LIFT: A New and Practical Approach to Noise and Multiple Attenuation

Jason Choo, Jon Downton, Jan Dewar, Core Lab Reservoir Technologies Division, Calgary

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A New Approach

Traditional noise attenuation methods attempt to separate signal from noise by transforming data into a domain where the signal or noise is modeled mathematically, and signal and noise can be separated. Many methods simply stop at separating noise and signal. That is, the signal model itself is the output of the noise attenuation program. Some compensate for the 'too clean' synthetic look of the output by adding back a percentage of the original input data.

LIFT (Choo and Sudhakar, 2003), a new amplitude-friendly technique to attenuate noise and multiples, takes a new approach by adding back an estimate of the signal lost during the modeling, rather than simply outputting the signal model or the signal model with a percentage of the original data added back. This is a fundamental shift in noise attenuation strategy. This approach greatly improves signal preservation. It is very flexible in that it can incorporate a variety of application domains, filtering tools, and ways of modeling data, as appropriate to address particular noise problems. As well, it is a practical and robust amplitude-preserving way to pre-condition data for pre-stack migration, to prevent migration artifacts and costly re-runs.

Noise Attenuation Current Practices

Many and varied strategies have been used to model the signal or noise, all making various assumptions. For instance, the K-L transform assumes that the signal is flat in time with only amplitude variations. The Radon transform is more flexible in that it allows signal to follow varied trajectories, but a few fixed types of trajectories (hyperbolic, parabolic, and straight lines for example) cannot fully cover all signal behavior. The F-X prediction filter is a popular tool to attenuate random noise. It makes a general signal model assumption: that signal is similar from one trace to the next and spatially predictable by convolution filters - a less restrictive signal model than that of some other noise attenuation algorithms.

The Model Will Always be Imperfect

For many of these noise suppression techniques, the signal model itself is the output of the noise attenuation program. Some go a bit further by adding back a percentage of the original input data. This raises the question: why add back a percentage of input when we know this means some of the noise we worked so hard to exclude is being put back in? It is done because we know the signal estimate is imperfect. Adding back some of the input data, that is, adding back [some percentage x (signal + noise)], is an attempt to make up for the fact that the modeling did not fully capture all of the signal. Adding back some of the noisy input data is a way to diminish edge effects, overcome spatial smearing and other artifacts created by the assumptions of the mathematical model. Practically speaking, the reason for adding-back input data is so the result will look more ‘realistic’ and less 'synthetic'. But adding back a percentage of the original data produces an output where the signal level is actually distorted, not preserved. Another technique sometimes used is to add back a percentage of the modeled noise. This technique does not distort the signal, but delivers a needlessly reduced signal-to-noise ratio. A different approach is desired that will both preserve the signal *and* deliver improved signal-to-noise ratios.

A Fundamental Shift Enables Signal Preservation

Many approaches to improving noise attenuation algorithms focus on incremental improvements in the signal model description. However, in view of the fact that the model can never describe the signal perfectly, what is needed is a fundamental shift in approach to what is done with the estimated signal and noise models. Rather than simply modeling the signal, or even adding back a percentage of the input, LIFT estimates the residual signal lost during the signal modeling and incorporates this in the data re-construction. Figure 1 illustrates the concept.

LIFT is really a simple idea, but may require a complex workflow to achieve optimal results in both signal preservation and noise attenuation. In practice, getting from Input to Signal Model (Figure 1) can be complicated, requiring appropriate combinations of tools and QC inspections, all in suitable domains. Calculating Residual Signal can also be an involved exercise in choosing the appropriate combination of tools, QC methods, and domains. The whole LIFT approach is data adaptive, and can be - and often is - iterative.

LIFT General Methodology

In the LIFT technique, signal or noise can be modeled in a variety of well-established ways, such as FX Decon (for random noise), FK (for linear noise), simulated geophone arrays (for ground-roll), AVO inversion (for primaries) or Radon transform (for multiples). The steps chosen will depend on the nature of the particular noise problem being addressed.

Application: Attenuating Source Noise

A very successful application of LIFT in land data has been to attenuate difficult source-related noise. A typical LIFT methodology for this is to use array forming - a computer simulation of geophone field arrays - to address ground-roll noise. Within the LIFT sequence, the source-related noise is then estimated and suppressed. The effectiveness of this method is illustrated by Figures 2 and 3. Figure 2 shows some typical land shot records from western Canada. Geometric divergence correction is the only process that has been applied. Air blast and ground-roll noise are evident. Figure 3 shows the shot records after the LIFT sequence to attenuate source-related noise has been run. Note that in addition to preserving primary amplitudes, this technique attenuates noise on the affected traces only, leaving those traces that were already 'clean' essentially untouched. The approach can be iterative and parameters can be fine-tuned for particular datasets.

