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Protecting Our World, Conquering New Frontiers
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FOS-based Monitoring of underwater port structures

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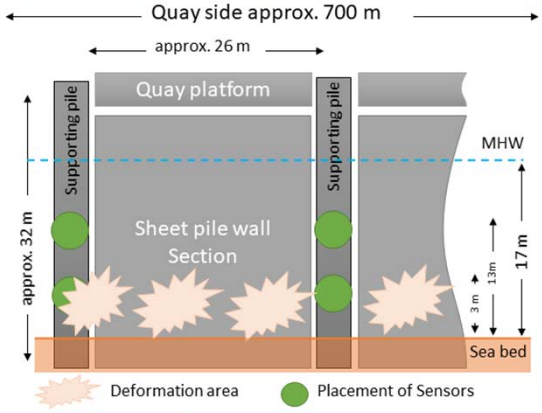
Motivation

Underwater infrastructure: Quay walls

→Basic part of the port infrastructure a

Possible reasons for failure of quay wall

- Age (e.g., material aging)
- Geotechnical reasons (e.g., piping by hea
- Damages by collisions



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→ Deformation monitoring requ

→Realization: **Geosensor Net**

Idea: Integration of **fiber-optical strain sensors**

Requirements

- Reliable system
- Permanent monitoring
- Capable to measure under varying conditions (e.g., water level variation, turbidity, temperature)
- (approximately) real-time visualization → monitoring web-interface
- Alarming module
- (High) coverage
- Expandability
- Privacy
- Moderate costs and installation effort
  → Installation on existing quay walls

➔ **Aim:** Quality-ensured **monitoring system**

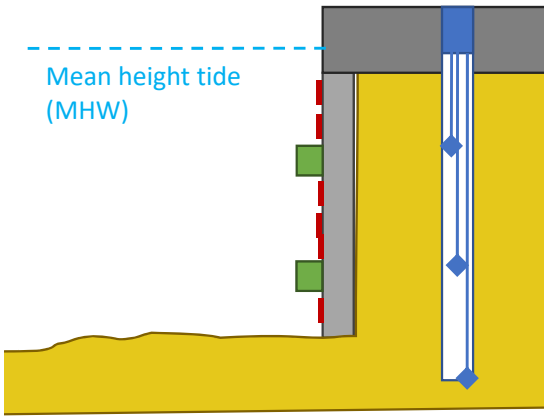
Central questions

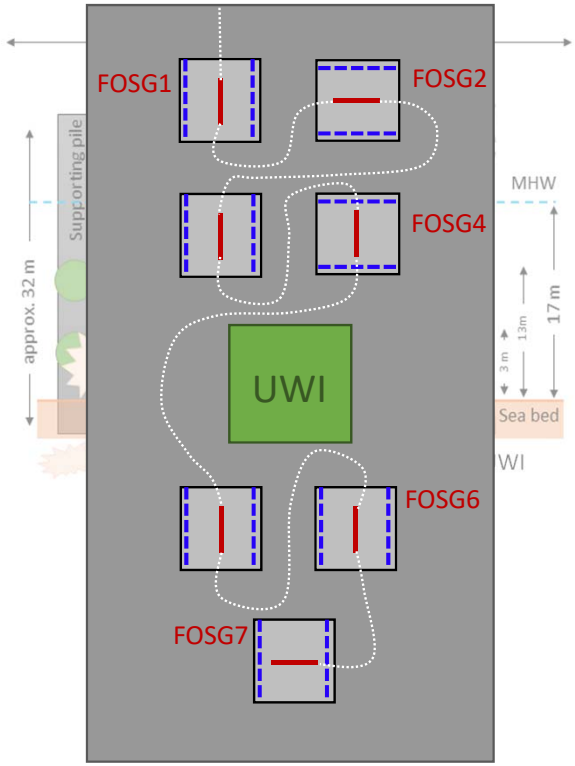
Deformation monitoring based on a geosensor network:

- How to set up a multi-sensor system for underwater monitoring on existing quay walls?
- How to describe the quality of a deformation monitoring?
- How to ensure the quality of the data and the data acquisition process?
- Which quality can be achieved by the considered monitoring system?

