AN OWN-DEVELOPED CT/DR SYSTEM FOR VISUALIZATION AND DEFECT RECOGNITION IN NDT

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SUMMARY

We have developed an industrial X-ray computed tomography system that also provides digital radiography images (CT/DR) for dimensional and general non-destructive testing inspection in AIMEN, in collaboration with the University of Santiago de Compostela (Spain).

The system, fully operational at 2009, includes a detector array of 1280 active elements with submillimetrical spacing, together with a 225 kV mini-focus tube, integrated in a 3-axis positioning system of flexible configuration. The total length of the detector is 1 m. Some of the most remarkable features of the system are the image variable magnification and the capability of capturing both tomographic and radiographic images.

Specific software is being developed for visualization and automated defect recognition of the acquired images. The software accomplishes visualization and automated analysis for radiographs, sinograms and CT reconstructed images including the generation of 3D images from the CT slices.

INTRODUCTION

Nowadays, X-ray technology is often applied in Non-Destructive Testing (NDT) for industrial production. This technology is used in different areas, usually oriented to specific production. The technological centre AIMEN is oriented to welding technology but also has different research departments. In the AIMEN Inspection - NDT department different kind of pieces are analyzed: from welds to composite aeronautical pieces and even biological probes. This implies a large amount of different type of images in terms of size and density, what led to the development of a customized CT/DR system in AIMEN in which the user can adjust every acquisition and energy parameter.

The development of the system implied the implementation of both the hardware and the basic software for acquisition and simple reconstruction and the software for displaying and analyzing the images generated by the CT/DR system.

Computed tomography

Computed tomography, (CT) is a technology based on x-ray photons that allow the user to reconstruct slices of 3D objects, without its destruction. It was born as a diagnostic technology in medical imaging, although its application in the industry is consolidating in the Non-Destructive Testing field. CT gives full 3D quantitative information of inspected pieces, allowing the user to detect, to locate and to measure different features of the object to analyze.

It is a radiographic technique, based on the radiation transmission through the object to inspect. The radiation passes through the object reaching the detector (measured signal). This signal represents the initial photon intensity generated on the x-ray source modulated by the absorption process that is related with the density, the atomic number and the width of the object to be analyzed, following the expression:

$$I=I_0 exp(-\mu z)$$

where I is the intensity captured by the detector, I_0 is the incident intensity to the object, μ is a constant that depends on the material (attenuation coefficient) and z is the width.

The logarithm of the ratio between attenuated and non-attenuated intensity represents the line integral (Radon transform) of the attenuation coefficients in the material and it is defined as a projection. The logarithm is calculated for different angles of incidence to reconstruct the 2D image of the inspected object. The matrix of projections for all angles covering 360 degrees is called the object's sinogram. The final image is reconstructed from the sinogram, using a filtered back-projection algorithm, based on the Fourier slices theorem [1].

The reconstruction algorithm will vary depending on the CT system geometry, which also defines the scan generation [2]. The CT developed in AIMEN is a third generation system, where the object is completely irradiated by an x-ray fan beam and covered by the detector array, a linear scintillator array [3]. The AIMEN CT results in an affordable solution with three different radiographic scan modes: planar digital radiography (DR), single slice and multi-slice CT, with submillimetrical resolution and capability of imaging objects of different geometry and material.

RESULTS.

CT/DR SYSTEM.

System description

The industrial CT/DR system developed in AIMEN is comprised of an X-ray tube up to 225 kV and 0.2 mm focus size (Baltograph XSD). It is a tungsten target monopolar tube, with a water cooling system.

The detector includes a scintillator to transform x-ray energies to visible and a linear array of 1280 photodiodes of 0.8 mm size. The technology is based on cadmium tungstate with high conversion efficiency for the working energies. The photodiode signal is read through a multi channel readout VLSI chip (XCHIP on XDAS signal readout board of Sens-Tech Ltd). Each XDAS readout board integrates 128 readout channels, by multiplexing and analogue-differential transmission to a control board for ADC conversion, that indexes data to the computer by a digital I/O PCI framegrabber.

Positioning of the system has been implemented as a tri-axial system allowing a flexible configuration and scan sequence. It integrates two motorized linear stages of 1000 mm travel where the detector and the tube are assembled for synchronized movement. The electronic boards of the detector are assembled in a box shielded with aluminium and lead. The object to inspect is positioned on a rotary stage up to 300 kg load with a mechanized plate (Figure 1), that is situated over a linear horizontal stage (with a free stage linked to it in parallel). The source-to-detector distance is 2000 mm and it is possible to vary the source-object distance, to accomplish a variable magnification from 1 to 5.