Application: Attenuating Random Noise

Figure 4 shows a comparison of signal-to-noise ratio achieved by random noise attenuation using the LIFT technique versus signal-to-noise ratio achieved via a more traditional approach to noise attenuation, as represented by post-stack FX Decon. Note that FX Decon, a popular method for random noise attenuation, actually under-performs and mixes the data. The LIFT result has higher S/N ratio, does not suffer from smearing, and handles individual noisy traces much more effectively.

Application: Residual Multiple Attenuation

The methodology to attenuate multiples is first to perform a de-multiple algorithm of choice - usually Radon de-multiple or perhaps even SRME. This is followed by LIFT to attenuate residual multiple energy. In the LIFT sequence, signal can be modeled in a variety of ways, for example, by Zoeppritz-based AVO inversion (such as Fatti et al., 1994). Due to the assumptions of Zoeppritz's equations, a Zoeppritz-based AVO inversion will consider multiples and converted waves to be noise and will exclude them in its reconstruction of signal. In this way, Zoeppritz-based AVO inversion models primary signal. From there, the LIFT sequence then adds back an estimate of the signal removed during the signal modeling, attenuating residual multiple energy from the original data in an adaptive nonlinear fashion.

A common situation where residual multiple attenuation via the LIFT Technique works well is offshore data where the time-offset curve of the water bottom multiple reverberation is not hyperbolic. This occurs wherever the sea floor has rugged, rapidly changing topography. A Radon transform typically assumes that a multiple exhibits a parabolic or hyperbolic t-x curve, and, in addition, assumes that the apex of the curve is at zero offset. Most standard Radon methods cannot handle situations where the multiple reflections do not honor these assumptions. As well, the limited size of the spatial aperture of a seismic gather affects the ability of Radon transform to separate multiple and primary reflections. As noted by Sacchi and Ulrych (1995) and summarized by Wang (2003), the limited spatial aperture causes edge effects, impairing the separation of primary and multiple reflections in the Radon transform domain (the events do not transform as they should to points in τ-p space, rather, they transform to smeared interfering lines). The LIFT sequence is very effective in attenuating residual multiple energy that Radon alone cannot handle (Figure 5).

Application: Safely Pre-condition Data for Pre-stack Migration

Because LIFT can attenuate noise and multiples pre-stack with optimal preservation of the signal, it is an amplitude-friendly, effective way to attenuate noise prior to pre-stack migration. Properly pre-conditioning data before expensive pre-stack migration enables a better migration result, relatively free of migration operator artifacts. Pre-conditioning the data in this way prior to PSTM prevents expensive re-runs of pre-stack migration.

Conclusions

LIFT is a significantly different approach to noise attenuation than what has been done historically. The LIFT technique offers a way to attenuate noise while better preserving signal. As well as applications in attenuating random and coherent noise, including attenuating difficult multiples that other methods could not handle, LIFT has proven to be an excellent technique to pre-condition data for pre-stack migration, preventing migration artifacts and saving costly re-runs.

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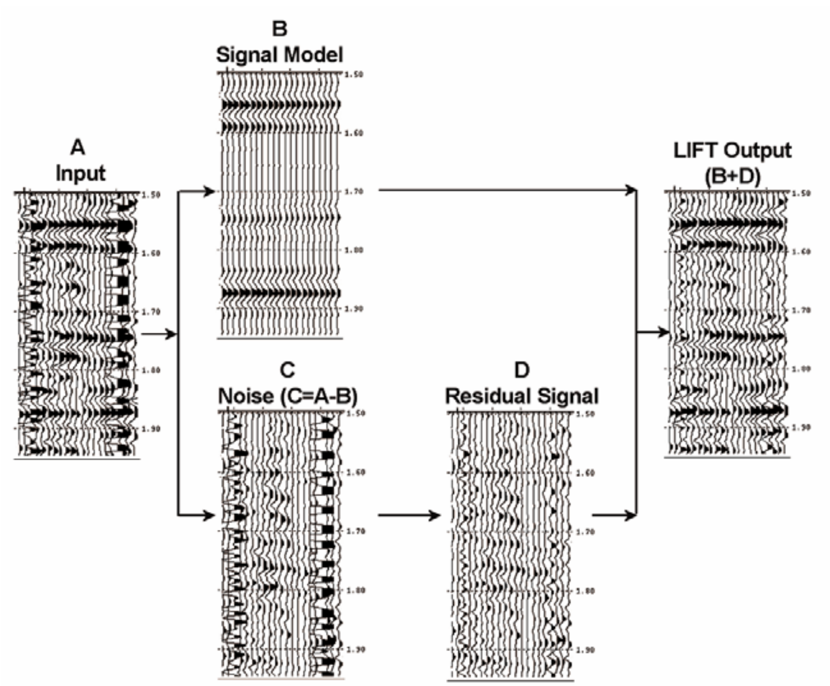