Monitoring System

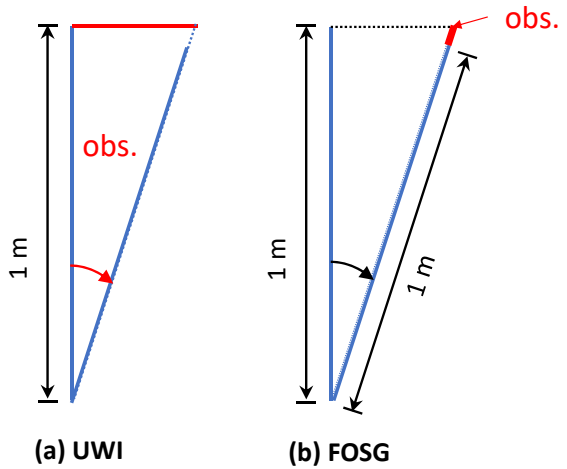
- Extensometers
- Underwater inclinometers (UWI)
- Inclinometer chains
- Fiber-optical sensors (FOS)
- Environmental sensors: temperature, tide gauge



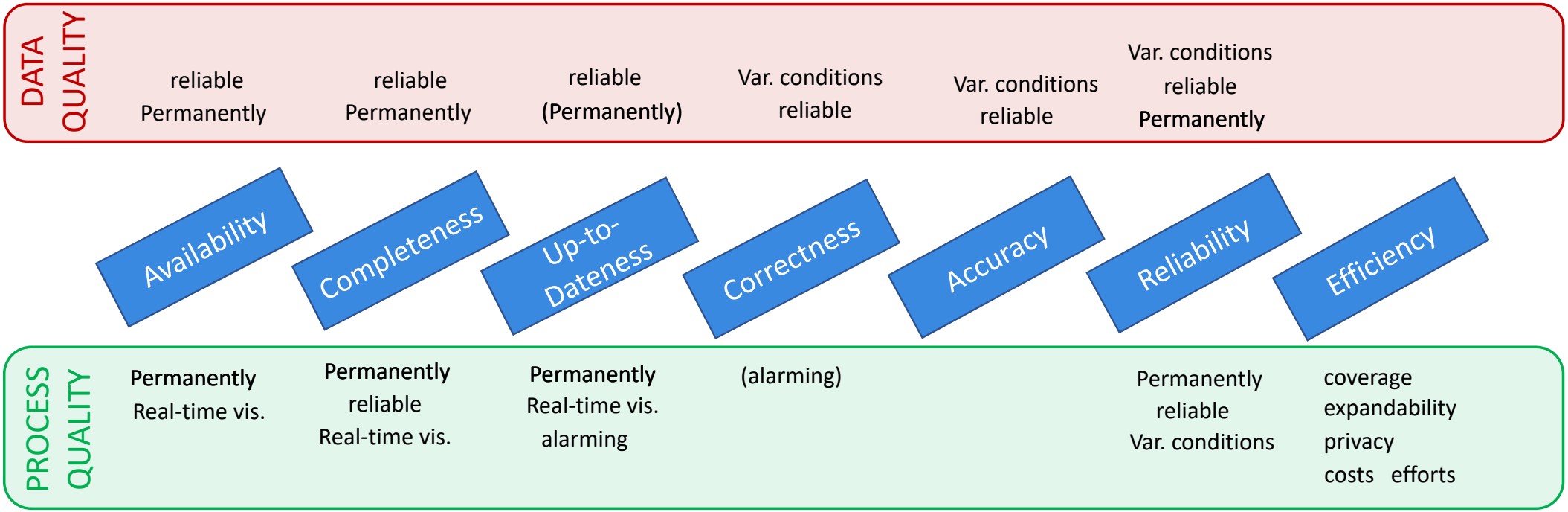


Multi-sensor system: Integration of FOS

- Idea: change of inclination angle
  ➔ strain of the surface
- Installation of **Fiber Bragg Gratings (FBGs)**
  → Derived observation: **strain**
- **FBG** observations: Influence of temperature and strain → acquisition of temperature



