Consiglio Nazionale delle Ricerche

*D*esign and Development of a Station Oriented to the Non-Destructive Test Analysis of Aeronautical Components

Luciano Azzarelli, Salvatore Minutoli, Ovidio Salvetti

B4-39
dic-1998

European Project CANDIA
Theme "Data Fusion and Diagnosis"

Design and Development of a Station Oriented to the Non-Destructive Test Analysis of Aeronautical Components

L. Azzarelli, S. Minutoli, O. Salvetti

Istituto di Elaborazione della Informazione, CNR
Via S. Maria 46, I-56126 Pisa

Contract P985022N, 3 February 1998

Contract of collaboration IEI – Alenia

Progress Report

This report describes the state-of-the-art of the activity carried out at IEI in the frame of the contract P985022N, dated 3 February 1998.

This contract refers to a research co-operation on the argument 'Data fusion and Diagnosis', having the main objective to study, define, develop and experiment a prototype of a processing station oriented to non-destructive test assisted analysis of aeronautical components (in the following referred as 'CND station').

In particular, the report describes the activities performed for the development of the following phases, mentioned in the contract in subject:

Phase 1 – Design of a CND station

Phase 2 – Development of a prototypical station

Phase 3 – Organisation and documentation of the software developed.

In the description of the activity, we refer to the specifics pointed out in the report NT 56X97001, in date 23 June 1997, and to the real information and data received from the partner Alenia. In particular, in lack of specific inputs, the work has been based on the equipment at our disposal, that is the Alenia CGS2, ETIS systems and an IEI CCIR-compatible TVC for the computer-controlled acquisition of B/W image time sequences. In this frame, the software packages have been chosen by IEI according to optimisation and performance criteria.

Summary

General considerations

The activity carried out has followed two main lines:

- design and development of a prototypical system including the main functionality of the CND system
- design and development of specific algorithms for diagnostic image analysis

The work done has been based on an initial phase of general definition about the specifics of an overall project of a general-purpose CND structure.

An information structure for CND has been defined both in terms of centralised and distributed architecture. In both cases, anyway, an entry level has been introduced able to make available a set of main functionality, which in their turn can be activated in sequential or parallel way.

The main functional environments of the CND structure have been individuated as follows:

- data and diagnostic image acquisition
- data and image processing
- data and image visualisation
- general system utilities.

The first functionality regards the use of different kinds of specific devices by means of which multi-format information should be inserted in the global system. Each acquisition device requires a proper set-up and generates data peculiar of the inspection process performed. Usually, the acquisition process requires a specific pre-processing phase in order to obtain data qualitatively significant. The data acquired should be then evaluated: this means that an acquisition unit should also have a suitable local environment for simple data processing, archiving and transmitting.

The data and image processing functionality individuates a composite environment, where both interfacing facilities and complexity of computation are required.

In this environment specific algorithms can be run for performing the data analysis. Since an image based analysis process is usually carried on by executing a sequence of algorithms, a main feature should be the availability of a proper user interface by means of which the algorithms themselves can be scheduled in an easy way.

This environment has been also designed in order to be modifiable by inserting single procedures specifically dedicated to solve certain classes of known problems.
Another important functionality the CND system should have is the possibility to access and represent the information also in a visual form. In this case, packages of computer graphics should be available, not only to visualise one-, two-, three- or higher dimensional data but also to synthesise information obtained from various sources. According to the concepts mentioned, the facility to dispose of a laboratory for graphics is quite important, and this has been foreseen by allowing the insertion in the CND system of some high level package.
Finally, the fourth functionality is related to a dedicated environment containing a number of tools useful to perform utility operations. Typical functions that can be activated in this environment are the management of a communication network for data and image transmission or data conversion between different internal formats (see Figure 1).

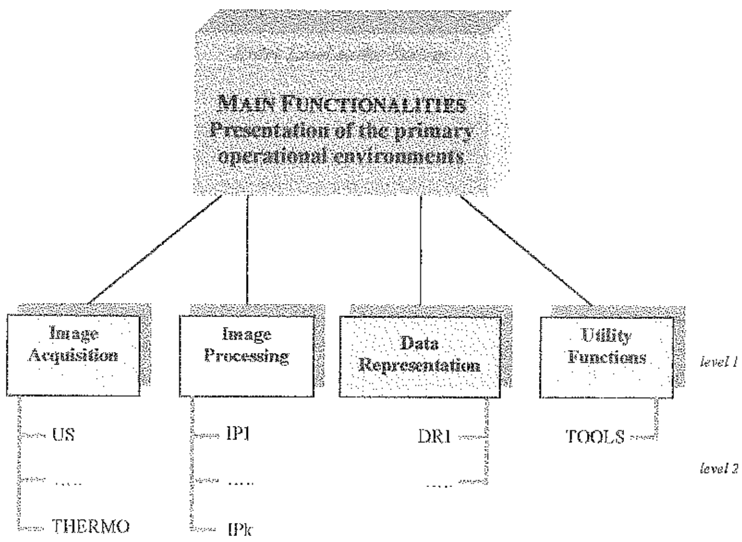

Figure 1. Functional environments of the CND structure.

