Simultaneous Sources: a technology whose time has come
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Summary

It is a rare and exhilarating moment when an emerging technology develops so rapidly that it warrants a special session at the SEG Annual Meeting, while, at the same time, it remains so compact that most of what is known on the topic will be presented at that session. We find ourselves in that situation in this special session on the use of simultaneous sources in the marine environment. In this talk I will give an introduction to the session including some history of the problem, both within and outside of the geophysical community, as well as motivation and current issues that are stimulating research and commercial efforts.

Introduction

The subject of dealing with interfering information is by no means new. One need only look to nature for numerous examples of species that have found it necessary for survival to be able to differentiate their offspring from others who look identical and sound identical (at least to humans). In electronics, one could argue that differentiation of signal and “noise” – which usually means everything not considered “my signal” – is mainly aimed at removing interfering signals from other unwanted sources. And despite the hyperbole of my summary above, the topic is not new to geophysics either; moreover, it is not even new in the marine acquisition environment. What is relatively new is the concept of purposely deploying multiple impulsive sources and firing them in such a way as to interfere with each other with the plan of separating the sources in subsequent data processing steps.

The motivation for using multiple sources is straightforward. If the sources will each yield distinct information, then the subsurface can be sampled more efficiently. Moreover, having multiple sources active in a survey provides other benefits such as flexibility in survey geometries. There are many potential benefits to this aspect, but a timely one is to enable azimuthal diversity in marine surveys. As a result, there is tremendous potential value to the seismic industry if this approach can be successfully developed and commercialized. I begin with a little history of the problem.

A little history

As I stated above, one could view the whole signal-to-noise problem as one of interfering sources, but rather than try to address such a broad, and generally well-known topic, I will highlight a few interesting examples that are not so well known to geophysicists and hope thereby to provide some insight. An interesting early paper on this topic studies the so called “Cocktail Party Effect” which relates to the well known phenomenon that, despite all of the loud talking from many people (sources) in a crowded cocktail party or bar, one is often able to focus on one particular person’s speech. It is even more remarkable that it is possible even when that person is some distance away and interference levels are very high (Cherry, 1953). Indeed studies indicate that as volume increases (and this is well known to happen as the evening wears on), the ability to separate is still powerful. Perhaps even more interesting is the ability to “tune out” the boor standing right next to you. This early paper led the way for today’s understanding and technology in speech recognition. According to a 1992 MIT Media Labs paper by Aarons “A Review of the Cocktail Party Effect” (search Wikipedia for “cocktail party effect” for a link), the initial motivation for studying this effect was due to air traffic controller issues. At the time, the controllers all listened to all the pilots over a single speaker in the room, which made it a difficult job. Cherry’s work led Broadbent (Broadbent, 1958) to study the problem which led to the classic Broadbent Filter theory which he summarized as:

1. Some central nervous system factors, rather than sensory factors are involved in message selection.
2. Effects vary with information content of the messages.
3. When information must be discarded, it is not discarded at random. If some of the information is irrelevant, it is better for it to come from a different place, to be at a different loudness, to have different frequency characteristics, or to be presented to the eye instead of the ear. When no material is to be discarded, there is little advantage in using two or more sensory channels for presenting information.

Interestingly, Cherry worked in telecommunications and had been involved in radar research during WWII and Broadbent in psychology. Point number 3 is significant in that it foreshadows the methods for separating interfering seismic signals that will be discussed in this session. Both scientists are recognized in their field for their pioneering work which led to the study of speech recognition and human communication theory. Recently, Ikelle (Ikelle, 2007) discussed this approach as it applies to seismic data.
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Before we turn to the background of the problem in geophysics, I will highlight another interesting development from the telecommunications industry. In 1998, a patent was issued to a researcher at Bell Labs and heralded as a breakthrough that overcomes the sampling theorem. So called BLAST (Bell Labs Layered Space-Time) purported to overcome conventional relationships between frequency bandwidth and information content by employing multiple broadcasting and receiving antennae and exploiting propagation differences to separate the interfering signals. The patent was based on previous work at Bell Labs but principally on work by Foschini (Foschini and Gans, 1998). Since that time, the telecommunications industry has commercialized this approach under the acronym MIMO which stands for Multiple Input Multiple Output. Moreover, it has sparked a new paradigm in that industry and today, one finds extensive research on the topic.

