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# Intelligent signal processing

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## Introduction

For the past 40 years or so, interest in the use of (artificial neural networks has been motivated by the recognition that he human brain operates in a manner that is entirely different from a conventional digital computer. A neural network is made up of an interconnection of a large number of nonlinear computation units known as neurons, which operate in a highly parallel fashion. Interest in the use of neural networks was reignited in the 1980s largely due to (1) the popularization of the back-propagation algorithm as a tool for the training of multilayer perceptrons, and (2) the use of attractor neural networks (exemplified by the Hopfield model) as content-addressable memories and optimization networks. For a historical account of neural networks, the reader is referred to Cowan (1990) and Haykin (1994).

Neural networks represent an important constituent of *softcomputers* (Zadeh, 1993). Other constituents include fuzzy logic, genetic algorithms, and probabilistic networks. Indeed, these softcomputing techniques are responsible for a paradigm shift away from the conventional digital computer, which we are witnessing in the design of intelligent machines. Important classes of such machines include intelligent pattern recognition systems, intelligent robots, intelligent controllers, and intelligent signal processors. In this paper, we confine our attention to the latter class of machines.

The paper is organized as follows. In section 2 we describe the attributes of intelligent signal processors. In Section 3 we outline the important characteristics of neural networks that are basic to the construction of intelligent signal processors. In Section 4 we discuss time-frequency analysis and principal components analysis as important adjuncts to neural networks for preprocessing. In Section 5 we present some results demonstrating the application of these techniques to a difficult radar detection problem. Section 6 concludes the paper by presenting some final thoughts on the subject.

# Receiver operating characteristic (ROC) in nondestructive inspection

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## Abstract

A suitable and objective method to investigate the performance of inspection systems is the Receiver Operating Characteristic (ROC) which is based on the general theory of signal detection. All diagnostic systems include the task of separating a signal from a background of noise. The idea of the ROC method is to characterise the accuracy of an inspection system by evaluating the correct detection rate versus the false alarm rate for a set of different thresholds between signal and noise applied during this task. This method is called detection ROC because it deals only with the pure detection of a signal (defect). If there are several types of defects one can also measure the accuracy of the defect classification and the correctness of the indicated defect importance with the help of the so-called Joint ROC. For the industries it is particularly important to find the unacceptable defects which has to be repaired. For this case the masked ROC is calculated where only the correct or false indications of critical defects are taken into account.

The power of the method is demonstrated in terms of three examples: ultrasonic testing of fibre reinforced plastic materials used in space- and aircraft manufacturing and of welds typical for railway systems and radiographic weld inspection. Of interest was here the dependence of the testing performance from the ultrasonic frequency, from the experience of the inspectors and from the digitisation procedure, respectively. Special tests - reducing the number of samples - were undertaken to show until which minimum amount of statistical basis the result is stable.

## Compensation of ultrasonic transducers response by adapting excitation signals, application to defects evaluation

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**Abstract**

Despite the precautions taken by mean of calibration procedures, the evaluation of real defects in ultrasonic non destructive testing presents great discrepancies when we change the transducer by an other supposed to be of similar characteristics. These discrepancies are ascribed to the variations in the spectral responses of the transducers utilised. We have achieved a method which permits, by an adapted excitation, to compensate the differences in the transducers responses and we have shown that this permits a 6 dB gain upon the evaluation disparity of real defects.

## Statistical method to evaluate the amplitude of cyclical noisy signal in IR thermography

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**Abstract**

Noise rejection is of primordial importance in Thermoelasticimetry. The evaluation of stresses by means of the thermoelastic effect requires high accuracy measurement of the dynamic temperature changes of a sample under cyclic mechanical loading. One has chosen a statistical method to reject the noise of sinusoidal signals (quite important for a standard infrared camera (0,05 K)) and to estimate their amplitudes. Digital treatment of a series of thermographic images allows for the calculation of the temporal distribution of every pixel.

Without loading, these distributions are similar to the Gaussian distribution of a white noise. Under cyclical loading one obtains the distribution of the sum of sinusoidal signal and white noise. Therefore this distribution is wider than the Gaussian one. Its width is a function of the signal amplitude. Thus, comparing both distributions, it is possible to estimate the amplitude of the cyclic signal.

