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# Miniaturized Sensor Platform for the Determination of Impedance Spectroscopic Parameters in Environmental Monitoring

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**Summary:**

The soil moisture and the hydraulic properties of a soil matrix can only be characterized with considerable effort. Soil moisture is usually measured at specific points using moisture sensors, but a detailed spatial distribution of soil moisture cannot be derived from this. In order to achieve a comprehensive analysis of soil properties in 2D or 3D, a system for electrical impedance spectroscopy (EIS) or electrical impedance tomography (EIT) is presented, which is designed for field use.

**Keywords:** electrical impedance spectroscopy (EIS); electrical impedance tomography (EIT); blue-green infrastructure; sponge city; soil moisture

## Introduction

Decentralized measures based on nature-based system solutions (including blue-green infrastructure) have proven to be essential for adapting to climate change and, in particular, to the intensification of heavy rainfall events, which overload existing sewer systems. These include green roofs, planted surface infiltration, raingardens, or retention area infiltration such as ponds. Increasing sealing in urban areas as well as low water retention capacity in the surrounding landscape elements and increasingly frequent heavy rainfall events lead to an overload of the rainwater and combined sewer system with consequences such as flooding, damage to infrastructure, buildings and people. During normal rainfall events, rainwater is quickly drained away via drainage systems such as canals or ditches and is not available to the local water balance to supply plants and trees, as well as contributing to groundwater recharge. In agricultural areas, heavy rainfall events lead to soil erosion and the entry of pollutants into surface waters and groundwater due to the lack of landscape barriers [1].

So-called decentralized solutions have become established as an adaptation measure, which throttle the inflow towards the sewer, retain water, store it, evaporate it and infiltrate it locally. Various forms of blue-green infrastructure such as green roofs, storage ponds and different types of infiltration systems are used here. This results in a reduction in runoff into the rainwater or combined sewer system, which prevents pluvial flooding due to overloading in the sewer. In addition, this contributes to the storage and use of rainwater for plants and their cooling effect, as well as increasing resilience to drought and heat and renewing groundwater through infiltration on site [2].

The principle of the sponge city is based on effectively absorbing rainwater, storing it, evaporating it and, if necessary, releasing it into the groundwater in a purified state. However, the functionality of the sponge city principle essentially depends on the retentive materials used and their properties in the subsoil. The characterization of the hydraulic properties of these materials can be determined by the soil moisture content. Soil moisture content is an essential index that is suitable for characterizing the water dynamics of the subsoil and its coupling nature with the overlying road conditions in terms of water infiltration, water storage and groundwater recharge, etc. However, due to the spatial heterogeneity of the subsurface and complex influencing factors, it remains a major challenge to map soil moisture content on a field scale in an urban environment.

## Method and Results

Conventional methods for estimating soil water content such as direct sampling and the tensiometer cannot provide large-scale measurements or detailed spatial data on soil moisture. The principle of spatial impedance tomography presented here can provide a 2D or 3D measurement of local soil moisture.

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Electrical impedance spectroscopy (EIS) or electrical impedance tomography (EIT) is a method for analyzing the electrical properties of materials and systems by exciting harmonic electrical signals at different frequencies. The recorded impedance vs. frequency is then related to the physical parameters or properties of materials and systems. Powerful and license-free tools are available for the evaluation of impedance spectroscopic data, such as "Electrical Impedance Tomography and Diffuse Optical Tomography Reconstruction Software" (EIDORS). EIDORS is a software package for image reconstruction in electrical impedance tomography (EIT) and diffuse optical tomography (DOT) [3]. Fig. 1 shows the general structure of the EIS system. Fig. 2 shows the pattern of the connected electrodes.

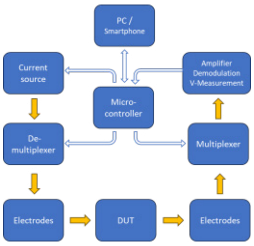


*Fig. 1. Scheme of the EIS system.*

In order to obtain a complete set of measurement data, a defined current ($I_{typ}$=1mA) was fed into the measuring arrangement at 2 electrodes and the voltage was measured between the other electrodes.

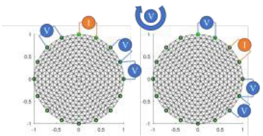

*Fig. 2. Measuring principle.*

This process was cyclically shifted clockwise by one electrode at a time to record a set of 208 measurement data. For the test setup, 16 electrodes with a diameter of $D_E$=4mm were placed in a measuring cylinder with a diameter of $D_C$=15cm. The measurement frequency for all tests was $f_0$=30kHz.

The results of the test setup are shown in Fig. 3. The measuring cylinder was filled with water and a plastic test tube with a diameter of $D_T$=3cm was placed in different positions. As the plastic has a much higher impedance than the liquid used ($H_2O$+NaCl), the position of the plastic tube is shown as an area with very low conductivity and confirms the proof of principle.

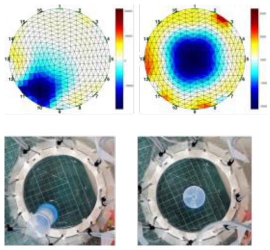

*Fig. 3. Results from first experiments.*

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