Time and cost efficient approaches for vibro-acoustic system identification

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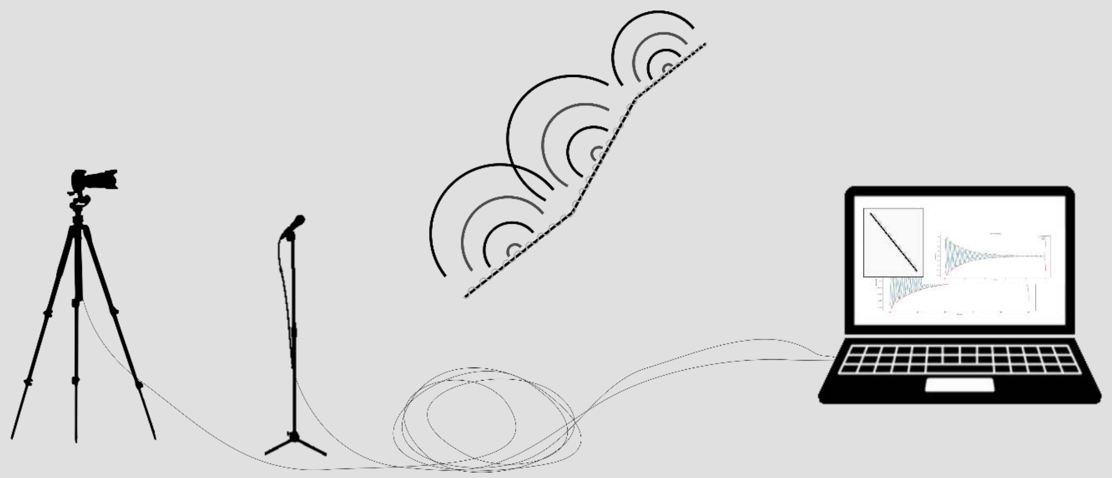
Motivation

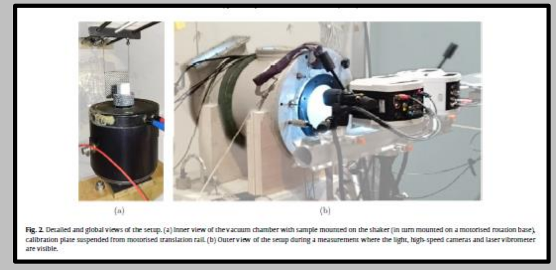
- Concept: digital twin for design, testing and monitoring of products
- Challenges for vibro-acoustic digital twins
  - Material behaviour
  - Coupling acoustics and structural dynamics
  - Boundary conditions
  - Computational cost (necessary simplifications)
- Advances in high-speed camera technology and image processing: dense, contact-less, full-field displacement sensor
- Outlook: camera & microphone as complementary sensors
  - Sound power measurements
  - Source localization (low frequency)
  - Finite element model updating
  - Boundary conditions in acoustic virtual sensing



Camera based displacement measurement

- Fields of application: Modal analysis, parameter estimation, model updating, structural health monitoring

In-situ modal analysis[5]



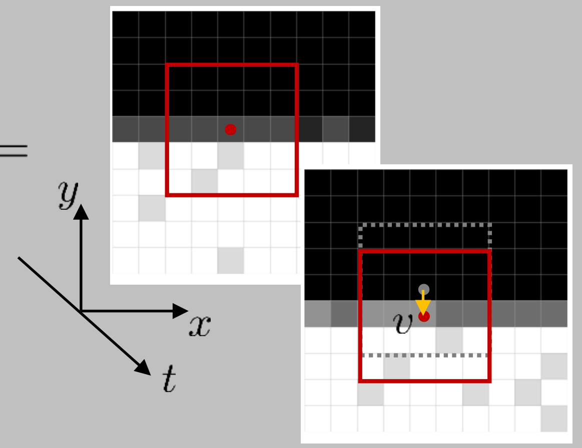
Porous materials: Hooke's matrix [7]

Advantage	Drawback
Full-field	Frequency limited
Spatially dense	High noise floor
Transient	Sensitive to environmental condition
Contact-less	Surface preparation
Position (geometry)	Extensive post-processing
Direct visualization	Data transfer & storage

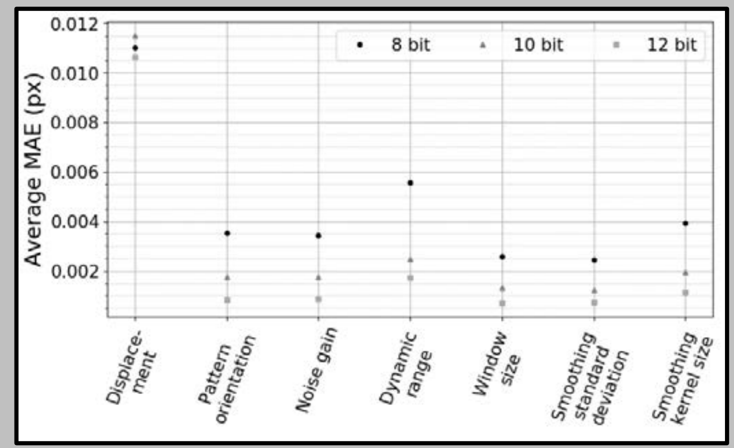
- Image processing method: optical flow

$$I(x+u, y+v, t+\Delta t) = I(x, y, t)$$

with I.. intensity,
(x, y).. spatial dimensions,
(u, v).. displacements, t.. time