# Quasi frequency diversity processing of ultrasonic signals - A review

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## Abstract

Signal processing techniques capable of improving signal to noise ratio in the presence of strong backscattered grain echoes interfering with the echo reflected from material defects are considered in this paper. A number of algorithms belonging to a class of Quasi Frequency Diversity (QFD) techniques are presented and compared. The best known method in this class is the Split Spectrum Processing (SSP), which has been proven successful in suppressing material noise. The SSP is based on the idea of expanding the received ultrasonic signal into a set of split signals corresponding to a number of narrow frequency bands. However, performance of the SSP is highly dependent upon number of split signals, their center frequencies and bandwidths, that may be difficult to estimate properly. Robust and adaptive QFD techniques are proposed as a solution to this problem. Two robust QFD techniques based on removal of narrow frequency bands from the ultrasonic signal spectrum are presented in the paper. The first one, referred to as Cut Spectrum Processing (CSP), does not require any spectral parameters at the price of an increased computational burden. The resultant CSP algorithm includes one single parameter, which can be easily tuned interactively by the operator. The second technique, referred to as Fragment Spectrum Processing (FSP) is based on an idea of fragmentation of the signal spectrum by using a set of irregular comb filters, i.e., filters having a frequency response consisting of a large number of alternating stop- and pass-bands. Efficiency is accomplished by using a set of the comb filters with virtually different (possibly orthogonal) frequency responses. The adaptive QFD technique presented here is based on the fact that the polarity thresholding SSP can be formulated as a multilayer perceptron artificial neural network operating in feedforward mode with binary neurons and bipolar input signals.

The SSP and QFD algorithms described above have been implemented as a software package for PC capable of processing ultrasonic B-scans and evaluated using real ultrasonic signals originating from cracks and notches in welded reference blocks typical for nuclear power plants.

## Specific features of NDT data and processing algorithms: New remedies to old ills

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**Abstract**

Non destructive testing data from in-service inspections have specific features that require the most sophisticated techniques of signal and image processing. Each step in the overall information extraction process must be optimised by using recent approaches such like data decomposition and modelisation, compression, sensor fusion and knowledge based systems. This can be achieved by means of wavelet transform, inverse problem formulation, standard compression algorithms, combined detection and estimation, neural networks and expert systems. These techniques are briefly presented through a number of Électricité de France applications or through recent literature results.

## Edge detectors using Greco-Latin squares

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**Abstract**

In this paper a 5x5x5x5 Greco-Latin Squares experimental design model has been applied to detect horizontal, vertical and both diagonal edges in a 5x5 pixels mask. After detecting a type of edge (i.e. horizontal, vertical or diagonal), an edge is localized by using the linear one-way analysis of variance model. Comparisons between row or column or diagonal means called contrasts are carried out by F-test on contrasts. These, in turn are used to detect the location of an edge within the mask. Decision is made about presence or absence of an edge for a pixel located in the center of a 5x5 mask and then the mask is moved throughout the image to trace the edge map. The procedure is simple, efficient and robust as supported by computer generated edge detection examples.

## Digital image processing in holographic nondestructive testing (HNDT)

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**Abstract**

All interferometric methods as for instance holographic interferometry, speckle metrology, shearography and topometry are based on the transformation of phase differences of interfering wavefields into observable intensity variations, that is, interference fringes. The analysis of fringe patterns by eye, however, is highly subjective and time consuming. To use interferometric methods for optical shop testing in an industrial environment a drastic decrease of the evaluation time combined with increased reliability of data is necessary. In recent years, various methods for computer aided quantitative and qualitative evaluation of fringe patterns have been developed. Locking back, one may state that the crucial step from the laboratory to the factory floor became possible by applying efficient computational equipment and algorithms combined with new data reduction techniques for the digital evaluation of interferograms. On two examples - the unwrapping of noisy mod $2\pi$ images and the knowledge assisted recognition of material faults in interferograms - it will be demonstrated how digital image processing and analysis can improve the reduction of relevant data in holographic nondestructive testing.

## Design of morphological processors for ultrasonic nondestructive evaluation of materials - a review

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**Abstract**

Sequential morphological operations are capable of extracting signal features while suppressing random noise and undesired signal patterns (e.g., speckles in ultrasonic imaging). They utilize a structuring element which interacts with the signal in order to suppress noise and enhance certain desirable information. In this paper we identify a group of sequential morphological processors that exhibit a performance similar to lowpass, bandpass and highpass filters. Furthermore, a class of morphological processors are presented which offer peak detection and edge detection. Deterministic and stochastic properties of combinational (parallel and/or serial) morphological processors have been studied. In particular, the information content of ultrasonic signals has been used to design a suitable structuring element with optimal performance. The results obtained by applying morphological processors to experimental ultrasonic signals show that combinational morphological processors can improve flaw detection when the signal is contaminated by impulsive thermal noise and/or microstructure scattering echoes.

