

DESCRIPTION OF TWO TOMOGRAPHY SYSTEMS DEVELOPED AT IPEN-CNEN/SP

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ABSTRACT

In this work, two computed tomography systems were developed for industrial application. The first one was of the first generation, which use a 5.08 cm (2") NaI(Tl) detector. The second was developed with a 40 cm bar of plastic scintillator detector using two phototubes in its extremities in order to be used as a sensitive position detector. In both systems a ^{60}Co source was used to carry out the CT experiments. The data acquisition board, the mechanical control interface and the software were specially developed in our laboratory to be used in this project. The tomography systems were tested using a phantom placed between the detector and a collimated ^{60}Co source. The source activity was of 12 MBq (325 μCi). The phantom used was the standard phantom designed and prepared by the University of Bergen (Norway). The phantom is composed of solid polypropylene with 400 mm diameter with two 50 mm diameter holes. The phantom was placed between the ^{60}Co source and the detector collimated with 5mm lead window and it was rotated 360° in stepwise angle of 6 degree. The holes of the phantom were filled with materials of different densities; such as air, lead and rape seed oil.

1. INTRODUCTION

For the last few years, industrial computed tomography (CT) in Brazil has had its application in non-destructive testing, for scientific studies. Today, the interest of a wide range of industries, such as chemical and oil sectors in the use of computed tomography began to appear in large number, for improving design, operation and troubleshooting of industrial processes. Computerized tomography for multiphase processes is now a promising technique and has been studied for advanced research centres. To follow this trend and to keep update, the IPEN laboratory began a study for the development the computed tomography methodology.

Scanners for transmission tomography employ radiation sources, such as an encapsulated gamma ray source, positioned on one side of the object to be scanned, and one or a set of collimated detectors arranged on the other side. In the scanners of the first generation, one detector facing a single source moves around the object and provides a number of projections. Generally, the objects analyzed in industrial tomography field have high density and large dimensions, as in the case of the diameters of the oil refining columns. Consequently, high energy radiation source is required in order to be capable to cross the material. On the other hand, usually a dense detector material or a large detector is necessary

to absorb the photons from the source [1,2]. Detectors made with NaI(Tl) (3.8 g/cm^3), CsI(Tl) (4.3 g/cm^3) and BGO Bismuth-Germanium-Oxyde ($\text{Bi}_4\text{Ge}_3\text{O}_{12}$, 7.13 g/cm^3) are used in a multidetectors array. This system requires a complex hardware because each scintillator needs independent electronics, e.g., phototube, high voltage unit, preamplifier, amplifier and counter. In addition, for large objects several detectors are required to fit the object surface, making the system expensive and complex. An alternative is to use a unique bar of detector since it can be used as a position sensitive detector. Barouch and Marriete [3] have developed a system using a CsI(Tl)_bar. This kind of detector can be useful mainly in the case of industrial CT applications for large objects because it uses only two photomultipliers, thus requiring more simplified electronics, compared with those used in multiple detectors version. Besides, its cost is significantly cheaper.

Initially, a tomography of first generation one detector-one source was developed using a NaI(Tl) detector, 2" x 2" for comparison. The data acquisition board and the mechanical control interface were specially developed to be used in our Computed Tomography system. For testing these developments a tomography of the first generation (one NaI(Tl) detector-one ^{60}Co source) was used to carried out the TC experiments using the hardware and software developed. **(ESTE PARAGRAFO ESTA UM POUCO CONFUSO)**

Plastic scintillators have low density ($\cong 1 \text{ g/cm}^3$) and low Z materials [4]. These properties could dissuade the use of plastic for tomography purpose. However, these limitations can be overcome using a large dimension plastic scintillator taking in account its easy manufacture in the dimension and shape required at a low cost. The use of plastic scintillator has the advantage of being capable of involving large objects and exploring the faster response of the plastic scintillator ($\cong 2.5 \text{ ns}$), property that could be useful for fast image acquisitions such is the case of multiphase systems.

2. EXPERIMENTAL PROCEDURE

The first generation parallel beam computed tomography (CT1) scanner system consisted of a NaI(Tl) detector and an encapsulated ^{60}Co radioactive source located opposite to the center of the detector was developed. The detector used was a 5.08 cm (2") diameter NaI(Tl) crystal coupled to a photomultiplier Hamamatsu Model R329-02, HV supplied by Ortec mod. 556 and amplified with Ortec mod. 460. The schematic drawing and the data acquisition board of the CT1 is shown in Fig. 1. The data acquisition board and the mechanical control were also developed. The data acquisition board is constituted of two 8 bit ADC with corresponding to 256 channels positions (0 to 5V) for each one. It can be used versatility for multipurpose applications, so that, it can be used for one detector (CT1) version, a multi-detector array (1 board for each 2 detectors) or as well as in CT with a position sensitive detector (CTpsd).

