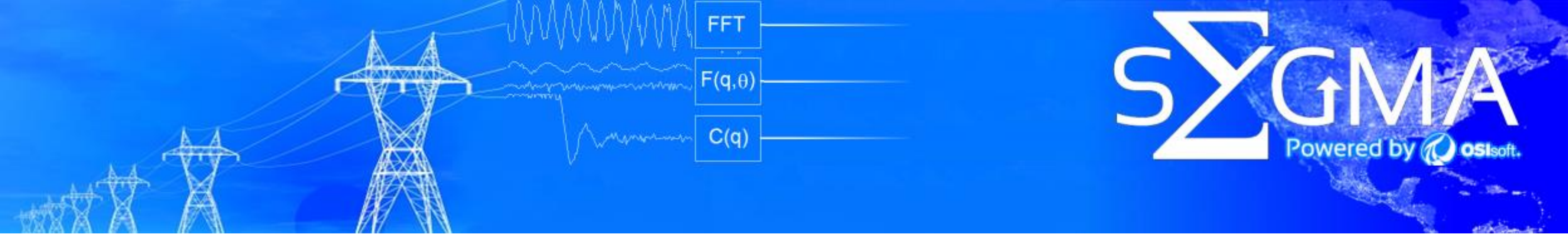

A Smart PMU with Edge Processing at the UCSD Synchrophasor Grid Monitoring and Automation Lab

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OSIsoft, National Instruments & the University of California, San Diego

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A few words on SDSC SyGMA Lab

The SyGMA lab: key player in the emerging technology on electric grid instrumentation, development of new data processing, modeling and model validation tools based on synchrophasor data for advanced grid monitoring and automatic control of electric networks.

- OSIsoft: Data Storage and Data Processing
- National Instruments: PMU hardware and Control Algorithms
- SDG&E (A Sempra Energy utility): PMU applications and Control Algorithms on RTDS
- SDSC (San Diego Supercomputer Center): Facilities and business services

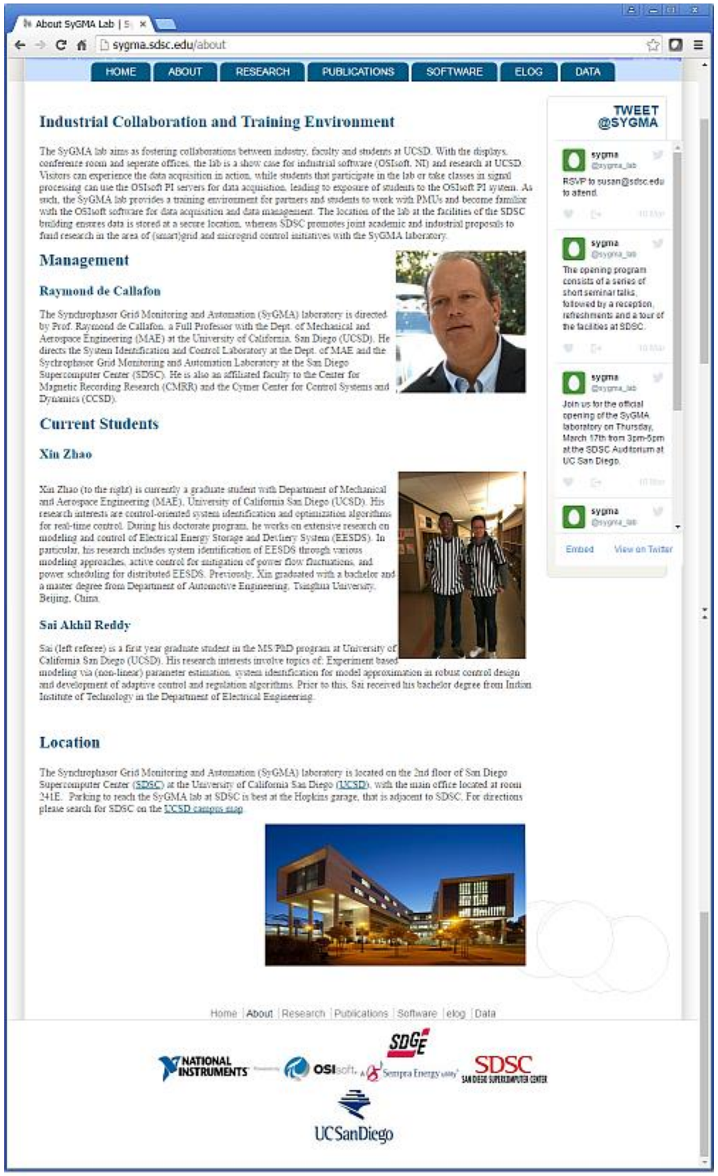
SΣGMA Powered by OSIsoft.

