Powerline harmonic noise in MRS data cancellation by sinusoidal subtraction An efficient solution to cancel powerline interferences

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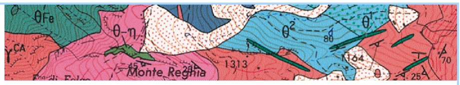

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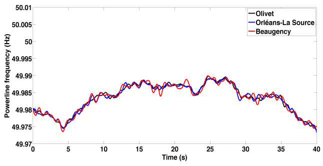
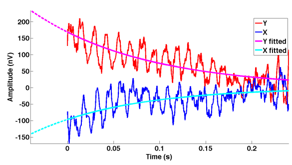
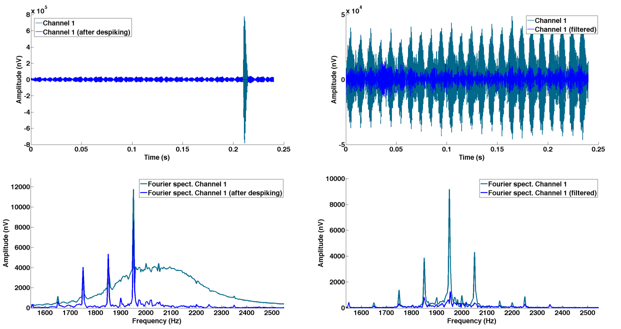
The surface magnetic resonance method (SNMR) is a valuable technique for hydrogeological studies, since it provides information on the porosity, hydraulic conductivity and water content. However the bad signal-to-noise ratio often encountered limits its application range. In particular, in suburban areas, strong powerline harmonics severely degrade the SNMR signals.
The powerline fundamental frequency is subject to small variations in time that make high order harmonics filtering difficult using a classical notch filter without distorting the MRS signal. Harmonics cancellation using sinusoidal subtraction is an alternative, but requires a high accuracy of the instantaneous fundamental frequency value to be efficient. The power grid frequency being regulated we expect that the instantaneous frequency could be monitored with a good S/N ratio using a remote frequencemeter, synchronised with the SNMR device, and later used for processing. Based on this accurate instantaneous frequency measurement we developed a processing method based on the subtraction of a powerline harmonics model of constant amplitudes. We performed numerical experiments to quantify the efficiency of this method, and compare it with classical notch or multi-channel filtering.
Studying real noise measurements, we encountered cases where harmonics amplitudes do not remains stable over time. We therefore proposed a processing method that include time-variant amplitudes in the powerline harmonics model. Amplitudes are modeled using a b-spline decomposition and estimated through an inversion procedure. A test on synthetic data is presented to assess the theoretical applicability of the method.



Fundamental powerline frequency synchronously measured in three locations (at the regional scale: ~30km distance).



Exemple of four parameters non-linear fitting after synchronous spikes detection (SNR=0.59).



Time-serie and spectrum before/after despiking (left) and before/after sinusoidal subtraction (right): the channel 1 signal is made of a synthetic signal embedded in real noise measurements. The synthetic signal takes the form: $MRS(t) = E_0 \cos(2\pi f_0 .t + \phi).\exp(-t/T_2^*)$.

a)

	$E_0(nV)$	$T_2^*(ms)$	$f_0(Hz)$	$\phi(rad)$	SNR
Model	300	120	2045.1	2	
Pure stacking	314.1	112.3	2045.20	1.91	0.79300
Despiking	289.4	120.1	2045.07	2.04	0.97105
Despiking + Notch	170.1	120.2	2044.09	2.65	0.98192
Multichannel filter	264.2	121.5	2044.96	2.09	0.99555
Despiking + Multichannel filter	254.4	124.4	2044.95	2.10	0.97105
Despiking + Sinusoidal sub.	267.8	127.1	2045.07	2.02	0.98811

b)

	$E_0(nV)$	$T_2^*(ms)$	$f_0(Hz)$	$\phi(rad)$	SNR
Model	300	120	2045.1	2	
Pure stacking	415.1	81.9	2045.44	1.67	0.11473
Despiking	325.8	106.4	2044.95	2.15	0.59466
Despiking + Notch	199.4	108.9	2044.09	2.63	0.77353
Multichannel filter	266.5	121.3	2044.92	2.11	0.11473
Despiking + Multichannel filter	274.1	117.0	2044.91	2.11	0.59466
Despiking + Sinusoidal sub.	276.1	123.9	2045.04	2.03	0.72472

c)

