With drilled wells expected to exceed 45,000 a year globally by the end of 2018, it is hard to underestimate the importance of wellbore survey accuracy. Concentrated areas of interest and evolving drilling technology are resulting in wells being placed closer together than ever before, making surveys not only a necessity but an integral part of a safe and successful drilling process.

**Why is the survey accuracy so important?**
The most basic goal of any wellbore survey is to ensure that the drilling plan is followed, given that the uncertainty of the surveys is much smaller than the geological target; this is a necessary condition to hit the geological target. Wellbore surveys also serve to accurately update and verify reservoir models, which have an important value for future drilling development and valuation of the field. Wellbore surveys are an essential part in the context of risk mitigation, helping operators avoid HSE events like penetrating high-pressure reservoir zones too early or drilling into existing adjacent production wells, which could lead to loss of life and environmental damage. Finally, accurate surveys help minimise financial losses by reducing the number of necessary production shut-ins while drilling new wells and preventing the loss of a slot from a drilling pad which might occur if the drilling plan is not closely followed.

**Vulnerabilities with current technology**
Traditional magnetic MWD survey systems are based on the Earth’s magnetic vector, an unstable reference that can lead to erroneous or unexpected results. Complex and
expensive magnetic modeling techniques have enabled reductions and control of some of these errors. However, declination error, axial interference from magnetic material in the tool string, formation and magnetised mud among others are frequently found, with different levels of impact, in current ‘corrected’ MWD data. In the case of horizontal wells with orientations on or near East or West directions, the impact of the errors is larger and the corrections tend to be much less reliable.

Gyroscopic survey systems are based on the Earth’s rotation vector – a stable reference – that allows computation of the tool azimuth, or bearing, with respect to geographic (true) north. While spinning mass gyro sensors have been successfully used for decades on wellbore surveys, including while drilling applications, they are prone to gravity-dependent (g-dependent) errors. These errors, resulting from mass unbalance changes and other imperfections, often require careful calibration, pre-job tests and sophisticated on-line correction methods. Alternatively, it is possible to conduct single-shot surveys while the drilling operation takes place, but they present operational challenges, such as increased rig time due to trips in and out of the hole, additional personnel, as well as the need for a conveyance method like electronic wireline.

Capitalising on new technology

Recent developments in the area of solid-state gyroscopes, specifically high accuracy Coriolis Vibratory Gyros (CVGs) bring the benefits of small size, low power consumption and simplicity, while maintaining a level of accuracy comparable to or exceeding that of the best mechanical spinning mass gyros currently used in oilfield applications. Capable of sustaining tens of thousands of g, these solid-state systems are not susceptible to g-dependent bias error effects and offer greater ease of use. Another benefit is related to survey time; the CVGs can start collecting data immediately after power has been supplied while the spinning mass gyros need time to reach the nominal spinning speed as well as for the temperature to be settled.

Better together

The way of verifying the accuracy of a survey tool is through quality control (QC). There are several approaches to QC a survey, but it is well known within the wellbore survey community that the most reliable method of survey QC is derived from comparing two or more independent and un-correlated survey methods. This is increasingly common practice for some operators, since verified accuracy leads to lower risks and ultimately reduced costs.

In addition to quality control, an accurate value of azimuth from the gyroscopic tool can be used to investigate possible issues with the magnetic model utilised by the MWD tool. Current magnetic models use satellite information and aeromagnetic, land or marine magnetic surveys to build a theoretical model of different components of the Earth’s magnetic field. Even though much effort goes into this highly sophisticated process, it has been reported that local magnetic anomalies, particularly when considering aspects related to depth and declination, are not properly accounted for and result in significant survey errors that are outside the expected uncertainty predicted by their respective error models. These errors are not identified with the standard QC; they are only evident when the data are compared with a gyroscopic survey.

Having an accurate downhole azimuth enables verification and estimation of the magnetic field parameters downhole, which is where the magnetic survey tool takes its measurements. This can be performed post-drilling to correct the positioning of the well or while the drilling process takes place, which allows improvement in wellbore placement in addition to more accurate positioning.

