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Surface NMR Processing and Inversion – I: Noise cancellation

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SUMMARY

I present a method of cancellation of power line and other noise in the surface NMR experiment. The method presented here allows a user to determine the frequency and amplitude of power line noise, and the resulting harmonics, in order to remove the noise from the desired signal. This process, which obviates the use of reference loops, offers similar noise cancellation to that routinely used in modern practice.

Key words: Surface NMR, groundwater, noise cancellation, power line noise.

INTRODUCTION

One of the main features of signal processing in surface nuclear magnetic resonance (SNMR) is the need to eliminate or reduce the effects of power line, sferics, and anthropogenic noise from the desired signal (Dalgaard et al., 2012). Traditionally, this necessitates the use of one or more reference coils that are placed in the vicinity, but not too close to, the main transmission loop used in the sounding. The general rule of thumb for the use of reference loops conducted is to have the noise-detection coil(s) be placed about 3 loop-diameters away from the main loop. In the case of a 75 m loop, this means that at least 450 m of wire must be placed in the direction of the prevalent noise source, with an additional amount laid out in order to obtain a reference signal that is of similar magnitude to the noise found in the main loop. Noise cancellation with remote loops is typically completed with a transfer function that correlates signal in the main loop with signal in the reference loop (eg, Mueller-Petke and Yaramanci, 2011).

In this paper, I propose a novel method of signal detection that can be used to detect and remove noise signals from the main loop itself without the need for additional coils in the field setup. I show that this new method is capable of reproducing SNMR signals that are on par with current practice (eg, Walsh, 2008): and that sometimes yield improved results. This is demonstrated with some SNMR recordings from Australia.

METHOD AND RESULTS

All soundings presented in this paper were conducted with the Vista-Clara GMR surface nuclear magnetic resonance device (Walsh, 2008).

The method proposed here is based on the use of probability theory as extended logic (see Gregory, 2010). This method allows the user to pose the question: ‘What is the most likely frequency and amplitude of power line noise in my data sample?’ The answer is given by a posterior examination of the fitting parameters, based on logic. We begin by proposing a base frequency for the power line signals. In the cases presented here, we take 50 Hz as the prior power line frequency. A basis set of data is then proposed as the signal of interest; and it is created from a cosine and sine of the power line signal under investigation. By maximising the likelihood of the signal given the data, the frequency and amplitude of the base power line signal is reproduced. In the examples shown here, I use the first 20 harmonics of a 25 Hz signal as a prior. This is to allow for other contributions of signal than the 50 Hz commonly encountered.

Figure 1(a) shows the time-series recording from a noisy SNMR sounding experiment conducted in East Timor. The main excitation loop was placed less than 500 m from a high-tension power line that transfers power to the township of Baucau. Panel (b) shows the estimated power line signal from the most likely power line frequency. All harmonics (from a prior of 25 Hz) up to 3900 Hz are estimated, for a total of 156 harmonics. Panel (c) shows the resulting SNMR sounding time-series. The RMS of the original signal is 132 µV, while the RMS of the derived signal is 23.6 µV, resulting in a noise reduction of about 5.6. Figure 2 shows the amplitude (a) and phase (b) of each contributing harmonic to the power line estimation.

This process is repeated for each individual record in the total sounding experiment and, in every case, the base frequency, amplitude and phase of each power line signal is estimated. Figure 3 (a) shows the amplitude of power line signal for every individual record of the SNMR experiment, while panel (b) shows the distribution of base frequency during the recording.

In addition to a complete estimation of power line signal for the noisy example data shown above, I also present a case where the noise contribution is marginal or intermittent. Figure 4 shows an example of a clean example of SNMR data, taken from an experiment in North Queensland. In panel (a), we see the time series of the recorded signal (black), as well as the estimation of the power line signal present in the data. Clearly, this is clean data! Panel (b) shows the amplitude of each contributory power line harmonic. The most powerful signal for this record is estimated at only about 25 nV at 50 Hz. There is slight contribution at higher harmonics.

