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Computer Vision Aided Structural Identification: Feature Tracking Using Particle Tracking Velocimetry versus Optical Flow

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Overview

- Introduction
- Methodology
  - Particle Tracking Velocimetry
  - Lucas-Kanade Method for Optical Flow
  - Phase-Based Motion Magnification
- Experimental Testing
  - 3-story shear frame
  - Reinforced concrete beam
- Results and Discussion
- Conclusions

Introduction

- Computer vision aided structural identification and SHM
  - High spatial density of measurement locations
  - Non-contact sensing, without heavy cabling.
  - Easy implementation

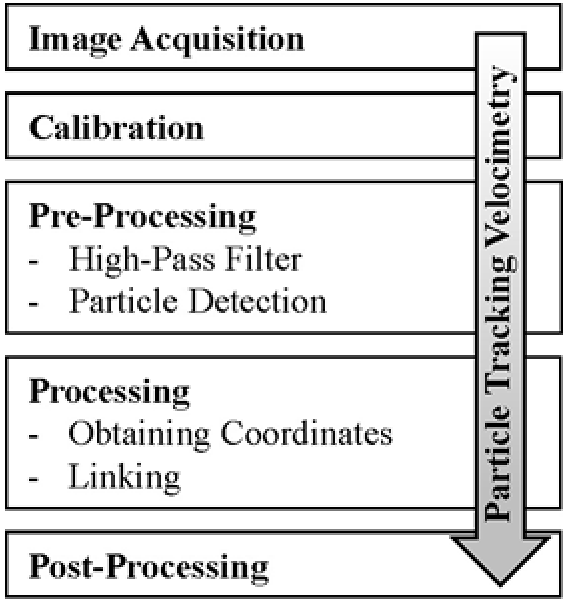
- Open research problems
  - Changing lighting conditions
  - Only displacement responses are reliably extracted

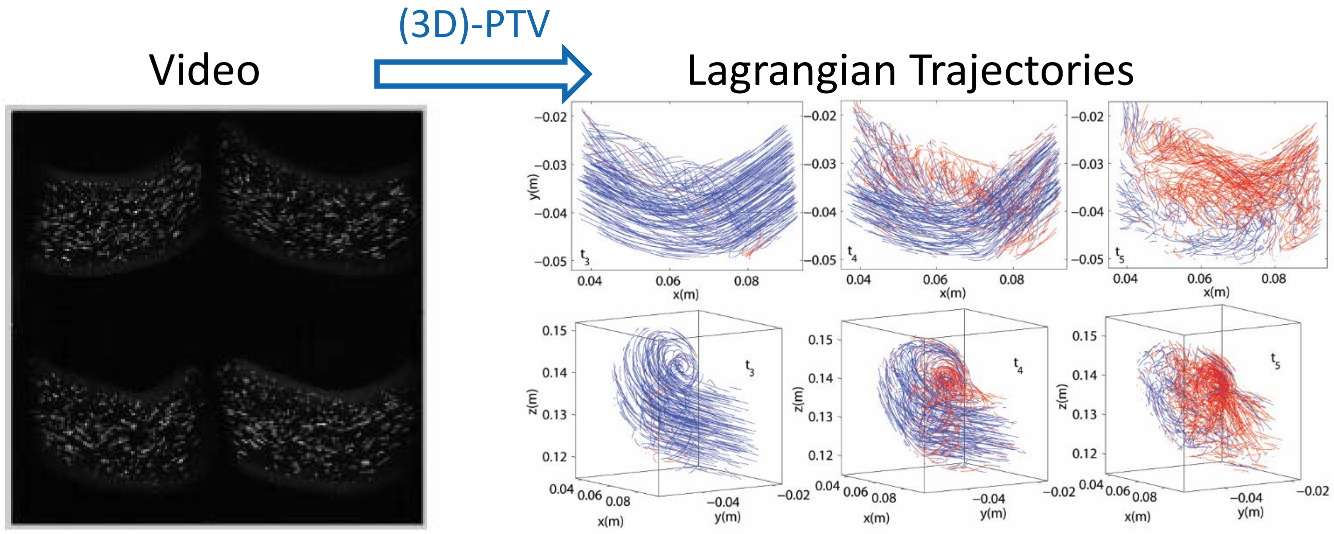
- Focus of this work
  - Validation and comparison of two computer vision tracking methods for structural identification
  - Utilization of phase-based motion magnification for magnifying imperceptible motion in videos.

