17th World Conference on Nondestructive Testing, 25-28 Oct 2008, Shanghai, China

Detection of Internal Rail Defects Based on the Smoothed Randon Transform in The Presence of Ultrasonic Grain Noise

Mounir DJEDDI, Patrice AKNIN

The French National Institute for Transport and Safety Research
2 avenue du général malleret-joinville f-94114 arcueil – France
Phone : +33 (0)1 47 40 73 78, Fax +33 (0)1 45 47 56 06
{djeddi,aknin}@inrets.fr

Abstract

Most ultrasonic inspection systems rely on ASCAN mode to detect rail crack. The decision of the presence of a defect is then made based on a threshold set by the inspection operator. However, this operation is made more difficult when there exists ultrasonic and electronic noise, which leads to the false alarms or missing detection.

The aim of this research work is to detect internal rail cracks in ultrasonic BSCAN mode images using a modified Radon transform, which is able to detect segment lines by considering a finite uncertainty on the line orientation and thickness in the presence of interfering ultrasonic clutter. The originality of this transform resides on the fact that it uses different mask functions to characterize the neighbouring region of the line pixels in the BSCAN image. In this paper, we present two main functions, the Gaussian cone mask and the Gaussian band mask.

A Major advantage of this new technique is its on-line implementation thanks to the fast computational of the transform in function of a particular angle only which mainly related to the direction of the incident ultrasonic beam.

In this paper, we illustrate the performance of our method over standard methods by carrying out a set of tests using simulated BSCAN images with simulated cracks and noise based on phenomenological characteristics as well by using images obtained from the simulation of physical clutter model. The validation has been also carried out on real BSCAN images obtained from a real ultrasonic inspection bench mounted on the SNCF train and results demonstrate the good behaviour of the new detector compared to the usual one.

Finally, we present a graphical user interface under Matlab, which automates the simulation, analysis and detection of our approach.

Keywords: Smoothed Radon Transform, BSCAN, grain noise, detection, crack, Gaussian mask.

1. Introduction

The development of railways networks and the growth of transportation speed and frequency led authorities and companies to care about security by sponsoring research programs to develop efficient systems for the detection of rail defects. Nowadays, in order to guarantee the railway networks use onboard devices to detect internal cracks into the rail head. Specific trains with a speed of up to 50 Km/h are used to inspect the two rails with one or several ultrasonic probes. The following figures show the inspection train and the ultrasonic probe support structure used by the SNCF[2].

Figure 1. SNCF ultrasonic inspection train (left), ultrasonic probes support (right)

The real data used in this research work have been collected using three ultrasonic sensors positioned as shown in figure 2.

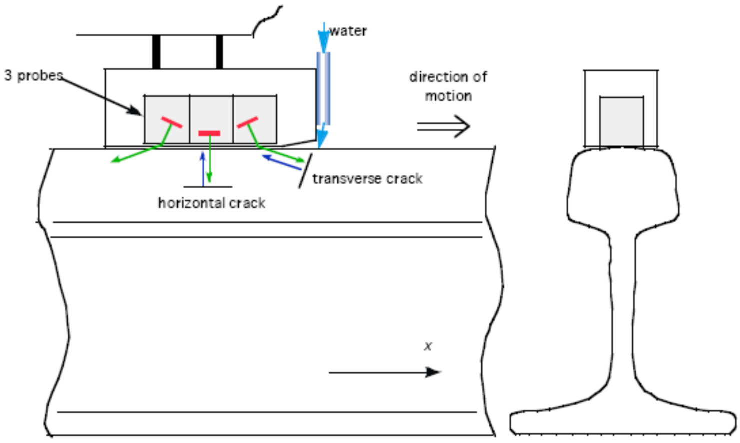

Figure 2. Inspection probes mounting

One vertical probe is used for longitudinal cracks and two inclined probes for transversal cracks with privileged angle at 68°. Ultrasonic pulses are triggered at constant space distance, driving by the running speed of the train.

The ultrasonic device of new generation presents new facilities. Their storage capabilities in conjunction with real time signal processing possibilities allow to design original detector in a different space, the BSCAN space. BSCAN representation is built by ASCANs aggregation. As shown in figure 6, the BSCAN is often presented in false color mode (color is dependant of the US echo amplitude), where each column is a single ASCAN signal obtained with one position *x* of the probe, and each line codes a time of flight.

