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IADC/SPE-SPE-180652-MS-MS

Improving Directional Survey Accuracy through Real-Time Operating Centers

Shawn DeVerse, Surcon Ltd
Stefan Maus, Magnetic Variation Services LLC

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This paper was prepared for presentation at the IADC/SPE Asia Pacific Drilling Technology Conference and Exhibition held in Singapore, 22–24 August 2016.

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Abstract

Standard directional surveying practices are subject to numerous error sources which can cause inaccurate placement of the wellbore. This is problematic because inaccurate wellbore placement increases collision risk, reduces reservoir drainage, and impacts subsurface models. Web-based software was developed to provide rig site personnel with a simple interface to transfer survey data in real-time to survey analysts in a remote operations center. The web interface is easily accessible via standard web browsers and enables users to upload data in any format without the need to manually configure or manipulate data fields. Independent survey quality analysis by remote operating centers is the most effective way to validate directional survey accuracy and to ensure it is free from gross or large systematic errors that exceed the assumptions of the positional error model. Furthermore, by applying multi-station analysis corrections and using in-field referencing geomagnetic models, the positional uncertainty of the wellbore trajectory can be reduced by 50 percent or greater. These methods improve wellbore placement substantially at a low operational cost, thus significantly increasing the value of the wellbore.

Introduction

When directionally drilling wellbores, there is no direct way to measure the three dimensional position of the well path. Therefore, we rely on indirect survey measurements of the wellbore inclination and azimuth (direction) in order to interpolate the wellbore trajectory. Standard measurement while drilling (MWD) is the most common method for measuring the wellbore inclination and azimuth. However, standard MWD methods are subject to numerous error sources which cause significant uncertainty in the computed wellbore position (Torkildsen 1997). Error sources include gross human error, random error attributed to instrument noise, systematic error from poor instrument calibration or magnetized steel in Bottom Hole Assembly (BHA) components, reference model errors, and external magnetic error from nearby offset wells. The industry steering committee on wellbore survey accuracy (ISCSWA) developed a standardized error model, or tool code, for MWD surveys in order to provide a mathematical

framework for quantifying the positional uncertainty from these various error sources, with the exception of gross error. The tool code enables the computation of Ellipsoids of Uncertainty (EOUs) of the wellbore position. These EOUs combine to an elliptical cylinder as shown in **Fig. 1**, which contains the well path with a given confidence level, typically chosen as 95%. The ISCWSA error model is used to assist drillers when assessing well placement uncertainty and the associated collision risk with offset wellbores.