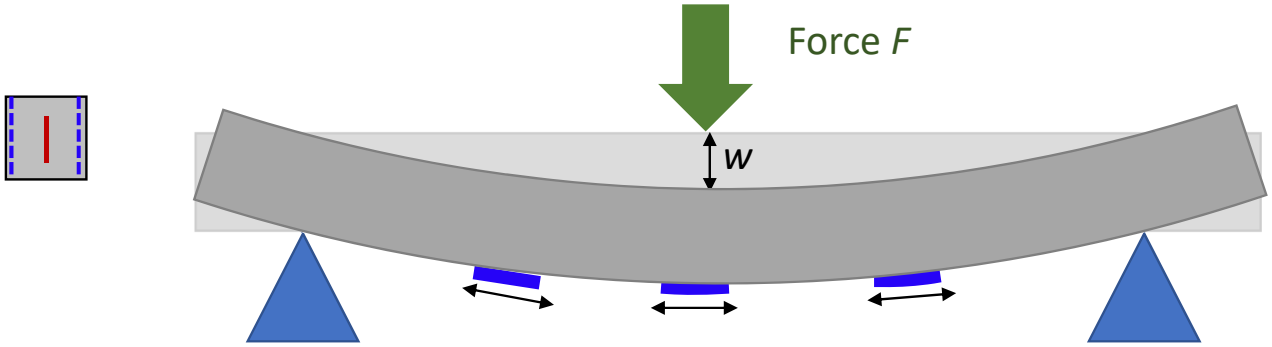
Quality Model

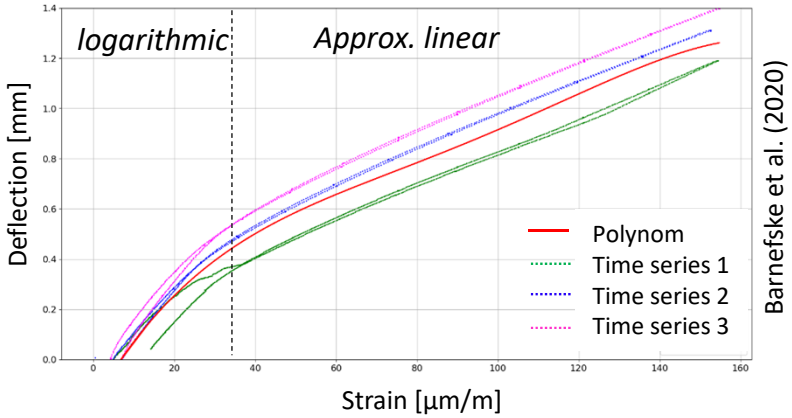


(adapted from Schwieger & Zhang, 2019)

Monitoring

Ensuring correctness (and accuracy): Calibration (Barnefske et al. 2020)

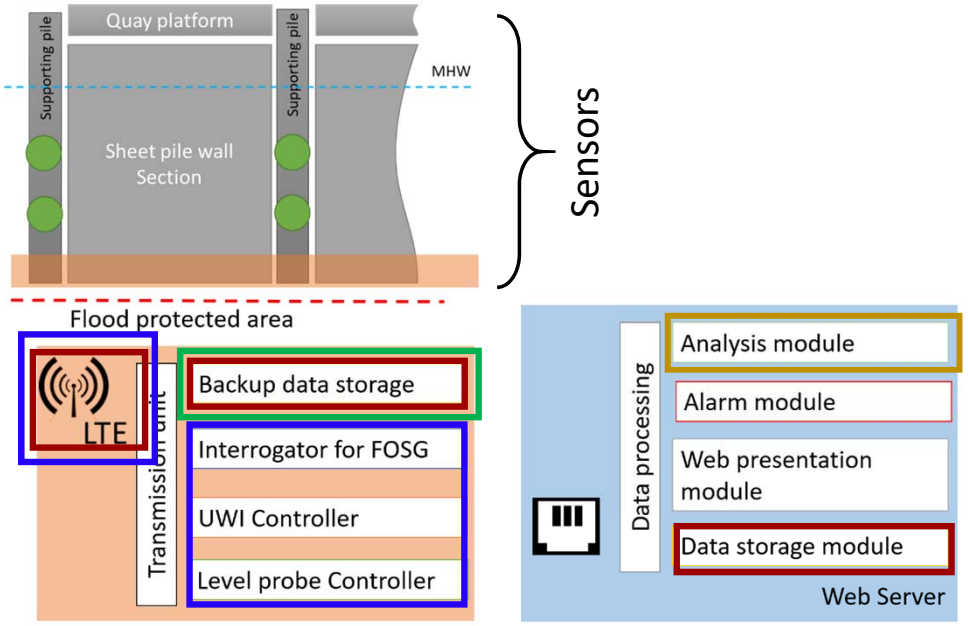




Mathematical model and empirical methods
→ references for deflection *w(F)* and longitudinal strain

➔ Calibration function
Standard deviation = 0.17 mm

Monitoring system: Realization



Availability
→ failure rate (data)

