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Addressing Control Challenges of Discontinuous Processes with Multi-Fidelity Model Predictive Control

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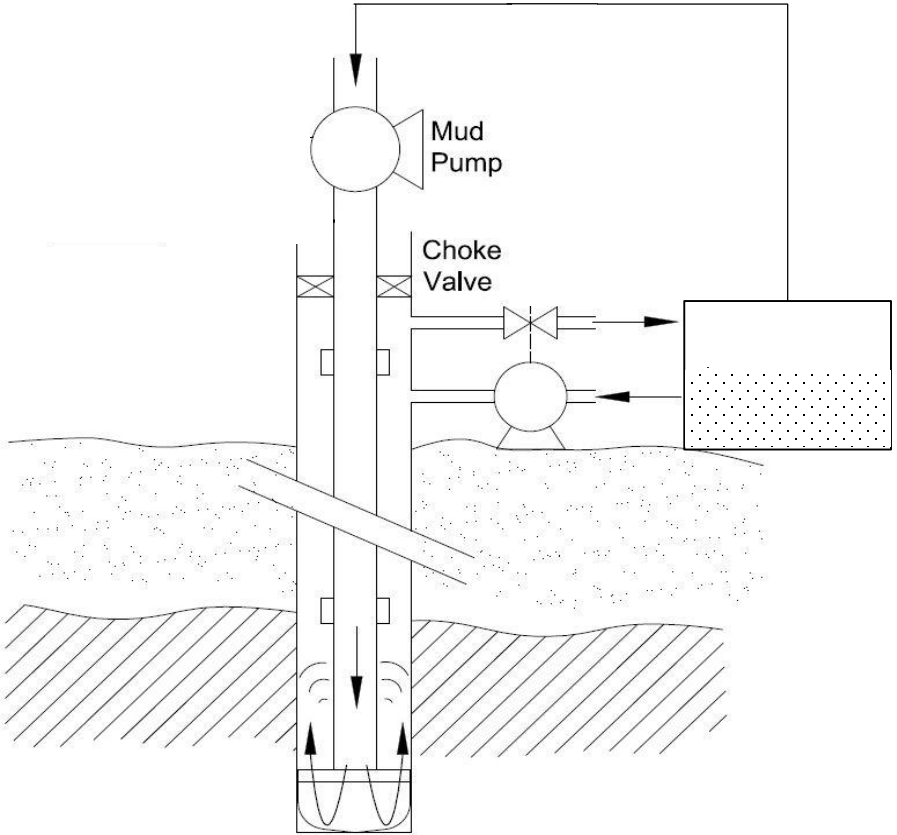
Why Automate Drilling?

- Benefits of Automated MPD
  - HSE– faster response to problems
  - Economic– operate closer to constraints, shorter drilling time

- Benefits of Advanced Control
  - Optimized control resulting in greater accuracy and ability than PID controllers

http://graphics8.nytimes.com

How is a Well Drilled?

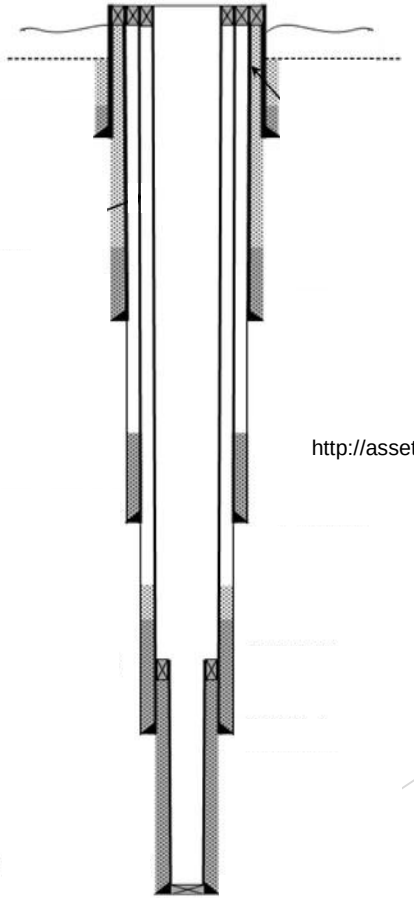


http://www.drillingcontractor.org

http://www.marcellus-shale.us

How is Drilling Discontinuous?