Benefits for Industry

Industry Sponsored Lab at the SDSC

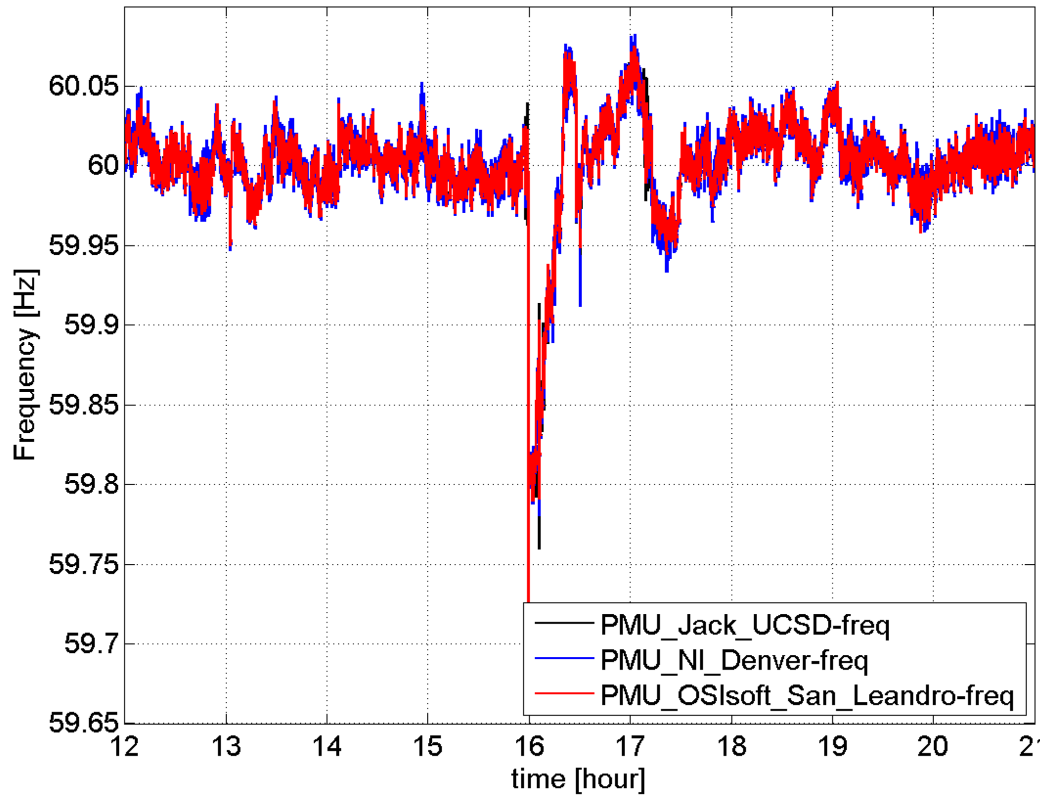
http://sygma.sdsc.edu/

- Show case for industrial software (OSIsoft, NI) through research
- Lab facilities with data acquisition
- Collaborations with utility companies
- Access to students with experience
- Joint proposals for (micro)grid monitoring and automatic control
- Foster collaborations between industrial partners and UCSD
- Shared IP and PMU applications on NI hardware and OSIsoft PI server



"Smart" PMU: *local* signal processing and detect/store events *centrally*

- How to implement "local" signal processing?
- Can "local" processing used to detect individual events?
- Can event detection be distributed on each PMU?



May 30 data: 972000 data points (30Hz sampling noon-9pm)

Approach (and outline of talk)

Infrastructure based on real-time local processing of PMU data:

- National Instruments Compact RIO system (cRIO)
- cRIO configured as a 3 phase PMU system (with control output)
- Filtering of phasor data to obtain Filtered Rate of Change signal
- Formulate event detection based on FRoC signal

NI cRIO system

- 667 MHz Dual-Core Processor and Artix-7 FPGA with 1 GB nonvolatile storage, 512 MB DDR3
- NI Linux Real-Time OS with 2 Gigabit Ethernet, 1 USB device, 1 USB Hi-Speed host, and RS232
- 4-slot Artix-7 FPGA chassis

General purpose “control box” with reconfigurable hardware/slots

NI cRIO system

- 667 MHz Dual-Core Processor and Artix-7 FPGA with 1 GB nonvolatile storage, 512 MB DDR3
- NI Linux Real-Time OS with 2 Gigabit Ethernet, 1 USB device, 1 USB Hi-Speed host, and RS232
- 4-slot Artix-7 FPGA chassis

General purpose "control box" with reconfigurable hardware/slots becomes a "PMU" with

- 3 Phase Voltage/3 Phase current input
- GPS antenna module
- Proper NI LabView software

End Result: real-time streaming phasor data in a cRIO

NI cRIO system

Reconfigurable hardware for cRIO PMU:

- NI 9246: 20 A, 30 Apeak, 24-Bit, 50 kS/s/ch, 3-Ch AI Series Module
- NI 9242: 250 Vrms L-N, 400Vrms L-L 24-Bit, 50 kS/s/ch, 3-Ch AI Series Module
- NI 9467: GPS Time Synchronization Module

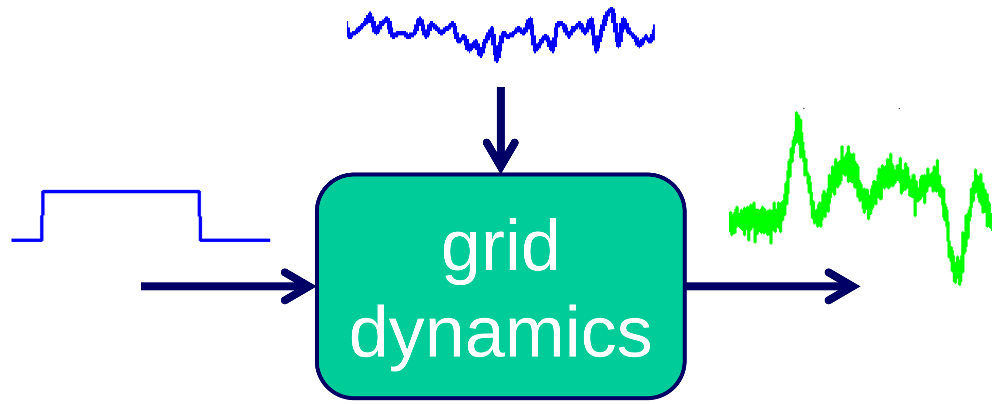
Software:

