Development of the Robust RML Algorithm for Electromechanical Mode Estimation

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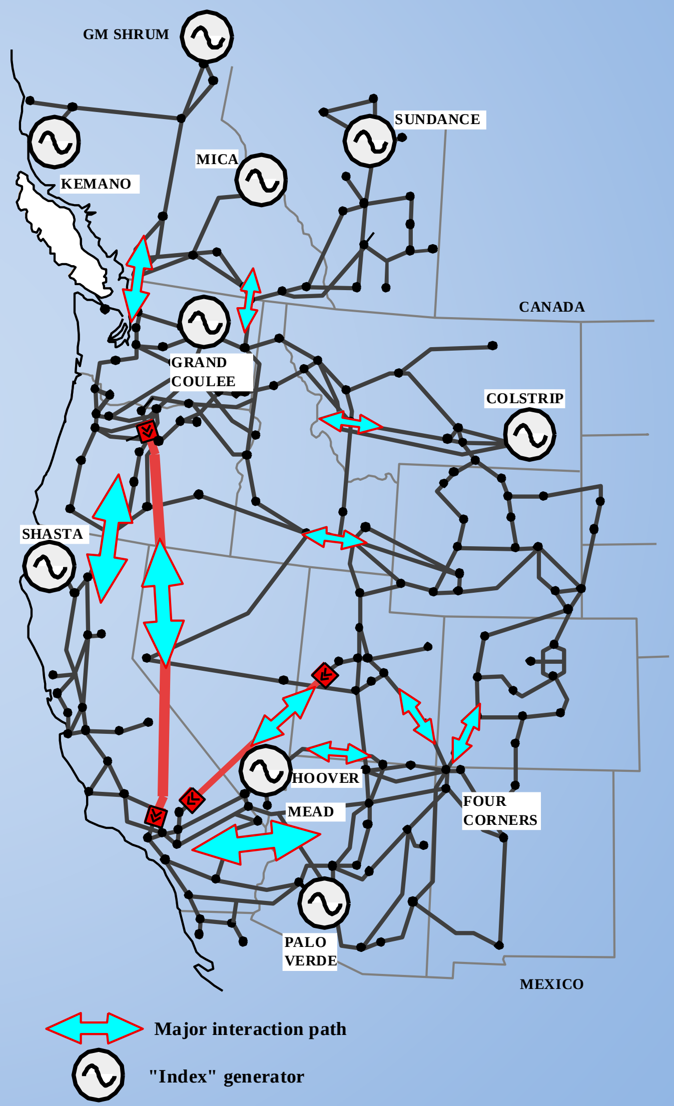
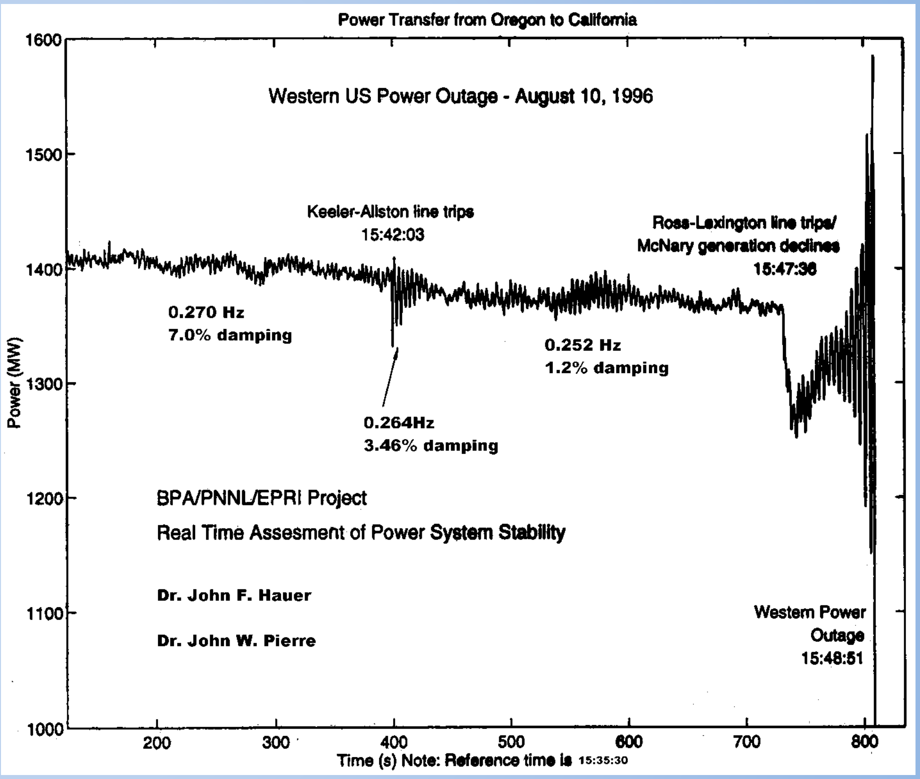
Electromechanical Modes

