The decline of conventional seismic acquisition and the rise of specialized acquisition:  
this is compressive sensing  
Christof Stork* & David Brookes, ION Geophysical

Summary

Many seismic acquisition surveys today have some form of customization and specialization to reduce cost, address operational issues, or efficiently resolve a difficult geologic objective. This trend has been clearly aided in the recent past by the following: 1) Acquisition systems are more flexible and provide capability to specialize, 2) Geologic and reservoir objectives are getting more demanding and diverse, and 3) Geophysicists have more experience and expertise with acquisition opportunities. This trend of specialized acquisition will probably accelerate in the future because of: 4) Better processing tools that allow for very irregular and non-uniform acquisition, & 5) New processing tools that benefit from specialized acquisition, and 6) Better risk management tools by companies to accept unconventional acquisition.

The recent discussions on “compressive sensing” shares strong parallels with specialized acquisition. Both perspectives try to find the best acquisition compromise between cost, geologic resolution, noise, and operational restrictions. Both perspectives rely on using advanced processing for successful imaging with unconventional acquisition.

Modifying seismic acquisition based on the performance of new processing tools adds risk and should be done cautiously for this expensive process. But, there is a lot to be gained from finding the best acquisition compromise. Not only can costs be significantly lower, but key geologic & reservoir objectives can be resolved. The new processing methods significantly alter the considerations for the best compromise. Better risk management consideration by companies and some new aggressive risk analysis tools will aid the adoption of these specialized, unconventional acquisition & processing approaches.

Introduction

Conventional acquisition is often designed using criteria of a regular acquisition pattern and minimizing near offset holes to improve shallow imaging. These criteria greatly simplify processing and reduce potential acquisition artifacts that may not be fixable in processing.

Moreover, since the new processing methods are more sensitive to noise, considering noise is crucial and should play a large role in acquisition design.

It is surprising that acquisition does not vary more around the world given that geologic objectives, seismic noise, and operational constraints vary dramatically around the world.

We define conventional approaches as land cross-spreads and marine NAZ/WAZ surveys. These conventional patterns may be modified, but the basic pattern is the basis of many acquisition surveys around the world.

Lifting the criteria of a regular acquisition pattern and minimizing near offset holes allows for much, much greater acquisition flexibility. This flexibility can be used to reduce costs, improve azimuth/offset coverage, improve converted wave illumination, optimize complex structure illumination, or reduce noise. These can each be big things.

Examples of using this acquisition flexibility to specialize seismic surveys are:

1) Irregular OBC layout to optimize illumination sub-salt;
2) Circular shooting to increase azimuth and offset coverage for sub-salt;
3) Simultaneous or fast dithered sources
4) Using distributed 2D digital arrays on land to damp surface noise;
5) Acquiring converted waves for improved reservoir inversion; and
6) Enabling interferometric acquisition during non-shooting time.

The new processing methods that allow for the additional acquisition flexibility are:

a) Improved interpolation and regularization methods
b) FWI for determination of near surface velocities
c) Several types of iterative methods that eliminate the impact of acquisition irregularity
d) Flexible multiple prediction and removal methods

A key challenge with specialized acquisition is addressing the risk. Because of their cost, time of planning/acquisition/processing, and senior management involvement, acquisition surveys should have low risk. The desire for low risk encourages using proven conventional survey designs. However, by using aggressive risk analysis tools, the risk for specialized surveys can be greatly reduced.
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Example 1:
Land Acquisition with Distributed 2D Arrays

We compare 2 land acquisition geometries using 3D finite difference modeling over a modifications of the SEG/EAGE Overthrust model, shown in Figure 1. The modifications add a low velocity surface on the top with density and velocity variations that cause much surface back-scattering. This model produces low & high wavenumber back scattering. The noise from model is apparent in the shot gather in Figure 2.

Figure 1: A cross-section through the 3D EAGE/SEG Overthrust model after adding the 500 m thick low velocity surface layer. The low velocity surface layer has velocities of 1100-1500 m/s while the original model has surface velocities of 2178-3000 m/s. Note that thin blocks are added.

Figure 2: Sample shot gather computed by 3D acoustic FD modeling from the model. The data is dominated by noise from the scattering in the low velocity surface layer.

Figures 4a & 4b show processing & imaging results that compare conventional land acquisition with orthogonal shot & receiver lines with a sparse shot and distributed 2D array receiver pattern, which is shown in Figure 3. The noise in the images comes from the back scattered surface energy. For the conventional acquisition, we could only perform 2D filtering of surface noise while for the distributed 2D array we could perform 3D filtering within each 2D array. The distributed 2D array results are clearly superior for this type of noise.

We attribute the poor quality of the conventional acquisition to the side & back scattered noise in this data that the 1D arrays and 2D filtering are not able to attenuate.

We attribute the superiority of the distributed 2D array pattern to that the receiver grid within a 2D array is fine enough to attenuate the surface noise.

The distributed 2D array causes problems in the processing, especially with the shallow section which has irregular coverage. However, the benefit gained from the surface noise attenuation is greater than the detriment of the unusual acquisition. In this case, the distributed 2D array may be the better compromise in areas of much back-scattered noise.

