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Pantograph-catenary monitoring via wavelet transform

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Abstract

Wavelet decomposition is proposed as an innovative tool for analysing and classifying data acquired during test runs performed in Italy along the line Florence-Rome from high-speed trains. It is based on the multi-resolution analysis typical of the wavelet transform: such analysis was applied to the traction current measurements. Wavelet tool allows an automatic analysis of the data collected and to detect singular break arcs due to losses of contact of the pantograph. Software used for processing data was the Wavelet toolbox package developed inside Matlab environment. Some examples of analysis from experimental data are reported in the paper.

1 Introduction

In electric railway traction, the current collection results from the sliding contact between the moving pantograph and the overhead contact wire: a crucial problem for railway companies is to prevent damages to the overhead line equipment and to pantographs in case of high speed trains. Test runs were performed on board of an ETR500, a high-speed train of Italian Railways, with a double pantograph and an acquisition system inside a measurement coach. Previous research activity ([1], [2], [3], [4], [5]) revealed that a new measurement system, based on a single or double phototube sensor, can detect

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break arcs between the pantograph and the contact line. A twin phototube sensor is physically placed on the top deck of the locomotive, in front and rear the pantograph, at a distance from the pantograph of 4 meters about. The sensor detects the passage of UV emissions, with an output signal binary – on/off state – producing square wave signals. The ETR500 is also equipped with an equipotential wire (EW), i.e. a conductor connecting the front and the rear pantographs, able to compensate the losses of contact with current conduction, whenever one of the two pantographs looses the contact. It can be noted that such device reduces the duration and the number of the losses of contact; nevertheless it represents a selective and precise sensor able to detect the losses of contact (i.e. a sudden loss of contact relative to one pantograph always produces a fast variation in the current adsorbed from the EW). Due to the presence of the EW during the high-speed test runs, the data measured from the twin phototube were correlated with the data collected from the EW itself.
In this paper the multi-resolution wavelet analysis is applied to the signals acquired from the measurement coach, in order to investigate if the wavelet transform analysis can extract useful information for monitoring the status of the overhead line, detecting the losses of contact between the pantograph and the overhead line. The available informations furnish an important way of checking the effectiveness of the wavelet analysis, based only on tractive current acquisitions. The signals are decomposed in wavelets using the Wavelet Toolbox, belonging to the Matlab®/Simulink® environment. This choice was motivated for its completeness, powerfulness and reliability, and for the intrinsic block structure of the Simulink graphical interface models, that automatically complies an easy-to-use modular approach. Moreover it constitutes a common tool with a large distribution in universities and industries: therefore new libraries or models can be easily added-on in the software. The toolbox presents a user oriented graphic window, suited for a selection of the wavelet family and level of decomposition and for zooming and shifting the signal putting into evidence every interesting point, in terms of level of approximation and details.

2 Wavelet analysis

Recently wavelet theory ([6], [7], [8]) has been used as a signal analysis and processing tool for several applications (image compression, pattern recognition etc.). The main feature that makes wavelets attractive is that the Wavelet Transform (WT) of a function f(t) gives a function of two parameters: time and scale, the latter being the key point of WT. Unlike the Windowed Fourier Transform (the signal is filtered through a time window and then Fourier Transform is performed), which works with a fixed window, WT works with a scaled window allowing the visibility of the whole frequency content.
Furthermore it is possible to define a multi-resolution scheme, on bases of wavelet functions at different scales, that acts on a signal like a subband filtering procedure. This leads to the possibility of decomposing a signal (f^0 in Figure 1)

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into a sum between a blurred version of the signal itself (f^M) and a series of details (d^i). It is evident that this property is useful in pattern recognition applications, since the different details can enhance and/or show characteristics not visible in the original signal.

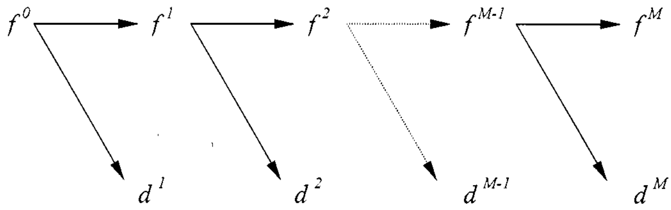

Figure 1: Multi-resolution scheme.

