DOE/OE Transmission Reliability Program

VARPRO-Based Modal Analysis of Ambient Sychrophasor Data

(+ bonus persistence measure)

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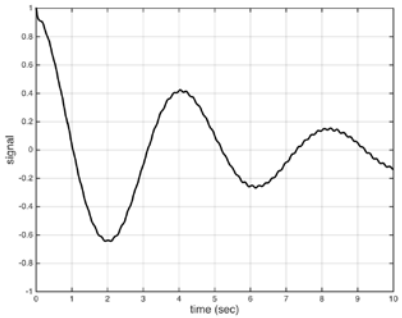
Background:

Model fitting vs. Curve Fitting



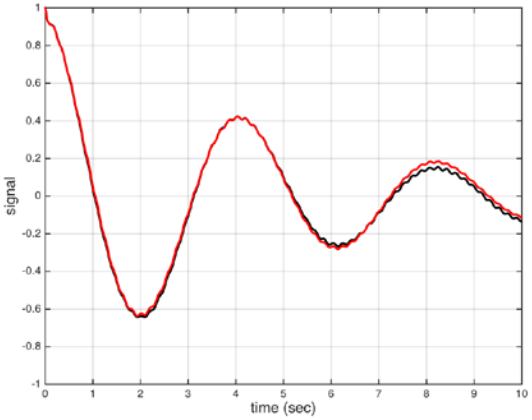
DATA

create system model

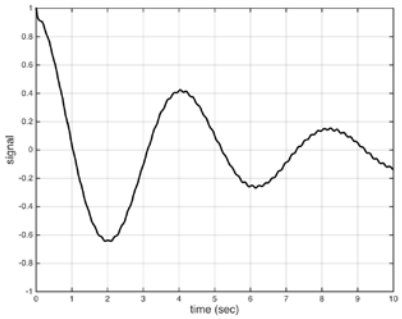
Prony, matrix pencil, ERA, etc.

then

Ping the model…

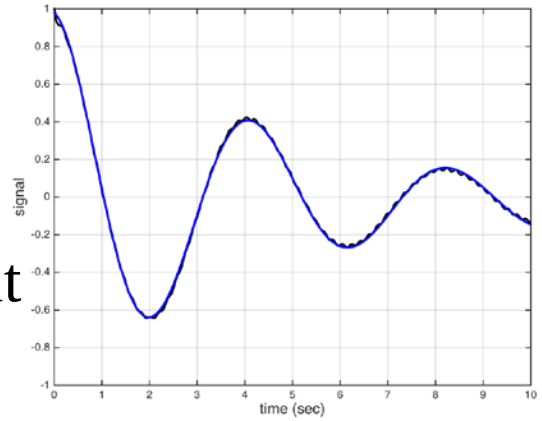


check result



Curve fit

VARPRO, etc



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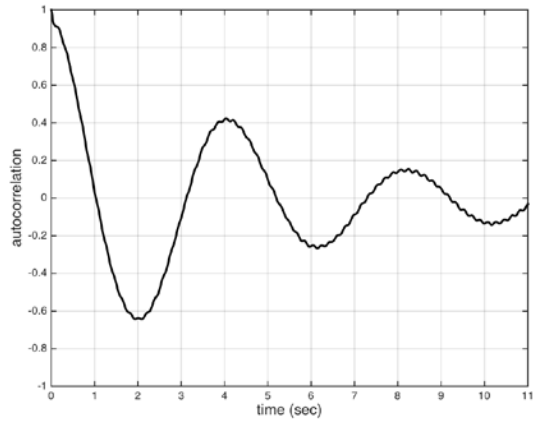
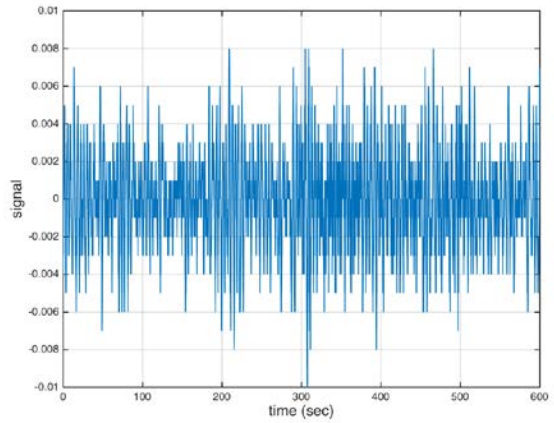
Objectives

- Apply VARPRO curve-fitting technique to modal analysis of ambient data.



