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Application of models for directional drilling technology

O. J. Oloro [1,*], G. I. Efenedo [2], F. E. Ukrakpor [3]

[1]Petroleum Engineering Department, Delta State University, Abraka, Nigeria
[2]Electrical/Electronic Engineering Department, Delta State University, Abraka, Nigeria
[3]Mechanical Engineering Department, Delta State University, Abraka, Nigeria

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ABSTRACT

The aim of this study is to develop a program to compare directional survey models and select the most accurate. When drilling a directional well, the actual route of the well must be regularly checked to ensure that it is in agreement with the planned route. This is done by measuring the position of the well at constant intervals. A program was established to be used for the five methods (Minimum Curvature, Tangential, Angle Averaging, Balanced Tangential, and Radius of Curvature) for well path design. The directional survey extents are assumed in terms of inclination, azimuth, and 3D coordinates. Comparing the result from the program developed which was used for the different methods it was observed that this new method is faster and more reliable. T-test statistical method to compare the values gotten for the vertical section from the plan with that of the actual survey was used. The results obtained using the average angle, minimum curvature, balanced tangential, and radius of curvature are very small hence any of the methods can be used for calculating the well trajectory but the Tangential shows considerable error and is highly strayed from the plan in the build section hence it should not be used in directional survey calculation. The conclusion drawn from the t-test carried out, therefore, is that there is no significant difference in the vertical section values between the plan and the fives methods considered.

1. Introduction

The technique used to find the extents needed to compute and plot the 3D well track is called a directional survey. When drilling a directional well, the actual route of the well must be regularly checked to ensure that it is in agreement with the planned route. This is done by measuring the position of the well at consistent intervals. These surveys will be taken at very close intervals (30 ft or every connection) in the critical sections (e.g., in the build-up section) of the well. Whilst drilling the long tangential section of the well, surveys may only be required every 120ft, (or every third connection). The surveying program will generally be specified in the drilling program. If it is noted that the well is not being drilled along its prearranged course, a directional orientation tool must be run to bring the well back on course (Atashnezhad et al., 2014). At multiple locations along the well path, three parameters are measured—MD, inclination, and hole direction. In the early days of drilling exploration, it was common to set the drilling rig right above the target and drill a vertical well into it. A mathematical tool for interpolating between survey stations is then required (Eren and Suicmez, 2020).

This study aims to develop a program to compare directional survey models and select the most accurate one for computation in directional drilling. Indeed, the objective is to develop a program for computations of the well route and the best model for directional drilling technology.

During drilling it is close to impossible to make the actual trajectory precisely match the designed well path. For that reason, it is important to monitor the well trajectory and take corrective actions as the well is being drilled. To achieve this goal there must be reliable survey measurement tools and methods that determine inclination, azimuth and perhaps the tool face orientation at different points along the well track. The points of measurement are called survey stations. The measured parameters are then used to calculate the wellbore position in terms of

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* Corresponding Author.
Email Address: joloroeng@yahoo.com (O. J. Oloro)
https://doi.org/10.21833/ijaas.2022.10.013
Corresponding author's ORCID profile:
https://orcid.org/0000-0002-6164-071X

the 3D coordinates Northing (N), Easting E, and True Vertical Depth (TVD). The inclination angle is measured concerning the vertical while azimuth is measured concerning either magnetic or true north. But azimuth is typically reported about true or grid north. As a result, azimuth needs to be corrected before being reported or used in calculations. True north is an absolute north reference. Magnetic Declination is an angle from true north to magnetic north, and Grid Convergence is an angle from true north to grid north (Schumacher and Kim, 2014).

1.1. Methods for calculating wellbore trajectories

Several methods are available for finding the trajectory of a wellbore (Xiushan, 2018). The main variance in all the methods is that one set uses straight-line estimates and the other accepts that the wellbore is of a curve and is approximated with curved segments. Itemized below are five of the approaches in ascending order of favorite and also the intricacy of the techniques:

1. Tangential method
2. Balanced tangential
3. Angle Averaging method
4. Radius of curvature
5. Minimum of curvature

1.2. Tangential method

The Tangential is also known as the backward station or terminal angle method. It is the simplest and old method used for years (Khaled, 2016). This method is very inexact based on its guess, especially in build and hold formation where it shows less vertical and more horizontal shift than there is as well as in turn and hold configuration where it displays more vertical and less horizontal displacement than is present (Ma et al., 2016). The tangential makes the well appear too shallow and the lateral displacements are also too large.

1.3. Balanced tangential method

This technique conjoint the trigonometric functions to offer the normal inclination and direction angles that are used in normal computational procedures. This technique provides a smoother curve that should more closely approximate the actual wellbore between surveys. The longer the distance between survey stations, the greater the possibility of error.

1.4. The averaging method (also known as the angle averaging technique)

The averaging method considers the average of the angles over a course length increment in its calculation (Ma et al., 2016). It is based on the guess that the wellbore is parallel to the simple average of both the drift and course angles between two stations.

