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Multi-modal fibre optic shape sensing for the SmartX morphing wing demonstrator

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Delft University of Technology

- Introduction
  - Optical fibre sensors
  - SmartX morphing wing
- Theory
  - Working principles
  - Setup
- Results and discussion
  - Calculations
  - Bend up / Bend down
  - Twist
- Conclusions
  - Findings
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  - Future/Ongoing work

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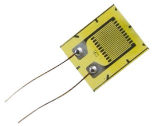
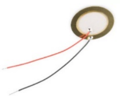
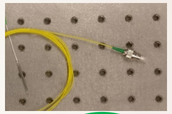
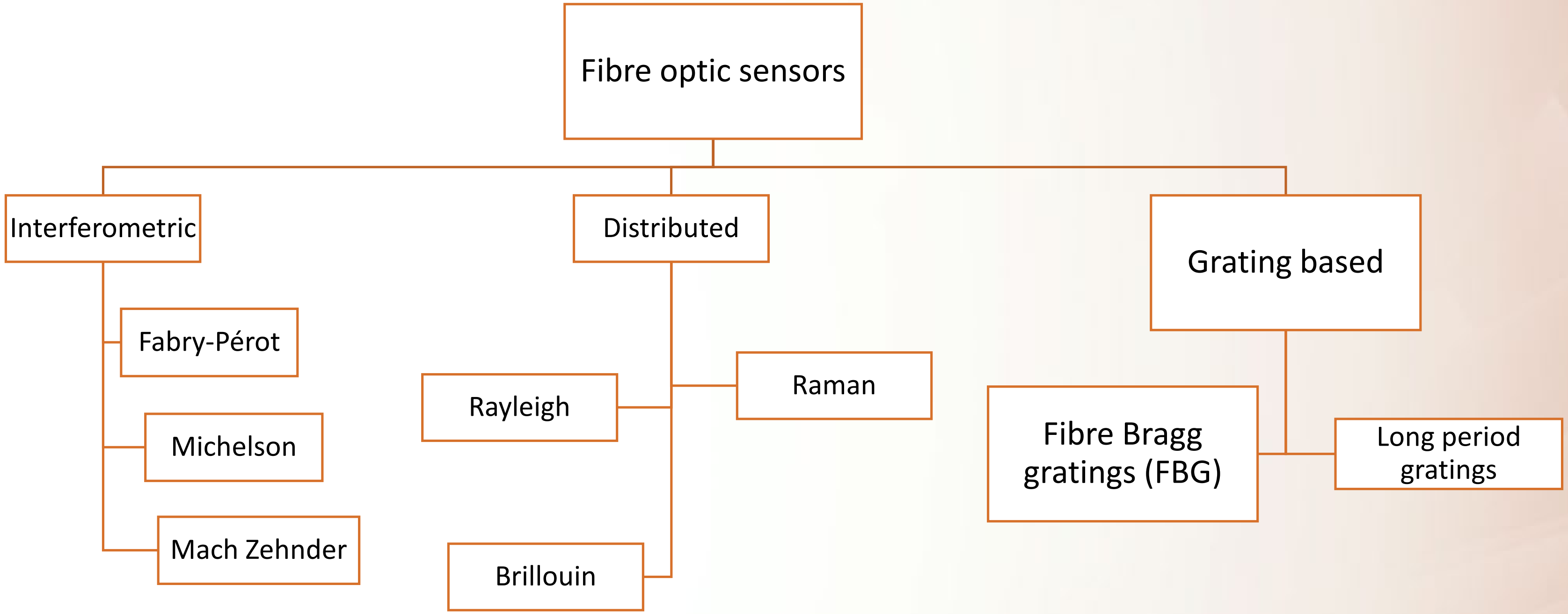
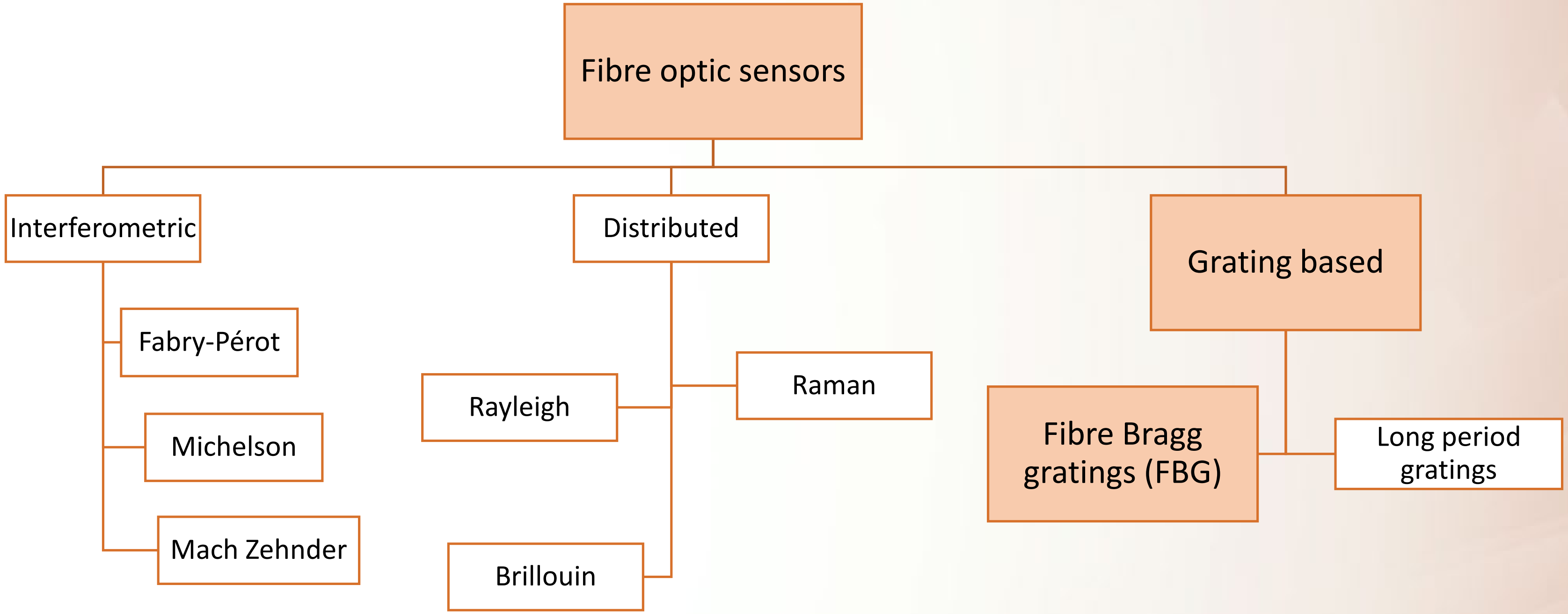