3 Wavelet analysis of experimental acquisitions

A multi-resolution analysis of the total tractive current is considered, in case of data acquired from the Italian high speed train ETR500, travelling along the railway, from Rome to Orte. The problem at hand requires a first selection of the mother wavelet for analysis: such selection is of a primary relevance. In fact the mother wavelet selection can greatly modify the quality of the disturbance detection, specially if the decomposition involves more than one level. In plain words, for first level approximations the mother wavelet is primarily time dependent, with large swings. For increasing levels of detail, swings are reduced and the time dependence is less characterizing. Therefore short transients are better evidenced at lower details (e.g., first and second details), while long transients are detected at higher details. As a consequence a single wavelet, suitably chosen, can reveal both fast and long transients. After accurate and extensive tests, the wavelet selected belongs to the Daubechies family, with four levels of detail.

Case of a single relevant loss of contact.

Consider the signals shown in Figure 2. Each plot is referred to one kilometre of test run, at an average speed of 220 km/h. The upper two subplots show the duration (in ms) of break arcs detected from the front and from the rear phototube, respectively. In the lower subplots the total tractive line current and the current from the equipotential wire are shown, both in kA. Note that a break arc can be detected only from the equipotential wire acquisitions and undetected from the twin phototube, in the case of a loss of contact of the second pantograph unmonitored with the phototube. As a convention, losses of contact on the unmonitored pantograph correspond to positive peaks of current measured from the equipotential wire, otherwise negative peaks correspond to

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losses of contact on the monitored pantograph. Each plot is a function of the number of samples. Losses of contact revealed from the EW are marked by arrows.

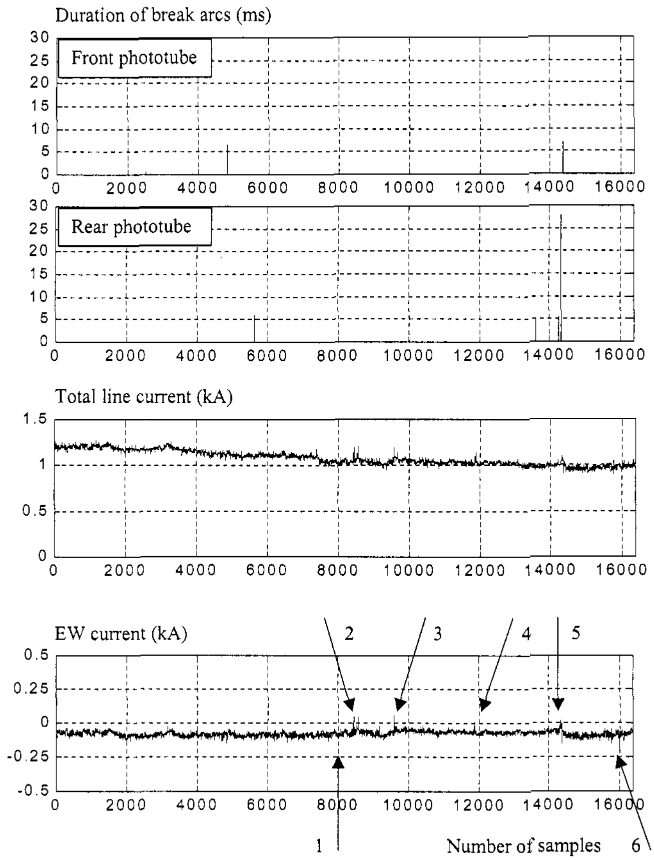

Figure 2: Signal acquisition: case of a single relevant break arc.

A relevant phenomenon is revealed in all details, representing the break arc revealed both via the phototube, and via the EW (arrow 5). Four break arcs (corresponding to arrows 1, 2, 3, 4 of the EW acquisition) on the unmonitored pantograph are revealed by the wavelet analysis: none of them has a fast transient, because of their negligible effects on the lower details. The last arrow 6 is revealed both from the EW acquisition and from the wavelet analysis, but it is undetected from the phototube sensor. It may be considered as an example of unrevealed arc of small duration, undetected from the phototube sensor.

