AgentOil: a multi-agent-based simulation of the drilling process in oilfields

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1 Introduction

Oil&Gas have become the world's most important source of energy since the mid-1950's. For instance; Britain oilfields produce each year about 76 million tonnes of oil equivalent. This provides 76% of the UK's total primary energy [1]. In oilfield wells, a drilling rig is used to create a bore-hole in the earth's subsurface with a Bottom hole assembly (BHA), which is a composition of several drilling tools with various functionalities, searching for natural resources.

While drilling, the increasing temperature damages the tools. To monitor the status of tools, sensors are attached to them in order to read useful data like temperature. Read data are sent up-hole to the field engineer (several kilometers above the down-hole tools). When deemed necessary, the latter activates the drilling mud coolers to reduce the temperature of down-hole tools by pumping cooled mud down-hole. However, this process suffers from four flaws: (i) Existing wells rely on analogue telemetry that has long response time and unreliable signal. (ii) The effectiveness of the mud cooler may become inefficient in high temperature conditions. (iii) The process relies heavily on constant human monitoring and intervention. This makes it error-prone, unresponsive, and fault-intolerant. (iv) The current decision-making process is highly centralized up-hole.

To overcome these flaws, we propose a spec-driven multi-agent system (MAS) for mitigating high temperature by distributing the monitoring and control process between different agents that coordinate with each other through voting rules. To demonstrate our proposal, we present AgentOil, a multi-agent-based simulation tool to simulate the drilling process in oilfields.

2 Main purpose

Most of the works in the MAS domain in Oil&Gas industry are still theoretical, and the concentration is mainly on supply chain and management aspects, while the drilling process is not addressed. In order to implement the proposed system

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properly, we rely on the literature of drilling mechanics and geothermal equations. In particular, we consider the following key parameters[4]. Measured Depth (MD) is the length of the well bore-hole, while True Vertical Depth (TVD) is the vertical distance from the surface until the lowest drilling tool (the bit). Inclination (drilling angle) is the deviation from vertical that relates the MD with TVD using the Pythagorean equation. The rate of increase in temperature per unit depth in Earth is called Geothermal Gradient. The estimation of the down-hole temperature of drilling tools is shown in Equation 1.

$$DownHoleTemp = SurfaceTemp + \text{TVD} * GeothermalGradient \tag{1}$$

Drilling parameters are used to control the drilling process. Mainly, we focus on three essential parameters: Force (Weight on bit or WOB), Rotation (Revolutions per minute or RPM) and Flow rate of drilling mud. The speed of drilling process (Rate of penetration or ROP) is shown in Equation 2 [2].

$$ROP = K \frac{\overline{WOB}^{K}}{a^{p}} r \tag{2}$$

Where K: Formation factor, is a constant related to a given earth formation hardness; $\overline{WOB}$: function of WOB; r: function of RPM; a^P: function of the flow rate and the bit characteristics (c.f. [2] for more details).

Within AgentOil, the down-hole tools are considered as agents and enhanced with a coordination mechanism to mitigate high temperature autonomously in real-time by controlling a down-hole actuator through a voting process, where the vote of each tool is determined from its temperature specification. In order to aggregate the votes, AgentOil implements three well-known voting rules in the MAS domain[3]: Plurality, Borda count and Condorcet.

When the temperature of one tool exceeds its specification limit, voting is triggered by its agent. A tool agent votes, as per one of the implemented voting rules, to start the down-hole actuator, and an overall decision is aggregated. Starting the actuator reduces the drilling speed, hence it delays the time to reach higher temperature. Although this leads to slower drilling, it mitigates the temperature raise, thereby save the tools from failure allowing them to drill deeper. To minimize the drilling speed reduction, the actuator is not activated if there is no need. The whole process is done in real time without the intervention of up-hole entities (c.f. [4] for a detailed description of the proposed system).

3 Demonstration

AgentOil (Figure 1) is implemented using RePast simphony [5], a multi-agent simulation environment. A simulation run represents a whole drilling run in real-life drilling scenario where the BHA is made at surface to drill to a specific depth (a.k.a. Total Depth) before the need to go up to surface to change it with new

[4] The first author has five years of experience in Oil&Gas industry.

