defects that would be present in the passing pantograph(s). The algorithms used to process the data (mainly from the accelerometer) are based on the correlation with so-called characteristic curves, which are built for each type of defects.

Before performing the correlation, the measurement data from the acceleration sensor needs to be processed in several steps to correct for, among others, speed differences, the Doppler effect and low frequency signal drifting.

It was found during tests on the Velim ring (Czech Republic) that only the part of the signal preceding the pantograph passage is of interest, since the motion of the catenary after its passage mainly reflects the catenary damping, and thus no information about the pantograph state can be extracted from it. Moreover, the measured time signal is converted to a position signal which is then switched, resulting in the type of curves presented on the left of Figure 7.

This type of signal is then correlated with characteristic curves, which are built by averaging several measurement data sets corresponding to the same situation (same pantograph, same type of defect, etc.).

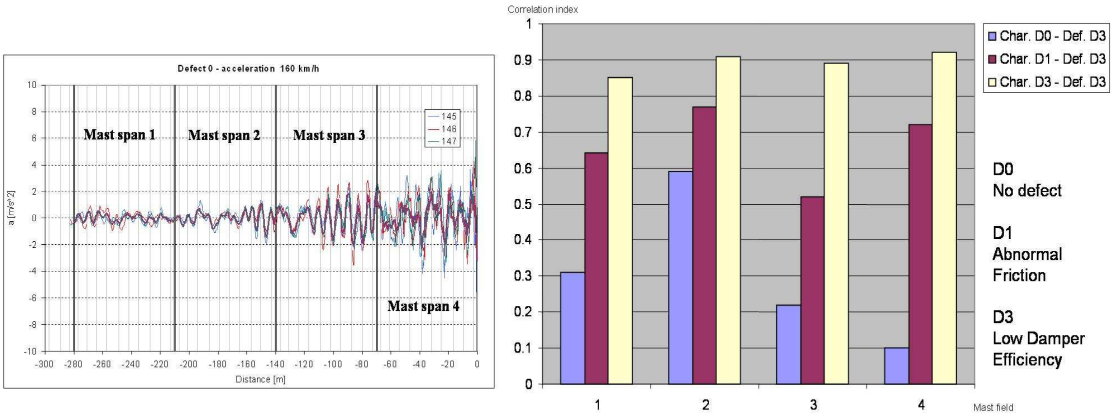


Figure 7: Methodology used to detect defects in the acceleration signal.

Results from such correlations are presented on the right of Figure 7, where one plots, for each of the four spans preceding the station, the correlation index of a data set with characteristic curves. This shows the ability of the methodology to detect defects, and to discriminate among them. Indeed, one clearly notices that when analysing a data set corresponding to defect “D3”, the correlation index is much higher with the corresponding characteristic curve than with curve “D0” (no defect) or “D1” (which corresponds to another defect).

The last level of analysis is performed by the DSS (cf. Figure 6), which enables the operator to visualise the evolution of the state of the rolling-stock, by comparing data sets over time.

2.4 The on-board monitoring system

The on-board monitoring system is based on the same principles as the track-side monitoring station. It is composed of an instrumented CX pantograph (considered as a sensor), which inspects the catenary. This sensor is connected, through an acquisition unit, to the RTDA, whose role is to automatically detect, identify and localise the defects present in the catenary in real-time. This constitutes the on-board analysis. An additional feature consists in the DSS, which allows performing trend analysis and prediction of maintenance operations, using data from several measurement runs.

