IPTC-18761-MS

Real-Time Directional Survey Quality Improvement Using Web-Based Technologies

Stefan Maus, MagVAR LLC, and Shawn DeVerse, Surcon Ltd.

This paper was prepared for presentation at the International Petroleum Technology Conference held in Bangkok, Thailand, 14–16 November 2016.

Abstract

Optimal wellbore placement and collision avoidance requires accurate real-time steering of directional wells. Uncertainties in the wellbore position are accounted for by industry standard error models. However, these error models are only valid if the directional surveys are quality controlled and gross error is prevented by appropriate procedures. Particularly effective quality control is achieved by independent validation. A novel real-time web application was developed for the transfer of directional survey data between the rig site and a remote operations center. Surveying professionals at the rig site upload or import survey data into the web application in real-time. The survey measurements are then automatically validated through independent quality checks to identify gross error. Remote survey analysts can access the pre-qualified survey data and evaluate it for systematic or random error that would indicate non-compliance with the instrument performance model. Surveys can also be corrected in real-time when systematic error is identified and provided back to the rig site personnel for accurate steering and wellbore placement. This web service has been implemented and refined on over 50 rigs in North America. Examples for common types of errors that were prevented and/or corrected are incorrect magnetic declination, wrong north reference, excessive drillstring interference, poor instrument calibration, sensors misaligned with the wellbore and incorrect survey order. The impact of these errors if not prevented could easily cause 100 ft. or more in positional error at the bottom hole location. Real-time survey quality analysis provides higher confidence in wellbore placement, reduces risk of collision, and maximizes reservoir drainage.

Introduction

Wellbore placement by Measurement While Drilling (MWD) employs the use of orthogonally positioned accelerometers and magnetometers to measure the orientation of the bottom-hole assembly (BHA) relative to the Earth’s gravitational and magnetic fields. Taking survey measurements at regular intervals along the well path enables computation of the wellbore trajectory through minimum curvature interpolation.

Standard MWD surveying is subject to numerous error sources which can lead to inaccurate wellbore placement. These sources of error are divided into three categories: gross, random, and systematic. Gross errors occur from human mistakes, instrument failure, or environmental factors that cannot be predicted or estimated. Random and systematic errors occur with some measure of predictability and can therefore be estimated and quantified. The standard approach for estimating positional uncertainty in the wellbore caused by random and systematic survey error is to use Instrument Performance Models (IPM), also referred to as tool codes. Tool codes provide the mathematical framework to compute Ellipsoids of Uncertainty (EOUs) which represent positional uncertainty evaluated at a particular sigma, or confidence level (Grindrod 2016). Figure 1 shows how EOUs form an elliptical tunnel when propagated along the well path which characterizes the statistical distribution of where the actual wellbore could exist. Quantifying positional uncertainty is a critical step in the well planning and drilling processes because it enables drillers to evaluate collision risk and understand wellbore placement.

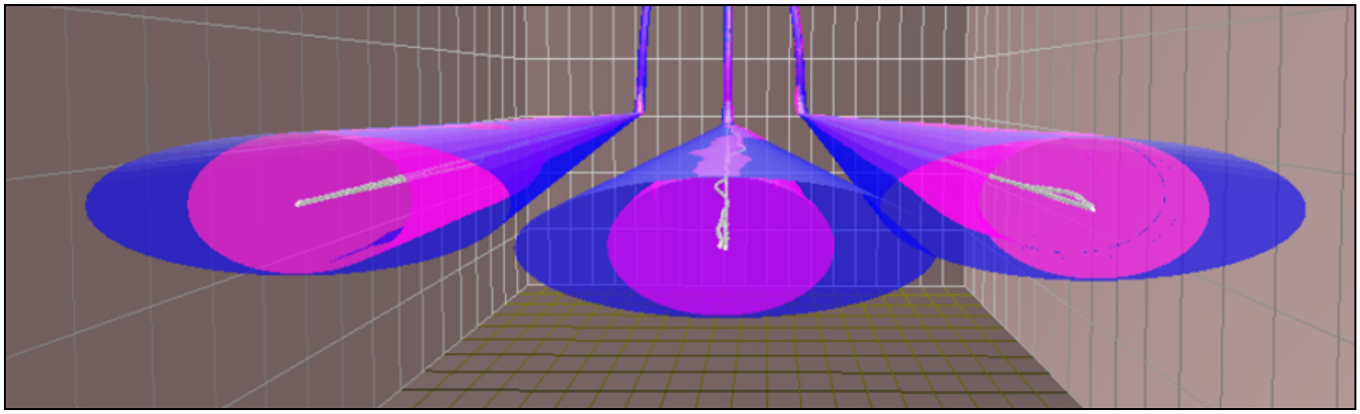

Figure 1: Ellipsoids of uncertainty computed from the IPM at each survey station. These EOUs indicate the region in which the wellbore could be located at a given confidence level. The blue ellipses represent standard MWD, while the smaller pink ellipses illustrate the reduction in uncertainty achievable using a more accurate geomagnetic In-Field Referencing (IFR) model.

It is important to note that the MWD tool code used for EOU and anti-collision calculations specifies the permissible magnitudes of the various error terms. Another assumption also made is that surveys are free of gross error, since gross error cannot be predicted or modeled (Torkildsen 1997). To validate EOUs and anti-collision scans, it is therefore essential to quality control MWD survey measurements to verify that they are free of gross error and do not contain excessive random or systematic error. If the quality control step is not performed, then there can be very little confidence that the tool code is representative of the actual errors in the wellbore position.

There are three values computed from MWD survey measurements which can be used for quality control purposes. They are B total (strength of the magnetic field), Dip (direction of magnetic field with respect to horizontal plane), and G total (strength of the gravity field) (Ekseth 2010). These measurements are used as metrics for survey quality, because regardless of the orientation of the wellbore and BHA, the measured B total, Dip, and G total should be equal to the values provided by the geomagnetic and gravity reference models. Therefore, any differences between the measured values vs reference values (Δ B total, Δ Dip, and Δ G total) can be attributed to some combination of measurement error and reference error. This concept is the basis for standard single-station MWD survey quality control tests.