- LabVIEW 2015 base with RT and FPGA modules
- Electrical Power Suite (EPS) 2015
- PMU source code (under development)

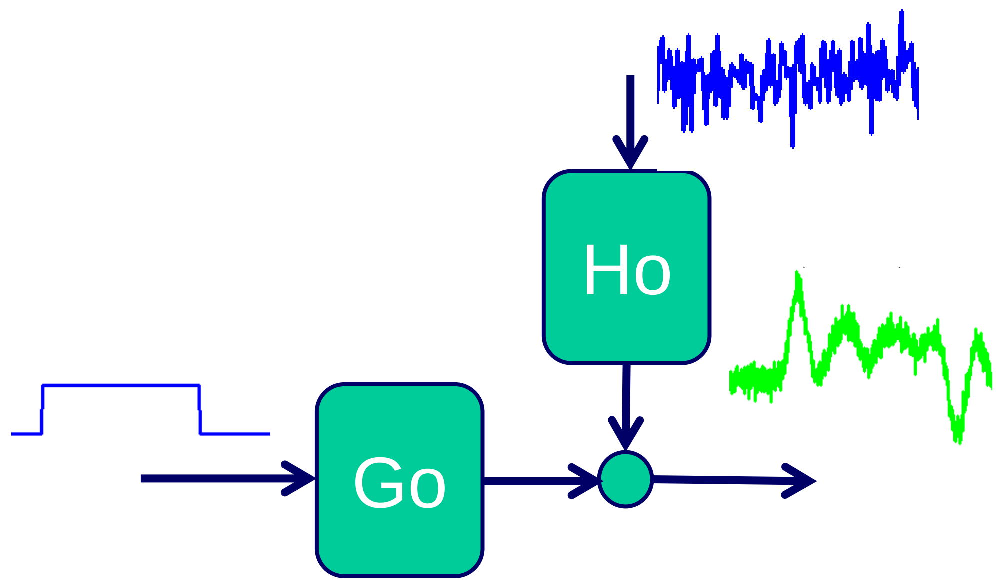
Filtering of Phasor data

Approach is based on dynamic and statistical analysis of PMU data

- Assume PMU observation is linear combination of:
  - Main event signal filtered by grid dynamics
  - Small/random events filtered by grid dynamics

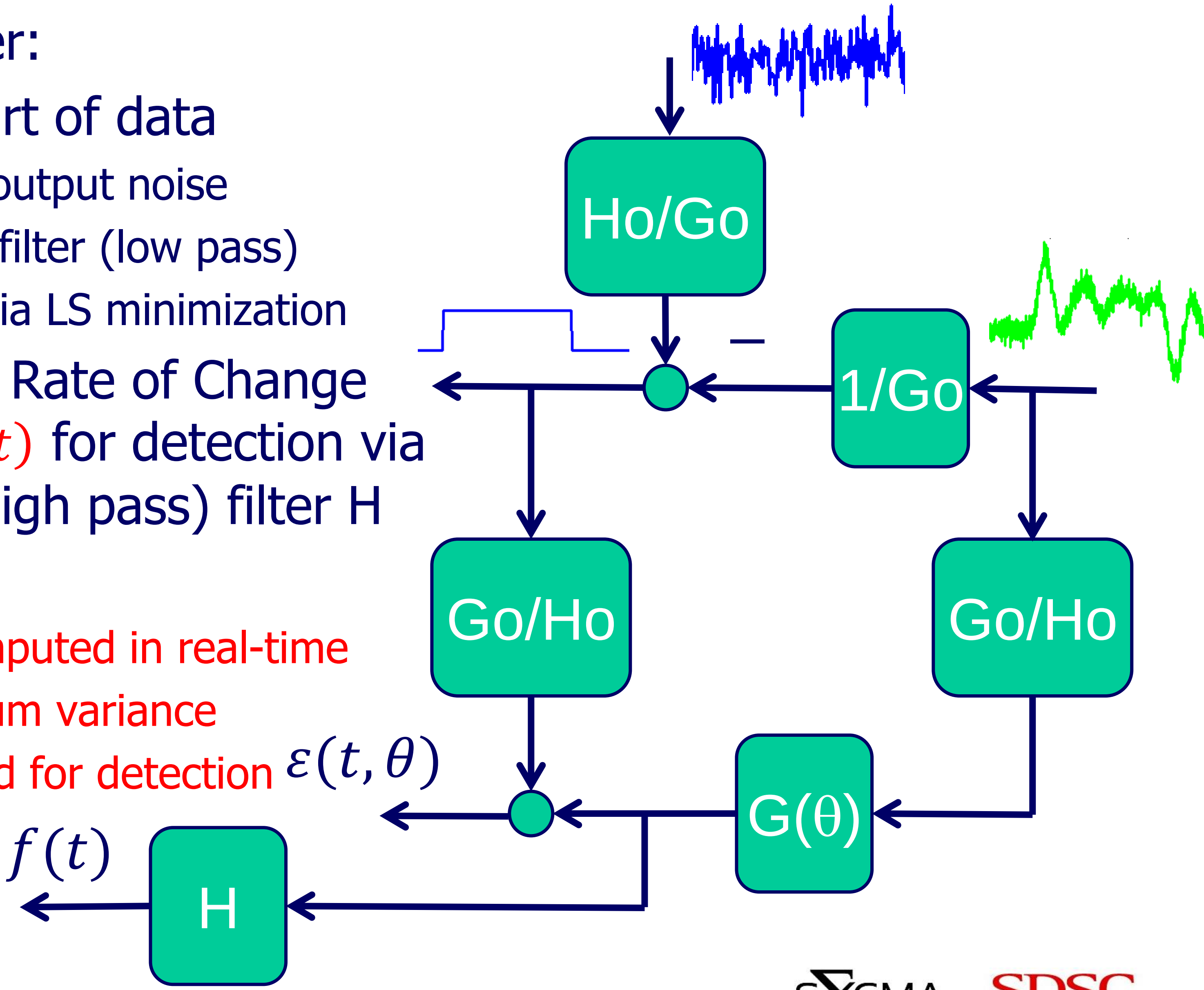


- What's new here:
  - Use knowledge on main modes (grid frequency and damping)
  - Compute optimal detection signal by reconstruction of (filtered) main event signal

