An Improved Electric Impedance Tomography Dedicated to Agriculture Applications

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Abstract: - An improved electric impedance tomography for agriculture applications is presented. The instrument was designed to acquire data for reconstruction of images of internal soil samples, based upon measurements of electrical impedance made from a set of electrodes set up around the samples. When compared to other techniques, gamma and X-rays tomographic methods are not only less expensive but also do not require ionization radiation. The instrument applies currents of 50kHz, allowing up to three different patterns, i.e., sinusoidal, square, and triangular, and uses high performance DSP(Digital Signal Processing) to manipulate data. We used a TMS320C30, which has advantages such as performing arithmetic operations including multiplication in one cycle, I/O assisted by an internal DMA coprocessor, and two independent buses for external memory. In addition to presenting hardware performance, an example of pesticide infiltration analysis in soils was carried out.

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1 Introduction

Nondestructive testing practitioners challenged with testing of complex products may choose sophisticated methods and systems, such as computerized tomography, emission tomography or both magnetic resonance imaging systems, developed for other applications. Computerized tomography (CT) permits imaging of objects in axial cross sections. This technique was pioneered by Cormack[1] and Hounsfield[2]. In CT the axial images can be stored in the form of a stack of two-dimensional (3D) matrixes of numbers. Despite the proven success of these techniques in diverse fields, studies in applications of both scattered photon and impedance images have continued to gain momentum within the last decade.

Electric impedance tomography is an innovative methodology, which produces images of electric property distribution in a conductive body. These images are obtained by measuring the electric potential generated by injection of an electric current mounted around in external electrodes attached to the periphery of the body. The first work on the impedance electric field tomograph was published in the beginning of the eighties Barber et al[3]; Jossinet[4]; Webster et al [5][6]. In 1982, Brown et al [7] used an electric impedance tomographic system having 16 electrodes in a cylindrical container, which produced an image of a forearm section immerged in saline solution. In 1995, McAdms and Jossinet [8] presented a complete review on impedance variations in human tissue.

At present, electric impedance tomographic systems can be found making use of a large number of electrodes, individually programmable by a controlling microcomputer or even dedicated microcontrollers. As an example, architecture presented by Jossinet [4] allows as many as 32 electrodes and can generate up to 480 images in one second.

This study, presents both an electric impedance tomography system dedicated to agriculture, which can also be a powerful tool for studying soil phenomena, and an experimental analysis of pesticide infiltration in soil.

2 Computerized Tomography in Soil Science.

Computerized tomography, as a new method for investigation in soil science physics, was introduced by Petrovic et al [9], Hainsworth and Aylmores [10], and Crestana et al[11]. Petrovic demonstrated the possibility of using X-ray transmission computer tomography to measure soil bulk density. Crestana demonstrated that CT can also be applied not only to measuring water content of soil but also to follow dynamically and three dimensions the motion of water in soil. Also, using a third-generation CT scanner, several techniques can be applied, e. g., differential tomography and real time and spatial distribution scanning modes. Linear dependence was demonstrated for the Hounsfield units (HU) used in CT and water content. The application of CT methodology in soil science has proven to be of great advantage when compared to classical methods such as gravimetry or γ-ray direct transmission. Using CT makes possible either measuring either local heterogeneity within the soil at pixel resolution or soil bulk density and water content pixel by pixel, and even non-invasively obtaining two and three-dimensional images of soil samples, independent of the geometry and shape of each sample. Two and three-dimensional measurement of soil physical parameters such as bulk density and water content is an important step in modeling and analyzing soil science problems. In agriculture there a need exits for nondestructive experimental techniques with millimeter or sub-millimeter resolution capable of investigating intricacies present in the variety of processes occuring in soil. Some examples of coupled and time-dependent soil processes are compaction, root penetration, crusting, seedling cracking and swelling, wetting and drying or thawing and freezing cycles, miscible and immiscible displacement of nutrients in the presence of roots, and preferential flow of pollutants in fractured porous media. CT is becoming a powerful and highly promising tool for studying such soil phenomena. In 1987, Cruvinel developed a direct transmission X and γ-rays computerized minitomograph scanner for multidisciplinary use with the possibility of using several different beam energies and radioactive sources as well as X-ray fluorescent targets.

