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ASME 2014

**12th Biennial Conference
on Engineering Systems Design and Analysis**

June 25-27, 2014 • Copenhagen, Denmark

ROBOT ASSISTED MODAL ANALYSIS ON A STATIONARY BLADED WHEEL

L. Bertini, B. Monelli, P. Neri, C. Santus, A. Guglielmo

Paolo Neri*, PhD student

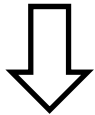
*Università di Pisa – Dipartimento di Ingegneria Civile e Industriale
Largo Lucio Lazzarino 2, 56126 Pisa. e-mail: paolo.neri@for.unipi.it



Introduction

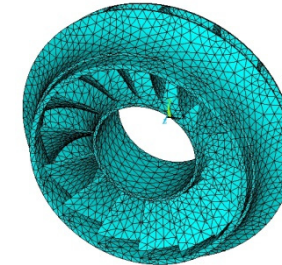
BLADED WHEELS:

Cyclic load



VIBRATIONS

- Fatigue
- Fretting
- Efficiency
- Noise



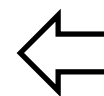
Analytical/numerical
(FEM)

Experimental



Time
consuming

AUTOMATIC
PROCEDURE





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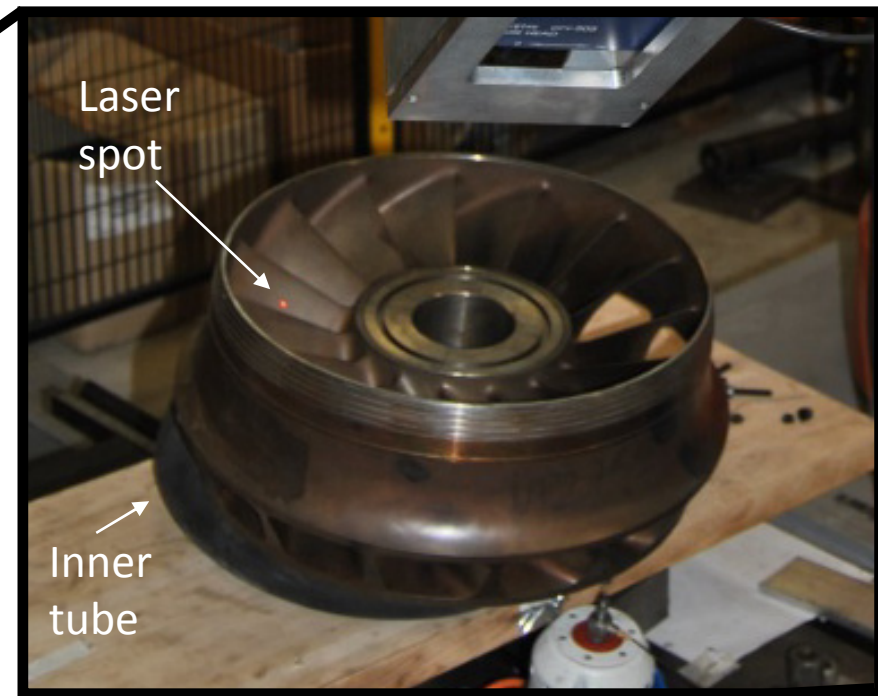
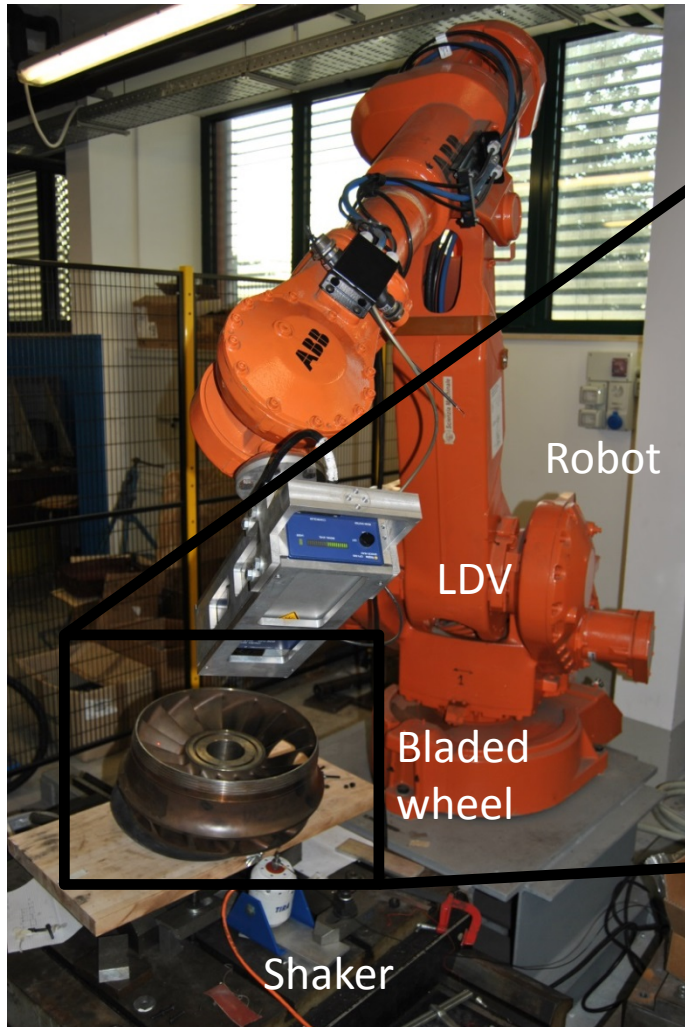
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ROBOTIC STATION

