Feasibility of seismic while drilling without the use of a pilot signal based on synthetic modelling

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SUMMARY

Seismic While Drilling (SWD) dataset was recorded by Distributed Acoustic Sensing (DAS) fibre optic cables installed in two monitoring wells while drilling a new well at the Otway Carbon Capture and Storage site. The data was recorded passively using the drill bit as a seismic source in a crosswell geometry. Consequently, the main challenge of such a setup is the unknown source trigger time which can be resolved by correlating with a recorded drill bit pilot signal using a sensor on or near the rig, which is not the case here.

Without pilot recording, this case study investigates the feasibility of SWD and characterising the drill bit source by applying the Time Reversal method to synthetic data. A ground model of the Otway site was generated using well logs and geological formations information. Elastic modelling was performed to synthesise data using a weighted combination of vertical and horizontal sources to imitate a drill bit generating different levels of primary and shear energy. Then, a Kirchhoff-based implementation of the Time Reversal method was used to backpropagate the data.

The results achieved are promising. The representative modelling enabled a better understanding of the wavefield generated by the drill bit. Source focusing was investigated by backpropagating the modelled wavefield. Calculating the RMS energy sum over an extended backpropagation time led to a reasonable estimate of the source location and wavelet.

Key words: Seismic While Drilling (SWD), Distributed Acoustic Sensing (DAS), Drill-Bit Source, Time Reversal.

INTRODUCTION

Acquiring surface seismic data requires extensive preplanning due to the tremendous amount of equipment to be mobilised to the field. Any effort to reduce the amount of used equipment would reflect positively on productivity, reducing the overhead costs and the associated risks. For example, eliminating the active vibroseis source trucks would reduce the costs and eliminate the human risk of their operators. Seismic-While-Drilling (SWD) is a passive seismic technique where the drill bit is used as a seismic source to infer subsurface geological information (Miranda et al., 1996). Several SWD methods have been developed and used for various geophysical applications extending to the mining industry (Zhou et al., 2015). These methods commonly employ receivers on the surface or within nearby wells to listen passively to the noise emitted by drilling. As the seismic source has an unknown signature, recording the drill bit signature or pilot is essential to successfully decode recorded drill bit noises and resolve the source emission time (Rector and Marion, 1991). Most literature methods require an additional receiver along the drill string to record the pilot signal of the drill bit, which is then cross-correlated with other receivers to imitate an active seismic survey.

Ideally, one would like to continuously record the pilot signal as close as possible to the drill bit location. However, that limits the real-time ability to process and interpret the recorded data as current downhole recording options are memory-based, do not allow real-time high-bandwidth telemetry, and lack accurate time clocks (Egorov et al., 2021). Downhole receivers are also an engineering challenge that adds complexity and cost. Alternatively, a receiver is usually placed on the drilling rig to record a time-delayed version of the drill bit pilot signal. On the downside, reliance on the latter option mainly faces availability issues and can have depth limitations as its quality degrades with the increasing drilling depth (Silvestrov et al., 2021). Additionally, the cross-correlation of a pilot signal recording can propagate undesired recorded pilot noise into the correlated records (Yoon et al., 2015).

This case study is motivated by recorded SWD data dating back to 2019 during the preparation for Stage 3 of the CO2CRC Otway project (Pevzner et al., 2020). In a cross-well configuration (Figure 1), fibre optic cables installed within monitoring wells CRC-2 and CRC-3 were used to record distributed acoustic sensing (DAS) data while drilling shallow and deep sections of the CRC-4 well consecutively. The CRC-4 well was drilled with a downhole motor from the same well pad as the CRC-3 well using a Polycrystalline Diamond Compact (PDC) bit. Drilling the mostly vertical shallow section of the CRC-4 well, up to around 950m measured depth, was recorded using a fibre optic (FO) cable installed in the vertical CRC-2 well, approximately 630m apart. Drilling the deeper deviated section was recorded using a FO cable installed in the CRC-3 well. Relative to the CRC-3 well, the top of the deeper section is offset by around 96m, and the bottom is 399m apart. It is worth noting that no recording of the drill bit pilot signal was performed. Hence, in this abstract, we will focus on SWD through synthetic modelling to investigate the possibility of eliminating the need for a recorded reference pilot signal, ultimately simplifying the data acquisition requirements and saving cost.