- Caused by generators in different parts of the power system "swinging" against each other
- Low frequency oscillations: 0.1 to 2 Hz
- Attributes of interest:
  - Frequency
  - Damping
  - Shape



Importance of Electromechanical Modes

- Modes are important to power system stability
- Undamped modes cause growing oscillations resulting in cascading blackouts
- Cascading blackouts cost billions of dollars and endanger human life



The Robust RML Algorithm

- Robust Recursive Maximum Likelihood
- Analyzes ambient data from the power grid
  - Doesn't <u>require</u> special data
- Allows calculation of the covariance matrix
  - How are we doing?
  - Can't be found with alternative Robust RLS algorithm
- Robustness allows the algorithm to handle unfriendly but unavoidable data

The Need for Robustness

- Monitoring the power grid is a real-time application
- Data collected from the power grid is full of non-typical data
  - Missing data
  - Outliers
  - Oscillations
- Mode estimates need to be reliable despite these difficulties

Robust RML Algorithm

- $\underline{\hat{\varphi}}(t) = [-y(t-1) \cdots - y(t-n_a) \;\; u(t-1) \cdots u(t-n_b) \;\; \bar{\varepsilon}(t-1) \cdots \bar{\varepsilon}(t-n_c)]^T$
- $\overline{\psi}(t) = -\hat{c}_1(t-1) * \overline{\psi}(t-1) - \cdots - \hat{c}_{n_c}(t-1) * \overline{\psi}(t-n_c) + \underline{\hat{\varphi}}(t)$
- $L(t) = \frac{\gamma(t)*P(t-1)*\underline{\psi}(t)}{\rho''*\gamma(t)*\underline{\psi}^T(t)*P(t-1)*\underline{\psi}(t)+1-\gamma(t)}$
- $\varepsilon(t) = y(t) - \hat{y}(t) = y(t) - \underline{\hat{\varphi}}^T(t) * \underline{\hat{\theta}}(t-1)$
- $\underline{\hat{\theta}}(t) = \underline{\hat{\theta}}(t-1) + L(t) * \rho'$
- $P(t) = \frac{1}{1-\gamma(t)}\left[P(t-1) - L(t) * \underline{\hat{\psi}}^T(t) * P(t-1) * \rho''\right]$
- $\bar{\varepsilon}(t) = y(t) - \underline{\hat{\varphi}}^T(t) * \underline{\hat{\theta}}(t)$

The Robust Function

- Value depends on the level of prediction error
- High prediction error often means non-typical data
- We want to ignore the non-typical data

$$\rho(\varepsilon) = \begin{cases} \frac{1}{2}\varepsilon^2, & if\ |\varepsilon| \le 3\sigma \\ \frac{1}{2}(3\sigma)^2, & if\ |\varepsilon| > 3\sigma \end{cases}$$

$$\rho'(\varepsilon) = \begin{cases} \varepsilon, & if\ |\varepsilon| \le 3\sigma \\ 0, & if\ |\varepsilon| > 3\sigma \end{cases}$$

$$\rho''(\varepsilon) = \begin{cases} 1, & if\ |\varepsilon| \le 3\sigma \\ 0, & if\ |\varepsilon| > 3\sigma \end{cases}$$

