Data processing of full waveform time domain IP data

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Introduction

Recently, it is possible to receive full waveform TD-IP data, for example with the ABEM Terrameter LS. The full received voltage-decay curve can be used for a Cole-Cole based inversion of the TD-IP data. Such an inversion program called *IP3DInv* was developed at the University of Cologne by Langenbach (2017)[1].

The received signal due to the IP response of the subsurface is superimposed by drift, spikes, harmonic and random noise. In Figure 2 you see the received voltage in blue against the time, the red curve represents the induced voltage.

$$\mathrm{U}_{measured} = U_{response} + U_{drift} + U_{harmonic} + U_{random}$$

Those effects disturb the data quality of the timeseries and reduce the usable range of the resulting transient. In the following the pre-processing of TD-IP data is described which bases on a LOTEM processing scheme after Helwig (2000) and Scholl (2001).

Data acquisition

In 2012, 14 time domain IP profiles of a length of 100 m were measured with the ABEM Terrameter LS in Krauthausen, Germany. A gradient array was chosen with an electrode spacing of 2.5 m, the cables for the receiver and transmitter electrodes were separated to avoid capacitive coupling[2] (see Fig. 1). In total for over 200 electrode combinations per profile timeseries were received, each consisting of 7 to 11 transients (see Fig. 2, rawdata).

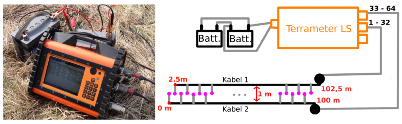

Fig. 1: Left: Photo of the Terrameter LS and two batteries. Right: Field setup consisting of two batteries, two multicore cables and 41 electrodes which are connected with the multicore cable by jumper cable.[1]

Pre- processing scheme

Normalization

The inversion is done by the program *IP3DInv* which acts on the assumption of an induced current of 1 A. Therefore the received voltage has to be normalized by the current. A stable current function justify this procedure.

Despiking

Spikes can be caused by the current switches and by disturbances as electric vences. The first one is eliminated by neglecting the first 8 timepoints after the current switch off. Other outliner can be detected by the ratio to its neighbouring points.

The deviation from the average value of the last and coming 10 timepoints should not be higher than 250% , otherwise the outliner is replaced by the averaged value.

Reduction of harmonic noise

Main source of the harmonic noise is the railway ($\mathrm{f}_2 = 16\frac{2}{3}$ Hz) and the power line ($\mathrm{f}_1 = 50\,$Hz). These frequencies can be determined by a fast Fourier Transformation (FFT). The filter for the harmonic noise reduction after a switching off can be described by the equation below:

$$\Delta V(t) = \begin{cases} \frac{1}{n}\sum_{k=-(n-1)/2}^{(n-1)/2} \Delta V(t-k) & |(n+\frac{n+1}{2}) < t < (T_{f1}+1+n) \\ \frac{(\Delta V(t)+\Delta V(t-T_{f1}))+(\Delta V(t)+\Delta V(t+T_{f1}))}{2} & |(T_{f1}+n) < t < (T_{f2}+1+n) \\ \frac{(\Delta V(t)+\Delta V(t-T_{f2}))+(\Delta V(t)+\Delta V(t+T_{f2}))}{2} & |(T_{f2}+n) < t \end{cases}$$

$\mathrm{T}_{f_1} = 10$ ms and $\mathrm{T}_{f_2} = 30$ ms are half-periods of the disturbance frequencies f_1 and f_2 which have the form of a sinus curve. The filter acts like a moving average. By the addition of the potential differences $\Delta V(t)$ and $\Delta V(t+T_{f_1})$the disturbance frequency is eliminated but the value is shifted over a half period in the positive t-direction, therefore $\Delta V(t-T_{f_1})$ has to be taken into account as well. The time shift can be prevented by the calculation of the mean of both.

The implemented harmonic noise filter contains a case distinction for the area of the next switching on signal. It is implemented analog to the equation above.
The harmonic noise filtered data you can see in Figure 3 in blue, voltage against time.