However, in all these techniques, there is a need for either a radioactive source or X-ray tubes and unlimited access to the object under examination, from opposite views. In cases where this condition can not be satisfied, as is the case with in situ measurement, of soil physical parameters, other methods could prove useful. One such method is the Electric Impedance Tomography, which requires no ionization radiation and the electrodes can be attached where desired.

3 System Design

Figure 1 shows in block diagram the architecture of the electric impedance tomographic system designed for agricultural applications. The overall architecture was designed with an array of 32 current generators, each of which has a separately programmable pattern shape and output level. The experimental chamber for object analysis consists of a PVC tube, 20 centimeters in diameter, 5 centimeter in thickness and 15 in height. Its base was sealed with non-conductive plastic material. Coupled to the experimental chamber are 32 electrodes, constructed with stainles steel, 1mm in diameter and 6 centimeters in length in direct contact with the electrolyte. However, different types of metals can also be used as electrodes, providing characteristics such as lower resistivities and capacity to withstand oxidation processes are preserved.

The processor used in this project is third-generation, i. e., the TMS320C30, offering high performance with 32 bits word lengh. The addressing space consists of 16 million words of memory containing program, data, and input/output space. Integer arithmetic and floating-point and logical operations use 32 bits. All arithmetic operations are executed within one cycle. DSPs can manipulate large amounts of data carrying sampled digital signals.

Software for image reconstruction was based on Poisson’s formula with solution on the unitary circle and the backprojection procedures [12],[13].

With the advent of accurate, reliable and inexpensive positioning systems, the possibility of taking into account within-field spatial and time variability was born, with the promise of both economic and environmental benefit for agriculture. Parallel advances in sensing systems, precise application mechanisms and control system and information processing power computers have led to the development of the

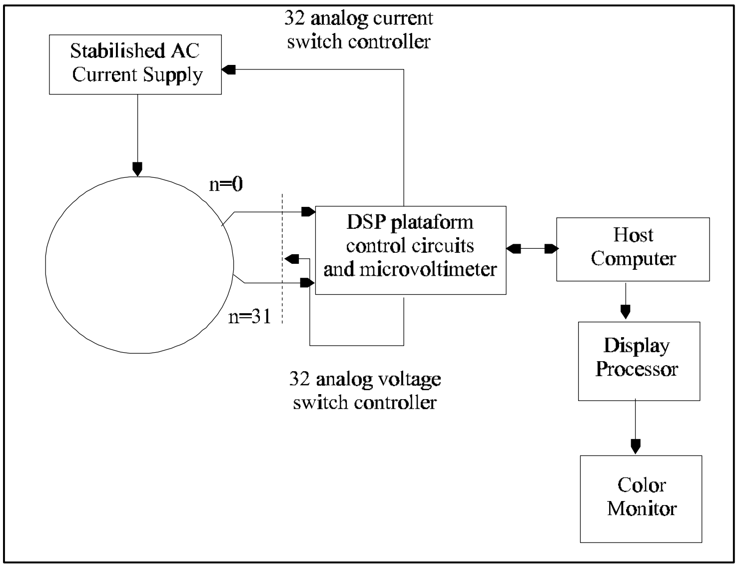

Figure 1 – Block diagram of the improved electric impedance tomography system for agricultural applications with a DSP TMS320C30

concept of precision agriculture. Precision agriculture may be defined as the targeting of inputs to field crops according to locally determined requirements at the meter or even centimeter level. The concept has been technology-led, with laboratory technologies in the field so that spatially variable input application could be implemented in production agriculture. However, interpretation of spatial and time variability and in situ instrumentation are very much less well developed. It is therefore widely recognized that much research is necessary in these areas in order to provide a solid foundation to the entire concept of precision agriculture and its implementation in production agriculture[14],[15]. Thus, one of the main characteristics qualifying the electric impedance tomograph as a dedicated system for agricultural applications is its portability, which allows in situ measurements.