TIME REVERSAL METHOD

Using a passive source comes with challenges, especially as they are not controllable. The locations of the passive sources and their trigger times are unknown and need to be estimated to use passively recorded data effectively. Time reversal methods backpropagate the recorded wavefield back to its originating point in space and time. Theoretically, to explain the concept, Time Reversal for acoustic wave propagation in inhomogeneous media is considered here for simplicity (Fink, 1992). The wave equation of the pressure field $p(x,t)$ at receiver location x is as follows:

$$\nabla\left(\frac{\nabla p}{\rho}\right) = \frac{1}{\rho v^2}\frac{\partial^2 p}{\partial t^2}$$

Where $v(x,t)$ and $\rho(x,t)$ are the velocity and density, consecutively. If $p(x,t)$ is a solution to this wave equation, $p(x,-t)$ is also a solution; however, it is a non-causal one. Therefore, we limit ourselves to $p(x,T-t)$ where T is the total recording time. This solution requires recording the wavefield at each subsurface location x over $0 \leq t \leq T$ interval before retransmitting it in reverse time, which is non-feasible. Thus, having a measurement of the wavefield and its normal derivative at a limited portion of the medium allows for calculating it at all other points within the medium using the Kirchhoff integral, which becomes more realistic. This follows Huygens principle, where every source creates a propagating wavefront, generating secondary sources at all points within the medium.

Ultimately, using the actual medium velocity, the backpropagated wavefield gets focused at the primary source location and t corresponding to the direct wave arrivals. Otherwise, the source energy would be out of focus at positive and negative onset times. Another variable affecting energy focusing is the used velocity, where focusing would be best using the actual velocity and would be off spatially with the wrong velocity.

APPLICATION TO SYNTHETIC DATA

The application of the time-reversal method is illustrated using synthetic elastic data. To understand the wavefield generated by the drill bit interaction with formations being drilled within the deeper section of the CRC-4 well, we create a representative velocity model using well logs and formation boundaries from the monitoring CRC-3 well (Figure 2a). For simplicity, and as the two wells are a few hundred meters apart, a layered 1D velocity model is created. Elastic modelling is initially performed for a source at a depth of 1200m from the Kelly Bushing along the well trajectory, simulating a single source firing in time at that depth. A weighted sum of the vertical components of vertical and horizontal sources is used with a Ricker wavelet of 50Hz peak frequency, which was then differentiated in depth to simulate a drill bit source recording on DAS. A combination of vertical and horizontal sources simulates a single drill bit source firing with different levels of p-wave and s-wave components. For receivers in the vertical monitoring well, one-meter spacing is used over depths of 277m to 1667m. Figure 3a shows the resulting modelled seismograms; for comparison, the actual recorded data at the same depth is shown in Figure 3b. Main event curves from both seismograms can be identified despite the different onset travel times and the repetitive nature of the actual data. Given the nature of the modelled source and the DAS recording, the representative modelling enabled a better understanding of the wavefield generated by the drill bit.

The modelled synthetic seismogram in Figure 3a was backpropagated using the actual p-wave velocity model. Figure 4 demonstrates the time-reversal energy focusing for the modelled wavefield. As the modelled data primary and shear arrivals have opposite polarities above and below the source depth, it resulted in destructive interference at the exact onset time and source location. Yet, this did not impede the source location estimation as the energy focusing is better indicated by calculating the maximum RMS energy over an extended propagation time period. Figure 5a shows an image of the RMS energy summed over a 100ms propagation time around the actual onset time. The white asterisk indicates the midpoint between the two maxima of the energy sum indicated by magenta crosses. This midpoint estimates the source location in space and depth, which in this case occurs at a depth of 1199m and an x position at 591m. Figure 5b shows an RMS energy trace at that x position. The estimated source location is within 9m of the actual source location at 1200m depth and 600m x position. Additionally, a reasonable estimate of the source wavelet was achieved, as shown in Figure 6. Similar results were obtained using the s-wave velocity but are not shared here.