Experimental setup



Reference frame

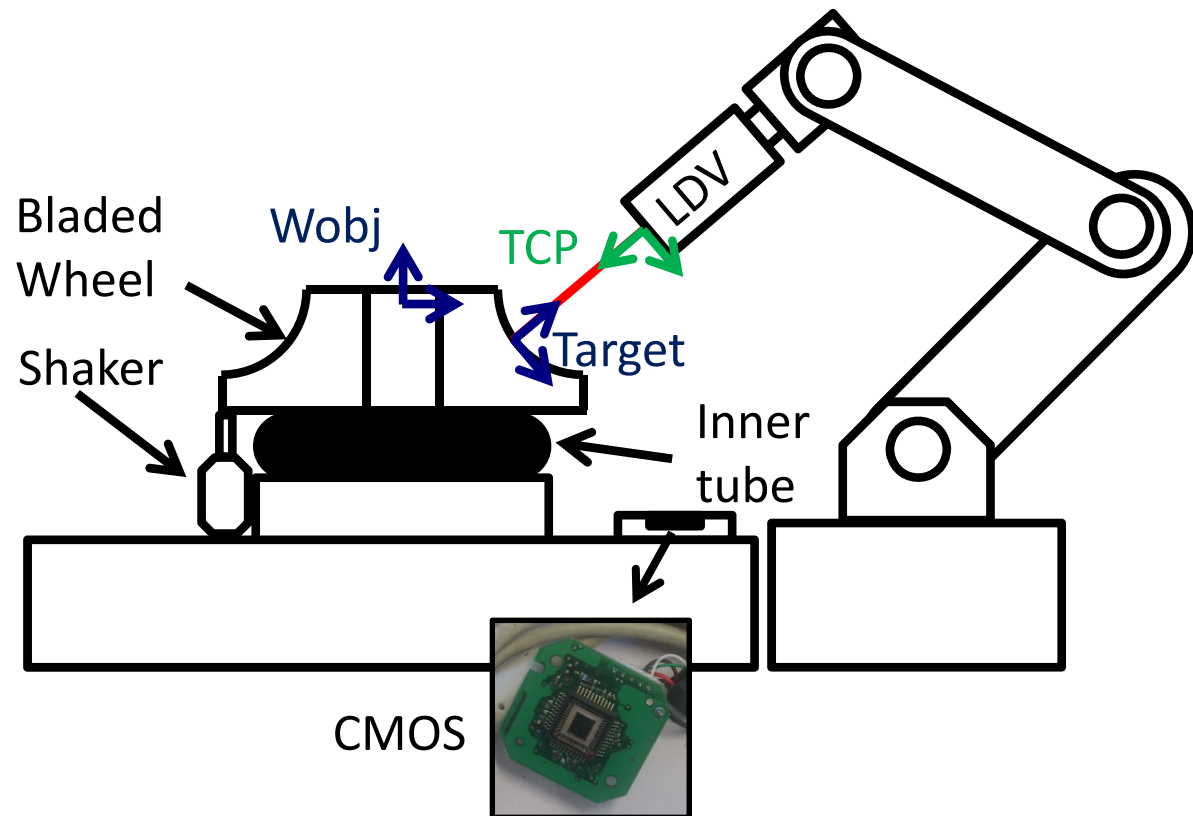
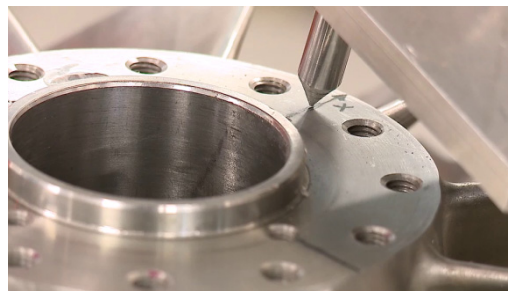