4 Measuring pesticide content in soil

To illustrate an application in agricultural science we have applied the electric impedance tomographic system for measurements, of pesticide concentration in soils. We analyzed soil samples from the experimental field of Pindorama-SP, part of the Agronomic Institute of Campinas, with coordinates of 48°55'W, and 21°13'S, inside an area of 50X100 meters of Brazilian podzol (Paleuhumult). With agriculture use of pesticides, preservation of both production sustainability and environmental became an urgent problem. Today, it is quite well known that excess use of pesticides represents a risk to both human and animal health. An example is the constant use of the pesticide atrazine by Brazilian farmers, considered a cancerous substance, water has been found high Atrazine concentrations in both surface and table. Therefore, methods for direct field use have acquired great importance for monitoring the interactive processes involving chemical products and the water-soil-plant-atmosphere system. Figure 2 illustrates electric impedance images of soil samples, where current results are presented with alteration in contrast due the presence of Atrazine in concentration ranging from the 1% to 10%.

We observed that this method allows calibration with reproducibility, and such pesticide concentration ranged in the gray scale from 18 to 215. The measurements were carried out by means of a sinusoidal current with frequency of 50.0 ± 0.1 kHz and voltages of 2.0 ± 0.2V. Moreover, the amplitude of the electric potential observed on the electrode

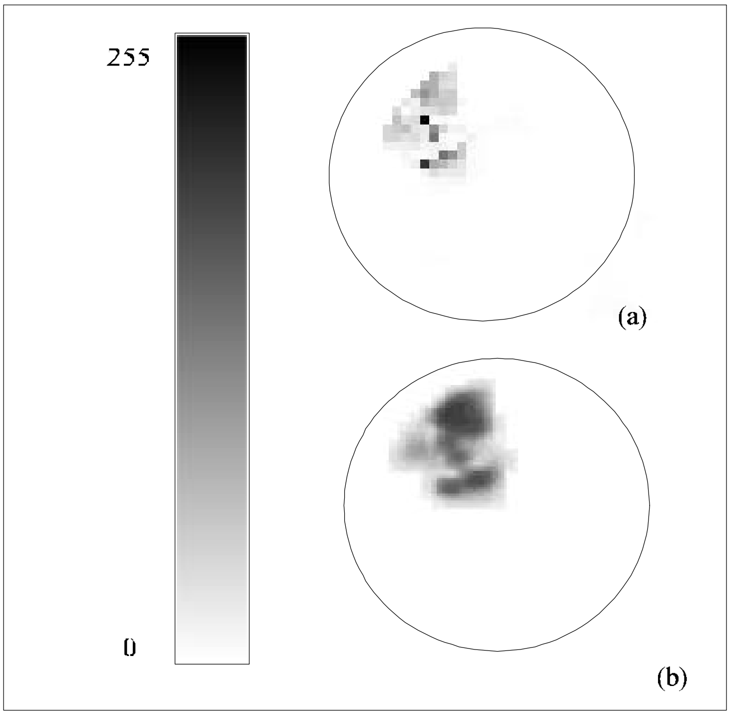

Figure 2 – Differential electric impedance images obtained from soils presenting Atrazine in two concentrations, i.e., 1%(a) and 10%(b).

pairs was on the order of 50μV. Besides, the images presented in Figure 2 were low-pass filter for noise reduction and improvements in the signal-to-noise ratio by approximated factor of 20.

These results illustrate the potentialities of the electric impedance tomography technique for agricultural applications.

5 Conclusion

The study described in this paper was conducted in order to assess the feasibility of the improved electric impedance tomographic designed at the Instrumentation Center of the Brazilian Enterprise for Agricultural Center Research. A prototype system was developed and tested in the field. Results gave shown electrode sensitivity of current to voltage converters, and usefulness of the TMS320C30 Digital Signal Processor. We found that system can locate and distinguish high from low resistivity regions by producing adequately reconstructed slices of impedance distribution. Future efforts should be made in spatial resolution and image quality. Improvements furthermore, electric impedance images, measuring pesticide concentration in soils, were also carried out.

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