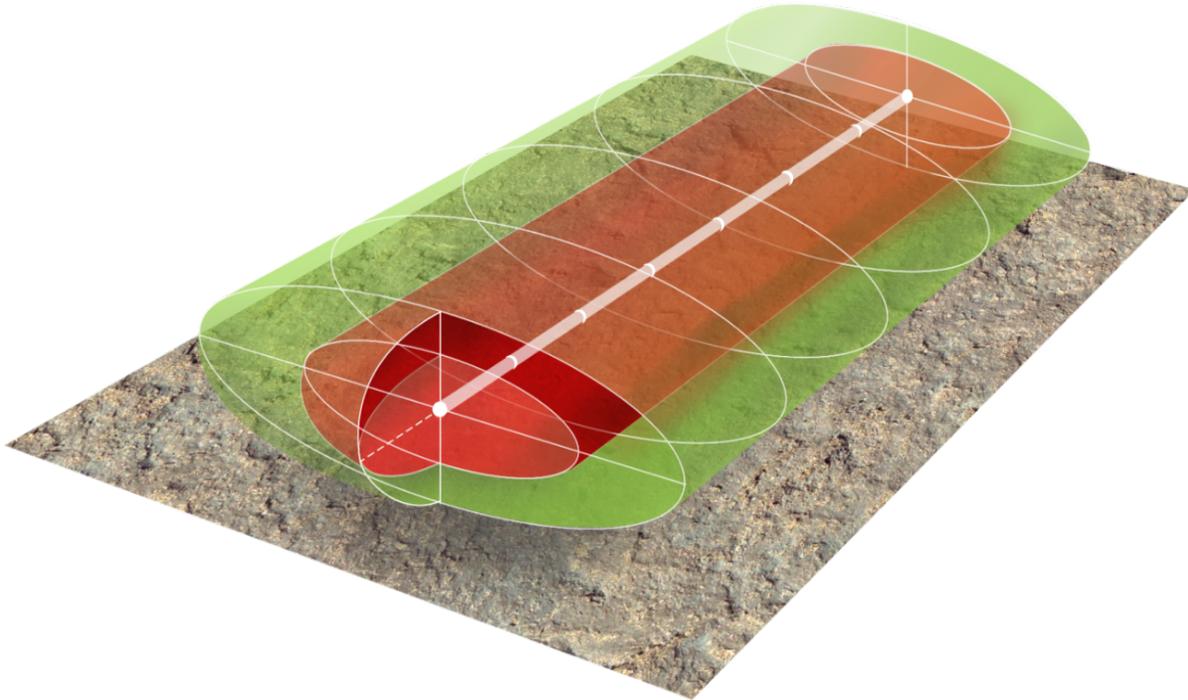


Figure 1. Elliptical cylinder representing the statistical distribution of the wellbore position computed from the ISCWSA error model.

There are numerous assumptions made regarding MWD survey quality when using the MWD tool code to model EOUs for collision risk. Currently, there is no industry standard for quality control (QC) of MWD survey data. Many surveying companies use QC tolerances to provide some basis of field acceptance criteria for survey measurements. However, these tolerances are often arbitrarily based on legacy values and are not actually based on the assumptions made in the MWD tool code. These QC tolerances can also vary significantly between surveying companies, despite often times using the same surveying technology and/or the same EOUs to evaluate collision risk. Furthermore, there is often a lack of well-defined operational processes for identifying and preventing gross human error. This creates the opportunity for introducing significant errors into the wellbore position. Therefore, it is critical to the accuracy of the wellbore position to establish a rigorous quality control process that effectively mitigates against gross human error, as well as systematically evaluates MWD survey quality against the assumptions made in the MWD tool code used for EOU computation and collision avoidance planning.

MWD Surety Validation

An MWD instrument houses six sensors - three accelerometers and three magnetometers positioned orthogonally as demonstrated in **Fig. 2**. These sensors measure the Earth's gravity and magnetic field vectors, which can be used to compute six survey values: inclination, magnetic azimuth, tool face, total gravity, total magnetic field, and dip angle. The first three, inclination, magnetic azimuth, and tool face, are used to directionally steer the wellbore. The remaining three parameters, Total gravity, total magnetic field, and dip angle are called the measured QC parameters and are used to validate the accuracy of the survey. Ideally, the measured QC parameters should be equal to the expected values given by reference models of the local gravity and magnetic field (Ekseth 2010). Any difference between the measured QC parameters and the reference values is caused by error sources such as inaccurate reference values, random noise in the measurement, local magnetic field distortions or systematic errors associated with the instrument sensors. Of course, the QC parameters are not expected to perfectly agree with the reference values. Acceptable tolerances can be computed directly from the MWD tool code, as described below. If the measured QC parameters are within the acceptable tolerances, then the survey passes QC. If on the other hand the measured QC parameters are outside of the tolerance interval, then the survey fails QC and is not used. This concept of qualifying MWD surveys against the MWD error tool code assures that the wellbore is placed with the expected accuracy and that well placement uncertainties are within the computed EOU.

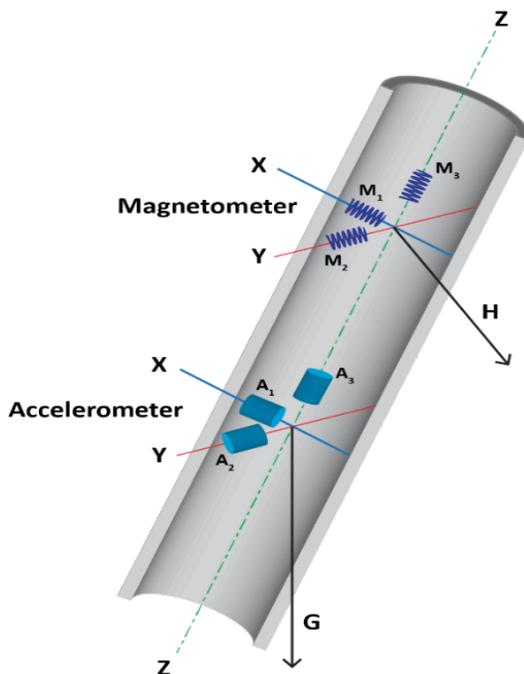


Figure 2. Orthogonal placement of accelerometers and magnetometers housed within an MWD instrument.