1) Tool Center Point:

CMOS sensor
Focus length
Robot procedure

2) Work object:

Robot procedure



Experimental equipment



Hardware and software involved:

- 6 DoF anthropomorphic robotic arm



- Single point LDV



- Shaker



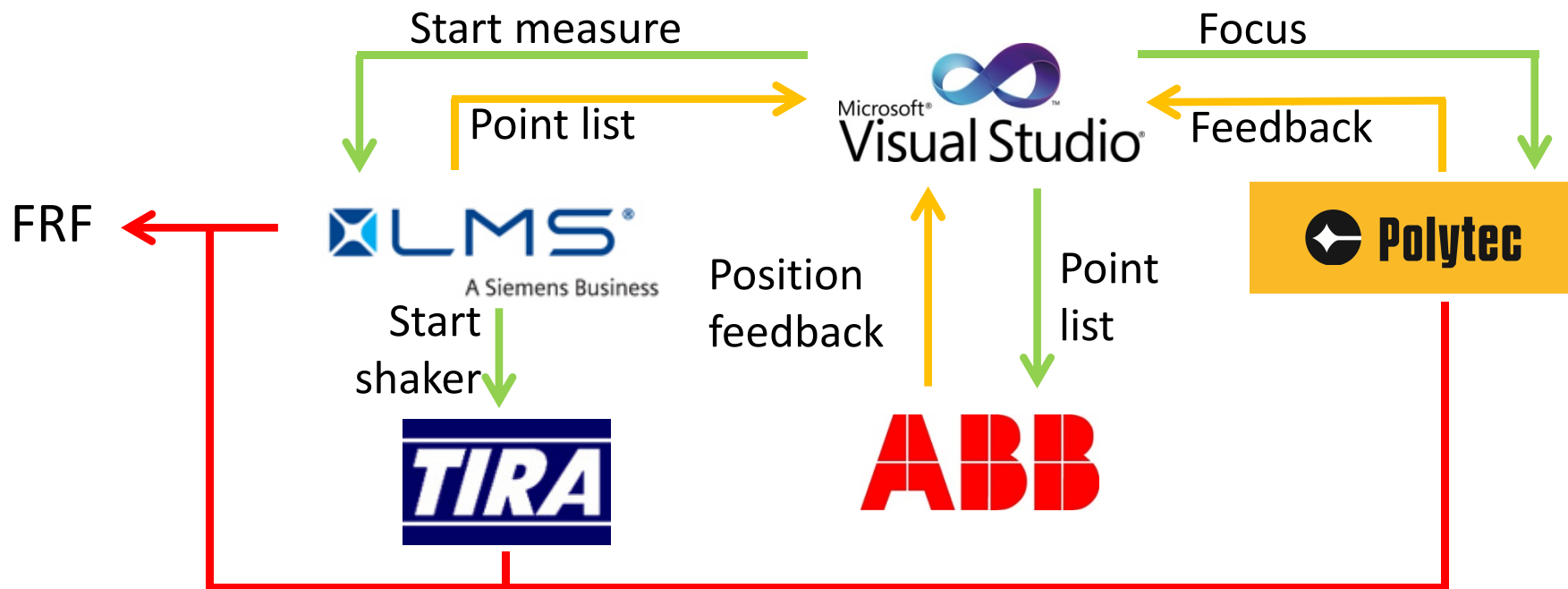
- SCADAS & Test.Lab software



UniPi developed
VB Program



Test automation





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BLADED WHEEL MODAL SHAPES

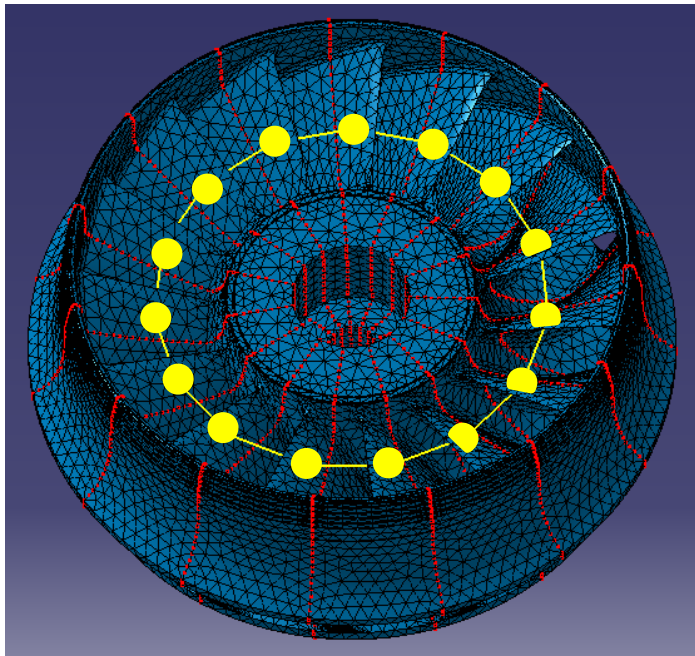
Complex VS real (1)

Cyclic symmetric geometry: $\delta_{mk}(t) = A_m \cos((d_m k \Delta\vartheta + \varphi_\vartheta) \cos(\omega_m t + \varphi_t)$

Number of Nodal Diameters:

$$0 \leq d_m \leq d_{max} = \left\lfloor \frac{N_B}{2} \right\rfloor$$

$$\frac{2\pi}{N_B}$$



$$\mathbf{v}_m = A_m \begin{bmatrix} \cos(d_m \Delta\vartheta + \varphi_\vartheta) \\ \cos(d_m 2\Delta\vartheta + \varphi_\vartheta) \\ \dots \\ \cos(d_m k \Delta\vartheta + \varphi_\vartheta) \\ \dots \\ \cos(d_m N_B \Delta\vartheta + \varphi_\vartheta) \end{bmatrix}$$

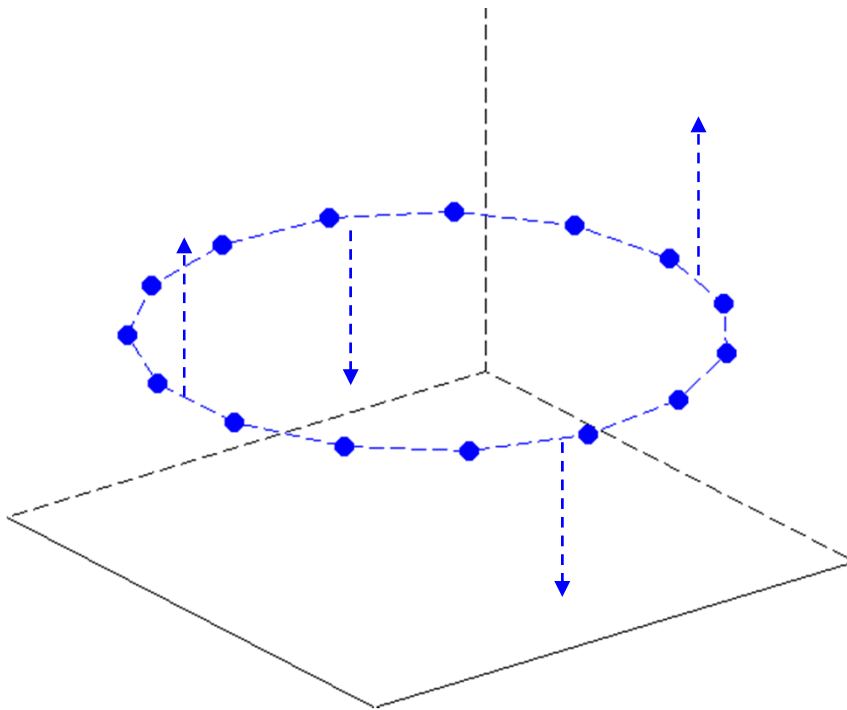
$$\mathbf{v}_m = A_m \begin{bmatrix} e^{i(d_m \Delta\vartheta + \varphi_\vartheta)} \\ e^{i(d_m 2\Delta\vartheta + \varphi_\vartheta)} \\ \dots \\ e^{i(d_m k \Delta\vartheta + \varphi_\vartheta)} \\ \dots \\ e^{i(d_m N_B \Delta\vartheta + \varphi_\vartheta)} \end{bmatrix}$$