Figure 1: A very simplified schematic to illustrate the LIFT method.

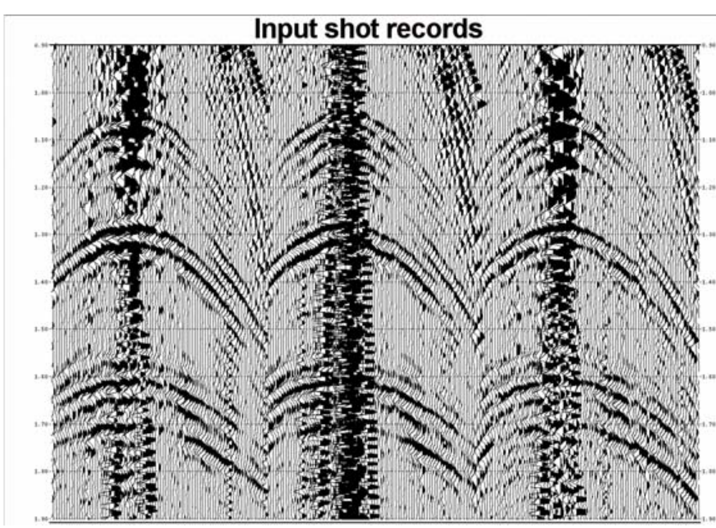

Figure 2: Input shot records.

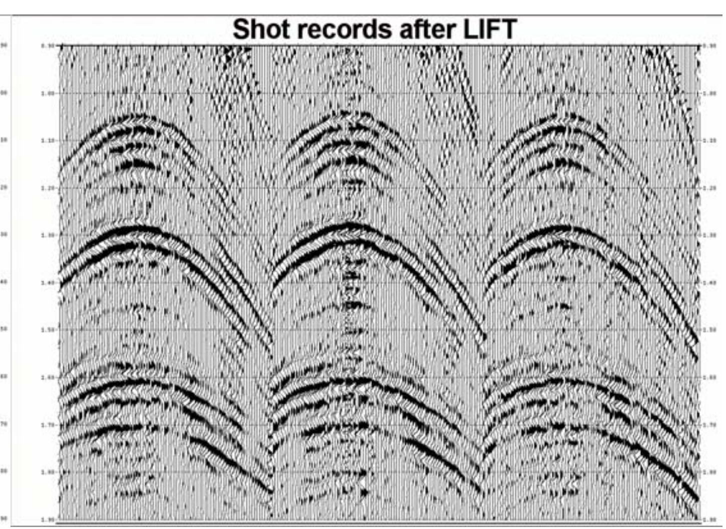

Figure 3: The shot records after LIFT to attenuate source-generated noise.

