Project Report

1. PRF# 58748-DNI9
2. Project Title: Modeling and Control of Large-scale String Dynamics for Unconventional Oil & Gas Production
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Research Progress:

The goal of this project is to investigate robust and accurate controls methodologies to enable a fully autonomous down-hole drilling system. As current outcome of this project, one journal paper is published, and another journal paper and one conference paper are under preparation.

The down-hole drilling system is widely used in oil and gas industry for well-bore creation and energy production. This system has several characteristics that differentiate its modeling from other engineering applications: 1. Large axial-to-radius ratio: the down-hole drilling system can extend to thousands of feet from the ground by connecting hundreds of drill pipes in series. 2. Nonlinear nature at the bit/rock interaction interface: the non-smooth characteristics in the bit/rock interaction can often lead to nonlinear behaviors such as bifurcations and periodic orbits (stick-slip and bit-bouncing behaviors). The stick-slip and bit-bouncing behaviors are detrimental to the down-hole drilling system. Therefore, an effective and efficient control scheme to mitigate these vibrations is crucial. Moreover, control of drilling speed in the axial dimension is also important to ensure proper drilling rate of penetration.

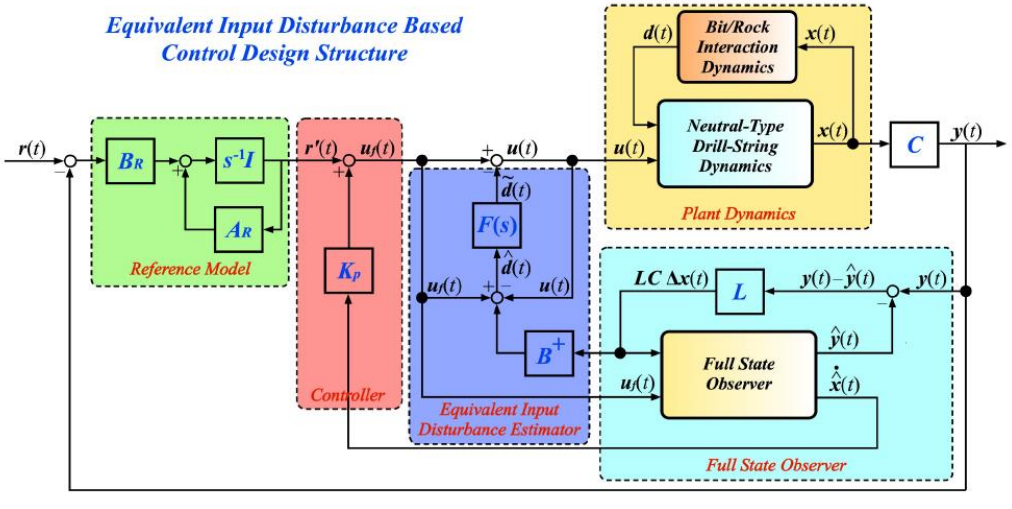

Fig. 1. Control Structure of the Control Method

In this project, we studied a control approach using a distributed parameter system based control. It typically has the control design based on partial differential equations (PDEs) or models derived from PDEs. Compared with approaches based on a lumped parameter model, the distributed parameter system based method may capture more detailed high-frequency transient behavior of such a long string structure. Existing controls based on PDEs mainly addressed torsional dynamics, without explicitly considering the control in the axial dimension. As shown in existing studies, the torsional and axial dynamics are indeed coupled in the drilling system, and thus the control design should explicitly consider the coupled dynamics to enable effective performance. Besides, controlling the drilling penetration rate also requires proper control in the axial dimension. Thus, in this project, we addressed

the control for both the axial and torsional dimensions based on a NDDE model with a coupled axial-torsional dynamics. To address the disturbance and uncertainty in the drill bit-rock interaction, we used the equivalent input disturbance (EID) method. By proposing a new Lyapunov-Krasovskii functional, the stability of the NDDE system is ensured without the necessity of setting a tight boundary constraint on the nonlinear external forces.

As shown in Fig. 1, the control system consists of a neutral-type down-hole drilling model, a reference trajectory internal model, a full state observer, a disturbance estimator, and a feedback controller. Fig. 2 demonstrates the controller performance. The red dashed line stands for the desired trajectory reference, and the blue line shows the drill bit speed response under the EID controller. It is evident that the actual bit speed follows the reference trajectory.

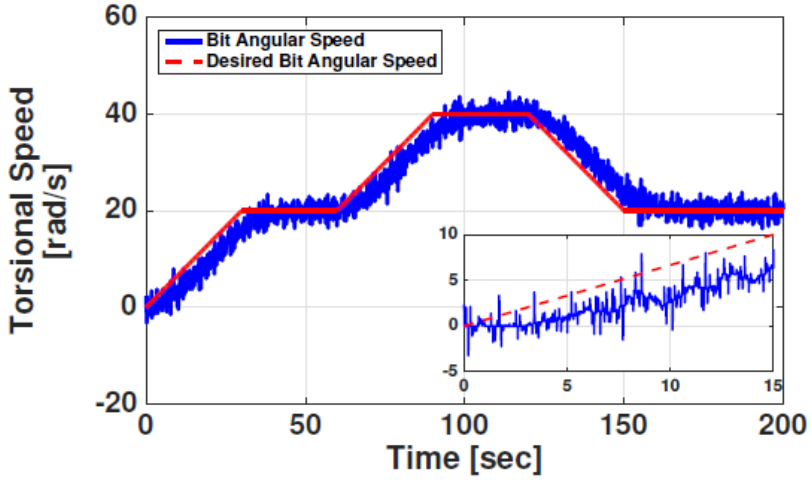

Fig.2. Control Performance Trajectory Tracking – Bit Angular Velcotiy Trying to Track the Desired Speed in Red (Drill Bit Velocity Profile Under Uncertainties)

Impact to the PI's Career:

This research project is very valuable to the PI's career development. It offers seed fund for the PI to initiate fundamental research on nonlinear and robust controls to enable autonomous drilling system, an open research area that has not been well studied. This allows the PI to build strong foundation and generate preliminary results in this high-impact area and apply for larger-scale project in the future. The flexibility on the research deliverables offered by this grant also allows the PI to think out of the box and achieve more rewarding research outcomes.

Impact to students:

One graduate student and one undergraduate student participated in this project. Through this project, the graduate student has published one journal paper, and has two additional papers under preparation for submission. The project helped the undergraduate student gain much experience on high-level research to enhance his credentials for graduate school application. The project can also help him prepare for internship positions in local oil and gas industry.