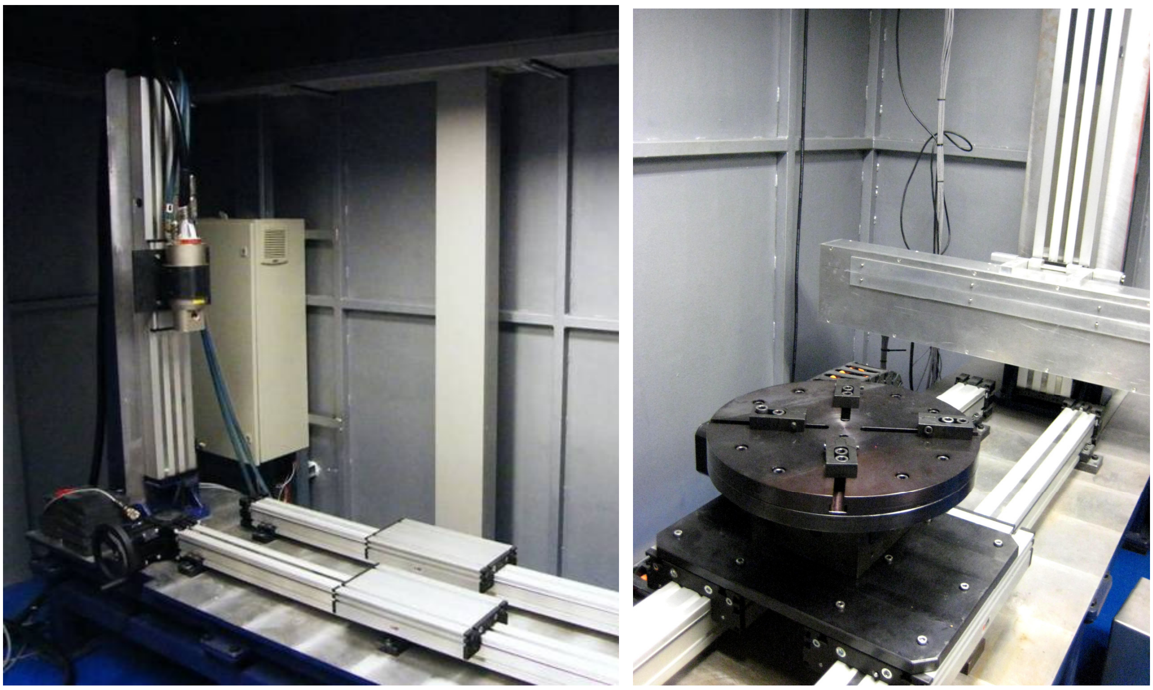

Figure 1. *Left:* Photograph of the x-ray tube and horizontal stages (before installation of the rotary stage). *Right:* rotary stage and plate, and the detector box.

The control of the positioning system is based on a PID controller (MINIVISION system of Tex Computer, s.r.l.) with the scanning sequences programmed in CNC. Different scanning mode codes run from remote control software (LabVIEW code) on a dedicated computer. This solution allows the AIMEN system to acquire both tomographic slices and digital radiographs, and also to modify the image magnification factor, in a very flexible configuration for image acquisition.

The tomographic system has been installed in an own-designed bunker (see Figure 2 below), accomplishing with the mandatory requirements for control and security as indicated from the Nuclear Security Council (CSN, Consejo de Seguridad Nuclear) in Spain.

Figure 2: Bunker in AIMEN.

Acquisition and control computer system.

Control software has been developed in LabVIEW code integrating both mechanical positioning and data acquisition. Read data is stored in binary format, for late reconstruction.
The code carries out the initialization of the system and allows for the selection of parameters related to acquisition (integration time, number of subsamples), scan mode and geometry (slice spacing – down to 0.1 mm-, number of projections, see Figure 3).