Case study – magnetic model verification

An operator recently employed the OmegaX drop tool, which makes use of the CVG technology and consists of two independent 3-axis gyro survey tools. The tools are connected with a crossover and each tool had its own independent batteries and centralisation. This configuration provides the benefits of data redundancy as well as higher accuracy obtained when the two surveys are combined and the uncertainty is therefore reduced. The wellbore had the typical profile of an unconventional well in US land. It had a vertical/low inclination section to near 6500 ft, a rapid build section to 90˚ inclination and a long lateral section. The well was drilled with traditional MWD tools employing IFR for magnetic reference modelling, and multi-station analysis was performed on the data as the drilling process took place. OmegaX was dropped before a required bit trip when the bit was near 12 000 ft measured depth (MD). Because of the formation and the drilling conditions, and to avoid getting stuck in the hole, an agitator was placed in the drill string which prevented the drop tool reaching the BHA; the drop tool only went down to 8500 ft MD.

The inclination comparison shows good agreement within the expected uncertainties predicted by the error models. The azimuth also shows good agreement between the MWD and OmegaX. The difference in azimuth between the two surveys produced a separation on the horizontal coordinates that is also within the separation uncertainty predicted by the error models for both tools, as can be seen in Figure 1.

This survey was the fourth of a series of surveys from the same pad. The previous three surveys showed similar results, inclination and azimuth values that are slightly different between the magnetic and the gyroscopic surveys, but within the error model uncertainty. After analysing all the data, it became evident that there was a systematic difference in azimuth between the surveys. Even though it is not possible to establish the source of the discrepancy in an absolute way, it is possible to speculate on the possible sources for the difference, which is of the order of 0.2˚. Due to the nature of the gyroscopic tools, errors are expected to exhibit a random behaviour, and acknowledging that four is a very small number of wells, the likelihood of all gyro surveys having an error with the same sign is near 6%. Another possible explanation is that there is an error

Figure 1. (Top) Spinning mass gyro while drilling; (Bottom) solid-state equivalent.
on the estimation of the declination utilised by the magnetic tools. An error in declination will produce surveys with a systematic azimuth error, and this is the most likely source of the azimuth discrepancy seen in the data. As more data is gathered and the tool becomes a proven survey technology, it will be possible to investigate these issues further.

The operator was able to reduce the uncertainty of the drilled wells and also establish a basic assessment of the quality of the magnetic modelling and corrections performed on the MWD surveys.

Redefining accuracy
The CVG based tools have been field tested for over a year, with 40 000 ft and more than 1000 hrs of exposure to the drilling environment as well as nearly 200 000 ft of survey in drop mode. The commercial version of the gyro-while-drilling tool is expected to be launched in the first half of 2019. The tool is designed to provide the following benefits:

- Increased accuracy in the final position of the well when run as a drop or some other survey tool post drilling.
- It allows corrections in real time to MWD data resulting in highly accurate placement of the wells.
- It can replace the MWD tool on top hole section, particularly in areas of magnetic interference.
- It can provide a cost-effective alternative to drilling blind or with inclination only surveys; verticality as well as direction can be monitored real time, enabling all the benefits of wellbores with low tortuosity in the top hole section.
- Low tortuosity benefits relate to achieving the planned final depth for extended reach wells as well as the placement of artificial lift means.

**Conclusion**
Survey accuracy is a fundamental part of the directional drilling process, with severe implications for risk and profitability. The application of high-quality solid-state gyroscope technology and the resulting improvements in survey accuracy, data quality reliability, and operational simplicity are enabling new alternatives to current survey techniques. Magnetic survey measurements can now be independently verified, and combined gyroscopic and magnetic measurements can be used to further reduce survey uncertainties. Additionally, there is now a feasible alternative to the complex and expensive magnetic modelling employed with MWD surveys.

**Figure 2.** EOU comparison between corrected MWD and OmegaX.

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