Particle Tracking Velocimetry (PTV)

- PTV is an optical measurement technique to track Lagrangian trajectories of individual features (*particles*).
  - Applicable in 2D and 3D configurations.
  - Ability to deal with features that are not continually in the field-of-view.
- PTV requires high contrast features.
  - Background subtraction.
  - Introduction of artificial features (markers) onto the structure.

Workflow of PTV





Gülan et al., (2012), Experimental study of aortic flow in the ascending aorta via Particle Tracking Velocimetry

Lucas-Kanade Method for Optical Flow

Brightness Constancy Assumption

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

$$\frac{\partial I}{\partial x}u + \frac{\partial I}{\partial y}v + \frac{\partial I}{\partial t} = 0$$

The Lucas-Kanade Method

$$\begin{bmatrix} u \\ v \end{bmatrix} = \boldsymbol{H}^{-1} \begin{bmatrix} -\sum_i I_{x_i} I_{t_i} \\ -\sum_i I_{y_i} I_{t_i} \end{bmatrix}$$

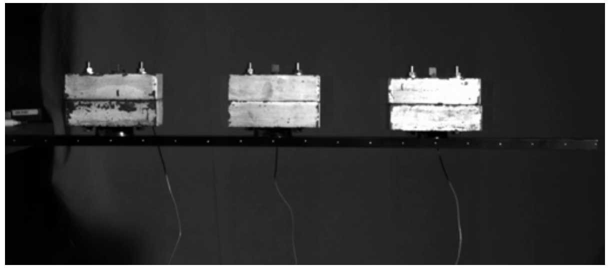
$$\boldsymbol{H} = \begin{bmatrix} \sum_i I_{x_i}^2 & \sum_i I_{x_i} I_{y_i} \\ \sum_i I_{x_i} I_{y_i} & \sum_i I_{y_i}^2 \end{bmatrix}$$

- $\boldsymbol{H}$ should be invertible
- Eigenvalues should not be too small
- $$\frac{\lambda_2}{\lambda_1} = \begin{cases} \text{small} & \text{well-conidtioned} \\ \text{large} & \text{ill-conditioned} \end{cases}$$
  $$(\lambda_1 < \lambda_2)$$

Phase-Based Motion Magnification (PBMM) on Videos

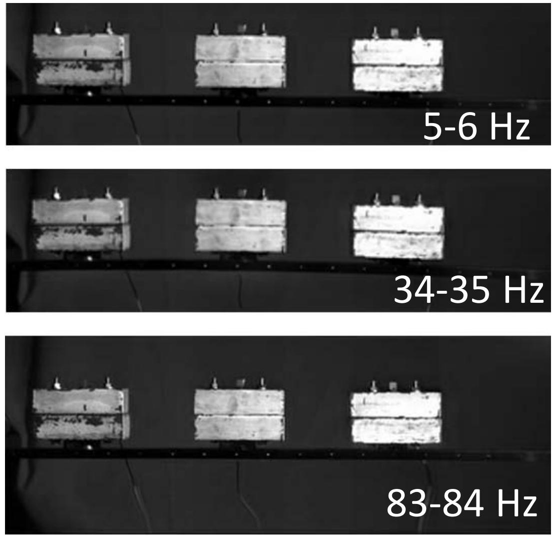
- Motion amplification in selected temporal frequency bands of a recorded video by modifying the local phase of the coefficients of a complex-valued steerable pyramid over time in different spatial scales and orientations.
- Feasibility in (lab-scale) SHM applications explored previously in 2D, and recently in 3D.