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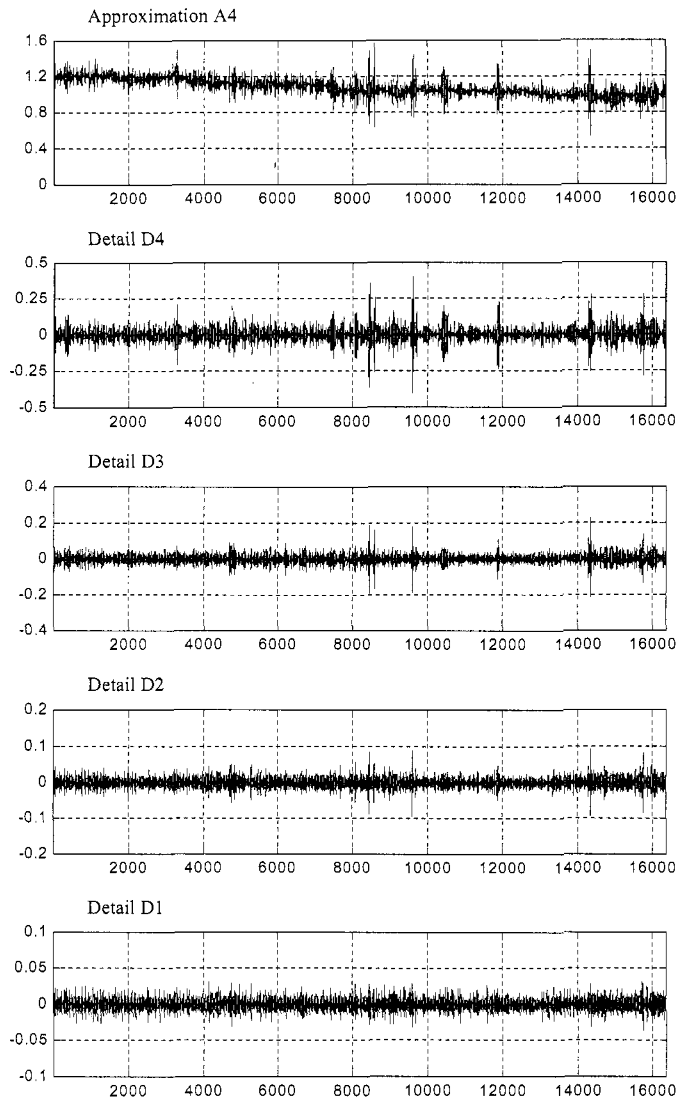

Figure 3: Wavelet decomposition: case of a single relevant break arc.

<u>Case of a multiple loss of contact.</u>

Consider the signals shown in Figure 4. Data are acquired along another different kilometre of test run, at an average speed of 207 km/h. This example shows the presence of three relevant losses of contact, detected both from the equipotential wire and from the twin phototube, in addition to many minor losses of contact, evidenced by ten arrows.

