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Real-time EMI Mapping and Sounding - Equipment and Software

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SUMMARY

The paper is devoted to an approach of rapid frequency induction soundings data collection, processing and visualization. Recently developed equipment NEMFIS implementing electromagnetic induction method is briefly described as well as the software that controls the instrument, collects and process the data. The software was developed for mobile operating system based Pocket PC devices. It manages the NEMFIS via wireless Bluetooth' connection, downloads the data and performs real-time processing and visualization (maps, pseudo-sections and diagrams construction). The measured data are synchronized with the coordinates from GPS receiver, that can be wireless external or the Pocket PC integrated. Comparing the traditional approach of survey with prior layout of measuring grid and data post processing the approach presented here has wider capabilities and significantly higher productivity. The paper includes basic formulas for calculating apparent values of conductivity as well as estimation of the depth of investigation. Brief case history of the developed system is presented in the paper.

Introduction

Nowadays shallow depth electromagnetic induction (EMI) methods are quite popular for many geophysical investigations, particularly for ecological, geotechnical, archaeological and agricultural surveys.

One of the recent equipment implementing EMI method is NEMFIS (Fig. 1, Manstein et al. 2003, Balkov et al. 2007). Being three coil device with fixed geometry it performs soundings within frequency range from 2.5 to 250 kHz and intended to explore the ground conductivity at the depth up to 10 m. Alternating magnetic field is generated consequently on several (up to 14) fixed frequencies that are chosen to be proportional to the skin depth. Receiver coils are arranged in the transmitter plane lying at straight line (Fig. 1) and those are specifically designed to cancel a primary field. Receivers cancel the primary field in the air by obeying the following relation: $M_1/r_1^3 = M_2/r_2^3$, where M_i and r_i– are moments of the receivers and distances to the transmitter.

The NEMFIS device can be controlled wireless by the Pocket PC and synchronized with BlueTooth GPS. The Pocket PC software allows processing and visualizing results during the data acquisition realizing real-time mapping, profiling and constructing pseudo-sections.

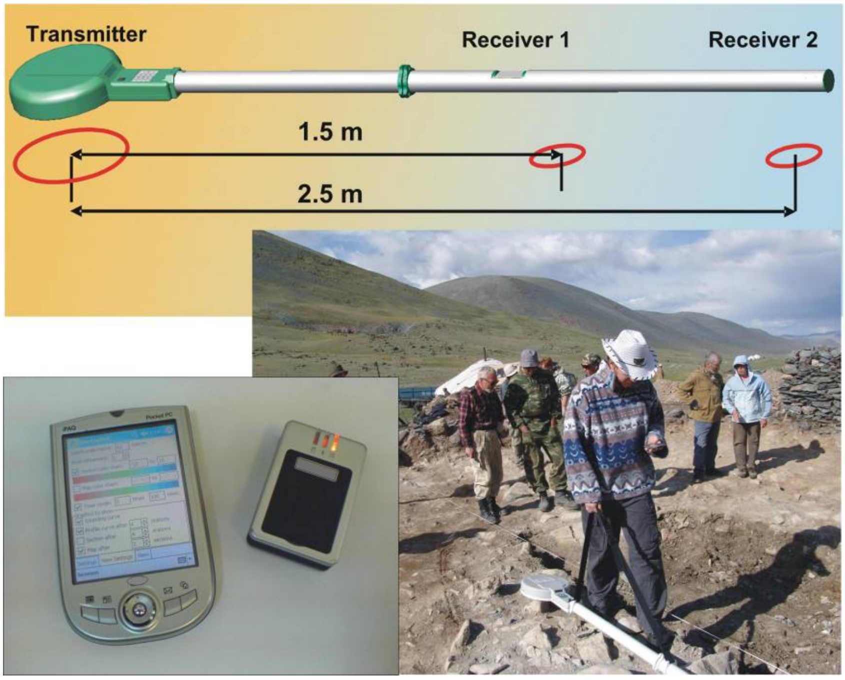

Figure 1: NEMFIS device, Pocket PC controller, Wireless GPS receiver and its field application during burial mound investigation.