Curve fitting – is "*easy*" for signals that look like this.



How do you apply curve fitting to signals that look like this?

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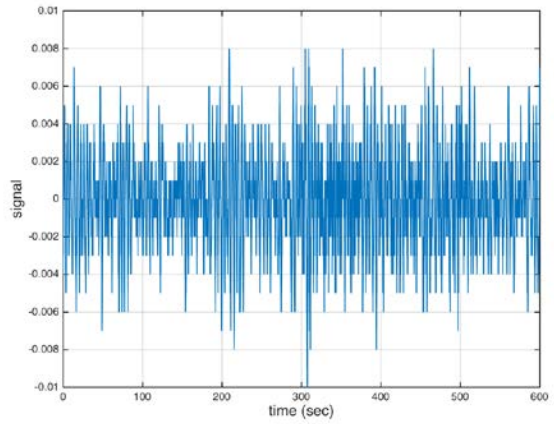
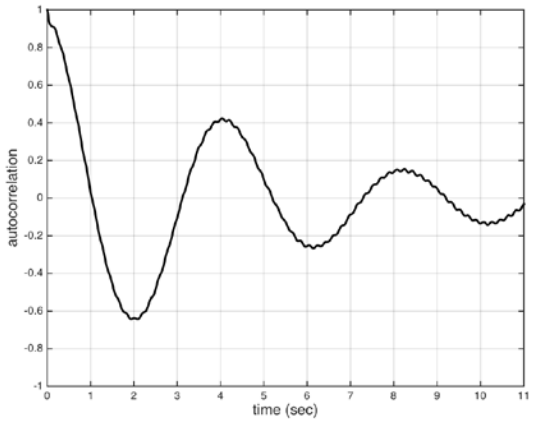
Objectives

- Apply VARPRO curve-fitting technique to modal analysis of ambient data.

Switcheroo!





The "easy" curve is the autocorrelation of the random-looking signal.

This auto correlation may be analyzed using model-fitting (Yule-Walker, etc.) or curve fitting techniques.

Our approach uses curve-fitting and other model-free techniques.

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Summary: Results for past year

- Applied VARPRO curve fitting technique to analyze ambient data. Made GUI. Will implement at BPA phasor measurement lab.(What we set out to do.)

Additionally,

- Recommend including autocorrelation signals in monitoring GUI (coming up).

And

- **Introduced persistence measure based on normalized energy in autocorrelation.**

NEW!

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Details: The Challenges

- Ambient data is noisy.
- Modal analysis is difficult with a short time windows. (see next slide.)
- The system characteristics may change, during a long time window.
- Empirically, frequencies tend to be easier to estimate than damping.
  - If we estimate modes, the damping component is typically smaller and more susceptible to errors.