- Frequent pipe connection procedures-- stops mud flow
- Several layers of casing pipe
  - Each pipe is cemented individually
- Drilling must stop completely for each casing pipe installation
  - Drillstring removed entirely, set aside, then reinserted to continue operations



http://assets.dongenergy.com

Challenges of Drilling Automation

- Drilling is a *highly nonlinear* process with frequent starting and stopping
- The *saccadic nature* of drilling requires frequent tuning of models
- Periodically *unavailable and unreliable measurements* make feedback difficult

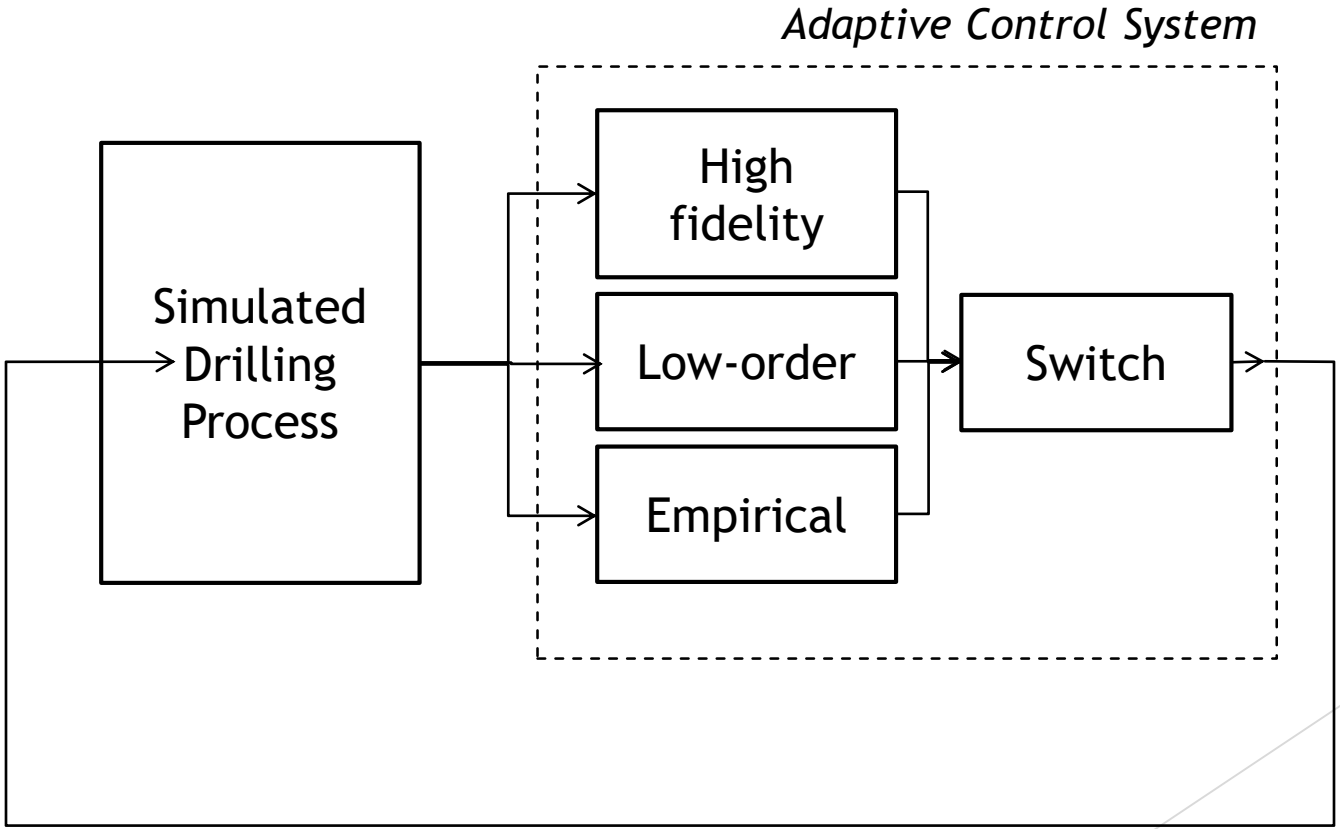
http://www.rockstone-research.com

Adaptive Control Structure Aims

- Couple the *accuracy* of high fidelity models with the computational *speed* of a FOPDT model in real-time predictive feedback control