Computation of QC Tolerances

The QC tolerances can be computed directly from the assumptions made in the MWD error model tool code in order to create a consistent standard method of QC. The MWD tool codes contain error model coefficients which specify the Gaussian one-sigma error magnitudes of the dominant error sources. These coefficients, together with their weighting functions and propagation modes, are used to compute the ellipsoids of uncertainty of the wellbore position (Torkildsen 1997). Similarly, these error terms can also be used to compute the expected one-sigma error in the measured total gravity, total magnetic field, and dip angle (Maus 2014). Since dip angle is correlated with both total gravity and total magnetic field, the expected errors are correlated and the measured QC parameters should be plotted three dimensionally, where each axis represents one of the QC parameters as shown in **Fig. 3**. Using the same magnitude of error as assumed in the MWD tool code, the resulting ellipsoid represents a one sigma error distribution for the total survey measurement. The QC ellipsoid is then scaled to the same sigma level used for anti-collision risk analysis. If the measured QC parameters fall within the ellipsoid, **Fig. 4**, then the survey passes QC. If the survey measurement falls outside of the ellipsoid, **Fig. 5**, then the survey measurement fails QC and should be retaken or discarded.

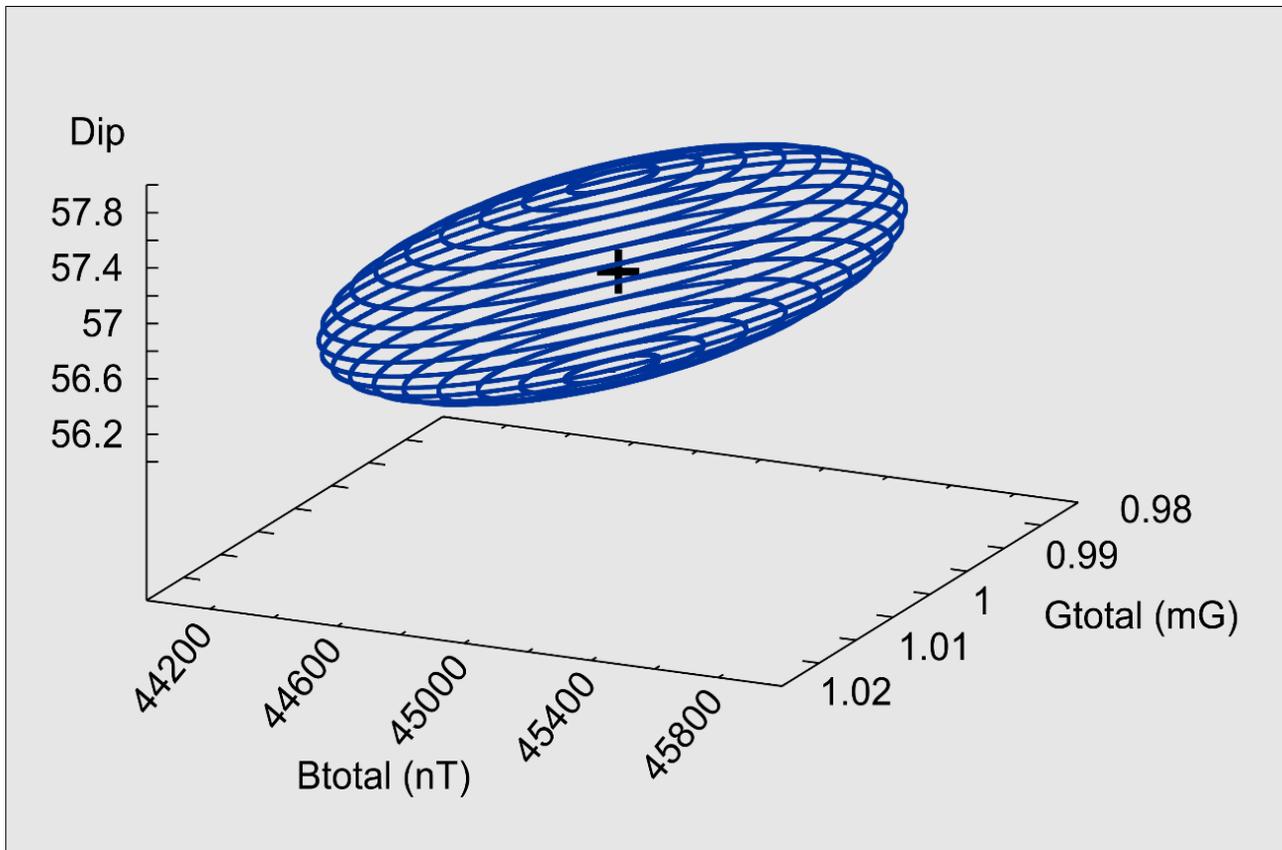


Figure 3. Error in total gravity (Gtotal), total magnetic field (Btotal), and magnetic dip are plotted as an ellipsoid.

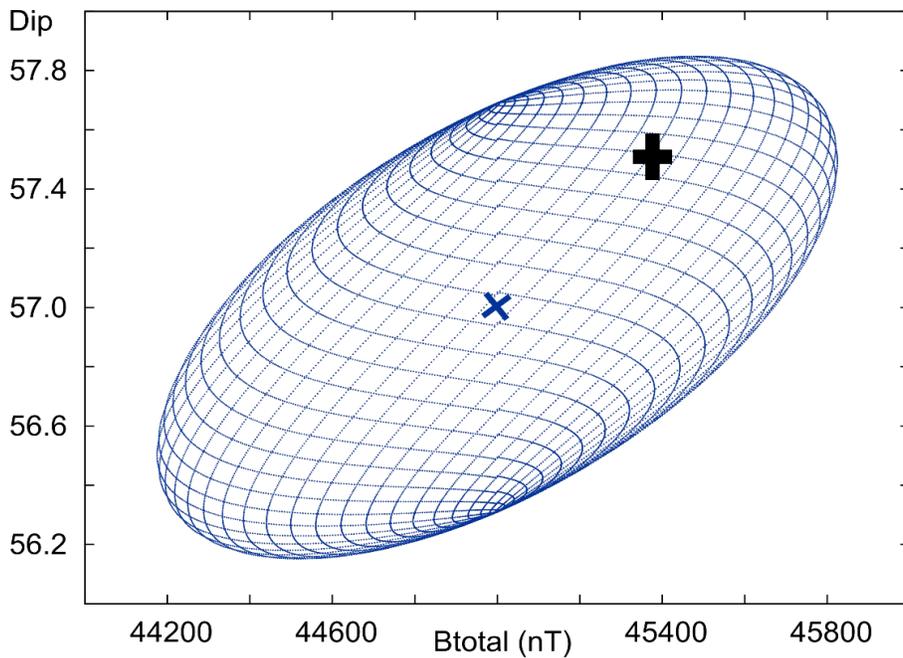


Figure 4. Survey error plotted three dimensionally falls within QC ellipsoid.