	Resistance Strain gauge	PZT	Fringe projection (photogrammetry)	Optical fibre
Wiring	Multiple wires based on number of channels	Multiple wires based on number of channels	Requires projector and a Camera	Single fibre
Working in harsh environments	Not immune to EMI	Not immune to EMI	Needs illuminated and controlled environment	Yes. Light is the information carries
Number of sensors	Depends on number of sensing points; Wiring issues	Depends on number of sensing points; Wiring issues	Detector to capture the projections	Multiple sensors in one fibre
Installation	Complexity with large number of sensors	Complexity with large number of sensors	Bulky	Negligible weight & embeddable

Active research areas


Fibre optic sensors
Interferometric
Fabry-Pérot
Michelson
Mach Zehnder
Distributed
Rayleigh
Raman
Brillouin
Grating based
Fibre Bragg gratings (FBG)
Long period gratings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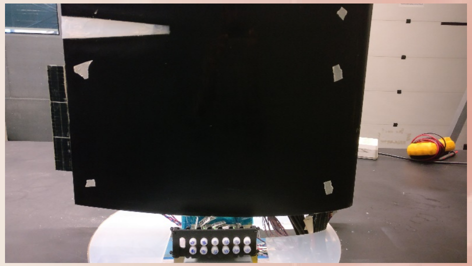
Wing and morphing section