- Maintain controller *reliability* in the presence of disturbances and model mismatch
- Tune and switch *without interrupting the process*

http://3ji87cbqtq1n271x3jchks4g.wpengine.netdna-cdn.com

Enhanced Reliability with Switched Control



Controller Details

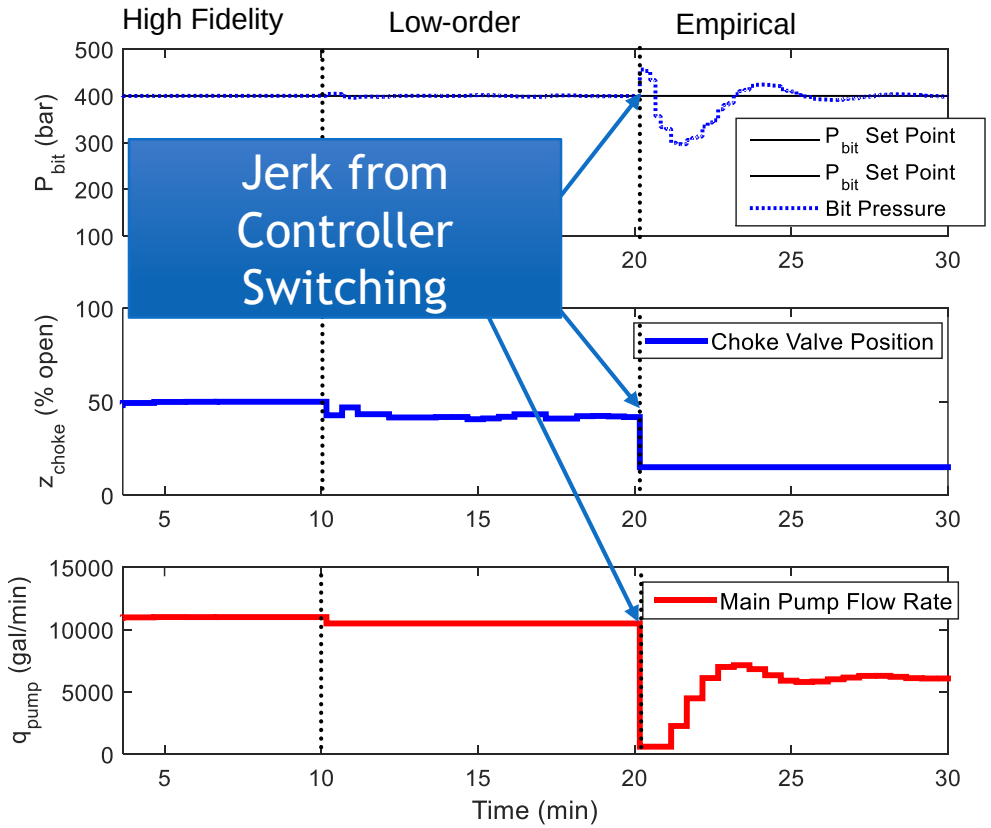
• High fidelity	• Low-order	• Empirical
• *SINTEF Flow Model* • *NMPC* • *Shooting method* • *4 sec control horizon* • *Bias update* • *Absolute error objective function*	• *Stamnes et al.* • *NMPC, 4 states* • *MHE* • *Estimates friction & annulus density* • *10 sec horizon* • *L1-norm objective function*	• *FOPDT* • *Linear MPC* • *4 sec control horizon* • *L1-norm objective function*

