

# Optical methods for vibration monitoring

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# Presentation content

- Motivation of the survey
- Identified Technologies
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# Motivation and scope of the study

- Study is a part of Energiforsk Vibrations -research program
  - <https://www.energiforsk.se/program/vibrationer-i-karnkraft/>
- Study scope is concentrated on vibration measurements for trouble-shooting purposes in nuclear power plant environment
- Stationary structures are mainly considered
  - Turbines, generators, emergency power units, piping, pressure vessels
- Only non-contact optical vibration monitoring methods are included in this study

# Identified Technologies

- Laser Doppler Vibrometer (LDV)
- Motion Magnification
- Digital Image Correlation (DIC)
- Electronic speckle-pattern interferometry (ESPI)
- Holographic interferometry
- Video Stroboscope
- Laser displacement measurement

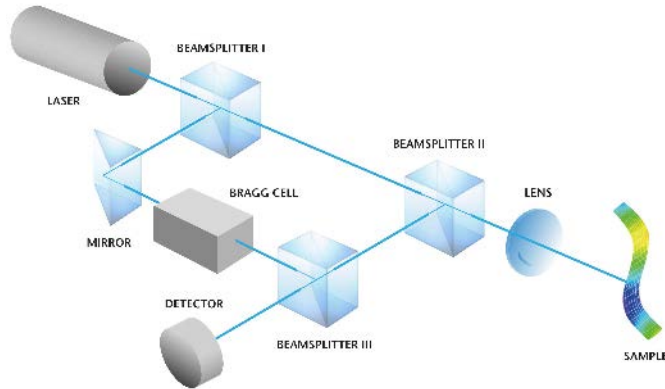
# Laser Doppler Vibrometer (LDV)

- Single-point Vibrometer
  - Multi-point Vibrometer
  - Differential Vibrometry
  - In-plane Vibrometry
  - Rotational Vibrometry
- Scanning Vibrometer (SLDV)
- 3D Scanning Vibrometer (3D SLDV)
- Multi-Beam Laser Vibrometer (MB-LDV)
- Tracking laser Doppler vibrometry (TLDV)
- Continuous-scan LDV (CSLDV)

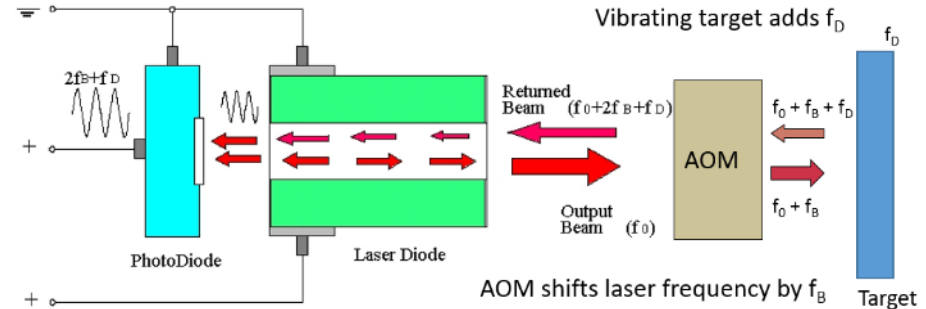


CSLDV Modal analysis of Wind turbine [1]

# Principle of LDV



Laser-Doppler vibrometer – a precision optical transducer used for determining vibration velocity and displacement at a fixed point [[www.polytec.com](http://www.polytec.com)]



OMS Laser Doppler Vibrometer - The laser-diode self-mixing [[www.omscorporation.com](http://www.omscorporation.com)]

# Available Commercial Products



[www.polytec.com](http://www.polytec.com)

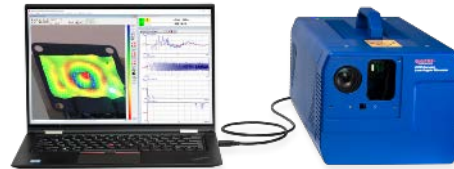
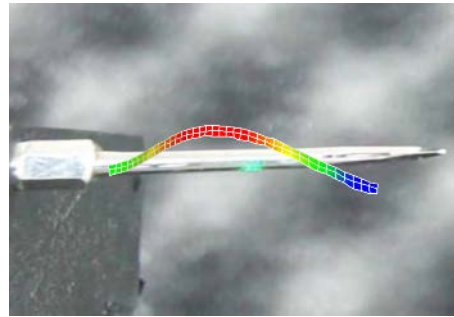