# Materials NDE by non linear filtering applying heat transfer models

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## Abstract

In active thermal Non Destructive Evaluation, properties of interest are obtained analysing time evolution of an informative parameter (e.g. excess temperature, absolute or relative temperature contrast, etc.). The fundamental problem to get rid of different kinds of noise is not deeply studied up to now. Popular filtering techniques, both is space and time domain, are discussed.

The analysis of the thermal signal through a suitable heat transfer model has been suggested by many authors. This technique has been applied to NDT of layered materials if a simple analytical expression describing the real problem is found. New more powerful digital tools allow to extend this approach to other applications. For instance the extraction of useful information from raw data, in case of non selective maximum of the contrast signal, is taken into account.

In this paper the use of non linear filter in time-domain is described to improve the signal to noise ratio of thermal-infrared NDE. The filter is based on the heat transfer model of the test procedure, taking into account actual boundary conditions. The description of the heat transfer allows to separate the useful signal from noise. Therefore the analytical models of classic thermal/infrared NDE are reported.

The suggested method allows to filter data and, at the same time, estimate useful quantities. The basic procedure is an iterative non-linear best fit of experimental data.

Solving the direct problem it is possible to simplify the testing procedure, tuning the filter to the actual experimental conditions. The NDE accuracy is increased taking into account heat losses. Finally it is possible to choose the parameters which have to be estimated. In such a way the same approach can be used for different tests as thickness or absorbed energy or surface heat exchange coefficients measuring.

Thermal diffusivity measurements are carried out according with the flash method and processed by the suggested procedure. A filter suitable for thermal/infrared NDE on homogeneous porous materials is designed and tested for the moisture mapping. Experimental results are reported and discussed.

## The influence of image digitisation and calibration of a scanning system upon weld inspection

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### Abstract

The capability of a high-resolution scanning system for industrial radiographic films was tested dependent upon the specification and calibration of the systems using ROC method.

## New developments in the detection of defects by photothermal thermography

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### Introduction

The general principle of the control by thermography consists in submitting an object to an external excitation, forcing it to react, and then observing the thermal reaction by an infrared camera. A large variety of systems can be used as an excitation: vibrations, microwaves, magnetic induction, air, water and light. The results we present here exclusively concern this last point; thus, the technique is called Photothermal Thermography (Photo = luminous excitation and thermal - induced effect). Others also call it Video Pulse Thermography. When used in non destructive testing, the technique permits the detection of subsurface singularities. We present, hereafter, some visualization techniques and programs which help NDT operators to give a better diagnosis: faster, more reliable, and more precise.

## Advances in signal inversion with applications to infrared thermography

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**Abstract**

Approaches to performing the thermal characterization of defects in solids are discussed including phenomenological treatment of experimental data, use of classical heat transfer solutions and minimization of functionals. Simple analytical expressions proposed by various authors in order to estimate defect size, depth and thickness are verified by using well defined reference temperature data.

## Use of finite difference method for prediction propagation of ultrasonic waves in solids

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**Abstract**

Successful interpretation and analysis of ultrasonic wave records depend on understanding the expected waveforms in the presence of material and structural defects. Measured signals can be compared to the predicted ones, and signal processing operations can use the predicted waveforms in various ways such as targets of filters, as teaching base for neural nets and expert systems and such. While exact elastic solution can usually be obtained only for simple geometries, finite difference method offers a flexible method that can accommodate defects and other discontinuities. In this paper, finite difference method is used to solve the elastic wave equation and obtain the wave propagation pattern. Particular attention is given to long distance wave propagation. Standard non-staggered methods produce spurious signals caused by numerical dispersion and require small grid size, resulting in a significant increase in computer memory requirements and in calculation time. Staggered grid, on the other hand, along with high-order method, reduce these requirements and improve the accuracy, thus enabling practical solutions to these problems.