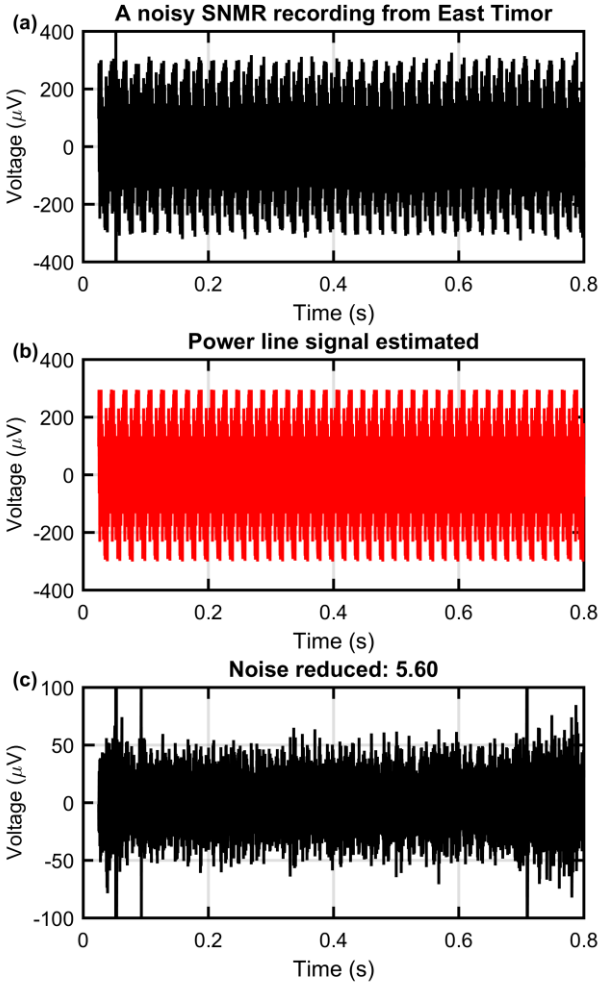

Figure 1: (a) An example of the time-series from a noisy SNMR sounding. (b) Estimation of the power line contribution of the signal. (c) Reduced signal obtained from removing power line noise. This results in an increase of the remaining signal by a factor of 5.6.

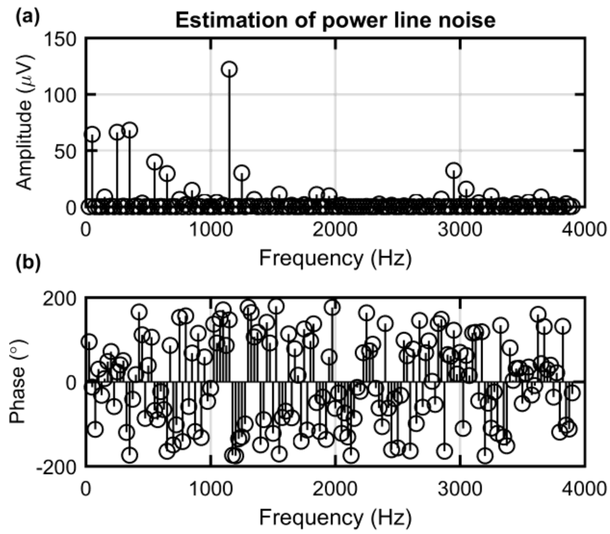

Figure 2: Amplitude (a) and phase (b) of each contributing power line signal to the SNMR time-series.