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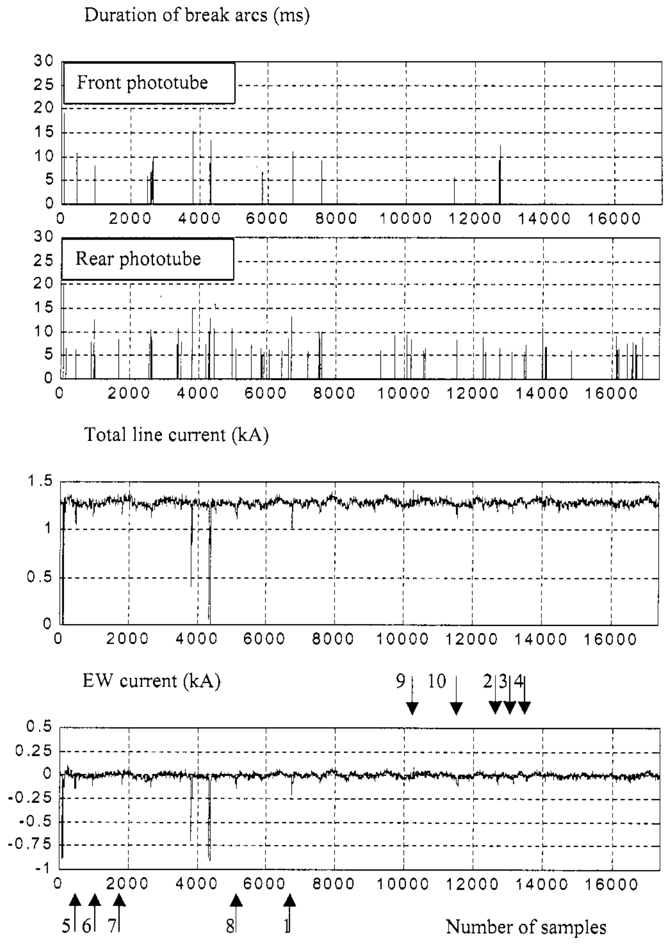

Figure 4: Signal acquisition: case of multiple relevant break arcs.

In Figure 5, the line current signal is decomposed with an approximation of level 4 and its 4 details. The three relevant break arcs are evidenced in all details, along with the minor losses corresponding to arrows 1, 2, 3, 4, 5, 6 and 8. Only the losses No. 1, 2, 5 and 6 are fully detected from the phototube, losses No. 3, 4 and 8 are partially detected from the phototube, fully detected from the equipotential wire, while the minor loss No. 7 is undetected from the phototube. Loss No. 9 is revealed from the wavelet analysis: it is detected from the EW, undetected from the phototube because of the unmonitored pantograph. Loss No. 10 is unclearly detected from the wavelet decomposition: it may represent a small break arc.

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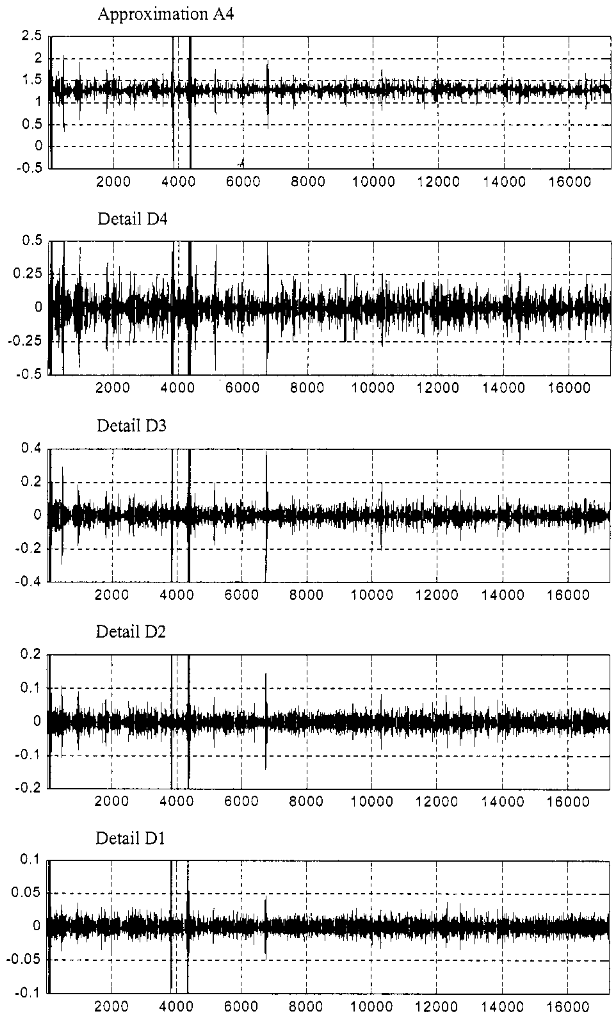

Figure 5: Wavelet decomposition: case of multiple relevant break arcs.

Case of electric welding effect.