6 individual morphing sections

Section #1

Upper wing section view
Morphing section #1



Lower wing section view
Morphing section #1

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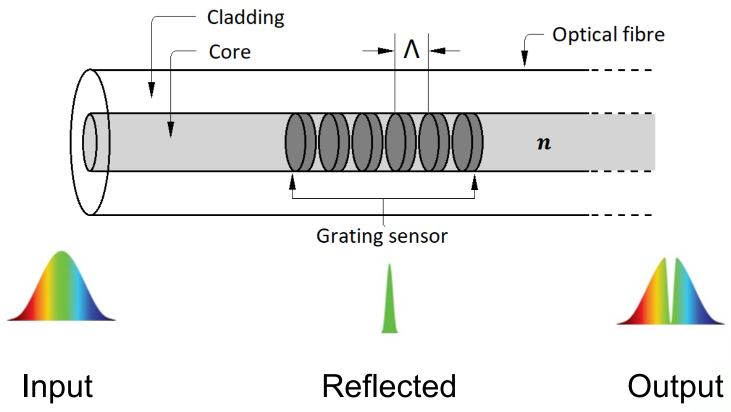
- Principles of :
  - Bragg Grating
  - Fabry-Pérot

$$\lambda_B = 2n_{eff}\Lambda$$

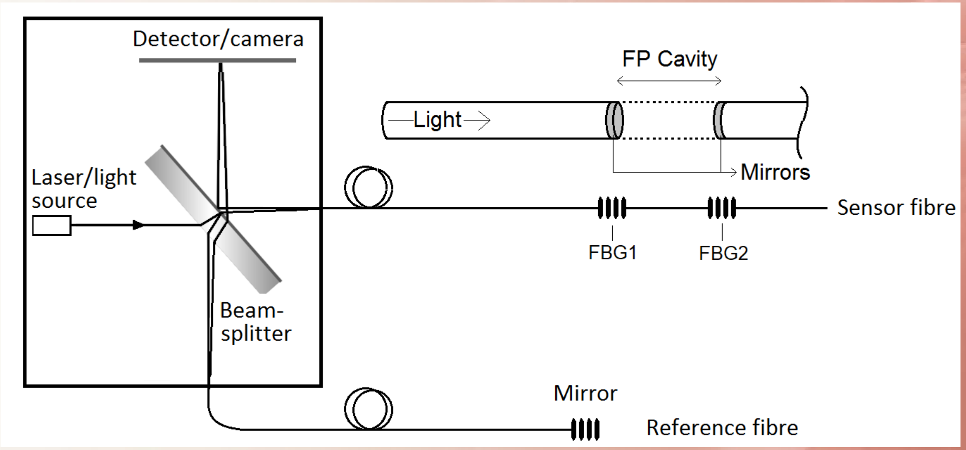
$$\Delta\varepsilon = \frac{\Delta\lambda_{BS}}{(1-\rho_a)\lambda_B} \qquad \varepsilon = \frac{\Delta d}{L}$$



