Acquisition trial of DrillCAM: real-time seismic with wireless geophones, instrumented top drive and near-bit accelerometer

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Summary

DrillCAM aims to deliver continuous geophysical measurements while drilling to enable drilling optimization and automation. The first field trial was conducted in an onshore well and delivered a complete dataset from surface to 10,000 ft. Three datasets were continuously recorded including from 1) a large array of surface wireless geophones, 2) accelerometers placed on the top drive and 3) a downhole vibration tool near the drill bit. Novel wireless geophones delivered seismic data close to real time during drilling and enabled flexible adaptive geometries with depth. An innovative continuously recording downhole tool comprising a sub-millisecond sampled accelerometer acted as an invaluable stethoscope at the rockface next to the bit. Data analysis is ongoing to harvest the value of this unique data for drilling optimization.

Introduction

Seismic-while-drilling (SWD) has been demonstrated to deliver valuable information not available from other sources (Poletto and Miranda, 2004; Naville et al., 2004). Significant challenges associated with instrumentation and signal levels were identified and partially overcome, whereas incorporation of geophysical information by drillers remained limited (Naville et al., 2004). In recent years, the drilling industry put significant emphasis on optimization and automation as key directions enabling any further improvements. Automation and optimization require a step change in sensing capabilities as well as real-time analysis. Just like self-driving cars were enabled by a myriad of new sensors monitoring the surrounding environment in 360 degrees and all possible conditions affecting driving, automating drilling requires to measure and infer a lot more information to characterize conditions near and ahead of the bit. To appreciate the step change one needs to compare amount of sensors and capabilities of regular cars and self-driving cars. A LIDAR sensor alone at the top of a self-driving car beams 1.4 million laser points per second to create a 3D map of the surroundings. A similar trend is emerging in drilling manifested by growing availability of fast EM-based telemetry and increased popularity of downhole drilling and vibration measurement data. Yet, these measurements are still insufficient to achieve robust optimization and automation. This drilling-wide push for better instrumentation could be a good signal for the geophysical community that the time has come to revisit what we can do for drilling in the context of instrumentation advances and greatly improved computational algorithms including those based on artificial intelligence. DrillCAM (Drilling CAMera) introduced by Al-Muhaidib et al. (2018) was conceived to fill this sensing gap to assist drilling optimization and automation as well as to address specific exploration challenges described below. Seismic-while-drilling is one of many DrillCAM components, but the scope is broader and includes multiple additional geophysical measurements and techniques to address drilling optimization and automation: from drillstring vibration health to estimation of formation properties at the bit to imaging ahead of the bit.

Figure 1 shows schematics highlighting key initial sensing components evaluated: surface geophones, rig sensors and downhole sensors at the bit, all working together. For imaging ahead of the bit, both rig and downhole sensors can record pilot data. Data acquired while drilling shallow

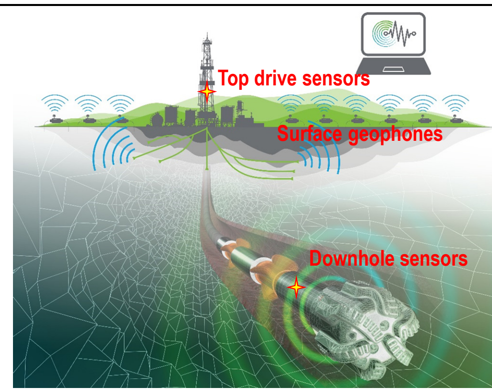

Figure 1. Sketch outlining main components of DrillCAM system.

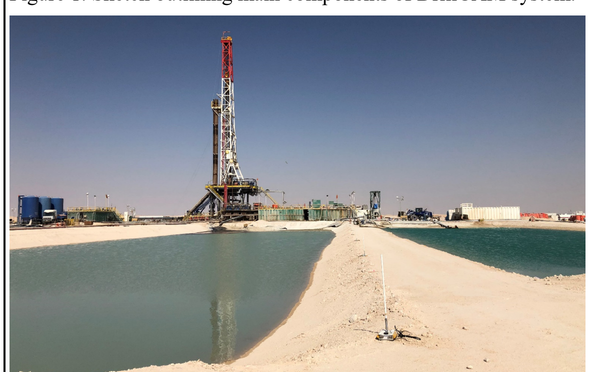

Figure 2. DrillCAM field trial at an onshore rig. Line of wireless geophones with antennas is seen going towards the rig.

