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DrillCam Field Trial - Extracting the Weak Signals by Drill-Bit Noise Deconvolution

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Summary

we present the initial result of the DrillCam pilot experiment. The objective is to remove the drill bit source signature, and extract the desired subsurface response. This is achieved by applying both cross-correlation and deconvolution using a pilot trace placed at the top-drive. The results are compared with each other to demonstrate the ability of the proposed deconvolution operation to better remove the drill-bit source signature.

Introduction

Seismic-while-drilling (SWD) measurements have been demonstrated to constrain subsurface velocities and assist drilling (Poletto and Miranda, 2004; Naville et al., 2004). Recent research has addressed and resolved instrumentation challenges and found solutions to enhance the signal-to-noise ratio of the weak desired signals (Naville et al., 2004). Predicting over-pressured zones ahead of the bit and imaging the subsurface structures in the vicinity of the bit can be essential tools to drillers to navigate and steer the drilling operation in complex structures. Therefore, providing these tools in real-time is a key challenge, and finding an optimal solution to overcome this challenge could help optimize and automate the drilling process. Al-Muhaidib et al. (2018) and Hemyari et al. (2019) introduced DrillCam (Drilling CAMera) that further aims to resolve the exploration and drilling challenges such as drillstring vibration health and formation property estimation ahead of the bit, while the drilling operation is in progress.

In this abstract, we present the initial result of the DrillCam pilot experiment. We aim to remove the drill bit source signature to extract the desired subsurface response. We applied both cross-correlation and deconvolution using a pilot trace placed at the top-drive. The results demonstrate that the deconvolution of the random drill bit source is an essential step to retrieve the weak subsurface signal.

Method

The DrillCam acquisition geometry consists of 2,588 wireless receivers transmitting data close to real time, and the layout of the geophones is shown in Figure 1. The DrillCam system has delivered continuous SWD measurements, where the drill depth spans a range from surface to about 10,000 ft. A recorded seismic trace in this gather is constructed by the convolution of the earth response e(t) with the drill bit source signatures s(t). In the frequency domain, this seismic trace is given as follows:

$$D(\omega) = E(\omega)S(\omega),$$

where $D(\omega)$ is the recorded seismic trace in the frequency domain, which results from the multiplication of the subsurface response with the drill bit signature in the frequency domain. The earth response is extracted by removing the effect of the random source by correlating all the traces with the top-drive pilot trace. Mathematically, the classical cross-correlation to extract the desired earth response is given in the frequency domain by (Claerbout, 1992):

$$E_{xcorr}(\omega) = D(\omega)S^*(\omega), \qquad (1)$$

where $E_{xcorr}(\omega)$ denote the retrieved earth response, and the cross-correlation is obtained by multiplying the spectrum of the recorded signal with the conjugated spectrum of the drill-bit signature. The cross-correlation operation often yields severe artifacts, which mask the desired weak earth response. Ideally, the deconvolution operation is performed in the frequency domain by the following spectral division (Vasconcelos and Snieder, 2008):

$$E_{decon}(\omega) = \frac{D(\omega)}{S(\omega)} = \frac{D(\omega)S^*(\omega)}{S(\omega)S^*(\omega)}, \qquad (2)$$

where $E_{decon}(\omega)$ is the desired earth response, and the deconvolution operation undoes the phase, which is given by the numerator (i.e., equivalent to equation (1)), and accounts for the amplitude (i.e., dividing by the squared amplitude spectrum). As a result, the correlation artifacts are minimized and the weak earth signal is enhanced by the deconvolution operation.

Results

The 2,588 wireless geophones and the top drive 3C receiver are separately and continuously recording 30 s traces starting at the top of each minute. A typical drill bit noise gather from a depth of about 2,200 ft is shown in Figure 2. Note that the record consists of the 283 receivers along the 2D line denoted by the arrow in Figure 1. The 30-second record is also zoomed to show only the first four seconds and it mainly consists of the drill bit noise convolved with the subsurface earth response.