Table 1. Simulation initial parameters

Parameter	Default Value	Description
Number of Agents	5	Number of tool agents in the simulation
Voting Rule Choice (1: Plurality, 2: Condorcet, 3: Borda count)	1	Voting rule used in the voting system for this simulation run
Starting Run Depth (m)	4500	Measured depth at the start of the run
Total Depth (m)	5000	Measured depth at the end of the run
Drilling Angle (degree)	30	Bore-hole angle compared to vertical line
Hole Diameter (inch)	6	Diameter of the bore-hole
Initial RPM (0 - 100)	100	Initial RPM set by the user
Surface Temperature (degC)	20	Temperature at surface
Geothermal Gradient (degC/m)	0.03	Temperature incremental rate per meter
Initial WOB (0 - 30 klbf)	1	Initial WOB set by the user
WOB Increase per Tick (klbf)	0.05	Amount of constant increase in WOB

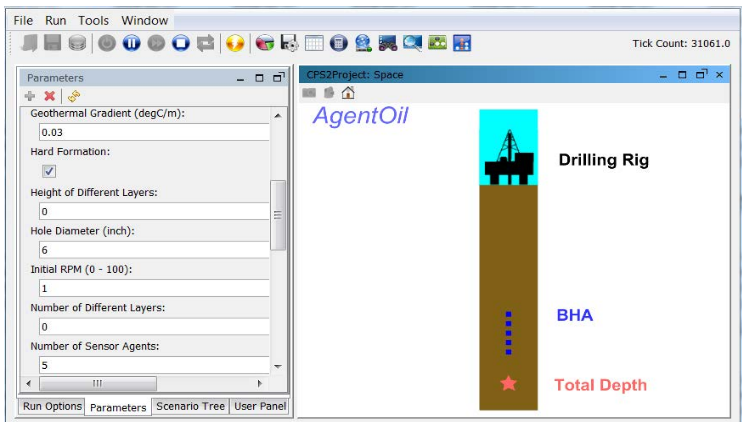

Fig. 1. AgentOil snapshot: Initial parameters (Left), 2D Drilling visualization (Right)

tools. Table 1 lists some of the initial parameters[5] that the user can change before starting. Once the simulation starts, all tool agents are created and set accordingly in the environment. A simulation tick corresponds to one minute. Thus, the results are normalized as speed is given in m/min. In each tick, drilling parameters are updated to calculate the ROP (Equation 2). Therefore, the BHA goes down the hole, and temperature increases with depth (Equation 1).

The ultimate goal is to strike a balance between maintaining a high drilling speed and guaranteeing the tools integrity by controlling the down-hole actuator. Each agent is aware of the temperature specification of its tool, and decides whether to start a voting cycle accordingly. A simulation run can end either successfully by reaching Total Depth if the mitigation measure down-hole is sufficient or unsuccessfully with a tool failure before reaching Total Depth. Additionally, a complete log of the simulation run is provided in both cases.

AgentOil allows to simulate a varied number of drilling tools, and in the following evaluation we use five tools to adhere to most common real life scenarios. Figure 2 shows the results in terms of time and depth of running AgentOil tens

[5] Full list is not provided due to space limitations.

Fig. 2. Gain in time and depth with the proposed system

of times with the proposed system (colored curves) and without it (gray curve) for different values of fixed WOB (x-axis). Figure 2 (left) illustrates the time elapsed before failure (how much time the tools survived in high temperature environment). Correspondingly, Figure 2 (right) plots the drilled depth before failure. In both figures, three voting rules were examined: Condorcet (green), Plurality (red), Borda count (blue). From Figure 2 (left), it can be noticed that all colored curves are above the gray curve, which means that all runs of the proposed system (with different voting rules) are better than runs without enabling the proposed system. Figure 2 (right) shows that the colored curves are below the gray curve (more drilled depth), significantly with high WOB.

4 Conclusions

AgentOil provides the ability to control the most important drilling parameters and simulate drilling runs in different hole sizes in drilling sections with the necessary information of each drilling run. We used AgentOil to implement the proposed multi-agent system and produce results. The results show that the down-hole tools agents are capable of mitigating high temperature down-hole autonomously in real-time by socially reacting to the increase in temperature. This increases the life cycle of down-hole tools allowing them to drill deeper.

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