Complex VS Real (2)

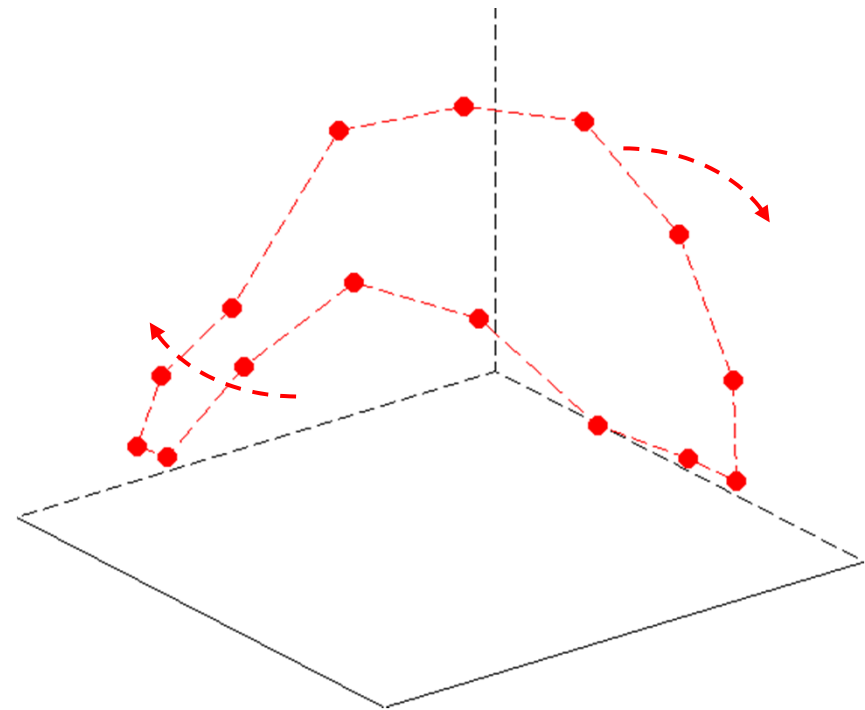


$$d_m = 2$$

Real mode reconstruction:
stationary wave



Complex mode reconstruction:
rotating wave



MAC matrix



Modal Assurance Criterion:

r -th & s -th eigenvectors comparison

$$M_{rs} = \frac{|\bar{\mathbf{v}}_r^T \mathbf{v}_s|^2}{(\bar{\mathbf{v}}_r^T \mathbf{v}_r)(\bar{\mathbf{v}}_s^T \mathbf{v}_s)}$$

$$\begin{cases} M_{rs} \cong 0 \rightarrow r\text{-th \& } s\text{-th are different modes} \\ M_{rs} \cong 1 \rightarrow r\text{-th \& } s\text{-th are the same mode} \end{cases}$$

Perfect mode-correlation:

		Mode set 1				
		1	2	3	4	...
Mode set 2	1	1	0	...		
	2	0	1	...		
	3	1		
	4				1	
	...					1

$$\mathbf{v}_m = A_m \begin{bmatrix} \cos(d_m \Delta \vartheta + \varphi_\vartheta) \\ \dots \\ \cos(d_m k \Delta \vartheta + \varphi_\vartheta) \\ \dots \\ \cos(d_m N_B \Delta \vartheta + \varphi_\vartheta) \end{bmatrix} \longrightarrow \varphi_\vartheta \text{ influences } M_{rs}$$

$$\mathbf{v}_m = A_m \begin{bmatrix} e^{d_m \Delta \vartheta} \\ \dots \\ e^{d_m k \Delta \vartheta} \\ \dots \\ e^{d_m N_B \Delta \vartheta} \end{bmatrix} \left(e^{i\varphi_\vartheta} \right) \longrightarrow \varphi_\vartheta \text{ disappears from } M_{rs}$$