CONCLUSIONS

We describe a case study based on synthetic modelling and present an investigation of a time-reversal method to characterise the drill bit as a passive source. Given the nature of the modelled source and the DAS recording, the representative modelling enabled a better understanding of the wavefield generated by the drill bit. As direct arrivals from above and beneath the source had opposite polarities, backpropagation of the wavefield resulted in a non-single point focusing around the onset time. Yet, this did not impede the source location estimation as the calculated RMS energy sum over an extended backpropagation time led to a reasonable estimate of the source location, especially in depth. Additionally, a reasonable estimate of the source wavelet was achieved. These promising results pave the way for a more extensive study and potential application to field data, where the ultimate goal is to simplify data acquisition and save costs.

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REFERENCES

Egorov, A., A. Bakulin, I. Silvestrov, and P. Golikov, 2021, Research Note: Automated data-driven alignment of near-bit and top-drive vibration sensors for seismic while drilling and beyond: Geophysical Prospecting, **69**, no. 7, 1560-1568. http://dx.doi.org/10.1111/1365-2478.13119.

Fink, M., 1992, Time reversal of ultrasonic fields. I. Basic principles: IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control, **39**, no. 5, 555-566. http://dx.doi.org/10.1109/58.156174.

Miranda, F., L. Aleotti, F. Abramo, F. Poletto, A. Craglietto, S. Persoglia, and F. Rocca, 1996, Impact of the seismic 'While Drilling' technique on exploration wells: First Break, **14**, no. 2. http://dx.doi.org/10.3997/1365-2397.1996004.

Pevzner, R., K. Tertyshnikov, E. Sidenko, and L. Ricard, 2020, Monitoring Drilling and Completion Operations Using Distributed Acoustic Sensing: CO2CRC Stage 3 Project Case Study: First EAGE Workshop on Fibre Optic Sensing.

Rector, J. W., and B. P. Marion, 1991, The use of drill-bit energy as a downhole seismic source: Geophysics, **56**, no. 5, 628-634. http://dx.doi.org/10.1190/1.1443079.

Silvestrov, I., E. Hemyari, A. Bakulin, Y. Luo, A. Aldawood, F. Poletto, Y. Liu, Y. Du, A. Egorov, and P. Golikov, 2021, Processing of Seismic-While-Drilling Data from the DrillCAM System Acquired with Wireless Geophones, Top-Drive, and Downhole Vibrations Sensors: SPE Middle East Oil & Gas Show and Conference.

Yoon, B., K. G. Park, C. Lee, K. Yang, Y. Song, T. J. Lee, and I. Park, 2015, Pre-processing for Seismic While Drilling Data with Unfavorable Pilot Condition Acquired in the Vicinity of Geothermal Well in Pohang, Korea: World Geothermal Congress.

Zhou, B., I. Mason, S. Greenhalgh, and S. Subramaniyan, 2015, Seeing coal-seam top ahead of the drill bit through seismic-while-drilling: Geophysical Prospecting, **63**, no. 1, 166-182. http://dx.doi.org/10.1111/1365-2478.12172.