Linear trend removal

The timeseries can be superimposed by low-frequent noise. As first approximation it can be reduced by a linear drift removal.[3]

$$\Delta V(t) = \Delta V(t) - y(t)$$

For the calculation of the linear trend y(t) the potential difference of the first and fifth transient are used for the linear fitting. The result of the linear trend removal can be seen in Figure 3, red curve (voltage against time).

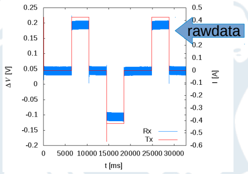

Fig. 2: Measured voltage (blue) against time, current in red [1]

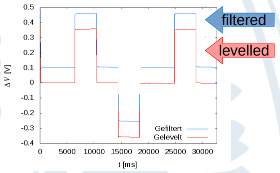

Fig. 3: Voltage against time, blue: harmonic noise reduced data, red: levelled data [1]

Cutting and Stacking

Single transients are cutted from the timeseries and calculated as switching on transients (see Fig. 4). This is done by mirroring and shifting of the current function. Transients with a non-reasonable behaviour are detected and removed automatically.
Every single transient $\Delta V_n(t)$ which should be used for the stacking can be chosen manually or automatically. Afterwards the arithmetic average $\Delta V(t)$ and the standard deviation $\epsilon(t)$ are calculated.

$$\Delta V(t) = \frac{1}{m}\sum_n \Delta V_n(t)$$

$$\epsilon(t) = \sqrt{\frac{1}{m}\sum_{n=1}^{m}(\Delta V_n(t) - \Delta V(t))^2}$$

with *m*: number of transients

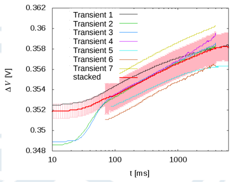

Fig. 4: Voltage against time: single transients (multicolor) and stacked one (red), standard deviation in bright red [1]

Conclusions

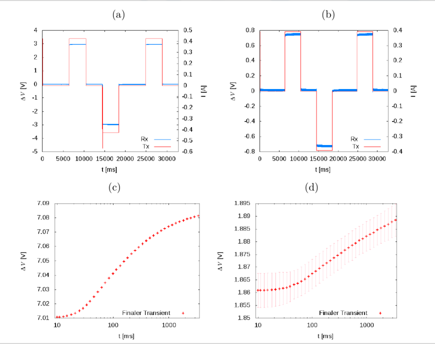

Fig. 5: Measured voltage in blue, current function in red for two electrode combinations shown in (a) and (b). In (c) and (d) the processed transients (red dots) and calculated standard deviation (bright red errorbars) of all timepoints for the measured voltage showen in (a) and (b) are plotted. The timeseries of the second electrode combination is noisier than the data from the first one.[1]

The quality of the resulting transients is adequate enough for the requirements of the inversion program *IP3DInv*, even for data with a high noise level, the weighting of the data is determined by the standard deviation.
For instance, two processed transients are presented in Figure 5. In Fig. 5 (a) a timeseries with a low noise level is shown, the resulting transient is imaged in Figure5 (c). It has an insignificant low standard deviation. Contrastly, the transient of a timeseries with an ordinary noise level (Fig. 5 (b)) has a much larger standard deviation (Fig. 5 (d)) but a comparable trend as the transient of a timeseries with a low noise level.

References:

[1]: Langenbach, H. (2017). Anwendung des neu entwickelten 3D Zeitbereichs-Inversionsalgorithmus IP3DInv für die Induzierte Polarisation auf Messdaten aus Krauthausen, Deutschland. PhD thesis, University of Cologne.
[2]: Dahlin, T. and Leroux, V. (2012). Improvement in time-domain induced polarization data quality with multi-electrode systems by separating current and potential cables. Near Surface Geophysics, (10):545–565.
[3]: Dahlin et al. (2002). Measuring techniques in induced polarisation imaging. Journal of Applied Geophysics, (50):279–298.