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X-RAY AND GAMMA-RAY COMPUTERIZED MINITOMOGRAPH SCANNER FOR SOIL
SCIENCE AND BIOMEDICAL APPLICATIONS

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ABSTRACT

A X-Ray and Gamma-Ray computerized minitomograph scanner system has been developed for applications in soil science and in biomedical systems. Previous results were obtained using a miniature X-Ray tomograph scanner dedicated to biomedical analysis (Cesareo et al., 1982). As a new methodology in instrumentation and in soil research (Crestana et al., 1986), the minitomograph has proved to be useful for measuring water content ($\theta \pm 3\%$) and soil bulk density ($\rho \pm 1\%$). The system features are : translation and rotation scanning modes, 200 mm effective field of view, pulse counting method for signal processing and 1.0 mm spatial resolution.

The performance of the system was demonstrated by experimentally measuring water content in soil samples collected from the Ap horizon of a Barretos, Brazil, fine sandy loam soil.

Also applications have been carried out of the CT-scanner to biomedical systems, in order to study the absorption of Iodine by plants and Gadolinium by internal organs of mice.

1. INTRODUCTION

A new method for investigation in soil science physics has been introduced by Crestana et al. (1985), Hainsworth & Ailmore (1982), Petrovic et al. (1982).

This method uses computerized tomography and it has proved to be a great advantage when compared to the classical methods such as vimentry (Schwab & Frevert, 1985) or gamma-Ray direct transmission (Davisson & Evans, 1952).

We have developed a dedicated X-Ray and Gamma-Ray computerized minitomograph scanner for soil science.

The computational programs were all developed in Pascal language. They are used respectively for control and data acquisition, reconstruction and for quantitative analysis of the linear attenuation coefficient at any chosen region of the image.

This paper describes the CT-scanner realized in S. Carlos, Brazil and dedicated to soil science. This scanner is very similar to the one realized in Rome and employed in many fields, as non destructive testing and biomedical applications (Cesareo et al., 1982).

2. PRINCIPLES OF THE TOMOGRAPHY METHOD

In tomography a cross-sectional image is obtained by calculation based on profiles of transmitted photon beams along multiple projections through the body with an adequate algorithm. In the image obtained each point represents a linear attenuation coefficient.

Figure 1 schematically shows the situation for discrete scanning as well as the division in planar section cells (pixels).

The linear attenuation coefficient $\mu(x,y)$ can be calculated using the equation

$$N = N_0 \exp \left(- \int_s \mu(x,y) ds \right)$$

where N is the number of transmitted photons and N_0 is the number of incident photons along any directions across the sample.

In practice, the integral equation (I-1) becomes a discrete sum. For each profile we have a set of rays-sums resulting in a set of M projections.

In the present work, the images have been reconstructed by using the filtered backprojection algorithm with a Ram-Lack filter (Ramachandran & Lakshminarayanan, 1971).

3. SYSTEM'S DESIGN

The system configuration and block diagram are shown in figure 2 and 3 respectively.

The hardware is basically a mechanical table with two step-motors, one for rotation and another for translation motions; radioactive source; collimators; radiation detector with NaI(Tl) crystal; electronic pulse counting and processing system; microcomputer with two floppy disk-units 5 1/4"; high resolution video and graphic printer.

We have used an 8 bits microcomputer based on a 6502 microprocessor.

3.1. INTERFACE AND ELECTRONIC PULSE SYSTEM

The interface subsystem has been developed using two peripheral interface adapter 6821 - PIA and 74LS04 and CD4050 integrated circuits.

We have been using the range of addresses from $\$C0D0$ to $\$C0DF$.

The A ports (PA) of the peripheral interface adapter A are programmed as output.

These ports are used for step-motors controller. The signals sent through the data register (DRA) are shown in figure 4.

The B ports (PB) of the peripheral interface adapter A have been programmed in different modes where PB0, PB1 are outputs, and PB3, PB4 are inputs.