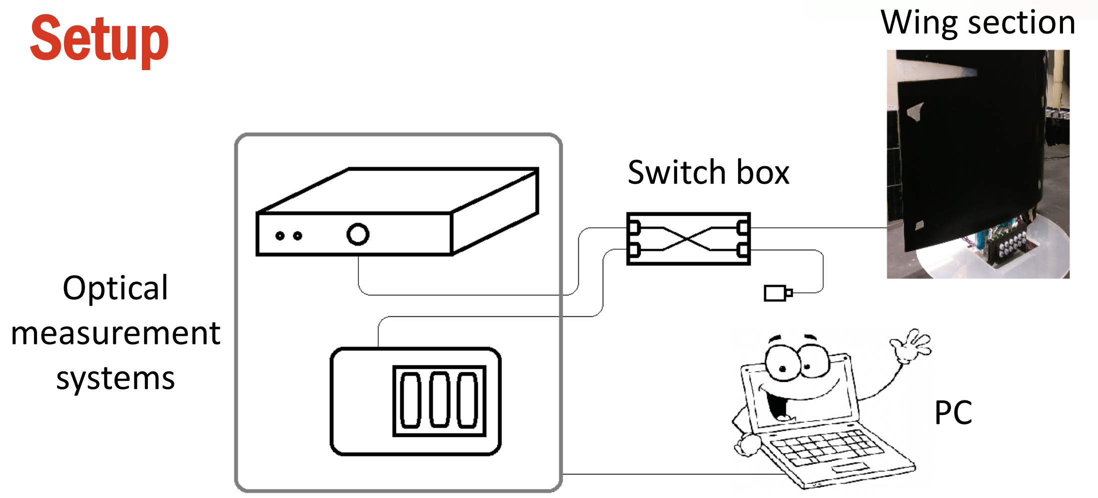
Λ: Periodic spacing

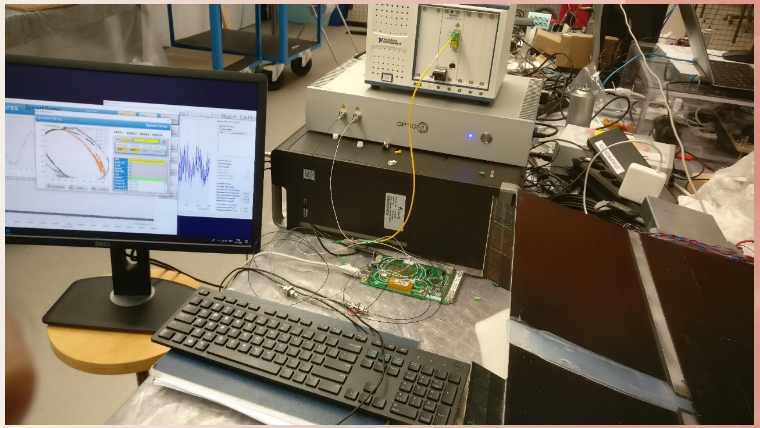
λB: Grating wavelength

$neff$: Core refractive index



Setup





Test conditions

- Static tests
- Only morphing section #1 considered
- Offline measurement (Not in the wind tunnel)

FE model – 3 morphing cases

Snapshots of the abaqus model showing the sliding concept and what happens during bend up/down and twist for better understanding

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Calculation

- Preliminary study involved static deformation for 3 morphing settings facilitated by actuators
  - Bend up
  - Bend down
  - Twist
- Liner regression fitting to determine the deflections in between the calibration points
- Transfer function that relates the tip deflection to the strain acquired from both the optical sensing methods
  - $Bend\ up\ \&\ bend\ down;\ Tip\ deflection : a * fbg2 + b * fbg3 + c * fp12 + d * fp34 + e$
  - $Twist;\ Left\ tip\ deflection : f * fbg1 + g * fbg4 + h * fp12 + k$
  - $Twist;\ Right\ tip\ deflection : l * fbg1 + m * fbg4 + n * fp34 + o$

Bend up and bend down

Bend up	(NI) ε FBG		(O11) ΔL				
Actuator input (deg)	FBG_2 (μ)	FBG_3 (μ)	ΔL FP_1-2 (μm)	ΔL FP_3-4 (μm)	**Tip deflection (mm)**	**Estimated tip deflection (mm)**	Error (mm)
5	143,17	144,00	-7,6	-7,598	**2**	**2,1**	0,1
10	300,31	306,72	-25,2	-25,414	**6**	**1,93**	-4,07
15	441,64	443,60	-78,4	-79,386	**9**	**8,48**	-1,69

Bend down	(NI) ε FBG		(O11) ΔL				
Actuator input (deg)	FBG_2 (μ)	FBG_3 (μ)	ΔL FP_1-2 (μm)	ΔL FP_3-4 (μm)	**Tip deflection (mm)**	**Estimated tip deflection (mm)**	Error (mm)
5	-138,00	-137,00	8,4	8,346	**5**	**3,16**	-1,84
10	-287,32	-280,00	29,0	27,178	**10**	**11,58**	1,58
15	-427,14	-423,00	86	85,6	**15**	**13,31**	-1,69

Twist

Right	(NI) ε FBG		(O11) ΔL				
Actuator input (deg)	FBG_1 (μ)	FBG_4 (μ)	ΔL FP_1-2 (μm)	ΔL FP_3-4 (μm)	**Tip deflection (mm)**	**Estimated tip deflection (mm)**	Error (mm)
5	-24,05	23,8	-5	6	**2**	**0.66**	-1.34
10	-53,65	51,3	-8,5	16	**4**	**5.18**	1.18
15	-101,75	100	-11	25	**6**	**5,98**	-0.02

Left	(NI) ε FBG		(O11) ΔL				
Actuator input (deg)	FBG_1 (μ)	FBG_4 (μ)	ΔL FP_1-2 (μm)	ΔL FP_3-4 (μm)	**Tip deflection (mm)**	**Estimated tip deflection (mm)**	Error (mm)
5	-24,05	23,8	-5	6	**2**	**1.25**	-0.75
10	-53,65	51,3	-8,5	16	**4**	**4.65**	0.65
15	-101,75	100	-11	25	**6**	**5.97**	-0.03