Consider the signals shown in Figure 6. Data are acquired along another different kilometre of test run, at an average speed of 211 km/h. This example shows the presence of the electric welding effect, detected only from the twin phototube, in addition to few minor losses of contact. Such effect is due to a defective sliding contact. Because of the roughness of the contact wire and of the collector strips, mainly due to wear, incorrect tensioning and positioning of the wire, the current collection is irregularly distributed over the contact surfaces. Therefore hot spots and micro-welding phenomena occur over the contact

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surfaces. If the train is running at high-speed (the higher the speed, the more critical the effects) the welded spots are instantaneously broken off and the contact wire further deteriorates. In such zones the wear of the collector strips and of the contact line increases and continuous sparking occurs. Therefore the electrical welding effect produces a sequence of continuous sparking, seriously damaging the overhead contact line with the need of a frequent maintenance.

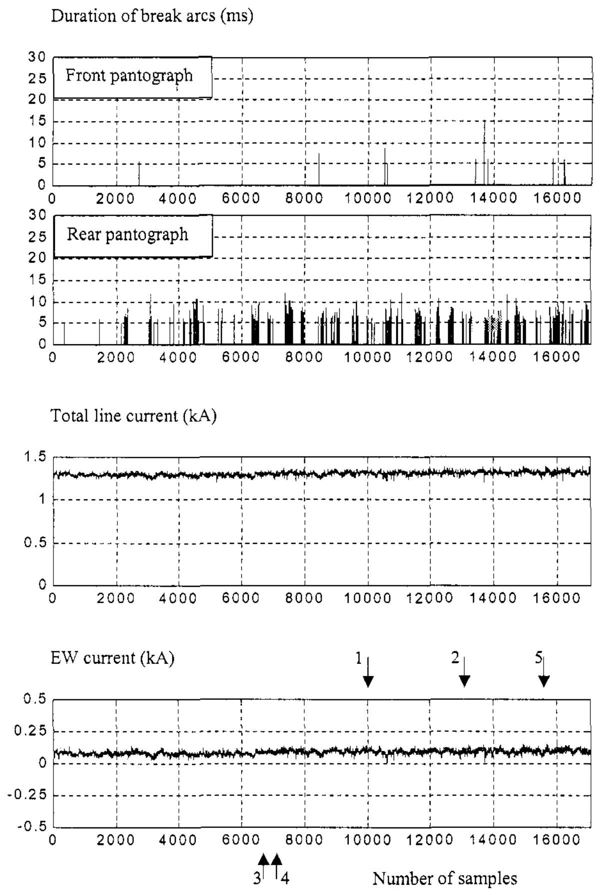

Figure 6: Signal acquisition: case of electric welding effect.

In Figure 7, the line current signal decomposed with an approximation of level 4 is shown along with its 4 details. Minor break arcs are revealed from the EW (arrows 1,2 and 4). Poor information is given on the break arcs evidenced from arrows 3 and 4, while the high frequency signals showing the electric welding effect on the phototube sensor are totally undetected from the wavelet analysis. Such consideration was to be expected, due to the small influence of the electric welding effect on the line currents.