Up-to-Dateness
→ real-time capability
→ const. Time intervall

Completeness
→ rate of omissions

Efficiency
→ installation effort
→ costs

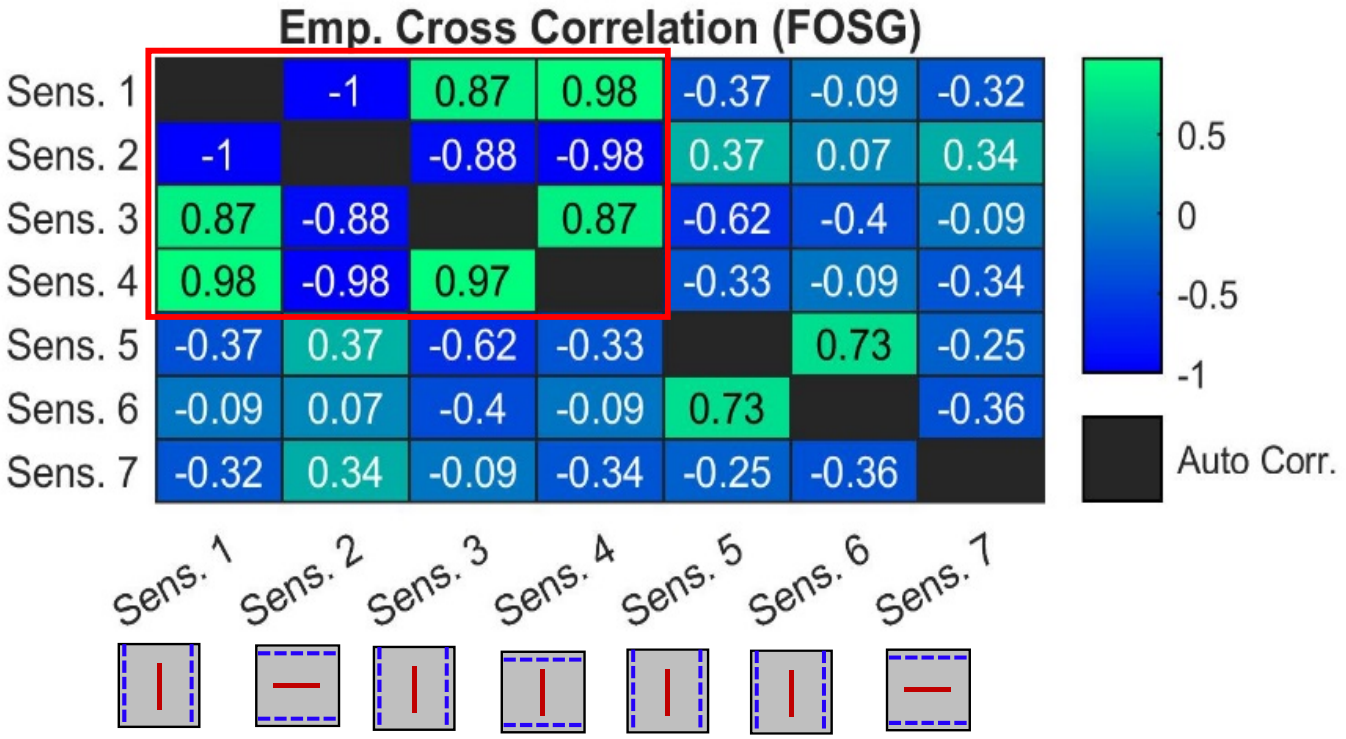
Reliability
→ susceptibility to failure
→ Detection of errors (data)
→ Data consistency

Monitoring system

Reliability (Data consistency): Empirical **verification** of the FOS-based approach

Assumption: (Spatial) correlation between neighboring sensors

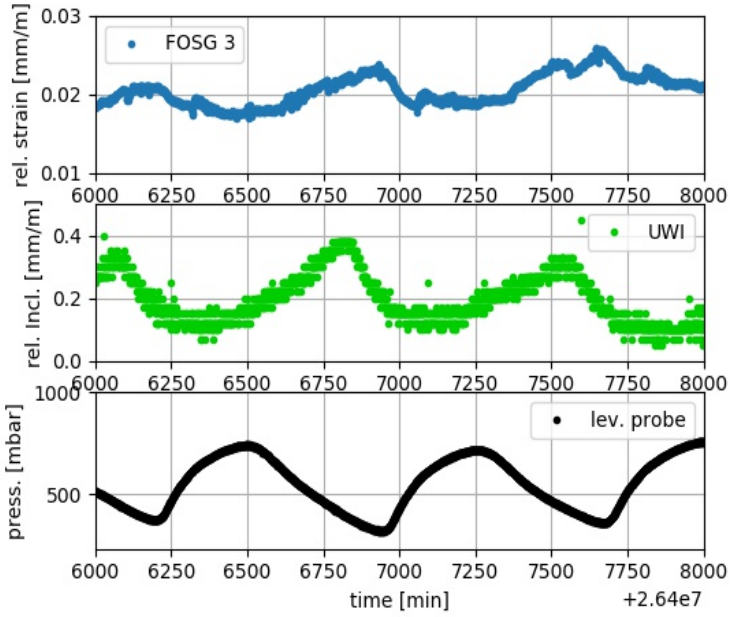
→ Investigation of different mounting types



