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3-D well path design using a multi objective genetic algorithm

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ABSTRACT

Optimizing wellbore trajectories to reach an offset subsurface location, involving a complex combination of vertical, deviated and horizontal well components, requires the minimization of both wellbore length and frictional torque on the drill string. This is particularly the case for shallow horizontal wells which are often limited in their extent by torque. By minimizing both wellbore length and torque it is likely that a wellbore designed to reach a specific target can be drilled more quickly and cheaply than other potential trajectories. However, these two objectives are often in conflict with each other and related in a highly non-linear manner. A multi-objective genetic algorithm (MOGA) methodology is developed and applied with two objective functions, viz. wellbore length and torque, to develop a set of Pareto optimal solutions that can aid the selection of less risky/less costly well trajectory designs. The MOGA performance is compared with single-objective function studies of a specific wellbore scenario. The results indicate that the MOGA methodology outperforms single-objective function approaches leading to rapid convergence towards a set of Pareto optimal solutions. Analysis reveals that by adopting an adaptive approach that allows the behavioral parameters of the genetic algorithm (GA) to evolve as iterations progress, the MOGA proposed converges more rapidly toward better ultimate solutions than if the GA behavioral parameters are held constant over all iterations of the algorithm. Algorithm code listings for the MOGA and GA applied in the analysis presented are included as appendices.

1. Introduction

One of the most expensive operations involved in the exploration and development of oil and gas reservoirs is typically the drilling of the wellbores. In the prevailing market conditions of relatively high costs and low oil and gas prices across much of the world most oil and gas companies are particularly keen to minimize their drilling costs Khaled et al., 1999.

Previous studies indicate that the cost of drilling a horizontal well is about 1.4 times the cost of drilling a vertical well (S. D. Joshi, 2003). The attraction of drilling horizontal and directional wells is that they can contact a greater volume of the reservoir and can transect the highest quality zones more effectively than vertical wells, resulting in higher production and recovery rates. In both cases one of the most important factors affecting the cost of drilling is length of the wellbore and the time taken to drill to the reservoir target. Thus any possibility to reduce the length of the wellbore, within the constraints of acceptable curvatures and geological obstacles, typically reduces the time it takes to reach the target and thereby reduces the total drilling costs. Optimizing wellbore lengths, subject to a defined set of constraints, typically is desirable as a means of improving the economics of drilling operations.

In the recent years, optimization has been used extensively across the petroleum industry for a variety of purposes, process plant optimization, transport scheduling and to various aspects of the drilling operation (e.g. Shokir et al., 2004; Atashnezhad et al., 2014; Guria et al., 2014). With respect to wellbore trajectory planning Shokir et al. (2004) used a genetic algorithm and Atashnezhad et al. (2014) used a particle swarm optimization algorithm with the single objective function of minimizing wellbore length, subject to a number of defined constraints. A recent application of multi-objective genetic algorithm (MOGA) to drilling is provided by Guria et al. (2014) in their application of a multi-objective optimization genetic algorithm to two- and three-objective functions related to determining optimum drilling variables related to an oil

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field offshore Louisiana. That work applied an elitist non-dominated sorting genetic algorithm to (i) maximize drilling depth, (ii) minimize drilling time and (iii) minimize drilling cost with fractional drill bit tooth wear as a constraint. Another application of MOGA, relevant to petroleum field operations, is proposed by Yasari et al. (2013) to apply a non-dominated sorting genetic algorithm to find optimized and robust water injection policies for three injection wells.

In this paper a new MOGA optimization model for well trajectory planning is developed for optimizing drilling operations. The model optimizes the recommended well path by taking into account two-objective functions: 1) to minimize wellbore length and trajectory to a specified sub-surface target location (i.e. length); and 2) to minimize torque on the drill string during the drilling operation (i.e., torque).

We recognise that when designing wells at specific locations there are other factors that need to be taken into account in addition to wellbore length and torque (e.g., wellbore tortuosity and its influence on the ease or difficulty in running a specific well completion design; combined drilling and completion costs associated with drilling a particular well path; dealing with problem formations above a reservoir in a certain way, i.e., setting casing above it or below it certain specified points; entering the reservoir at a certain angle and penetrating it at a certain inclination). Some of these additional factors can be dealt with as constraints that selected optimum well paths need to achieve. It would also be possible to consider these as optimization objectives in their own right in the MOGA algorithm. In this study we focus on just the two key objectives, i.e., wellbore length and torque, to prove the benefits of the MOGA concept. We will be conducting future research to expand the MOGA methodology to consider some of these additional factors, both as constraints and additional objectives.