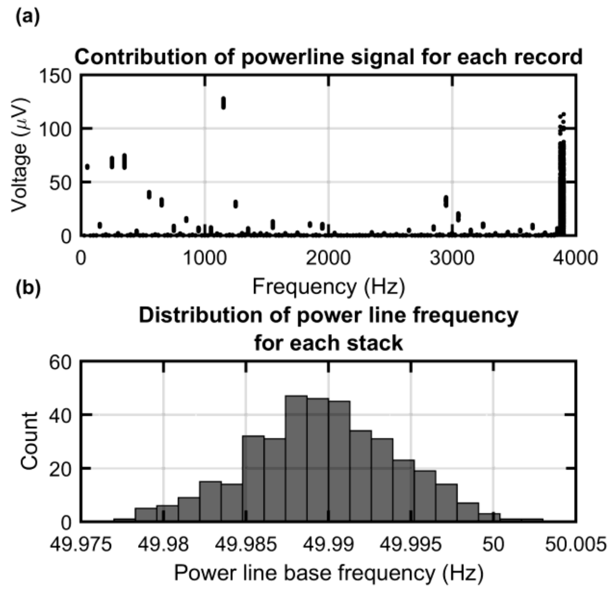

Figure 3: (a) Amplitude of power line noise removed from all records in the SNMR experiment. (b) Distribution of power line base frequency for all records in the experiment.

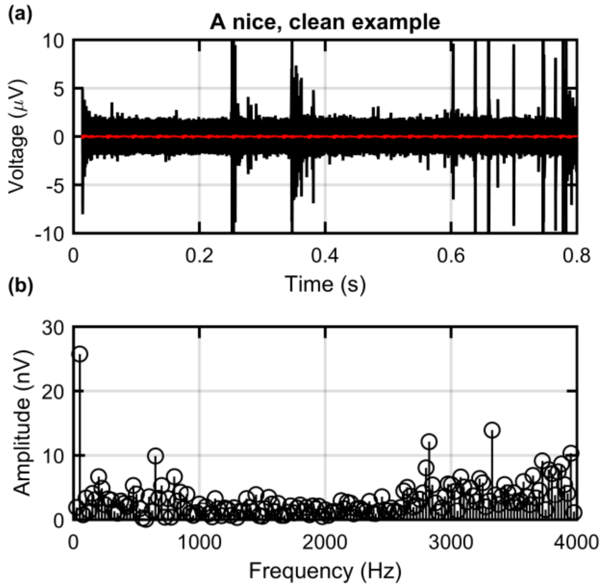

Figure 4: (a) SNMR time-series from a noise-limited area in North Queensland. Black trace shows the recorded signal, and the red trace shows the power line estimation. (b) Amplitude of power line noise present in the data. Most of the energy comes from the 25 nV signal at 50 Hz.

In many of my field studies, I have followed the practice of deploying the transmit loop, taking a few readings, and examining the data for power line noise. If there is a lot of noise present, I would deploy a noise reference coil. In a case such as shown in Figure 4, I would have made the judgement call that no noise coil is necessary and continued with the reading. However, Figure 5 shows that there is power line signal present in the experiment: it must have been from a generator turned on somewhere in the distance.

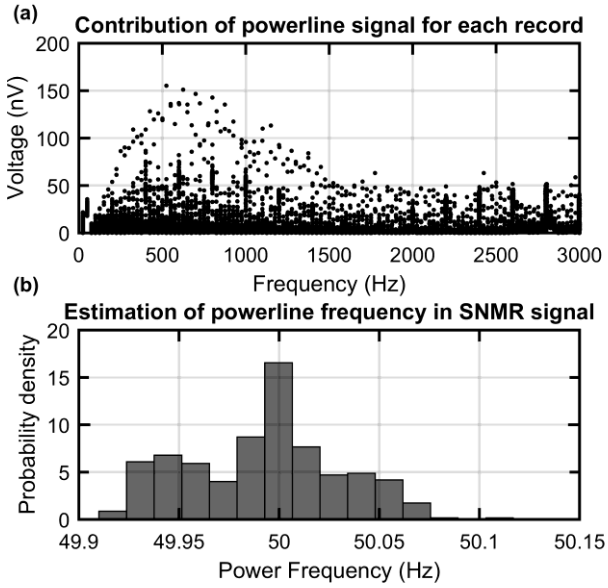

Figure 5: (a) Contribution of power line signal for each record. Signal can get up to 150 nV contribution for a single frequency. (b) Estimated frequency of the base power line signal.

