Value of Information and Sensor Network Design

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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, …

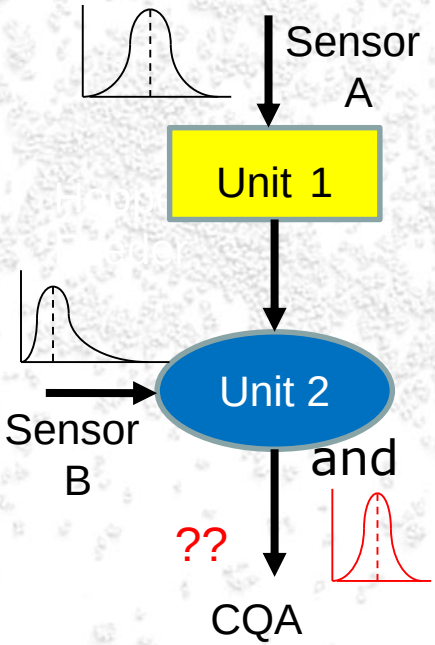
Objectives

- 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



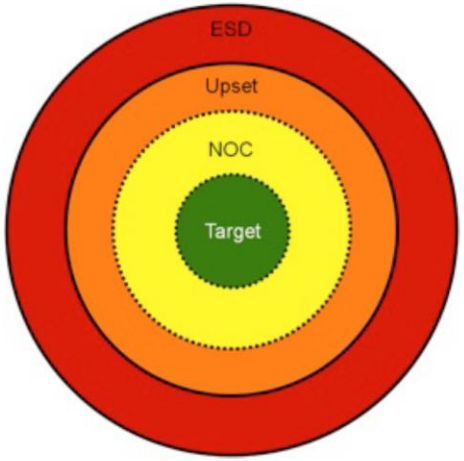
Methods

- 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)