Implementation scenarios

The overall information structure composed of all the above mentioned environments can be implemented both in a centralised or distributed way.

In the first case, a single computing system should have available all the functionality described allowing the activation of single procedures or operations through a high level interface, in which the complete knowledge of the system has been coded.

The centralised system is thought mainly as a laboratory unit, where local archiving and data formats are sufficient to perform the analysis of the diagnostic information. In this context, experiments can be done about the connection of CND inspection devices or the development of new procedures.

The distributed solution is the best solution for a CND system. In this case several specialised workstations can co-operate in order to perform simultaneously all the typical operations needed for the CND diagnosis.

A single station can implement one or more of the functionality above described and can act on a set of diagnostic machines which is usually quite heterogeneous, being composed of several hardware and software devices with different set-up conditions and data production (see Figure 2).

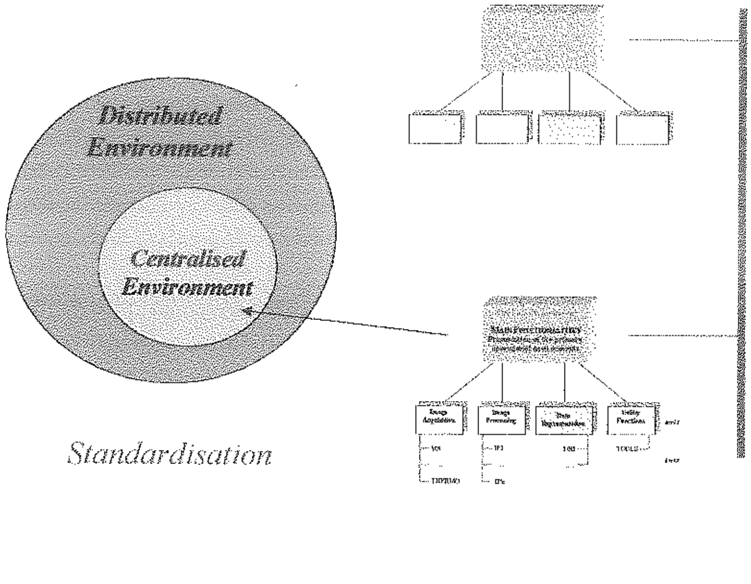

Figure 2. Possible configuration of a CND structure.

In this context, two very important aspects are mandatory:

1. a powerful communication network management
2. a real standardisation of data and processing protocols.

Centralised station

The centralised station should perform three main operations:

- high level interfacing, both at the level user and at the process interaction
- data validation, after a controlled analysis phase on the data
- management of local archives. Two kinds of archives are foreseen, called Short Term Archive (STA) for storing the acquisition data during a working session, and Long Term Data (LTA) which should contain all the data that have been validated after proper controls.

All the operations should be based on the requirement to support a local data standardisation, mainly due to the necessity of recovering existing diagnostic machines.

A connection is possible to a dedicated station having the goal to manage a global integrated database of data, images and associations between them (see Figure 3).

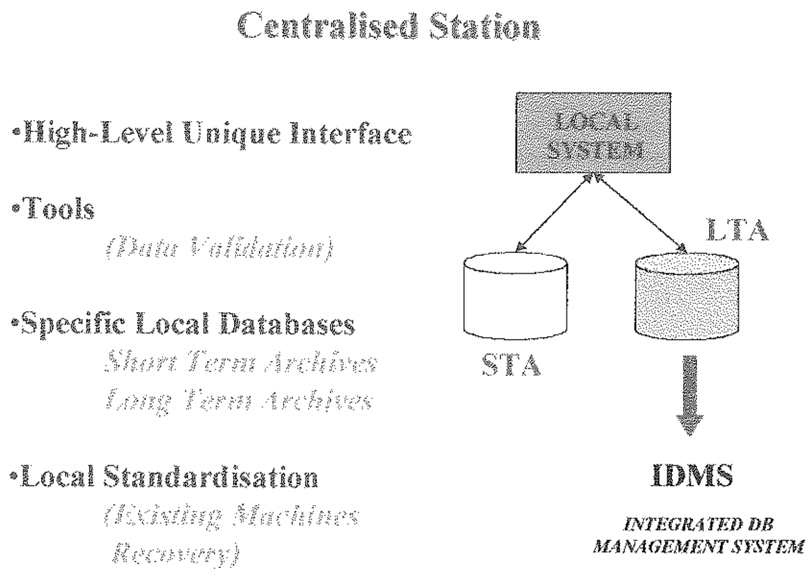

Figure 3. Main features of a CND centralised station.

