Continuous wavelet transform of railway track
defectoscopic signals in the MATLAB wavelet toolbox

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Abstract. Rail networks across the world are getting busier with trains travelling at higher speeds and
 carrying more passengers and heavier axle loads than ever before. The combination of these factors has
 put considerable pressure on the existing infrastructure, leading to increased demands in inspection
 and maintenance of rail assets [1]. Nowadays, rails are systematically inspected for internal and surface
defects using various non-destructive evaluation (NDE) techniques, the most common of which
are ultrasonic and magnetic flux leakage (MFL) methods. The article is focused on the analysis of
defectoscopic signals received using the magnetic wagon-defectoscope of Lviv Railway (MFL method)
by the continuous wavelet transform (CWT).
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1. Introduction

The most important question in all NDE methods — is selection of information
about defects from defectoscopic signals received during the checking railway
(defectogram). At present, wagon-defectoscope operator’s experience is essential
for making the correct decision about technical condition of rails. To improve
the operator’s work efficiency, which is mainly based on expert visual assessments,
it is necessary to automate the analysis of the recorded signals. That is why we turned
to the powerful tool of digital signal processing such as wavelet transform (WT).
The main WT applications — analysis and processing signals, non-stationary in time
(such as defectoscopic signals) when the analysis should include not only the signal frequency characteristics, but also information about some local coordinates, which reveal themselves in one or other frequency components.

WT divides into continuous (CWT) and discrete (DWT). DWT focuses on speed (by sampling values of scale (frequency) and time (samples)) and the possibility of a complete reconstruction of the signal after analysis (by orthogonal wavelet functions), which led to its use, mostly for denoising and compression of signals. As for CWT, it requires only one wavelet function — mother, whose creation is not problematical (unlike DWT) and allows to identify those signals that are similar to the mother wavelet.

Therefore, we should focus on consideration of opportunities of CWT to identify the signals from defects in defectogram.

2. Analyzing defectoscopic signals by CWT

This research was carried out in a package Wavelet Toolbox of the computer mathematics system MATLAB. Wavelet Toolbox provides functions and an app for developing wavelet-based algorithms for the analysis, synthesis, denoising and compression of signals and images [2].

The analysis process includes the following steps:

1. **Starting the Continuous Wavelet 1-D Tool.** From the MATLAB prompt, type `wavemenu`. In the opened Wavelet Toolbox — main menu window click the continuous Wavelet 1-D menu item. The continuous wavelet analysis tool for one-dimensional signal data appears (Fig. 1 without loaded signal for analyzing and calculated wavelet coefficients).

   ![Fig. 1. The continuous wavelet analysis tool for one-dimensional signal data with loaded and analyzed defectoscopic signal](image)
2. **Loading a signal.** To do this, in the menu “File” choose “Load Signal” and in the appeared dialog box select the signal to be analyzed. The fragment of defectoscopic signal with a pattern from transverse crack in the head of rail (Fig. 2 and the upper part of Fig. 1) was selected as an object of research. This fragment was received during the checking railway Lviv-Syanky-Chop, 06.11.2009 (km: 36 picket: 6 speed: 47 km/h). At the edges of it, the signals from the rail joints are shown, and along the whole of its length — the signals from the rail substrates (similar to background noise) are also shown.

![Fig. 2. The fragment of defectoscopic signal with a pattern from transverse crack in the rail head received during the checking railway Lviv-Syanky-Chop, 06.11.2009 (km: 36 picket: 6 speed: 47 km/h)](image)

3. **Configuring CWT parameters.** Panel in the right part of Fig. 1 serves for selecting the appropriate settings. Name of the loaded signal is displayed in the Data (Size) field. In the Wavelet field it is selected the type of wavelet for CWT (mother wavelet function), which should be similar to the signals that we are interested in, because CWT is a correlation between a mother wavelet at different scales and the signal [3]. If none of the standard Matlab wavelets fits for research, it is possible to create own wavelet by clicking on the main menu Wavelet Toolbox button “New Wavelet for CWT” and then to follow by the recommendations from the official website Matlab [4, 5]. As the mother wavelet, for our study, it was used a wavelet adapted for detection of signals from the transverse cracks in the rail head — cr21 (Fig. 3). The process of its creation is described in [6].
In the Sampling Period field, the sampling period of the signal should be specified. Wagon-defectoscope velocity for the aforementioned fragment was 47 km/h and discrete samples were taken with the frequency 100 samples/m. Multiplying these two values gives the sampling frequency approximately equal to 1306 Hz, then the period is the reciprocal to frequency — 0.000766 s. In the Scale Settings group, it is necessary to select scale mode. Step by Step Mode for setting the minimum (1), maximum (40), and step values (1) were selected.