1.5. The radius of the curvature method

This method comprises very intricate computation and hence needs a programmable calculator or computer to do the calculations involved. It becomes an unacceptable method when data are closely spaced, as the subtractions in the equation may create either dividing by zero errors or an incorrect TVD when the borehole is a straight line but deviated.

1.6. Minimum curvature

This has arisen as the recognized industry normal for the computation of 3D directional surveys. The well's trajectory is signified by a series of circular arcs and straight lines (Sawaryn et al., 2021). The minimum curvature assumes that the hole is a spherical arc with a maximum radius of curvature or a minimum curvature between stations (Abughaban et al., 2017). The wellbore follows the smoothest possible circular arc between stations.

2. Types and sources of data required

The data type required to carry out this study are;

1. A well plan data for an X-well is shown in Table 1.
2. Measurement While Drilling (MWD) survey data for the X-well as shown in Table 2 which includes;

    a. Measured Depth (MD)
    b. Inclination Angle (I)
    c. Azimuth (A)

Table 1: Well plan data for an X-well

MD	I	A
0	0	0
30.00	0.00	0.00
150.00	0.00	0.00
270.00	0.00	0.00
390.00	0.00	0.00
540.00	11.48	350.00
690.00	17.67	12.80
791.20	21.50	35.00
934.74	29.38	63.84
1050.00	32.98	75.52
1170.00	40.85	85.41
1260.00	42.00	86.53

Table 2: Real-time survey data for well X

MD	I	A
0	0	0
30.00	0.97	121.00
150.00	1.32	134.27
270.00	0.26	145.00
388.00	0.00	198.70
532.00	9.06	336.51
675.30	24.90	0.50
791.30	27.18	26.69
934.74	29.38	63.84
1049.30	29.03	89.89
1164.55	39.59	87.69
1252.50	42.20	87.80

The well plan and MWD survey data used in this study were gotten from an X-well recently drilled in Port-Harcourt, Rivers State Nigeria.

3. Procedure

STEP 1: Design of program using the Fortran programming language for all the formulas needed for calculations under the scope of this work.

STEP 2: Testing of a program using data gotten from the work done by Khaled (2016).

STEP 3: Computation of the 3D coordinates and other calculations necessary using the tested program, with the data gotten from the X-well.

STEP 4: Comparing and analyzing results using tables and graphs.

Program Algorithm

```
program Tangential
double precision: pi, E1, MD1, MD2, R1, V1, b1, b2, TVD1
real: I1, I2, A1, A2
print*, 'Enter the values of b2 and b1'
read*, b2, b1
pi=4.0*atan (1.0)
MD1=b2-b1
print*,'The Result of MD1 is:', MD1
print*, 'Enter the values of I2 and A2'
read*, I1,A1
E1=MD1*sin(I1*pi/180)*sin(A1*pi/180)
print*,'The Change in Easting is', E1
R1=MD1*sin(I1*pi/180)*cos(A1*pi/180)
print*,'The Change for Northing is:', R1
V1=MD1*cos(I1*pi/180)
print*, 'The Change in TVD is:', V1
TVD1=b2+V1
print*,'the Result of tvd is:', TVD1
Vs1=R1*cos(Vsd*pi/180)+E1*sin(Vsd*pi/180)
print*,'The vertical section is '
print"(f10.2)", Vs1
CDis1=SQRT((R1)**2+(E1)**2)
print*,'The closure distance is:', CDis1
CDir1=atan((E1/R1)*pi/180)
print*,'The closure direction is:'
print"(f10.2)", CDir1
end Tangential
Input Interface
```

Needed data for the computation of the 3D coordinates are Measured Depth (MD), Inclination angle (I), and measured bearing "Azimuth" (A).

3.1. Validation of the FORTRAN program

Two literature pieces of data were used in validating the FORTRAN program. The first was the data used by Guria et al. (2014) and the second was from Khaled (2016).

4. Result

The results from each method are presented in Tables 3-7. In Table 3, the first column is the TVD which increases down the column. The second, third, and fourth columns also follow the same trend as shown in Table 3. The tangential method shows significant error, and the nonconformity from the plan is highly conspicuous, hence the least precise followed by the angle averaging method shown in Table 5.

Table 3: Tangential method result

TVD (meters)	N (meters)	E (meters)	Vertical Section (VS) (meters)
0	0	0	0
30	-0.26	0.43	0.38
149.97	-2.19	2.41	2.01
269.98	-2.63	2.73	2.25
387.97	-2.64	2.73	2.25
530.17	18.16	-6.31	-3.16
660.15	78.49	-5.78	7.53
763.34	125.83	18.02	38.96
888.33	156.86	81.18	106.45
988.50	156.97	136.78	161.27
1077.31	159.93	210.16	234.10
1141.76	162.17	268.56	292.04

Table 4: Balanced tangential result

TVD (meters)	N (meters)	E (meters)	VS (meters)
0	0	0	0
30	0.22	-0.13	-0.09
149.98	-1.62	2.08	1.78
269.96	-2.8	3.22	2.70
387.96	-3.03	3.38	2.82
531.06	7.37	-1.14	0.12
666.81	47.89	-5.38	2.77
771.01	95.98	6.74	22.82
897.31	140.76	53.03	75.99
997.30	153.20	106.05	130.35
1092.10	154.74	170.71	194.34
1157.09	156.95	226.96	250.16

In Table 4, the first column is the TVD which increases down the column. The second, third, and fourth columns also follow the same trend, however, the value of the Easting and Vertical section is higher in this method. The balanced tangential and minimum curvature methods are highly superimposed on the plan as shown in Table 4 and Table 7, respectively.