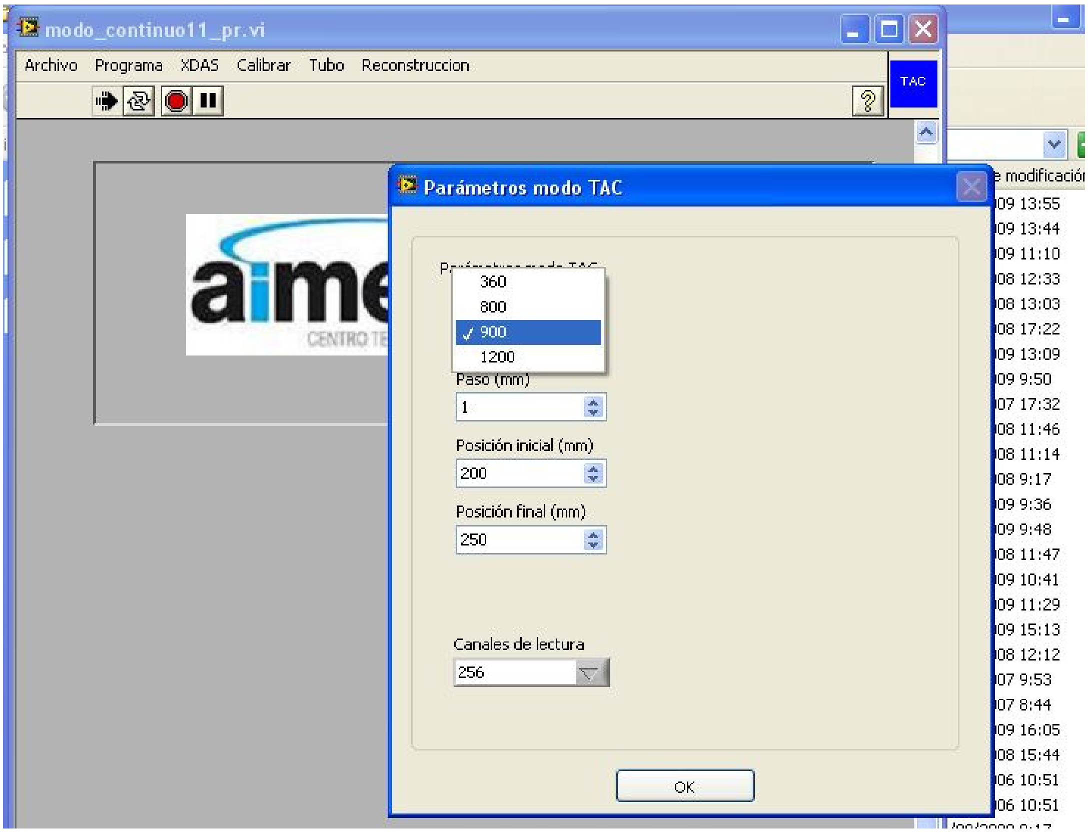

Figure 3: Snapshot of the control software, specifying CT acquisition parameters.

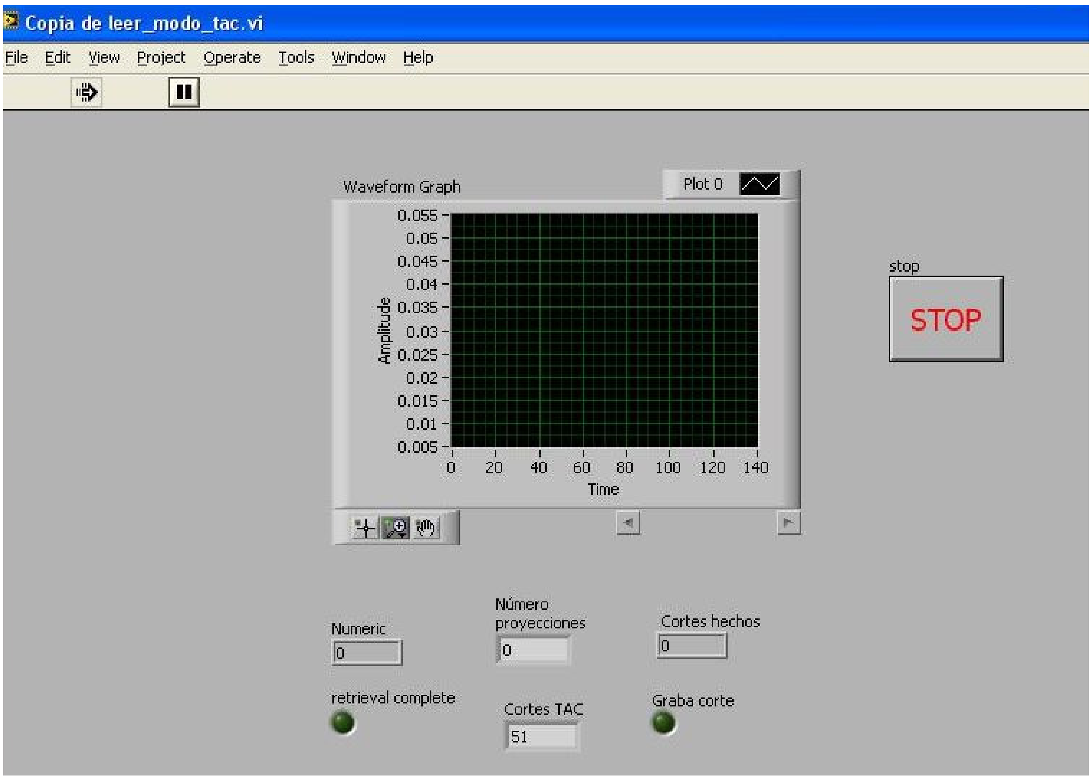

Figure 4: Snapshot of the acquisition screen.

Synchronization of the signal readout of the detector with the system positioning sequence is performed by trigger and acknowledgment signals between the PC and the local PID controller. X-ray parameters (high voltage, current) can be remotely modified with the LabVIEW control software through a RS232 connection.

Figure 5: Control unit for the X-ray tube and the tomographic system.

