Rapid Acquisition of Audio Frequency Magnetotellurics

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SUMMARY

We illustrate that rapid acquisition of audio magnetotellurics (RAMT) is an alternative methodology to construct the impedance tensor. A solenoid is used as the magnetic sensor and a capacitively coupled, long wire antenna (LWA) as the electrical sensor. Recent improvements in data quality, automated processing flows and apparent resistivity to depth transforms resulted in a cost effective and practical alternative for quickly acquiring audio magnetotelluric 1D soundings. Case studies for groundwater, engineering and mining illustrate how the method may be useful for decision making, and hopefully enable more widespread adoption of low cost resistivity measurements.

Key words: Audio Frequency, Magnetotellurics, RAMT.

INTRODUCTION

Electrical resistivity is a property of the shallow earth that influences decisions within the largest range of industries including mining exploration, engineering and groundwater management. The ability to acquire, process and interpret resistivity measurements is achieved through a variety of geophysical methodologies that range from active-source airborne and ground electromagnetic and resistivity techniques to the passive techniques of magnetotellurics (MT). The necessary field equipment and survey configurations for active source methods require multiple people, with support vehicles in some instances for generators, putting the cost of providing resistivity measurements above the threshold of many that would get significant value from using geophysics.

The electromagnetic radiation from worldwide thunderstorm activity propagates large distance in the earth – ionosphere waveguide, and, with a small contribution from ionospheric activity, provides a natural energy source for probing the earth. At great distances, the EM fields generated by lightning strikes behave like plane waves and can be used to provide surface impedance measurements that are in turn used to determine the conductivity profile of the earth. Audio frequency magnetotellurics (AMT) is an electromagnetic sounding technique that uses this natural radiation in the 10Hz to 20kHz frequency range to gather surface impedance measurements for resistivity sounding. The electric and magnetic fields are recorded as time series and then processed to construct the impedance tensor element Z_{xy} and the apparent resistivity ρ_a and phase Φ as functions of frequency $\omega=2\pi f$,

$$Z_{xy}(\omega)=\frac{E_x(\omega)}{H_y(\omega)}\rho_a(\omega)=\frac{1}{\mu_0\omega}\left|Z_{xy}\right|^2\varphi(\omega)=\arg(Z_{xy})$$

which are the basis for an interpretation of the earth in terms of layers of different electrical resistivities (1D interpretation). Although logistical requirements are much less than for active source methods, the AMT technique is not widely used in practice as it is relatively slow to acquire and is susceptible to signal distortions due to current channelling at frequencies below the frequency range of the measurement, usually called 'static shifts' (Jones, 1988; Sternberg et al, 1988, Tipaldi et al, 2010).

Kepic (1995) found that by using a capacitively coupled, insulated long wire antenna (LWA) for the electric field sensor instead of a traditional grounded electric dipole, AMT data could be acquired with an orthogonal magnetic sensor. The LWA used was a 30 metre length of cable containing two insulated electrical wires with a 2 cm section removed from one of the wires. This LWA is capacitively coupled to the Earth instead of the galvanic coupling of the electrical dipole's metal stakes. This distinction has several interesting aspects:

- It allows for a higher mobility of the AMT system as direct contact with the ground is no longer necessary.
- The capacitive coupling suppresses low frequency signals so any static shift problems would be drastically reduced if not removed altogether.
- Wu and Thiel (1989) postulated that an insulated antenna is a better electrical field probe for surface impedance investigations in the AMT frequency range than a staked dipole antenna.

Cameron (2002) showed that the rapid acquisition of AMT (RAMT) is a viable technique for acquiring the surface impedance for 1D interpretation. The initial RAMT sensor was connected through a basic anti-alias filter to the analogue to digital converter inside a laptop through the 3.5mm stereo input jack. This original system was a step in the right direction of a low cost geo-electric alternative but it had a poor signal to noise ratio and poor low frequency signal preservation. Further developments of RAMT hardware, processing, and interpretation have resulted in a field-ready system with improved signal to noise ratio and bandwidth, and with streamlined processing and interpretation tools.

METHOD AND RESULTS

The RAMT system incorporates a machine-built circuit board design for the analogue front-end and an iPhone with digital lightning jack and solid state memory as the recording platform. The useable frequency range is 500 Hz to 20 kHz. The magnetic field sensor has a 1/f characteristic and the electric field is measured with a 30 m long capacitively coupled antenna. The automated processing flow includes spike rejection, windowed Fourier transform with frequency domain averaging, calculation of apparent resistivity and phase, and resistivity – depth transforms based on Schmucker (1973) and Bostick (1977) for a first-look interpretation. A single operator of the RAMT system can acquire a 1D sounding within 2 minutes and process this sounding within 10 minutes to show the results along with a series of quality control plots. Further routines have been written to enable easier interpretation of the AMT data through integration with Google Earth and output into formatted CSV files for loading into 3D visualisation programs.