[www.optomet.com](http://www.optomet.com)

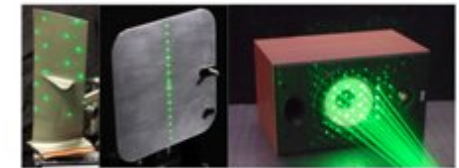
# Available Commercial Products



3D SLDV on a whole vehicle body [[www.polytec.com](http://www.polytec.com)]



Imaging vibration measurement [[www.optomet.com](http://www.optomet.com)]



Optical Measurement Systems multi-beam laser vibrometer [[www.omscorporation.com](http://www.omscorporation.com)]



## Limitations

- Measurement time needed; limited by scanning speed
- Relatively expensive, especially 3D LDVs
- Eye-safety

## Advantages

- Working distance up to 300m
- High frequency range
- Real-Time Visualization
- Quick Measurement Setup
- Non-contact measurement
- Good dynamic range

# Motion magnification methods

## Methods:

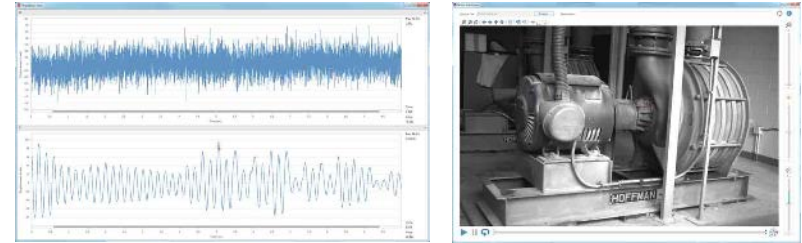
- Phase-Based Video Magnification [1]
- Eulerian Video Magnification [2]
- Learning-Based Video Magnification [3]

## Commercial products:

- Looking Glass Technique [4]
- Motion Amplification™[5]

[1] <http://people.csail.mit.edu/nwadhwa/phase-video/>

[2] <http://people.csail.mit.edu/mrub/evm/>



Displacement and Frequency Measurement example from RDI Technologies using Motion Amplification™ method [5]



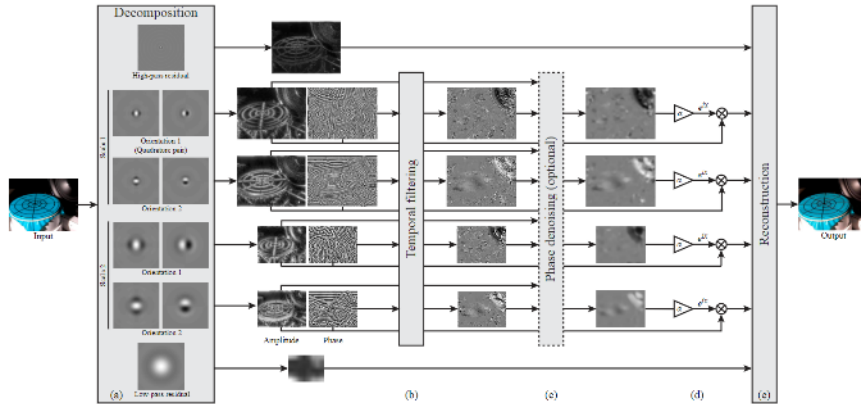
Video Vibration Tracking - DragonVision™ Video Deflection Technology [4]

[3] <https://people.csail.mit.edu/tiam/deepmag/>

[4] <https://www.erbessd-instruments.com/articles/vibration-tracking>

[5] <https://rditechnologies.com/>

# Phase-Based Video Magnification



Wadhwa, Neal, et al. "Phase-based video motion processing." *ACM Transactions on Graphics (TOG)* 32.4 (2013): 80.