First analysis of digital images (radiographs, sinograms) was implemented with the Matlab Image Processing Toolbox [4], as well as the reconstruction algorithm for tomographic images. The algorithm is based on the filtered back-projection method, and the resulting images were stored in the Analyze SPM format [5].

Radiographic images, on the other side, are stored as computer files, in a proprietary format, that include a header where information related to pixel size, number of rows and columns bits per pixel and several other parameters is stored.

System commissioning

System commissioning is of crucial importance for accurate data reconstruction. The geometrical parameters of the system must be characterised: magnification (depending on horizontal stage positioning), object rotation axis alignment (with the centre of the detector array) and horizontal alignment of the linear array.

Calibration of the detector signal has also been established to avoid image artifacts related to variations in the detector channels response (ring artifacts, noise [6]). The individual channels readout is calibrated by means of air scans, measuring the intensity without object for increasing X-ray current values. This calibration can be implemented daily or before a complete tomographic acquisition.

IMAGING SOFTWARE

Displaying, processing and feature extraction of images is performed by own-developed software. The AIMEN CT system is capable of generating both radiographic and tomographic images with spatial resolution up to 0.5 mm for CT slices and larger (up to 0.3 mm) for radiographs. Instead of employing some open-software programs than can be found, we have developed a displaying tool to unify both the reconstruction and the visualization in the same platform.

GUI Tool

The main characteristic of the software developed is the user-friendly interface. It makes possible to work with different image formats, as those obtained in our CT system, and available for manipulating and performing feature extraction of different image properties. When the software is running, a main window is created as shown in Figure 6. The upper section of the window includes the menu tool bar, where most of the application menus can be deployed, and a navigation tool where several icons allow the user to navigate back and forward over the set of loaded images.

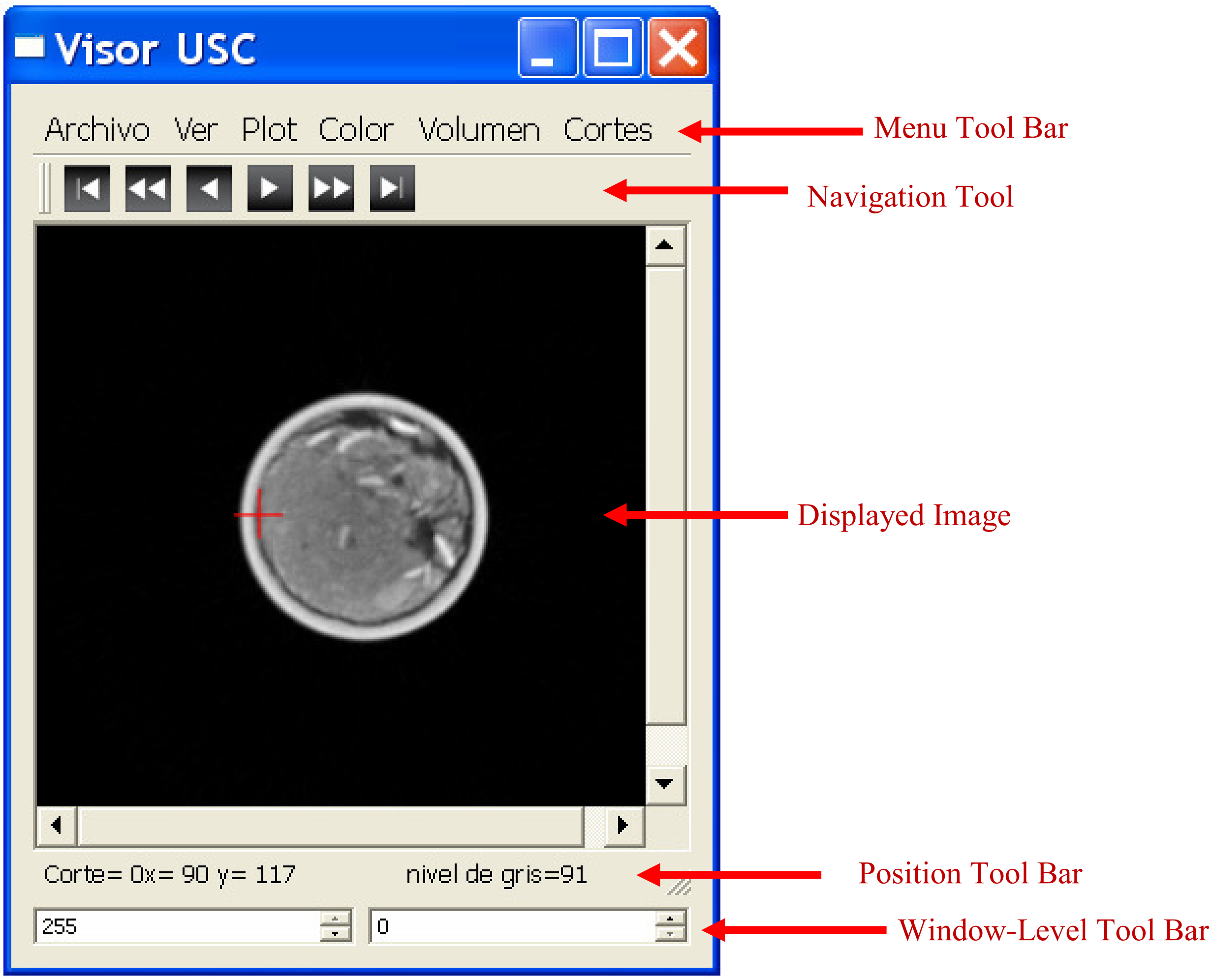

Figure 6.- Display tool. The different tool bars are depicted.