It is common in standard MWD surveying practice to rely on these single-station tests as the only metric for survey quality assurance. However, these tests are considerably lacking in their ability to fully validate the assumptions made by the tool code. For instance, typical QC tolerances used by MWD contractors for passing or failing surveys are often arbitrary limits based on legacy practices. A more informative and standardized approach would be to use QC tolerances that are derived from the same tool code used to compute the EOUs. Furthermore, it is not enough to evaluate each survey individually because single-station QC tests are extremely limited in their ability to distinguish different types of error. It is preferable to evaluate single survey points against the entire survey data set in order to identify trends that could indicate what types of errors are occurring and to gain a better understanding of how the various errors may actually impact the wellbore position. Finally, single-station QC tests are not capable of detecting certain types of gross human errors such as applying an incorrect north reference or misreporting the final survey measurement. This makes it critical to independently calculate survey inclination and azimuth from the raw sensor measurements and to independently compute reference values to verify against human mistakes that would otherwise go unnoticed.

Web Application for Independent Survey QC and Validation

Independent survey quality validation and analysis requires specialized tools and skillsets which are not readily available to most rig-site personnel. As a result, the most powerful form of survey quality assurance comes from independent and expert analysis by specialized professionals in remote operating centers. Historically, it has been challenging to transfer the necessary MWD survey data to remote centers without compromising data integrity or adding cumbersome and time consuming steps to the drilling process. A web-based application was developed to provide an interface between rig-site users and remote operating centers that optimizes the transfer of directional survey data in such a way that minimizes time consuming steps while simultaneously providing automatic data validation ensuring data integrity. The web application is a leap forward from traditional methods of emailing text files and spreadsheets between end users because it not only speeds up the entire process, but it significantly reduces the occurrence of transcription and clerical errors. Another benefit to web technology is that it is easily accessible by almost anywhere on the globe by simply logging in through a standard internet browser. This eliminates the need for specialized software. An intuitive rig-site user interface (shown in Figures 2 – 6) enables the user to upload, visualize, and receive survey data with minimal training. User permissions can be customized to ensure that drilling data is secure and only accessible by authorized individuals.

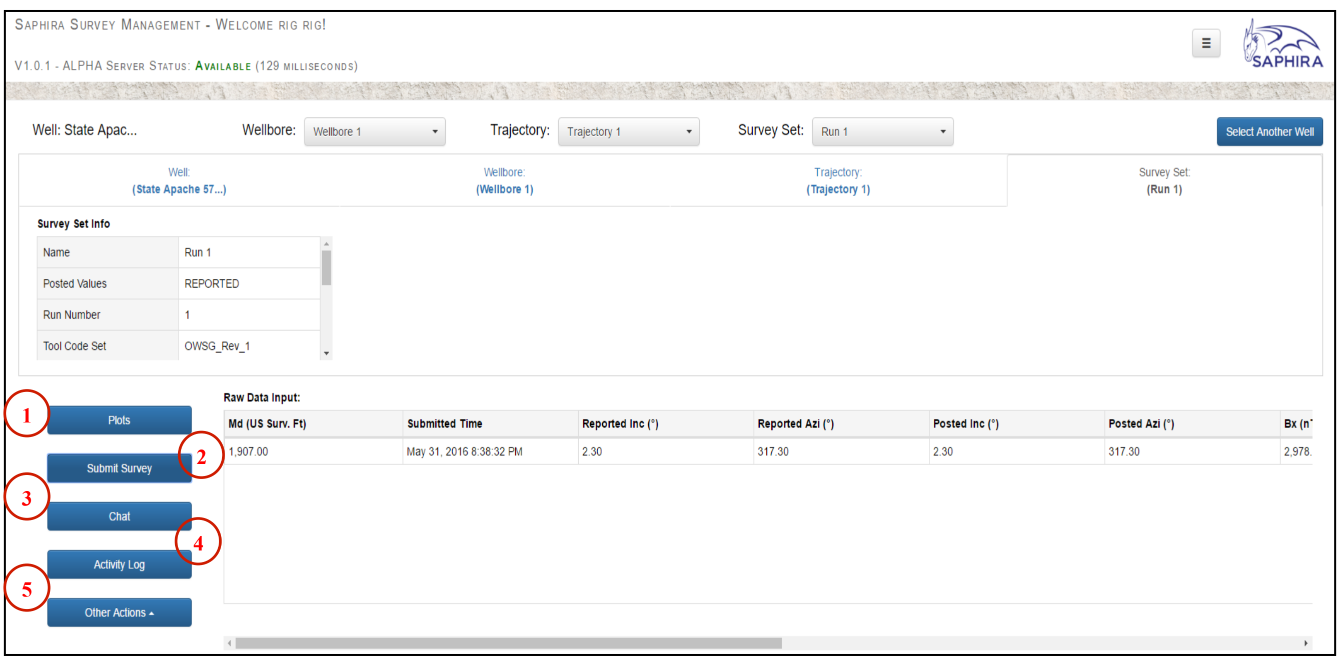

Figure 2: Rig-site web interface is simplified for ease of use.

1. Plots: enables rig user to visualize MWD survey data
2. Submit Survey: surveys can be submitted by uploading direct files or by manual entry
3. Chat: facilitates communication between rig user and remote operating center
4. Activity log: tracks results from QC tests and other validation checks
5. Other actions: additional functionality including survey import/export and file storage