Robust RML Algorithm

- $\underline{\hat{\varphi}}(t) = [-y(t-1) \cdots - y(t-n_a)\ \ u(t-1) \cdots u(t-n_b)\ \ \overline{\varepsilon}(t-1) \cdots \overline{\varepsilon}(t-n_c)]^T$
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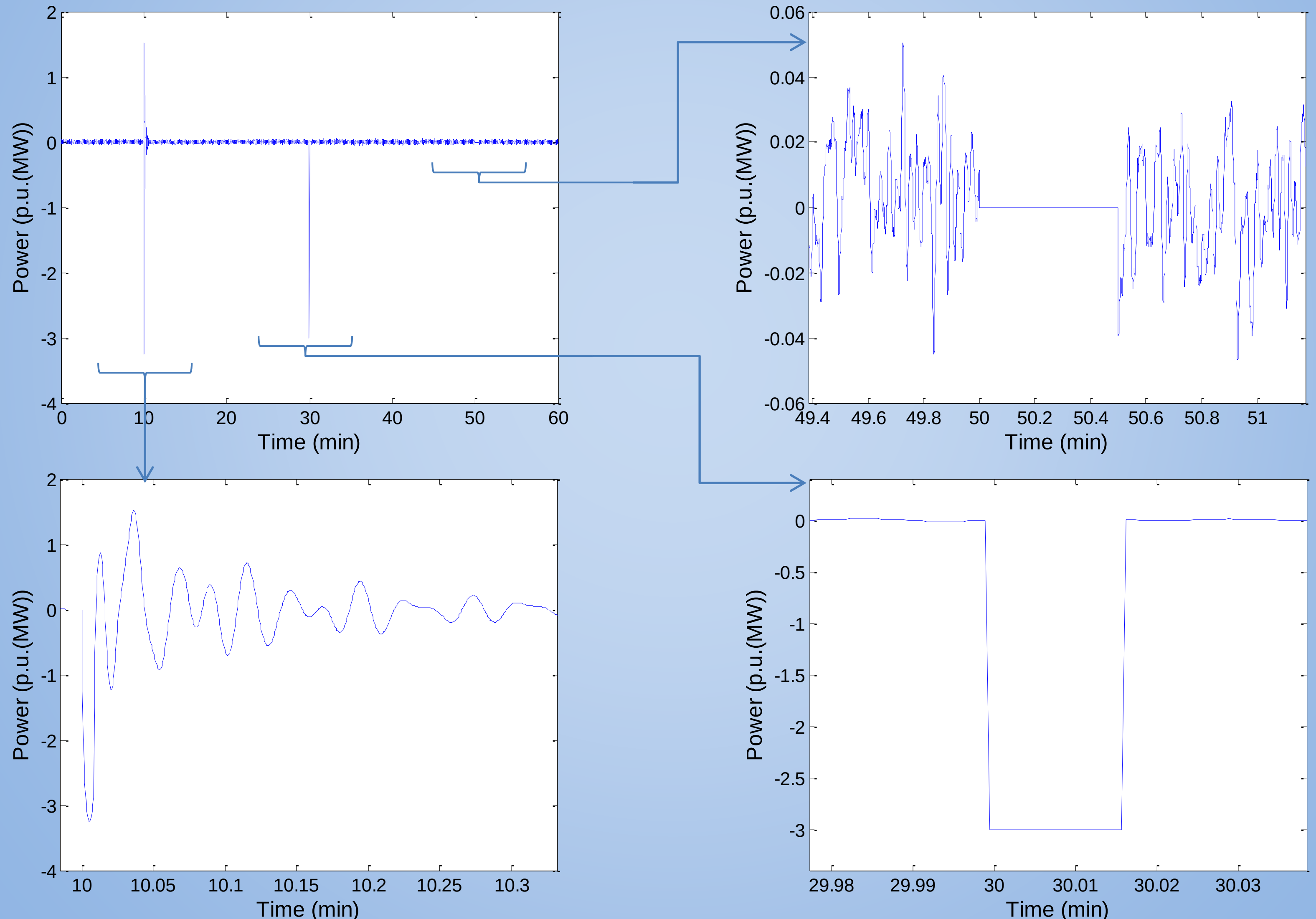
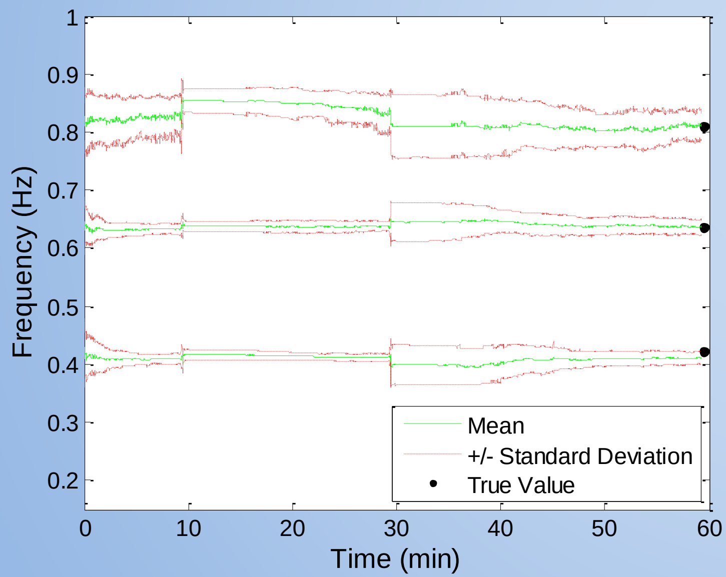
Simulated Non-Typical Data