By upgrading the acquisition platform from a large laptop that interfered with the recordings to the solid state device of an iPhone along with recording via a digital connector (lightning jack) and custom built App, the raw audio data recorded is of significantly higher quality, with lower signal to noise, than was achievable with the original design outlined in Cameron (2002). The acquisition rates can be adjusted within the App as well as visualising the location for the station in a Google Earth presentation enabled by the GPS integrated in the iPhone (Figure 1). The iPhone therefore is a very small and high quality electronic device capable of recording 32GB worth of data as well as acting as the navigational instrument to move from one station to the next.

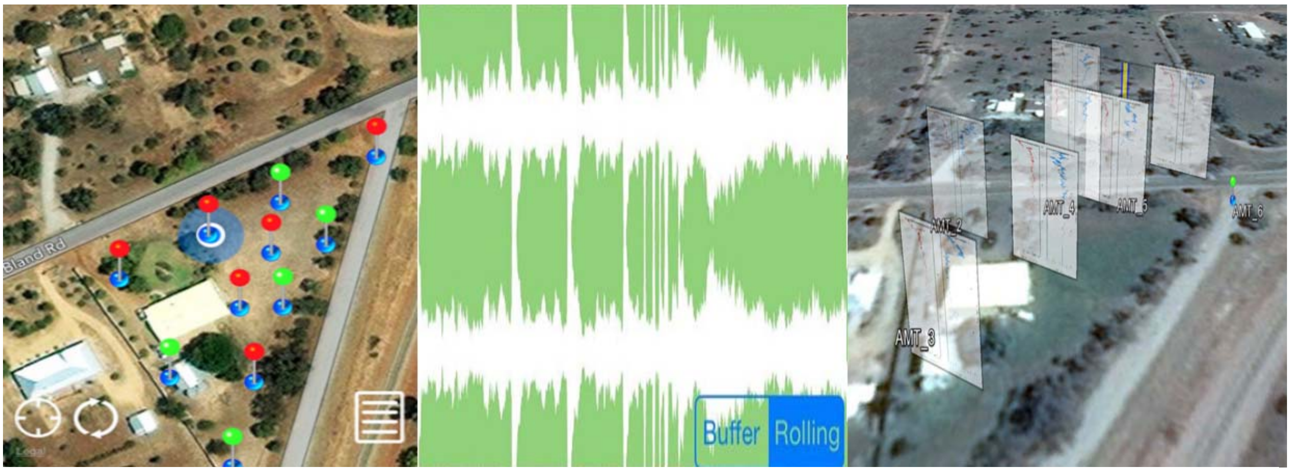

Figure 1: Acquisition of AMT data enabled through iPhone App to visualise survey stations (left) and channel data (centre) along with PC-based Google Earth image presentation of maps of apparent resistivity and phase measurements (right).

RAMT surveys can be designed as a series of 1D sounding stations, a 2D traverse (Figure 2) or a grid of stations to be able to visualise the results of apparent resistivity in a 3D model (Figure 4). The raw data can be uploaded to cloud based processing for quick turnaround within 10 minutes per station. By outputting the apparent resistivity data vs depth for each station as a CSV file, the processed AMT data can be loaded into 3D visualisation software as 'drill holes' and then interpolation can be performed in 3D to generated isosurfaces of constant resistivity. These workflows have been very effective for quickly surveying an area and determining the subsurface resistivity and then presenting the results via Google Earth imagery (Figure 1) or in deeper details with resistivity ranges of interest highlighted. Figure 3 illustrates a ground water sounding where the majority of the resistivity profile is not within the blue box suggesting the absence of a deeper groundwater source at this location. More examples will be shown at the conference.

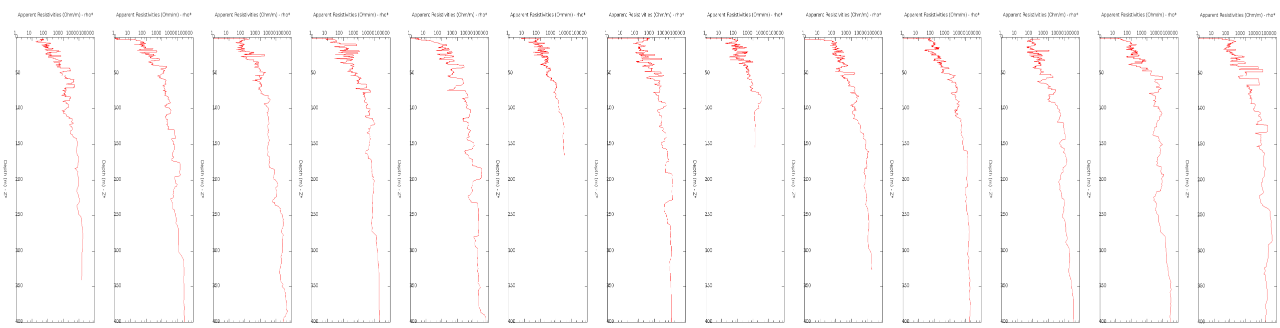

Figure 2: Presentation of multiple AMT apparent resistivity versus depth curves across an RAMT Traverse.