MOGA involves a process of developing a random set of potential solutions making up a population of solutions to be tested for fitness. Each individual solution generated is typically referred to as an individual or gene. The population is subjected to a series of evolutionary iterations (i.e., developing new solutions/genes by genetic processes such as mutation and crossover with different characteristics in each generations), with the solutions being tested for fitness and ranked in each generation, and the most fit for purpose being carried forward to the next generation. This process means that each generation progresses, or converges, towards the best set of solutions. Finally, the best solutions are identified and their performances compared in relation to the multiple objective functions. In this study the MOGA is coded using MATLAB software, with the detailed code provided in Appendix A. The model is applied to the horizontal well drilling trajectory scenario (based on a real well drilled in Egypt) studied for trajectory optimization purposes by Shokir et al. (2004), using a single-objective function genetic algorithm, and Atashnezhad et al. (2014) using particle swarm optimization. We describe how our MOGA model works in detail and provide an analysis of the results for the specific, complex, wellbore trajectory selected.

The case study is based on a real well drilled in Egypt, and previously used to demonstrate wellbore trajectory optimization using a genetic algorithm by Shokir et al. (2004) applied to the deviated well trajectory calculation algorithm originally proposed by Adams and Charrier (1985), using the length of the wellbore between specified surface and bottom-hole locations as the objective function.

2. Mathematical formulation

With the dual objectives of finding optimal solutions that provide the minimum well length, honoring the wellbore constraints imposed, so that the torque on the drill string is also minimized, it is necessary to provide mathematical formulations for those two clear objective functions, i.e.: 1) the wellbore length; 2) the torque on drill string while rotating. These two objective functions are described in mathematical formulations in the following sections.

2.1. Well path length

Fig. 1 illustrates all the components involved in the calculation of the length of each curved section of a directional wellbore. There are several methods available to measure the wellbore length of a directional well. Our formulation uses the radius of curvature method. In the radius of curvature method, constant curvature between two points and the radius of the curvature is given by equations (1)–(3):

$$a = \frac{1}{\Delta m}\sqrt{(\theta_2 - \theta_1)^2 \sin^4\left(\frac{\varphi_2 + \varphi_1}{2}\right) + (\varphi_2 + \varphi_1)} \tag{1}$$

$$r = \frac{1}{a} = \frac{180*100}{\pi * T} \tag{2}$$

$$\Delta m = r\sqrt{(\theta_2 - \theta_1)^2 \sin^4\left(\frac{\varphi_2 + \varphi_1}{2}\right) + (\varphi_2 + \varphi_1)} \tag{3}$$

Based upon the wellbore trajectory illustrated in Fig. 2, with multiple curved and linear components, the total measured depth of the wellbore can be obtained from equation (4):

$$TMD = D_{KOP} + D_1 + D_2 + D_3 + D_4 + D_5 + HD \tag{4}$$

Detailed formulas to calculate the non-vertical and horizontal components of the wellbore trajectory (D_1, D_2, … D_5) are provided in Appendix A.

2.2. Torque

Torque and drag analysis in relation to wellbore tubulars has been studied in detail and is now well understood (e.g., Sheppard

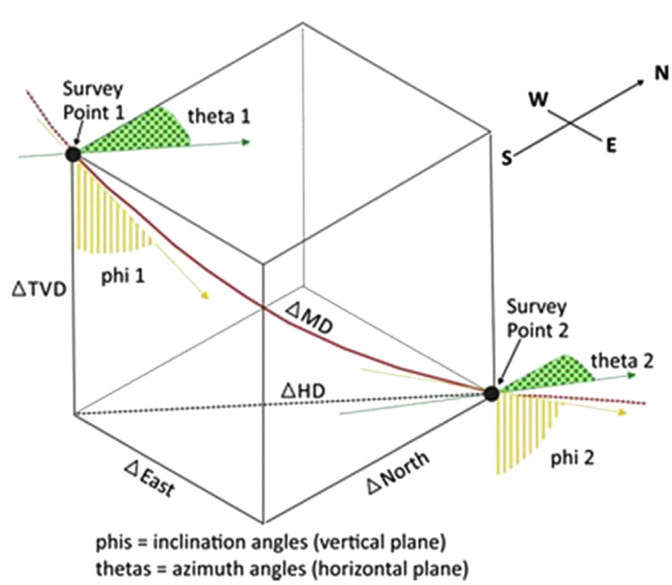

Fig. 1. Calculation of the length for a deviated section of the well trajectory after Atashnezhad et al. (2014) describes the terms used to define the different angles and components of the wellbore trajectory. MD = measured depth; TVD = true vertical depth.