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Application of Reduced-Order Models and Machine Learning to Enhance Downlink Communication in Rotary Steerable Systems for Oil & Gas Drilling

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Abstract

In directional drilling, traditional downlink communication to rotary steerable systems (RSS) is typically achieved by modulating flow pulses at the surface of a non-Newtonian fluid, such as drilling mud. However, this method is limited by the slow propagation speed of pressure waves, the complex rheology of the fluid, and its impact on the formation. The liquid component of the drilling fluid invades the porous and permeable formation until the solids in the mud, commonly bentonite, clog sufficient pores to form a mud cake. This process alters the permeability of the well, potentially compromising its integrity.

This study introduces an alternative downlink mechanism that relies on modulating the rotational speed of the drill string at the surface. While not necessarily faster than flow-pulse methods, the rotational speed downlink is gentler on the formation, reducing the risk of drilling fluid invasion and mud cake formation. Reduced-order models (ROMs) are developed to represent the coupling between drill string dynamics and downhole fluid behavior, ensuring efficient signal transmission. Machine learning (ML) algorithms running at high-frequency speeds within the RSS control unit are employed to detect and decode these rotational speed modulations in real time, providing reliable and robust communication.

This research demonstrates that the proposed method preserves essential fluid dynamic behaviors, enhances downlink reliability, and minimizes formation damage. By combining ROMs and ML, the approach provides a scalable and formation-friendly communication framework, representing a significant advancement in the application of ML to these type of industrial fluid dynamics, as well as in drilling automation for real-time control in complex drilling environments.

Keywords: Rotary Steerable Systems, Industrial fluid mechanics, downlink, Reduced-order models, Machine learning