# Inverse scattering of pulsed thermal waves

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**Abstract**

Preliminary results on inversion of pulsed thermal wave images have been presented elsewhere [1-4]. In that work a technique was introduced for removing the blurring of thermal wave images of planar subsurface features such as delaminations. The purpose of the development of the technique was to provide an algorithm for inverting a *single* image obtained at some time after the interrogation of the sample with a thermal wave pulse, and to obtain the shape of the scatterer with a *single* calculation on that image. The method involves no tomographic reconstruction and does not rely on any kind of successive approximation scheme. Recently, we have extended the method to include thermally anisotropic materials and also multiple scattering effects. [5]

# Informative parameters and noise in transient thermal NDT

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**Abstract**

Detail description of physical and derived informative parameters used in transient thermal NDT is presented. Features of temperature-domain and time-domain parameters are discussed. Expressions for signal-to-noise ratio are specified and efficiency of spatial filters applied to IR thermograms with defects is discussed. Spatial frequency spectrums are obtained in non-defect and defect areas using fast Fourier transform.

## On methods for shape correction and reconstruction in thermographic NDE

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**Abstract**

In this paper, various methods are proposed to correct distorted infrared images recorded over curved specimens. This problem is particularly important in thermal inspection applications, in order to avoid misinterpretation of the results. In the paper four methods are discussed: point source heating, video thermal stereovision, direct IR image calibration and shape from heating. Particular emphasis is given on the last two methods. Details of the methods are given and results presented for each method along with particular advantages and drawbacks.

## Use of neural networks and expert systems for evaluation

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**Abstract**

This paper considers recent developments in the techniques for evaluation, in particular those which are useful, as alternatives to complex mathematical expressions, for modelling non-trivial, non-linear relationships. Neural Networks and Expert Systems, with the ability to learn, are considered in depth and a number of practical examples are included to show the techniques in operation.

## Applications of artificial intelligence in nondestructive evaluation

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**Abstract**

To meet the increased demand for reliable inspection in complex NDE tasks, artificial intelligence (AI) can provide new and effective approaches to many problems. AI expert systems (often rule-based) offer solutions to problems for which numerical algorithms mat not be suitable and for which nonnumeric information in important. Expert systems allow data fusion to utilize information from different NDE sensors, and can deal with uncertainty more effectively. Another advance in AI perhaps is in artificial neural networks which have been increasingly used in NDE. These and other AI capabilities have been applied successfully to several NDE systems which will be discussed in this paper.

## Fuzzy min-max neural network based classification of underwater layered media due to attenuation effects

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**Abstract**

A feed-forward fuzzy dual-connected neural network classifier that uses min-max amplitude ranges to define classes is designed and evaluated for underwater layered media recognition based on a computer simulation of synthetic data. A supervised fuzzy min-max learning rule updates the weights corresponding to the input data sets used for training. A simple nonlinear structure modeling underwater layered media response to acoustic inputs accounting for time delay in layers and the exponential decay of the output signals' amplitude due to attenuation effects is employed for simulations used to test the classifier. Following the training stage, the classifier is tested with different test data sets. The results suggest that the application of fuzzy min-max neural networks in pattern recognition will enable automatic classification of the layered media with reasonable accuracy.

## Wavelet transform based transient detection

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### Abstract

In this work, the problem of detection of transients in noise is considered. A method for the detection and classification of transients based on the matched discrete orthonormal wavelet transform is proposed. The idea behind the method is to increase the transient / background ratio by expanding the signals in the time-scale space, identifying the bands containing transients and using various linear / nonlinear operations, such as the Teager's energy operator, for enhancement. Matched wavelet filters are designed from typical transient waveforms by using the Frazier-Kumar method in order to increase the correlation between the wavelet family and the transients to be detected. Transients are also analysed via the short-time Fourier transform, the Gabor representation and the Wigner distribution.

## The role of modeling in the determination of probability of detection

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### Abstract

The reliability of nondestructive evaluation (NDE) methods has traditionally been determined through costly round-robin test block trials. Here, an alternative model-based approach is described, where computer simulations are used to predict the probability of detection (POD) versus flaw size curves for components. Uses of such POD curves are shown to include estimating NDE inspection performance, setting of inspection parameters, evaluating the influence of inspections on component reliability, and designing parts with inspectability requirements.