Distributed system

The main components of the designed distributed system are:

- centralised stations
- image acquisition stations
- image processing stations
- data representation stations
- a database and communication station.

The first four types of stations derive from the concepts already exposed, and their presence is a direct consequence of the CND diagnostic cycle.

The database and communication station has been introduced in order to homogenise all the information that circulates in the system. Its main goal is to manage a huge integrated database, which represents the knowledge of the system, and the communication protocols among the several stations belonging to the system itself. (see Figure 4).

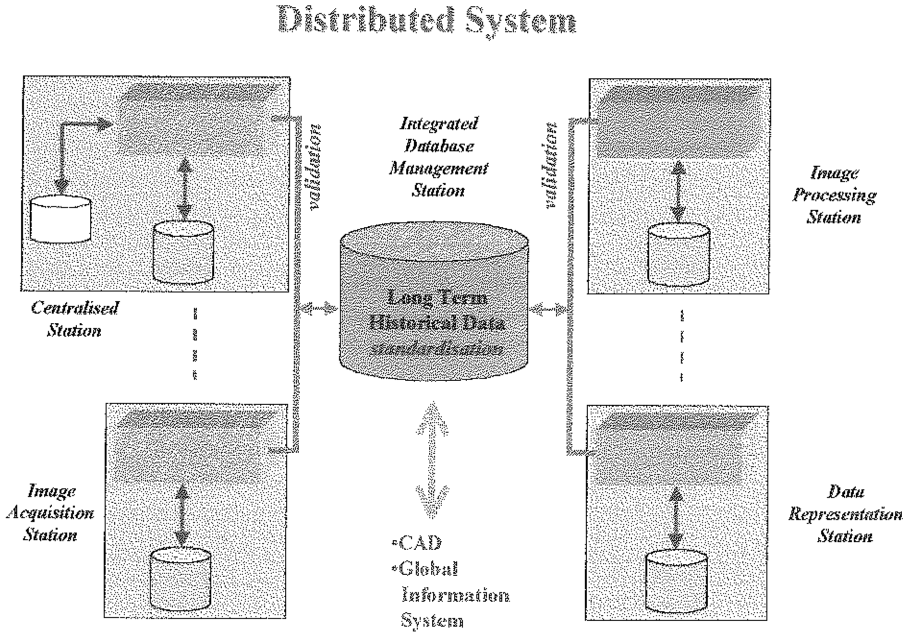

Figure 4. Main components of the designed distributed system for CND.

Project criteria

The project defines an operational context, that is the influence on the procedure development, in which a set of constraints are pointed out:

1. user requirements
2. technical requirements
3. computational requirements

All these features are not directly interesting the architectural solution adopted, in the sense that they can be applied in both cases, at a general (distributed) or more local (centralised) level.

The typology of user requirements has been described in terms of:

- **Type of control**, that is performed. In this case, for instance, morphometric and structural aspects should be carefully considered
- **Inspection method**, that is the actual procedure which is applied to inspect the material, in particular real-time approach or a sampling investigation.
- **Specific constraints**, in terms of spatial and radiometric resolutions, accuracy and precision of the measurements, reliability and repeatability of the experiments.

From the point of view of the computational requirements, the following aspects has been considered:

- **Architectural aspect**, mainly in terms of modularity, flexibility, fault tolerance and scalability. Also in this case, these concepts can be applied to any system configuration.
- **Implementation aspect**, mainly in terms of integration of the functions and automation of the different processes

Finally, the technical requirements have been pointed out in terms of:

- definition of image quality
- characterisation of the defects to be detected.

The first one influences directly the acquisition, pre-processing and general elaboration phases, while the second one is strictly related to the recognition, classification, measurement and evaluation processes performed on the compressed data generated after high level processing.
In this context, also the facilities of data updating and run-time interaction should be considered as the capacity of extending the system by inserting new functions and also computing units (stations). A main aspect to perform properly all these operations is the implementation of a standard environment useful to import and export information in a consistent and easy way.

The prototype of a CND system

On the basis of the project guidelines pointed out, a prototype of a centralised station has been developed in order to test all the functionality facilities needed to implement the final CND diagnostic system.

The prototype has been realised on a personal workstation, under O.S. Windows 95, and it implements the following operations (see Figure 5):

- image acquisition
- image processing
- data visual display
- utility management.