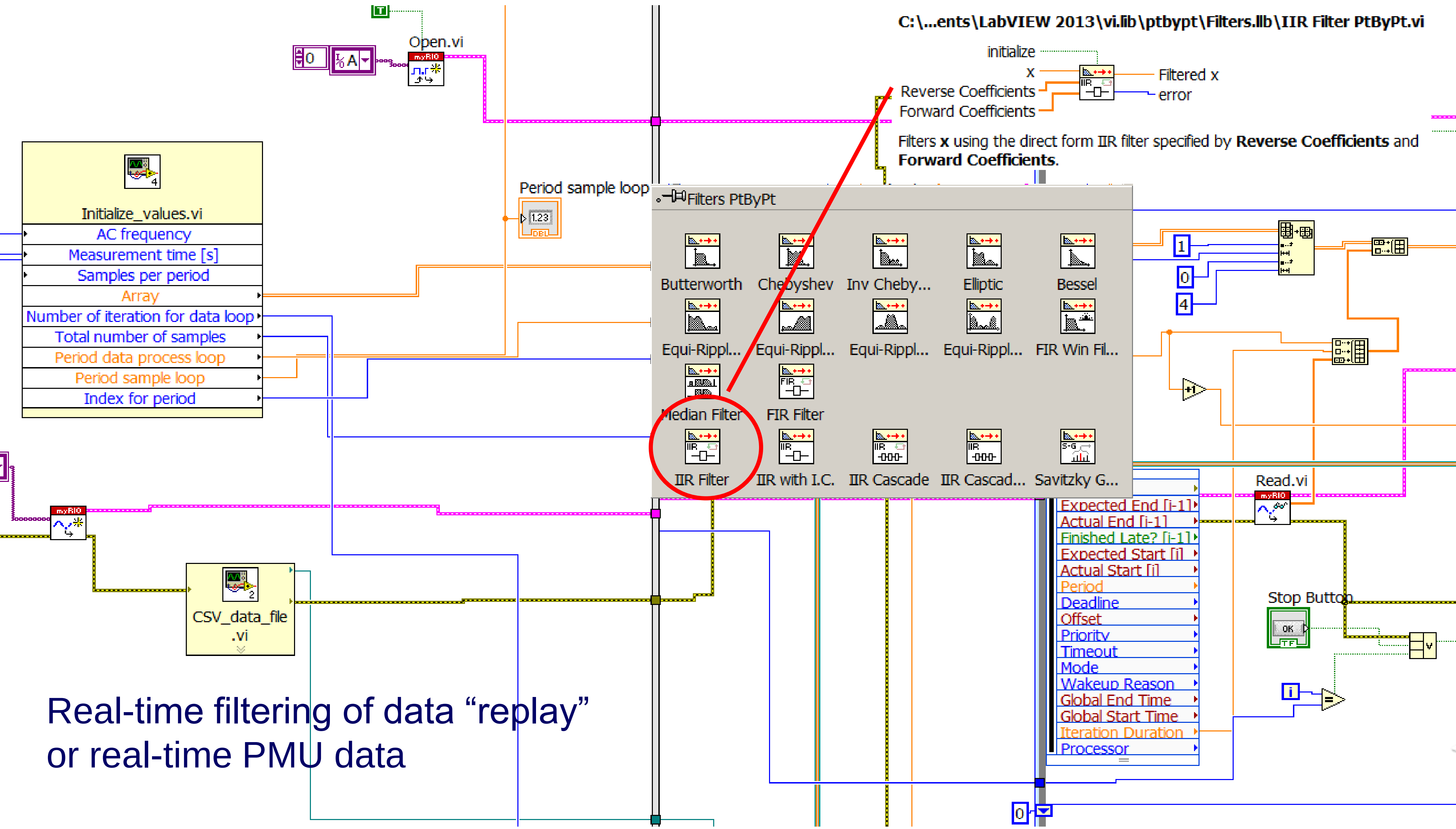


Computation of filter:

- Select "small" part of data
  - Model noise as output noise
  - Add fixed noise filter (low pass)
  - Compute filter via LS minimization
- Define a Filtered Rate of Change (FRoC) signal $f(t)$ for detection via differentiation (high pass) filter H
- End Result:
  - $f(t)$ can be computed in real-time
  - $f(t)$ has minimum variance
  - $f(t)$ can be used for detection