The PB5, PB6 and PB7 ports are not used. The signals sent received through the data register (DRB) are shown in figure 5. The signals correspondent to bits 0 and 1 are sent from the computer to the pulse handling system. The test for end count signal is sent from the counter to the microcomputer. The A port of the peripheral interface adapter B has been chosen for the acquisition.

The data from the electronic pulse handling system are coded BCD. For the data register (DRA) one will have the configuration shown in figure 6.

The B port (PB) of the peripheral interface adapter B is programmed to control of the following signals, data transference, digitize, terminus module (TM) and previous module (PM).

For the data register (DRB) one will have the configuration in figure 7.

The CD4050 integrated circuits are used as line buffers improving the fan-out and fan-in conditions of the interface and control circuit. Figure 8 shows the schematic diagram for the interface control system.

3.2. CONTROL CARDS FOR STEP-MOTORS

This subsystem generates the signals to step-motors. The signals define the rotating sense, and the control cards leave the power in stand-by when necessary.

Figure 9 illustrates the schematic diagram of one subsystem step-motors' control cards.

3.3. CONTROL CARDS FOR THE TOMOGRAPHIC TABLE POSITION

This subsystem uses optoelectronics devices and comparative circuits to define specific coordinated positions for the tomographic table. The output signals are sent to the PB3 and PB4 ports of the peripheral interface adapter A. Figure 10 illustrates a schematic diagram the tomographic table position's control cards.

4. APPLICATIONS TO SOIL SCIENCE

We have applied the computerized minitomograph scanner system to measure water content in soil.

We have used soil samples collected from the Ap horizon of a Barretos, Brazil fine sandy loam soil. Air dried soil was passed through a 1.0mm sieve and packed into thin wall "plexiglass" boxes. Thickness ranged from 1.9 to 2.1 cm. For packing the soil samples we employed the methodology usually adopted in soil physics (Hillel, 1981).

To obtain samples with different water contents ranging from 0.8% to 30% we used four samples of soil equilibrated with water. This was obtained adding a known volume of water to a known volume of previously air dried soil.

A typical tomography of a soil sample with 10% water is shown in figure 11; tomographs of soil samples containing various water contents have been also analyzed and the attenuation coefficients have been deduced (figure 12) from the images. Further, the quality of the images has been evaluated by using the plexiglass test object shown in figure 13 (top) and the method of the contrast transfer function (CTF) (Taylor & Lupton, 1986).

Figure 13 (bottom) shows the image of the test object by using a collimation, and a pixel width of 1 mm. Other images have been carried out with collimators of 0.5 and 2 mm diameter.

A loss of spatial resolution at a pixel width of 2 mm can be deduced from the images and was confirmed by the CTF, as shown in 14. On the other hand, the spatial resolution was not improved decreasing the pixel width to 0.5 mm.

5. APPLICATIONS TO BIOMEDICAL SYSTEMS

For studying the absorption of iodine solution by plants, differential tomographs have been carried out, at energies above and below the K-discontinuity of iodine at 33.164 keV. To this purpose, Ray tube with secondary interchangeable targets has been employed (Cesareo & Viezzoli, 1983). Secondary targets of Cerium (K=34.5 keV) and Barium (K=32keV) have been used, and the difference between two tomographs has been finally determined, which is only sensitive to the presence of iodine (Cesareo et al., 1988). A typical result is shown in figure 15.

With the same method, the accumulation of Gd-DTPA complex in specific organs of mice has been studied, after intravenous injection. An Am^{241} (200 mCi) source has been employed, which emits 60 keV gamma-rays are selectively attenuated by Gadolinium.

The tomographs of a section of a mouse-kidney is shown in figure 16.

6. CONCLUSIONS

Main conclusions obtained are:

- (1) The calibration curve in linear attenuation coefficient $\mu(\text{cm}^{-1})$ versus water content in soil $\theta(\text{cm}^3/\text{cm}^3)$ at 60 keV indicates the viability for water content measurements in soil science. This confirms previous results of Crestana et al. (1986).

) The standard deviation from the mean attenuation did not change significantly with the beam width, however, the counting time was adjusted so that equal number of photons contributed to each image. For the images generated with the computerized minitomograph scanner system the better spatial resolution at a pixel width of 1.0mm was confirmed.