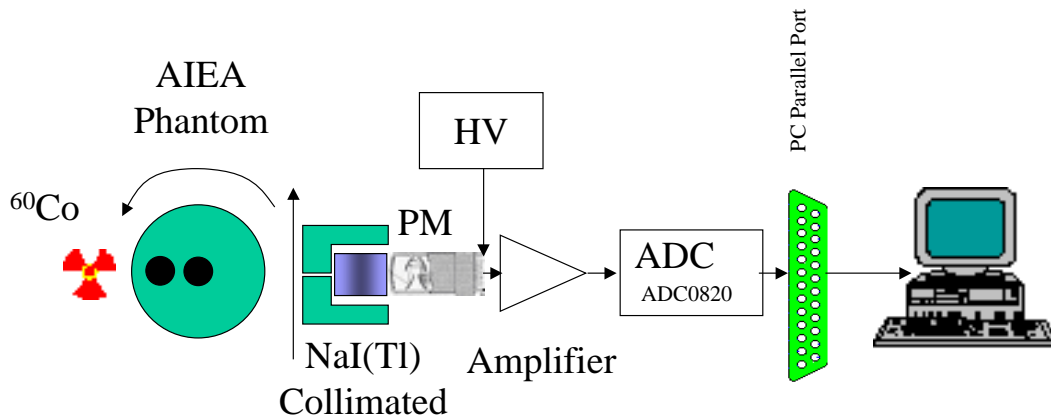


Fig. 1. Scheme of the computed tomography system using a NaI(Tl) detector

The tomography system was tested using a phantom placed between the detector and a collimated ^{60}Co source. The source activity was of 12 MBq (325 μCi). The phantom used was the standard phantom designed and prepared by the University of Bergen. The phantom is composed of solid polypropylene with 400 mm diameter with two 50 mm diameter holes. The phantom was placed between the ^{60}Co source and the detector uncollimated or collimated with 5mm lead window and it was rotated 360° in stepwise angle of 6 degree. The holes of the phantom were filled with materials of different densities; such as air, lead and rape seed oil.

The reconstruction algorithm used was the filtered back projection technique and was developed in the MATLAB code [5]. The software uses the filtered back-projection algorithm to perform the inverse Radom transform for parallel projection data. The filter is designed directly in the frequency domain and then multiplied by the FFT of the projections. The projections are zero-padded to a power of 2 before filtering to prevent spatial domain aliasing and to speed up the FFT [1]. The computational program reconstructs the image from projection data in two-dimensional array using a matrix where the columns are parallel beam projection data for different angles (in degrees) at which the projections were taken. The software assumes that the centre of rotation is the centre point of the projections. Linear interpolation and the cropped Ram-Lak are used in this software [6].

For de development of an industrial computed tomography designed with a plastic scintillator position sensitive Detector (CTpsd), light attenuation in the plastic scintillator along the plastic scintillator length was evaluated. Thus, in order to know the light auto-absorption (self-quenching), a 100 cm cylinder with 4 cm diameter of PS made with PPO (0.5% w/v) and POPOP (0.05% w/v) in a polystyrene matrix was prepared. A photomultiplier (Hamamatsu Model R329-02) was coupled to the cylinder extremity of the PS detector. A collimated ^{60}Co gamma source was positioned, step by step, on different positions of the PS cylinder. The pairs of X (cm) vs pulse height (volts) was fitted to a mono-exponential function:

$$V = V_0 \times \exp\left(-\frac{X}{X_{37}}\right) \quad (1)$$

where X is the distance in centimetres from the source to the PS extremity coupled to the photomultiplier, V_0 is a constant representing the maximal pulse height generated by the

photomultiplier signal and X_{37} is the PS length ($\cong 27.9$ cm) which reduces the light level to $V_0 \times \exp(-1)$ ($\sim 37\%$) from its original value. Consequently, the distance of the interaction point in relation to each photomultiplier can be estimated by the equation (2):

$$X(cm) = X_{37} \times \log_e \left(-\frac{V}{V_0} \right) \quad (2)$$

For two photomultipliers, the best estimate of the incidence position can be determined by the equation (3):