4. Performing a Continuous Wavelet Transform. To calculate the wavelet coefficients it is necessary to click on the “Analyze” button. Result of CWT is shown in the scalogram (second from the top in Fig. 1). Scalogram is a visual method of displaying a wavelet transform. There are three axes for representing time (samples), scales and coefficient values [7]. To show (or hide) the wavelet coefficients line (figure of coefficients in a particular scale — 3rd from the top in Fig. 1) and local maxima (figure of local maxima on each coefficients line- 4th from the top in Fig. 1)) select (or deselect) Coefficients Line and Maxima Lines respectively. Colour for displaying coefficients on scalogram can be selected using the tools provided in the lower right corner of Fig. 1.

Fig. 3. Wavelet adapted for detection of signals from the transverse cracks in the rail head
3. Results

A value of wavelet coefficients on scalogram is shown by varying shades of grey colour. The higher values of the wavelet coefficients are, the darker they reflected. Defect is represented by a vertical line of dark colour, which indicates that the shape of its signal is very similar to the adapted wavelet. Since the transverse crack amplitude in the fragment of defectoscopic signal is sufficiently large (its detection will not make any problem for an operator) there is a necessity to reduce it to the detection level of this defect (3 signal amplitudes from substrates — $3 \cdot a_{\text{sub}}$) to test the sensitivity of CWT where the operator can make mistake.

Defectogram segment with the reduced amplitude of a signal from the defect (which is actually masked by the background signal from the substrates) is shown in the top of Fig. 4. Result of analysis is represented under the signal in Fig. 4.

As it can be seen, the coefficients of CWT in the place of transverse crack (2172 sample) are well allocated in a range of small scales (high frequencies), which indicates the possibility of detecting weakly developed defects.

Figure 5 shows the dependence of the wavelet coefficients values from scale in the location of transverse crack. Wavelet coefficients have their maximum value in the range of scales from 8 to 21, and preferably that the assessment of the defect presence was made by the smaller scale (corresponding to high frequencies), so it will determine its location more accurately. Scales from 5th to 8th also can be used for this purpose, it all depends on whose minimum amplitude signals we need to identify.
From the above, we can formulate the basic terms of quality defects detection by CWT:

1. A good choice of mother wavelet for CWT.
2. Selection of the optimum scales quantity (for transverse cracks is offered in the range of 8 to 21 — see Fig. 5), by which we can judge about the presence or absence of defect with high probability.
3. Optimum thresholds on the value of the wavelet coefficients for each scale, which is selected according to the minimum signal level that is necessary to reveal.

4. Summary

1. MATLAB Wavelet Toolbox is a very convenient tool for analyzing defectoscopic signals.
2. The basic conditions for the qualitative detection of signals from defects of railway by CWT are formulated. These conditions are applied for all defects detected by the magnetic wagon-defectoscope.
3. Determined that CWT allows for detecting the signals from transverse cracks in the initial stages of their development that is, when their amplitude is approximately equal to $3 \cdot a_{\text{sub}}$ and it can be missed by the operator.

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Ciągła transformacja falkowa sygnałów inspekcji torów kolejowych w MATLAB wavelet toolbox

Streszczenie. Sieci kolejowe na całym świecie są coraz bardziej zatłoczone, przy coraz wyższych prędkościami pociągów i przewożą coraz więcej pasażerów przy większym nacisku na osi kół niż dotychczas. Połączenie tych czynników oznacza poważne zagrożenie dla istniejącej infrastruktury, co prowadzi do zwiększonego zapotrzebowania na ilość inspekcji i na koszty utrzymania aparatury kolejowej [1]. Obecnie, szyny są systematycznie sprawdzane pod kątem uszkodzeń wewnętrznych i powierzchniowych za pomocą różnych metod badań nieniszczących. Najbardziej upowszechnione z nich to metody ultradźwiękowe i magnetodynamiczna (Magnetic Flux Leakage Rail Inspection — MFL). Artykuł skupia się na analizie sygnałów defektoskopowych otrzymanych przy użyciu wagonu defektoskopii magnetycznej Kolei Lwowskiej (elektromagnetyczna metoda badań nieniszczących) wykorzystującej ciągłą transformatę falkową.

Słowa kluczowe: szyna, szczelina, CWT