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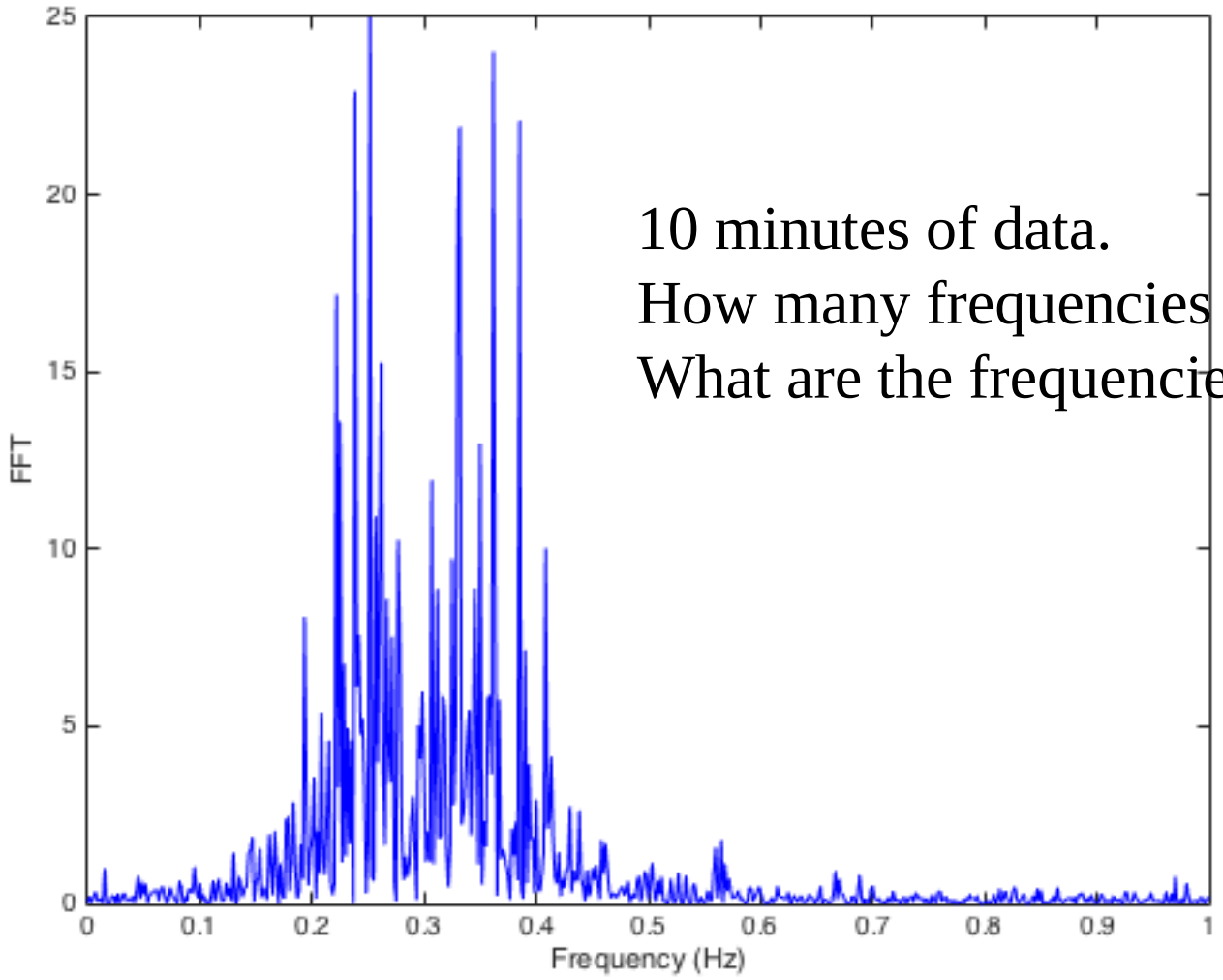
Challenges



10 minutes of data.
How many frequencies are present?
What are the frequencies and damping?