$$X = \frac{L + X_{37} * \text{Log}_e (V_1 / V_2)}{2} \quad (3)$$

The schematic drawing of the plastic scintillator tomography is showed in Fig. 2

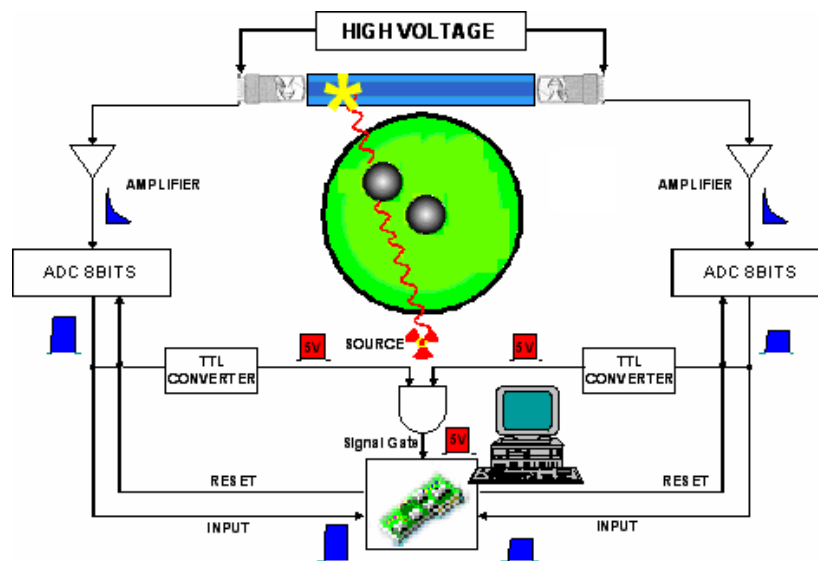


Fig. 2. Scheme of the CT system using the plastic scintillators as position sensitive detector.

For the tomography development, a plastic scintillator cylinder of 4 cm diameter and 40 cm high was prepared by thermal polymerization of the styrene monomer, with 0.5% PPO and 0.05% POPOP. The plastic scintillator cylinder was coupled to two photomultipliers (Hamamatsu Model R329-02) in each extremity to be used in the CT_{psd} mounting, as shown in Fig. 2. When the radiation interacts with the detector, the light photons scatter inside the detector and reach two detector extremities, generating two different signals (except for the middle detector position, which generates identical signals). Consequently, the farther the events occur from the photomultiplier (HV supplied by Ortec mod. 556), the lower signals are generated. In the sequence, the signal is amplified (Ortec mod. 460). For each signal, the maximum height value is converted to digital in approximated 0.6 microseconds (ADC0820).

After each ADC conversion happen the ADC0820s generate a signal (going down) which will be used to check the coincidence event. These two signals are inputted in a double NAND port (74LS00) which generate the coincidence signal, so, random noises from each photomultiplier can be eliminated. The eight bits generated in the ADC are read by the PC using two parallel port (LPT1 and LPT2). A ^{60}Co source of 12 MBq was used in this experiment. The phantom used is composed of a 30-mm cylinder of Aluminum and another cylinder of 30mm lead into a 110mm cylinder with water.

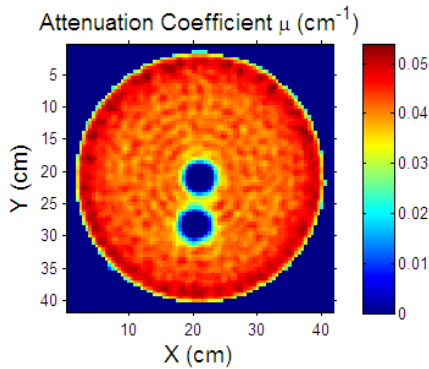
3. RESULTS AND DISCUSSION

The results obtained for the first generation parallel beam computed tomography (CT1) scanner system using a NaI(Tl) detector are showed in the reconstructed tomograms cases including the root mean square errors (RMSE) related to N(total pixels number) and μ (attenuation coefficient) for the specific conditions. In all cases 0.5 cm lead collimators for the source and the detector were used.

Fig. 3 presents the images obtained for the phantom with holes filled with different densities materials.

Case 1

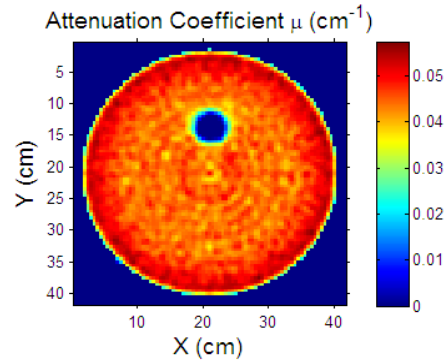
Collimator width: 5 mm
Holes empty (air)
Counting time: 15 s