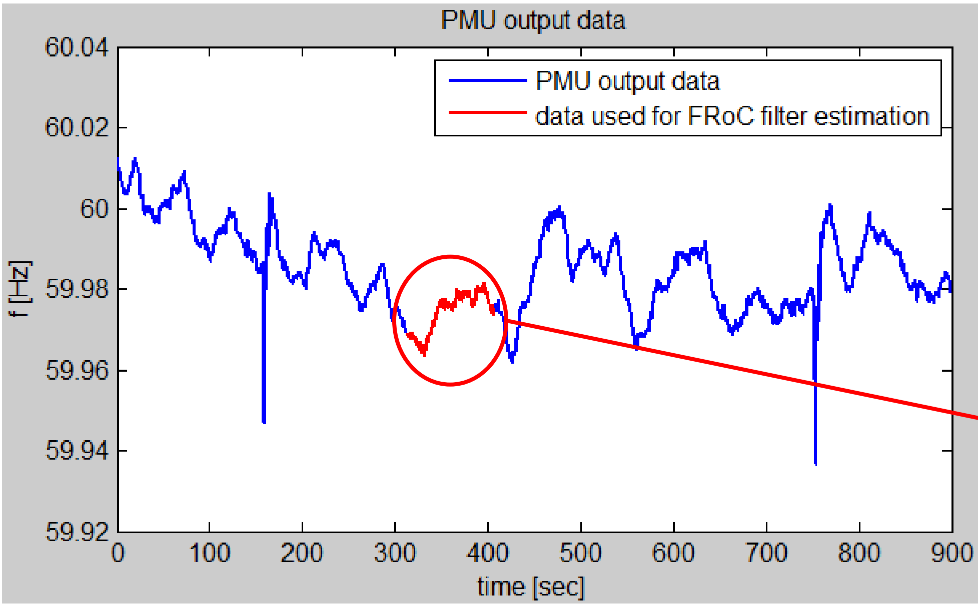


Filter Implementation in LabView



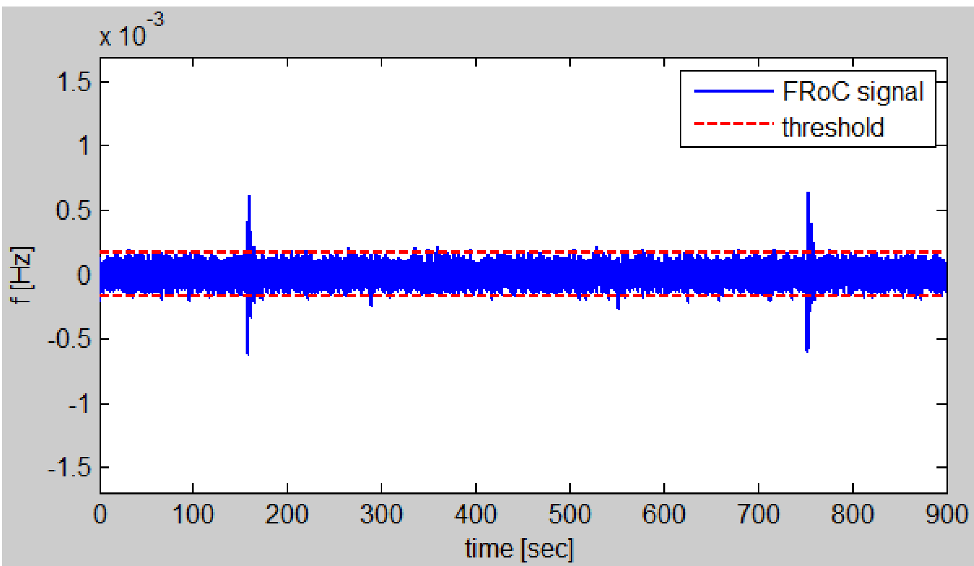
Real-time filtering of data “replay” or real-time PMU data

Filtering of Phasor Data



Select “small” part of data

Phasor data (only frequency here) used for the identification of the real-time filter