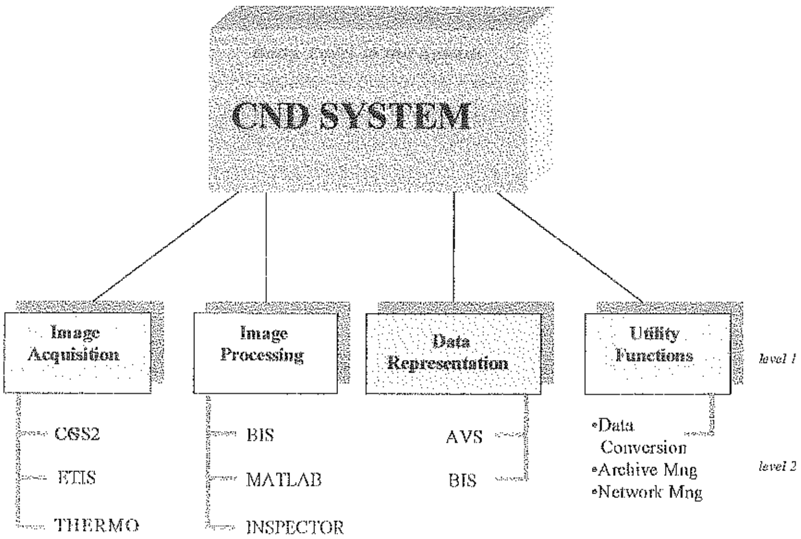

Figure 5. The implemented prototype of a CND system

Conforming to the design criteria, also a simple high level interface has been developed used to activate the different procedures and jump to the different possible environments actually available.

Then, each single procedure has been realised with a proper specific interface, according to the type of operations performed.

A main characteristic of the prototype is that it configures a hybrid system, since it is composed of components previously implemented according to quite custom criteria (for instance, using DOS O.S., different programming languages, different data formats, limited connectivity, and so on) and advanced software tools containing instead standard facilities.
In this way, we have obtained the possibility to test a system under critical condition, a quite useful way to study possible operational scenarios of a complete CND system. The implementation details of the prototype are described below.

User interface

A user interface has been realised under Windows 95, using Visual C++ language and the MFC library. This interface allows calling easily and directly anyone of the environments that allow performing operations for CND, either by ultrasound inspection (CGS2 and ETIS systems), either by thermographic acquisition (THERMO). The same platform can be used to control the devices used by the different systems and to process the inspection data; on the contrary, several platforms, connected via a local network, can be used.
At present, the user interface that can be installed on each computer is composed of different windows under hierarchical control (see Figures 6 ÷ 12).

Control Interface

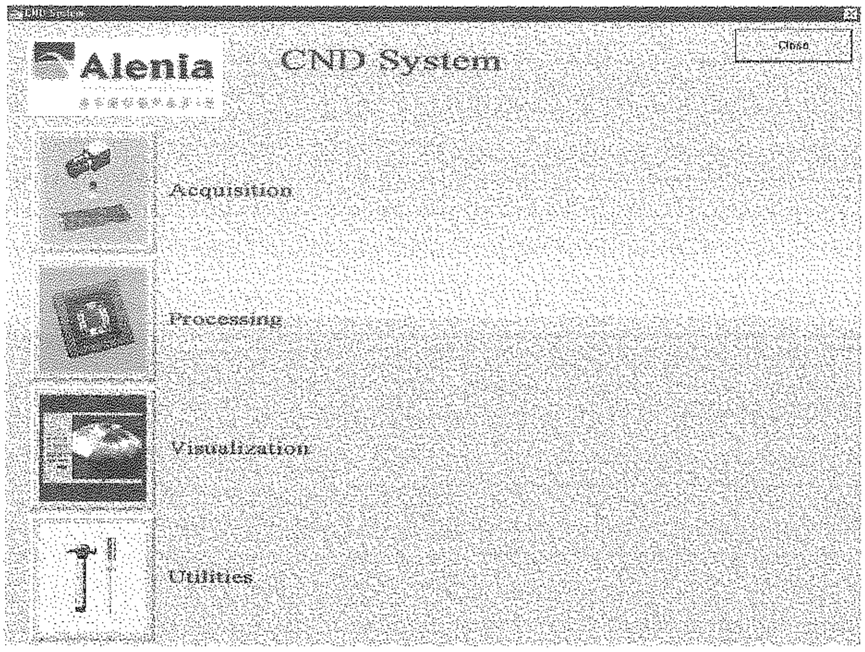

Figure 6. Control interface: main window.