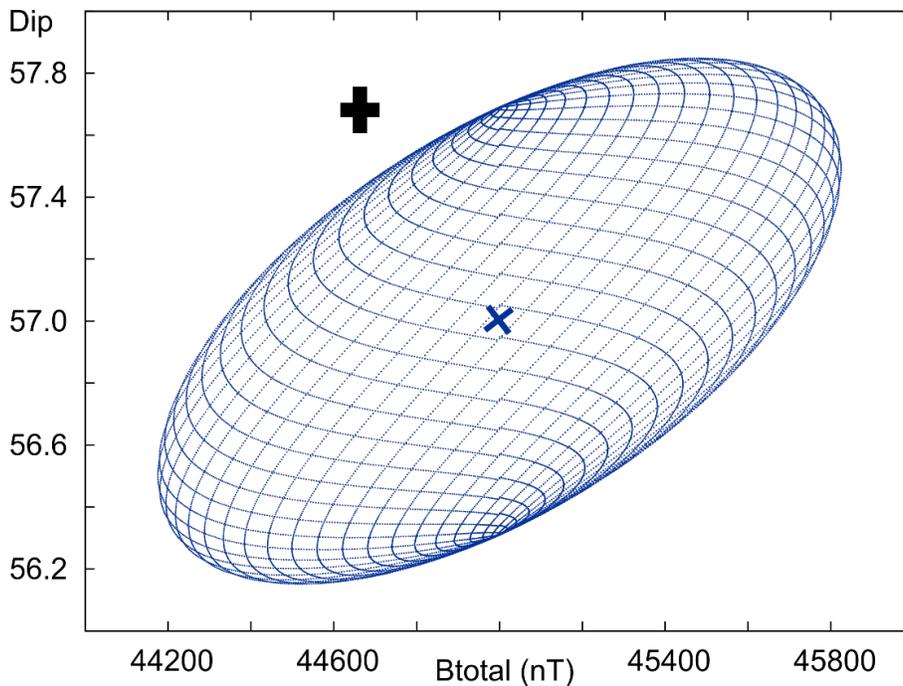


Figure 5. Survey error plotted three dimensionally falls outside QC ellipsoid.

Preventing Gross Error

There are several single points of failure where gross errors can occur and not be identified by the standard QC process. For example, if an incorrect grid convergence or reference declination is used to convert magnetic azimuth to grid or true azimuth, then it will likely go unnoticed. Clerical mistakes are another common source of gross error. If the depth, inclination, or azimuth is incorrectly recorded onto the definitive listing, or if survey stations are correlated to the wrong depth, then significant error could be introduced and never realized. Therefore, it is important to create a standard workflow that not only

controls the quality of survey measurements against the reference models, but also independently validates survey calculations and records for gross errors.

Web-based Technology

Independence is the most powerful form of quality assurance. Validating survey measurements externally from the rig-site MWD decoding software enables an independent and consistent method which can be standardized across multiple vendors and surveying technologies. Web-based software can provide a robust platform for efficiently implementing independent survey QC into all drilling operations with minimal training, cost, and integration time. A web application was designed to facilitate this process where survey measurements are received directly from the rig site and validated in real-time for quality assurance. **Fig. 6** outlines the process flow as it would be implemented into drilling operations.

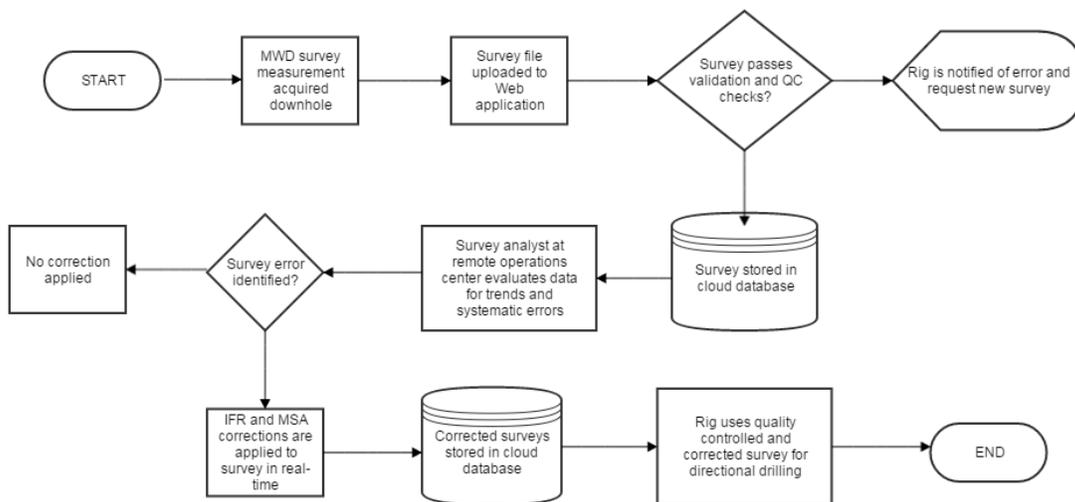


Figure 6. Operational process for validating MWD survey quality during drilling operations.