Data processing

A model of a homogeneous half space is used to process the NEMFIS soundings. Thus the results of processing are maps of apparent values or pseudo-sections. The solution of the following transcendental equation yields the apparent value of the conductivity (σ):

$$\varepsilon = \varepsilon_1 - \varepsilon_2 = -i\omega\mu \frac{M_T}{2\pi k^2}\left\{\frac{M_1}{r_1^5}\left[9-\left(9+9kr_1+4k^2r_1^2+k^3r_1^3\right)e^{-kr_1}\right]-\right.$$

$$\left.-\frac{M_2}{r_2^5}\left[9-\left(9+9kr_2+4k^2r_2^2+k^3r_2^3\right)e^{-kr_2}\right]\right\},\ k^2 = i\omega\mu_0\sigma,$$

where ε-differential electromagnetic force, measured by device, ω – is the circular frequency, μ_0 – magnetic permeability of the vacuum, M_T – transmitter moment.

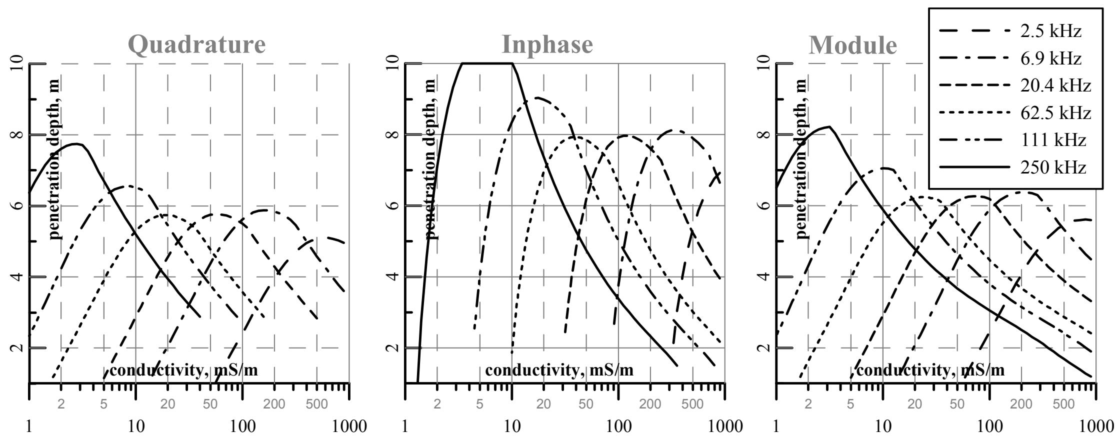

Figure 2: NEMFIS depth of investigation for the relative threshold of 5% and absolute threshold of 1 micro volt under the model of conductive overburden.

The NEMFIS depth of investigation with respect to a number of targets was estimated in Balkov et al. 2006. The fig.2. shows the results obtained under the model of conductive overburden. The diagrams allow to estimate detectable depth of insulating half space and thus the thickness of layer that contains the main part of eddy current induced by the NEMFIS. Diagrams demonstrate the depths obtained for quadrature and inphase response as well as for signal module. Hence the NEMFIS can be used in surveys with the depths about 6-8 m.

Data visualization and GPS synchronization

The Pocket PC platform based software allows controlling NEMFIS device, processing and visualizing its data. The measurements can be made on predefined coordinate grid which is typically prepared by measure tapes or on the chaotic grid in GPS steering mode.

The software has the possibility of real-time data transforming to apparent conductivity or resistivity. To make the transformation faster a low frequency approximation is used. It follows to formulas:

$$\mathrm{Re}(\varepsilon) \approx \frac{\omega^2 \mu_0{}^2}{16}(r_T^2 n_T)\left\{\frac{M_2}{r_2} - \frac{M_1}{r_1}\right\}\sigma,\ \mathrm{Im}(\varepsilon) \approx \frac{\omega^{5/2} \mu_0{}^{5/2}(r_T^2 n_T)}{15\sqrt{2}}(M_2 - M_1)\sigma^{3/2},$$

where r_T and n_T are the radius and the turn number of the transmitter. The range the approximation is valid for is shown at fig. 3a. One can find the minimal value of resistivity at the chosen frequency when the low frequency approximation is valid.

