TRAITEMENT NUMERIQUE DU SIGNAL EN CONTROLE NON DESTRUCTIF

DIGITAL SIGNAL PROCESSING FOR NDT
SYNTHÈSE :

La communauté des Contrôles Non Destructif (CND) commence à adapter et à utiliser les plus récents développements du traitement numérique du signal et de l'image.

Nous résumons ici les caractéristiques principales des situations du CND (en particulier la présence de bruit et la formulation en problème inverse) et nous commentons brièvement les techniques déjà utilisées ou en train d'émerger (ouverture synthétique, spectre par bandes, réseaux à apprentissage adaptatif, filtrage à référence de bruit, modèles stochastiques, réseaux de neurones). Cette synthèse se concentre sur les ultrasons, les courants de Foucault et la radiographie. L'objectif ultime des utilisateurs (à savoir la mise à disposition de systèmes de diagnostic automatiques) ne peut pas être atteint à l'aide d'algorithmes de traitement du signal seuls. Une coopération étroite avec d'autres techniques, comme l'intelligence artificielle, doit être recherchée.
EXECUTIVE SUMMARY:

NDT begins to adapt and use the most recent developments of digital signal and image processing.

We briefly sum up the main characteristics of NDT situations (particularly noise and inverse problem formulation) and comment on techniques already used or just emerging (SAFT, split spectrum, adaptive learning network, noise reference filtering, stochastic models, neural networks). This survey is focused on ultrasonics, eddy currents and X-ray radiography. The final objective of end users (availability of automatic diagnosis systems) cannot be achieved only by signal processing algorithms. A close cooperation with other techniques such as artificial intelligence has therefore to be implemented.
1. INTRODUCTION

Non-destructive testing (NDT) is a major task for industry in order to improve plant availability, safety, product quality and cost effectiveness. An obvious trend in NDT is the growing importance of automatisation and therefore of signal processing (SP) [1].

We will focus on ultrasonics (US), eddy currents (EC) and X-ray radiography (or gammagraphy) and try to show how digital SP techniques can help achieving better performances.

By signal processing we mean digital techniques (i.e. after digitization) that transform an input signal into an output signal or into parameters. In this very broad sense images are particular signals and not only averaging and Fourier transform but also TOFD, SAFT, 3-D reconstruction and neural networks ... are SP techniques.

SP is now a well established field in itself providing other technical fields for sophisticated algorithms, no matter the signals themselves come from geophysics, telecommunications or medicine. It is worth noting that whereas the latter signals are well known in SP and have motivated numerous developments (let's remember AR modeling, adaptive filtering, wavelets, Prony and Pisarenko methods ...), NDT typical signals such as A-scans or multi-frequency E.C. signals are not yet considered as "classical" ones by SP people.
This is partly due to a late recognition in the NDT field of the potential benefits of investing in SP. Hence many techniques used in NDT often were "ad hoc" techniques without reference to underlying mathematics and basic literature. It is rather amusing to find this simple idea of crossfertilization between distant fields as early as in 1970 [2]!

2. COMMON FEATURES OF NDT PROBLEMS

Non-destructive testings result generally in an inverse problem: given a set of external measurements compute location and size of defects inside the material. Although the basic equations differ from one method to the other ("direct problem" formulations are different) their common feature is that they cannot be simply inverted because of i) noise, ii) lack of measurements, iii) incomplete modeling, (iii) all together.

NDT noise itself is rarely the widespread additive Gaussian white noise. A first example is the response of coarse grained materials when tested with ultrasonics: each grain behaves as a reflector so that the whole response does not resemble a random white noise and classical averaging does not work. In EC testing of some steam generator tubes flattening noise can be decomposed into several narrow band components (it is therefore non-random, but it is not "stable" either). Moreover noise and flaw frequency spectra are the same: if we bandpass-filter this flattening noise we also filter out the useful information! A last example originates from gammagraphy testing of thick wall samples. The radiographs are corrupted by a granular noise due to thickness and film, which has to be modeled adequately before processing.

3. SIGNAL AND IMAGE PROCESSING IN NDT

3.1 Acquisition

Digital signal processing could be difficult and hence expensive to implement. Therefore one has to implement it only in these cases where all other means have failed. This is why smart experimental setups and acquisition schemes have been developed. Among them Synthetic Aperture Focusing Technique (SAFT)[3], Time of Flight Diffraction (TOFD) and numerous enhancements of these basic techniques [4]. SAFT is some sort of "beamforming" already known in array processing for underwater acoustics or RADAR. For each pixel of the insonified specimen the A-scan signals received at n transducers are averaged after time-shifting. The shifts are computed from the different distances between one transducer and the pixel under study. Scanning the sample results in an enhanced image because of constructive addition of waveforms.