The central section is the place where the image is displayed. Finally, the bottom section includes a display bar for depicting current x and y position of the pointer and two input boxes for adjusting bright and contrast of the displayed image.
The software includes several thousand of lines of code and has been developed in C++ by using Qt [7] as a multiplatform graphic library. In this way, the software can be run on the most popular operating systems (Windows, Linux, MacOS) without any substantial change. The main features of the developed software are following described:

Opening images

The images to display are computer files, with different formats and sizes, stored on the file system of the computer. They are divided into two different logic structures: the header and the body. The header stores the main characteristics of the image as number of files and rows, bytes per pixel, pixel size and information of the image acquisition. The body is a sequence of bytes related with the value of each pixel in the image (attenuation coefficients of the scanned material). Therefore, it is necessary to read and interpret the header before extracting the raw data stored in the body to open the image with all its information.

The software is designed as a graphic interface that allows the selection of the image to be opened from the file system (Figure 7). Once the image is selected, the header is automatically analyzed to identify its characteristics. The raw data is then extracted and stored in a buffer for future use. The way the software has been developed makes it easy to include the possibility of working with different image formats in the future.

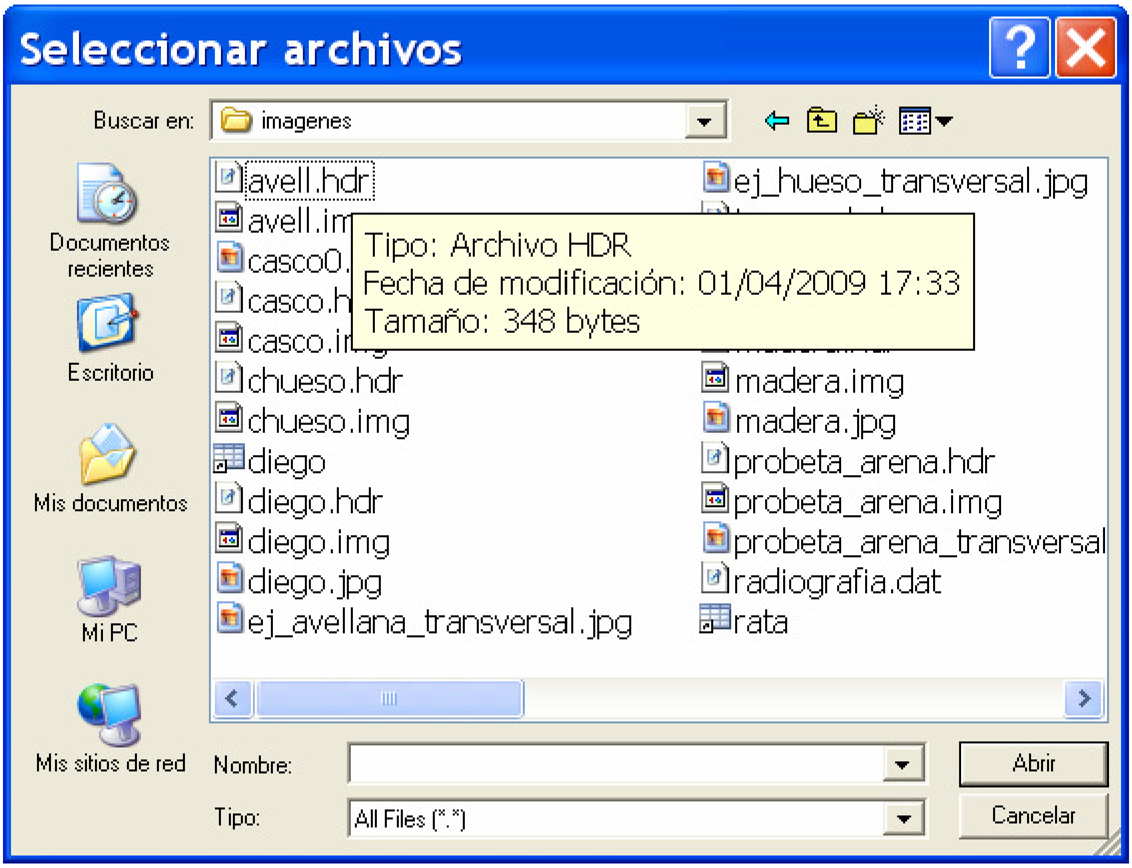

Figure 7.- Navigation file window.