# Early detection by stimulated infrared thermography. Comparison with ultrasonics and holo/shearography

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### Summary

Infra-red stimulated thermography is a fast and global method. Among the recently emerging NDE methods, it is probably the less intrusive one since it really needs no contact at all with the tested structure. A new inversion, using an early detection of the contrast, is presented to demonstrate how it recovers the depth of the defects with accuracy and removes partially the loss of resolution produced by the lateral heat diffusion.

Ultrasonics methods are well established NDT techniques and start to become remote and contactless with the development of laser ultrasonics. Holography/shearography are global methods which produce images of rather large a areas with a good spatial resolution.

A second goal of this paper is to compare the results obtained in thermography with these different new techniques. We have mainly used an artificial sample of carbon epoxy composite containing Teflon inserts and a sample of composite with impact damages. The comparison of the results obtained with the first sample was exploited in order to determine what are the practical interests of each method. The second comparison aims mainly to evaluate the precision of ultrasonics and infra-red thermography in the determination of the spatial extension of multidelaminations.

# Combination of FEM and HI for NDE purposes

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### Abstract

The holographic interferometry is a tool, to detect the displacement on the surface of a specimen, with an accuracy of less then the wavelength of the used laser. The Finite-Element-Method can be used, for instance to model problems of the structural mechanics. To verify the model with the behaviour of the real specimen, there must be an interface.

Two investigations were done on overlap-adhesive-bonds. First the material properties of the adhesive-layer could be determine and second the inhomogeneous surface displacement over an adhesive defect under thermal load could be explained, both with the surface deformation as interface between model and experiment.

# Processing suited to in-the-field applications of NDT

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## Abstract

Whilst there are several key NDT techniques, and others presently developing, it is clear that in almost every area, image processing can significantly enhance the information that the NDT technician can provide. However, as these developments proceed, we should not loose sight of the user's requirements, namely, that the NDT results are produced at the inspection site, rather than requiring post-processing or careful analysis at a remote base, and that any on-site processing should be fast. This need is reflected in the general move to PC-based systems, where a degree of data enhancement in real-time is available to permit on-site analysis. In this presentation, the work at AEA Technology, within the National NDT Centre (NNDTC), is used to demonstrate such processing and their benefits in the fields of thermography, ultrasonics, X-ray computerised tomography and radar.

It is concluded that NDT community benefits a great deal from the advances in signal processing presently being made. It is shown that these advances are not restricted to laboratory applications, and that the future should see a number of them in common usage at the inspections site.

# Imaging of magnetic properties using photothermal techniques in microwave resonance

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The interaction of microwaves with magnetic materials in determined by the high frequency magnetic susceptibility tensor. To achieve a spatially resolved measurement of this property two different photothermal approaches have been developed and applied [1]. One technique makes use for the heat dissipated in the material in the course of the absorption of microwaves. Modulating the microwave input power thermal waves are generated which can be detected by the photoacoustic effect or by laser beam deflection. The photoacoustic method was successfully applied to image the depth variation of the magnetization in layered magnetic tapes [2]. The laser beam deflection technique, in addition, provides a lateral resolution which has been used to visualize collective magnetic excitations in soft ferrites and in yttrium iron garnet slab [3, 4]. In the latter material also the spatial evolution of magnetostatic modes in the linear and in the non-linear regime could be studied. To improve the spatial resolution and the sensitivity, a second technique has been developed that relies on the local modulation of the high frequency susceptibility by a thermal wave generated with an intensity modulated laser beam incident on the sample [5, 6]. This technique has been used, for the first time, to obtain lateral resolved images of spherical magnetostatic modes excited at a microwave frequency of 9.2 GHz in an yttrium iron garnet sphere [7]. A further benefit of the photothermally modulated ferromagnetic resonance is the ability to visualize magnetic signals. The technique has been applied for the imaging of the magnetization distribution due to a magnetic signal recorded by a tape recorder on a particulate tape. As compared to the photoacoustic method and to the laser beam deflection technique, the photothermally modulated magnetic resonance provides a true three-dimensional tomographic method for magnetic properties with a superior sensitivity and spatial resolution. The signal strength and shape, on the other hand, depends beside the magnitude of the high frequency susceptibility also on its temperature derivative, which complicates the quantitative description of the signal generation process. In most systems investigated until now, the photothermally modulated ferromagnetic resonance signal is governed by the temperature coefficient of the spontaneous magnetization. Here the signal can be modelled straightforward on the basis of the magnetization behaviour. A dramatic intensity enhancement accompanied by a change of the signal shape is predicted on the basis of this mechanism when the magnetic transition temperature is approached. The predicted behaviour could be confirmed experimentally in the case of a yttrium iron garnet sample [8].