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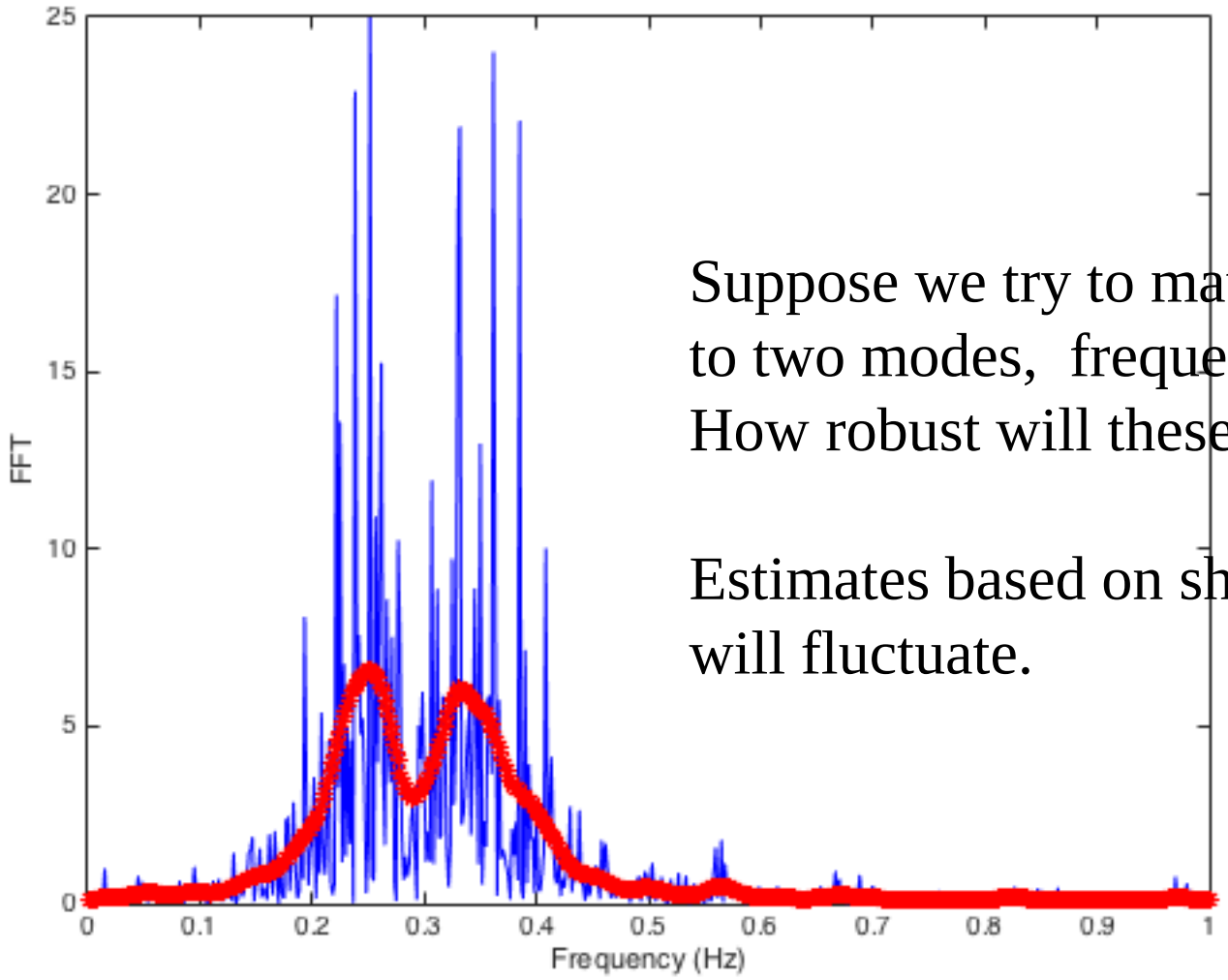
Challenges



Suppose we try to match data
to two modes, frequency and damping.
How robust will these estimates be?

Estimates based on short-term ambient da
will fluctuate.

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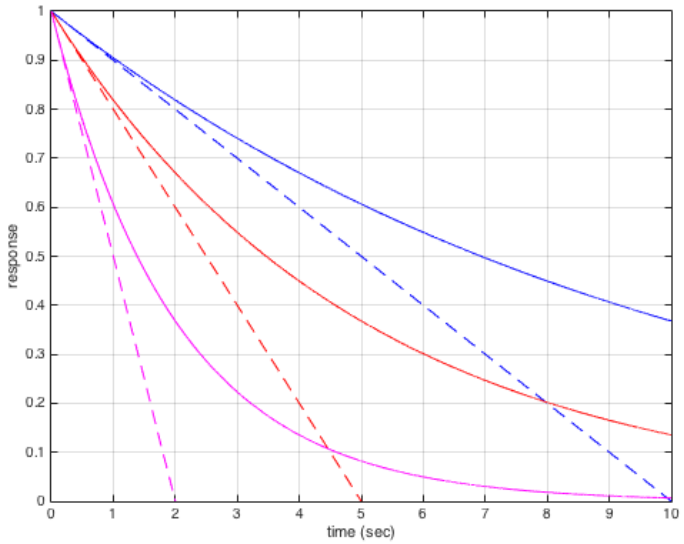
A *persistence* measure ?

- Instead of a modal decomposition (or in addition to), try a persistence measure of the duration/decay of a natural response.

The most obvious example is an exponential time-constant.



$$h(t) = e^{-\frac{t}{T}}\ u(t)$$

The larger the time constant, the longer the ”duration” or “persistence” of the response.