Results – Frequency

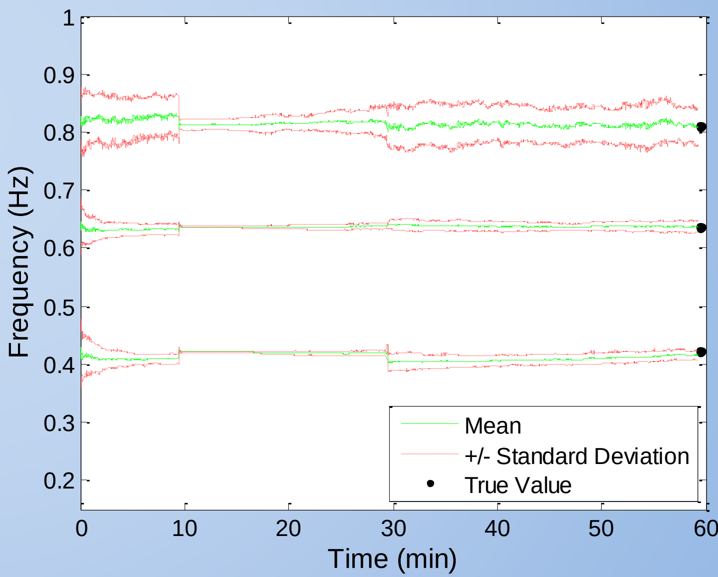
RML

Mean Update Time: 5.73 ms



Robust RML

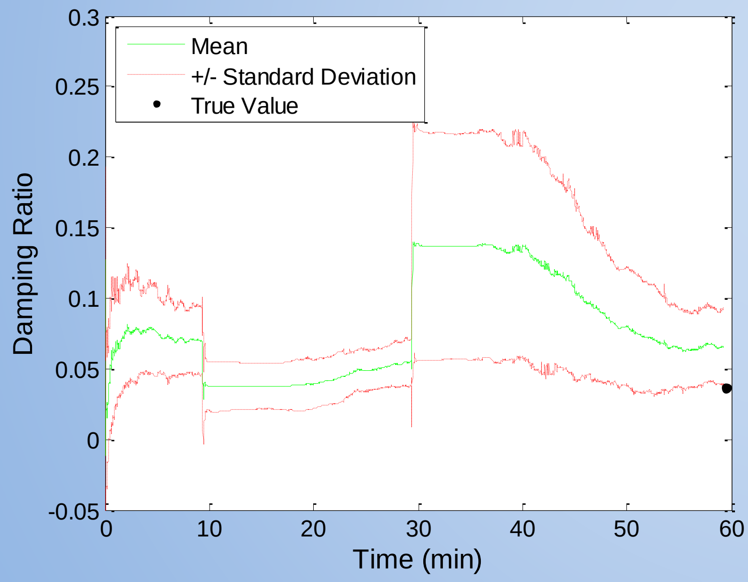
Mean Update Time: 5.56 ms



Results – Damping

