MTech Research Projects Overview

Vibrations and Nonlinear Dynamics Laboratory

Nidish Narayanaa Balaji

IIT Madras, Chennai 600036, TN, IN

January 7, 2025

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Nidish Narayanaa Balaji

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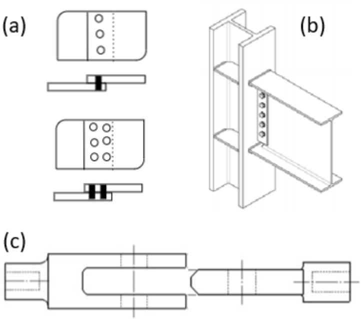
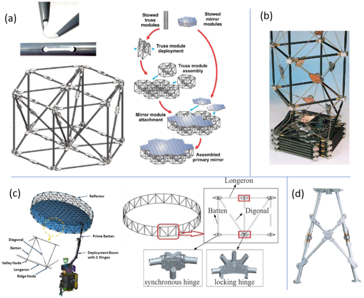
- Office Ph: (044) 2257 4042

1. Wave-Based Modeling for Assembled Structures



Joint types: (a) Single & double lap, (b) flange, (c) Clevis



3D frame structures, deployables, etc.

- Joints primary source of nonlinear behavior (softening, dampening, wear, etc.)
- Computational effort focused disproportionately on the **linear portions**.

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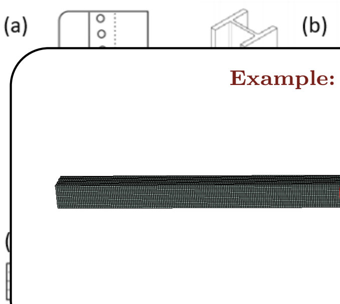
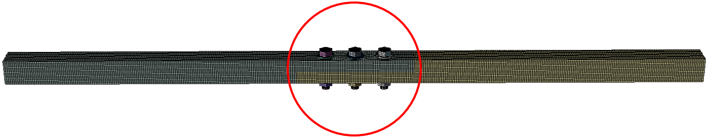


Example: A Lap-Jointed Beam



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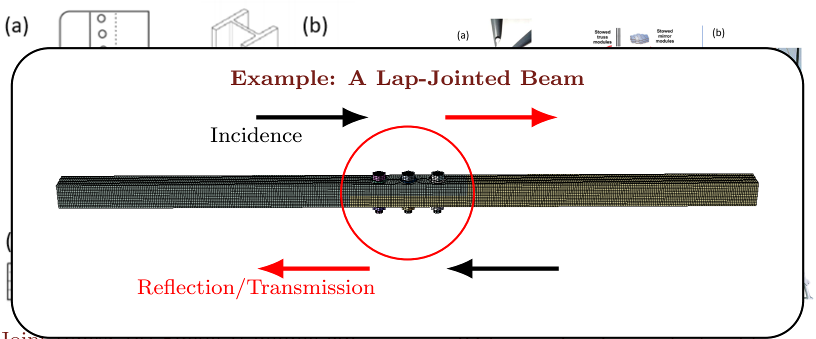

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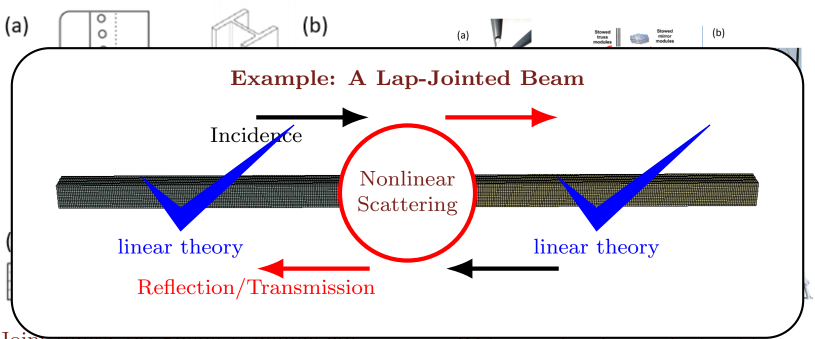