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complex sections can also fill a near-surface geophysical "data gap" and significantly improve positioning accuracy for low-relief structures and stratigraphic traps. These shallow sections rarely contain any wireline logging data, whereas while drilling data can be safely and confidently acquired each and every time. While borehole seismic can help, it is usually conducted in the presence of multiple strings of casing in the shallow part that introduces its own set of challenges. Unless we measure continuously – we cannot describe formations that are drilled or conditions of the bottom hole assembly (BHA) or drillstring. If we do not know these conditions, then every decision we take is more like a gamble and optimal process can only occur by luck. Lack of continuous high-quality data is also a subsurface barrier to new approaches to drilling optimization based on Artificial Intelligence (AI). These approaches are essentially based on the availability of good-quality representative statistics describing all possible drilling and subsurface conditions. If your training datasets are limited – power of AI predictions is low. Both rig and downhole sensors capture important drilling dynamics data characterizing drillstring and BHA vibrations near the bit. Continuous high-frequency data from such vibration sensors become a new norm instead of intermittent "burst" records that used to be common in the past. This is clearly analogous to the evolution of continuous high-frequency sensors on self-driving cars.

DrillCAM aims to advance and integrate an unparalleled suite of such continuous surface and downhole measurements that can deliver real-time solutions for drilling and geophysics. Here we focus on describing acquisition details of the first DrillCAM field trial.

First DrillCAM field trial on onshore well

DrillCAM trial was conducted with the following objectives:

- verify the feasibility of acquiring seismic signals from the drillbit in real time using wireless surface geophones,
- evaluate drillbit signal strength for drilling window 0-10,000 ft using roller cone and PDC bits,
- validate various pilot measurements of drillbit signal including seismic accelerometers placed downhole near the bit as well as at the top drive on the surface,
- compare and evaluate the value of information obtained with top drive and downhole sensors, and
- collect continuous data 0-10,000 ft to characterize formation properties and drilling dysfunctions as a first step towards AI-based approaches.

Since no integrated commercial system is available on the market, we identified the best fit-for-purpose components and assembled our own DrillCAM system. Most components were recent arrivals and their testing represented an additional technology objective. A typical onshore well was selected for the trial (Figure 2). The complete dataset was acquired from surface to about 10,000 ft using roller cone (34", 28" and 22" sections) and PDC bits (16" section).

Surface seismic sensors

Surface sensors for DrillCAM need to satisfy three main requirements listed in Table 1. Out of three main options available, it is clear that wireless receivers, transmitting data close to real time as opposed to blind memory nodes, are the only ones satisfying all three requirements. As a result, we opted for trial testing one of the wireless systems available commercially. A lightweight and cableless system was essential to enable placing sensors within the rig pad (Figure 3) so that both signal and noise can be captured at near offsets for efficient processing using high-density seismic acquisition. Likewise, the same features enabled easy deployment of adaptable geometries. While drilling shallow sections 2,500 wireless stations were deployed covering a smaller aperture with a denser sampling, whereas deeper sections were recorded with a larger layout and sparser sampling using same number of sensors. Sensor

Solution	Cabled systems	Nodal systems	Wireless receivers
Light weight cableless system with for ease of operation		✓	✓
Adapt to different geometries (e.g., receiver spacing and areal coverage)		✓	✓
Continuous recording in real time with no need for equipment and data retrieval	✓		✓

Table 1. Various recording solutions for DrillCAM.

Figure 3. Wireless geophones placed within the rig perimeter.

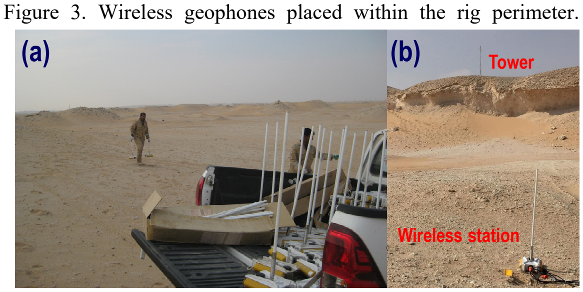

Figure 4. Placement of wireless geophone stations (a) and transmitting over jebels with additional radio tower (b).

repositioning was achieved during casing/cementing operations with little manpower (Figure 4). The final and

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most critical aspect for DrillCAM is the ability to collect data close to real time for quick delivery of various