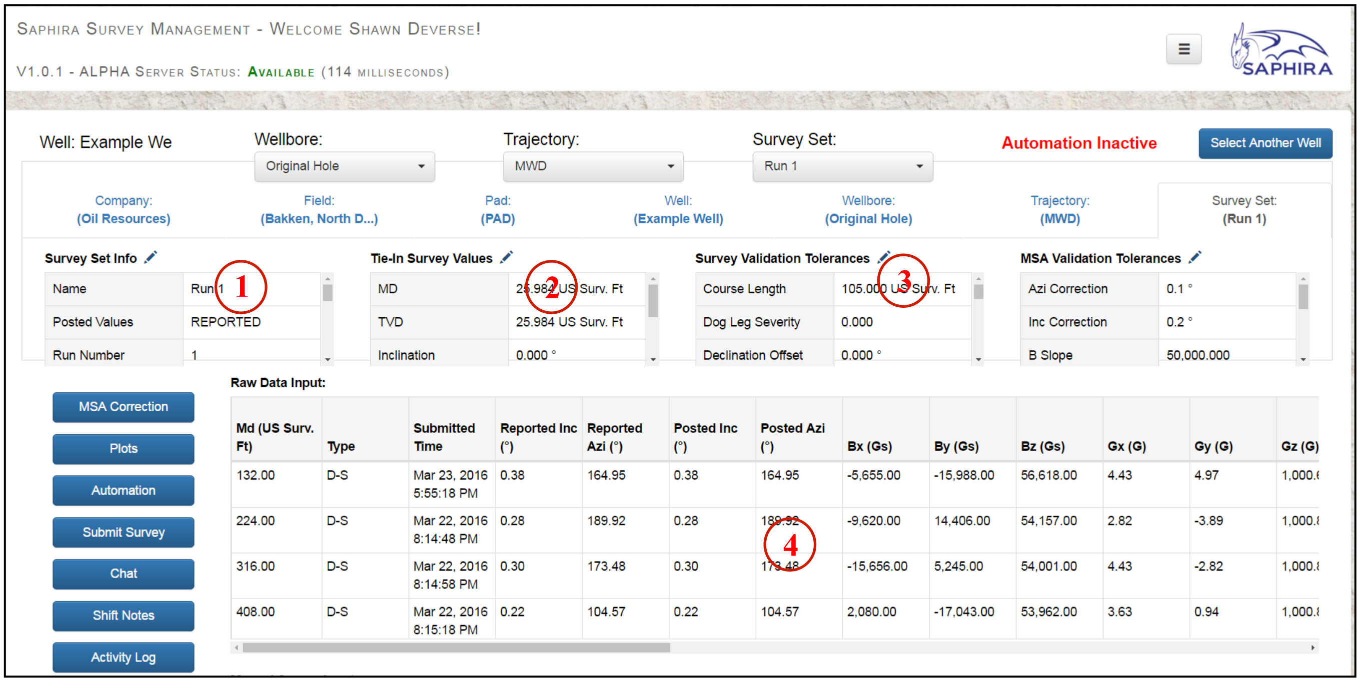

Figure 3: Expert user interface for advanced survey analysis.

1. Survey set info: metadata used to describe survey data, units, run number, and other parameters
2. Tie-in survey: used to initialize position of first survey in data set
3. Survey validation tolerances: parameters used to qualify survey data upon initial data entry
4. Raw survey data: all data associated with each MWD survey station

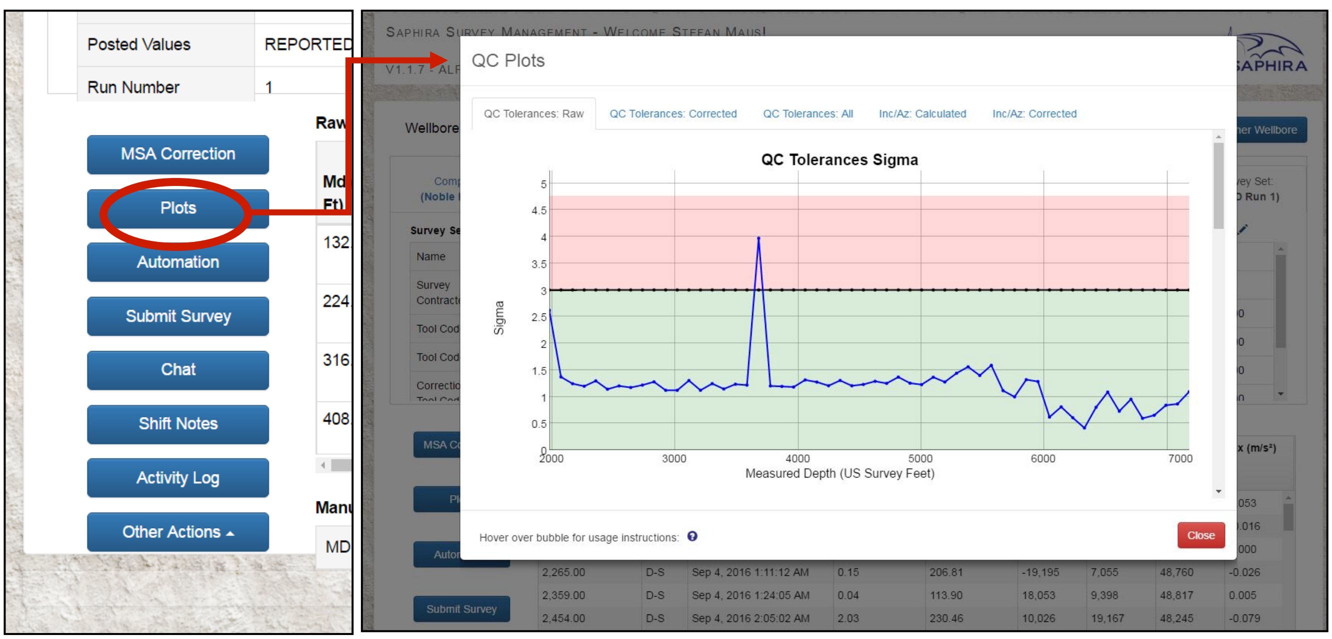

Figure 4: Plots are available to all users for MWD survey data visualization. QC plots of the combined sigma level (shown here) and the individual Btotal, Dip, and G total are helpful for evaluating trends in data, verifying reference value accuracy, and identifying sources of error. The 2.5 sigma outlier survey at the beginning of the wellbore is a result of magnetic distortion caused by conductor casing and the drilling rig. The source of the outlier at 3600 ft measured depth is unknown.