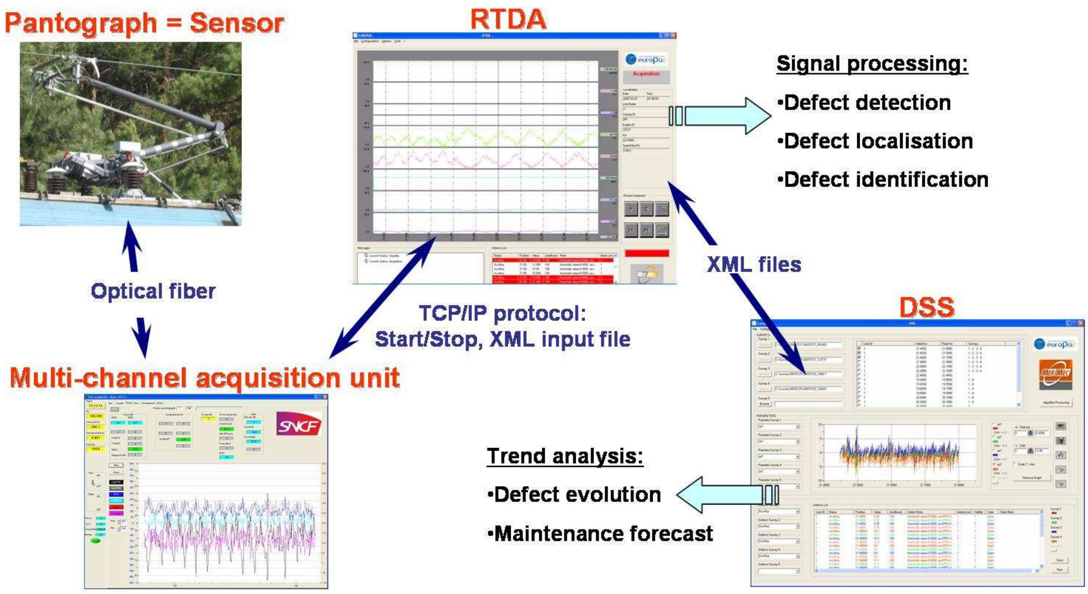


Figure 8: Principles of the on-board monitoring system. Pictures courtesy from SNCF and Mer Mec.

The methods that were developed for detecting the defects are independent of the software, which allows adapting the analysis to any particular demand. One of the methods tested during the project is based on the adapted wavelet theory[7]. The principle is to detect particular patterns in the signal, which correspond to defect signatures. This requires the creation of a defect signature database, using either simulation or experience gained from tests. As presented in Figure 9, which illustrates this principle, the procedure is the following: first, one simulates a type of defect that the monitoring system is looking for (cf. bottom right, in this case, a missing dropper). From this simulation, or from measurements, a signature is extracted and the corresponding adapted wavelet is built. The signal acquired by the monitoring system is then analysed using the adapted wavelet, which results in a “scalogram”, where one can see that the corresponding defect (in this case, missing droppers) are properly detected, and discriminated (the other types of defects are not detected).

The advantages of the adapted wavelet methodology over a more classical Fourier type analysis are manifold: detection is facilitated by the scale analysis, high-quality identification is obtained thanks to the use of adapted signatures, and localization accuracy is high due to the use of finite duration signals, compared to the infinite sine series used in the Fourier analysis.