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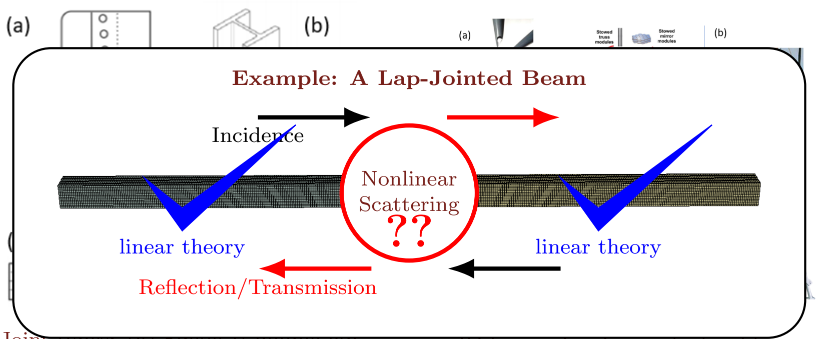

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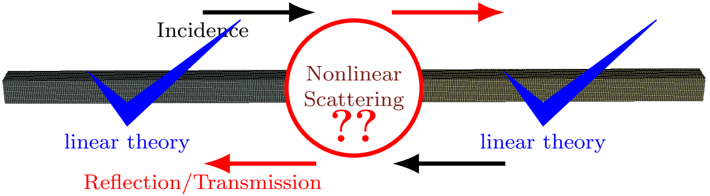
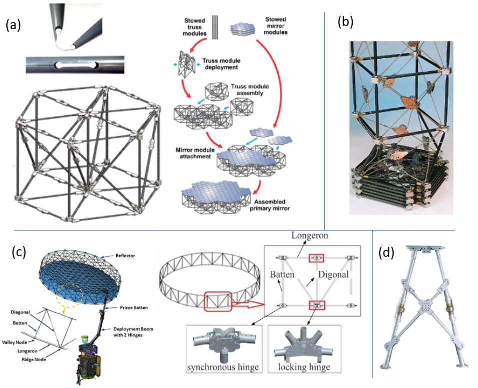


The idea is nothing new. But wave-based approaches allow us to be exact.

- Joints primary source of nonlinear behavior (softening, dampening, wear, etc.)
- Computational effort focused disproportionately on the **linear portions**.

1. Wave-Based Modeling for Assembled Structures

Project Topic: Implement PWE for Spatial 3D Frame Structures with Nonlinear Joints



- An Octave/MATLAB Toolbox exists where everything is implemented: https://github.com/Nidish96/wavevib
- You will have to provide dispersion relationships and validate the code.

(a) Joi... The idea ... to be **exact**.

- Join... ear, etc.)
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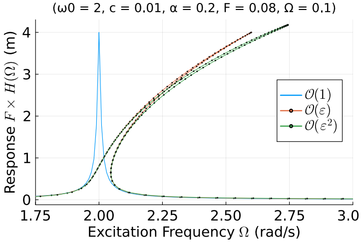
2. Spline-based Parallel Refinement in Numerical Continuation

Numerical Continuation

- A common complication in the study of nonlinear systems is that responses tend to be multi-valued.



- **Numerical Continuation** is a class of numerical techniques that allow us to **traverse through** such response curves through an implicit reparameterization.

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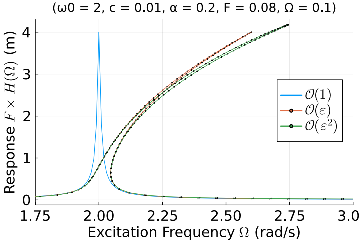

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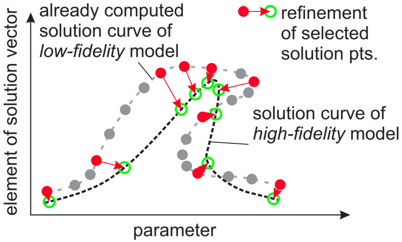
Parallelized Refinement

*Is it possible to **refine the accuracy of** a low-fidelity curve to obtain high-fidelity response curves in a dis-tributed manner?*



(Gross et al., 2024)

2. Spline-based Parallel Refinement in Numerical Continuation

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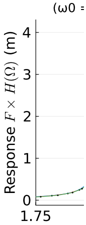
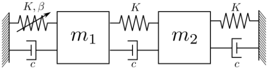


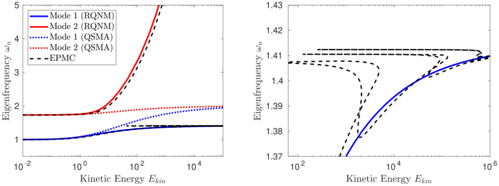
- **Numerica** numerical t **traverse t** through an implicit reparameterization.

