Portable Soil Electrical Conductivity Sensor System Based on Electromagnetic Pulsed Eddy Current method

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Abstract: Soil salinization is one of the major environmental geological concerns around the world. The rapid survey of soil conductivity is urgent to reflect the salinization degree in time, while current methods rely on lab-test or electronic probe-based ones, which are not efficient on saving cost and improving efficiency. In this paper, a new electrical conductivity sensor based on electromagnetic pulsed eddy current strategy is proposed to meet the purpose of rapid and efficient survey of soil conductivity. Relevant software was also designed and tested. To facilitate the in-field test, a portable system was constructed.

1. Introduction
Soil is the material basis for agricultural production and human survival, the quality of soil is essential to play its role. Therefore, rapid and accurate detection of soil conductivity to reflect the basic conditions of the soil is of great significance for agricultural production (1-2), which helps promote the development of agricultural activities. The conductivity of soil is a key parameter to indicate the quality of soil. Currently, lab-based tests and electrical probe-based in-field tests are mainstreams, such as the “four-electrode method” developed by Rhoades group in 1971. However, they failed to realize high throughout, continuous and dynamic monitoring.

In 1999, Kitchen group put forward the measurement of soil conductivity by using electromagnetic induction (EM) (3-4). At present, the potential detection method in EM is pulsed eddy current, which has several strengths compared with other detection technologies (4-8). First, the received signal is directly correlated to the magnetic field signal generated by the tested soil as conductor. Secondly, although the received signal is mainly influenced by external sources of interference, such as natural electromagnetic fields and artificial interference sources, the detection sensitivity can be improved by increasing the exciting power or enlarging the emission magnetic moment. Thirdly, different soil characteristics and detection depths are readily be probed by adjusting excitation frequency and exciting power, which makes the detected signal have higher processing significance.

Herein, we propose an electromagnetic pulsed eddy current method and a portable sensor system to meet the purpose of continuous, contactless and in-field detection of soil conductivity.

2. Basic Principle
The basic principle of the proposed method is based on the pulsed eddy current detection strategy. By using two coils, it adopts the pulsed square signal with certain duty cycle as the excitation and loads square signal. In this way, if the excitation at both ends of the coil is instantaneously cut off, a rapidly decaying pulsed magnetic field will be induced, which in turn induces a pulsed eddy current in the
conductor (test piece here). Finally, the pulsed eddy current will induce a decaying secondary magnetic field, which in turn causes a transient induced voltage on the detection coil. If there is a conductivity difference in the tested soil, it will affect the distribution of the pulsed eddy current in the soil. Meanwhile, the variation of induced magnetic field will be influenced by the change of eddy current, eventually leading to a change in the induced voltage on the detection coil. Therefore, the conductivity information in the soil can be obtained by analysing the induced voltage on the detection coil using the following equation.

$$EC_a = \frac{4(H_s / H_p)}{\omega \mu_0 S^2}$$  \hspace{1cm} (1)

where $EC_a$ is soil conductivity, mS/m; $H_s, H_p$ respectively are secondary magnetic field and primary magnetic field, respectively; $\omega=2\pi f$, $f$ is the transmission frequency, Hz; $S$ is the distance between the transmitting terminal and the receiving terminal, m; $\mu_0$ is the conduction coefficient of spatial magnetic field. Based on above equation, the soil conductivity thus can be detected.

3. The Soil Electrical Conductivity Sensor Based on the Pulsed Eddy Current Method

The schematic diagram of sensor is shown in Figure 1. The sensor coils, which is composed of the excitation coil and receiving coil, are placed above the soil sample. The excitation coil excites through the bipolar pulse square current.

According to the principle, the sensor was designed and fabricated. As shown in Figure 2, the sensor has two coils, CPU module, UHF-RF module, BD and GPS module, and a battery. The two coils, which are to emit and receive signals, locate at two ends of the sensor to increase the penetration depth of soil. A battery with an out-put voltage of 3.3 V supply the power of other modules. A power detection circuit was designed to monitor the battery status and send signal to charge if the power is lower than 30% of the initial. The Beidou (BD) and GPS module was designed to collect and send out the position information in the format of longitude and latitude. The UHF-RF module is to realize the half-duplex communication between the sensor and controller. A handle was designed for lifting the sensor.
To facilitate the in-field detection, an industrial computer and 10-inch screen were adopted to work with the sensor accompanying with a portable battery, as shown in Figure 3. When conducting detection in field, the sensor collects and sends out data, while a USB-adaptable HC-12-type remote wireless communication module receives the data in the computer. A portable battery supplies the power of the computer and screen. There are at least two ways to apply the system. The first one is hand-hold type. The battery and computer can be placed around field while the worker holds the sensor to collect data in the field. The second one is set as tractor-adaption type. The sensor can be assembled with tractor while the computer in the cab to control. Due to the unique working way of the proposed sensor system which is contactless, portable and wireless communication, the sensor can work and communicate remotely, as well as be put on tractor to collect data continuously.

Figure 3. The sensor system in field

A software was also written to accompany with the sensor system using C++ programming language. As shown in Figure 4 for the software interface. When the sensor is connected to the computer and is sending data, the software displays the real-time curve and text of the data, as well as the changing ratio and the position data.

Figure 4. The software interface of soil conductivity sensor

4. Conclusions:
Based on the emerging electromagnetic eddy current test strategy, a sensor system was developed to realize continuous, contactless and high throughout detection of soil conductivity. The system is portable and communicate wirelessly, thus it is available for two working ways, hand-hold and tractor-adaption. The system is promising in monitoring soil quality and other applications such as geological prospecting.
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