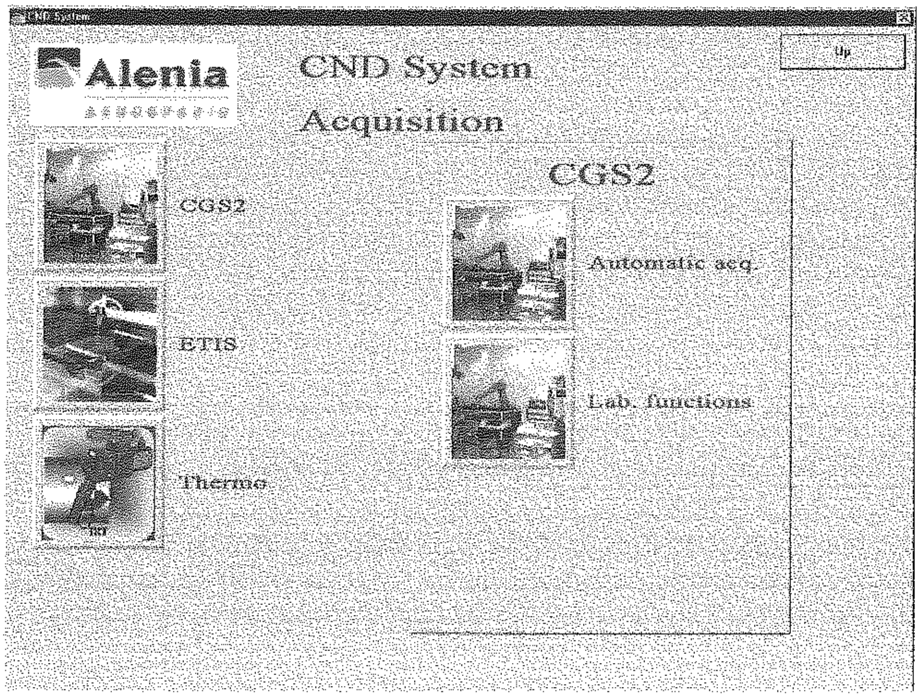

Figure 7. Control interface: Acquisition environment, CGS2 system.

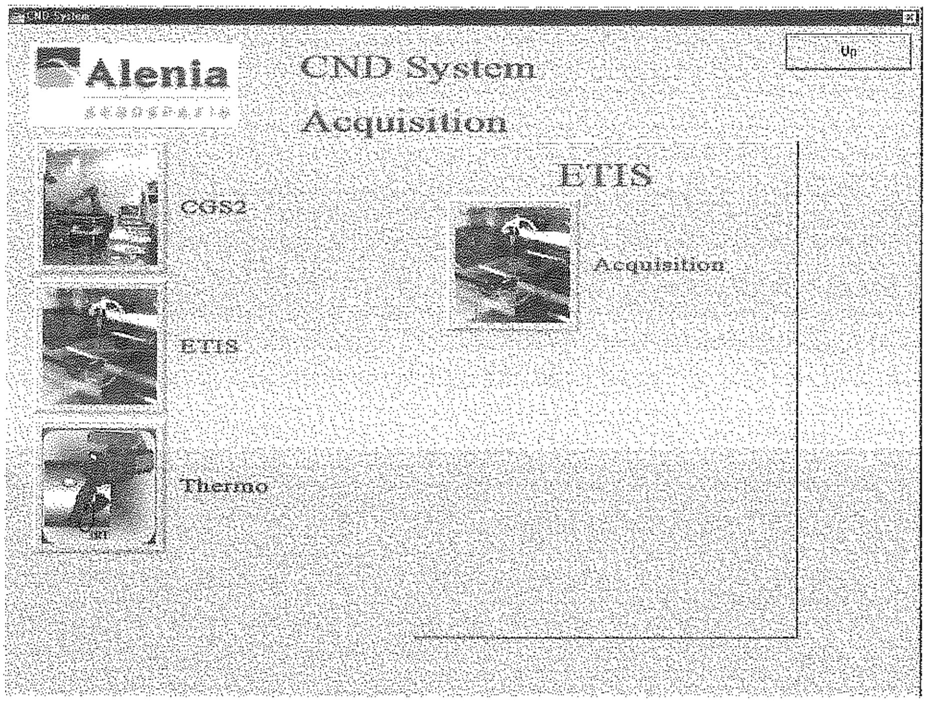

Figure 8. Control interface: Acquisition environment, ETIS system.

