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Can SINDy identify power grid frequency dynamics?

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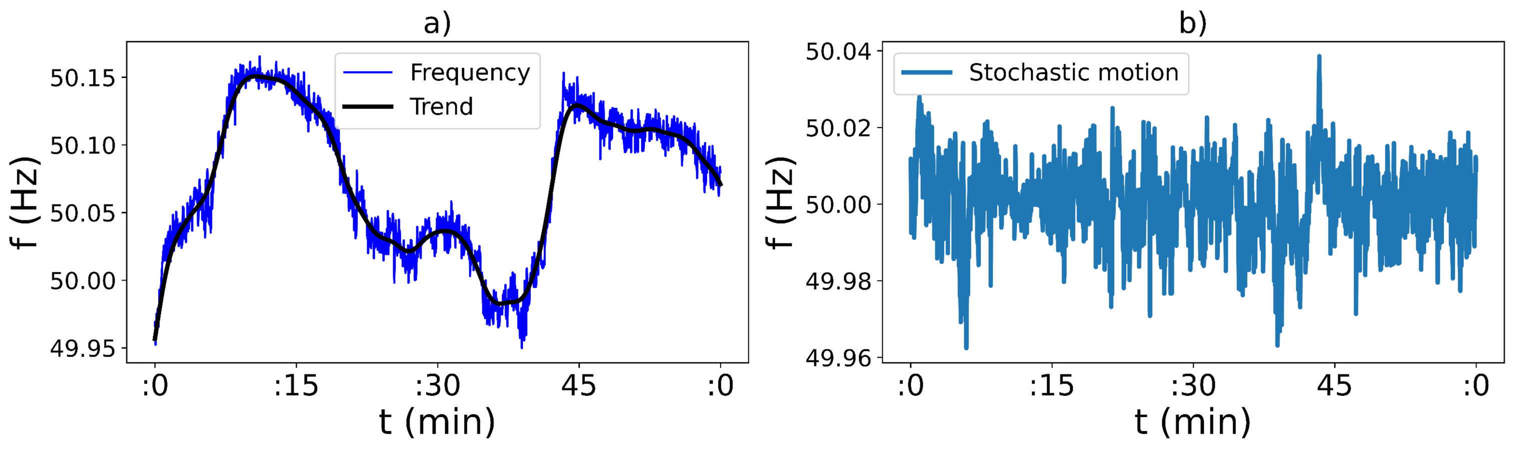
Motivation:

- Power grids are complex systems: They are driven by both stochastic and deterministic influences.
- No straightforward bottom-up models describing the dynamics are available on a continental scale comprising all necessary details.

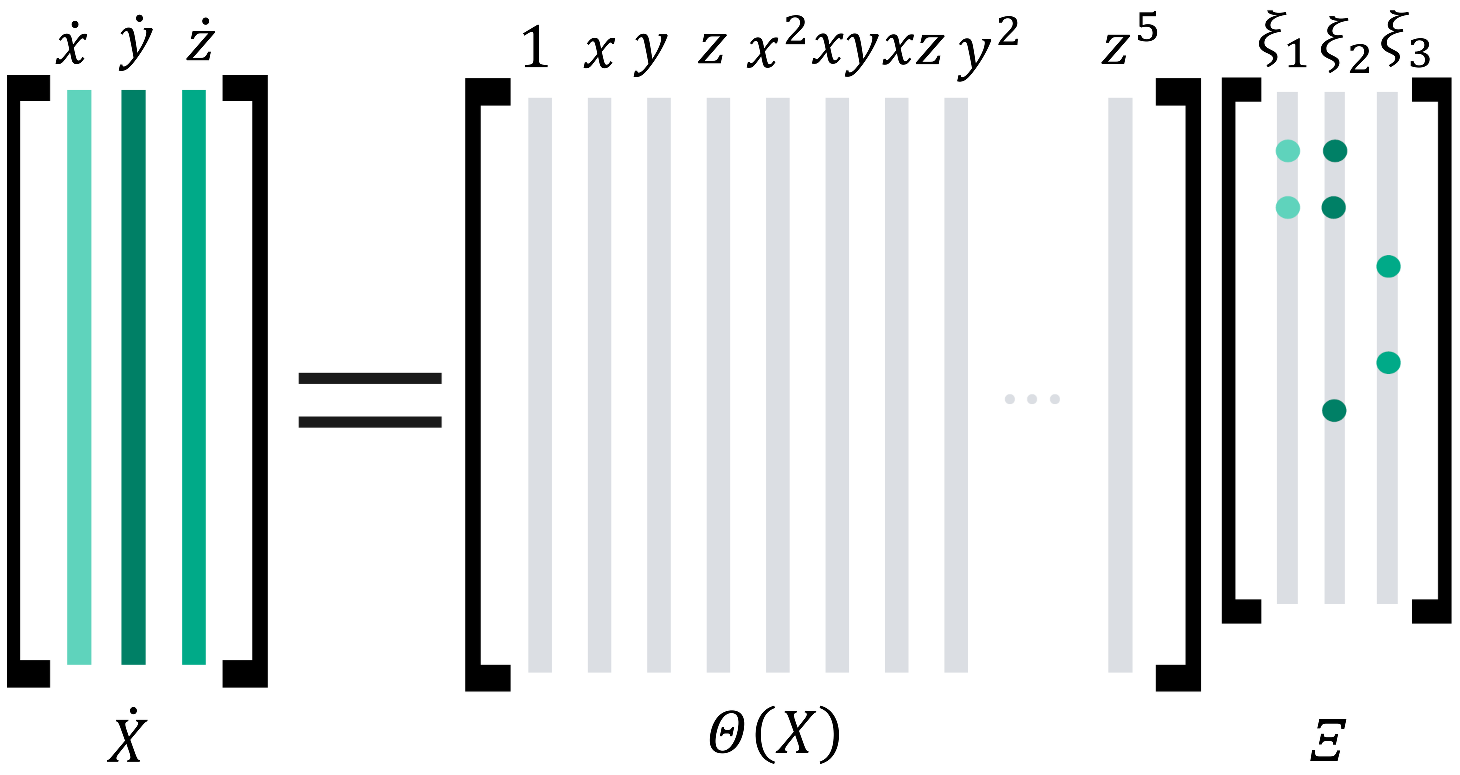
Deterministic trend and stochastic dynamics (Balearic grid)