Switch and Tuning Details

- Switch
  - *Compares prediction error over last 20 time steps*
  - *Switches if error is greater than a set tolerance*
  - *Picks the controller that converges quickest, within set tolerance*
- Tuning
  - *A separate instance of the high fidelity model simulates a doublet test over 12 min.*
  - *Simulated data is used to fit the gain and time constant in FOPDT model*

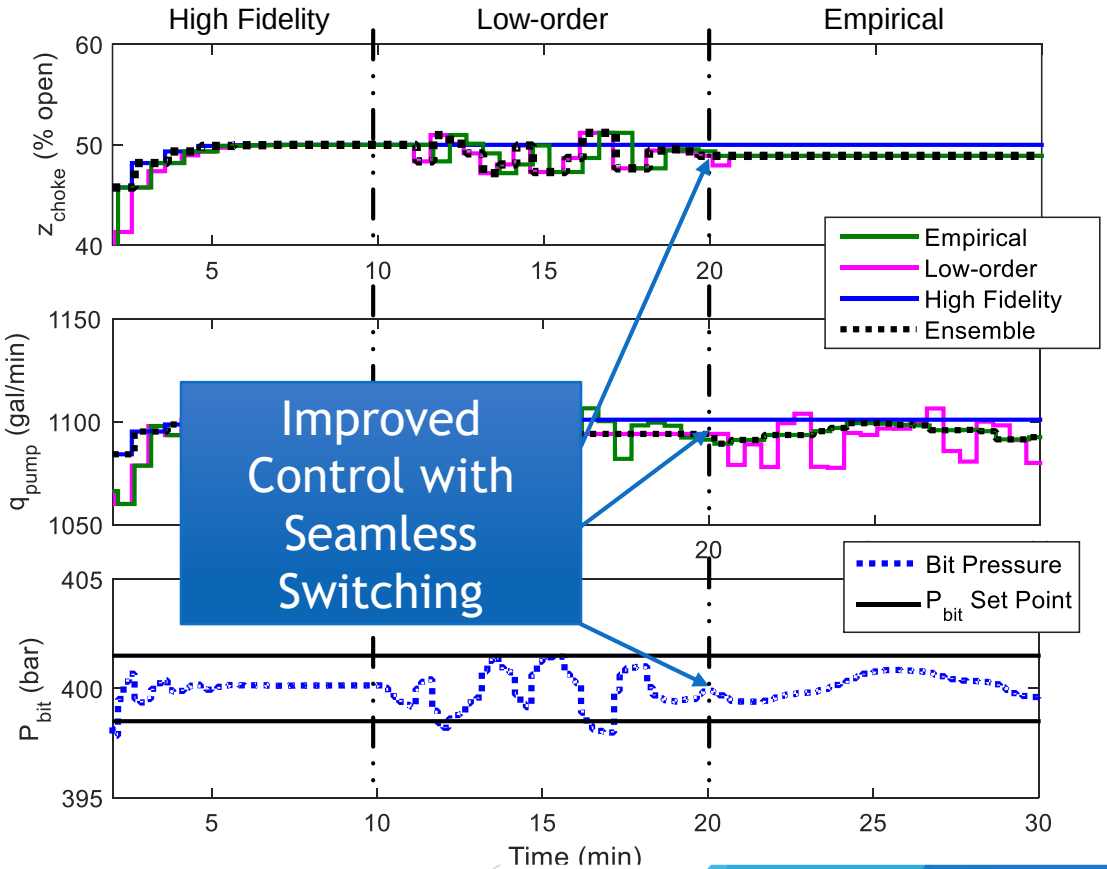
Ensemble Controller Switching Issues

- An *unacceptable jerk* in bit pressure, pump flow, and valve position was observed when switching between controllers
- Using the current process values to initialize *each* controller optimizer at each instance provided smooth transitions