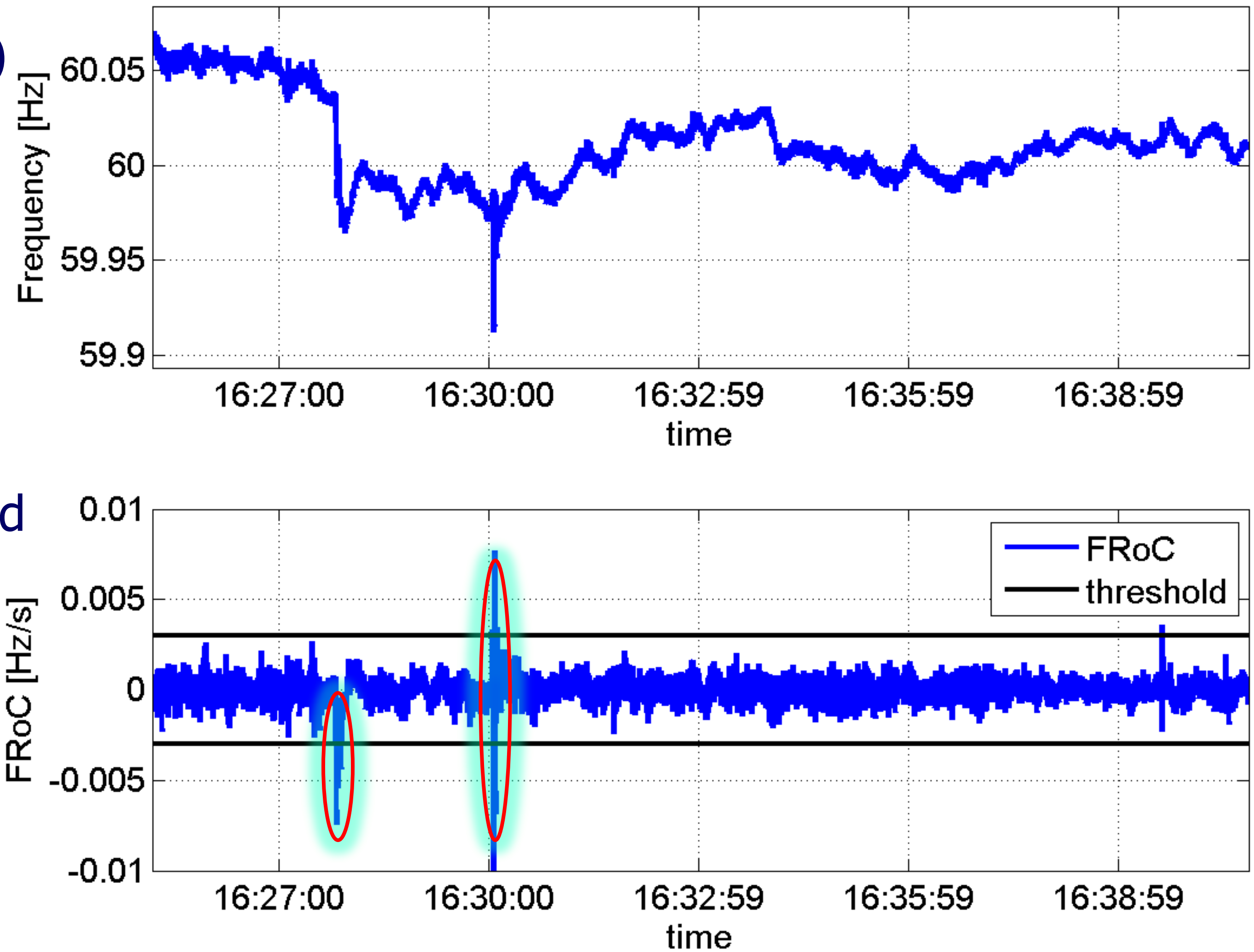
Create FRoC signal

Based on “small” part of data:

- Compute FRoC signal
- Compute 3 sigma bounds

FRoC Signal – event detection

- Small thresholds with small $FRoC(k)$ during ambient behavior
- Detection of events via:
  - Set threshold based on ambient data
  - $FRoC(k)$ outside threshold for *m* consecutive points