Project Topic: Spline-based Approaches for Continuation Refinement

- There are very clear cases where point-based methods fail.



Frequency-Energy Plots



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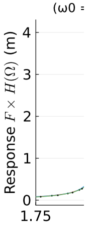

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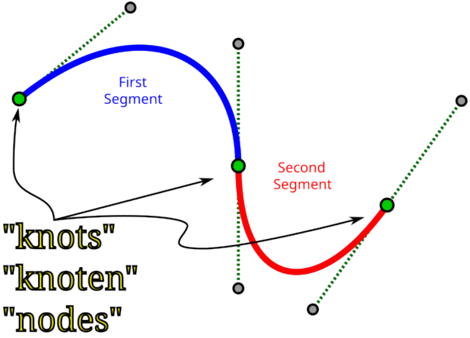

- Splines are segment-based, like rubber bands!

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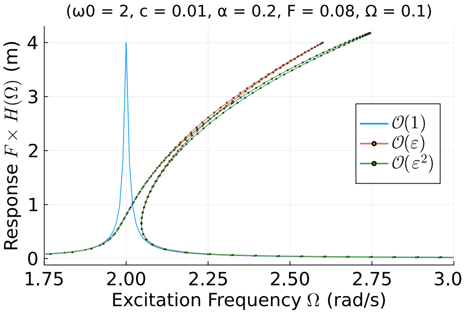
3. Parameterized System Identification

- The forced response of nonlinear systems is complicated by the fact that no transfer function can be defined.
- Since transfer function is $\frac{\text{Response}}{\text{Force}}$, we can plot this quantity by considering two cases:



$$\ddot{x} + \epsilon c\dot{x} + \omega_0^2 x + \epsilon\alpha x^3 = \epsilon F \cos\Omega t$$

Experimental data from a geometrically nonlinear clamped-clamped beam

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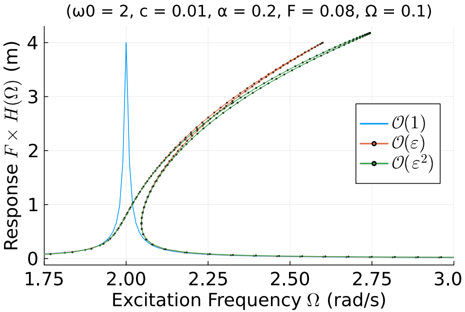

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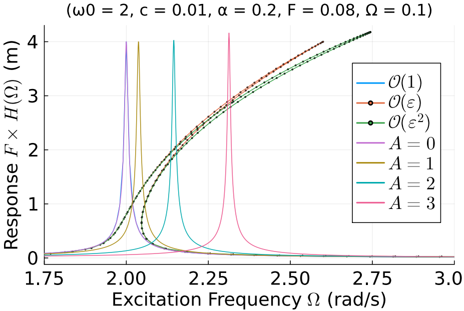

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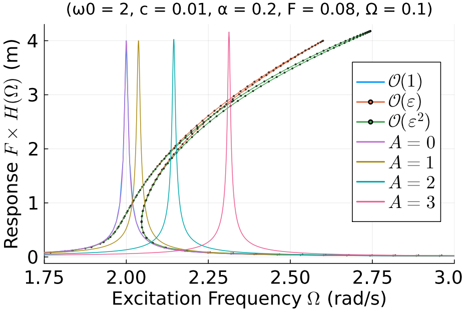