3.2 Image representation, modelisation and estimation

The aim is to better understand the content of the measured signals and then to be able to simulate it (together with its accompanying noise) for study and method evaluation purposes. The field of image processing has become a big consumer of sophisticated modelisation based on stochastic processes on one hand (Boolean and Markov models) and Bayesian procedures on the other
hand. Boolean models represent the granular noisy part of images by assuming it is a Poisson-type random spatial distribution of some basic pattern (usually the convex part of a Gaussian whose parameters are randomly chosen). This revealed relevant for radiograph modelisation [5]. Markov models account for the reasonable idea that statistical relationships between one pixel and the rest of an image are summarized in a window around this pixel. These models are used in many processing tasks and particularly in reconstruction [6]. Lastly the resolution procedure based on the classical Bayes' rule is an elegant way to introduce our "knowledge" on the desired image and on its transformation. To sum up, besides the mathematical aspects that can discourage NDT persons, the important point in this general stochastic approach is its ability to take prior knowledge into account as probability laws and disturbing noise as random processes. It is amusing (although well known) that introducing such apparently complex tools leads at the end to tractable calculations and interesting results.

3.3 Filtering and restoration

An important issue in US is to restore signals from austenitic welds because they are severely corrupted by noise. Several techniques has become popular since the work by [7]. They are called "averaging" although this reference to a "linear" mix could be misleading. Spatial averaging consists in selecting for example the minimum values in a number of waveforms produced by different probe locations close to each other, while frequency averaging does the same but from different frequency bands of a single signal. Both methods are based on the reasonable assumption that signal (i.e. defects) responses are coherent whereas noise (grain reflections) responses are not. Signal to noise enhancements of up to 10 dB have been reported.

In some steam generator tubes flattening noise filtering has to be done by specific digital techniques [8], [9]. They are based on a noise reference either picked from the signal itself or provided by an auxiliary signal (this is the so called correlo-filter [10]). When signal is not stationary one convenient way to filter it is to let a feedback loop estimate the filter coefficients from the measured samples. The output of the filter can be used as a noise estimation and subtracted to the original signal. This has been proposed for the first time in late '88 [11] and implemented in a system called EXTRACION [12]. An even more efficient implementation based on lattice filters is described in [13].

3.4 Classification

After clean signals have been recovered an automatic decision about their nature is desired. Besides the statistical techniques (principal component analysis, discriminant analysis and others [13]) a classification scheme got a tremendous favour at the end of the 70's [14]: the Adaptive Learning Network (ALN) is an empiric combination of candidate parameters, in which a non-linear polynomial model is constructed [15]. At each iteration the model "grows", that is the coefficients and the structure of the model are determined simultaneously. Model's output can be either a classification or an estimation of some parameter of interest. ALN has been tested both for US and EC signals. It has revealed to perform more or less like classical multidimensional
As the question of what are the optimal parameters remains open another approach has been proposed for EC signals [16]. The idea first used for hand print character recognition [17] consists in retaining only the first terms of some sort of Fourier development of the EC complex signal. These terms are then used as features for classification. Our experience about these Fourier descriptors applied to support plates discrimination is that they are too global to allow an accurate localisation of small flaws. Realistic results can also be found in [18].

Since rediscovery of Rosenblatt's perceptron in the 80's, NN have been proposed for numerous tasks. A particular combination has proved to be fruitful: i) a three-layer architecture (one hidden layer), ii) the back propagation algorithm to estimate the weights, iii) and classification purposes. Whereas NN have given an opportunity to revisit once more classical problems their very new features are i) efficient hardware implementation, ii) some preprocessing capability [19], [20]. Nevertheless the amount of relevant examples has a paramount importance in NN approach as well as in other approaches. It is surprising that nobody has compared ALN and NN at least from a NDT point of view.

4. CONCLUSION

This paper has presented a number of powerful signal processing techniques. They are needed in nondestructive testing because problems are difficult and data often embedded in noise. It was beyond the scope of the paper to give an exhaustive survey of SP techniques. It would have been interesting to comment on time-frequency representations, wavelets, fractals, higher order statistics, non-linear filters such as Volterra decomposition and others. It is the author's opinion that these new techniques will become familiar to the NDT community in the next years and will help solving more difficult problems. But signal processing is not sufficient to realize automatic diagnosis. This is why we will have to study hybrid systems mixing data fusion, finite elements modeling, 3D reconstruction and artificial intelligence.

5. REFERENCES


[18] Brown, Template matching- an approach for the machine sorting of eddy current data, Material evaluation, ASNT, (Nov. 1985)


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