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Findings

- Static deflections for bend up, bend down and twist of the morphing section were estimated using grating sensors
- Although calibration was done for a few actuator settings a good estimation of the tip deflection was achieved

- Average error of 1.3 mm for bend up/down with a maximum error of -4 mm
- Average error of -0.05 mm for twist with a maximum error of -1.34 mm

Future/Ongoing work

- Incorporate more data points for a better deformation estimation
- Higher measurement accuracy by considering more calibration points and accounting for errors

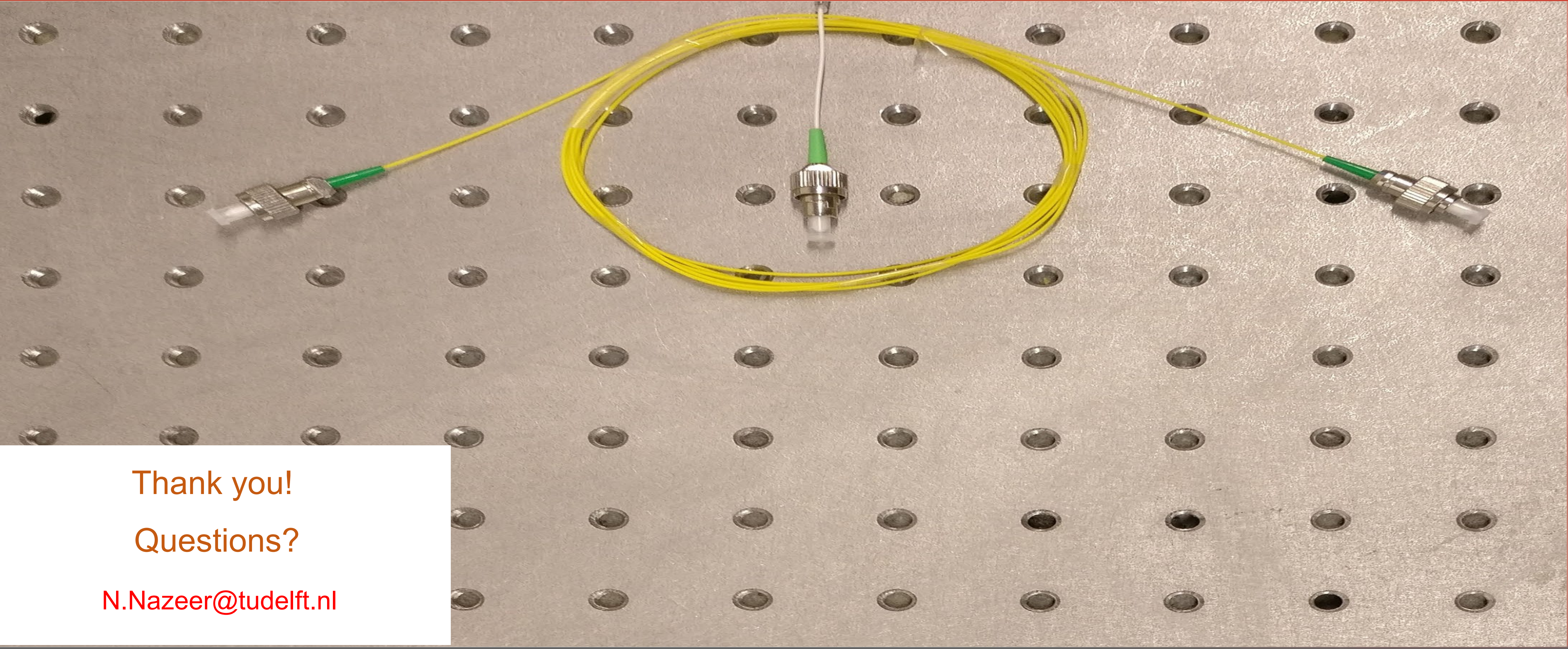
- Calibration of all 6 morphing sections of the wing
- Move towards dynamic monitoring of the wing sections

Summary

- Novel method to estimate the deformation of a morphing section
- Method incorporates least number of gratings to estimate the tip deflection

- Based on experimental model
- Combining structural mechanics with optics

- Multi-modal approach – Interferometry and FBG spectral sensing
- Capabilities to extend to dynamic monitoring of the full wing



Thank you!

Questions?

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