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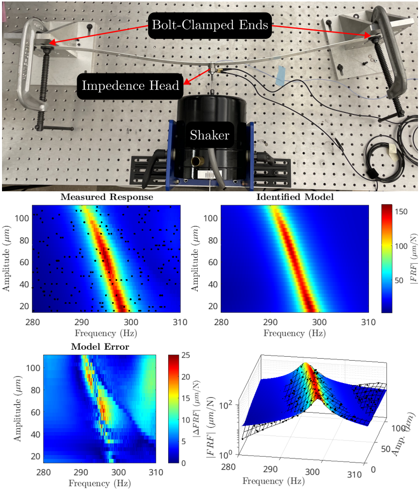
Project Topic: Development of Data-Driven Methods for Parameterized Linear System ID

$$\dot{\underline{x}} = \underline{\underline{A}}(\theta)\underline{x} + \underline{\underline{B}}(\theta)\underline{u}$$

$$\underline{y} = \underline{\underline{C}}(\theta)\underline{x} + \underline{\underline{D}}(\theta)\underline{u}$$



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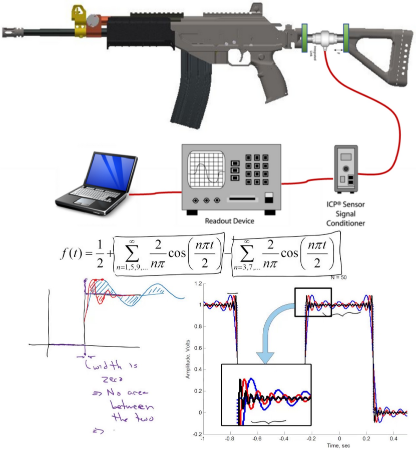
4. Dynamics with Non-smooth basis functions

- Classical Fourier series struggle with representing **non-smooth oscillations**. Examples: frictional contact, cracked beams, gun recoil studies, etc.



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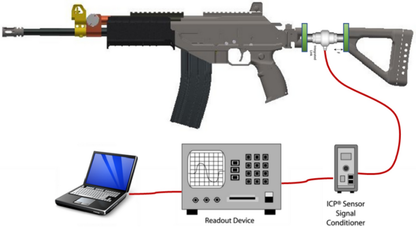

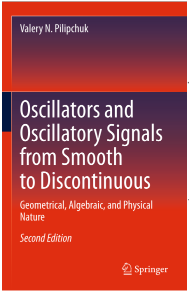

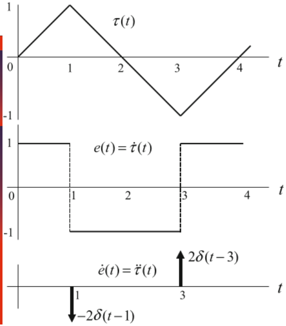

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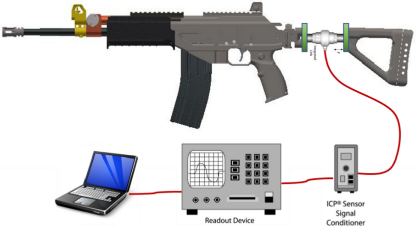
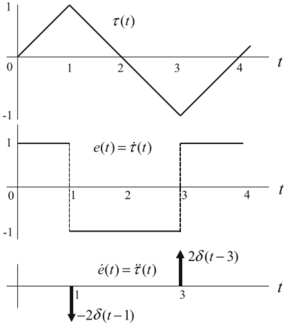
Project Topic: Exploration of Non-Smooth Basis Functions for Dynamical Response Synthesis of Impulsive Systems

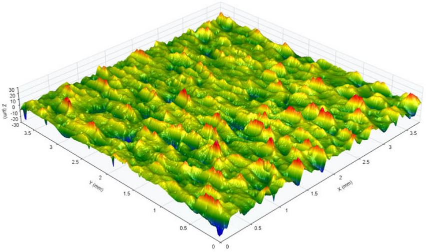
- Firstly we have to understand the feasibility for large-scale problems.
- Then we tackle the analysis of an impulsive system.