Figure 3: Sample layout of distributed 2D digital arrays. This layout has approximately the same number of shots and receivers per area as conventional shot & receiver lines.

Figure 4a: Image from conventional orthogonal shot & receiver lines. Noise is from much surface back scattering.

Figure 4b: Image from sparse shot and distributed 2D arrays. This image is better than from conventional acquisition, especially below the thrust fault.

Example 2:
Dual Coil Marine Example

Another example of an irregular, specialized acquisition geometry that addresses is using dual coil marine...
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acquisition for subsalt objectives as demonstrated by Moldoveanu et al. (2008) and Moldoveanu & Kapoor (2009). Although each individual CMP gather has very non-uniform and irregular distribution and neighboring CMP gathers vary significantly, on average over a large super-gather, all long offsets and azimuths are populated. This is a clever approach for acquiring the full azimuths and very long offsets without performing a hugely expensive full receiver acquisition for each shot. The imaging results in the papers look excellent.

This is an example of an unconventional, specialized compromise to the demands of subsalt imaging. Long offsets and full azimuths are important to subsalt imaging while the potential problems of non-uniform and irregular CMP gathers are not important. Before performing a costly field test of this approach, the effectiveness was demonstrated via accurate 3D finite difference modeling.

Example 3:
Simultaneous and Fast Dithered Sources

Much conventional acquisition has a single source that is repeated every 12-30 seconds. Simultaneous sources will have 2 or more sources every 12-30 seconds. Fast dithered sources may fire individually every 3-6 seconds. Both of these approaches can illuminate a greater part of the subsurface than a single source within the same time and potentially be much more efficient.

Simultaneous or fast dithered sources create the problem of significant interference between the sources. Without special treatment, this interference can dramatically reduce image quality. Figure 5a shows the result of a straight stack of dithered source data where the interference clearly produces significant artifacts. Specialized processing in Figure 5b largely eliminates the interference, but some minor artifacts remain. Since this dithered source example was simulated by summing separate individual sources, we can produce the perfect stack for comparison, which is in Figure 5c. Whether the small artifacts of Figure 5b are significant is dependent on the interpretation objective. Realistic modeling can address whether artifacts will be significant before acquisition.

Example 4:
Converted Waves

Converted waves in land or OBC settings can significantly help resolution of reservoir properties. However, acquiring converted waves has different priorities from acquiring P waves. When acquiring converted waves, there is greater emphasis on reducing surface noise, having long offsets, and full azimuths. These priorities can conflict with the P wave priorities in the same area.

We consider converted wave acquisition and processing to be a specialty process that is distinctly different from P wave acquisition and processing. Simultaneously acquiring converted wave and P wave data may require compromises for acquisition design of both. The proper compromise can optimize resolution of the reservoir properties.
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Figure 6 shows how converted waves can significantly improve reservoir inversion of density. The well logs confirm that the inversion that incorporates the additional PS data has better resolved density, which is often a key reservoir property.

Density Inversion:

Figure 6: Right angle display of density inversion that compares a PP only inversion with a PP+PS inversion. The PP+PS inversion has a much sharper definition of density that agrees better with the well log (not shown).

Aggressive Risk Analysis of Specialized Acquisition

Modern techniques can accurately simulate all components of the seismic wavefield: random noise, coherent noise, imaging/diffraction effects, and signal amplitudes. Each item needs to be included for proper simulation and care must be taken that each item is accurately handled. Often, only one or two of these steps are considered for acquisition design.

We need to be aggressive to ensure that the simulation process is complete. Including the proper random noise and coherent noise may require a field noise test.

When all of these items are properly simulated, we can quantitatively compare different acquisition designs and adequately test the processing methods. The simulation is not a simple process, especially if it requires a field noise test. However, the simulation is still comparatively much cheaper than a full seismic acquisition survey. There is much value in doing the simulation well and having confidence in the results.

Conclusions

New processing capabilities allow for very irregular acquisition coverage and reduced need of uniform near offset coverage. As a result, seismic acquisition can be much more flexible and specialized to either reduce costs, address noise, or improve resolution of geologic and reservoir objectives. There is much to be gained by coordinating acquisition with this new processing capability to find the best compromise.

This process of irregular, selective acquisition combined with new processing is very similar to that of compressive sensing. Compressive sensing methods also record a selective subset of the full 5D data and use advanced processing in the form of inversion to achieve a good image. The challenge is finding the optimal subset. Specialized acquisition determined through human intuition and testing is one form of compressive sensing.

But, coordinating acquisition with new processing is a tricky proposition. Traditionally, these fields are separated with different contractors performing each role and new processing considerations do not significantly influence acquisition. People responsible for seismic acquisition are appropriate to be wary of relying on processing to fix acquisition issues since if the processing fails, the acquisition cannot be easily fixed.

A key part of realizing the potential of coordinating specialized acquisition with new processing is reducing risk. You want to have very high confidence that the processing capabilities will work with your specialized acquisition to meet your geologic or reservoir objective. A key to providing this high confidence are realistic techniques to simulate noise and imaging challenges to properly demonstrate the effectiveness of the processing with specialized acquisition.

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EDITED REFERENCES
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