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Problem Statement

- Monitoring, control and real time release of products require systematic approaches to sensor network design (SND)
- Trade-off between cost and performance
- SND can be posed as multi-criteria optimization problem
  
  **Objective**: minimizing cost or maximizing one or more performance metrics
  
  **Constraints**: desired/acceptable level of observability, redundancy, reliability, robustness, ...

Objectives

- SND based on performance in process monitoring
- SND based on performance in process fault detection
- SND based on process control & dynamic robustness (future work)
SND Based on Process Monitoring

Questions

• Measurements are inevitably subject to errors
  Random noise and disturbances
  Gross errors, bias and outliers
• Measurement errors reduce accuracy of
  estimates of measured & key unmeasured CQA’s
• How to design sensor network that is reliable
  robust to measurement errors

Methods

• Design experiments to efficiently and systematically analyze
  correlation between measurement noise and estimates of CQA’s
• Evaluate and compare different data reconciliation (DR) and gross
  error detection (GED) techniques
• Develop solution strategies to solve DR and GED in real time
• Choose SND considering observability, measurement precision
  and redundancy, estimation reliability, robustness, ...
SND Based on Process Fault Detection

Questions

• Process faults may lead to severe events and nonconforming products
• Fault detection and diagnosis are critical
  Fast and accurate response
  Reliable and robust to disturbances
• How to design a sensor network to inherently facilitate process fault detection?

Methods

• Analyze the sources of process malfunctions and failures
• Develop appropriate metrics to assess fault detectability
• Integrate SND with techniques of fault identification and diagnosis while considering cost, observability, redundancy, ...
• Test the optimal design using simulations as well as actual experimental studies on a continuous dry granulation line
SND Based on Process dynamic robustness (Future Work)

Questions

• Advanced control strategies require accurate measurements and estimates of the current state of the system
• Traditional SND only focus on steady-state operation and fails to consider dynamics of process & its control system
• How to design a sensor network to maximize process and/or control performance

Methods

• Develop appropriate metrics to describe control performance and dynamic process efficiency
• Extend the proposed framework to consider the role of SND in maximizing dynamic process robustness
• Test the resulting sensor network based on the use of simulations and actual pilot plant implementation and compare with designs based on monitoring & detection functionalities
Implementation: Dry Granulation Line

Critical Process Parameters (CPPs) in green
Critical Quality Attributes (CQAs) in blue
Preliminary Results: Feeder-Blender System

Measurements:
- Powder flowrates
- Mixture flowrates
- API concentration

API Measurements contaminated with gross errors (bias)

Real Values  Measurements  Reconciled Values

DR without GED

DR with GED
## Project Timeline

1. **Analyze correlations between uncertainties associated with specific sensor measurements and accuracy of estimates of key unmeasured CQA’s**  
   - Duration: 2 Months

2. **Evaluate and compare performance of different DR and GED techniques on the granulation line**  
   - Duration: 3 Months
   - Implement efficient solution strategies to solve the resulting DR and GED problems in real time

3. **Develop appropriate metrics for SND focusing on process monitoring and fault detection**  
   - Duration: 3 Months
   - Present and solve SND problems using the proposed metrics while considering performance targets, such as observability, redundancy, reliability and robustness

4. **Test and compare different designs based on the use of simulations and actual implementation in the dry granulation line**  
   - Duration: 4 Months
Anticipated Industrial Impact

- A suite of data reconciliation (DR) and gross error detection (GED) strategies for dry granulation lines which can be used as templates for industry member application

- An efficient code for solving the resulting DR problem in real time and a recommended set of statistical tests for GED

- A set of metrics indicating values of information in sensor networks based on different sensor network design (SND) purposes, such as process monitoring and fault detection

- A generalizable framework for analysis, design, and implementation of sensor networks in continuous pharmaceutical process