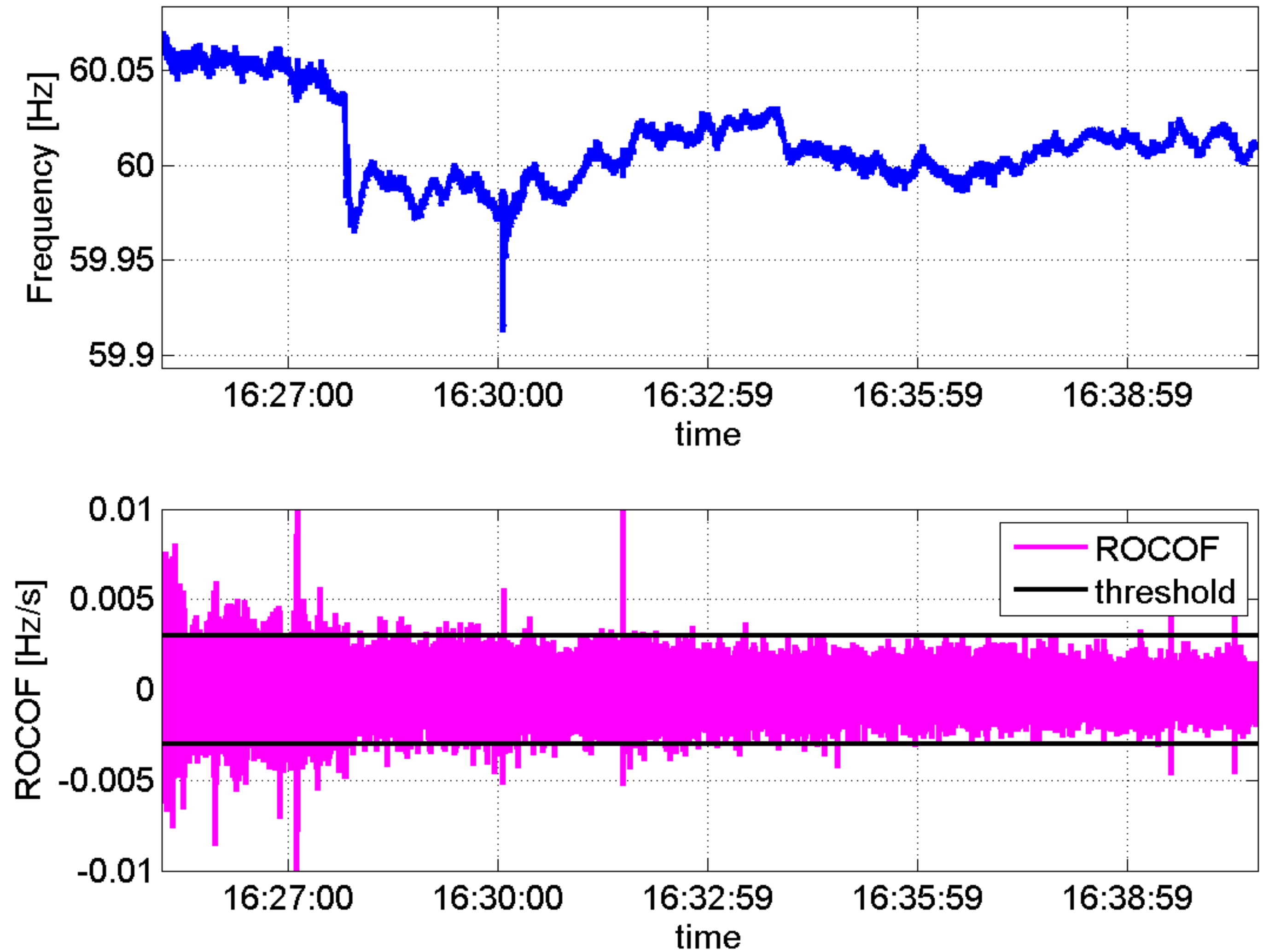


  - Classify event by saving/analyzing *N* data points

FRoC Signal – event detection

Compare with standard ROCOF

- Much larger than *FRoC(k)!*
- More false alarms

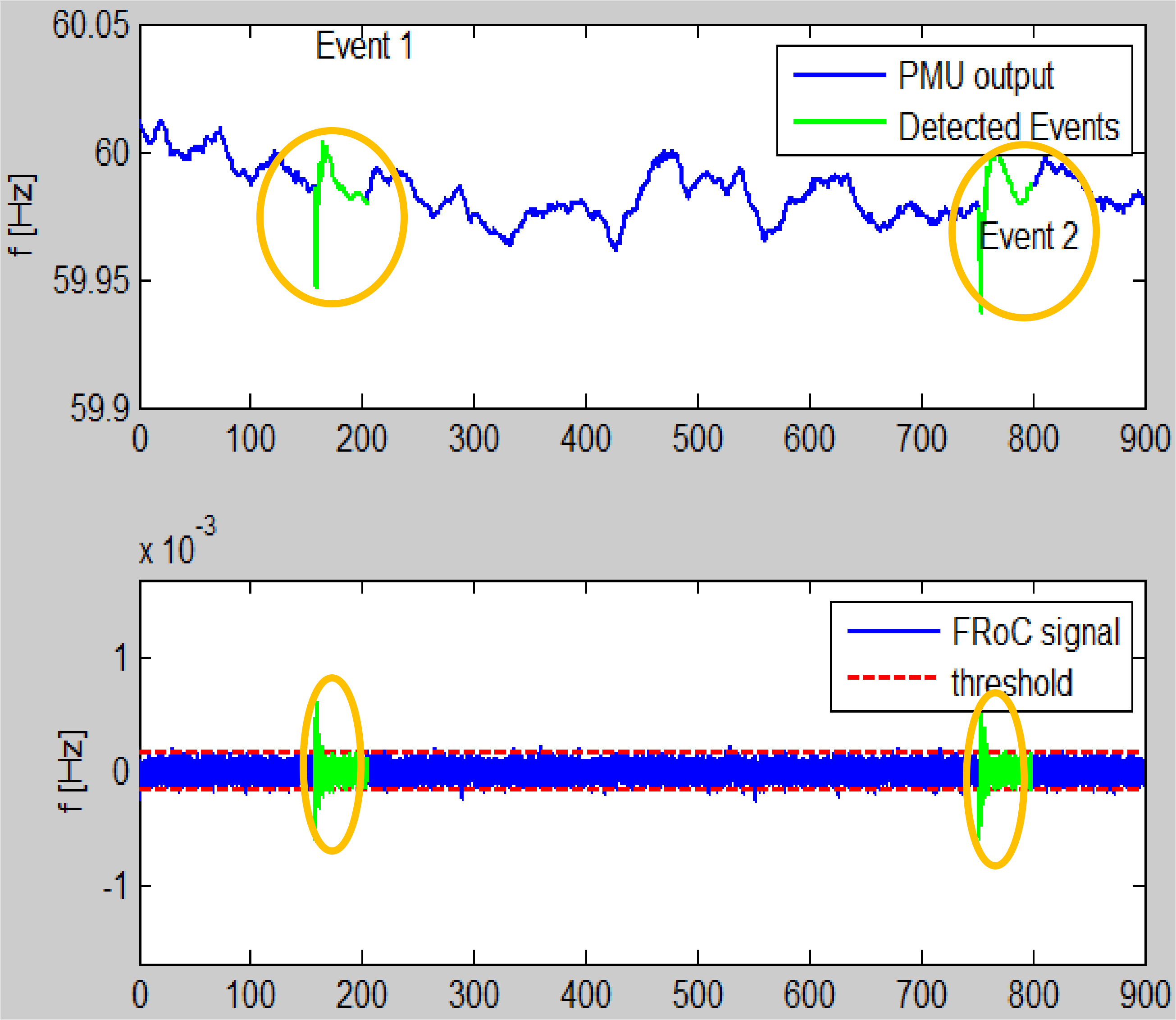


Local/edge Event Detection

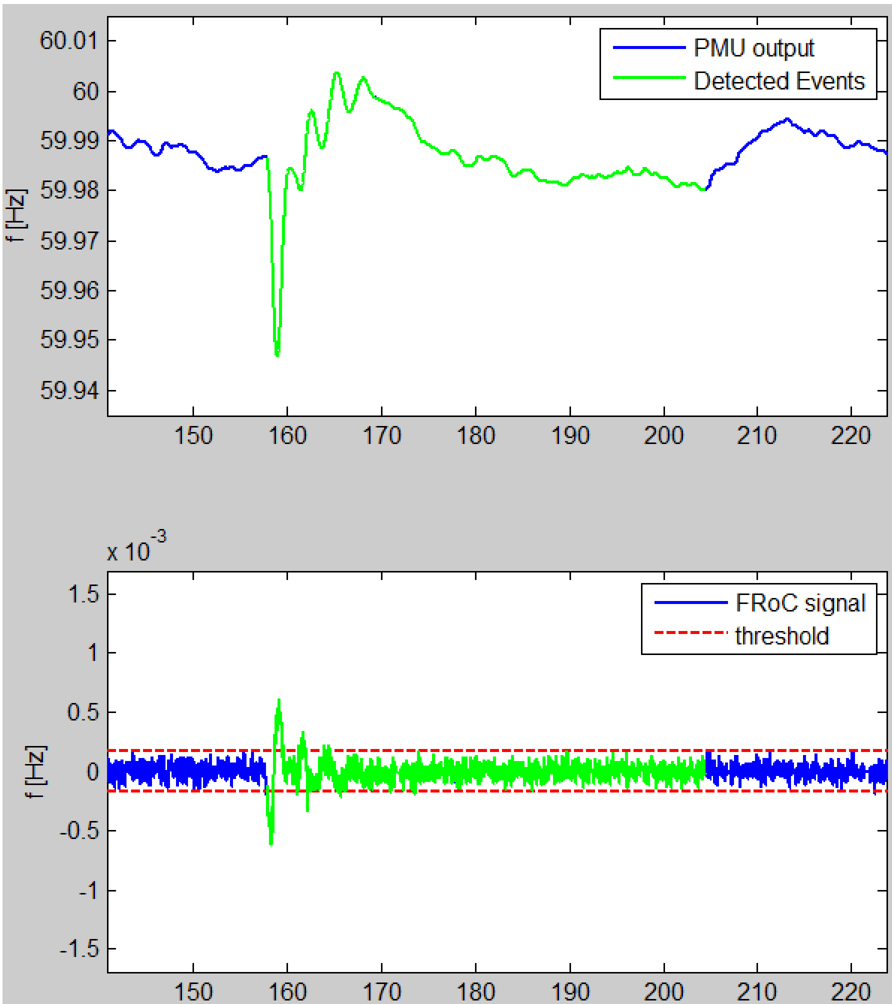
Automatic:

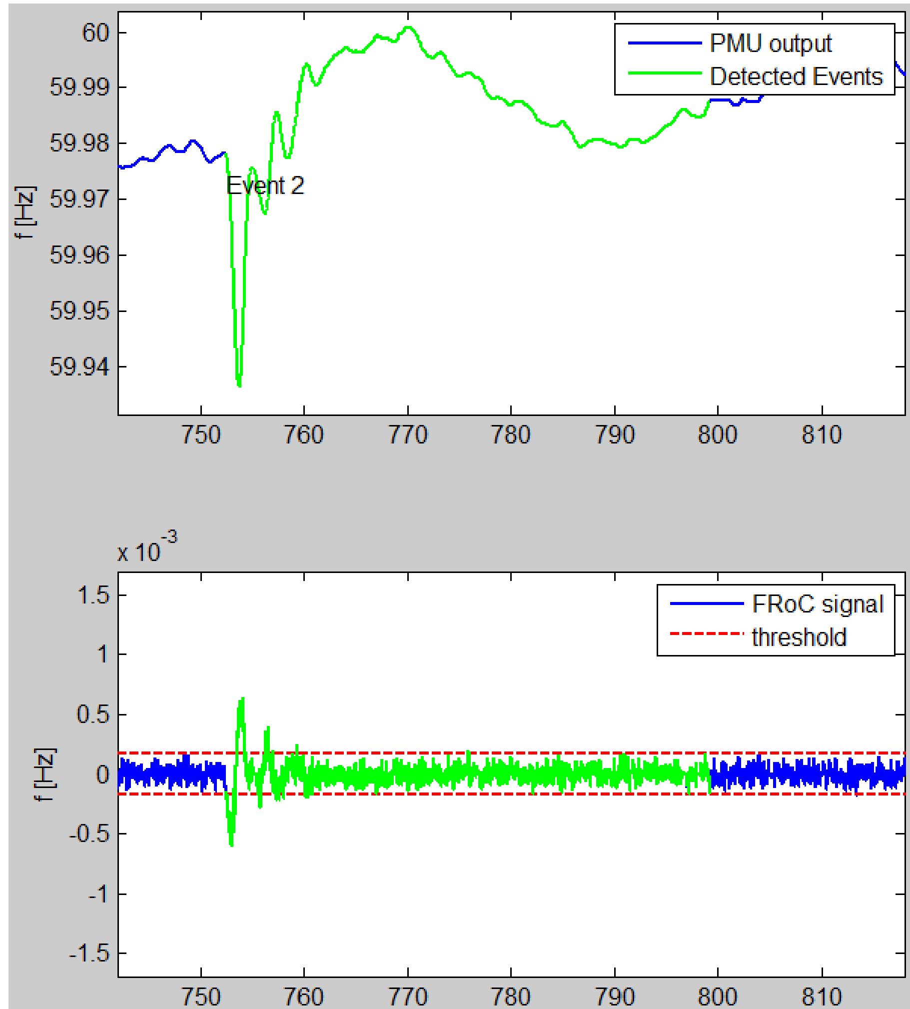
- Event Detection (via threshold on Filtered Rate of Change signal)

- PMU data and edge processing can all be implemented on the same device!



Event 1 and Event 2 in data (Chief Joe Break Test)





NI PMU with edge processing

- NI hardware based on compactRIO
- Special modules for 3 phase current/voltage measurements
- Special module for GPS time synchronization
- Processing of 3 phase voltage/current and GPS via
  - LabVIEW 2015 base with RT and FPGA modules
  - Electrical Power Suite (EPS) 2015
  - PMU source code (under development)
- Real-time filtering of phasor data for edge processing implemented in LabView
- Automatically detect events via
  - Adaptive filter estimation for $FRoC(k)$ + thresholding
  - Detect when $FRoC(k)$ outside threshold for *m* consecutive points