To approximate the data and construct two dimensional charts the bilinear method of interpolation is used. It is one of the simplest and fastest methods. It is important in the case of real time processing at the processors of medium power (typical Pocket PC processors have the frequency of 200-600 MHz).

To reduce the field work time the GPS receiver can be applied for getting current location. Measurements can be made continuously at arbitrary locations (chaotic grid). An external GPS receiver (optionally wireless) or the Pocket PC internal one can be used. The software shows in real time both the maps (sections) of processed signal and the GPS track (fig. 3b). The coordinates can be shown in the global GPS system or the local metric system relating to the first measurement. Non professional GPS receiver usually samples the coordinates once per second. To except not valid coordinates the software performs linear extrapolation of the longitude and latitude of the last points.

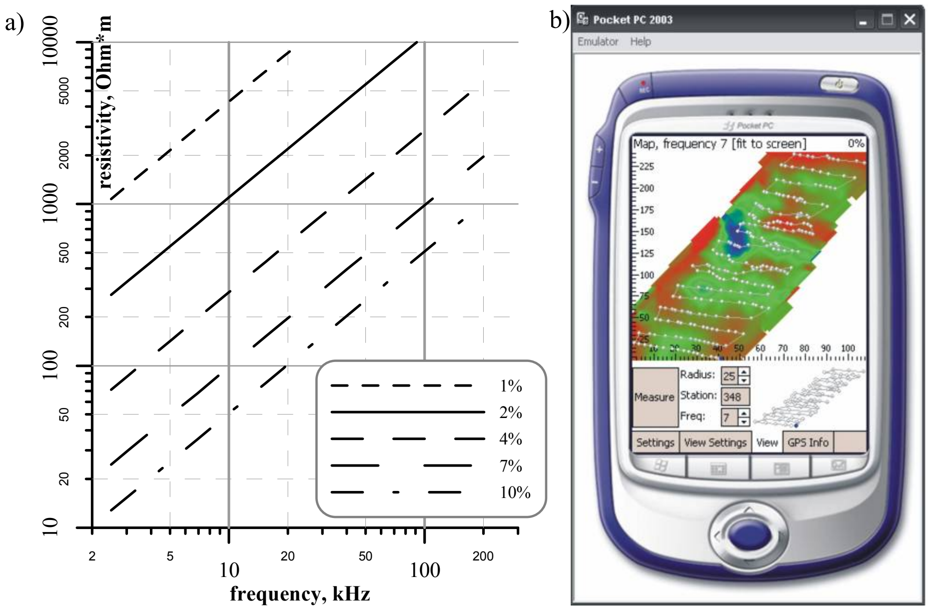

Figure 3: (a) The limits of low frequency approximation. (b) The Pocket PC emulation of real-time mapping using NEMFIS device (apparent resistivity map and GPS track).

Case studies

The first case story shows the result of the field works at the mountain ski resort in the Khanty-Mansiysk city, Russia. This area has complicated natural and artificial relief. The aim was to contour the zones of landslide risk at the part of ski run. The water saturation of the clay overburden by the sand was studied. The areas of high conductivity correspond to the most watered zones and can be interpreted as the risk zones. The fig. 3b shows the information that could be seen by operator during the field data collecting at the Pocket PC controller. It demonstrates the map of apparent resistivity showing that the middle part of studied area has a high resistivity i.e. more dry. The points at the maps show the sounding stations.