As described before, the software has been designed for opening the different image formats obtained with the CT system. Routines for reading both sinograms (images without previous reconstruction, see Figure 8) and reconstructed CT slices have been implemented in the software. 3D images based on the Analyze format can also be opened. A direct link to reconstruction files can be found in the software, thus obtaining a full image processing and visualization tool. Visualizing the sinogram before image reconstruction allows the user to choose individual slices or to discard a CT acquisition with artifacts (showing streaks, for example) avoiding the time needed for reconstruction.

Figure 8.- Example of sinogram visualization.

Image manipulation

Different options are available for modifying the general appearance of the displayed image by selecting different menus. Bright and contrast can be adjusted by means of a window-level tool, while the displayed pixel size can be fitted with a zoom tool. Finally, different colour palettes are included to apply pseudo-colour to images.

- Window-level. This tool allows a linear transformation of the gray level pixel values from an input interval that can be adjusted by the user. The tool is especially designed for displaying images with pixel values outside the range [0, 255], the common range for most of the available displays in the market. The interface includes two input boxes (see Figure 6) to adjust window and level to the desirable values and to visualize the resulting image in real time.

- Zoom. Zoom is especially useful for large size images that cannot be fully displayed at its original resolution. Zoom capabilities are available in the *Ver* toolbar menu, and are adjusted with either the mouse or the keyboard (keys Ctrl +, Ctrl -).

- Pseudo-colour. Human eye can distinguish among thousands of colours, but only several gray levels (no more than 100). Application of pseudo-colour palettes allows the user to enhance details of different structures in the image. The different options can be selected by means of the toolbar menu *Color* (Figure 9). This menu includes an option to reverse the value of the gray level value of the images.

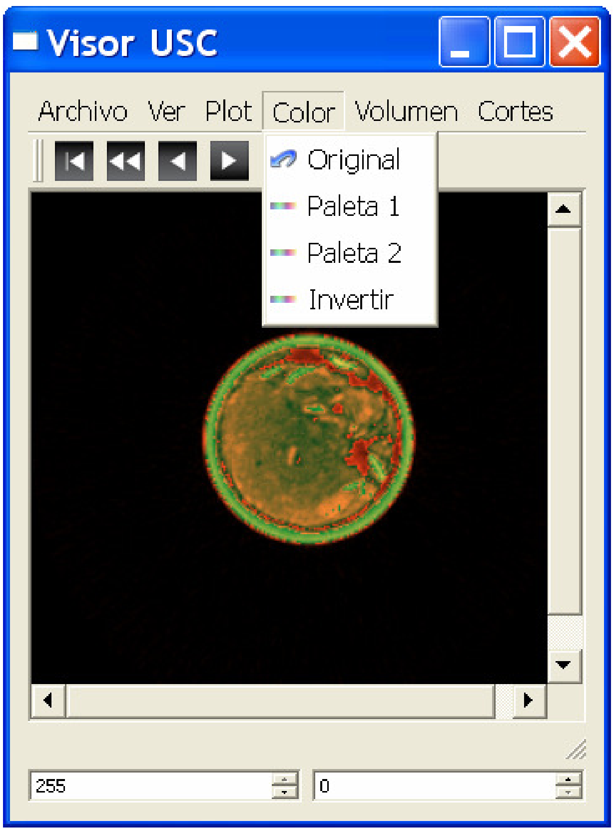

Figure 9.- *Color* tool in the visualization software.

Basic feature extraction

The software also includes tools for extracting basic image information. Position of the pointer in the image and its gray level values are always available at the *Position Toolbar* by clicking the right button of the mouse. When clicking, a red cross is situated at this point showing the corresponding pixel values (Figure 6). The plot menu allows the user to display the gray levels profile for the pixel coordinates (Figure 10) in a new plot window, which also includes a zoom tool in order to enhance some details of the graph.

A second option of the plot menu is the possibility of calculating the histogram of the gray-levels in the image. The histogram provides useful information for improving the contrast of the displayed image, in order to enhance the detection capabilities of the user.