Research question:

- Can we use the Sparse Identification of Nonlinear Dynamics (SINDy) method to identify the complex dynamics of grid frequency?

$$\Xi = \underset{\hat{\Xi}}{\operatorname{argmin}} \left\| \Theta(X)\hat{\Xi} - \frac{dX}{dt} \right\|_2^2 + \lambda \|\hat{\Xi}\|_2$$



Novelty of the paper:

- Expanding inference methodologies to explicitly incorporate time-dependence
- The paper demonstrates the practical utility of these methods by successfully applying them to empirical data sets obtained from various power systems

Data-driven model:

$$\frac{d\theta}{dt} = \omega, \quad \frac{d\omega}{dt} = -c_\omega \omega - c_\theta \theta + \Delta P(t) + \epsilon \xi(t)$$

- θ: bulk angle of the voltage signal
- ω: bulk angular velocity, $\omega = 2\pi(f - fref)$, $f_{ref} = 50Hz$
- ΔP: power mismatch, $\Delta P_{(t)} = P_0 + P_1 t$

Results:

➢ Successfully validating SINDy on synthetic power grid dynamics

- Linear noise-free validation model:

$$\frac{d\theta}{dt} = \omega, \quad \frac{d\omega}{dt} = c_\omega \omega + c_\theta \theta + P_0, \quad \frac{dT}{dt} = 1$$

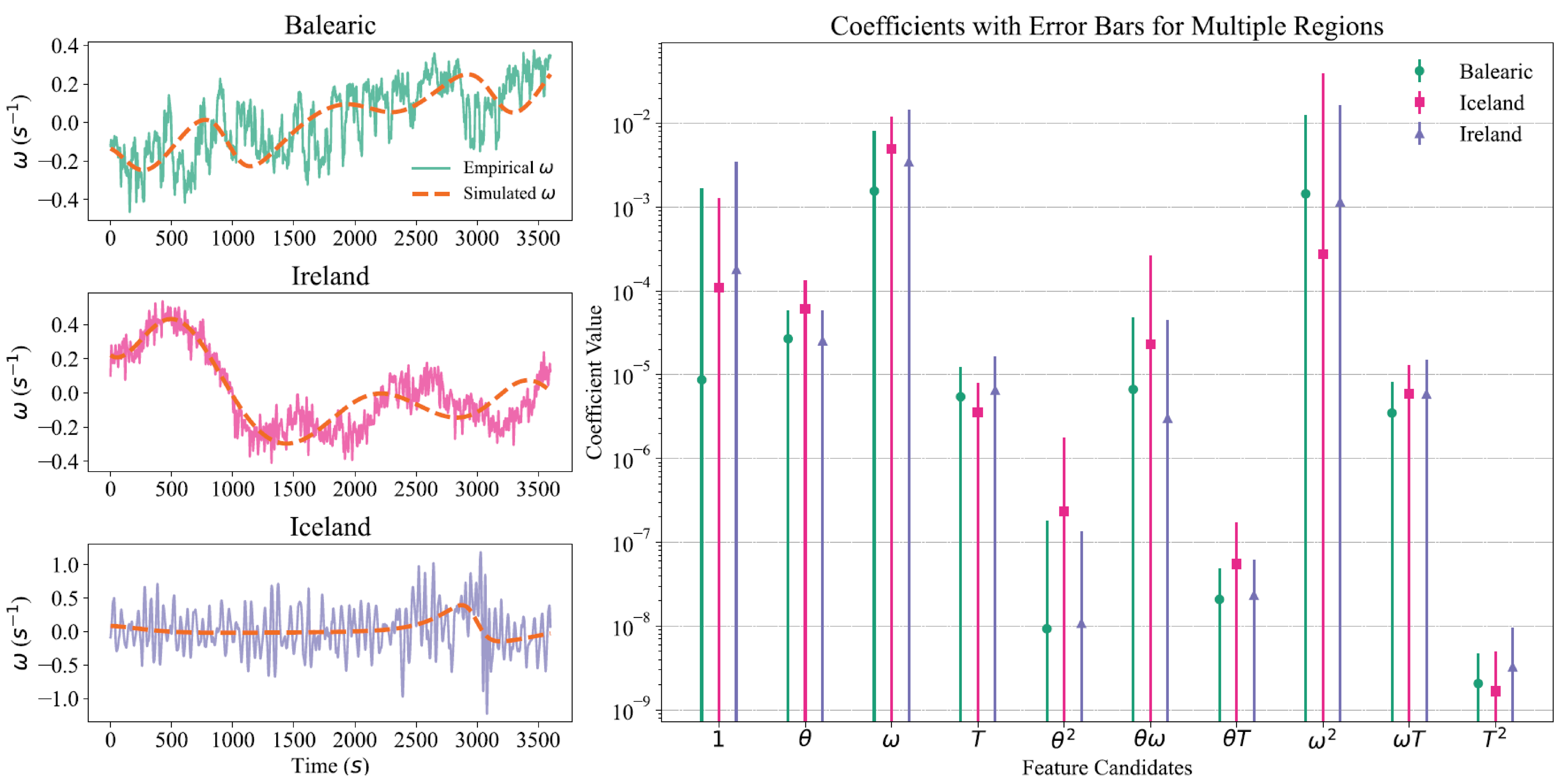
- Linear validation model including noise:

$$\frac{d\omega}{dt} = c_\omega \omega + c_\theta \theta + P_0 + \epsilon \xi(t)$$

- Linear validation model with noise and time-dependent driving:

$$\frac{d\omega}{dt} = c_\omega \omega + c_\theta \theta + P_0 + P_1 t + \epsilon \xi(t)$$

➢ Successfully validating SINDy on empirical dataset

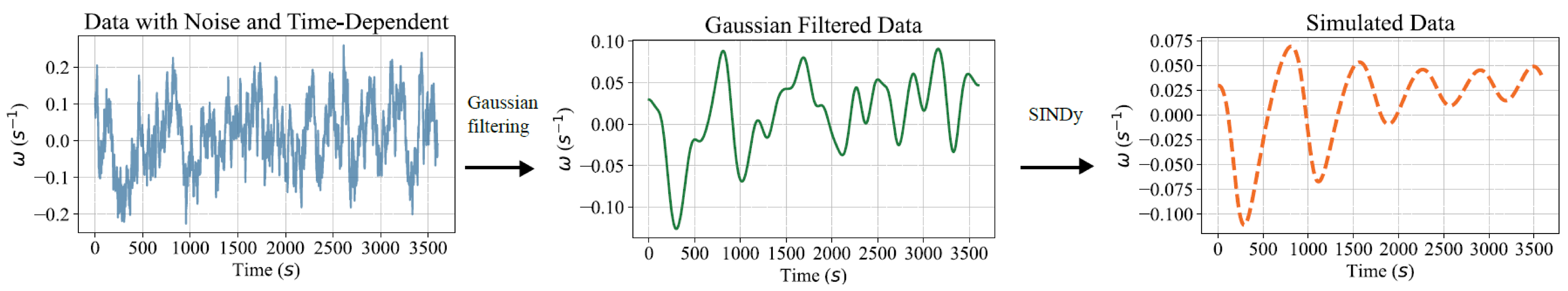


- The coefficient for θ ranges from 10^{-4} to 10^{-5} and the coefficient for ω falls within the interval 10^{-2} to 10^{-3}, aligning notably well with the values obtained during our validation process.
- The coefficients of $\theta\omega$ and ω^2 stand out. This indicates that non-linear relationships could play a critical role in the dynamics of the power grid.
- Within a one-hour interval, the contribution of the T -coefficient reaches an amplitude ranging from 10^{-3} to 10^{-2}

Outlook:

- Consider different optimization algorithms
- Extend the SINDy algorithm across to other data sets
- Address the limitations of assuming Gaussian white noise in our models

Schematic of the process:



[1] L. R. Gorjão *et al.*, "Data-Driven Model of the Power-Grid Frequency Dynamics," in *IEEE Access*, vol. 8, pp. 43082-43097, 2020, doi: 10.1109/ACCESS.2020.2967834.
[2] U. Oberhofer *et al.*, "Non-linear, bivariate stochastic modelling of power-grid frequency applied to islands," pp. 1-1, doi: 10.1109/PowerTech55446.2023.10202986.
[3] S.L. Brunton *et al.*, "Discovering governing equations from data by sparse identification of nonlinear dynamical systems." Proceedings of the national academy of sciences 113.15 (2016): 3932-3937.