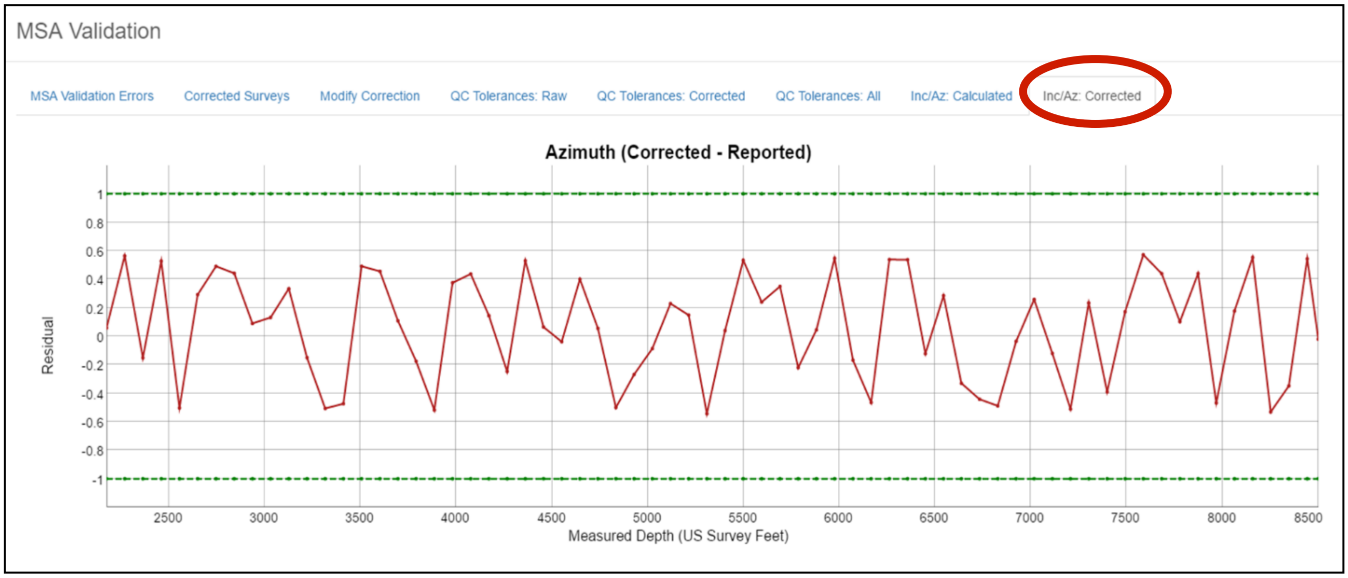

Figure 5: Plot showing the difference between corrected and reported inclination/azimuth helps users QC and understand survey corrections that are being applied. This plot shows an example of survey data corrected for large cross axial errors which cause variation in azimuth correlated with tool face.

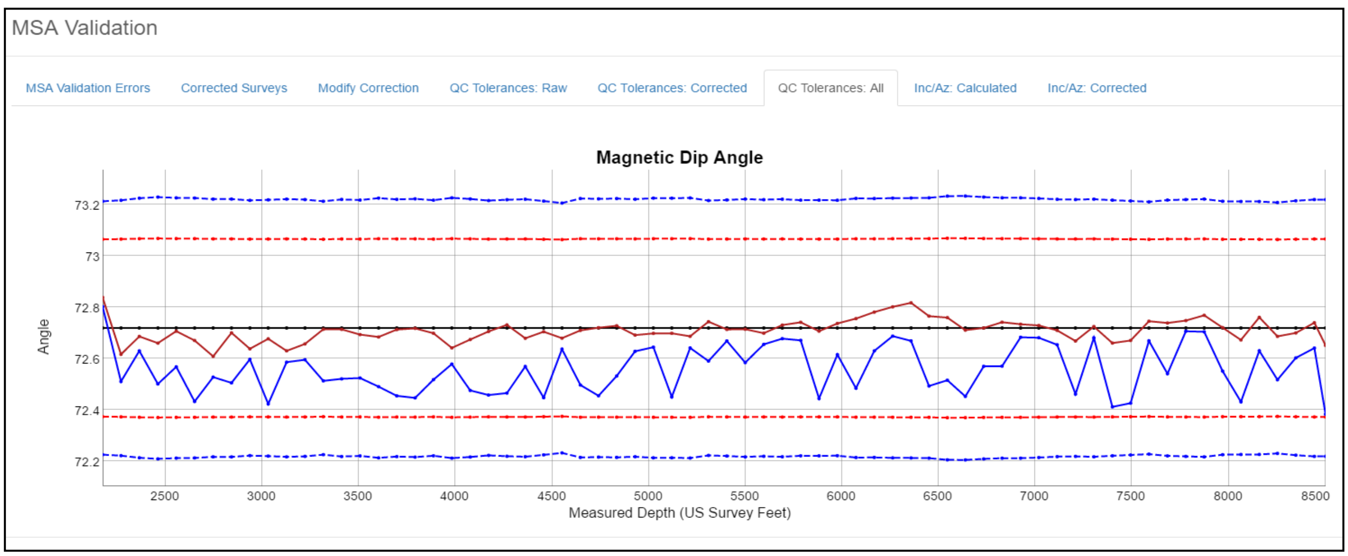

Figure 6: QC plot shows raw survey data (blue) overlaid with MSA corrected data (red) to help user verify that applied corrections are improving survey quality. This plot shows a reduction in variance and offset from the reference dip angle signifying an improvement in survey quality.

Surveying professionals at the rig site upload MWD survey data into a web application in real-time. The survey measurements are then automatically validated through independent quality checks to prevent clerical mistakes and identify gross errors. Remote survey analysts can then access the verified MWD data and evaluate it for systematic or random error that could indicate non-compliance with the instrument performance model, or tool code. Surveys can also be corrected in real-time when systematic errors are identified and provided back to the rig site personnel for accurate steering and wellbore placement. Figure 7 shows the process workflow as it is implemented in drilling operations.