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Introduce a System Persistence Measure

$$\Upsilon^2 = \left\| \frac{R(\tau)}{R(0)} \right\|_2$$

System Persistence Measure

Important Properties:

- Scales linearly with "stretching" of impulse response, regardless of shape.
- For exponentials, doubling the time constant, doubles the measure.
  - For single mode, non-oscillatory exponentially-decaying impulse response, **it equals the time constant**;
  - For single mode, oscillatory exponentially-decaying impulse response **it is half the time constant**.

Calculable from the autocorrelation!!

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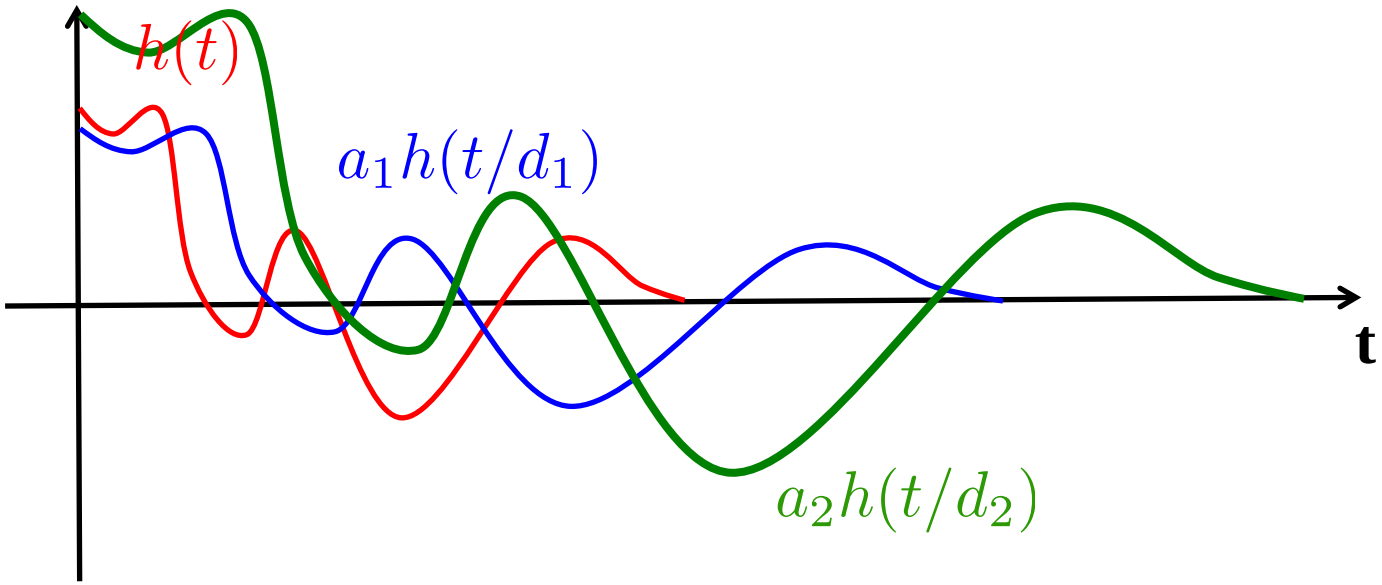
Stretching Property



$$h(t) \rightarrow \Upsilon_0^2$$
$$a_1 h(t/d_1) \rightarrow d_1 \Upsilon_0^2$$
$$a_2 h(t/d_2) \rightarrow d_2 \Upsilon_0^2$$

All these signals have the same shape. They differ in amplitude and stretching. The metric scales only with time-stretching. (Indifferent to amplitude.)

