Active Monitoring Apparatus for Underground Pollutant Detection Based on Electrical Impedance Tomography

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Abstract – Spills and leaking of solvents widely used in many industrial processes have contaminated the environment at many highly industrialized sites and nearby areas. Site assessment and monitoring during remediation of soils and groundwater affected by this kind of contamination is often difficult and expensive.

Geophysical techniques based on mapping a physical property of soil can be a useful tool for a rapid and fairly economic monitoring during site assessment and, even better, during the remediation process. Among these, Electrical Impedance Tomography (EIT) is an attractive example of an inverse problem as a technique for non-invasive diagnosis of conductive materials.

This paper, after a brief description of the tomographic inversion process, describes the architecture, the design specifications of the measuring system for 2D and 3D resistive EIT.

Keywords – Electrical Impedance Tomography, Environmental Monitoring, Inverse Problems.

I. INTRODUCTION

Spills and leaking of solvents widely used in many industrial processes have contaminated the environment at many highly industrialized sites and nearby areas. Generally, these contaminants may be present in the subsurface as chemicals dissolved at low concentration in the interstitial water and in the groundwater, but in most cases they exist in a purely organic phase (NAPL: Non-Aqueous Phase Liquid) floating on the water table and at the capillary fringe, or lying upon low-permeability units that they encounter in sinking in the subsurface under gravity or lying upon the bottom of the aquifer [1], depending on their physical-chemical properties.

Site assessment and monitoring during remediation of soils and groundwater affected by this kind of contamination is often difficult and expensive, due to the large number of variables which influence NAPL transport in the subsurface. Conventional techniques (groundwater monitoring wells, boring and sampling, physical-chemical and chemical analyses, etc.) used for geological, hydrogeological, physical and chemical characterization of contaminated sites often fail in locating NAPL [2].

Geophysical techniques based on mapping a physical property of soil can be a useful tool for a rapid and fairly economic monitoring during site assessment and, even better, during the remediation process. Among these, Electrical Impedance Tomography (EIT) is a promising monitoring tool. As a matter of fact it has been successfully employed to a wide range of problems including chemical process engineering, biomedical, geophysics and environmental applications.

In this paper we will restrict our attention specifically to resistive EIT in which the objective is to determine the three dimensional distribution of conductivity within the body of interest from a series of boundary measurements of either voltage differences between pairs of electrodes placed around the prospected soil or the power dissipated during current injection. This measurement procedure is repeated for various pairs of electrodes injecting current. It can be used to get two (2D) or three (3D) dimensional maps of soil electrical resistivity. It is quite interesting for the spatial and temporal definition of NAPL extent in the subsurface, as they cause drastic change in the electrical conductivity of soil.

Soil EIT requires a measurement system that can be depicted, in its essential lines, as shown in Fig. 1. Sensor displacement does not require any costly working, if compared to other measurement methods, since most sensors are placed on the ground surface, and a single boring is enough to ensure a good mapping of the soil conductivity.

This paper, after a brief description of the tomographic inversion process, describes the architecture, the design specifications of the measuring system for 2D and 3D resistive EIT.
II. THE EIT INVERSION

Under the assumption of inhomogeneous and isotropic soil, the underground conductivity can be described by a 3D scalar function \( \sigma = \sigma(\vec{r}) \) of the underground position vector \( \vec{r} \).

The tomographic inversion technique requires both direct and inverse problem solvers [3,4]. The direct solver is required for finding the solution of the following elliptical partial differential equation:

\[
V \cdot (\sigma V V) = 0
\]

where \( V \) is the scalar potential field subject to the boundary condition imposed by the current injection configurations. The solution of (1) with the prescribed boundary conditions can be thought as the application of a non-linear operator \( F(\cdot) \) (the forward model) to the soil conductivity field:

\[
V(\sigma) = F(\sigma)
\]

By means of numerical finite element solver the operator \( F(\cdot) \) can be approximated by a discrete non-linear operator \( F_D(\cdot) \):

\[
V_D(\sigma) = F_D(\sigma)
\]

where \( V_D \) is the potential at the \( i \)-th mesh node while the elements of the \( N \)-vector \( \sigma \) are the conductivities of the \( N \) mesh finite elements.

The tomographic inversion can be obtained by minimization one of the following two loss functions \( L^I \) and \( L^B_\lambda \):

\[
L^I = |V - F_D(\sigma)|_{\text{max}}^2 + \lambda |\sigma - \sigma_b|_w^2
\]

\[
L^B_\lambda = |P - P_D(\sigma)|_{\text{max}}^2 + \lambda |\sigma - \sigma_b|_w^2
\]

where \( V \) is the \( M \)-vector of measured voltage differences, \( P \) is the \( M \)-vector of measured power dissipated and \( \sigma_b \) is the \( N \)-vector of background conductivity and \( \lambda \) a regularization factor. This approach to the tomographic inversion is mandatory, since the EIT is a well known non-linear ill posed problem and requires special techniques for reducing the effects of uncertainty propagation [3,4,5].

III. THE SYSTEM ARCHITECTURE

Resistive EIT employs surface and subsurface electrode arrays to measure the conductivity distribution in soil. The EIT process is based on an active measurement principle. First of all it requires a system providing current injection at selected electrodes. Secondly it requires a system for measuring the soil "response" to the injected currents. The developed active sensorial unit for EIT is composed by a control unit, one or more injection and measuring units.

RS-232 interface between the realized apparatus and the host PC used for managing the measuring operations;
selection of the two injection electrodes;
selection of the two sensing electrodes;
data conversion and data storage.

Each current injection section and each measuring section are controlled by the control unit. It is shown in Fig. 2; it is based on a microcontroller PIC16F876 device from Microchip [6].

This unit has to control the following operations:

- three lines are used for the selection of the active injection board;
- four lines are utilized for the selection of the active electrodes;
- one line is necessary for selecting the feeder phase;
one line is devoted to selecting the unit (injecting or measuring).

It allows the selection of up to 7 injection/measuring units. Each unit is able to connected up to 16 electrodes.

In order to perform the tomographic inversion based on the measurement of the dissipated power it is necessary to measure the injected current also. The shunt is reported in the previous Fig. 3. The analog section of the data acquisition system for the current measurement is the same as the voltage measurement section (see Fig. 2).

By two different Demux devices, 2 different electrodes are selectable, also if they are connected to different injection unit.

The selecting unit is shown in Fig. 3. The selection of the electrodes is obtained with a control logic similar to that used for the current injection. The selected signals are applied to the data Acquisition Unit (AU) depicted in Fig. 1. The microcontroller unit select the electrodes for voltage/current measurement. The AU first stage is realized by an isolation amplifier (HCPL7800 from Hewlett-Packard). In the following stage a Controlled Gain Amplifier (CGA) processes the signal for analog to digital conversion by a 10 bit ADC (30 Ks/s) interfaced with a memory bank (64KB). The ADC resolution was defined by preliminary on field tests and numerical simulation of EIT. At last the acquired data are read from a Host-PC through a RS-232 link.

**IV. CONCLUSIONS**

In this paper the architecture of an experimental apparatus for EIT of polluted soils is presented. A host PC controls it through a RS232 link. A control unit controls the current injection and the measurement units by a system bus. A reduced prototype of the system has been realized and tested in laboratory and in field.

**REFERENCES**