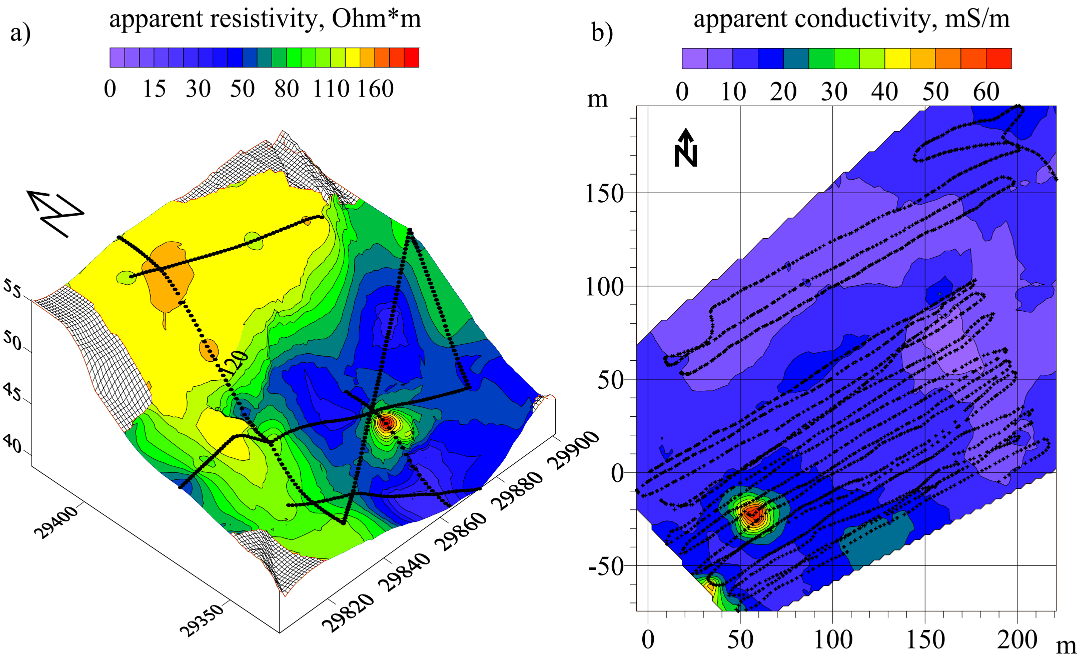

Figure 4: (a) Localization of the landslide risk zones at the ski jump (NEMFIS data at 20 kHz). (b) Distribution of conductivity around the gas flow at the Latera caldera site according to NEMFIS mapping at 40 kHz.

Another object was studied at the same area on linear segments layout. The aim was to contour the subsoil waters concentration. The subsoil water flow damaged the artificial mound of ski jump. A conductive zone that corresponds to the area with the high water saturation was contoured (see the fig. 4a). Geoelectrical results were successfully verified by the drilling.

Another case study shows the results obtained at the caldera site. The Latera caldera is situated near by Bolsano Lake, Lazio, Italy (Lombardi et al. 2008). Deep geothermal drilling in the 1970s showed that thermo-metamorphic reactions in a carbonate reservoir are the source of the $CO2$ (9%) and trace gases that are leaking to the surface. This area is one of the natural analogues of $CO2$ storage. The site is flat pasture of few hectares area. At the places of gas vents vegetation changes can be seen. At the site a wide range of study techniques were tested.

At the beginning of 2006 a number of shallow depth geophysical equipments were applied there. It was electromagnetic frequency soundings – NEMFIS device, electromagnetic profiling – Geonics EM-31 equipment and vertical electrical soundings - Iris Syscal tool. The map at 40 kHz is shown at fig. 4b. It indicates a conductive anomaly that corresponds to major gas vent. Other conductive zones show the configuration of the gas field distribution. The post-process and comparison with other methods showed good quantitative correlation and effectiveness of the Pocket software and the NEMFIS equipment.

Conclusion and Acknowledgements

A lot of successful field works performed by the NEMFIS device shows the effectiveness of its application for a wide range of shallow depth problems. The NEMFIS can be used as an excellent profiler with a number of frequencies to be used. Its data allow to construct pseudo-sections in a wide range of medium resistivity that gives the qualitative information about changing the resistivity with the depth. In the case of conductive medium the NEMFIS data could be inverted to reconstruct the real resistivity distribution.

The application of Pocket PC as a wireless field controller for a real-time GPS steering data collecting, processing and visualization allows to make the device more effective.

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