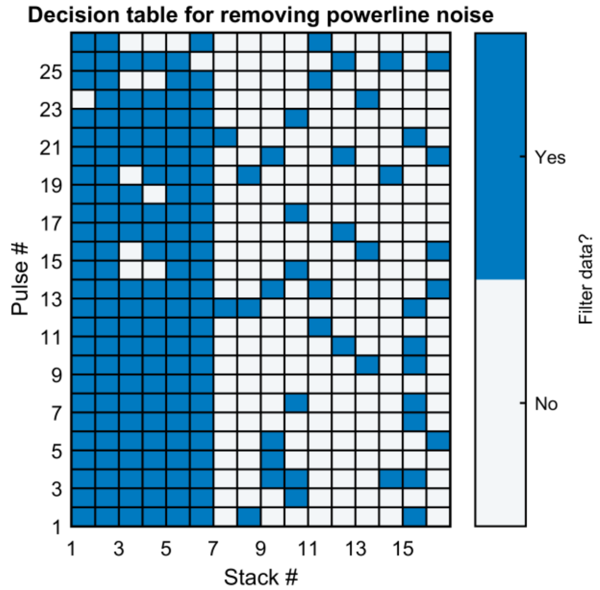

Figure 6: A decision table used to reference the removal of power line signal from each individual time record.

Since the method follows the principles of probability as logic, we can easily ask a follow-up question to our previous postulate: 'Is the most likely power line signal more likely than, say, a constant offset in the data?' If the answer is no, then power line removal is unnecessary. Figure 6 shows the results of following this line of reasoning for the North Queensland data set. In this figure, blue squares mark where the power line signal estimate is going to be useful in explaining some of the data. White squares are where it is not necessary. It looks like the remote power source was removed by stack 7. As a final demonstration, we show the stacked, averaged, power-filtered and band limited data from this experiment. Panel (a) of figure 7 shows the resulting stack from pulse-moment 2 using the processing technique presented here, while panel (b) shows the same stack resulting from commercial processing software. Both traces use the entire range of records in the stacking, and are band limited to ±200 Hz of the transmit frequency. It is evident that the signal in panel (a) shows greater reduction of power line signal, as well as a cleaner recording of the desired SNMR signal. It should be noted here that the time-series in panel (a) also completely preserves the completed time-series: there is no reduction in data density. This will become very important in the next step of signal processing which involves the detection of SNMR signals.

CONCLUSIONS

In this paper, I have shown that it is possible to estimate and remove much of the contribution from power line noise in an SNMR experiment through the use of extended logic. In all cases, the reduction of power line noise is done without the use of noise reference coils in the field and is estimated from the time-series data recorded in the primary loop. This technique demonstrates that noise reduction is possible in high- and low-noise conditions and that is possible to improve the resulting SNMR signal substantially.

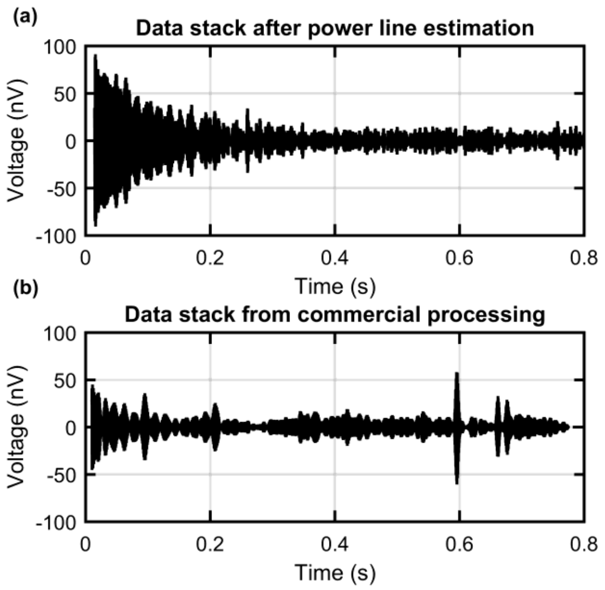

Figure 7: (a) Stacked time-series of SNMR experiment for pulse moment 2 using the method presented in this paper. (b) Same time series using a commercial method of signal stacking.

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