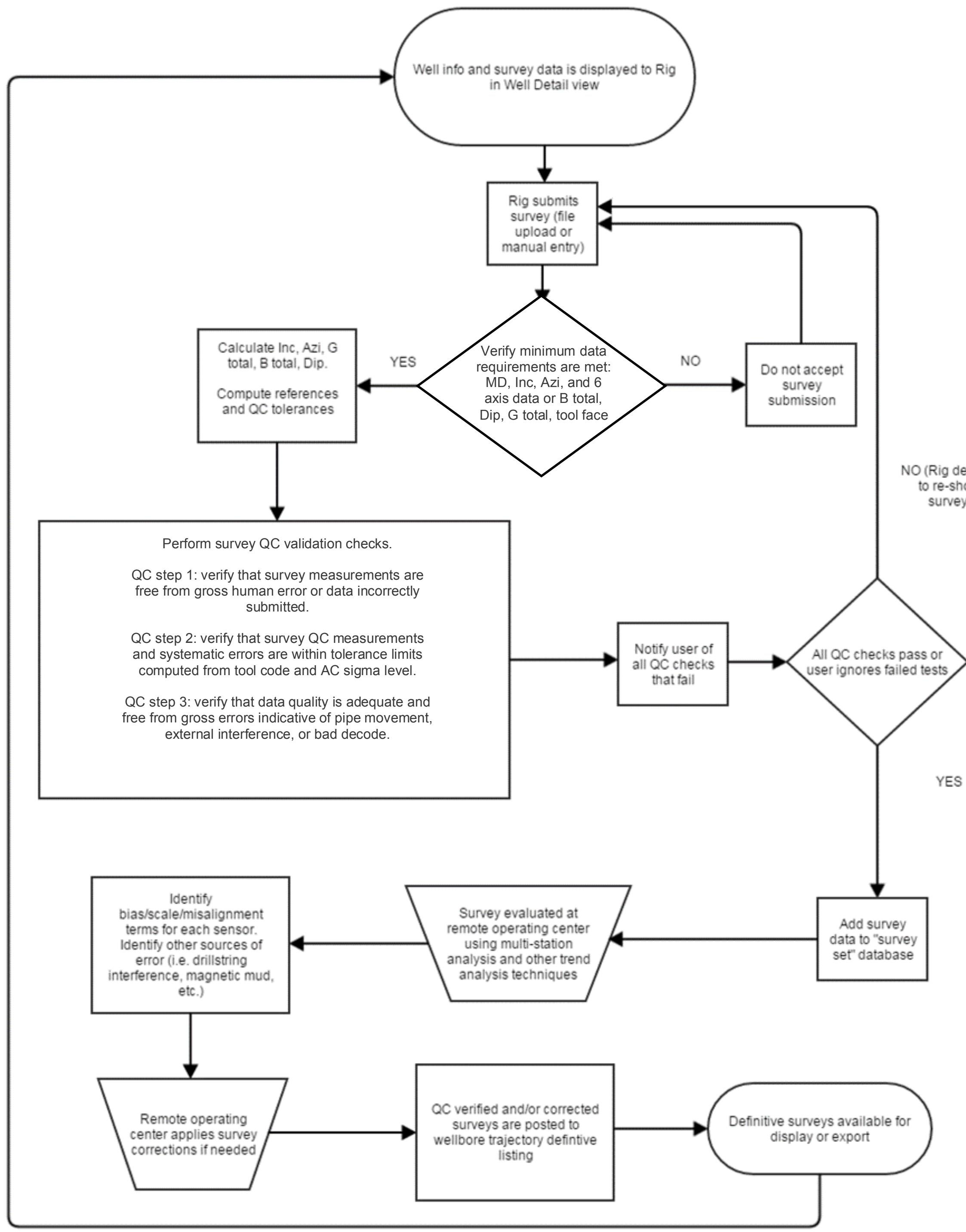

Figure 7: Process workflow for MWD data transfer and independent survey quality assurance.

The first step is for the MWD operator to upload the MWD data to the web application after taking a survey measurement as shown in Figure 7. At a minimum, the data should include the reported measured depth, inclination, and azimuth and the corresponding B total, G total, and Dip or the 6 axis data (accelerometer and magnetometer measurements). When the survey file is uploaded to the web application, the data processor will read the survey file and extract the relevant MWD data. By uploading a direct survey export file, one can minimize the occurrence of transcription errors. However, sometimes the surveying contractor is limited by their surveying software capabilities and must enter the MWD data manually into the web application. Once MWD data is entered, the web application recomputes inclination and azimuth from the corresponding 6 axis measurements when available and compares the results to the rig reported inclination and azimuth. This step ensures that the data is free of clerical errors and also provides an independent check against the north reference, grid correction, and magnetic reference values being applied.

Next, the survey measurement is validated against the tool code by evaluating the Δ B total, Δ Dip, and Δ G total using the appropriate QC tolerances. The QC tolerances are computed from the error coefficients specified in the tool code and scaled to the same sigma level used for collision avoidance planning. QC tolerances are also dependent on inclination and azimuth and therefore change with wellbore geometry. If the Δ B total, Δ Dip, or Δ G total fall outside the calculated QC tolerance limits, then the survey measurement has greater error than what was modeled by the tool code EOUs and the anti-collision assessment may be invalid. However, it is not enough to evaluate each survey individually without comparing it to the entire data set. For instance, if there is a systematic error present that is causing every survey to fail the B total and Dip QC tolerances, then the possibility of a gross error occurring without recognizing it as such becomes very likely. Therefore, it is useful to evaluate the surveys against the entire data set in order to identify trends that could alert the driller to gross errors indicative of external magnetic interference from offset well casing or a failing instrument. To accomplish this, another validation check is compare the deviation of the survey measurement with the standard deviation of the preceding MWD data. If the measurement exceeds a certain threshold, such as 3 sigma, then the survey could be considered a statistical outlier and suggests that there is particular problem such as a poor telemetry decode or the BHA is in near proximity to an offset wellbore.

Figure 8 is an example QC plot available within the web application to provide users with visualization of the sigma level MWD data.

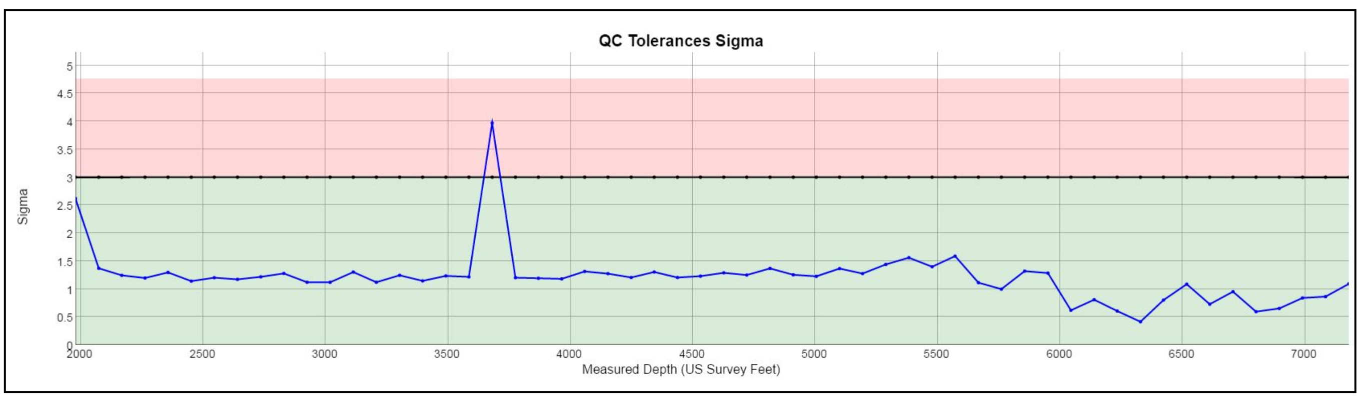

Figure 8: QC plot of sigma level of surveys. This plot condenses the information from Btotal, Dip and Gtotal into a single sigma value. If the operator uses 3 sigma for anti-collision, then the green region defines surveys that are consistent with the error model, which the one survey in the red region fails QC and needs to be discarded and re-taken.