A 1-hr drill bit noise data is correlated with a 1-hr top-drive pilot, and it yields the results in Figure 3 (left). The conventional cross-correlation (i.e., equation (1)) result is zoomed to the three seconds. The direct arrival from drill bit location at 2200 ft is not identifiable due to the presence of severe correlation artifacts denoted by the red arrow in Figure 3 (left). Also, the strong linear noise has a move-out velocity of about 900 m/s and it obscures the weak direct arrival from the deep source. To alleviate this problem, the drill bit signature is deconvolved from the drill bit noise gather by equation (2), and present the obtained gather in Figure 3 (right). The result shows the collapse of the correlation artifacts, which masked the direct arrival from the drill bit source. As a result, the new gather is less ringy than the one obtained by conventional cross-correlation. The move-out curve of the first-arrivals from the drill bit source, denoted by the yellow arrows, agrees well with the synthetic curve obtained from the checkshot of offset wells.

Conclusions

We presented here the initial result of the DrillCam pilot experiment, which was conducted using 2588 wireless receivers to record continuous drill bit noise. We demonstrated that applying the classical cross-correlation between drill bit noise and the top-drive pilot trace yielded non-optimal results. The weak signal from the drill bit was masked by the strong linear noise and cross-correlation artifacts. A deconvolution operation was invoked to remove the drill bit source signature and enhance the weak desired signal. The deconvolved gather showed a remarkable collapse of the correlation artifacts and revealed direct arrival signal, which agrees with the predicted arrivals from offset wells.

Acknowledgments

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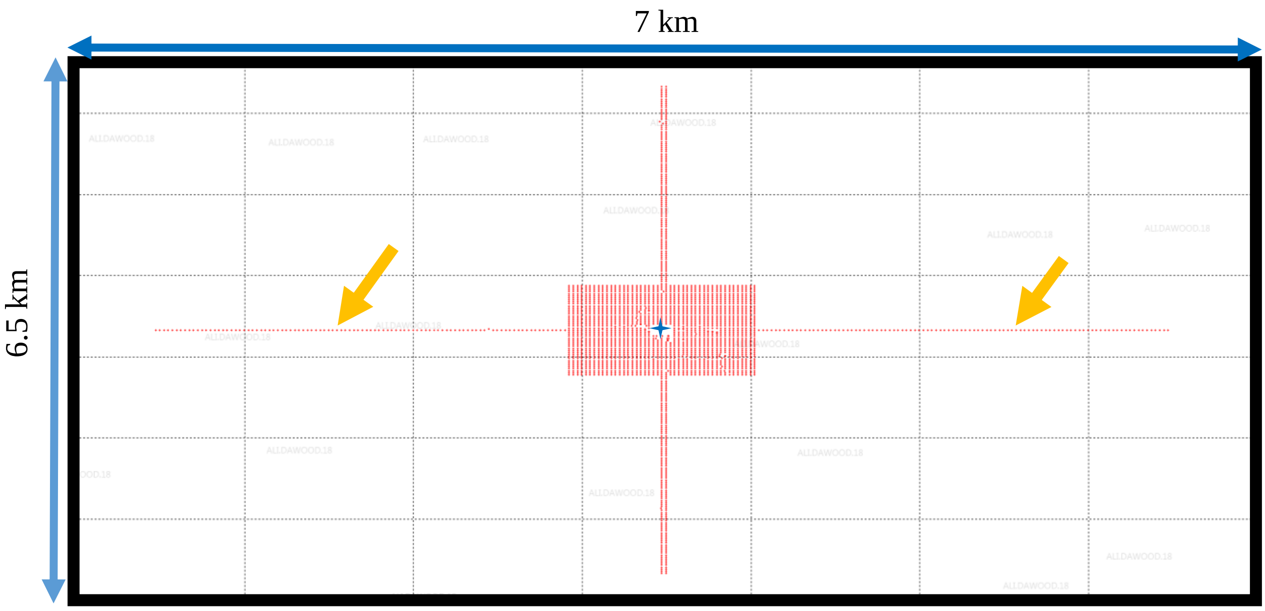