<http://people.csail.mit.edu/nwadhwa/phase-video/>

# Available commercial products



[[www.erbessd-instruments.com](http://www.erbessd-instruments.com)]



[[rditechnologies.com](http://rditechnologies.com)]

## Limitations

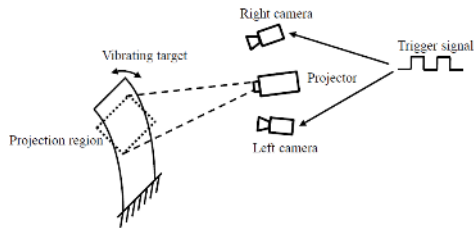
- Amplitude resolution limitations
- Frequency resolution
- Temporal Aliasing
- Lighting condition
- Visual barriers
- Measures only in-plane vibrations

## Advantage

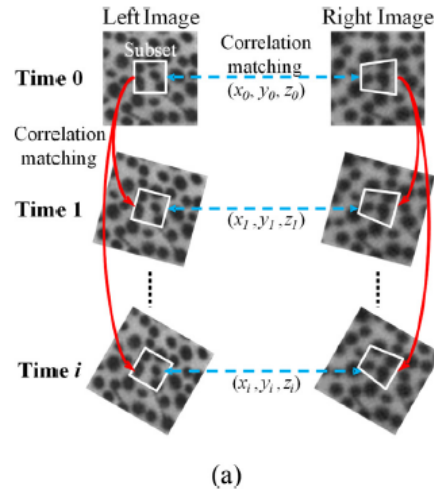
- No additional surface preparation needed
- Non-contact measurement
- No mass loading
- Quick measurement setup

# Digital Image Correlation

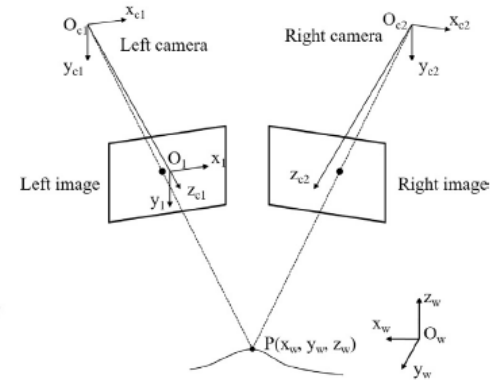
- 2D DIC
  - Speckle pattern
  - Projected pattern
- 3D DIC
  - Speckle pattern
  - Projected pattern



Pattern projection 3D DIC setup [1]



(a)



(b)

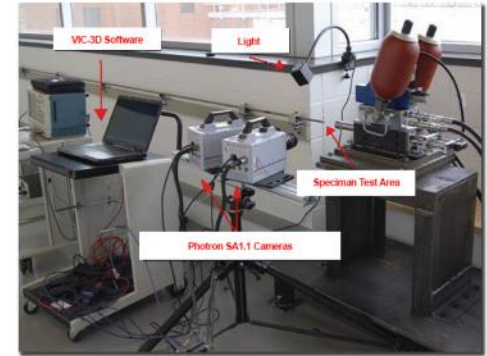
A schematic diagram of the principle of 3D-DIC. (a) Correlation matching procedure, (b) 3D reconstruction procedure involving two cameras. [2]

[1] Digital Image Correlation based on projected pattern for high frequency vibration measurements Sandro Baronea, Paolo Neria,\*, Alessandro Paolia, Armando Razionalea, 2017

[2] Health monitoring of wind turbine blades in operation using three-dimensional digital image correlation, Rong Wua, Dongsheng Zhang, Qifeng Yu, Yuxi Jiang, Dwayne Arola, Mechanical Systems and Signal Processing, 2019

# Available Commercial Products (3D DIC)

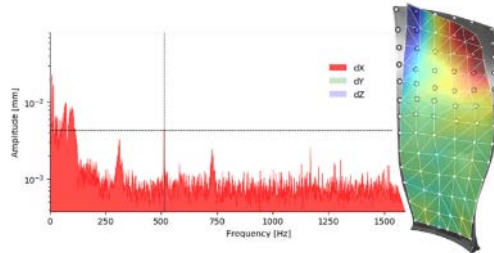
- Correlated solutions
- GOM Correlate
- Dantec Dynamics A/S
- LaVision



High Speed 3D DIC [correlatedsolutions.com]



Q-450 - High Speed DIC - Vibration Analysis  
[www.dantecdynamics.com]



GOM Correlate Vibration Analysis [www.gom.com]

## Limitations

- Speckle Pattern / Artificial target
- Camera calibration
- Post Processing
- Lighting Conditions
- Visual Obstacles
- Displacement based measurement; resolution limitations at high frequencies
- Temporal aliasing possible