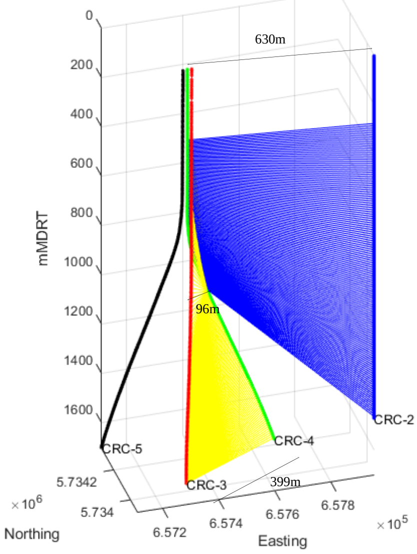

Figure 1. Diagram of the wells and the acquisition geometry. While drilling the CRC-4 well, the shallow section was recorded using a FO cable installed in the CRC-2 well. In contrast, the deeper deviated section was recorded with a FO cable installed in the almost vertical CRC-3 well.

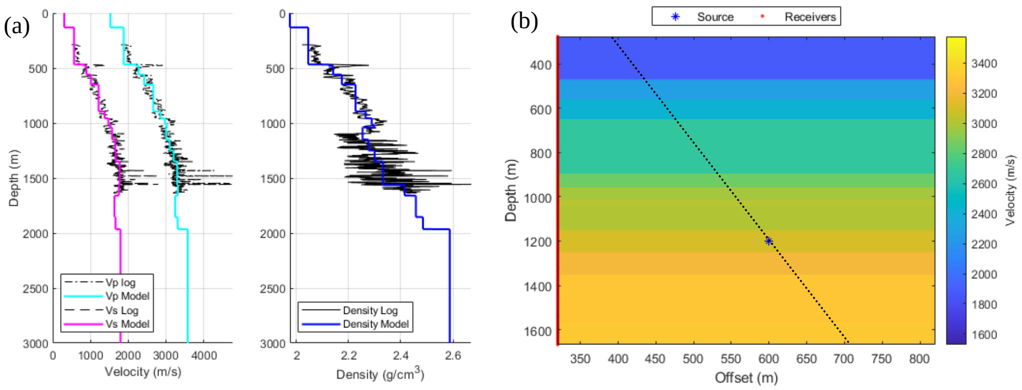

Figure 2. Velocity model generation for synthetic modelling: (a) 1D velocity model created from well logs (black) and geological boundaries. (b) Acquisition geometry overlay over a depth section of the 1D compressional velocity model (Red dots denote receivers at 1m spacing in depth. The blue asterisk indicates the source location within the trajectory of the well being drilled at 1200m in depth and 280m distance from the closest receiver).

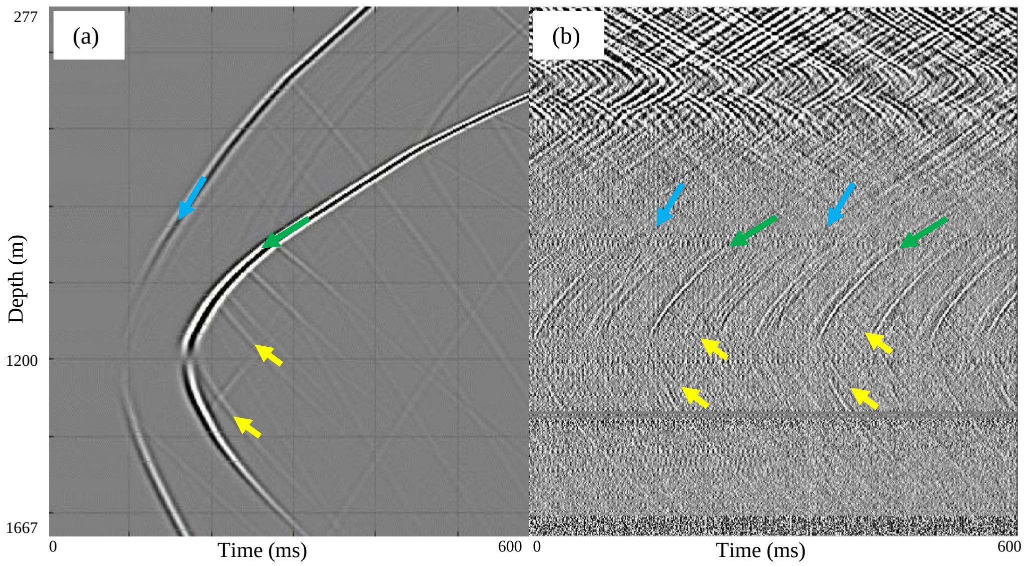

Figure 3. Seismograms from a source depth of 1200m from the Kelly Bushing (a) generated by elastic modelling and (b) recorded in the field. The field data is repetitive at random onset travel times compared to the modelled

data (Blue arrows indicate primary events, while green arrows indicate shear events. The yellow arrows indicate reflections from formations above the source).

