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A model for soil computed tomography based on volumetric reconstruction, Wiener filtering and parallel processing

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ABSTRACT

Soil quality is strongly related to agricultural productivity and some of the factors that determine this quality can be obtained by X-ray tomography. Using data derived from tomographs, this work presents the Volumetric Tomographic Reconstruction Model for agricultural samples, which allows, through the use of parallel processing techniques, a fast 2D and volumetric reconstruction. The model enables the improvement of the quality of X-ray projections based on Wiener filtering, 2D and also 3D visualization tools. The results showed that through this model measurements can be extracted of attenuation coefficient of soil samples as well as viewing and saving tomographic slices of the sagittal, coronal and transverse plane. It also showed that the interaction of the model strongly supports a better understanding of the different soil densities.

1. Introduction

To know the quality of agricultural soil, which is an important factor in agricultural productivity, it is important to observe its physical properties. Such properties are impacted, for instance, by the intensive use of mechanization in all operations of soil cultivation (seeding, plantation techniques and harvesting). There are some variables that contribute to the measurement of this quality, such as porosity and density, among others. The soil density, for example, helps to provide better physical characterization of the soil and it can be used as an indication of its level of compaction (Pires et al., 2011).

In the last few years, there has been an evolution in the area of soil physics conducted through the development and application of non-invasive techniques for the study of soil characteristics (Pires et al., 2010). Among the techniques used, there is the X-ray computed tomography, which stands out in regards to the other techniques applied in soil physics, such as the gravimetric and neutron probe (Teixeira et al., 2005; Pedrotti et al., 2005) due to its precision in extracting physical attributes, such as density and humidity, as well as allowing the non-destructive examination of soil samples (Aylmore and Hainsworth, 1983; Crestana, 1986). Another advantage offered by computed tomography, in comparison to the others, is the possibility of using image processing tools of Gonzales et al. (2004) to help the investigation of physical phenomena that occur in the soil.

In the agricultural area context, it can be noticed that the progress of the works of the soil tomographic technique has happened in three well defined aspects, described as:

- X-ray tomographic instrumentation.
- Computer architectures used in X-ray tomography.
- Algorithms of tomographic reconstruction and visualization.

The instrumentation aspect researches the development of new equipment and the improvement of existing equipment. The aim is to increase the portability of tomographic equipment, so as to enable its use in the field thus reducing the number of possible changes to the conditions where the object of study is found (Cruvinel et al., 1990; Naime et al., 1997; Macedo et al., 1999; Naime, 2001). This field of studies is also about the development of the geometry of the source-detector array of the acquisition equipment (Balogun and Cruvinel, 2003; Scannavino and Cruvinel, 2012). This field of study also deals with the geometry development of the source-detector array of the acquired equipment. In this area, the researchers have, over the last few years, produced significant results advancing the acquisition process of agricultural tomographers. Essentially, faster ways of acquisition

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and geometries that cause less destruction of the studied environment are being sought.

In the computer architecture aspect, the studies developed by Cruvinel et al. (2009) stand out. In the algorithms of reconstruction and visualization aspect, a large part of this development was due to the improvement of the reconstruction algorithms, with the application of different reconstruction techniques and several ways of filtering, which involve linear and statistical techniques as well as techniques based on the transformation (Laia et al., 2008; Laia, 2013)

In this panorama of the application of tomographic reconstruction in soil physics, it can be seen that there some points which are yet to be explored well and are open to research. Among them, we can highlight the lack of 3D reconstruction models that, through the combination of image processing and parallel processing techniques, allow further deepening of the studies of dynamic phenomena occurring in the soil, with emphasis on agricultural applications. Above all, the insufficient development of three-dimensional reconstruction models of agricultural samples that explore parallel paradigms of systems modeling is most noticeable. Algorithms developed on this model contribute significantly to the abbreviation of its runtime during the two-dimensional and three-dimensional tomographic reconstruction.

Another relevant aspect is the increase of the processing power that can be obtained with the use of parallel architectures based on clusters, in machines with multiple core processors, as well as with dedicated parallel architectures based in DSP processors. It is interesting to highlight that, given the development taking place in tomographic instrumentation for the agricultural area, the creation of a model enabling the exploration of the ability of these parallel architectures is something that is in accordance with all the progress happening in this area.

2. Material studied

2.1. Computed tomography and reconstruction methods

With regard to the X-ray tomography images, some work has been developed using the reconstruction in soil analysis. Naime (2001) used the PowerVis environment, built in the Borland Builder C++ environment to view the infiltration of water in the soil. Bastardie et al. (2005) investigated the distribution of spatial variability in soils using 3D visualization tools to analyze earthworm burrow systems.