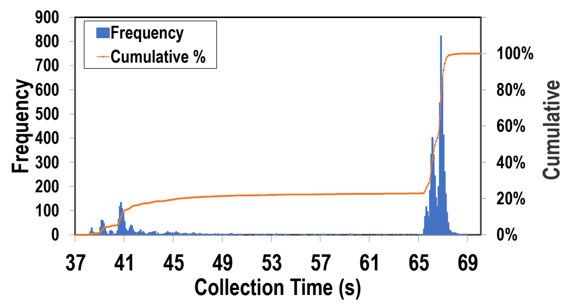

Figure 5. Histograms summarizing wireless collection time process for recording period of ~60 hr using 2750 stations. In less than 68 sec (from end of the trace) 100% of the data is available for real-time processing at the main recorder located on the rig.

solutions for drilling. This last aspect was quantified by measuring average distribution of collection times (Figure 5) that indicate when data arrives at a central recorder. It can be seen that data arrives in two main batches. Bottomline is that 68 sec after end of the trace, all the data is available at the rig central recorder for real-time processing. This is an excellent result that satisfies the near-real-time needs of seismic-while-drilling while enabling operational efficiency and flexibility. Conservative collection settings were set to maximize data recovery, whereas faster times are achievable with very small losses acceptable for DrillCAM applications.

Wireless stations are powered by removable batteries that can be easily swapped. Since charging status is also monitored from the central recorder in real time, battery swaps can be optimized to occur during non-drilling periods and daylight hours. Since conventional geophones are connected to the local wireless stations by a short cable – the sensor itself remains inserted during the swap and maintains consistent and repeatable coupling throughout the entire cycle of acquisition. Single geophones were used in this trial, however geophone arrays can be similarly connected to the same wireless stations maintaining all listed advantages.

Instrumented top drive

To measure drillstring vibration induced by the drill bit, the top drive was instrumented with two 3C accelerometers (Figure 6). The top drive rotates the drillstring and is mounted on top of the drillstring, and therefore such sensors are expected to measure axial, torsional and transverse vibrations of the drillstring-rig assembly (Poletto and Miranda, 2004). Since there was no commercially available wireless system certified for hazardous areas on the drilling assembly and able to record continuously, a cabled system was utilized. The top drive is extremely busy piece of equipment and finding an appropriate location was challenging. This is one clear case for future improvement where new instrumentation such as remote sensing can deliver vibration data from multiple locations while significantly simplifying the logistics and enhancing the safety of the operation. Remote sensing also has potential

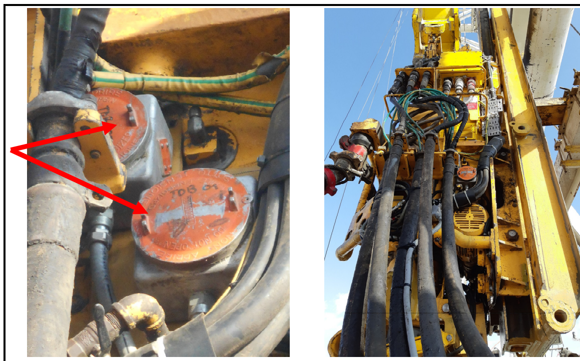

Figure 6. Two orange boxes (a) house top drive sensors attached to the body of the top drive. Their positioning with respect to the rest of the equipment can be seen on (b).

to take readings of the rotating drillstring while avoiding potential interference with other parts of vibrating surface equipment attached to the top drive.

Downhole sensor

Downhole sensors have been shown to provide a better pilot for seismic-while-drilling (Poletto and Miranda, 2004). Previously they were not readily available. Things started to change when the drilling community adopted 3C downhole accelerometers as a part of the BHA in order to characterize drilling malfunctions (Greenwood, 2016). While initially such tools recorded so called “burst” data (short windows of data with long silent periods), it has been realized that drilling malfunctions can develop rather quickly and may easily occur outside the recording periods. As a result, continuously recording tools are growing in popularity. This makes perfect sense for both instrumented rigs as well as geophysical applications. While such tools are referred to as recording “high-frequency” data by drillers, they have normal seismic 1-2 ms sampling and detailed tool specs are similar to SWD requirements (Table 5.1 in Poletto and Miranda, 2004) in terms of frequency range and resolution.

Figure 7 shows placement of such a downhole tool inside a bit sub right above the 28” rollercone bit used for one of the shallow sections. Such tools are quite small, do not interfere with drilling operations, and can be used essentially with any bit and hole size all the way to surface.