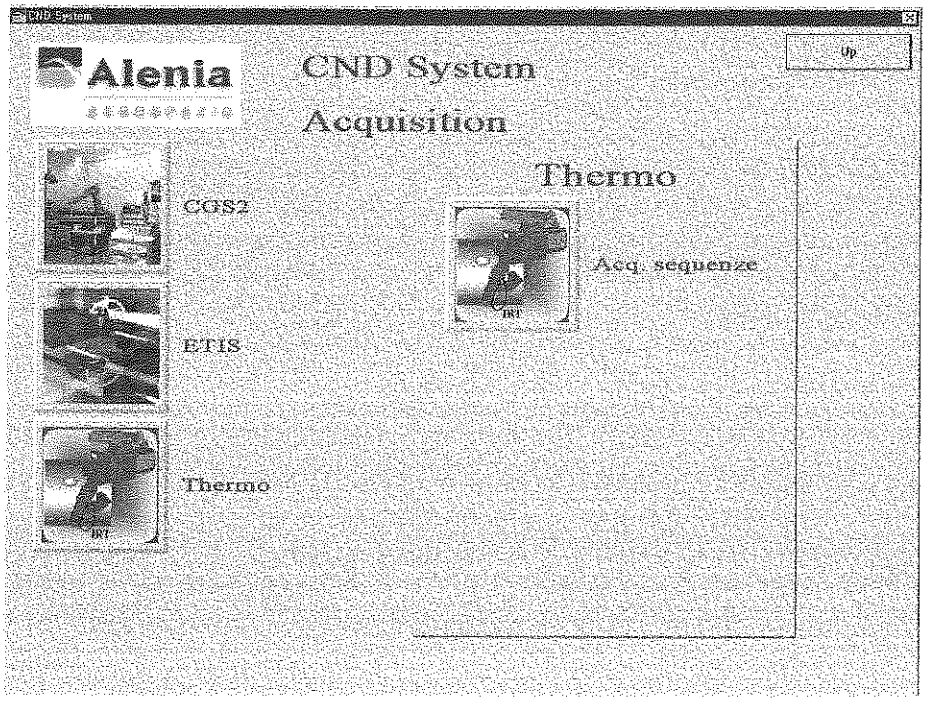

Figure 9. Control interface: Acquisition environment, THERMO system.

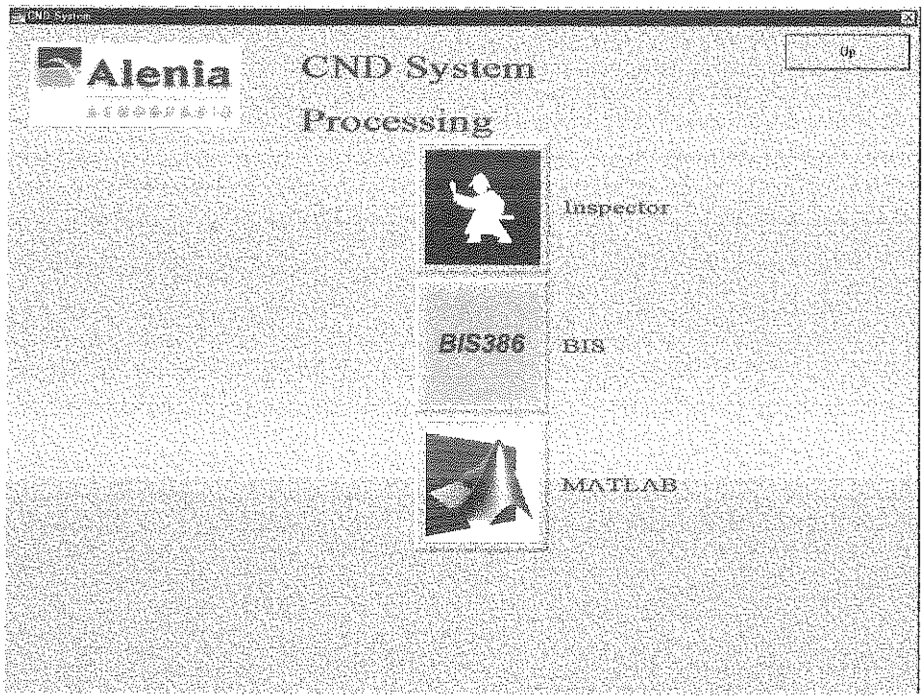

Figure 10. Control interface: Processing environment.