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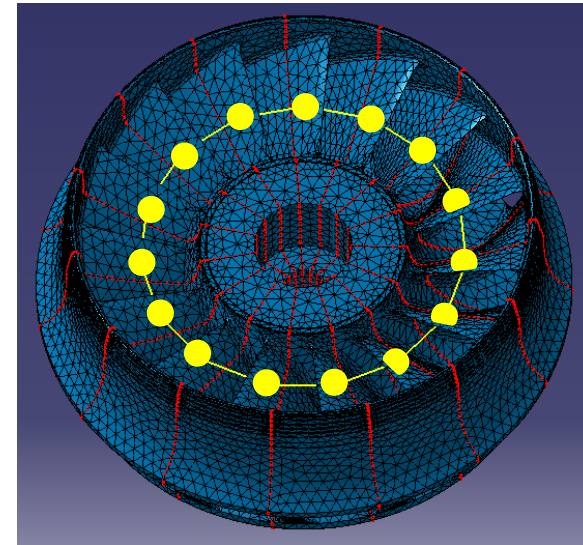
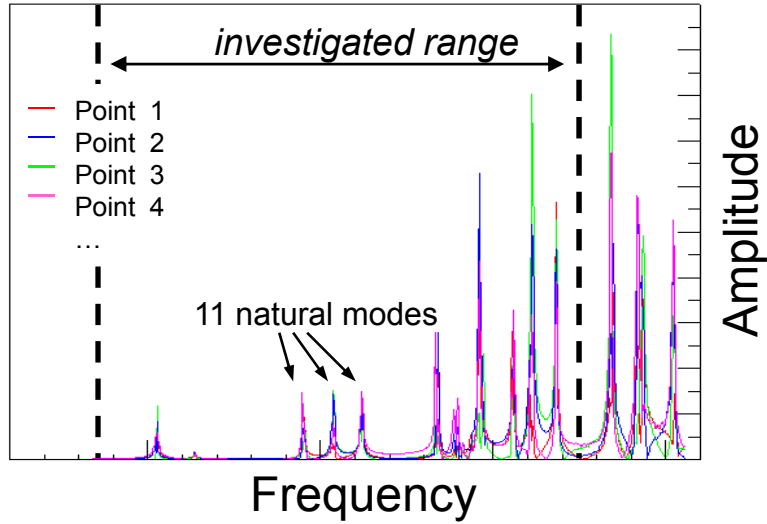
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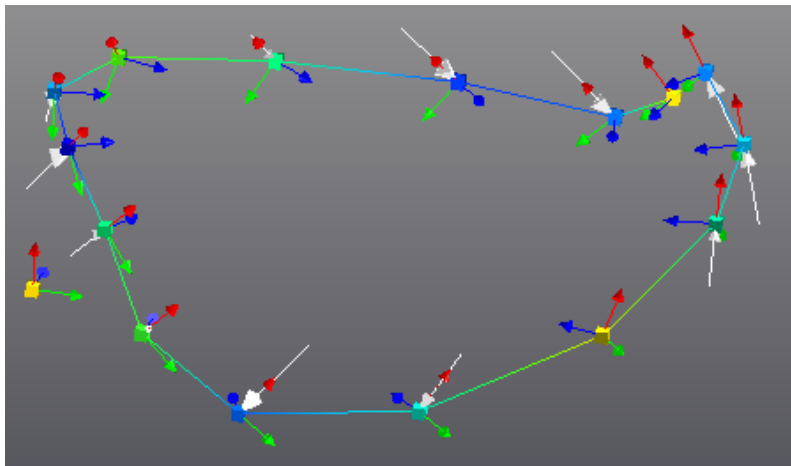
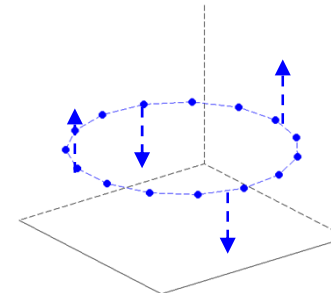
EXPERIMENTAL TESTS