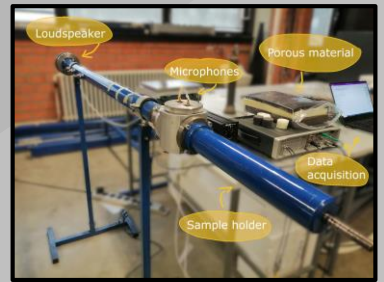
- Accuracy: simulative characterization



Poro-elastic material parameter estimation

- Poroelastic materials: energy dissipation in vibro-acoustic systems (e.g. sound insulation vehicles or machinery, room acoustics)

- Foam, fibrous material
- Acoustic/ structural absorber
- Viscous, thermal, resonance effects

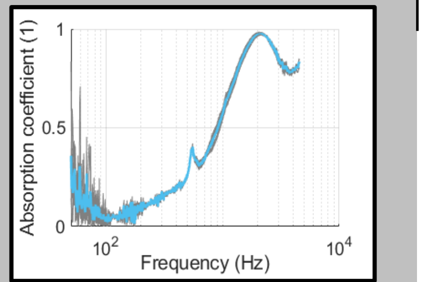


Impedance tube measurement (ISO 10534-2) → Material model describing sound propagation → Absorption coefficient

Acoustic parameters
- Equivalent fluid (DBM, JCA)

Elastic parameters
- Poroelastic (Biot)

Transfer matrix-implementation



Absorption coefficient → Model fit: stepwise → Material parameters

1. Random initial conditions
2. DBM → $[\sigma]$
3. JCA → $[\sigma, \phi, \alpha_\infty, c, c']$
4. Poroelastic → $[\sigma, \phi, \alpha_\infty, c, c', E, \nu, \rho_1, \eta_1]$
5. Final values

Constraint: elastic resonance

$$= \frac{1}{4h}\sqrt{\frac{(1-\nu)E}{(1+\nu)(1-2\nu)\rho_1}}$$

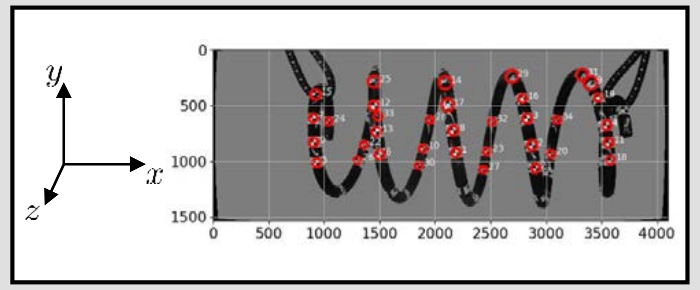
- Material parameters are required in the design of vibro-acoustic systems
- Dedicated test setups: expensive, time consuming , destructive
- Inverse characterization is a time and cost efficient alternative

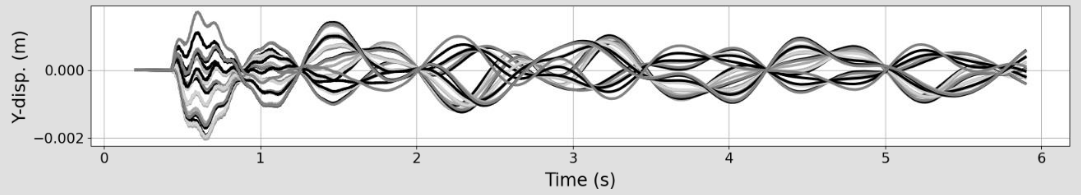
Short-coming	Approach
Low parameter sensitivity	Excitation of elastic resonance
Multi-modality	Stepwise approach
Computational cost	Transfer matrix model

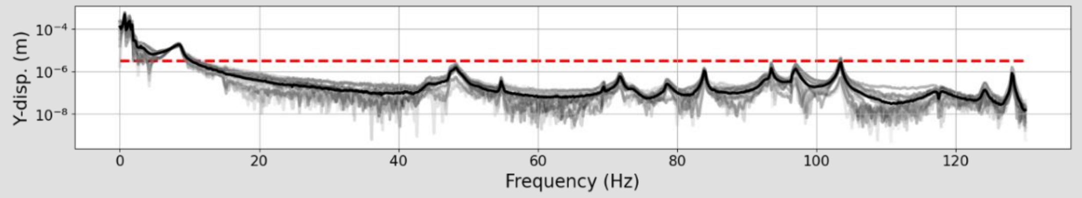
- Numerical and experimental validation
- Stepwise method: robust, convenient and fast but inaccurate

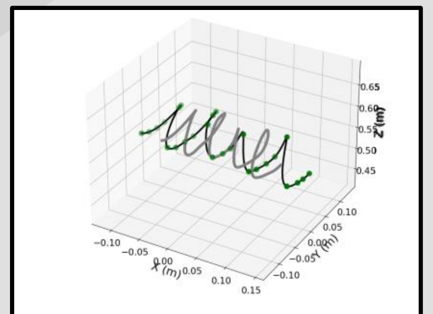
Applications

- Modal analysis of automotive coil spring
  - Hammer excitation
  - 260 fps recording
  - Estimated accuracy: 3 µm

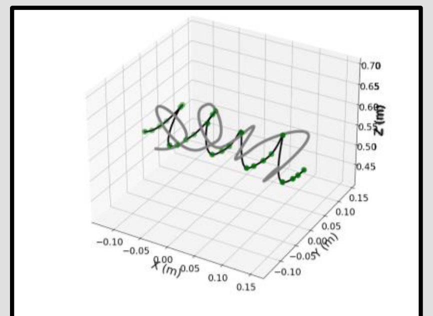








1st longitudinal (x)



1st lateral bending (y)

- Acoustic radiation of plat-like structures