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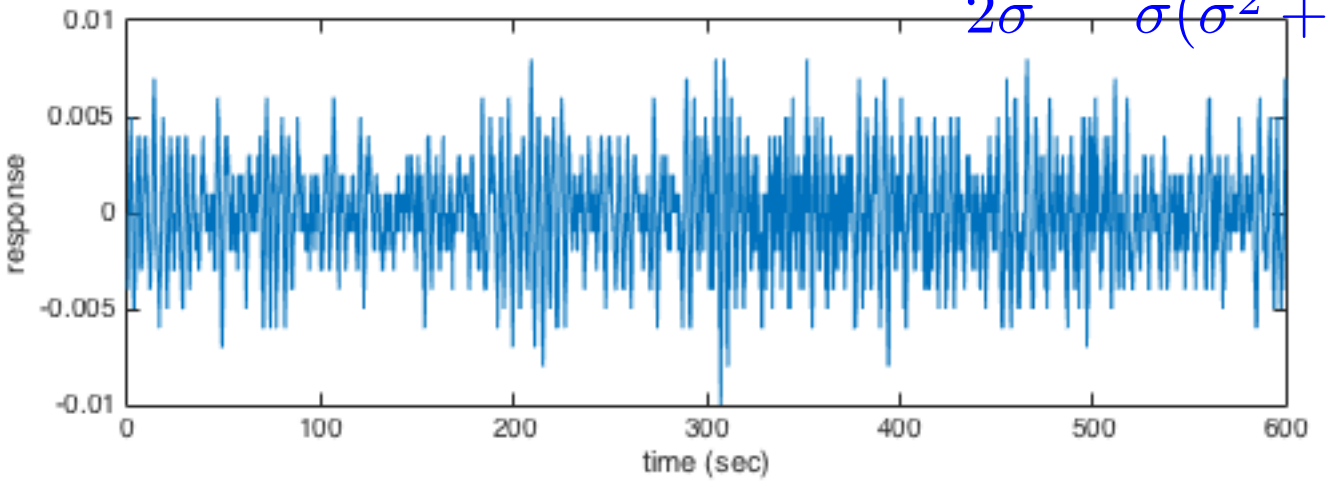
Example (real data)

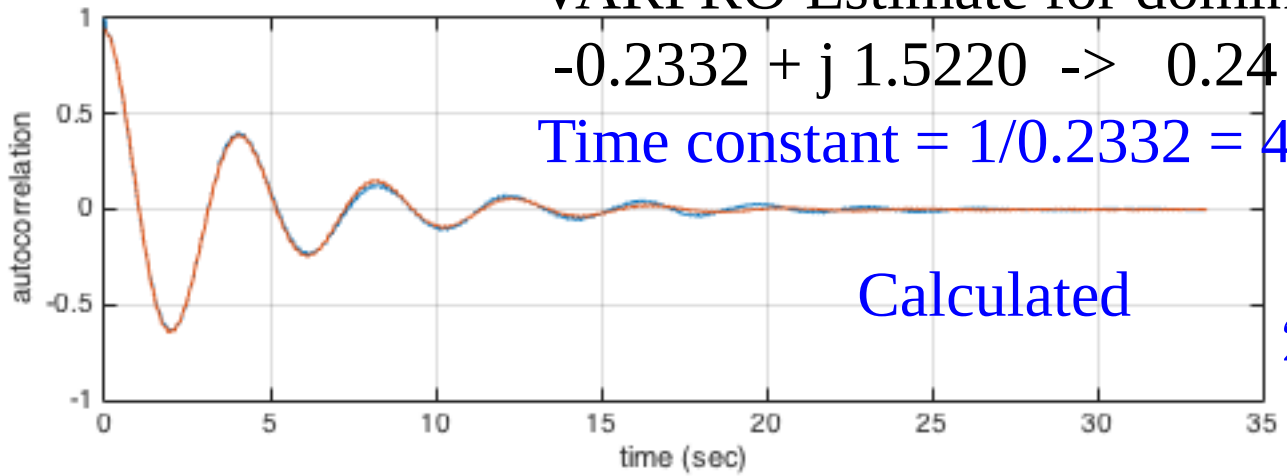
$$\Upsilon^2 = \frac{-1}{2\sigma} + \frac{-2\sigma^6}{\sigma(\sigma^2+\omega_o^2)(2\sigma^2+\omega_o^2)^2}$$