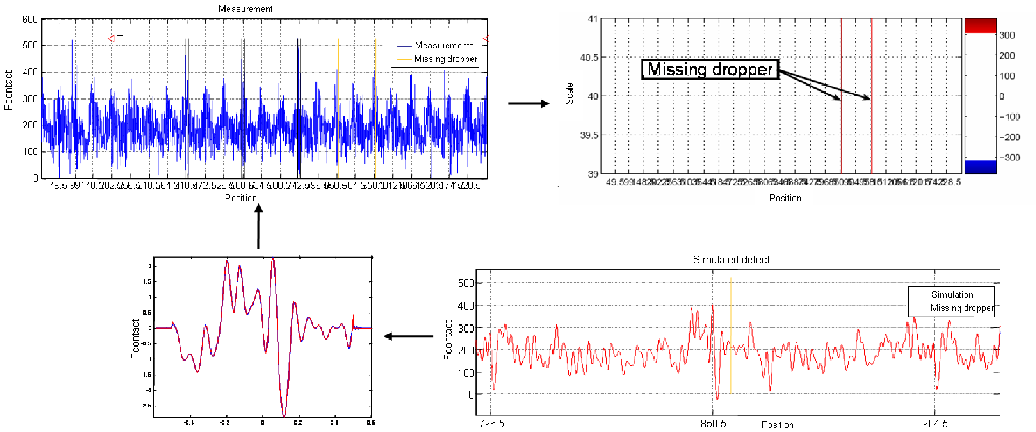
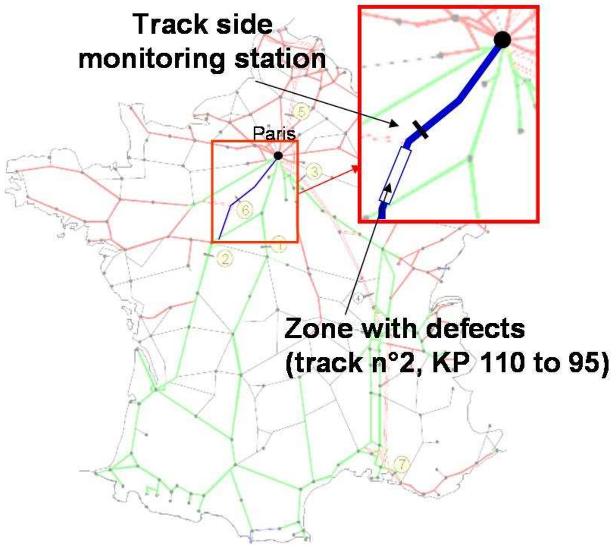


Figure 9: Adapted wavelets for detecting defects in the catenary.

As described in Figure 10 (left), this method was assessed on-line, during tests conducted on the French Atlantic high-speed line, between Paris and Tours. Several types of defects (splicers, missing or too short droppers, heavy steady arms) were installed intentionally in the catenary, and using the system described in Figure 8, installed on a TGV-Duplex running at 300 km/h, one detected, localized and identified in real-time around 66% of them (details of the detections are given on the right of Figure 10, in red). This gives perspectives for the use of the method on operational inspection trains such as the IRIS320 TGV used at SNCF.



Position (KP)	type	dropper n°
102,97951	short dropper	8
102,70051	short dropper	1
102,48901	heavy steady arm	0
102,32926	missing dropper	2
101,93326	splicer	2
100,80163	missing dropper	4
100,79713	missing dropper	5
100,50688	missing dropper	8
100,33588	missing dropper	1
100,09963	splicer	4
99,87238	splicer	6
99,70363	splicer	7
99,68113	splicer	2
99,32788	splicer	8
99,26488	splicer	1
99,11188	splicer	8
99,10288	splicer	1
98,92063	short dropper	4
98,91613	short dropper	5
98,53575	splicer	2
98,21625	short dropper	4
98,21175	short dropper	5
98,0295	short dropper	8
97,8585	short dropper	1
97,701	heavy steady arm	0
97,51425	missing dropper	4
97,50975	missing dropper	5
97,1115	missing dropper	8
96,94725	missing dropper	2

Figure 10: Location of the tests (left) and results obtained (right, defects detected are in red).

2.5 Conclusion

This publishable final activity report presents the major outcomes of the EUROPAC project, which gathered fifteen partners from six European countries over three years. The first result consists in a universal tool for simulating the pantograph-catenary dynamic interaction in three dimensions. This interoperable software, which allows taking into account perturbed situations, can be used to decrease the number of homologation tests for interoperability purposes or to support engineers during the design phase. The second outcome consists in a track-side monitoring station, which can be used as an inspection gate at the entrance of a network, or on specific lines, to detect defects in the passing pantographs. Finally, EUROPAC developed and implemented an on-board monitoring system, which automatically detects, localises and classifies the defects present in the catenary at high-speed. As a result of these tools, the number of incidents related to current collection, and the maintenance costs of the rolling-stock and infrastructure, can be drastically reduced. EUROPAC, through these three results validated by on-line tests, thus contributed to reversing the trend in favour to the environmentally-friendly railway transport.

3. Dissemination and Use

Separate document: Please refer to the EUROPAC final plan for using and disseminating the knowledge.

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