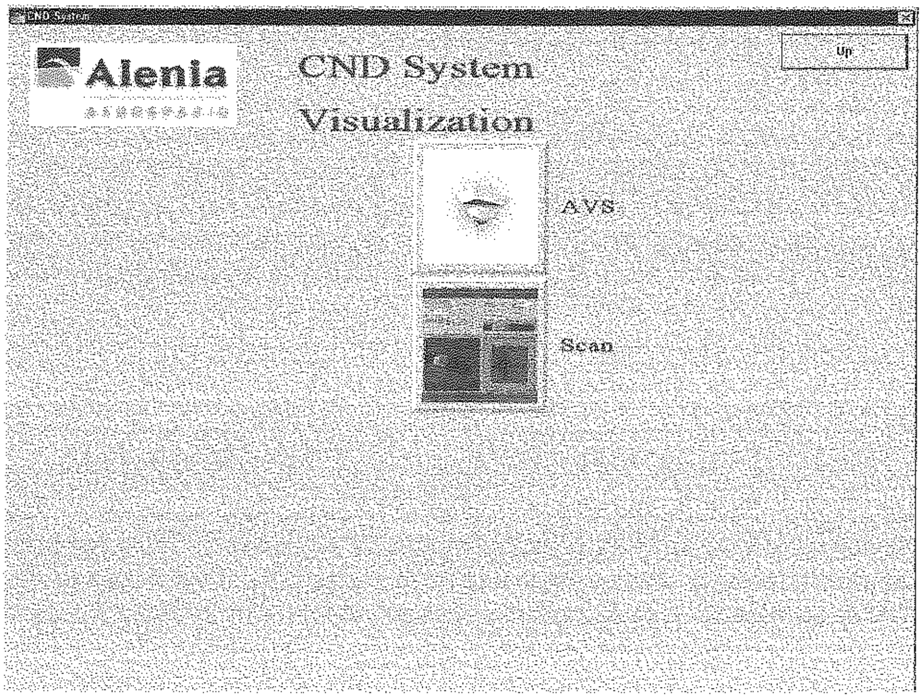

Figure 11. Control interface: Representation environment.

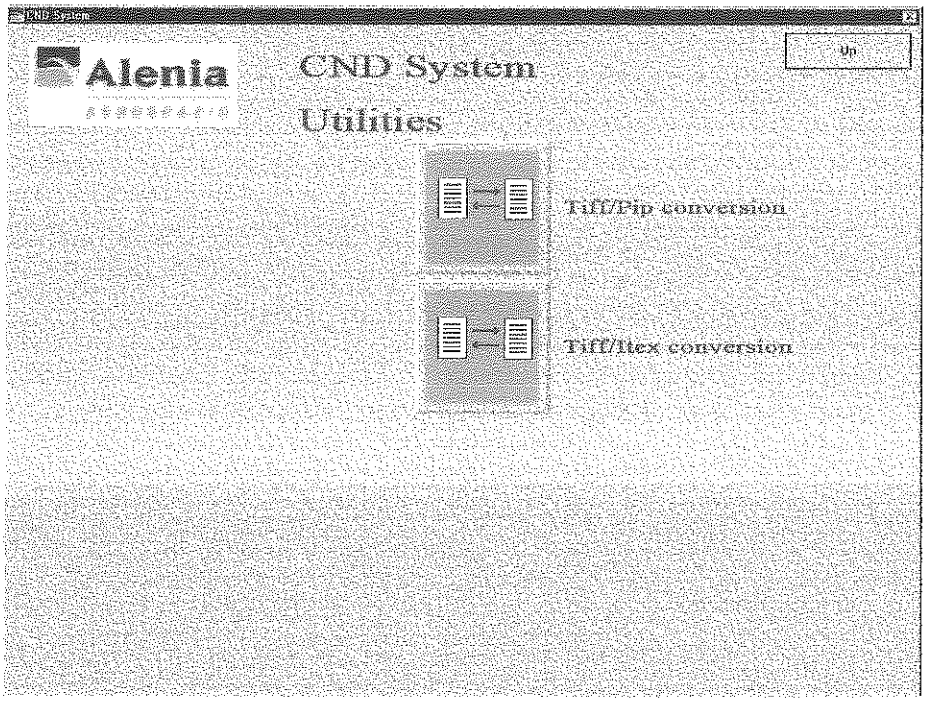

Figure 12. Control interface: Utilities environment.

Acquisition environment

This environment is subdivided into the following sections, specialised for signal and image acquisition by means of the systems realised by Alenia.

CGS2, environment for ultrasound inspection by means of the multi-axes inspection system CGS2, using different procedures

ETIS, environment for ultrasound inspection by means of the two-axes inspection system ETIS and other two-axes systems.

THERMO, environment for the acquisition of time sequences of images for thermographic inspection.

Processing environment

At present, the following software packages can be used to process acquired data.

BIS. This package allow to executes modules that apply photometric, geometric or analytic transformations of image files with PIP format; the processing modules are organised in under-environments, specialised for acquisition, pre-processing and analysis operations, and can be executed by means of a local interface operating in Windows environment.

Inspector. This package allow to executes the following main operations: acquisition of single images or of discontinuous sequences of images; image processing, by means of local or global operators; image analysis by means of dedicated procedures.

MATLAB. This package allows to execute predefined application modules, to define new modules and to realise custom procedures by linking existing modules. In particular, his package contains many tools for the analysis of one and two-dimensional signals (e.g. curve fitting algorithms, Fourier transform, Wavelet techniques).

Other packages can be inserted in the processing environment.

Display environment

Acquired or processed data (e.g. A, B o C-scan signals, volumetric data or thermographic maps), can be displayed either by using the above-mentioned packages or by using the AVS/Express system, that contains a set of modules for data processing and for 2D and 3D rendering.

Utility environment

This environment contains several modules that perform format transformations of image data.

Experimental procedure

In order to focus some problems arising in the processing of digital images and to test the main algorithmic solutions that are or might be used in the inspection system, a defect detection procedure has been realised. Figure 13 shows the block scheme of the whole procedure, that is composed of learning and inspection phases (respectively on left and right side of the figure).