VARPRO Estimate for dominant mode exponent

-0.2332 + j 1.5220 -> 0.24 Hz at 15% damping

Time constant = 1/0.2332 = 4.29 seconds



$\Upsilon^2 = 2.20$

Calculated

$2\Upsilon^2 = 4.40$

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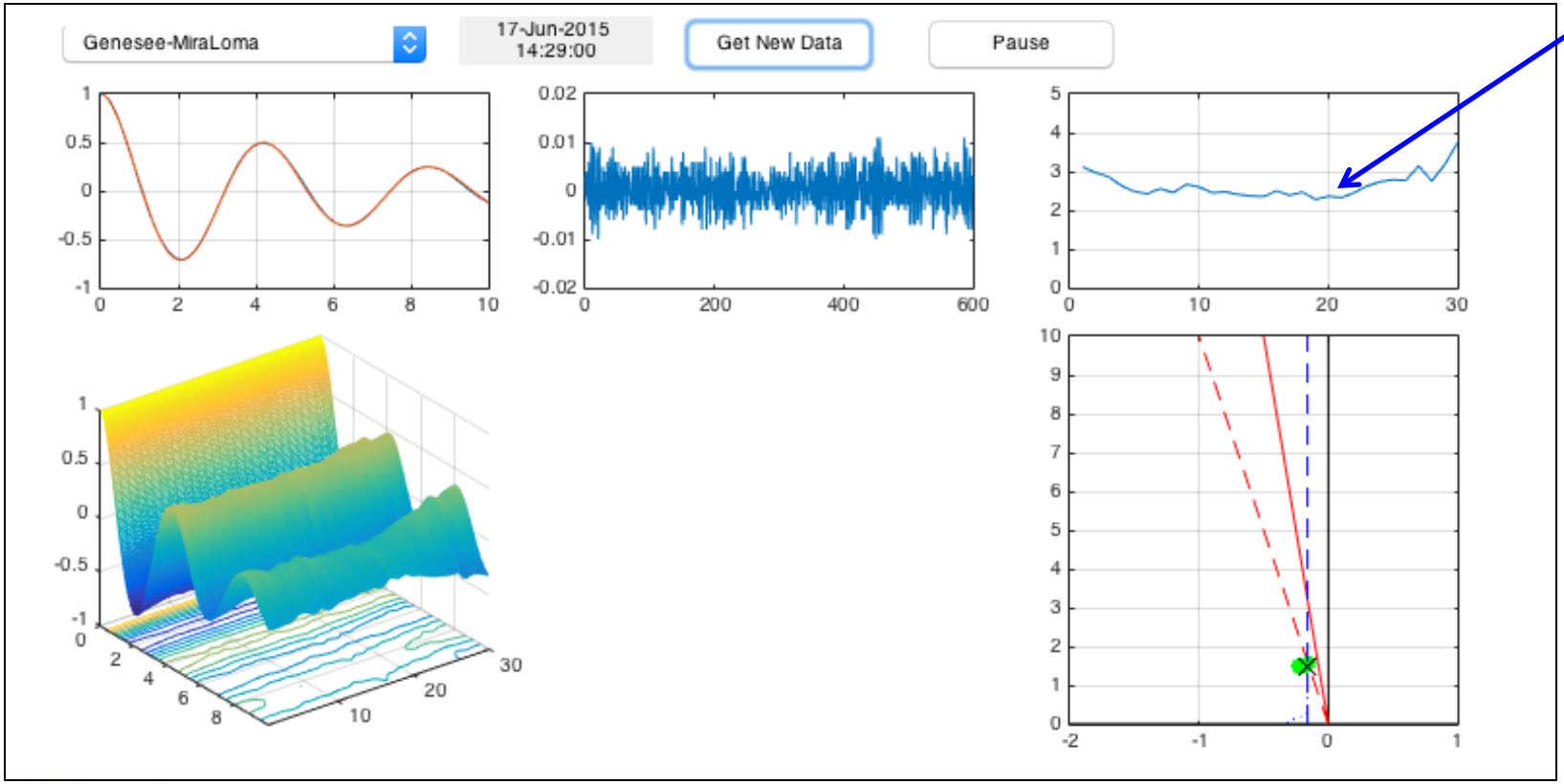
Recommendation

- Include “System Persistence Measure” in a modemeter application for tracking persistence of natural response.