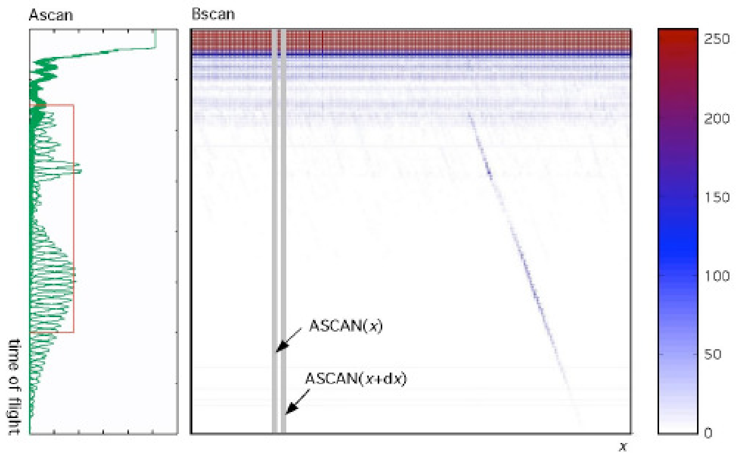

Figure 3. Example of real data BSCAN and ASCAN showing a transverse crack

The detection of cracks in BSCAN requires the analysis of the noise generated by ultrasonic propagation through the rail. This analysis will help us develop the adequate processing technique that reveals hidden cracks. In order to achieve this, we have constructed by simulation the different types of faults in the rail as shown in figure 4. It is worth to note that in this work, we will be mainly interested in transverse cracks.

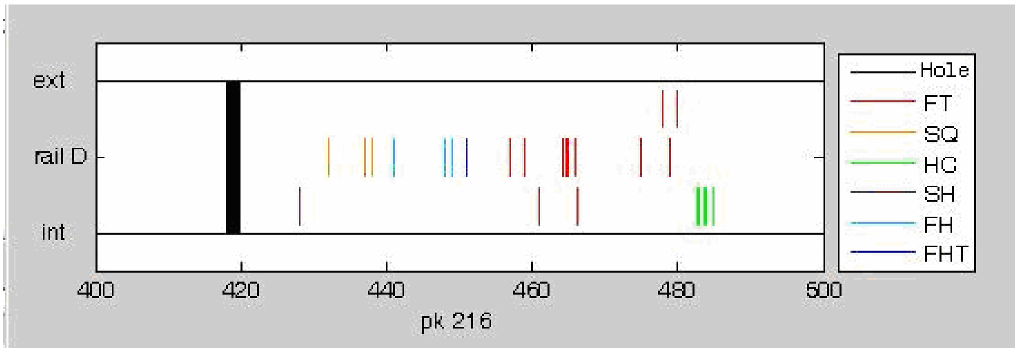

Figure 4. Simulation of rail track with different faults, Hole : reference fences, FT : transverse fault, SQ : Squat, HC : head checking, SH : shellings, FH : horizontal fault, FHT : horizontal and transverse fault.

2. Ultrasonic Simulations of defects and grain noise

2.1 Simulation of defects in rail

Simulations in laboratory have been done to generate artificial defects and to evaluate the impact of decentring a probe on the rail. The purpose is to quantify the acoustic field attenuation into the rail. The simulations have been done with the CIVA software by CEA (French Atomic Energy Commission) [6].
The software inputs are the geometry and characteristics of a rail (here it is a UIC 60 rail) and the ultrasonic sensors characteristics. Calculations are based on the reciprocity principle and the Kirchhof-Helmholtz integral calculation. Figure shows relative acoustic pressure into a rail with three different lateral positions of a 68° probe. The ultrasonic response of a crack depends of its size, its depth and its orientation:

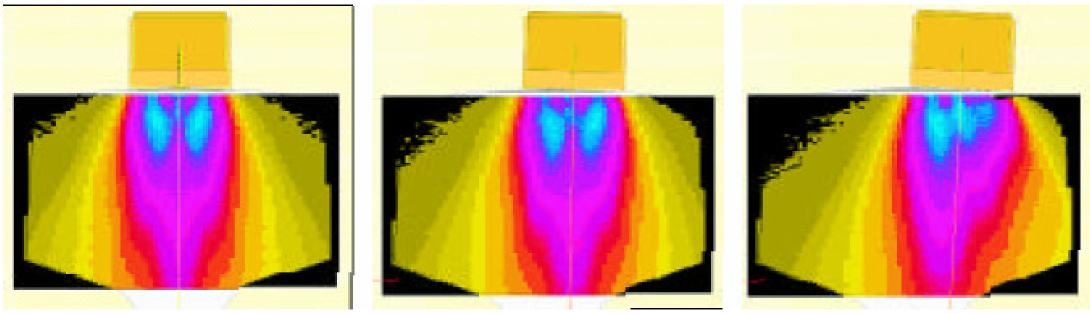

Figure 5. Simulation for BSCAN with cracks using CIVA software

2.2 Simulation of grain noise

In pulse-echo ultrasonic inspection the backscattering from the material structure appears in the BSCAN images as clutter, often referred to as grain noise or structure noise, which can hide considerably the cracks in the BSCAN, hence leading to the miss detection of the cracks. Considerable research works have been conducted in order to obtain models, which are able to generate noise close to real grain noise. In our work, we have used explicit statistical models of grain noise and defects based on the results given in reference [1].

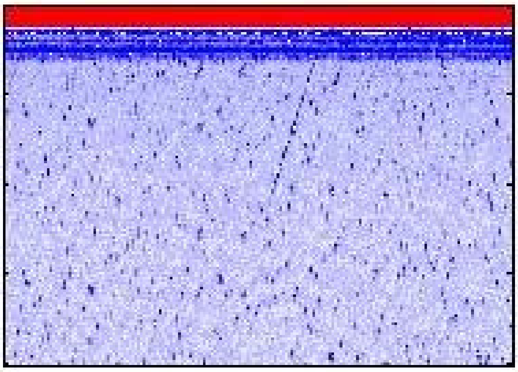

Figure 6. BSCAN of raw data showing a crack and grain noise

$$V(w) = H_{trans}(w)H_{trans}(w)\sum_{k=1}^{K_{tot}} \beta_k \frac{w^2}{x_k} \times \exp\{-2\alpha x_k w^4\}\exp\{-j2wx_k / c_l\}$$

Where H_{trans} is the frequency response of the transducer. Hence, in order to generate the noise, one has to follow the steps:

1. Specify the sampling frequency F_s and the number of samples N.
2. Specify the central frequency F_c and the bandwidth B_w of the band pass Gaussian filter defined in the frequency domain as

$$H(w) = \frac{1}{2}\exp\{\frac{-w^2\sigma^2}{2}\}$$

Where σ^2 is obtained by:

$$\sigma = \frac{\sqrt{2\ln 2}}{\pi Bw}$$

In our case $H_{trans}(w) = H(w)$. Finally, one has to specify the material attenuation coefficient α, the ultrasonic wave velocity c_l, the number of scatterers N_s and the minimum depth from which recording starts d_{min}. In order to compute $V(w)$ for a set of frequencies $w_n = 2\pi n F_s$, $n = 0,1,2,...,N/2$, one has to provide x_k and β_k. For x_k, this quantity follows a uniform distribution in the interval $[d_{min}, d_{min} + 0.5 c_l N/F_s]$.

The final time-domain signal is obtained using the inverse discrete Fourier transform and by considering that the obtained signal real.

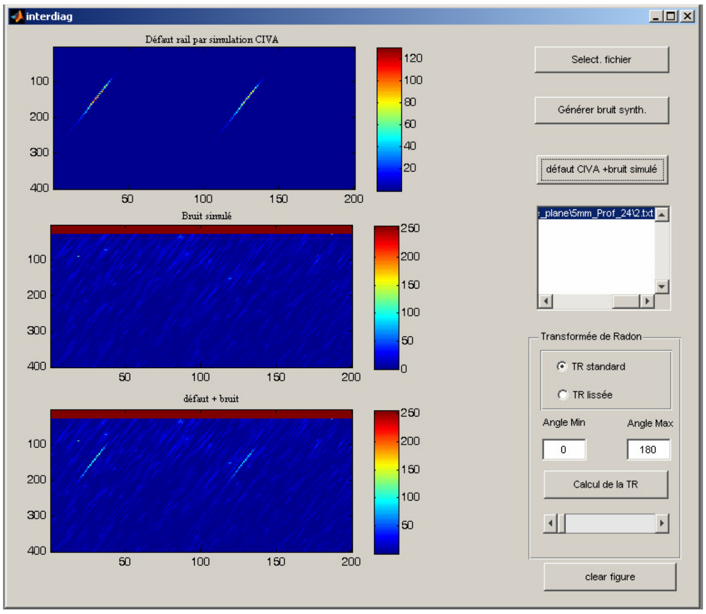

Figure 7. Crack simulation by CIVA (Top), simulation of oriented grain noise (Middle), fusion of the two previous simulations (bottom).