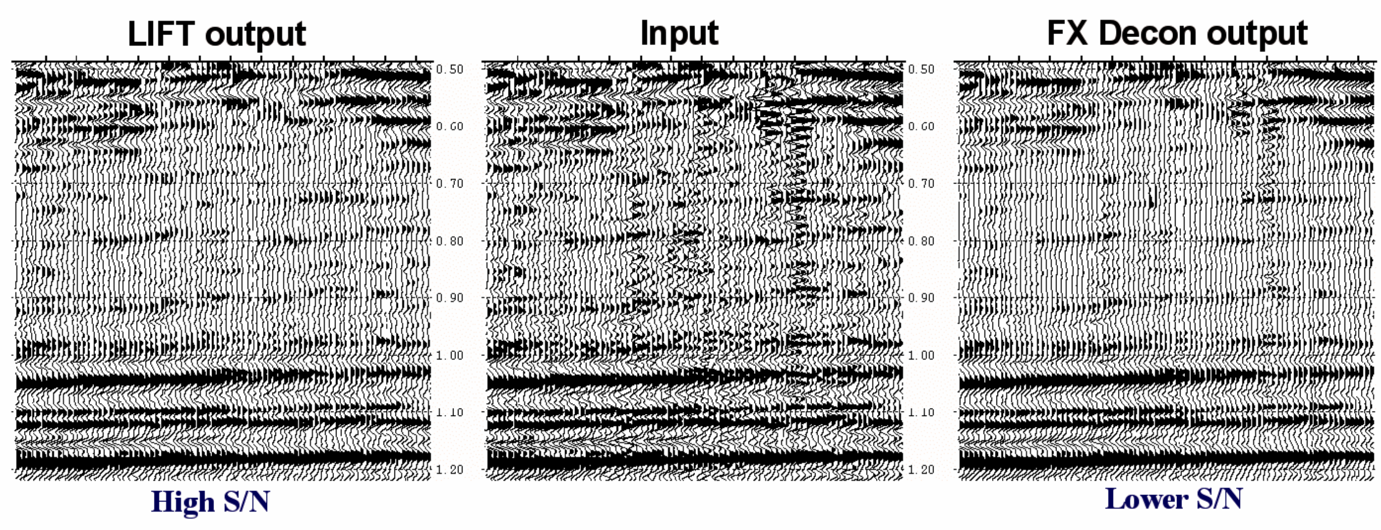

Figure 4: LIFT Technique for random noise attenuation compared to traditional approach, as illustrated by FXDN example. Note that FX Decon, a popular method for random noise attenuation, actually under-performs and mixes the data. The LIFT result has higher S/N ratio, does not suffer from smearing, and handles individual noisy traces much more effectively.

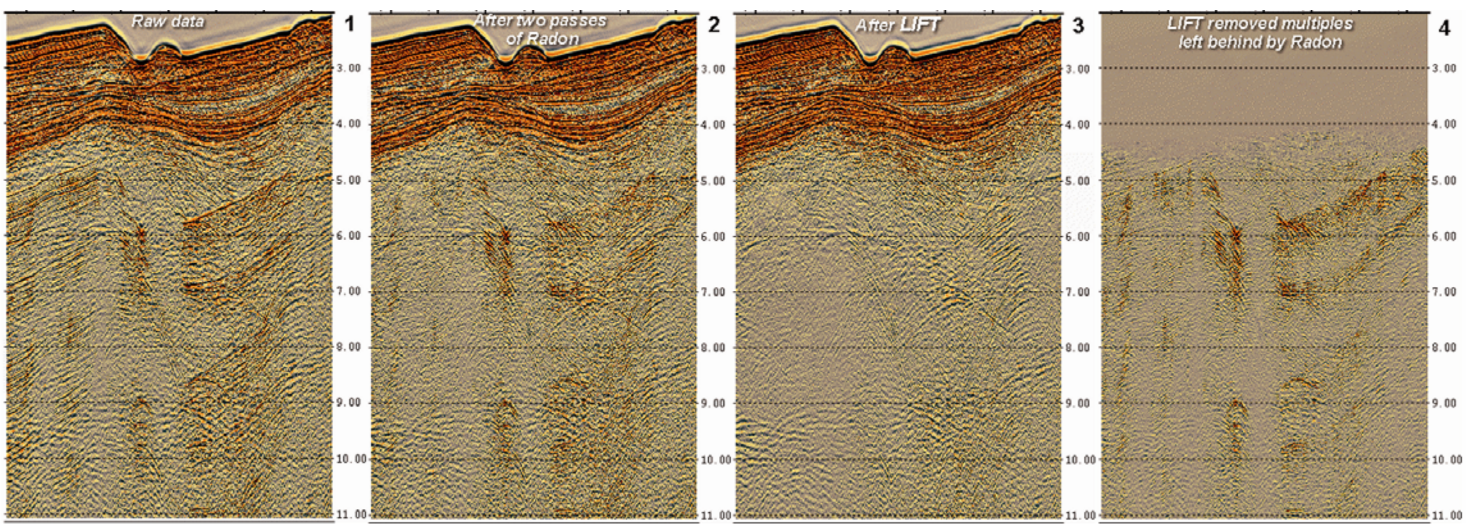

Figure 5: In this marine example, because the sea floor has rapidly changing topography, the traveltime curves of the water bottom multiples are non-hyperbolic and the time apex of the curve varies with offset. LIFT can attenuate residual multiple energy that conventional methods, such as Radon in this case, could not handle. Note also that diffraction energy - desirable for subsequent pre-stack migration - is clearly preserved through the LIFT process.