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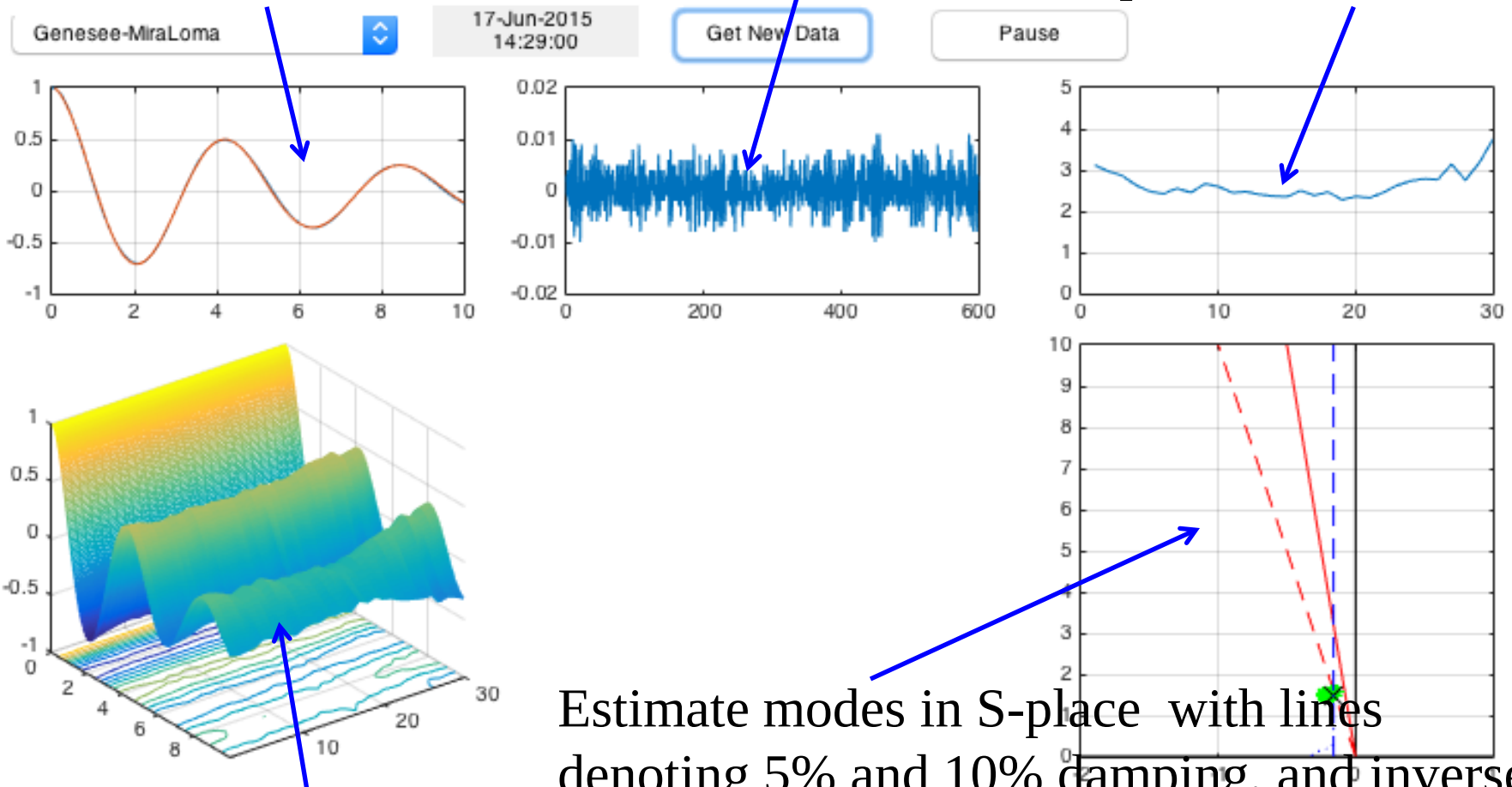
GUI

Autocorrelation and VARPRO fit

raw ambient data

persistence measure.



Estimate modes in S-place with lines denoting 5% and 10% damping, and inverse persistence measure.

Auto Correlation history

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Demo

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Looking Forward

Loose Ends:

- Implement in BPA phasor measurement laboratory. (July)
- IEEE Paper. (in draft)

And some technical things

- Frequency-domain form of metric (J.Pierre, S. Roy)
- Empirical bounds on estimates (S. Roy)
- GUI (all)

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