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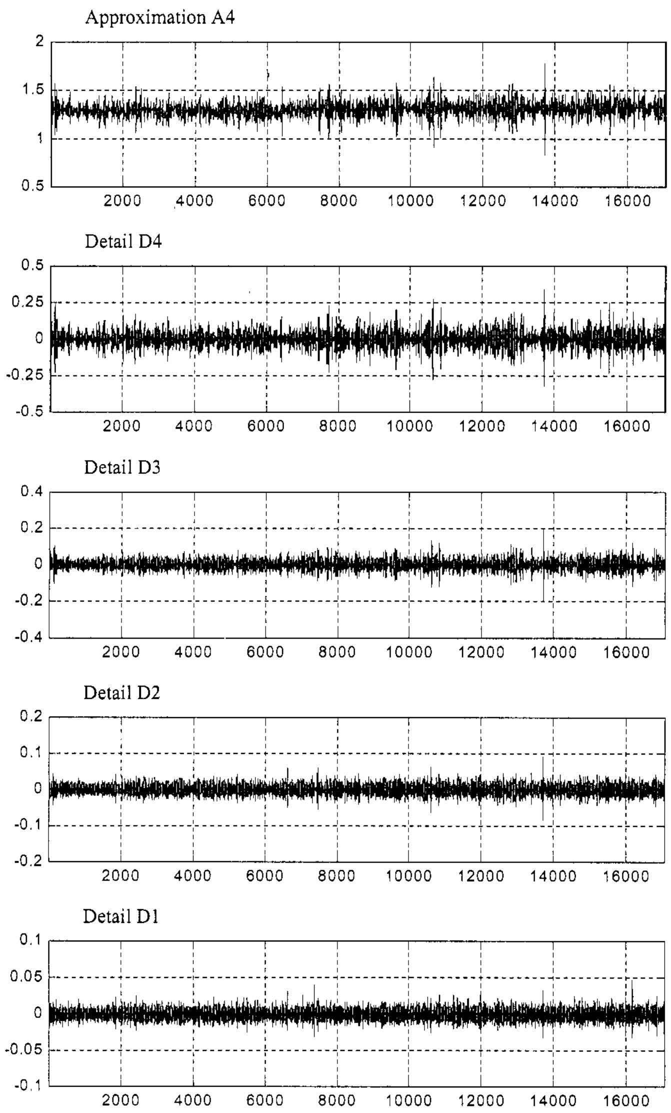

Figure 7: Wavelet decomposition: case of electric welding effect.

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4 Conclusions

In this paper an innovative method, based on the multi-resolution analysis typical of the wavelet transform is presented: such analysis was applied to the line traction current measurements. A similar analysis was performed in the discrete case of data acquired from the twin-phototube sensor, but it is not reported in this paper. Wavelet tool allows an automatic analysis of the data collected and distinguishes between the different phenomena of singular break arcs and of welding effect. In fact only the phototube can reveal welding effect: a combination of wavelet analysis and of phototube data analysis can automatically select the correct situation of the current collection. A relevant outcome of such analysis was its effectiveness in detecting break arcs using only line current acquisitions, avoiding additional sensor like the phototube or the equipotential wire.

References

[1] Balestrino, A., Bruno, O., Landi, A., Papi, M., Sani, L. & Violi, A.G., Phototube sensor for active pantographs. *CD-ROM of the World Conference Railway Research '99*, Tokio, 19-23 October 1999.

[2] Bruno, O., Landi, A., Papi, M., Sani, L. & Violi, A.G., Software for monitoring pantograph-catenary interaction via a phototube sensor. *Computer in Railways VII*, pp 683-692, Computational Mechanics Publications: Southampton and Boston, 2000.

[3] Balestrino, A., Bruno, O., Landi, A., Papi, M., Sani, L. & Violi, A.G., Innovative methods for evaluating the quality of the current collection. *Intern. Conference Railway Traction System*, 3, pp. 204-217, Capri 2001.

[4] Bruno, O., Landi, A., Papi, M. & Sani, L. Phototube sensor for monitoring the quality of current collection on overhead electrified railways. *Proc.IMECHE, Part F:Journal of Rail and Rapid Transit*, **215(3)**, pp. 231-241, 2001.

[5] Bruno, O., Landi, A., Papi, M., Sani, L. & Violi, A.G., Pantograph-catenary monitoring: correlation between breack arcs and harmonics in the traction current. *CD-ROM of the World Conference Railway Research '01*, Koln pp. 10, Koln, 25-29 november 2001.

[6] Graps, A., An introduction to wavelets. *IEEE Computational Science and Engineering*, **2(2)**, pp. 50-59, 1995.

[7] Sarkar, T.K., Su, C., Adve, R., Salazar-Palma, M., Garcia-Castillo, L. & Boix, R.R., A Tutorial on Wavelets from an Electrical Engineering Perspective, Part 1: Discrete Wavelet Techniques. *IEEE Antennas and Propagation Magazine*, **40(5)**, pp. 49-68, 1998.

[8] Terwiesch, P., Menth, S. & Schmidt, S., Analysis of transients in electrical railway networks using wavelets. *IEEE Transaction on Industrial Electronics*, **45(6)**, pp. 955-959, 1998.