RMSE(N) = 1.7045e-004 RMSE(μ) = 1.2864e-004

Case 2

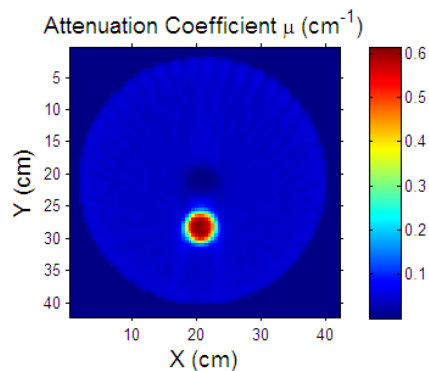
Collimator width: 5 mm
Central hole filled with rape seed oil
Counting time: 15 s



RMSE(N) = 1.2864e-004 RMSE(μ) = 2.2710e-001

Case 3

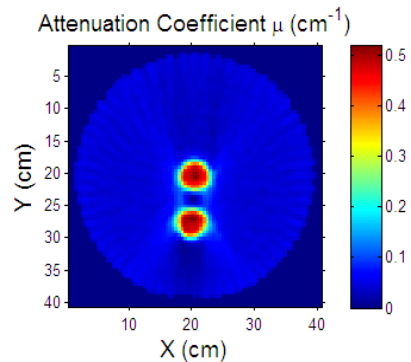
Collimator width: 5 mm
External holes filled with a lead plug
Counting time: 15 s



RMSE(N) = 3.7587e-004 RMSE(μ) = 3.6584e-001

Case 4

Collimator width: 5 mm
Both holes filled with lead plugs
Counting time: 15 s



RMSE(N) = 6.3555e-004 RMSE(μ) = 4.4298e-001

Fig.3 Reconstructed Tomogram of the Bergen phantom filled with different density materials

Table 2 presents the values of the attenuation coefficient obtained experimentally compared to the theoretical values [8].

Table 2 -Root mean square errors (RMSE) related to N(total pixels number) and μ (attenuation coefficient)

COEFFICIENT ATTENUATION

Materials used to fill phantom holes	Experimental Value (cm⁻¹)	Theoretical Value (cm⁻¹)
Oil	0.055	(0.0572)*
Lead	0.649	0.669
Polypropylene	0.055	0.0572

* Considered the same theoretical value of the Polypropylene

A good resolution was observed for all images, as shown in Fig.3. The density of the rape seed oil used was determined as being $0.92 \pm 0.01 \text{ g/cm}^3$, which is similar to 0.91g/cm^3 of the polypropylene used for the phantom. As expected, the attenuation found for the oil was the same of the polypropylene (Table 2). The attenuation coefficient found experimentally for the air, lead and polypropylene are comparable to the theoretical values described in the literature for these materials [8].

The results obtained for the plastic scintillator detector version (CTpsd) scanner system is showed in in Fig. 4.

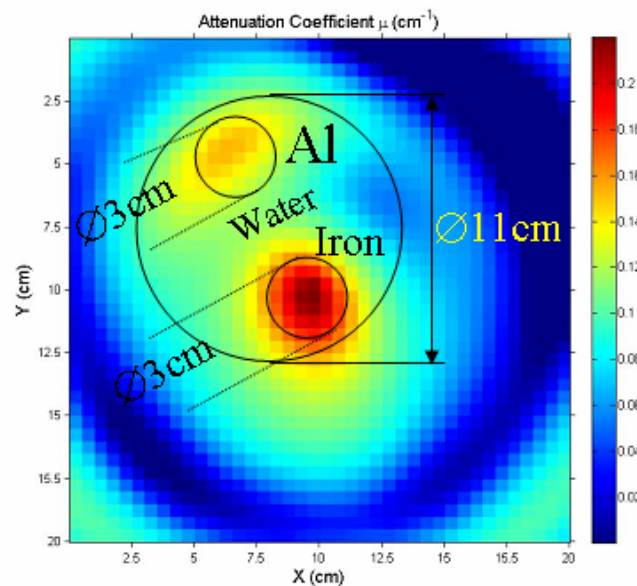


Fig. 4Reconstructed Tomogram for a phantom of $\varnothing=11\text{cm}$ water with two bars inside it (Iron and Aluminum)

As we can observe in Fig. 4 the image is not so good as that found for CT1 system using(ESPACO NaI(Tl) detector. There main reasons for that maybe could be the dimensions of the detector used. It was used PS cylinder of small size $\varnothing = 4\text{cm}$ against an ideal value of 10 to 15 cm.

4. CONCLUSION

A good resolution was observed for all images reconstructed from the first generation one detector-one source using a NaI (TI) detector CT system.

The development and the studies carried out with tomography of first generation one detector-one source using a NaI (TI) detector give us valuable experience to start the design and development of tomography systems.

On the other hand, the resolution for the images reconstructed from the CT designed with position sensitive plastic scintillator detector have not satisfactory results, requiring more studies and optimization.

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