Figures 9-11 show the quality control of the individual Btotal, Dip and Gtotal parameters. If the survey is in the green region, then this parameter is fully within the assumptions of the error model. If the parameter is in the red region, the survey fails QC due to this parameter. If the parameter is in the orange region, it depends on the values of the other parameters whether the survey fails QC or not.

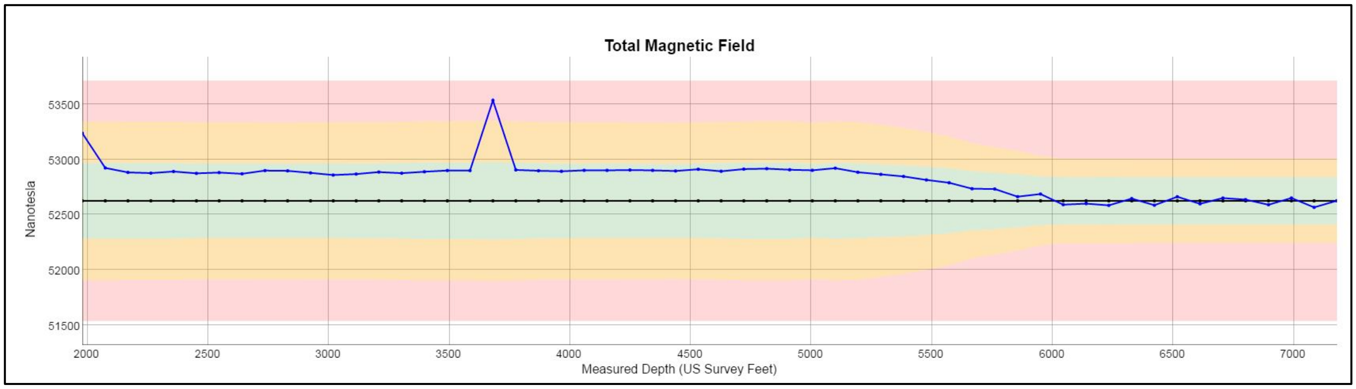

Figure 9: The QC plot for Btotal shows that the QC failure identified in Figure 8 is due to an outlier in the measured B total.

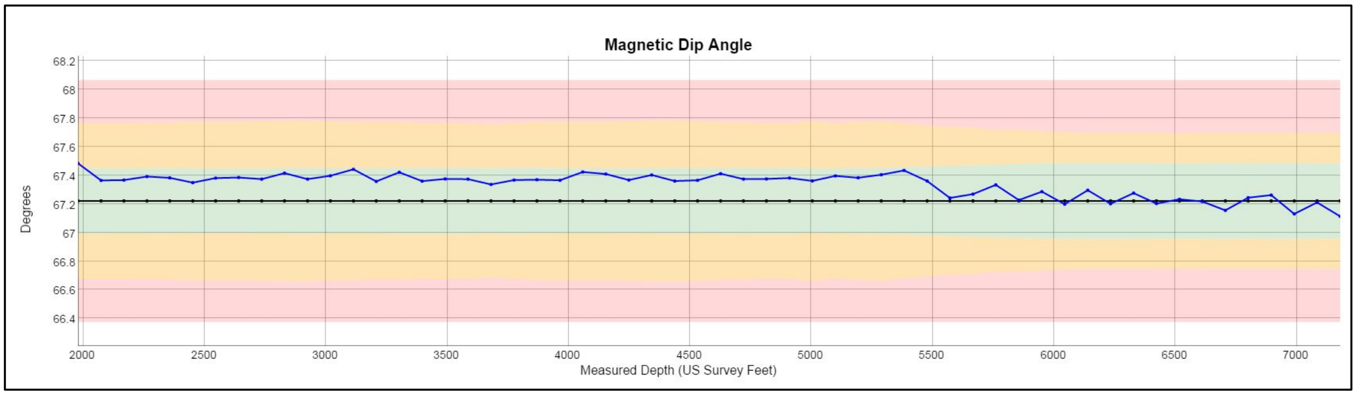

Figure 10: The dip shows a systematic offset, which can be attributed to interference from the drill string. But this interference is within the assumptions of the error model and the dip does not show any outliers.

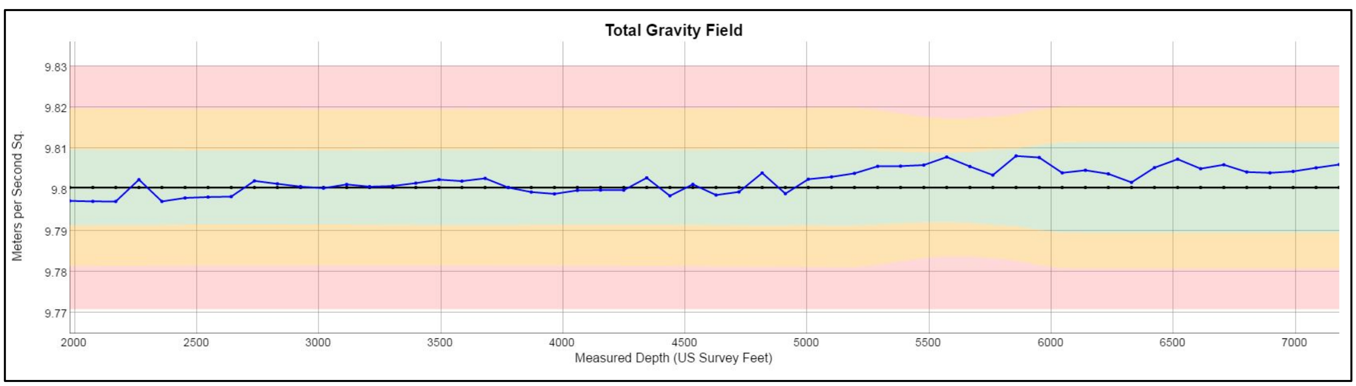

Figure 11: Gtotal shows a gradual trend, but is completely within the expected region of validity.