RML

Mean Update Time: 5.73 ms



Robust RML

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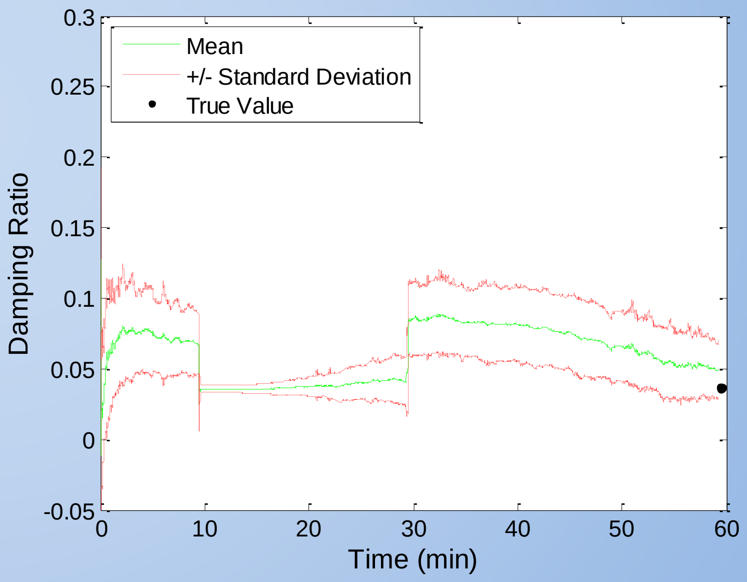
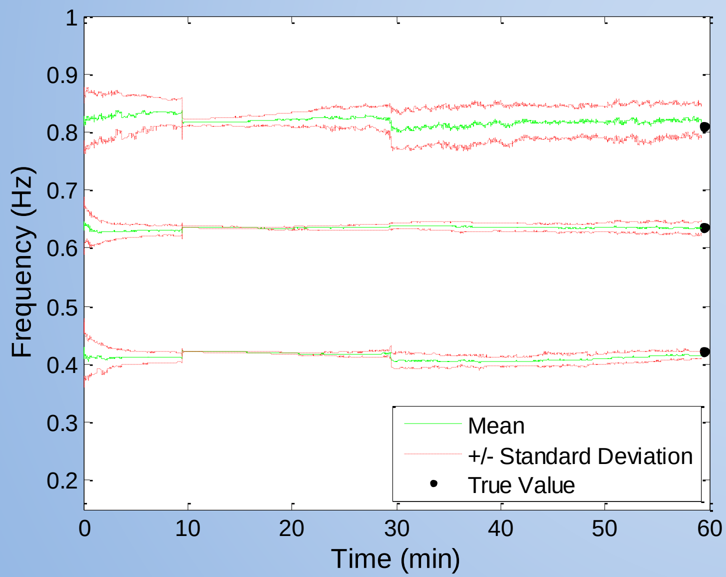