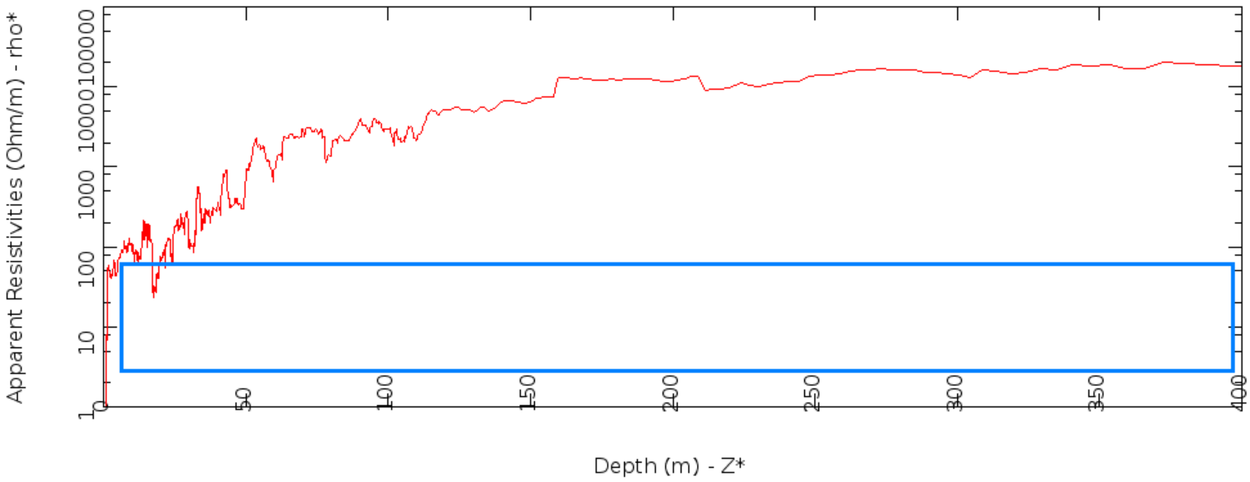

Figure 3: Plot of Rho* versus Z* (Schmucker, 1973) with blue box highlighting resistivities associated with groundwater acquifers.

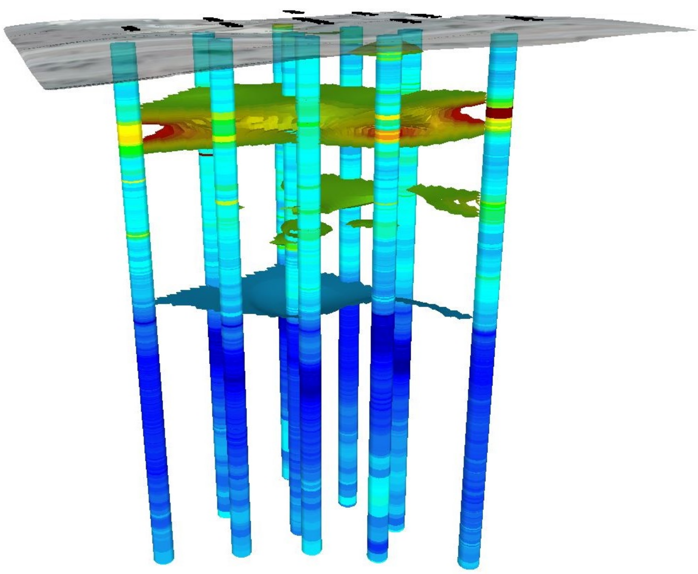

Figure 4: Geological 3D model illustrating multiple AMT 1D soundings loaded to look like drill holes from the surface allowing for 3D interpolation to generate isosurfaces of resistivity for interpretation.

CONCLUSIONS

The methodology and sensor design set out by Cameron (2002) has been improved with the redesign of the sensor resulting in improved signal to noise ratio and low frequency signal preservation. A more robust processing flow includes basic apparent resistivity versus depth transforms and cloud based online processing. The overall result is a cost effective alternative to traditional AMT soundings for layered earth (1D). Extensions to full tensor measurement and inversion processing are under development.

Case studies show the applicability of the RAMT system in groundwater, engineering and mineral exploration settings.

By providing the acquisition software as an App for an iPhone and access to cloud-based processing and interpretation, the RAMT system will hopefully contribute to more widespread adoption of resistivity measurements than is currently the case with passive EM methods.

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