1) The system can be used at all incident energies and with different radiation-sources such as isotopic sources or X-Ray tubes with secondary targets (Cesareo et al., 1988).

) The system is dedicated for soil science research, such as to perform bulk density and water content tomographic analysis.

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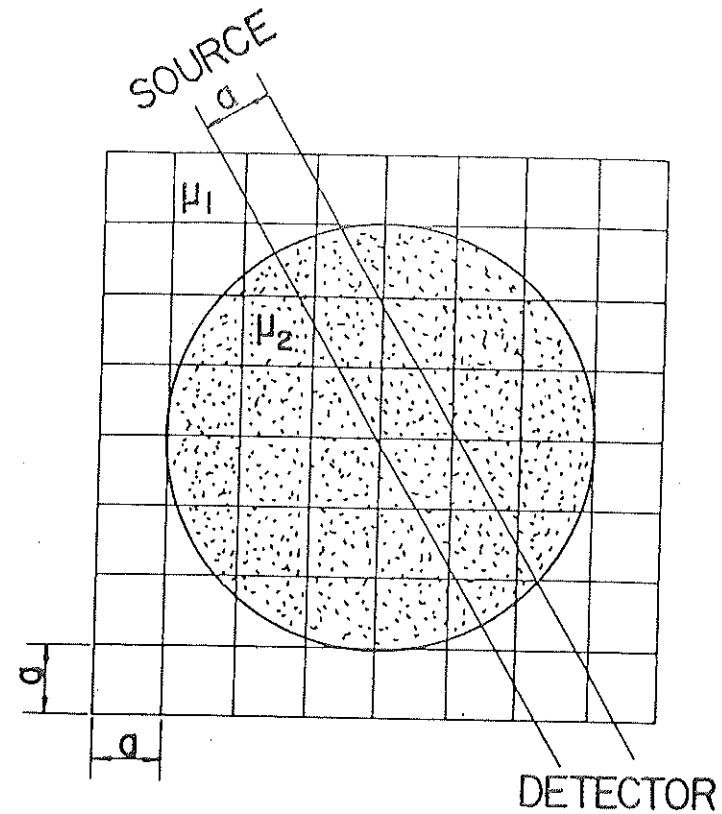
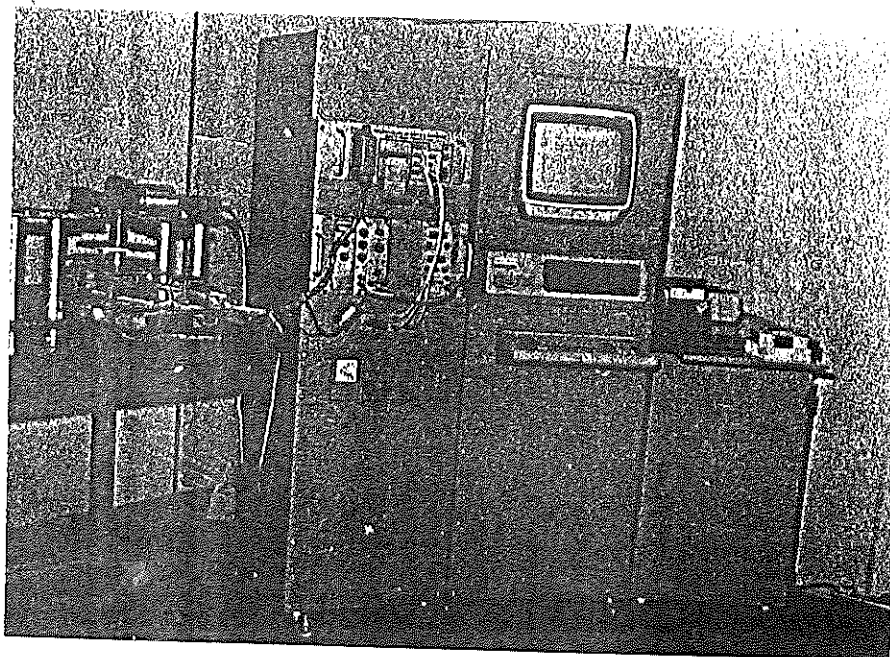


Figure 1 - Scheme of the source-sample-detector configuration.



