REAL TIME PRODUCTION MANAGEMENT (RTPM) OF PETROLEUM RESERVOIRS

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Motivation

- Need for better utilization of resources
  - Increasing need for fossil fuels (Van Doren 2010)
  - Decreasing petroleum production (Van Doren 2010)
  - 40% of expert workforce will retire in the current decade (Parry et al. 2006)
  - In the order of US$500B could be saved by better operation of the North Sea oil fields on Norwegian shelf alone (PETORO estimation, 2007)

- Significant potentials to provide decision support and improve the performance of oil production
  - Advanced instrumentation and control technologies (Hardware and Software)
  - Production and Seismic Data
  - Geological Models and Process Simulators

Objective: Closed-loop reservoir operation management

- To develop strategies to improve the oil recovery process by closed loop operation and optimization of the water flooding in a mature oil field.
Reservoir dynamics show two “coupled” effects: (Brouwer 2004)

1) **Diffusive characteristics:**
   - *Pressure driven flow*
   - **water** ➔ **oil**
   - moving water-oil front

2) **Convective characteristics:**
   - *Saturation dependent flow/permeabilities*
   - **water** ➔ **oil**

- To maintain the pressure of the reservoir and maximize recovery
- Water fills the void created by the produced oil and pushes the oil towards production wells
Problem Statement

Objective: Real-Time oil production management from a reservoir under water flooding to achieve the following goals:

- Maximize the oil production
- Minimize the oil production time
- Avoid problems such as fingering in the water flooding process

Expected outcome

✓ 10% increase in total oil recovery through optimization and control
Progress by ICP

- A detailed reservoir model is developed based on the ECLIPSE 100.
- ECLIPSE model is fitted to the historical field data (1943-2009).
- ECLIPSE Simulator will be considered as the process for data generation.
- ACTNUM function in ECLIPSE is used to extract a reduced model by eliminating inactive cells.
  - The reduced model is validated by ECLIPSE (~ 3 times faster simulation than original model)
- A closed-loop reservoir pilot is prepared to evaluate the results of the studies.
- A MATLAB toolbox is under development to represent the ACTNUM model
Different Levels of Control in the Process

The reservoir under production is a Semi-Batch process

- **Real-Time Optimization (RTO) to determine/update the trajectories (Supervisory Level Control)**
  - To maximize the production while minimizing the production time
  - Respect process and control constraints

- **Adaptive Models Predictive Control (AMPC) (Regulatory Level Control)**
  - Make the process variables follow their specified trajectory
  - Reject disturbances
Proposed Solution

- Develop a data-driven model based on the simulated data from ECLIPSE
  - POD, Subspace Identification, reduced-order model by Hankel transform
- Adapt the model to process data
  - ECLIPSE Simulated Data or Pilot Field Data
- Regulatory control: Design an adaptive MPC based on the model
  - Time scales:
    - Sample time: 1 week
    - Prediction horizon: 10 weeks
    - Control Horizon: ≤10 weeks
- Supervisory Control: Long term optimization to update trajectories
  - Over a long horizon, e.g. entire life of the reservoir or 10 years
  - Frequency: 1 per year
RTPM Framework

Challenges:

- High dimensional process with complex process model
- Developing accurate reduced order models
- Uncertainty and identifiability (very few and far between measurements)
- Continuously time-varying process
- Optimization with uncertainty for long term operation
Modeling

- Simulated data from ECLIPSE satisfying Identifiability conditions
- Different system identification techniques will be evaluated:
  - SIMs and LVMs (Shi and MacGregor 2001):
    - Easy to develop (no NLP for parameter estimation, no iterative identification)
    - Easily handle MIMO processes
    - Use the POD concept to develop reduced-dimension models
    - Different data arrangement from conventional system identification techniques
  - LVMs
    - No complication/bias in parameter estimation
    - Non-causal model structure: not easy to validate and analyze
    - Non-parsimonious Model
  - SIMs:
    - Causal model (state Space format)
    - Parsimonious Model (smooth prediction)
    - Difficult to avoid model bias (should be handled my adaptive techniques)
- Other possibilities:
  - Hankel transform (Van Doren 2010)
  - Model-free SIM (Favoreel et al. 1999)
Robust Model Adaptation

- Model development and maintenance poses a major challenge in applying MPC to industrial processes.
- Adapting model to any real-time data is more likely to deteriorate the model
  - Noise effects
  - Different operation mode effects (even operator interferences)
- Data screening and reconciliation should be considered to enhance the fidelity of the data
- A supervised approach is used for model adaptation
  (Dozal-Maejorada & Ydstie, 2007-2008)
  - Adaptation when prediction deteriorates
  - Constrained parameter estimation
Real Time Optimization
(Supervisory Level Control)

Long-term Optimization

\[ \max J = \sum_{k=0}^{p-1} \sum_{n=1}^{N_{pr}} \sum_{i}^{N_{seg}} q_{o,n,i}^2(k) \]

- \( P \) is the prediction horizon, \( N_{pr} \) is the number of producer wells, \( N_{seg} \) is the number of considered layers and \( q_{o} \) is the oil production rate.
- Optimization will be used to update the setpoint trajectories for the lower level controller (AMPC)
- Challenges:
  - Continuously time-varying process (if use multiple models, they need to be coordinated)
  - Optimization size
  - Possibility of using Latent Variable Models for batch process optimization (Flores Cerrillo and MacGregor 2004)

Increasing the simulation time by Projective Integration
(Kevrekidis and Samaey 2009)

- Inner integration at small time steps to damp out fast dynamics
- Extrapolation over a large number of time steps for the slow dynamics
- Suitable for Stiff differential equations and stochastic simulation

EWQ Meeting 2013
Summary and Project Outlook

- **Closed-loop reservoir management**
  - Problem is defined
  - The general framework is determined
  - Trajectory tracking control will be based on robustly adapted linear models
  - Optimization problem poses a challenge
  - Modeling and system identification will play a central role in this project

- **Will be completed over 3 years**
  - Technical development for closed loop operation and optimization of water flooding in 2013.
  - The implementation of optimal control strategy in simulation and real tests on the Yarigui-Cantagallo pilot field in 2014
  - Developing the strategy and software for company-wide implementation in 2014-2015

- **Previous experiences at CAPD will support the project** (Ydstie & Jiao, 2006)