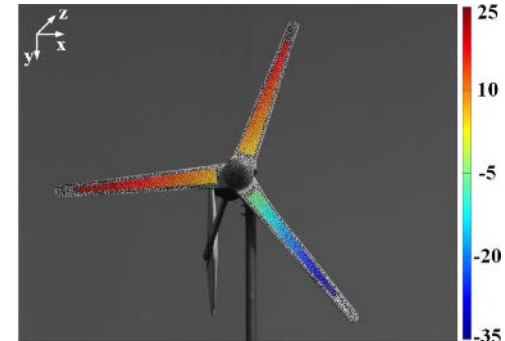
## Advantage

- High spatial resolution
- Non-contact measurement
- No mass loading
- No additional surface preparation needed with Projected Pattern method
- Instantaneous measurement with high spatial resolution; short acquisition time
- Also strain measurement possible



# 3D DIC Application examples

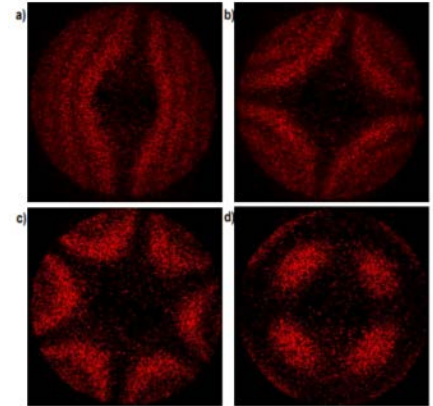
1. Health monitoring of wind turbine blades in operation using three-dimensional digital image correlation, Rong Wua, Dongsheng Zhang, Qifeng Yu, Yuxi Jiang, Dwayne Arola, Mechanical Systems and Signal Processing, 2019
2. 3D Digital Image Correlation for vibration measurement on rolling tire: procedure development and comparison with Laser Doppler Vibrometer, S. Galeazzi, P. Chiariotti<sup>1</sup>, M. Martarelli, E. P. Tomasini, Journal of Physics, 2018
3. Enhancing standard GVT measurements with digital image correlation, S. Manzato, E. Di Lorenzo, P. Mäckel, Proceedings of the 36th IMAC, A Conference and Exposition on Structural Dynamics, 2018  
(Measurement of displacement field of the wing end of an F16 during a GVT campaign)
4. Operation mode analysis by high speed DIC measurement on a mobile phone during vibration alert, 2012, isi-sys GmbH <http://www.isi-sys.com/operation-mode-analysis-on-a-mobile-phone-during-vibration-alert/>



Full-field displacement distribution of blades [1]

# Other identified technologies

- Electronic speckle-pattern interferometry (ESPI) [1]
- Holographic interferometry [2]
- High speed Videostroboscope
- Laser displacement measurement



Mode shapes of resonant vibrations of a circular slitting saw at different frequencies: a)  $f=607$  Hz, b)  $f=840$  Hz, c)  $f=1495$  Hz, d)  $f=5190$  Hz [1]

[1] Electronic Speckle Pattern Interferometry for Vibrational Analysis of Cutting Tools  
[Piotr Mrozekp.mrozek@pb.edu.pl](mailto:Piotr.Mrozekp.mrozek@pb.edu.pl)<sup>1</sup>, [Ewa Mrozeke.mrozek@pb.edu.pl](mailto:Ewa.Mrozeke.mrozek@pb.edu.pl)<sup>2</sup> and [Andrzej Werner.werner@pb.edu.pl](mailto:Andrzej.Werner.werner@pb.edu.pl)<sup>1</sup>  
[2] HOLOGRAPHIC INTERFEROMETRY FOR VIBRATION ANALYSIS OF MECHANICAL SYSTEMS  
Emina Petrovic, Ivan Ciric, Jelena Milisavljevic, Petar Djekic

# Available Commercial Products



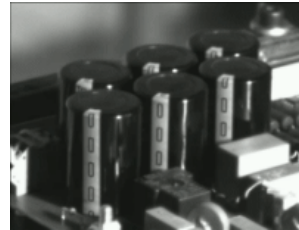
Shearography / ESPI Systems [[isi-sys.com](http://isi-sys.com)]



Ultra high-speed micro-vibration measurement [[www.keyence.com](http://www.keyence.com)]



High speed Videostroboscope [[isi-sys.com](http://isi-sys.com)]



# Summary

- Many useful optical techniques identified to measure vibration at nuclear power plant environment
  
- Next steps
  - Evaluate technologies performance in selected NPP case(s)
  
- Survey results will be published at the Energiforsk report

# bey<sup>0</sup>nd

## the obvious

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[www.vtt.fi](http://www.vtt.fi)