# Limited view computed tomography in nuclear inspection

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This paper discusses the theoretical and experimental development of Limited View Computed Tomography (LVCT) methods based upon Algebraic Reconstruction Techniques (ART). The LVCT/ART process was successfully applied to image the distribution of fouling on steam generator tubes.

Some nuclear steam generators contain approximately 3,000 Inconel 600 U-bend tubes of 30 metre length and 13 mm diameter. These are closely spaced, with a tube-to-tube gap of 7 mm. Tube separators, termed support plates, are used to hold the tubes in place. The gap between a tube and support plate (termed broach hole) is only 3 mm. A build-up of fouling in these holes can cause abnormal flow surges and level fluctuations during operation. These is a need for and inspection tool to image the extent of broach hole blockage before deciding on corrective maintenance.

Chalk River Laboratories (CRL) investigated methods to measure the degree of blockage using penetrating radiation. Theoretical calculations showed that sufficient density resolution could not be obtained by simultaneous movement of a single radioactive source in one tube and a single detector in an adjacent tube. Computer modelling revealed that a useful image of broach hole fouling could be constructed using several source and detector position. CRL conducted theoretical and experimental studies to measure broach hole fouling by Limited View Computed Tomography.

An Iridium-192 source was placed inside one steam generator tube and an array of gamma-ray detectors was placed in an adjacent tube. The source was moved in 1 mm steps over a range of 300 mm. For each source step, the radiation intensity recorded by each element of the detector array was measured. This information was transmitted out of the steam generator tube by a fibre-optic cable, which was connected to a high resolution charge coupled device camera operating under computer control. As each of the 300 x-ray images was captured, the information was processed by Algebraic Reconstruction Techniques. ART uses iterative algorithms to approximate the image that otherwise could not be attained through analytical solution. The result was a Limited View Computed Tomographic image showing a cross section of the broach plate region. The severity of broach plate erosion and the degree of broach hole fouling were clearly visible.

## Development of vision tools for welding applications

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**Abstract**

In order to adequately support our weld modeling work, new ways of acquiring and analyzing data were required. This involved not only instrumentation of the welding process with a variety of vision tools to provide the data required, but also developing image analysis tools for reducing the data and delivering the data to the modeller in a timely and accurate manner. Temperature and displacement diagnostics have been used most frequently and will be discussed in this paper. The availability and increased speed of workstations have enabled us to extend these tools form use for modeling to weld process control.

## A novel technique for defects classification form their ultrasonic pulse echoes

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**Abstract**

A new technique for defects classification form their ultrasonic pulse echo signals is proposed. Conformal mapping of the input-output defect model is used to enable the formulation of the defect characteristic function. Features form this function are extracted for use in a hidden flaw discrimination.

## Characterization of advanced composite materials by X-ray Compton scattering

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**Abstract**

Non destructive evaluation by Compton scattering uses an industrial X-ray tube and allows three-dimensional (3D) imaging of materials. The X-ray tube and detector are set on the same side of the object. By that way, non destructive evaluation of the wall of a tank, even full, is possible without the use of very high energy, because X-ray do not cross the whole object. Beside 3D imaging, this method allows point by point density measurements in the near-surface zone of any component (even dense and bulky). An accuracy of 1% was achieved not only on light composite materials, but also on dense ($\rho \approx 6.5$) components provided by powder metallurgy. A method allowing thickness measurement of a wall was also developed, especially suitable for multilayers compounds. The accuracy is $\pm$ 0.01 mm.

## Steel sheet surface quality monitoring by multiple spectral reflectance signal processing

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**Abstract**

This paper summarizes the work carried out to date in order to design a device providing-permanently and on-line - a reliable index of oxidation presence and importance on steel sheets leaving a continuous annealing furnace. Reliability namely means that the effects of roughness should not affect this index.

## Integrated hardware implementations for digital system

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Advanced digital systems interact with complex dynamic environments. They sense and process information and their actions modify the state of the environment. Such systems must be robust, reliable, and flexible. They must also satisfy performance and timeliness criteria. In many complex real-world applications, there is a clear need for distributed, parallel, and heterogeneous architectures with real-time and fault-tolerance capabilities.