***Figure 1**: DrillCam acqusition geometry: wireless receivers layout. The rig location is denoted by the blue star.*

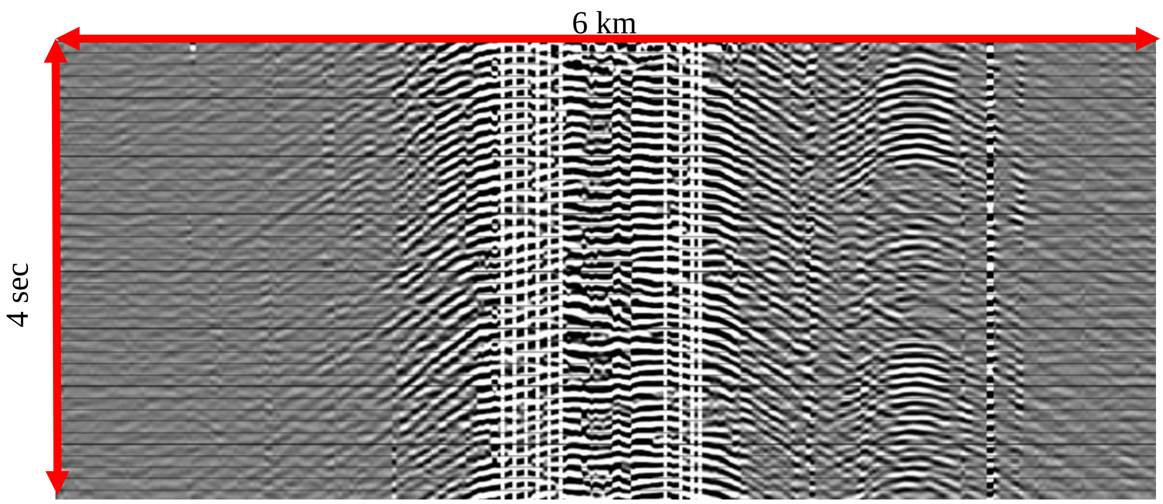

***Figure 2**: DrillCam field experiment: a typical drill-bit noise record showing the uncorrelated data recorded by 283 wireless geophones along the east-west line indicated by the yellow arrow in Figure 1.*

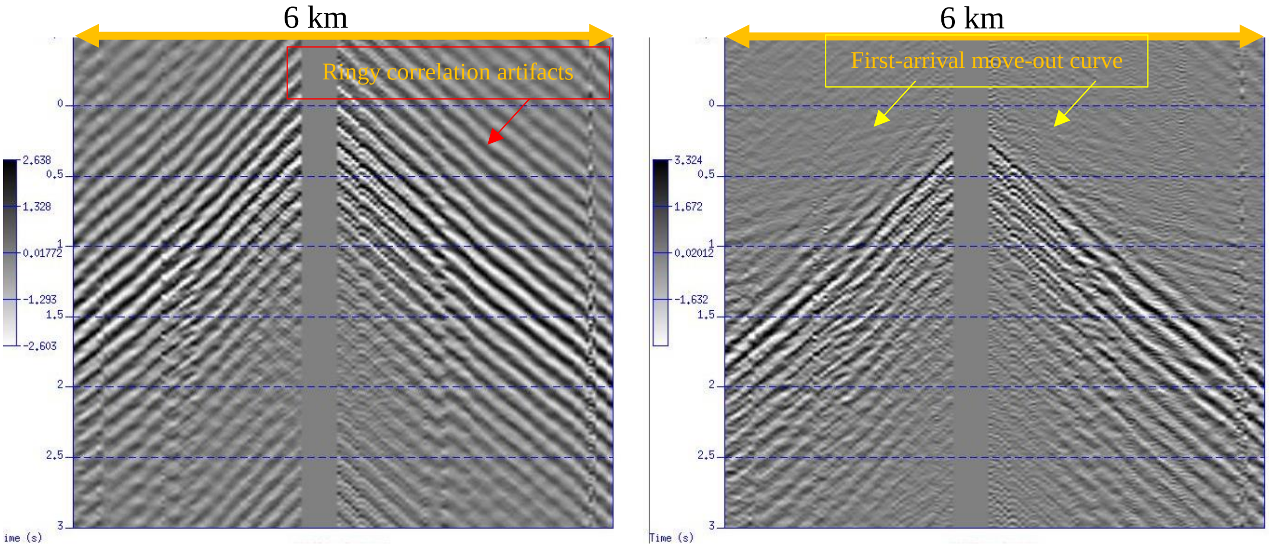

Figure 3*: Removing the drill-noise signature by conventinoal cross-correlation with top-drive pilot (left) and with deconvolion of the top-drive pilot (right). The deconvolution operation help collapse the artifacts denoted by the red arrow and revealed the weak first-arrivals from the source at 2200 ft depth level marked by the yellow arrows.*