Unlike wireless geophones and top drive sensors, downhole tools record data into memory so data can be retrieved only after pulling out of the hole. With the growing availability of fast EM-based telemetry there is potential to have this data transmitted to surface close to real time if such information is proven superior and critical for real-time drilling decisions.

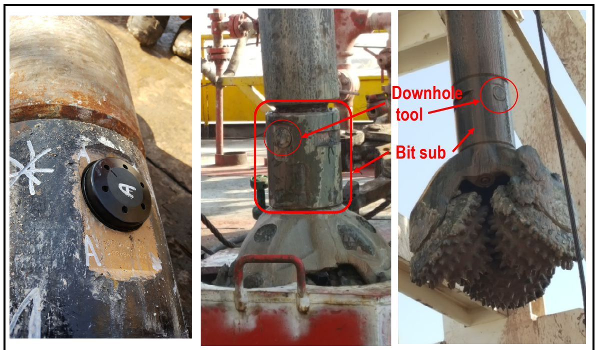

Figure 7. Downhole tool placed inside the bit sub near 28" rollercone bit.

Continuous recording and time synchronization

All three measurement systems record in parallel and deliver complete continuous data at a comparable time sampling thus providing a unique starting point to characterize drilling and non-drilling related activity. Figures 8, 9, and 10 show sample records of each data type collected during drilling of one of the shallow sections. Various DrillCAM applications often require combined usage of data from geophones, top drive sensors and downhole tools. This requires accurate time synchronization. Geophones and top drive sensors are separately and continuously recording 30 sec traces starting at the top of each minute. Since both systems are GPS synchronized with a time error of less than a fraction of a millisecond, combining these data at the rig is a straightforward task. As explained, downhole data is recorded into memory and retrieved at periodic intervals. At present no GPS synchronization is available before placement, whereas downhole clocks further experience some drift. Introducing more a accurate clock and making proper synchronization, could be one future improvement allowing faster analysis and more efficient integration with demanding seismic applications. In the absence of these acquisition improvements, correlation of surface and downhole drilling and vibration data remains the only data-driven option to synchronize the timing between surface and downhole datasets.

Conclusions

We have conducted the first successful trial of DrillCAM at an onshore well delivering a complete dataset of multiple continuous measurements from surface down to 10,000 ft. Three main acquisition components consisting of surface geophones, top drive sensors and downhole accelerometers, were integrated together for the first time using both existing and novel elements. Specifically, we evaluated wireless geophones and proved they can reliably deliver large volumes of data close to real time for DrillCAM applications. The use of wireless stations allowed sensor placement within the rig pad in areas crowded with equipment where cabled systems would not be viable. In addition, the wireless system enabled use of flexible and adaptable surface acquisition geometries with apertures that increase with depth that are optimal for seismic-while-drilling. A continuously recording 3C downhole accelerometer was successfully tested and delivered reliable data with sub-millisecond sampling. This data will be utilized for seismic imaging, formation characterization and identifying drilling malfunctions. Continuous recording of all data and completeness of the dataset (0-10,000 ft) make it a perfect candidate for various analysis techniques based on Artificial Intelligence.

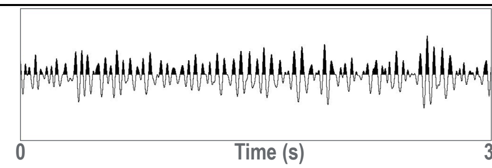

Figure 8. Sample data recorded on vertical component of the top drive accelerometer.

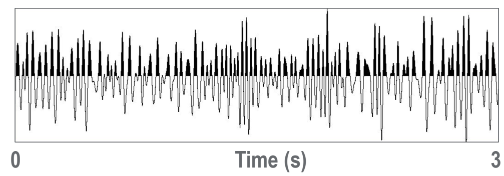

Figure 9. Sample data recorded on vertical component of the downhole accelerometer near the drill bit in 28" section.

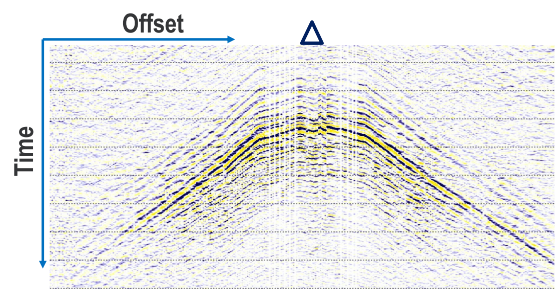

Figure 10. Surface geophone shown after correlation with vertical component of top drive accelerometer along one of the 2D lines.

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