Original Video

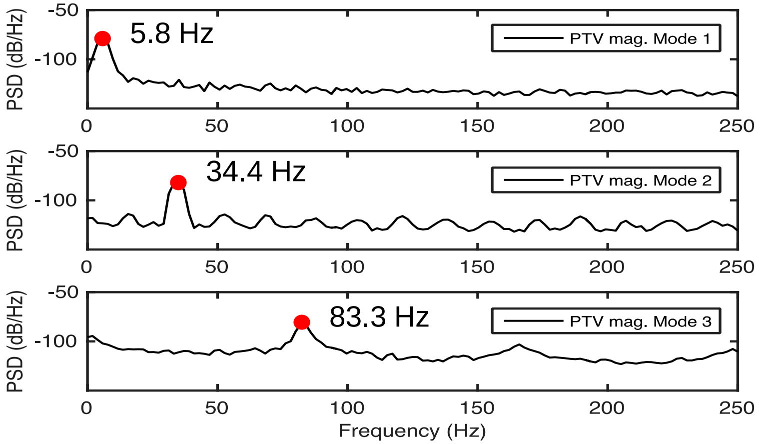


PBMM

Magnified Videos



Frequency Content

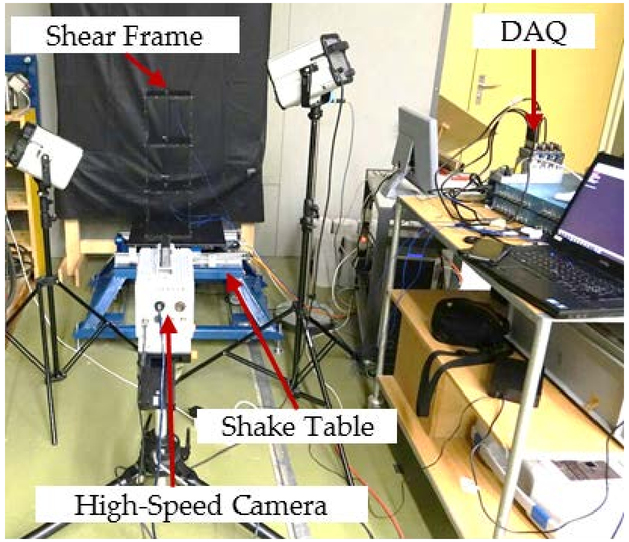


[Zimmermann et al., (2016) Structural Health Monitoring through Video Recording]

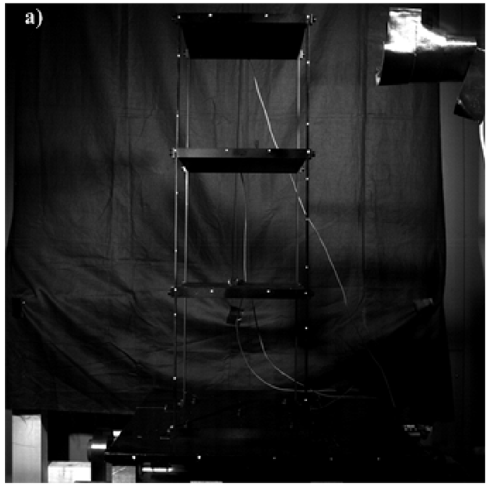
Experimental Test I

- 3-story shear frame
  - mounted on a uniaxial shake table,
  - uniform background and artificially introduced features (2-mm markers)
  - scaled Northridge ground excitation and hammer impact.
- Video was recorded by a high-speed camera
  - 500 FPS
  - 1024 x 1024 pixel resolution
  - an LVDT, a laser transducer and accelerometers are used as references