	$E_0(nV)$	$T_2^*(ms)$	$f_0(Hz)$	$\phi(rad)$	SNR
Model	300	120	2045.1	2	
Pure stacking	678.6	5000000000.0	2038.29	3.14	0.00500
Despiking	254.5	381.1	2051.87	0.05	0.05643
Despiking + Notch	395.3	63.8	2043.69	2.81	0.13366
Multichannel filter	264.6	117.0	2044.62	2.27	0.00500
Despiking + Multichannel filter	361.5	91.3	2044.52	2.31	0.05643
Despiking + Sinusoidal sub.	301.4	117.2	2044.84	2.11	0.09182

Comparison of synthetic signal parameters retrieval: the signal is made of a synthetic signal embedded in real noise measurements. 499 stacks are used. The same noise measurements are used for the three cases with different noise amplification. a) amplification=1; b) amplification=5; c) amplification=25. Noise was measured using ADU-07 RMT stations (Metronix) at a noisy site in Lailly en Val (45). The case c) exhibit mean signal amplitudes two time stronger than those recorded at the same site with a Numis poly (Iris Instrument) using a 37.5m, 2 turns square loop. The post-processing signal to noise ration estimates is estimated as follows: $SNR = \sum_k MRS(k)^2 / \sum_k (S(k) - MRS(k))^2$.

Harmonic model sinusoidal subtraction

The signal recorded in the reception channel can be described by the model:

$$S(t) = MRS(t) + H(t) + spikes(t) + N(t)$$

The powerline interference component of this model takes the abusive form:

$$H(t) = \sum_m h_m(t) = \sum_m A_m \cos(2\pi m f_f .t + \phi_m)$$, where f_f is the powerline instantaneous frequency.

After spikes removal, using the measured powerline frequency, phase and amplitudes of each harmonic is determined using the cross correlation with a reference sinusoid at the harmonic frequency. The complete harmonic model is later reconstructed as follows:

$$H(t) = \sum_m A_m \cos(2\pi m f_f(0).t + \phi_m + \Delta\phi_m(t))$$, with $\Delta\phi_m(t) = \int_0^t 2\pi m \frac{f_f(u)}{f_s} du$ the phase delay due to the fundamental frequency variation. The harmonic model *H(t)* is further subtracted to the signal *S(t)*, and the remaining noise can be cancelled by a multichannel filter and/or a stacking procedure.

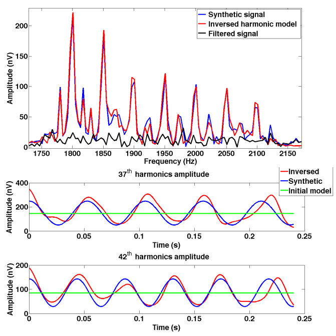
Inversion method to fit time-variant amplitudes

In order to find a better solution for the case of harmonic amplitudes significantly changing over a stack length, we define a new harmonic model:

$$H^*(t) = \sum_m A_m(t) \cos(2\pi m f_f .t + \phi_m)$$, where $A_m(t) = \sum_n a_n B_n^{\kappa,k}(t)$.

Each harmonic amplitude is defined as a linear combination of n b-splines functions. The $m \times n$ parameters a can be estimated solving a linear inverse problem. This problem consists in minimizing the following cost function:

$$\Phi = \tfrac{1}{2}\|S - H\|^2 + \tfrac{1}{2}\beta\|Cp\|^2 + \tfrac{1}{2}\gamma\|I(p - p_0)\|^2$$, where p are logarithmic parameters, C a smoothing operator and I a damping operator.



Synthetic test:

The synthetic signal is composed of 7 high powerline harmonics with an additive white noise (maximum amplitude=1000nV). Harmonic amplitudes are inverted using a 49 b-splines basis.

An efficient solution to cancel powerline interferences

> Measurements of the fundamental powerline frequency is the key for a good sinusoidal subtraction

- Signal parameters are better recovered even with a high noise level
- Time variant harmonics amplitude inversion is promising
- Performance of filtering combination strategies remains to be evaluated on a large site database

> GPS synchronisation of SNMR devices would allow direct application of this metod

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