Experimental results



One point in each sector

NND

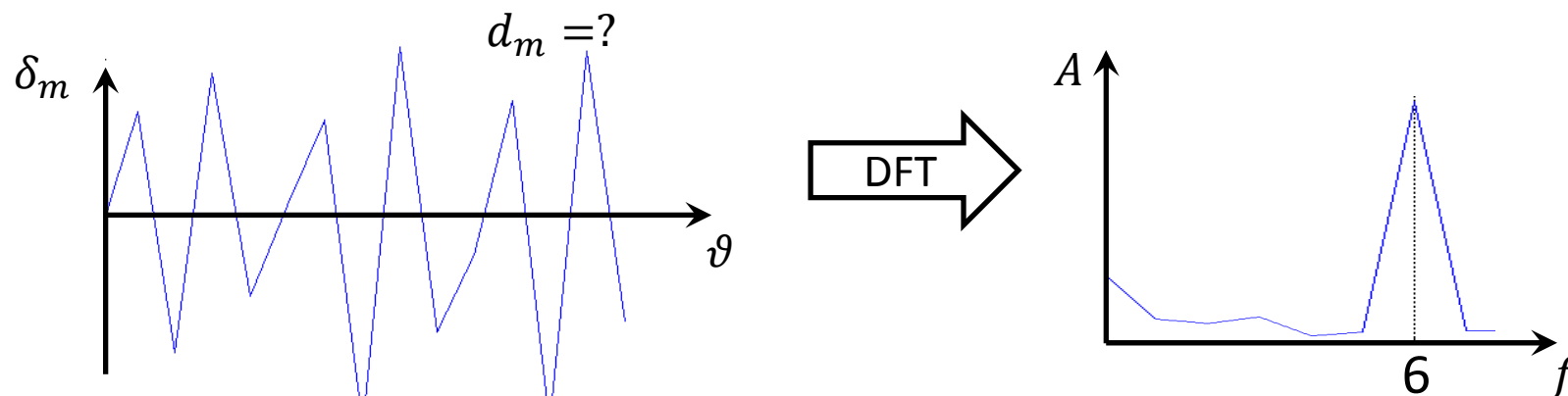
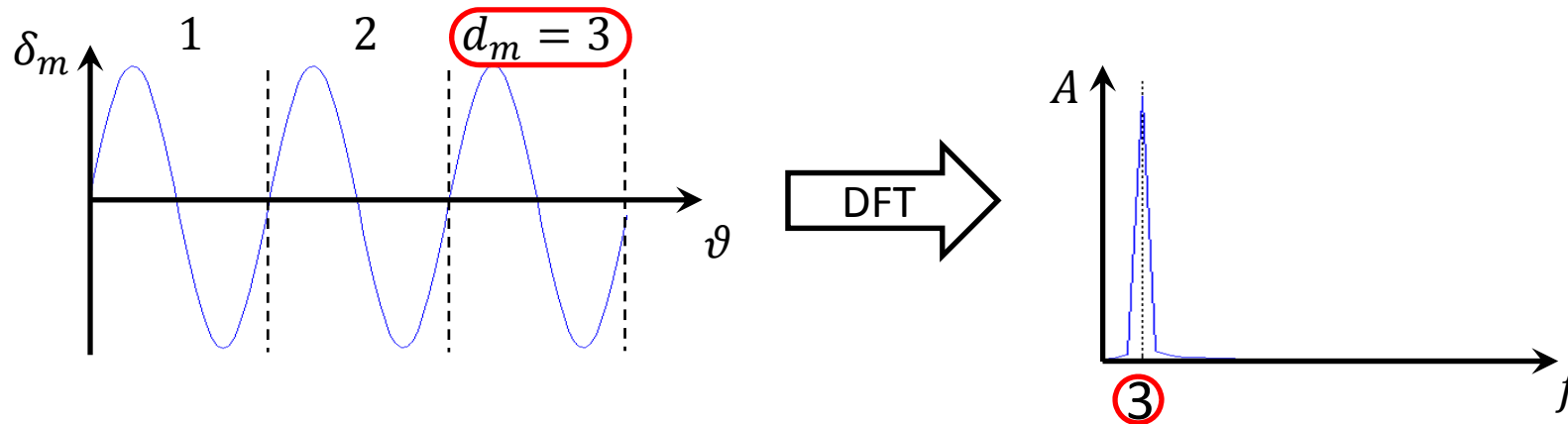