2.3 Denoising BSCAN images

The grain noise present in the BSCAN can hide considerably the presence of cracks. In order to reduce its effect, we have implemented a set of denoising algorithms. The interface proposes 5 algorithms: wavelet denoising, 2D median filtering, Steerable Filters, 2D Wiener filtering, histogram based filtering.

3. A new analysis tool : The Smoothed Radon Transform

Among all the image processing tools, Radon Transform has a central status for line detection [4, 5]. It calculates the perpendicular image projection on a turning axle.

$$\rho = x\cos\alpha + y\sin\alpha \quad (\alpha\text{=0 for horizontal axis})$$

The RT(α,ρ) point sums all the pixel that belongs to the line :

$$TR(\rho,\alpha)\Big|_I = \iint I(x,y).\delta\left(\rho - x\cos\alpha - y\sin\alpha\right)dx\,dy$$

In the ideal case and in the presence of a crack in the BSCAN, it is only necessary to compute the TR(0, α_0), where α_0 is the angle at which the crack is oriented in the image. This angle is dependant of the sampling and the velocity of the ultrasonic wave in the rail.

Due to the uncertainty relative to the imprecision in the measurement of the former quantities, we define the Smoothed Radon Transform (SRT), which takes into consideration the variability of the defect angle without reducing the performance of detection.

The SRT is computed thanks to a mask, which takes into consideration the uncertainty of the defect angle. Here, we present two types of masks used to detect cracks in the software. We call these two masks, Gaussian band and Gaussian cone respectively.

The smoothed Radon Transform (SRT) is obtained using the following expression:

$$TRL(\rho,\theta)=\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} f(x,y)V(x,y,\rho,\theta)dxdy$$

Here, the function $V(x,y,\rho,\theta)$ corresponds to a smoothing mask with values in the interval $[0,1]$.

Below, we present masks obtained by providing the number of columns and rows, the width of the mask in pixels for the Gaussian band and in degrees for the Gaussian cone, the sampling along the x-axis in millimetres and the sampling along the z-axis corresponding to the depth in microseconds. Finally, the velocity of the wave and the angle of shoot (by default it is set to 68°) are provided.

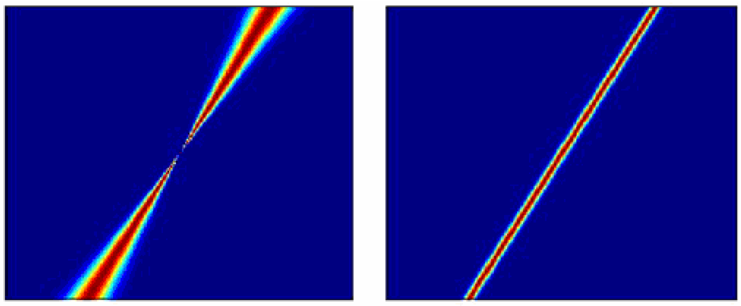

Figure 8. Examples of masks, Gaussian band (left), Gaussian cone (right)

The simulation of the Gaussian cone is obtained using the following expression:

$$V(x,y,\rho,\theta)=e^{-a^2/\sigma^2}$$

Where
$$a=\arctan\frac{x.cos(\theta)+y.sin(\theta)-\rho}{x.sin(\theta)-y.cos(\theta)}$$

As an example, we present below the contrast function for a crack angle variation βp=±5° about an angle of 15°.We observe clearly that for the Radon transform the contrast fades rapidly while it is not the case for the contrast associated with the Smoothed Radon Transform.

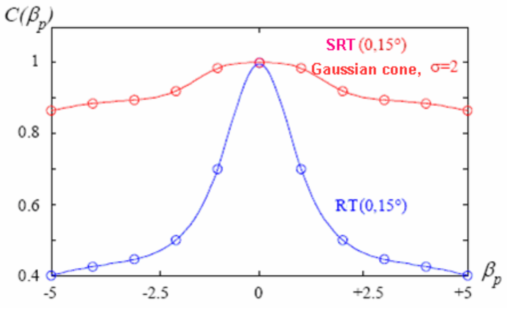

Figure 9. The effect of varying the crack angle

Thanks to the computation of the Gaussian mask, we can implement the detector based on the smoothed Radon transform (SRT). The pseudo-code is given in the table below [3]:

```
Pseudocode – Smoothed Radon transform based on-line detector
Enter N : the number of columns in the BSCAN
Enter L : length of the analysis window
Enter the overlap Lo
% computation of the SRT

Nblocks = int( 1 + (N-L) / (L-Lo) )   % compute of analysis blocks

for blockNumber = 1 to Nblocks
startIndex = (blockNumber-1)*(L-Lo)
block = x(startIndex to startIndex+L)
Res = mask*block       % calcul du produit B-Scan fois masque
SRT_Detector=sum(sum(Res))

Plot Detector
end for
```