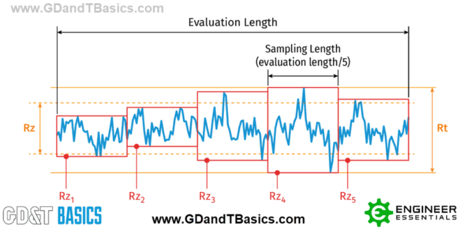




5. Fractal Rough Surface Modeling

- All realistic surfaces are Rough.





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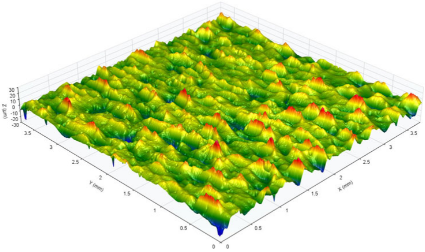

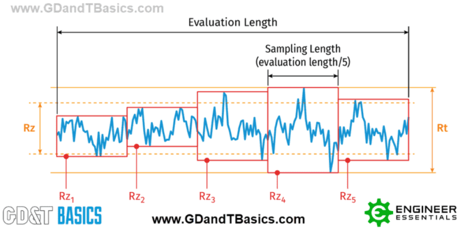

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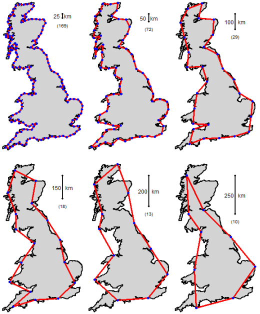
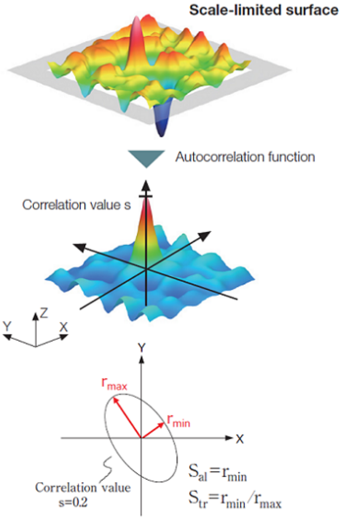
Most real-world features show fractality!





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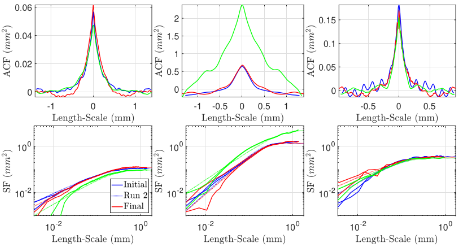
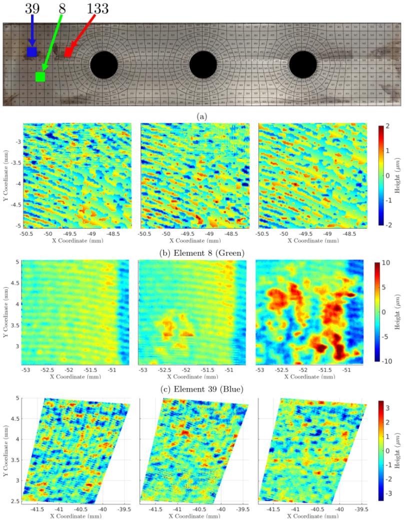
Spatial Auto-Correlation Functions



(a) (b) (c)



(a)

(b) Element 8 (Green)

(c) Element 39 (Blue)

(d) Element 133 (Red)

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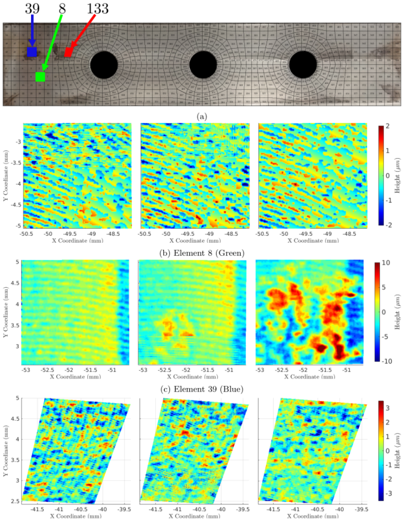
Project Topic: Investigation of Frictional Contact of Fractal Surfaces

- None of the classical phenomenologies hold true for fractal-regular surfaces.
- Fundamental work has been initiated in the study of contact of fractal surfaces, but still yet to mature.
- We will tackle:
  1. The problem of settling
  2. Normal Contact
  3. Tangential Contact
- Final goal is to obtain a reduced order description of the displacement-traction relationship applicable for a coarse finite element model.