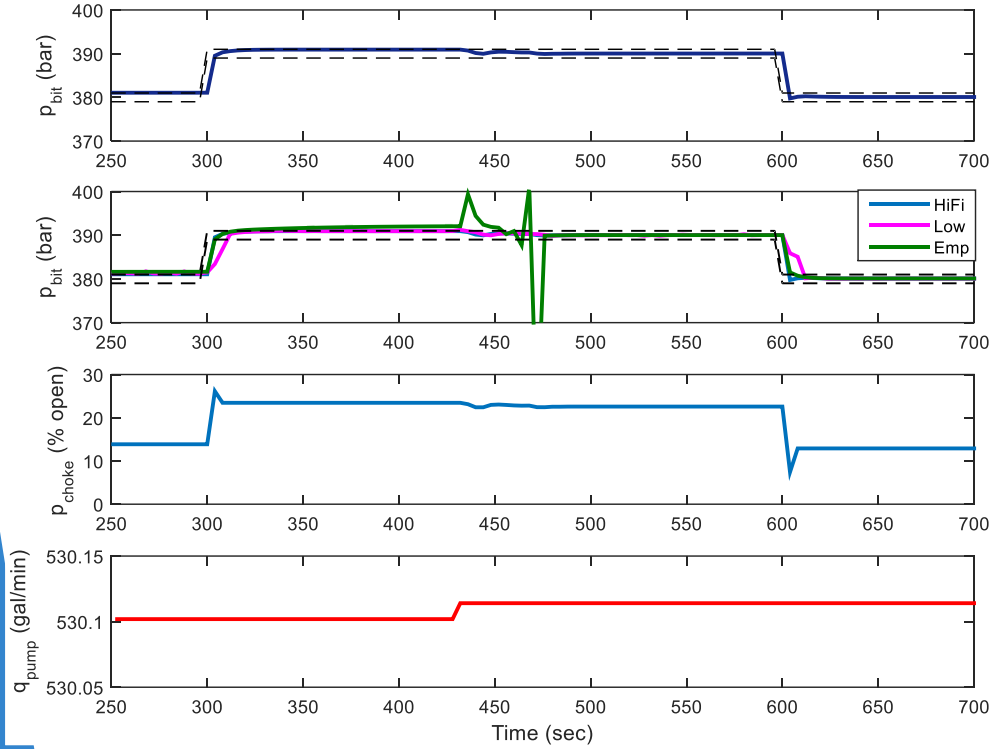


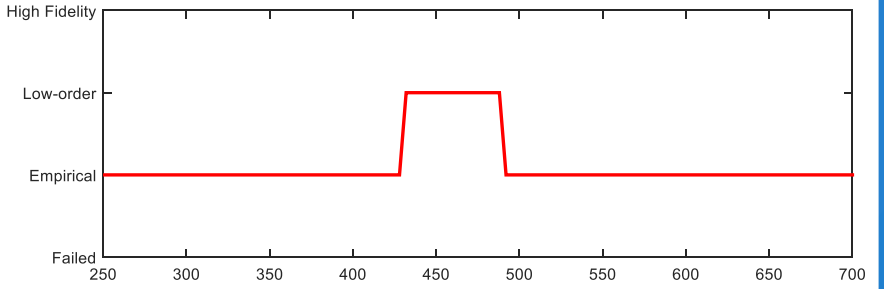
Seamless Switching During Normal Drilling

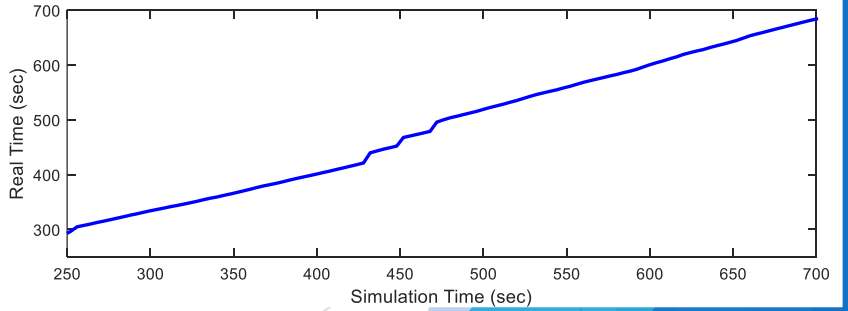
- At 10 and 20 minutes control is switched to the controller indicated
- Despite model inaccuracies the bit pressure is kept within the target range
- Switching between controllers is *seamless*