These developments are mentioned not only for their novelty and similarity to current developments in geophysics but also because of the impact these new paradigms had in their respective sciences and businesses. The work of Cherry and Broadbent certainly paved the way for speech analysis and recognition and could be considered seminal in the understanding of human communication theory in general. The work at Bell Labs and Foschini’s work, in particular, could be said to have revolutionized the wireless communications industry. It is possible that simultaneous sources could have a similar effect in our domain. Now, let’s turn to previous work on simultaneous and interfering sources in geophysics.

Interfering sources in geophysics

It has long been recognized that the economics of seismic acquisition depend on the time and motion of the people and equipment involved in relation to the area of the seismic survey to be acquired. This is a very complex topic and not the subject of this discussion, except, however, to note that the potential benefit of using more than one source at the same time in acquisition is well known. Indeed, on land with vibrator sources, this approach has been well documented (Garotta, 1983; Womack et al., 1990; and Bagaini, 2006). Moreover, this benefit is often cited as a motivation for the development of marine vibrator sources.

More recently, land simultaneous source technology has been extended to the so-called slip sweep technique (Rozemond, 1996), where vibrators are delayed rather than activated simultaneously. And significantly, HFVS (High Fidelity Vibroseis), pioneered by workers at Mobil has been in commercial use (Allen et al., 1998). The common thread in the approaches for land simultaneous sources is the use of some sort of encoding mechanism to enable separation of interfering signals. This type of encoding is not available with conventional marine sources and as a result, these particular approaches have not been pursued in the marine environment. However, de Kok disclosed an encoding technique that is feasible for marine applications (de Kok, 2003).

The main thrust of interfering sources research for marine acquisition has been aimed at removing “crew noise” which comes from other boats shooting in the same area. In prosperous times such as we now enjoy, many operators may desire to shoot data in the same area and as a result, the industry has adopted so-called time sharing rules which require that only one boat shoot at a time when the noise specifications reach prescribed levels. Because of the cost involved in time sharing, many attempts have been made to relax these stringent requirements to avoid time sharing. Lynn et al. (1987) studied the problem extensively and concluded that, so long as the interfering shooting vessels did not have synchronized firing times, the interfering signals could be suppressed simply by stacking the data. While this work did not contemplate purposely deploying interfering sources for use as signal, the key insight in this paper is that while interfering shots appear coherent and unmanageable in the shot domain, a result of ensuring unsynchronized firing times – a type of encoding of the interfering shots – is that interfering shots appear as incoherent arrivals in the CMP domain and thus are removed by filtering or stacking. This type of source encoding, and others, is a key element in separation techniques that will be discussed in this special session. In this vein, Vaage and other researchers at PGS have described using Lynn’s insight of unsynchronized source timings in acquisition to enable filtering of interfering sources (for example, Vaage, 2002).

Simultaneous marine source experiments

In 1997, Western Geophysical carried out experiments to test the possibility of using simultaneous marine sources. The motivation for this turn of events was similar in many respects to today’s: illumination deficiencies in conventional marine acquisition. The root causes of subsurface illumination deficiencies were documented as a result of the deleterious effects on imaging algorithms and were determined to be related to acquisition geometry. As a result of this field test, we reported that even if sources were fired simultaneously with synchronized firing times, if the sources were spatially separated, filtering related to the different geometries, including imaging algorithms such as DMO and prestack migration, would suppress the interfering sources (Beasley et al., 1998, and Beasley and Chambers, 1998). Data from this experiment in Figure 1 show a composite of the same line (nearly) shot first with a
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conventional single source and then shot a second time with interfering sources. The two results are nearly indistinguishable. The central portion of the section is the line shot with interfering sources and the outer two thirds is from the line shot conventionally. Small misties are attributed to 3-D effects from cable feathering, not interfering sources.