MWD operators upload survey export files directly to the web application after taking a survey measurement, using a standard internet browser as illustrated in **Fig. 7**.

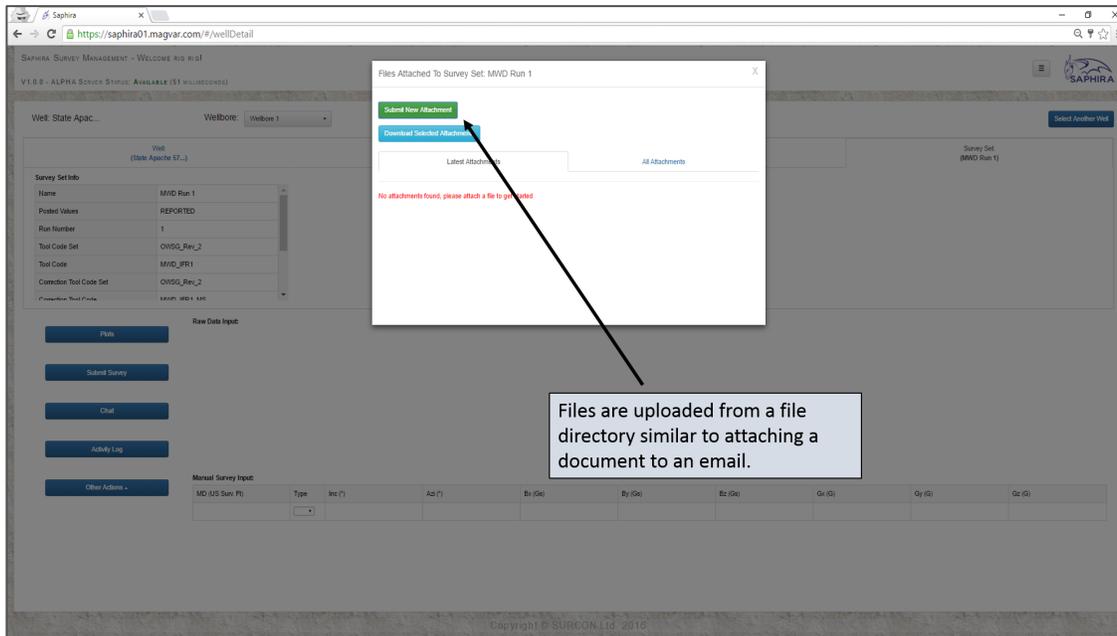


Figure 7. File upload process on web application

The survey undergoes numerous data validation checks to ensure that it is free from gross or excessive error. The following validation checks are applied:

- Measured depth: survey depth should increment positively along the well path and changes should not be greater than the pre-defined depth interval.
- Inclination: reported inclination should be equal to the calculated inclination from the raw accelerometer measurements.
- Azimuth: reported azimuth should be equal to the calculated azimuth from the raw accelerometer and magnetometer measurements plus the appropriate declination and grid correction.
- North reference: reported azimuth should be computed using the correct north reference (True or Grid).
- Survey quality 1: The measured total gravity, total magnetic field, and dip angle QC parameters should be within the tolerances computed directly from the appropriate MWD tool code.
- Survey quality 2: Measurement noise should be consistent with entire data set. Statistical outliers should be identified as likely to have excessive random or gross error. Changes in noise could indicate instrument failure or the presence of new error sources.

If a survey fails validation, the rig-site user is immediately notified of the problem and given the option to re-shoot the survey, double check for clerical error, or ignore the error. Users can visualize survey quality plots on the web interface to assist with troubleshooting and quality assessment. **Fig. 8** shows an example of a dip angle QC plot. Once the survey is accepted by the user, the quality controlled survey data is uploaded and stored in a cloud database. Surveys are made available to rig-site users and remote users via the same web interface used to upload the survey data as shown in **Fig. 9**.