Set Point Change During Normal Drilling

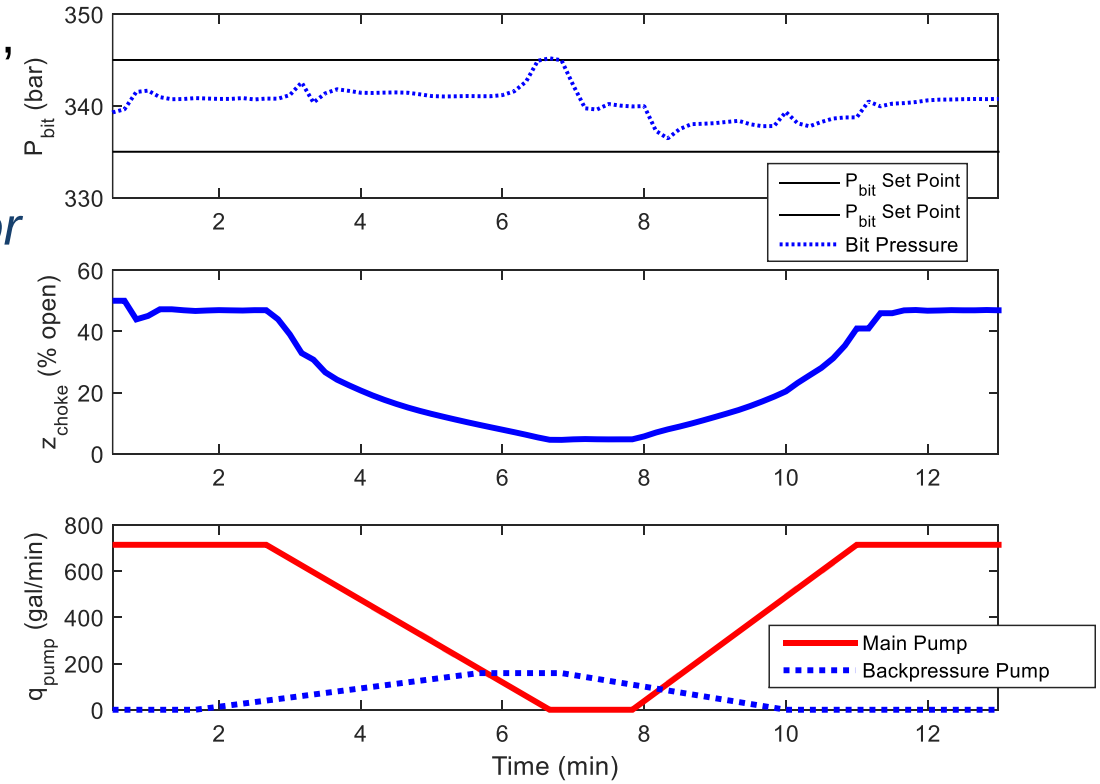






Pipe Connection with High Fidelity Model

- When the mud pump is down, bit pressure measurements cease and *the controller only uses the model predictions for control*
- The high fidelity controller predictions are sufficiently accurate to maintain the bit pressure within ±5 bar of the 340 bar set point with no bit pressure feedback measurements



Conclusions

- The proposed adaptive controller maintains model accuracy and controller stability without interrupting the drilling process
- Multi-fidelity predictive control provides a robust and adaptive framework for automated drilling
- Redundant control models allow for tuning and troubleshooting without interrupting the drilling process
- **Future work**: Kick attenuation, high fidelity estimator for model updates, addressing cuttings loading and pack-off

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