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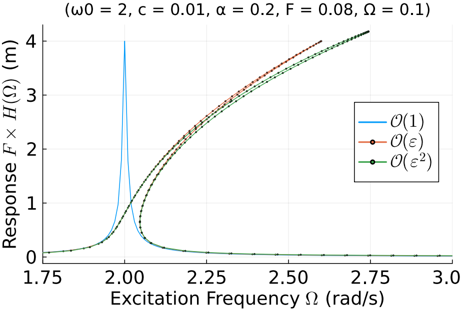
6. Julia Code Development for Nonlinear Vibrations

- **The Julia Programming Language** is gaining traction in the computational mechanics community.
- I have a lot of MATLAB code for numerical continuation, harmonic balance, and nonlinear dynamics in general that I want to move to Julia.



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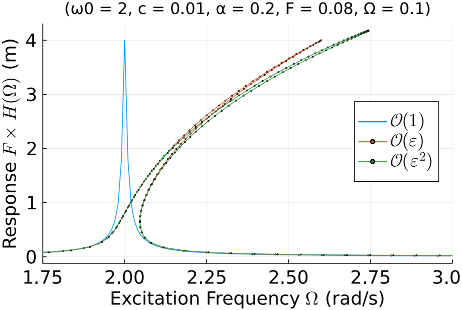
Project Topic: Development of a Julia Toolbox for Nonlinear Vibrations

- Our task will be to initiate the development of a standalone toolbox in Julia for nonlinear vibrations.
- There is little to no conensus in the community about the relative merits and demerits of different programming environments for such a task: MATLAB, Python (JAX!), Julia, etc.
- Just writing the same code (say Harmonic Balance) in each of these and profiling them will be of immense use to the community.



7. Other Topics

Development of a Raspberry Pi-based vibration DAQ System

- Development of a cost-effective solution has the potential to spawn a product (a toolbox suite or even hardware).

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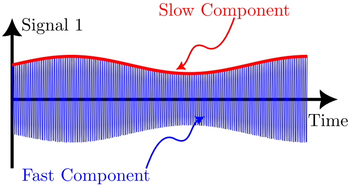
Investigation and Exploitation of Slow-Fast Decomposition of Dynamics



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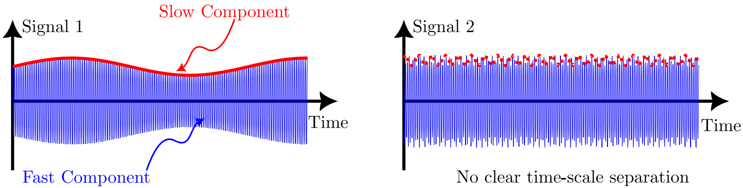
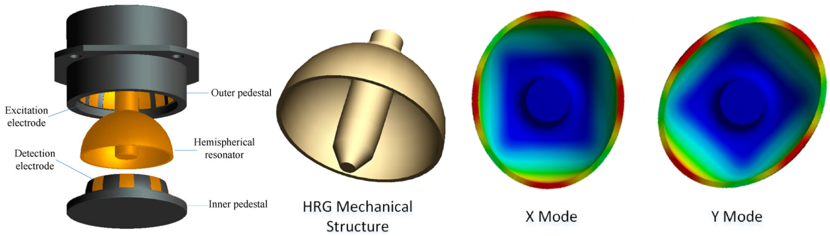


Stability of Non-Smooth Dynamical Systems

- Classical results of stability (Floquet theory) require at least C^1 continuity. Frictional contact problems do not have this.
- We've had success with averaged methods, but further investigations are necessary.

Other Topics

Design optimization of Hemispherical Resonator Gyros



Damage Detection

- Stochastic Approaches
- Guided Wave Approaches

Thank you!

Nidish Narayanaa Balaji

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