Figure 1. 1997 vintage 2-D line shot with interfering sources composited with a line shot conventionally. The central 1/3 of the figure was shot with interfering sources. Data processing included filtering to remove the interfering sources, DMO and migration.

Although we considered this to be a successful demonstration of simultaneous sources, acquiring data in this manner requires an additional shooting boat, which was not common practice in 1997 and this hindered development. Commercial development of this approach was also hampered by the unfortunate ensuing industry downturn.

Why simultaneous sources now?

The seismic challenges posed by the deep water, sub-salt Gulf of Mexico plays today are addressed with field efforts unimaginable just a few years ago. To collect wide azimuth surveys efficiently, multiple vessels are employed in a dizzying array of configurations – sometimes with several boats recording, and usually with several boats shooting. As a result, operators find that they must time share among their own vessels. This results in underutilization of equipment and, while the desired azimuth characteristics are obtained, other sampling quantities may be degraded. For example, if four boats are shooting and the nominal shot spacing is 37.5 m, time sharing results in shot spacing within one shot line of 150 m which poses challenges in data processing. If, for example, one could shoot the sources simultaneously, in pairs, shot spacing would be reduced to 75 m and the fold would double. In other words, if the interfering sources can be separated successfully, data quality can be improved with little extra field effort.

In general, if the sources generate independent information, survey efficiency increases nearly linearly as the number of sources firing simultaneously increases. This efficiency factor can be used to reduce cost and/or improve data quality. As a result, there has been a renewed interest in using simultaneous sources in recent years.

Field tests have been conducted over the past several years and one result has been reported by authors from Chevron (Steffani et al, 2007), expressing optimism for the commercial application of simultaneous sources. By the time of this meeting, 3 papers will have been published in the July 2008 edition of The Leading Edge on the subject (Beasley, 2008; Berkhout, 2008, Hampson et al., 2008). Finally, the wealth of contributions that form this special session clearly illustrates the growing interest and confidence that simultaneous sources will indeed play a major commercial role in the near future.

What’s next?

At this juncture, it appears very likely that simultaneous sources will play a significant role in large-scale marine acquisition. However, as I have indicated earlier, once a new paradigm invades a technology, it grows and spreads rapidly. It is easy to see that similar acquisition schemes can adopt simultaneous sources. For example, bottom referenced systems, whose costs are generally high relative to towed streamer acquisition because of the time required to shoot the survey, could become more efficient by cutting acquisition time and thus lowering costs. Similarly, borehole seismic surveys, whose costs are significantly affected by rig idle time, could benefit from faster acquisition that could be achieved with simultaneous source technology. Moreover, it is certainly clear that the separation algorithms being developed today will find use in land acquisition and could cause a rethinking of how we use simultaneous sources on land.

While these are exciting prospects, they represent only the first stage of development. In the future, acquisition systems could be redesigned and optimized for simultaneous source acquisition. In particular, a rethinking of sources would seem to be in order and would likely bear fruit. Going even further into the blue sky realm, it is clear that this technology is not just about marine acquisition – rather it relates to acoustic communication theory in general. It has the potential to play a role in acoustics similar to that of Foschini’s work in wireless communications.
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Conclusions

This special session in many ways marks a starting point for simultaneous source technology in geophysics. Although it is clear that the roots are deep and the subject is not new, in the strictest sense, to geophysics, it seems that we have reached a tipping point, or point of critical mass, that is necessary to introduce a new paradigm. Further, we can look to other sciences that have revolutionized their disciplines by successfully tackling the problem for encouragement that such a bold step will be successful in geophysics. Moreover, the potential benefits of increased acquisition efficiency are of such a magnitude that we must investigate this opportunity. In response, we see rapidly growing research efforts in simultaneous sources. For these reasons, I conclude that the time has come for simultaneous sources in geophysics.
EDITED REFERENCES
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