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Custom modular electromagnetic induction system for shallow electrical conductivity measurements

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Electromagnetic induction (EMI) is a contactless measurement method that offers fast and easy investigations of the shallow electrical conductivity, e.g. on the field-scale. Available frequency domain EMI systems offer multiple fixed transmitter-receiver (Tx-Rx) pairs with Tx-Rx separations between 0.3 and 4.0 m and investigation depths of up to six meters. Here, we present our custom EMI system that consists of modular sensor units that can either be transmitters or receivers, and a backpack containing the data acquisition system. The prototype system is optimized for frequencies between 5 and 30 kHz and Tx-Rx separations between 0.4 and 2.0 m. Each Tx and Rx signal is digitized separately and stored on a notebook computer. The soil conductivity information is determined after the measurements with advanced digital processing of the data using optimized correction and calibration procedures. The system stores the raw data throughout the entire procedure, which offers many advantages: (1) comprehensive accuracy and error analysis as well as the reproducibility of corrections and calibration procedures; (2) easy customizability of the number of Tx-/Rx-units and their arrangement and frequencies; (3) signals from simultaneously working transmitters can be separated within the received data using orthogonal signals, resulting in additional Tx-Rx pairs and maximized soil information; and (4) later improvements in the post-processing algorithms can be applied to old data sets. Exemplary, here we present an innovative setup with two transmitters and five receivers using orthogonal signals yielding ten Tx-Rx pairs. Note that orthogonal signals enable for redundant Tx-Rx pairs that are useful for verification of the transmitter signals and for data stacking. In contrast to commercial systems, only adjustments in the post-processing were necessary to realize such measurement configurations with flexibly combined Tx and Rx modules. The presented system reaches an accuracy of up to 1 mS/m and was also evaluated by surface measurements with the sensor modules mounted to a sled and moved along a bare soil field transect. Measured data were calibrated for quantitative apparent electrical conductivity using reference data at certain calibration locations. Afterwards, data were inverted for electrical conductivity over depth using a multi-layer inversion showing similar conductivity distributions as the reference data.