Comparison with Robust RLS - Frequency

Robust RLS

Mean Update Time: 5.36 ms



Robust RML

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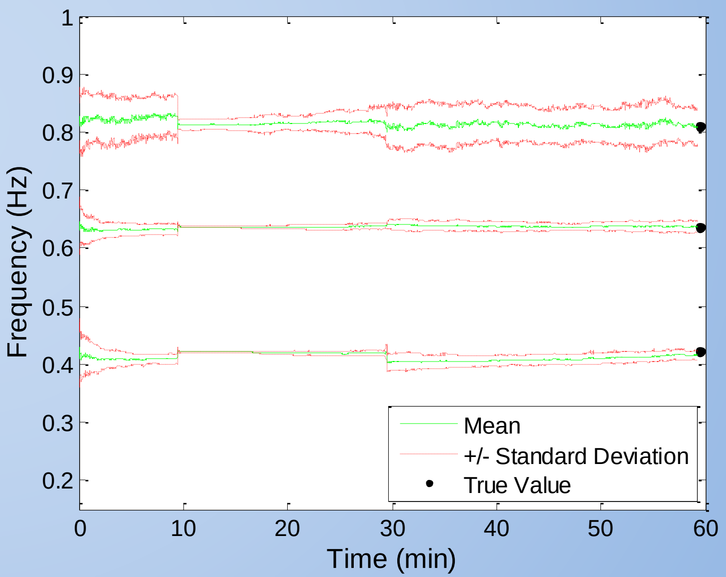

Comparison with Robust RLS - Damping

Robust RLS

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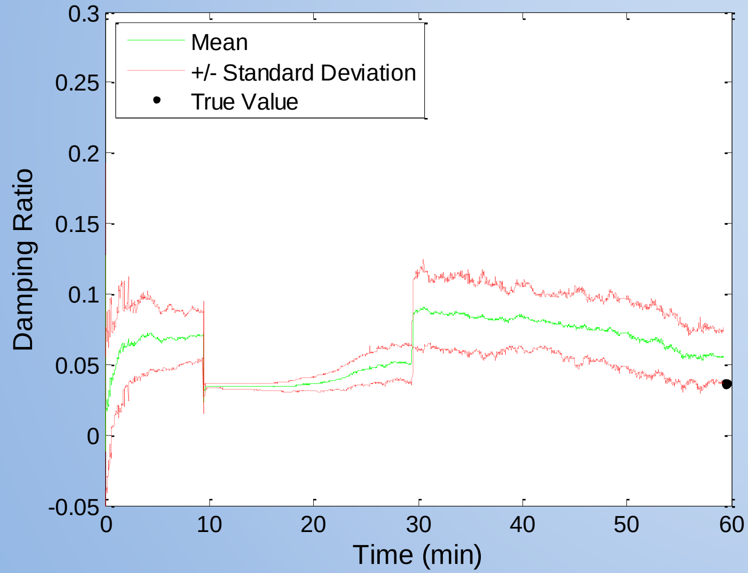

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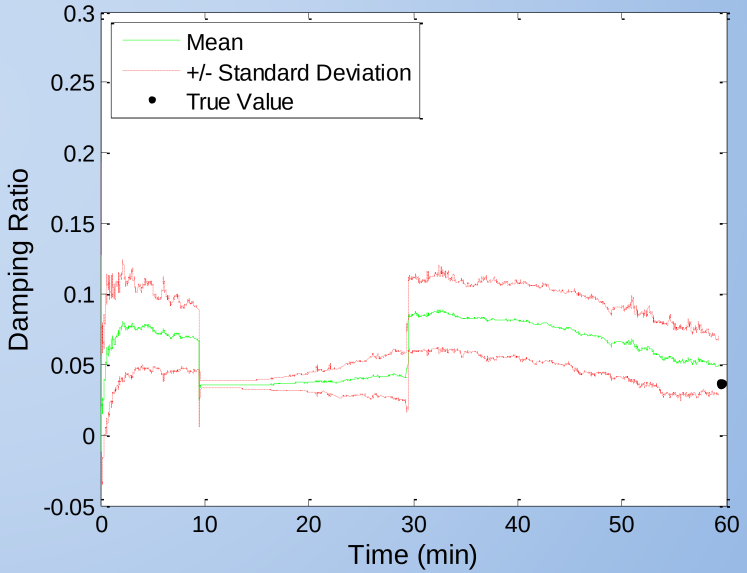

Conclusions

- Adding robustness to the RML algorithm allows it to better handle non-typical data
  - Smaller jumps in standard deviation and bias due to outliers
  - More accuracy improvement from oscillations
  - Better mode estimates over time
- The robust RML algorithm compares well with the robust RLS algorithm
  - Similar performance
  - Allows calculation of the covariance matrix
  - Slightly longer run time
- Future work will involve adding regularization to the robust RML algorithm

Acknowledgment

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Questions

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