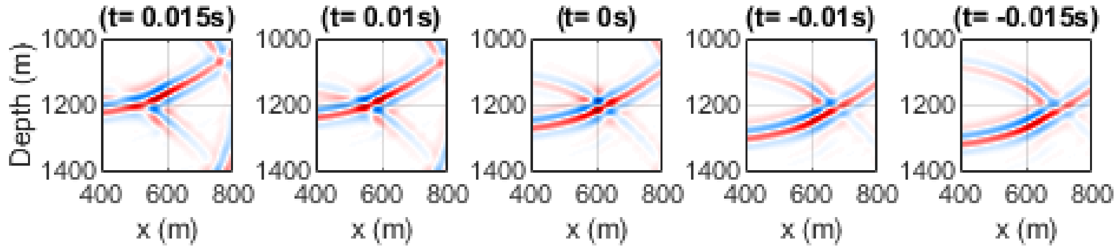

Figure 4. Source focusing using the actual velocity model. Each is a snapshot in time of the backpropagated wavefield where time is advancing from left to right. The wavefield energy is focused at t=0, where the source is actually located. The wavefield energy is defocused elsewhere.

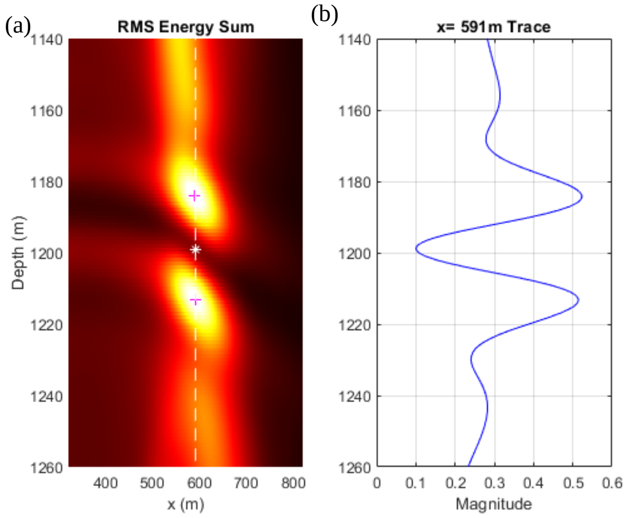

Figure 5. Characterising source focusing using RMS Energy. The left (a) image shows the RMS energy sum over 100ms propagation time around the onset time with two maxima and the mid-point estimating the source position. The right (b) plot shows an RMS energy trace for x=591m going through the mid-point.

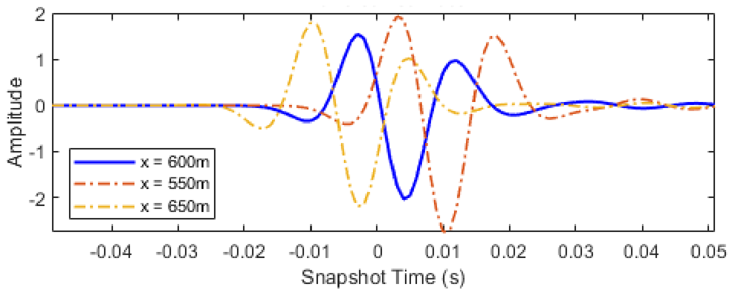

Figure 6. Estimated wavelet where source energy is focused (blue). The other two wavelets show how different the wavelet is at offset x locations at the same depth.