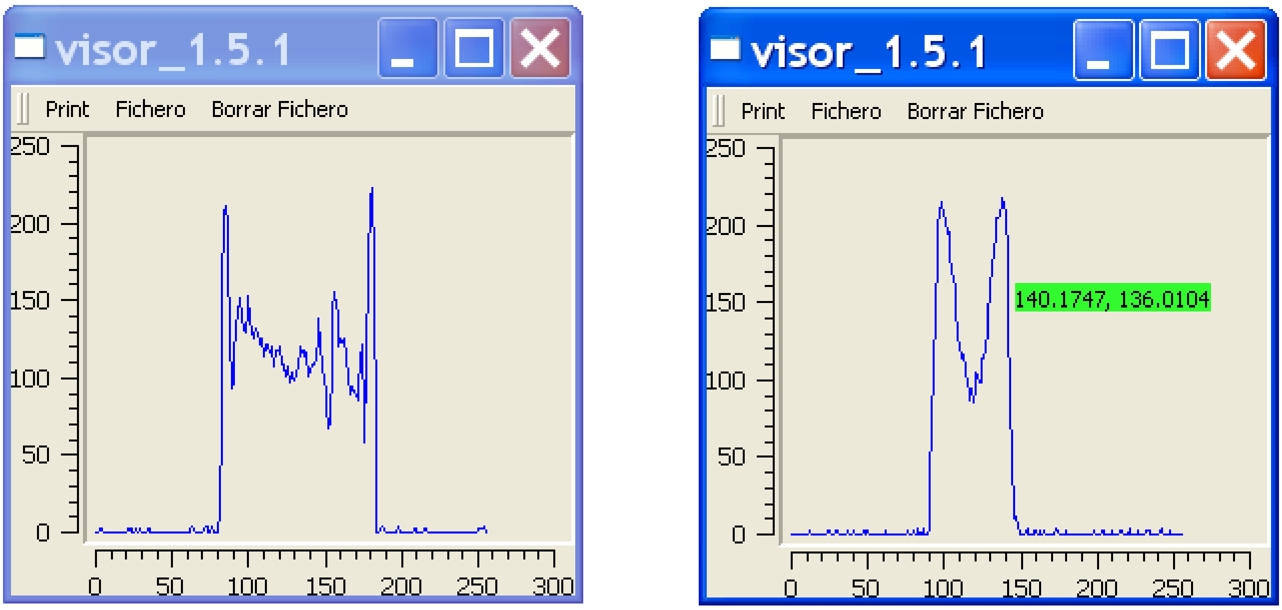

Figure 10.- Example of horizontal (right) and vertical (left) profiles for the given point (red cross) of image in Figure 6.

3D Tools

The software includes the possibility of visualizing 3D images, (Menu *Volumen* of the menu tool bar), as shown in Figure 11. This capability has been developed with OpenGL libraries. Therefore, this menu is only available on computers including graphic cards compatible with those libraries.

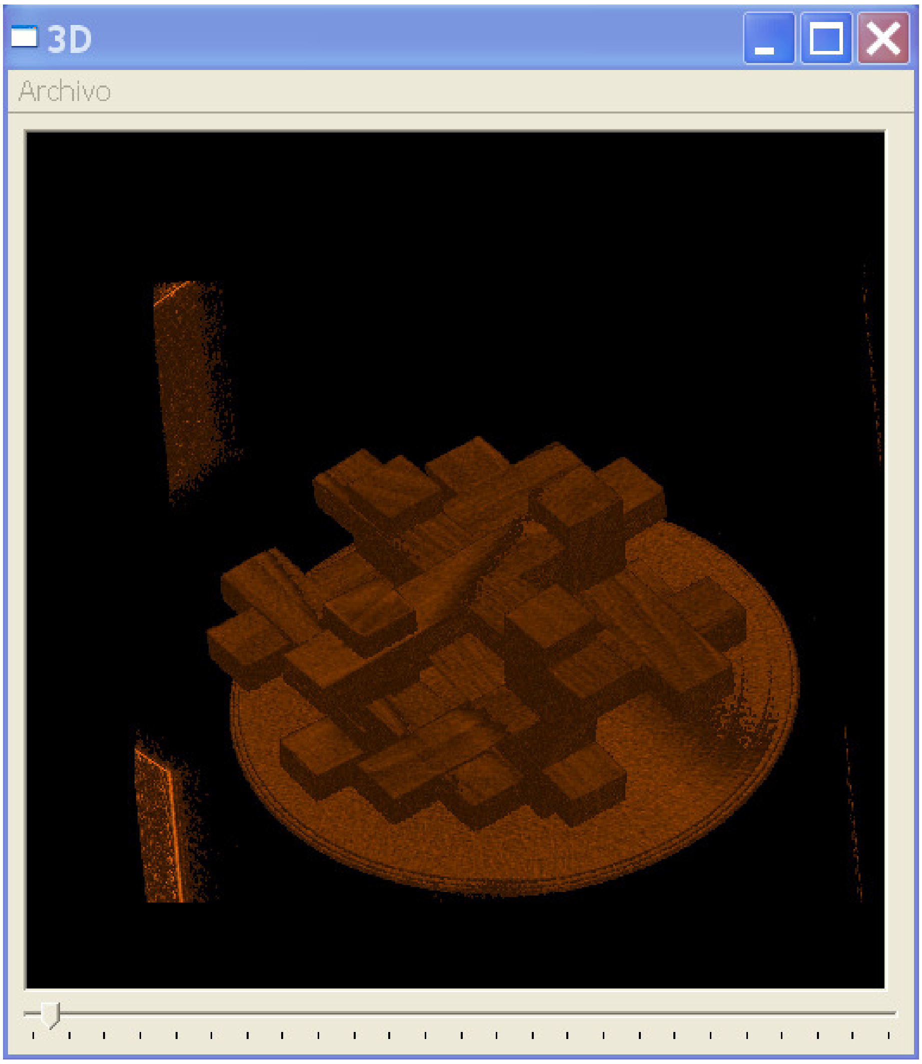

Figure 11.- Example of 3D representation of an image of pieces of wood.