We review modern parallel processing technology: taxonomy of systems and interconnection networks. Two parallel building-block processors are introduced and compared: the Transputer and the TMS320C40. Real-time and fault-tolerance concepts are also exposed. Finally, we conclude the presentation with a look at a few case studies, from current projects at the Computer Vision and Systems Laboratory.

## Parallelization of the synthetic aperture focusing technique for ultrasonic testing

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### Abstract

A new parallel implementation of the synthetic aperture focusing technique for ultrasonic testing (SAFT-UT) has been developed. This algorithm runs on small, inexpensive workstations, which are easily transported to a testing site. The performance is achieved in *realtime*, in that data can be processed as fast as it is acquired. The SAFT-UT technique is reviewed, and details of the new implementation are discussed. Performance data are presented for two platforms, a shared-memory parallel processor and a distributed-memory parallel processor.

## Applications of high resolution inversion to ultrasonic imaging of multi-layered structures

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### Abstract

A novel inversion algorithm has been developed which combines a "macro" layer-stripping approach with high resolution, L2-norm deconvolution. This algorithm has been implemented for real time data acquisition using a TMS 320C30 digital signal processor as well as for post-processing of the ultrasonic data. A further optimization-based procedure may also be applied, provided there exists adequate prior knowledge concerning the structure. Applications for these algorithms will be demonstrated for the detection of disbonds and delaminations in aircraft composite structures.

## The European project TRAPPIST: transfer, processing and interpretation of 3D NDT data in a standard environment

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### Abstract

The European CEC-funded project TRAPPIST aims to provide the pre-requisites to combination of various NDT-methods. The key components to achieve this goal are a multi-method NDT standard data format and a platform-independent software environment. Another important feature is communication of both NDT data and expertise between remote workstations through state-of-the-art European ISDN broadband network. A full scale prototype is under development to demonstrate feasibility of this system. A survey on recent literature showing originality of the TRAPPIST features is included in the paper.

## Optics and information processing at NOI: a good match for NDE

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In this presentation, I will provide an illustrative overview of some research projects going on at NOI, which are relevant to NDE. Areas covered in particular will be in information processing and in optical metrology. Example of projects presented will include various optical machine vision systems applied to industrial inspection, a fringe pattern analysis software applied to Moiré and holographic interferometry and some of the signal processing methods such as classifiers in optical spectrometric instrumentation and in remote sensing multi-spectral images.

## Non-invasive measurement of temperature changes in tethered flying blowflies by thermal imaging

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### Abstract

The changes in temperature occurring in the body of a flying blowfly are measured with the non-invasive technique of thermal imaging. It is found that during rest the temperature of the three main body compartments, i.e. head, thorax and abdomen, approximately equal the ambient temperature. Upon flight onset the thorax temperature increases about exponentially, with a time constant ≈ 30 s. In steady flight, the thorax temperature is ≈ 5 °C higher than the ambient temperature (≈25 °C). After flight, the temperature of the thorax decreases, again about exponentially, with a time constant of ≈ 50 s. A three compartment model of the insect body allows a quantitative description of these temperature changes, thus yielding values for the blowfly's thermal parameters.

# Substituting statistical for physical decomposition: are there applications for parallel factor analysis (PARAFAC) in non-destructive evaluation?

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## Abstract

We describe the three-way factor analysis method PARAFAC (PARAllel FACtor analysis) and its possible application to Non-destructive Evaluation (NDE). Because standard analysis methods usually separate a signal into abstract, mathematically convenient parts such as frequency bands, orthogonal variance components, etc., irrelevant signals often remain mixed with important ones. In contrast, Parallel Factor Analysis separates mixtures into functionally distinct parts, i.e., parts showing distinct patterns of variation in magnitude across varying measurement conditions. It is used, for example, to decompose the mixtures of curves generated by fluorescence spectroscopy of complex samples into the individual spectra of the constituent chemical compounds in the mixture; this is feasible because each compound shows distinct patterns of variation in fluorescence intensity across varying stimulus frequencies. In NDE, PARAFAC could similarly separate the mixture of signals (or image patches) from an object under test into those arising from each causally/physically distinct component of interest in the object, provided that there are several parallel test conditions, or multiple time slices, where the signals from different components of interest show distinct patterns of variation in magnitude across the conditions. Various normal and anomalous signals can then be isolated onto distinct factors, allowing anomalous ones to be identified and linked to their physical sources.