2 - Photography of the mini-CT-scanner realized at EMBRAPA
(S. Carlos, S.P., Brasil).

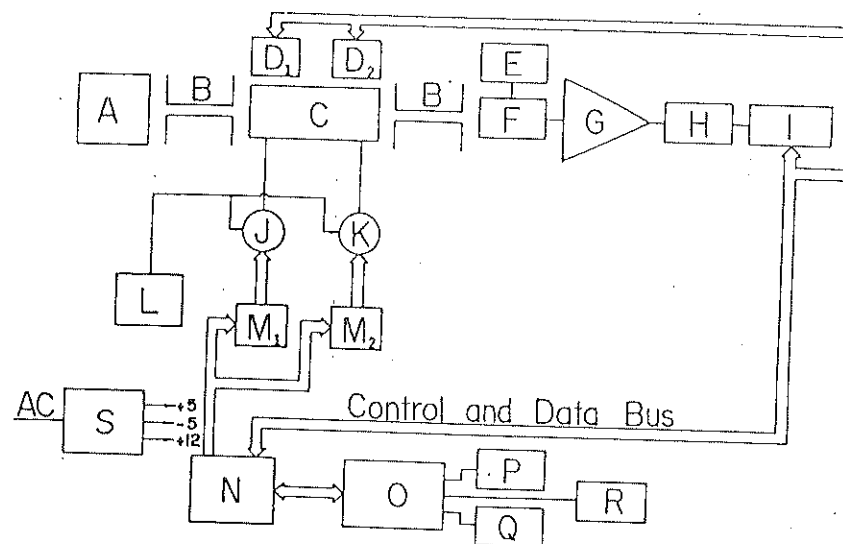


Figure 3 - Block diagram: A = X-ray of gamma-ray source
B = collimator
C = tomographic table
D₁ = control cards for rotation
D₂ = control cards for translation
E = HV power supply
F = detector
G = amplifier
H = single-channel analyzer
I = counter and timer
J = rotation step-motor
K = translation step-motor
L = power supply for step-motors and auxiliar ci
M₁ = rotation control-card
M₂ = translation control-card
N = interface and control
O = microcomputer
P = graphic printer
Q = video-monitor
R = drivers
S = electrical control.

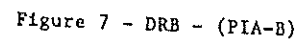
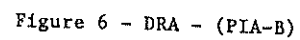
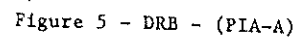


Figure 13 - Test object and image reconstruction on pixel width of 1.0 mm.

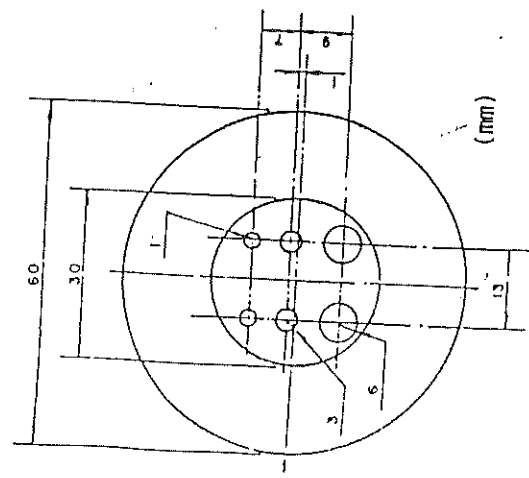
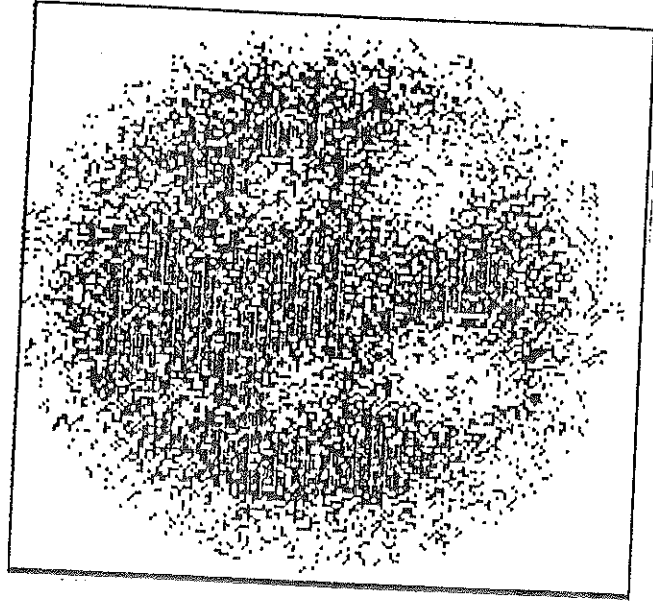