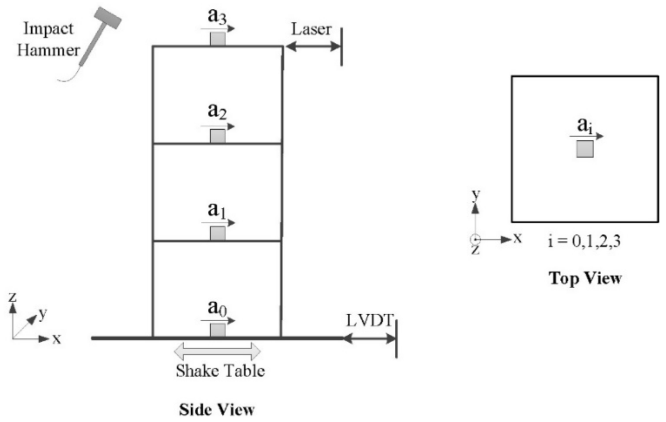
Test Setup



Camera View

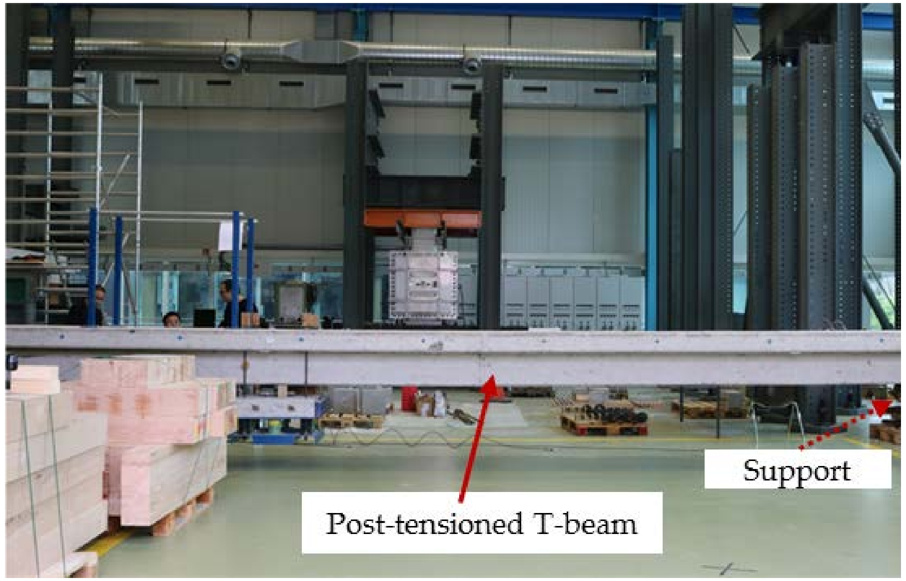


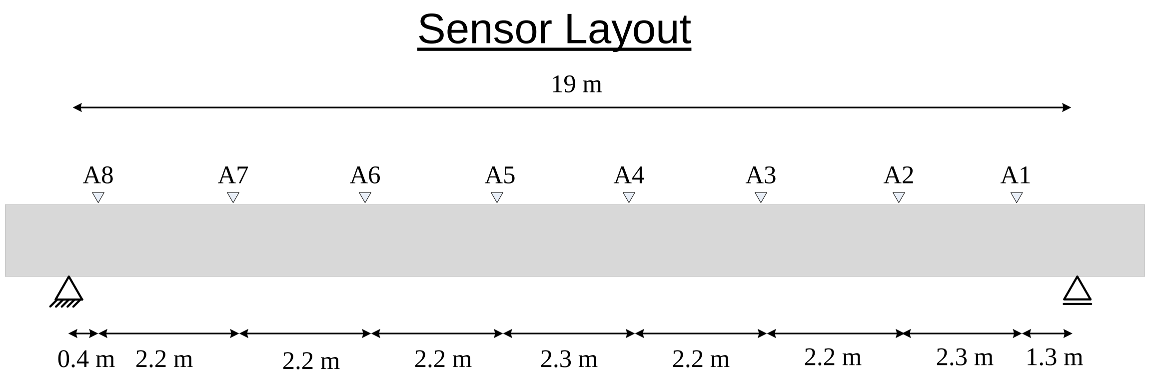
Sensor Layout



Experimental Test II

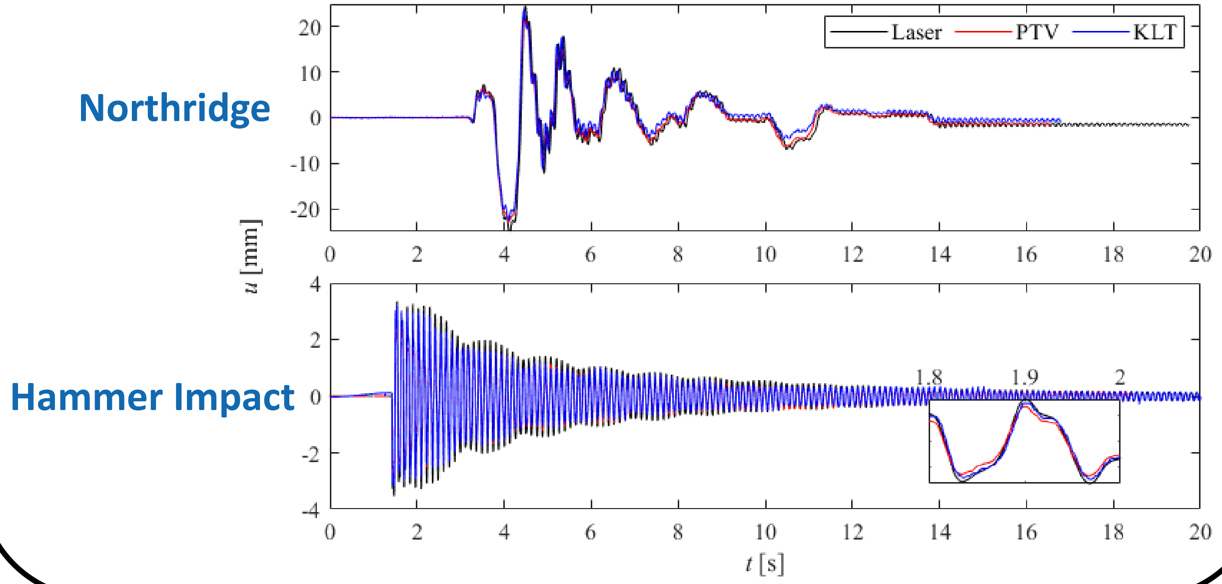
- 17.4-meter post-tensioned reinforced concrete T-beam
  - Irregular fore- and background
  - no artificial markers
- Sensing System
  - Sony RX100V with 50 fps and 1920x1080 pixel resolution
  - 8 uniaxial piezoelectric accelerometers along the span