When the 3D reconstruction is obtained, the software is able to generate slices of the 3D object in different projections, thus improving the visual capabilities of the user (Figure 12).

In conclusion a new CT system especially designed for wide NDT applications has been developed. The system includes the basic capabilities for acquiring, processing and displaying images obtained from the objects to analyze. Special emphasis has been done to simplify its use, therefore including user-friendly software with the tools for basic image processing.

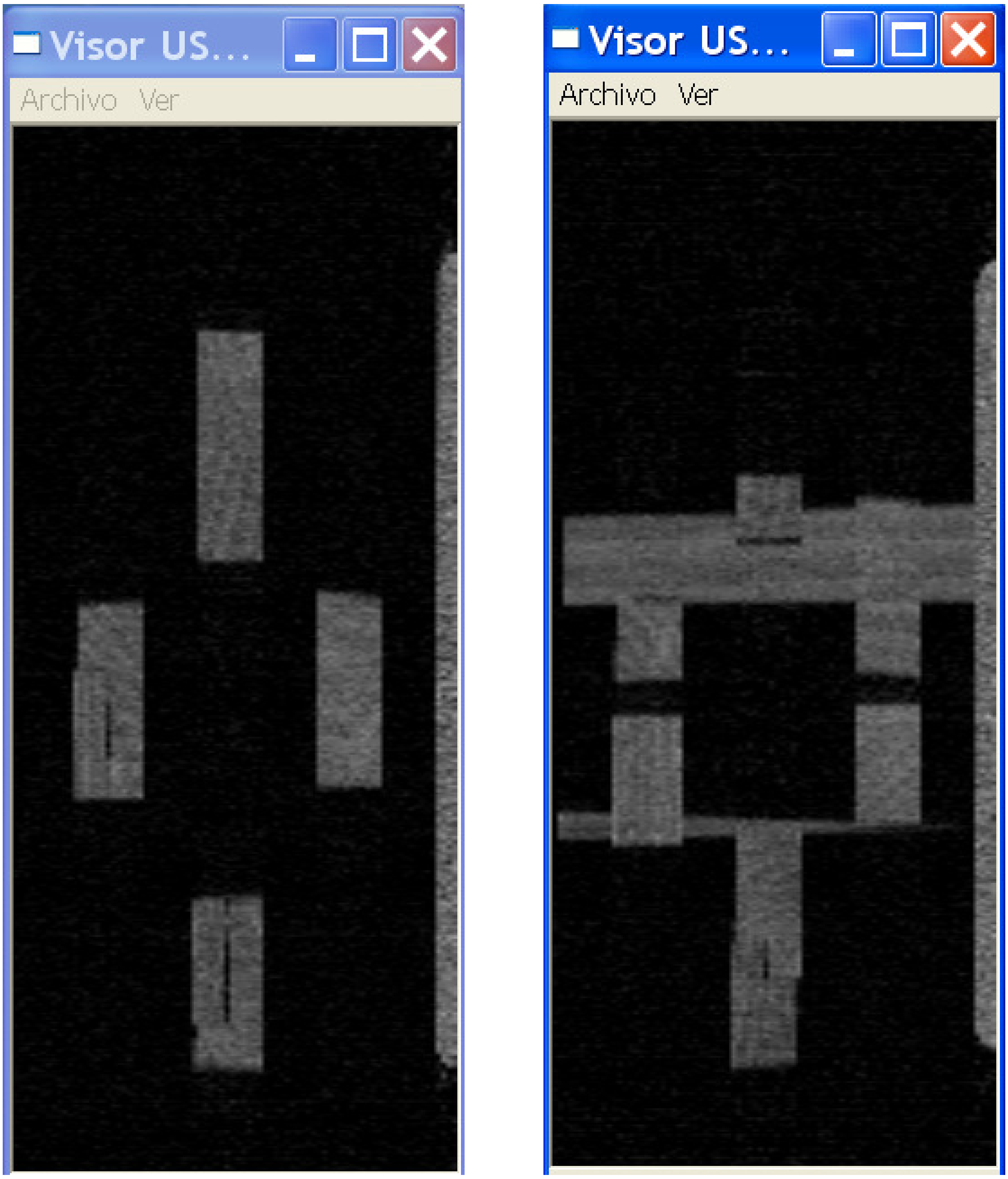

Figure 12.- Horizontal (left) and horizontal (right) projections of the 3D image depicted on Figure 11.

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