Figure 14 - Contrast transfer function and relative standard deviation for pixel widths of 0.5, 1.0 and 2.0 mm.

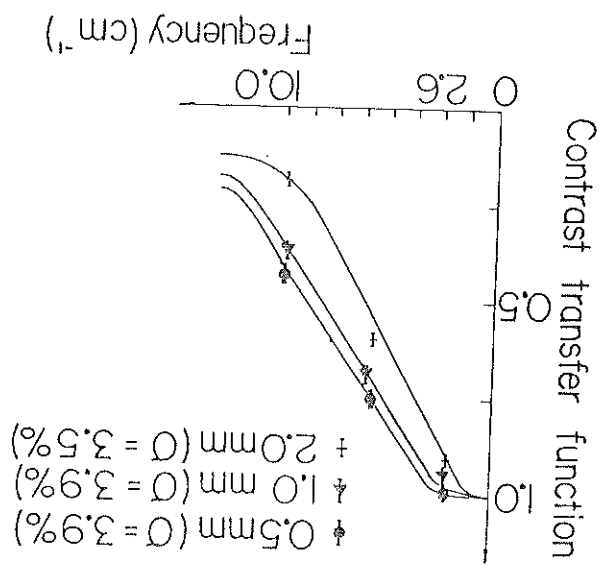


Figure 15 - Differential tomography showing the uptake and selective distribution of Iodine solution in the stem of an "azalea" plant. The maximum value of the attenuation coefficient is 0.416 cm^{-1} and is due to the Iodine-contribution only.

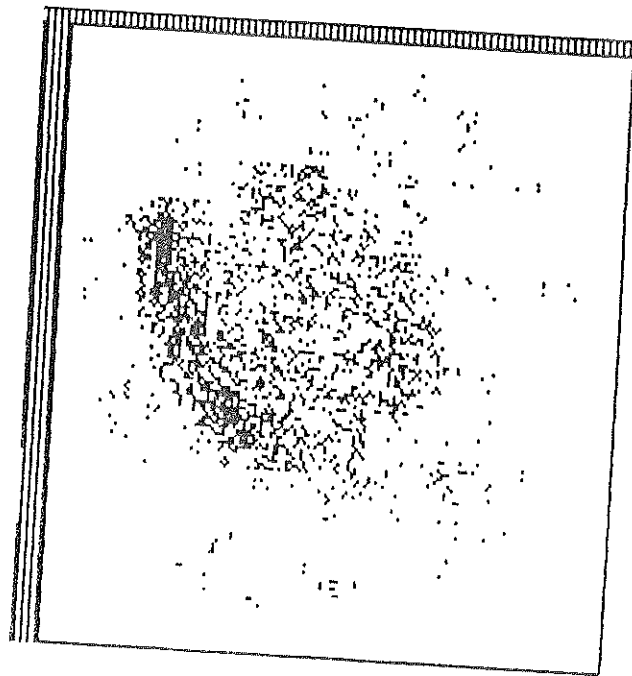


Figure 16 - Tomography of a section of the body of a mouse in which a Gd-DTPA complex was injected. The maximum and minimum values of the attenuation coefficient (0.274 and 0.210) inside the body can be compared with the value (0.210) of the attenuation coefficient of a "non doped" mouse.