The initial validation steps are fully automated and occur almost instantly thus giving the rig-site personnel immediate feedback if there is a problem. Alerting rig users to potential survey problems in a timely manner creates an opportunity to re-shoot the survey or elevate the concern to management before drilling begins again. Once the initial survey validation is passed, the MWD data is automatically uploaded into a cloud database where it is permanently stored and managed. This is a central step because storing the data on a cloud server makes it easily accessible by survey specialists in remote operating centers who can perform expert analysis in real-time. While the initial QC validation works well to detect potential problems in the survey quality, it does very little to identify the underlying cause of the problem or distinguish between the various sources of error. Alternatively, the survey data can be further evaluated using advanced MSA (multi-station analysis) techniques to determine individual error components attributed to sensor bias, scale, and misalignment. Trend analysis is also useful for recognizing patterns characteristic of magnetic drillstring interference, magnetic mud, and other environmental factors that contribute to survey error. Survey analysis is performed in real-time in order to estimate the potential impacts on wellbore position and to determine the most cost effective approach to managing or reducing survey errors before making operational decisions. If survey corrections are required, they can be applied through the same web tool used for processing and managing the MWD data. Corrected surveys are then displayed to the rig-site user on the same interface and made available for download or export as shown in Figure 12.

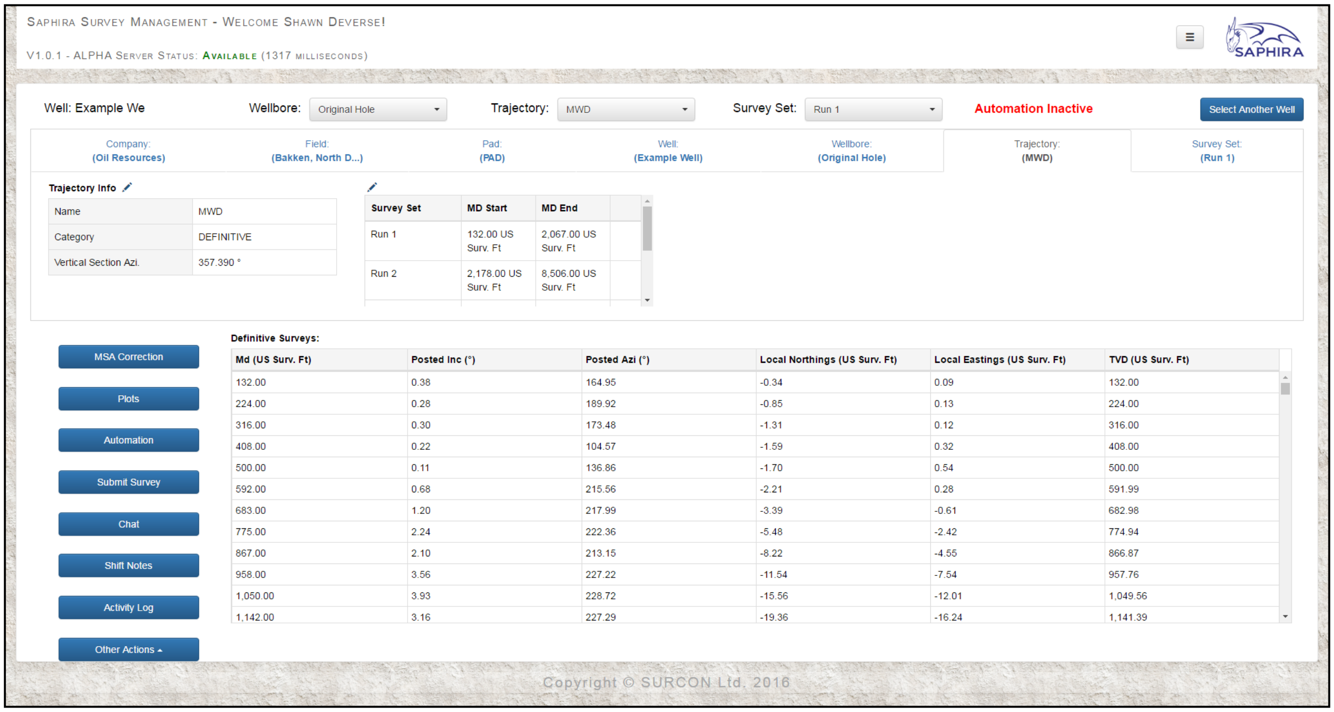

Figure 12: Corrected surveys are posted on web interface and available for download or direct export.

Results

This web-based technology has successfully been implemented across numerous drilling rigs in many of the major U.S. shale plays including the Bakken, Marcellus/Utica, Niobrara, Permian, and Eagle Ford. Examples for common types of errors that were prevented and/or corrected were miscalculated grid correction, incorrect north reference, excessive drillstring interference, poor instrument calibration, misaligned sensors, magnetic mud, and incorrect survey order. The impact of these errors, if not prevented, would have caused hundreds of feet of positional error at the bottom hole location, as in the example shown in Figure 13.