Table 5 shows the angle averaging method. The first column is the TVD which increases down the column and also follows the same trend but the value of Northing is the smallest when compared with the others. Table 6 is the radius of curvature and follows the same trend as shown. The results are closer to that of the angle averaging. The radius of curvature method shows insignificant deviation from the plan. Table 7 represents the results of minimum curvature, which is similar to that of Balanced Tangential. Table 8 is a comparison of results obtained for different methods when TVD, Diff actual, and North Displacement are compared.

Table 5: Angle averaging method result

TVD (meters)	N (meters)	E (meters)	VS (meters)
0	0	0	0
30	0.13	0.22	0.24
149.98	-1.34	2.12	1.86
269.97	-2.60	3.19	2.71
387.96	-2.86	3.23	2.70
531.51	-3.34	-8.13	-8.58
668.57	-44.35	0.21	-7.27
772.79	5.15	12.18	12.87
899.11	52.98	60.45	68.51
999.11	65.68	114.89	124.31
1094.31	67.05	179.84	188.57
1160.07	69.29	236.75	245.04

Table 6: Radius of curvature result

TVD (meters)	N (meters)	E (meters)	VS (meters)
0	0	0	0
30	0.10	0.18	0.19
149.98	-1.35	2.08	1.82
269.96	-2.62	3.15	2.66
387.96	-2.87	3.18	2.65
531.36	-3.24	-5.62	-6.09
667.98	-6.13	-5.03	-5.99
772.20	42.93	6.83	13.97
898.51	89.92	54.26	68.63
998.51	102.52	108.23	123.96
1093.57	103.89	173.08	188.11
1159.33	106.13	229.99	244.58

Table 7: Minimum curvature result

TVD (meters)	N (meters)	E (meters)	VS (meters)
0	0	0	0
30	0.22	-0.13	0.19
149.98	-1.62	2.08	1.78
269.96	-2.81	3.22	2.70
387.96	-3.03	3.38	2.82
531.07	7.37	-1.14	0.11
666.82	47.89	-5.38	2.78
771.02	95.98	6.74	22.90
897.32	140.76	53.04	76.49
f997.32	153.20	106.05	131.07
1092.11	154.74	170.71	195.25
1157.10	156.95	226.96	252.33

Table 8: Comparison of the five methods

Method	TVD	Difference from Actual (ft)	North displacement	Difference from Actual (ft)
Tangential	1628.61	-25.38	998.02	43.09
Balanced tangential	1653.61	-0.38	954.72	-0.21
Angle averaging	1654.18	0.19	955.04	0.11
Radius of curvature	1653.99	0	954.93	0
Minimum curvature	1653.99	0	954.93	0

4.1. Result from observation and analysis

The following observations and analysis can be drawn from the results.

1. The tangential method shows considerable error, the deviation from the plan is highly noticeable hence the least accurate followed by the angle averaging method.
2. The radius of curvature method shows negligible deviation from the plan.
3. The balanced tangential and minimum curvature methods are highly superimposed on the plan.

4.2. Comparison using t-test statistical method

Using the t-test statistical method to compare the values gotten for the vertical section from the plan with that of the actual survey for the Angle Averaging, Balanced Tangential, Radius of Curvature, and the Minimum Curvature, the result gotten is tabulated below; Table 9 shows the result of the t-test.

Therefore, since the obtained t-ratios from Table 9 are all far lesser than that of the tabled value (2.074) then the null hypothesis Ho is accepted. Also from Tables 3 and 5, it can be seen that the minimum curvature vs plan has the lowest t-ratio of 0.10, and the lower the t-ratio, the more accurate the null hypothesis.

Table 9: Result of the t-test

Method	T-Ratio
Balanced Tangential vs plan	0.11
Angle Averaging Method vs plan	0.23
The radius of Curvature Method vs plan	0.22
Minimum Curvature Method vs plan	0.10

Null hypothesis: Ho=mean of X–mean of Y=0; Significant level (α)=0.05; The degree of freedom (df)=12+12- df=22

5. Conclusion

The conclusion drawn from this work is that Comparing the result from the program developed which was used for the different methods it was observed that this new method is faster and more reliable (Khaled, 2016) and the t-test carried out, there is no significant difference in the vertical section values between the plan and the fives methods considered which are; the Angle Averaging, Balanced Tangential, Radius of Curvature and the Minimum Curvature methods.

This application of the Minimum Curvature method will therefore enhance the accuracy during both planning and drilling operations which will aid to lessen hazards and indecision surrounding striking fixed targets. This is likely for the reason that nonconformities can easily be noticed and the required directional rectifications or adjustments be beginning to fix the drilling bit to the right course during and before the drilling operations.

Compliance with ethical standards

Conflict of interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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