The fact of being able to observe internal body data, after the reconstruction of tomographic images, in a non-destructive and non-invasive way, is considered an important characteristic of the tomographic technique.

In the computed tomography context, the greatest contributions to its development were made by Cormack (1963) and Hounsfield (1973). Cormack developed a method for image reconstruction, using a finite number of projections and its back-projections. Housfield is recognized as the inventor of the computerized tomography for medical applications. These studies caused great impact in radiological diagnostics. In 1979, Cormack and Housfield were awarded the Nobel Prize in Medicine for their invention. Later, Cormack reported on a prior work of Austrian mathematician Radon and the first applications for reconstruction from projections in radioastronomy (Radon, 1986; Cormack, 1973; Bracewell, 1956).

Tomography uses a radiation collimated beam, which defines planes that are as thin as the beam itself and, through several parallel collimated beams, several planes can be defined. This way, instead of exposure on radiographic film, as happens in a conventional radiography (Cruvinel et al., 1990), from each line of beam propagation that goes from the source to the detector, values are obtained that form a projection, as Fig. 1 illustrates. From this, it can be said that the necessary data for the reconstruction are actually a group of line integrals throughout the rays that cross the object (Herman, 2009).

The procedural scheme for reconstruction from Radon Transform is in Fig. 2. In it, the $\overline{AB}$ ray in the $z = 0$ plane can be mathematically expressed by:

$$t = x\cos\theta + y\,sen\,\theta \tag{1}$$

where t is the perpendicular distance from the origin to the line. With the use of this radius equation, the integral of the $P_\theta(t)$ radius is given by:

$$P_\theta(t) = \int_{linha\overline{AB}} f(x,y)dt = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} f(x,y)\delta(x\cos\theta + y\,sen\,\theta - t)dxdy. \tag{2}$$

where $P_{\theta_i}(t)$ is a t function representing the parallel projection with θ_i angle. For continuous θ the $P_\theta(t)$ function is the Radon transform of $f(x,y)$. The projections given were obtained in parallel to the rotation in the x axis named by t.

The Fourier's theorem for the tomographic section shows that the Fourier Transform of a parallel projection of a $f(x,y)$ image, taken from a θ angle, is equivalent to the slice of a two-dimensional $f(x,y)$ transform, defined as $F(u,v)$, implying a $F(u,v)$ angle with the u axis in a way that the P_θ Fourier Transform provides the values over the BB' line, as Fig. 3 illustrates (Kak and Slaney, 1999). What follows this property is that, from the projections data, it is possible to estimate the image $f(x,y)$ by simply doing the Fourier two-dimensional inverse transform.

From the Fourier Transform, it is possible to derive the filtered back projection equation, that is, it could be separated into two different operations. The first is the filtering of the projection data for each θ angle, as:

$$Q_\theta(t) = \int_{-\infty}^{\infty} S_\theta(\omega)|\omega|e^{j2\pi\omega t}d\omega \tag{3}$$

The second operation is the filtered projections, which are retroprojected to obtain the object function, as it follows:

$$f(x,y) = \int_0^{\pi} Q_\theta(x\cos\theta + y\,sen\,\theta)d\theta \tag{4}$$

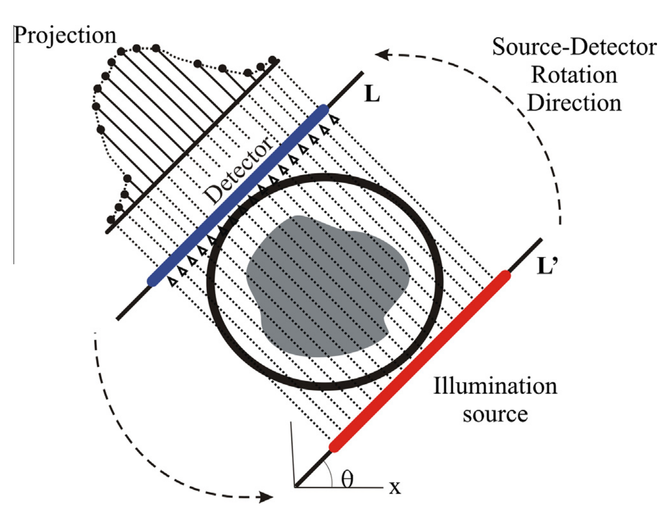

Fig. 1. Illustration of the transmission tomography.