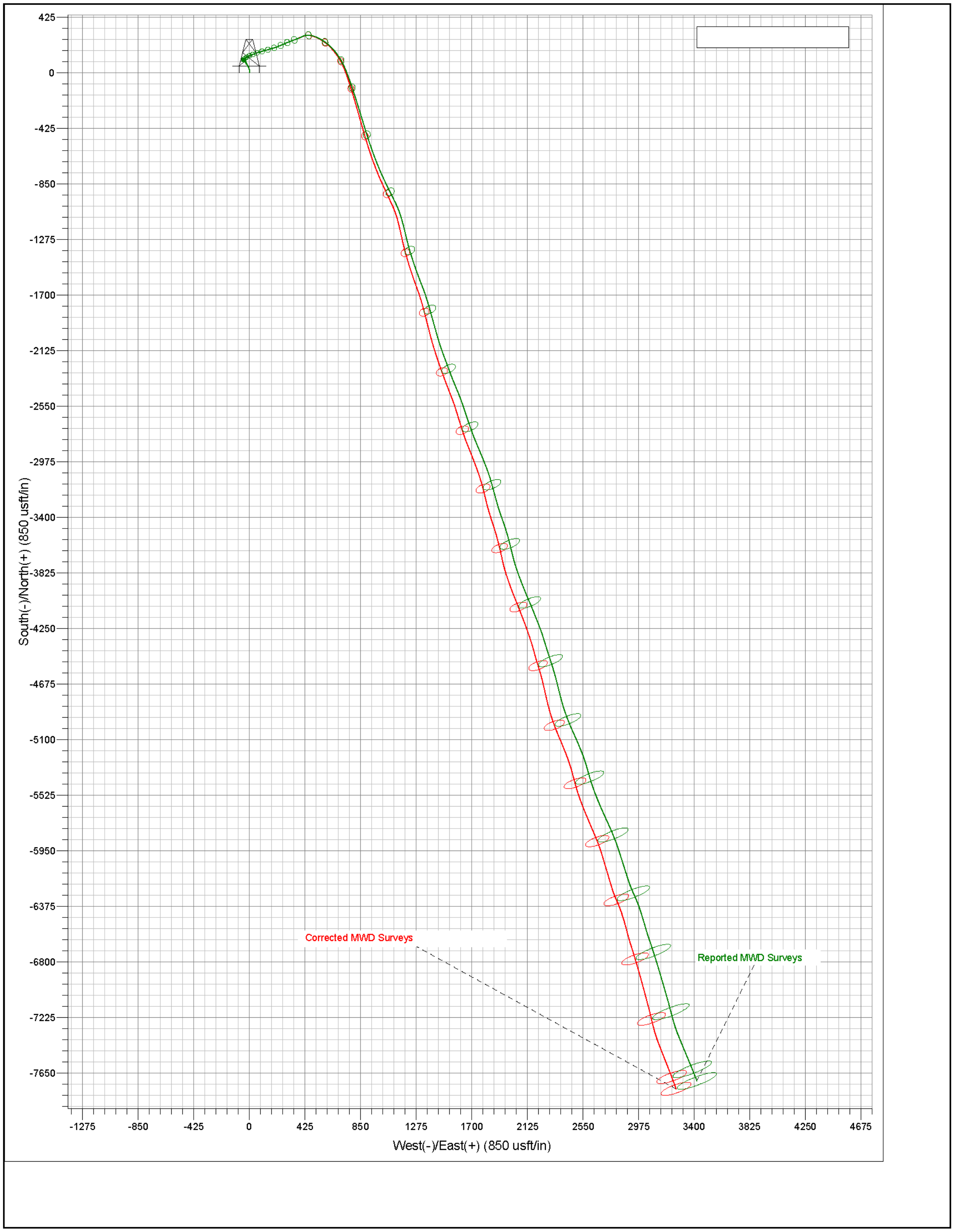

Figure 13: Plan view plot comparing reported MWD surveys against surveys corrected for north reference error.

Prevention of human errors and systematic errors which can cause significant misplacement of the bottom hole location is an important role of independent survey quality analysis. Another important benefit is detection of anomalous MWD data that could indicate a serious concern such as shown in Figure 14. In the example data set, one can see the last three data points appear to be outliers as compared to the rest of the data set. Without proper analysis of the data, it is impossible to determine if these apparent outliers are a result of changing wellbore geometry, a failing instrument, or magnetic distortions caused by offset well casing. After careful analysis, the survey outliers were determined to be caused by external magnetic interference. The decision was made to stop drilling and run gyro surveys in the offset well which showed that it was significantly closer than what was depicted by the original surveys. In this example, independent QC of the surveys in real-time was a key factor in preventing a possible wellbore collision that could have resulted in significant cost.

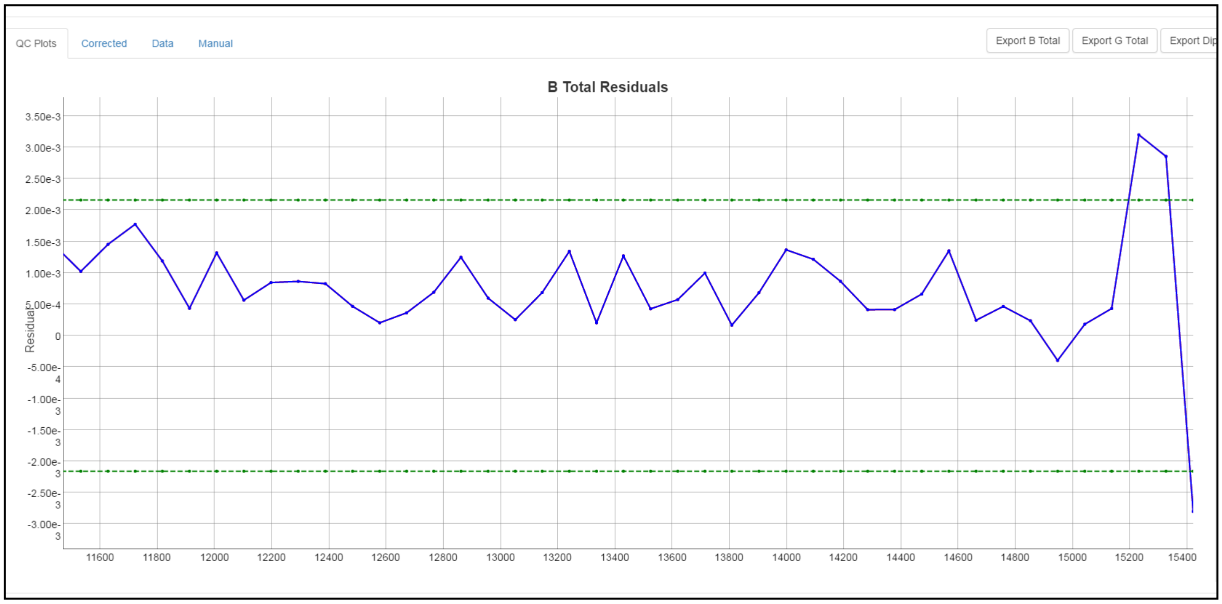

Figure 14:: B total residual plot (Δ B total) shows outlier surveys indicative of external magnetic interference caused by close proximity to an offset wellbore.

Conclusion

Well planning with EOUs computed from standardized tool codes is generally accepted as a safe and effective method for avoiding wellbore collisions. However, it is critical to understand that tool codes are based on assumed magnitudes of error, and if survey measurements have greater error than what was assumed, then the actual wellbore position can fall outside the EOUs computed at the well planning stage. In order to reduce this risk, it is recommended to perform independent survey QC validation on all survey measurements. The most effective method for MWD survey validation is to use web-based technology to independently calculate surveys from raw 6 axis data using independent reference values and to test QC parameters against tolerances derived from the tool code associated with the surveying methodology. Furthermore, surveys should be evaluated against the entire MWD data set for a particular tool run in order to identify statistical significance and perform multi-station analysis. When a survey fails to pass QC tolerance limits, then it is reasonable to assume that the survey has greater error than what was modeled by the tool code for anti-collision planning. Evaluating survey quality by offsite professionals with specialized expertise provides the most powerful form of quality assurance. Using web-based technology, this highest tier of survey QC can be effectively integrated into most drilling operations at reasonable cost and standardized across the industry which will ultimately reduce the number of wellbores drilled outside the EOUs computed when the wells were planned.

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