4. Software presentation

A toolbox including algorithms for suppressing ultrasonic clutter is presented in the paper. The toolbox, implemented in Matlab™, is provided with a user-friendly graphical interface facilitating the analysis of BSCAN images and the comparison of the algorithms. This interface enables us to load raw data and displays them in BSCAN form or generates BSCAN images by the simulation of grain noise and defaults. The BSCAN is then processed by a set of algorithms for denoising. The last step is to detect cracks using either the Radon transform or the Smoothed Radon Tresform. Some aspects of the interface are shown below.

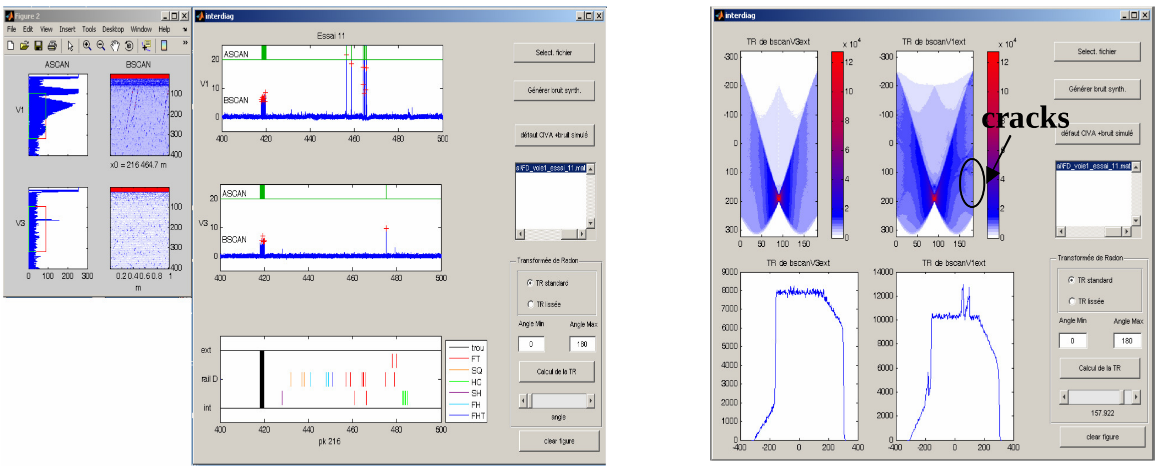

Figure 10. Raw data visualisation and faults detection (left), Smoothed Radon transform visualisation (Right).

5. Conclusion

This paper, we have presented theoretical and practical solutions for the detection of cracks in internal rails when the BSCAN images are subjected to grain noise. We presented a procedure for the simulation of BSCAN images with simulated rail cracks and grain noise.
We showed, we can increase the rate of good detection and decrease the false detection one by using denoising techniques associated to a new radon transform called the smoothed Radon Transform (SRT). The Latter is able to take into consideration the uncertainty in the computation of the defect's angle. In this work, we have been interested by data provided only by one probe. So in order to improve results, the signals from the two others probes containing additional information, which could complete the diagnostic of the defect, will be considered in future work using a data fusion technique between the three probes.

References

[1] M.G. Gustafsson, T. Stepinski, Studies of split spectrum processing, optimal detection and maximum likelihood estimation using a simple clutter model,
Ultrasonics 35, 1997, p31-52.

[2] H. Cygan, "Détection des défauts internes de rail; caractérisation des fissures transversales et horizontales",
Master Report, INRETS, Université de Technologie de Compiègne, 2001.

[3] M. Djeddi, P. Aknin, On-line detection of internal rail cracks in the presence of structure noise,
ON-TRAC Project Report, SYSTEM@TIC pole of Competitiveness, 2007.

[4] S.R. Deans, Hough transform from the Radon transform.
IEEE Transactions on Pattern Analysis and Machine Intelligence1981, vol. 3, no. 2, p185-188.

[5] R.O. Duda, P.E. Hart. Use of the Hough Transformation to Detect Lines and Curves in Pictures.
Comm. ACM 1972, vol. 15, p11-15.

[6] P. Calmon, S. Mahaut, S. Chatillon and R. Raillon, CIVA: an expertise platform for simulation and processing NDT data,
Ultrasonics, vol 44, 2006.