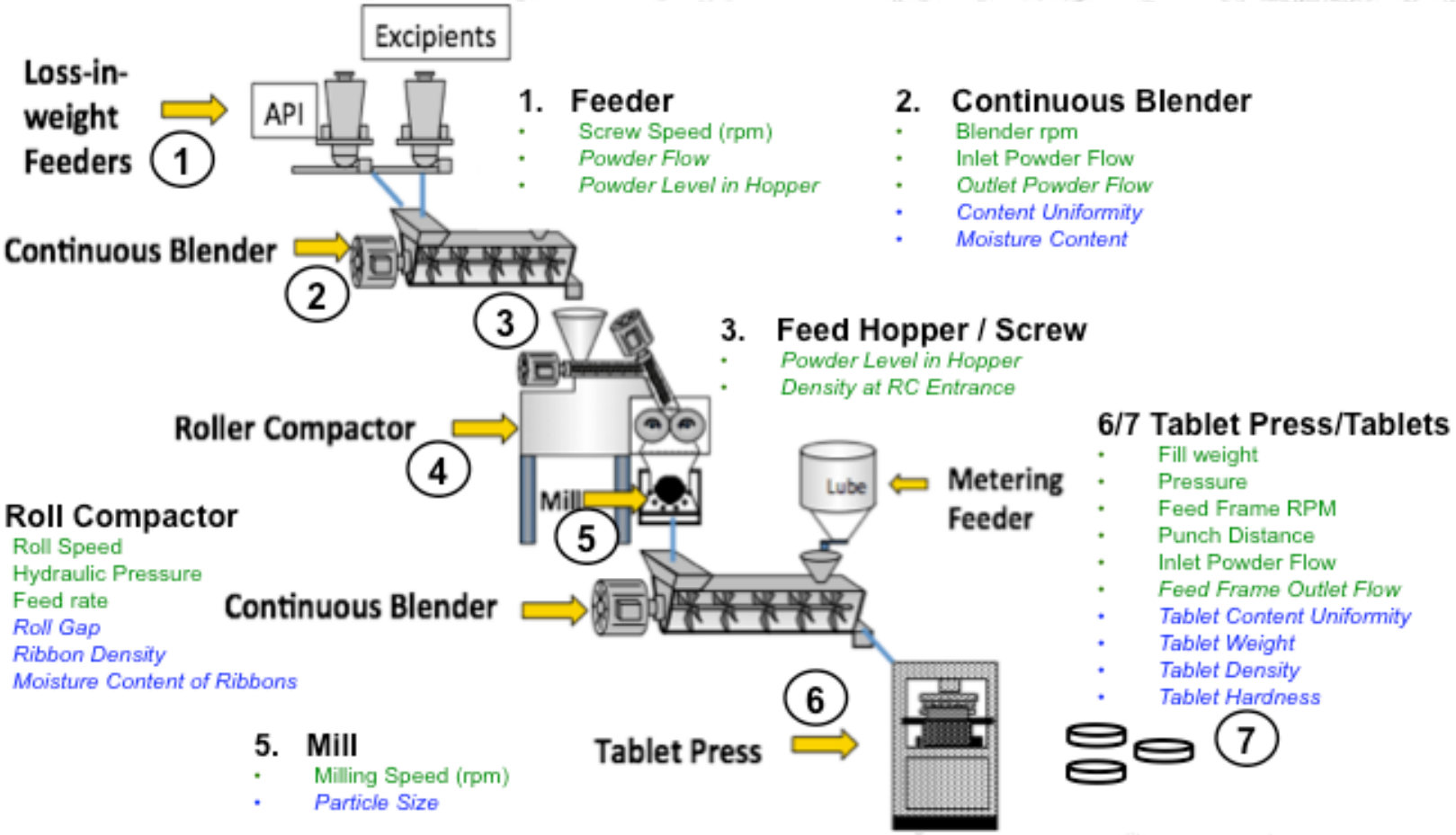
Questions

- 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

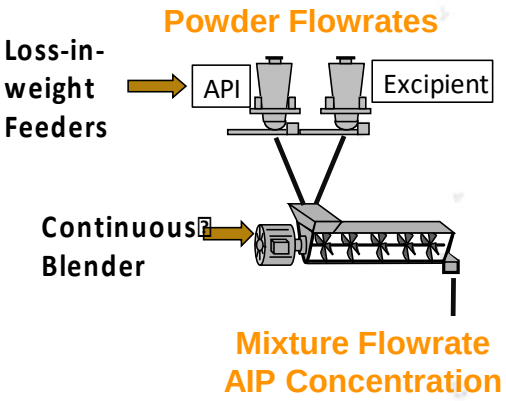
- Develop appropriate metrics to describe control performance and dynamic process efficiency
- Extend the proposed framework to consider the role of SND in maximizing dynamic process robustness
- Test the resulting sensor network based on the use of simulations and actual pilot plant implementation and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

Implementation: Dry Granulation Line

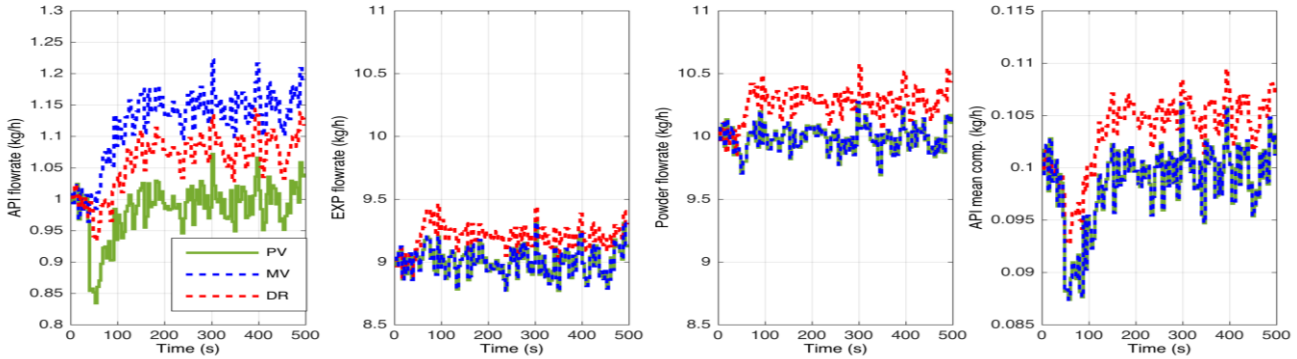


Critical Process Parameters (CPPs) in green
Critical Quality Attributes (CQAs) in blue

Preliminary Results: Feeder-Blender System



Real Values Measurements Reconciled Values

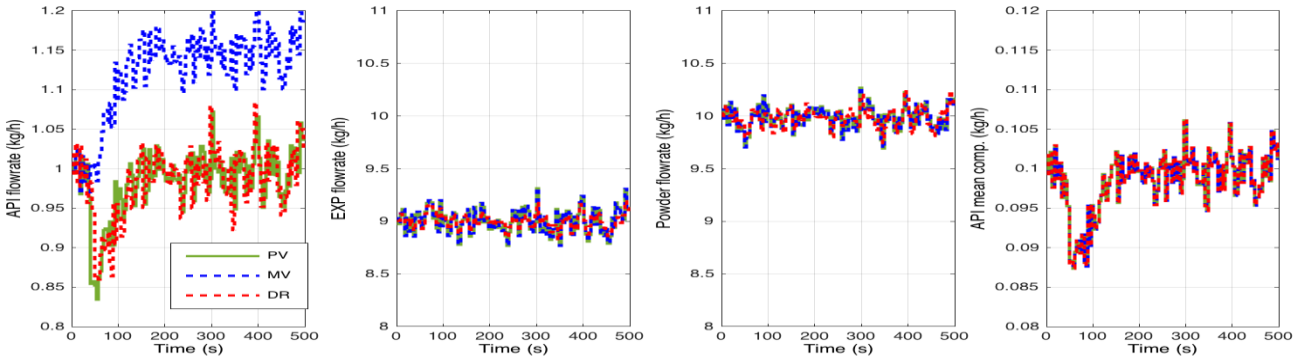


DR without GED

Measurements:

- Powder flowrates
- Mixture flowrates
- API concentration

API Measurements contaminated with gross errors (bias)



DR with GED

Project Timeline

- Analyze correlations between uncertainties associated with specific sensor measurements and accuracy of estimates of key unmeasured CQA's — **2 Months**

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

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

- Test and compare different designs based on the use of simulations and actual implementation in the dry granulation line — **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