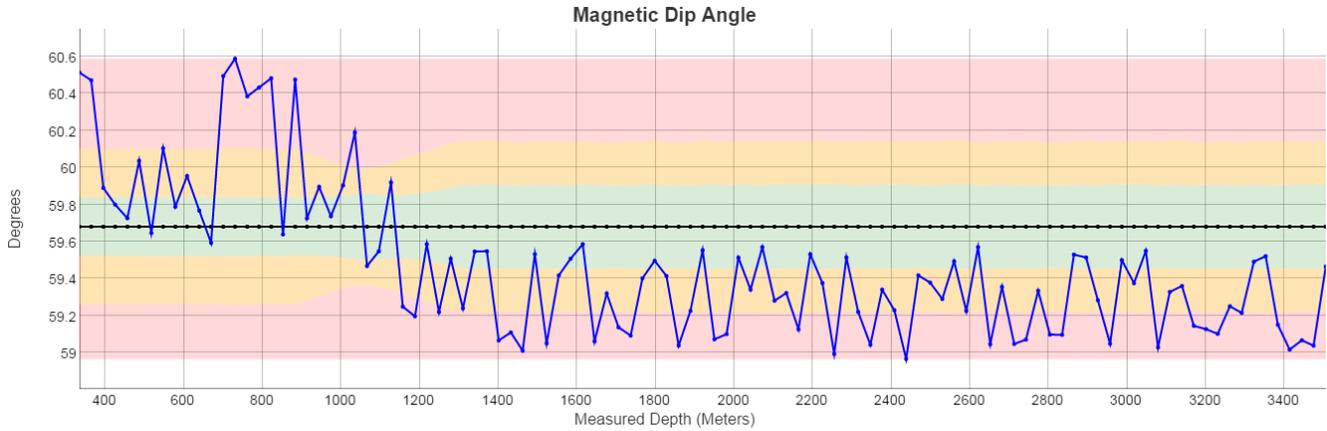


Fig 8. Magnetic dip angle quality control plot

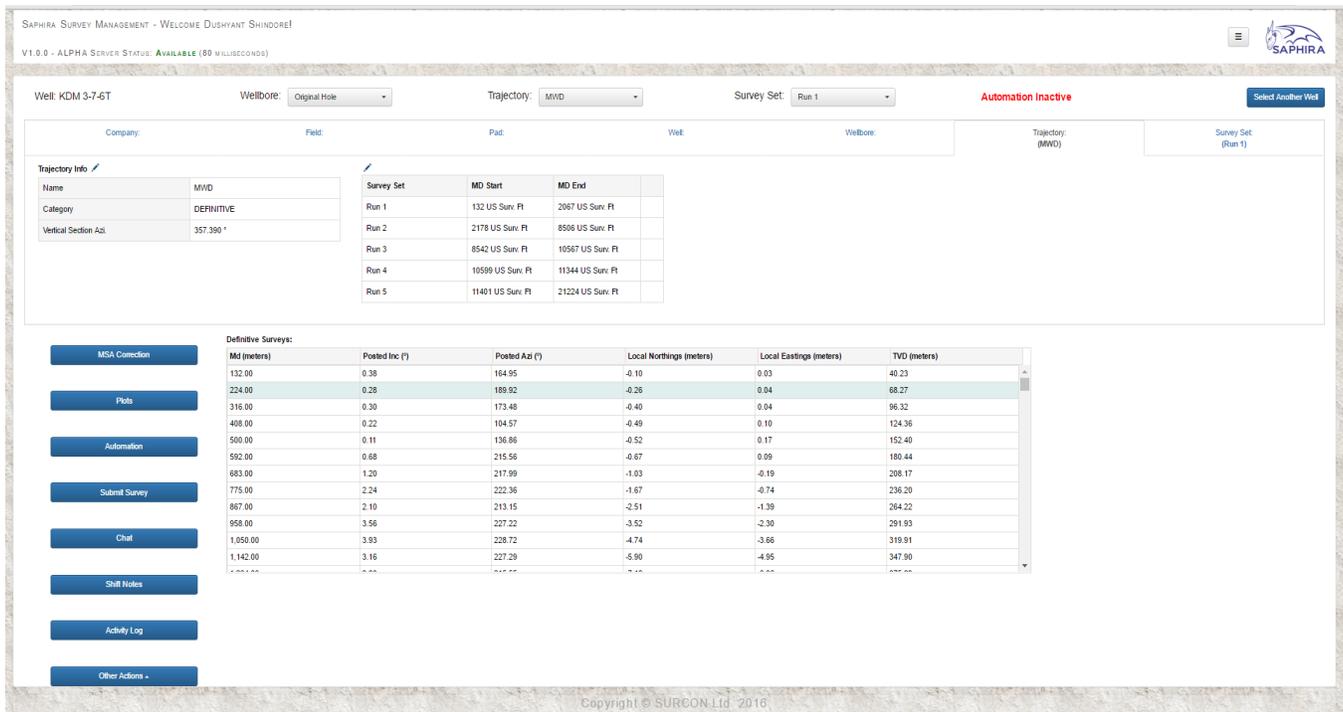


Figure 9. Validated and corrected definitive surveys are displayed to users and available for direct export.

Another benefit of managing MWD survey data via web based technology is that it enables quick and seamless access by remote operations centers. MWD survey measurements can be further evaluated against the entire survey data set for systematic errors such as sensor bias, scale, or misalignment using multi-station analysis techniques. **Fig. 10** shows an example of how a misalignment between the magnetic and gravity sensors presents itself in the survey data.

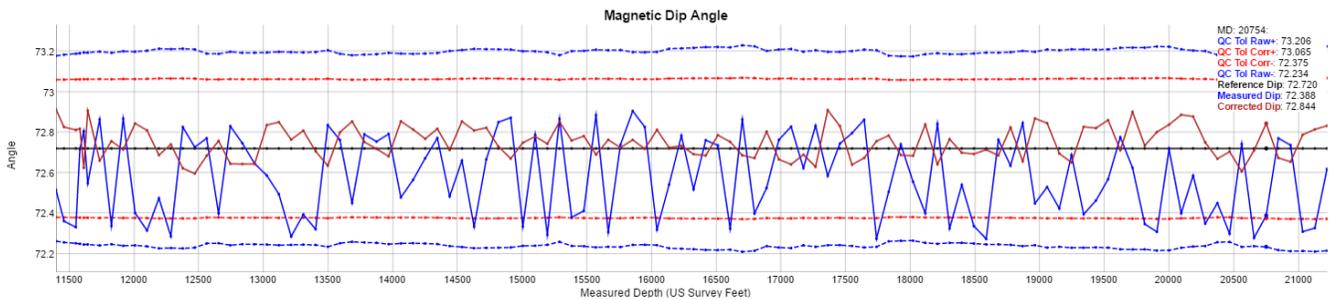


Figure 10. Measured magnetic dip angle (blue) plotted against corrected dip angle (red) to demonstrate cross-axis sensor

misalignment.

Surveys can also be evaluated for statistical significance such as excessive noise or uncharacteristic behavior, which could indicate magnetic interference from an offset well, movement in the drill pipe, or a failing MWD instrument. For example, pipe movement can be seen in the total gravity QC plot as an outlier in the accelerometer data. This type of expert analysis requires specialized skillsets rarely held by rig-site personnel, which makes it critical to access the survey data from remote operating centers. Remote survey evaluation using multi-station analysis not only provides the highest level of quality assurance, but also enables the application of survey corrections, which can reduce the ellipses of uncertainty and improve the accuracy of the wellbore position. Additionally, quality controlled and corrected survey data that are stored in a cloud database can easily be transferred to other applications such as survey databases, geosteering software, or well planning programs without the need for importing/exporting, copy/pasting, or emailing data, which are activities heavily prone to human mistakes and transcription errors.

Conclusions

It should not be assumed that standard MWD surveying will result in an accurate wellbore position without a standard and consistent method for validating the MWD measurements. Web-based technology offers a platform to independently QC data to verify that it is free of gross error and meets the assumptions of the MWD tool code. Independent survey quality control and analysis by remote operating centers is an improvement to traditional surveying practices because many gross errors often go overlooked and unchecked due to lack of transparency and rigorous QC procedures. Additionally, most rig site personnel do not have the specialized tools or training to expertly evaluate all of the various error types inherent to standard surveying methods. Novel web-based technologies have improved the efficiency of remote data transfer, making independent quality analysis and survey corrections much more efficient and cost effective. They should therefore be implemented across the board into any directional drilling operation.

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