Learning phase

An image of an undefeated sample is subdivided into an array of spots, whose dimensions depend on the minimum extension of the defects to be revealed.

The histogram of the pixels belonging to each spot is computed and the moments P of the histogram (e.g. mean value, variance and so on) are calculated. For each column of the array, the mean value m (P) and the standard deviation s (P) of the P parameters are then calculated. We can thus define the reference intervals [m (P) - c × s (P), m (P) + c × s (P)], where c is a constant, determined experimentally for the different kinds of samples.

Inspection phase

The image of the inspected sample is segmented in the same way as described before and for each spot the P parameters are computed. Each parameter is then compared with the corresponding reference interval determined in the learning phase, this way a binary array D is obtained: D is put equal to 0 only when all parameters lie into the reference intervals.

The array D constitutes the map of the anomalies contained in the acquired image; this map is further processed in order to classify the revealed defects according to their morphology.

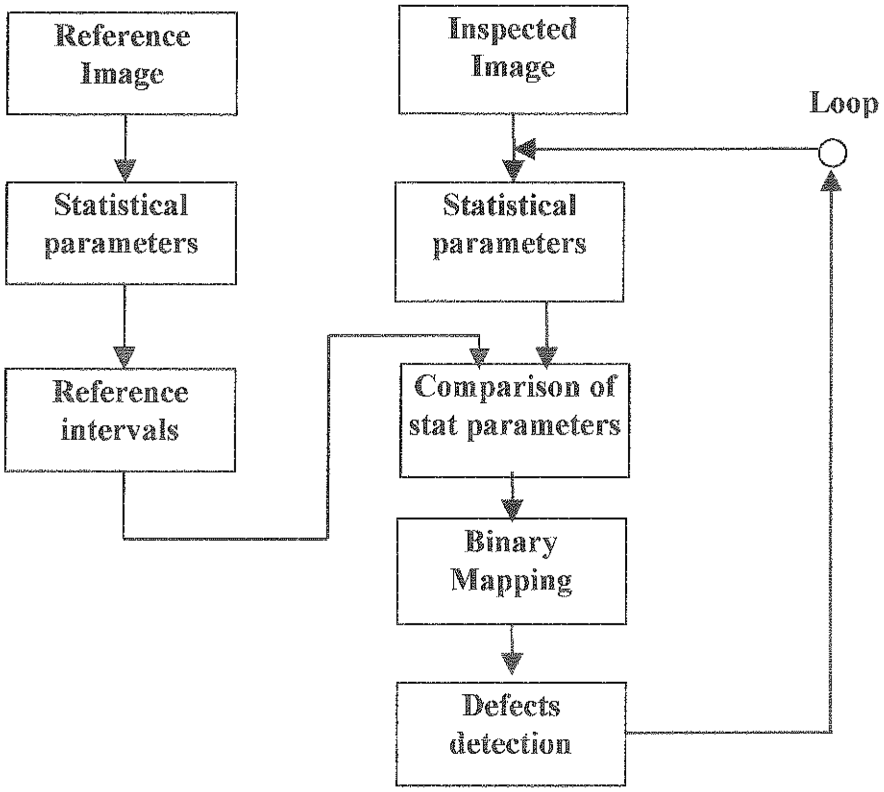

Figure 13. Block scheme of the procedure for defect detection.

Example

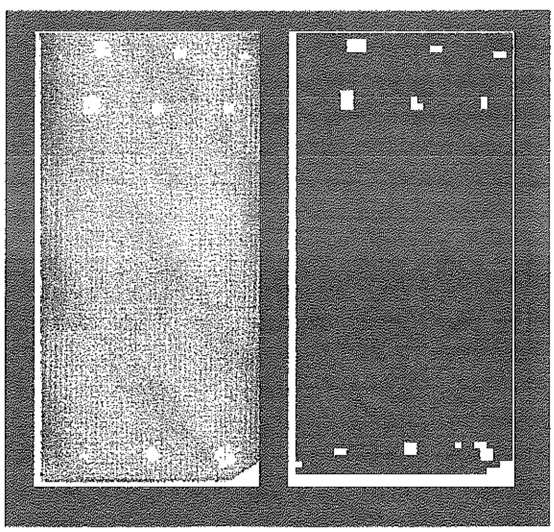

Figure 14. Example of anomalies detection.

Figure 14 shows an example of defect detection performed by the above mentioned procedure. On the right side of the picture, the C-scan map of a sample of composite material, inspected by the CGS2 system, is shown: the grey level of picture pixels are proportional to the intensity of the reflected ultrasounds waves. The right side of the figure shows the binary map obtained by comparison with the references intervals: the areas containing detected anomalies are represented with white pixels.