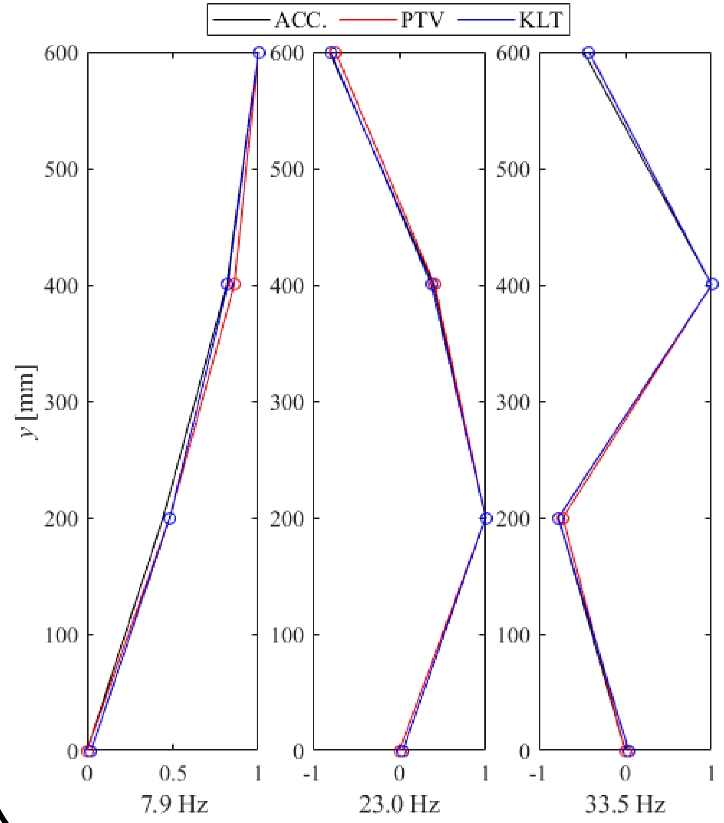


Results & Discussion – Shear Frame

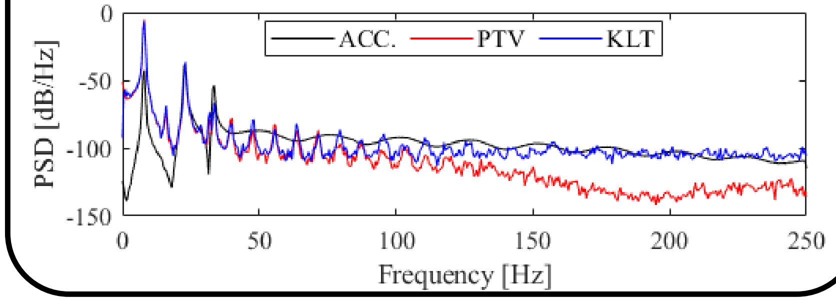
Time History



Identified Modes

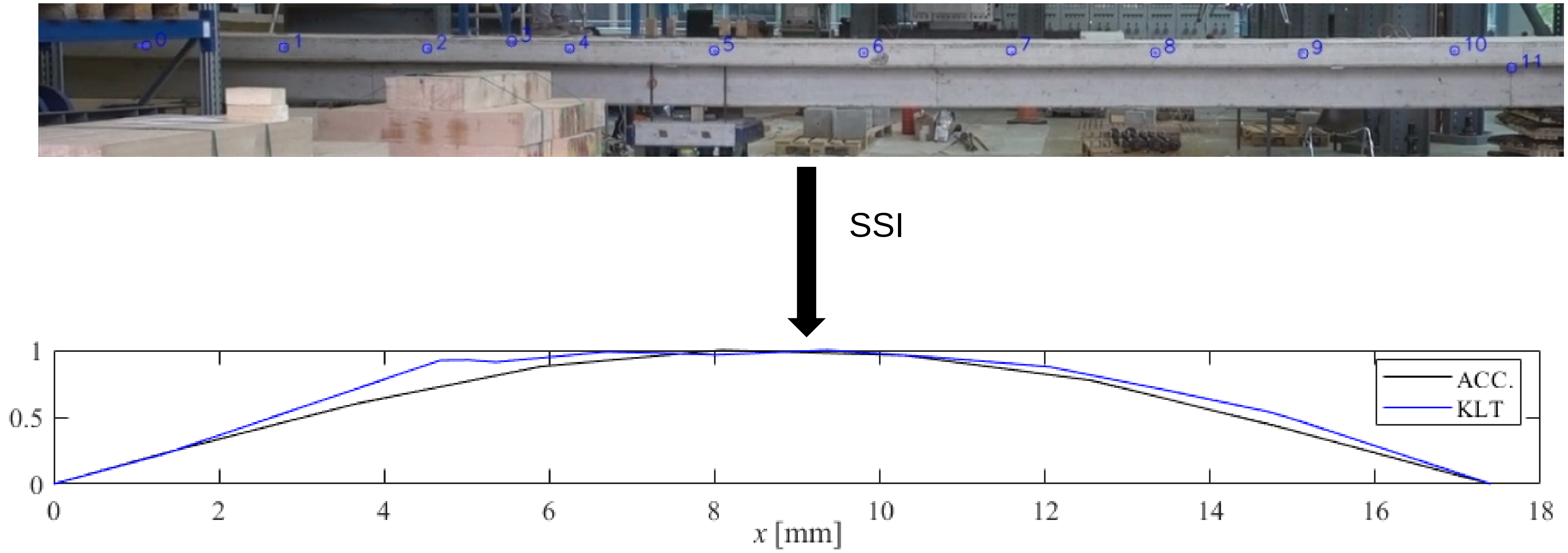


Frequency Domain



Results & Discussion – Concrete Beam

- Motion magnified 5 times within the 1.7-1.9 Hz frequency range (First bending mode).
- Despite very suboptimal fore- and background, features (formwork plugs) tracked successfully, resulting in an acceptable identification of the first bending mode shape.



Conclusions

- Two tracking techniques have been employed on video recordings for computer vision aided structural identification.
- Comparison against LVDT and laser sensors shows that both methods perform accurately in capturing the structural displacement response.
- PBMM was utilized to magnify motion around the first natural frequency of the post-tensioned beam.
- Resolution, reliable tracking features, and lighting conditions, etc. are key factors for reliable structural response tracking.

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Thank you for your attention!

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