NND recognition

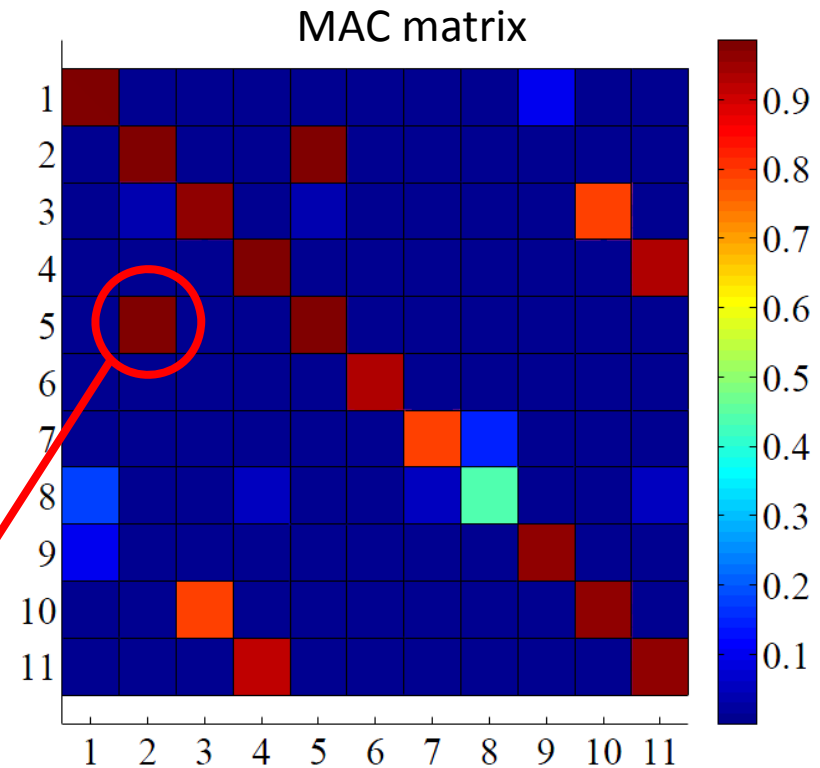
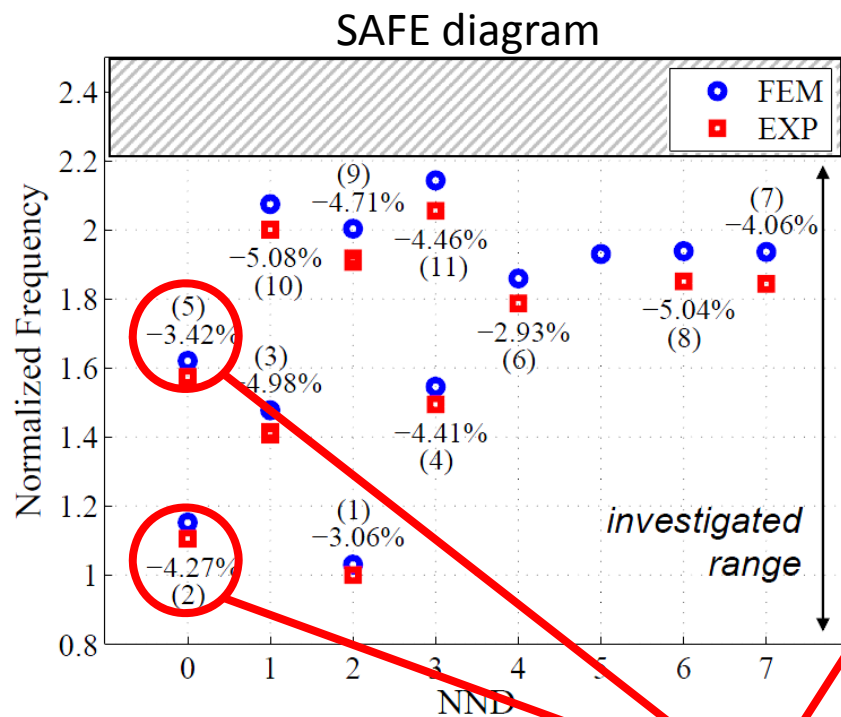


Eigenvector: $\delta_{mk}(t) = A_m \cos(d_m k \Delta \vartheta + \varphi_{\vartheta}) \longrightarrow \text{NND} = d_m \longrightarrow$ Eigenvector angular frequency

Discrete Fourier Transform



Results comparison



Modes with same number of nodal diameter



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CONCLUSIONS

Final remarks



1) Robotic station test setup:

- Reference frames definition
- Automated measurement
- Manual post-processing

2) Bladed wheel test results:

- Complex VS real reconstruction investigation
- DFT for NND recognition
- SAFE & MAC matrix comparison

Future development



- Data post-processing automation
- Complex reconstruction deeper investigation
- Number of measurement points per sector increment