Monitoring system

Reliability (Data consistency):

- Cross-correlation (FOS ↔ UWI)
- Investigation of the tidal influence
  → Dominating frequency (cycle time):
  $2.263 \cdot 10^{-5}$ Hz
  (12 h 16 min)



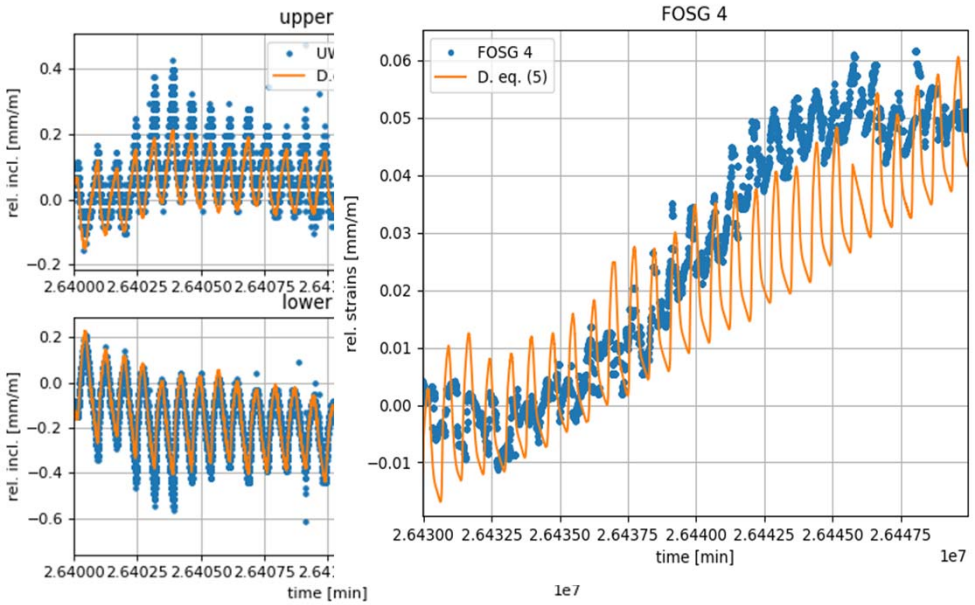
	$\widehat{C}_{UWI,FOSG}(0)$
FOSG 1	-0.83
FOSG 2	0,77*
FOSG 3	-0.82
FOSG 4	-0.80
FOSG 5	-0.42
FOSG 6	-0.12
FOSG 7	-0.00

Analysis

Analysis of (long-term) quay wall deformation
→ reduction of short-term effects

Modelling of deformations dependent to
- temperature (T)
- tide gauge (water pressure *p*):

→ Polynominal approach



$$f\left(T, \dot{T}, p, \dot{p}\right) = a_{04} + a_{14} \cdot t_k + b_{14} \cdot T(t_k) + b_{24} \cdot \dot{T}(t_k) + c_{14} \cdot p(t_k) + c_{24} \cdot \dot{p}(t_k)$$

Process Quality

→ installation of the geosenor network on the quay wall

Charact.	Parameter	Process	FOS	UWI	Extens.
Availability	Failure Rate	o	-	+	++
Complet.	Rate of omssions	+	+	+	+
Up-to-Dateness	Real-time capability	++	++	++	++
	Constant time intervals		++	++	++
Correct.	Match with true state		o	o	+
Reliability	susceptibility to failure	+	+	+	++
	Detection of error	+			
	Data consistency		+	+	(+)
Accuracy	Standard deviation		+	+	+
Efficiency	Costs	+	+	o	o
	Installation	+	+	+	o

Grading:
(++) very good,
(+) good,
(o) medium,
(-) to be improved,
(--) not acceptable

Conclusion and Outlook

- Integration of all considered sensors in an underwater monitoring system is possible
- Previous knowledge about the deformation behavior is required
  → Determination of long-term quay wall deformations
- Installation of FOS sensors: improvements required
  ➔ protection of the fiber and adapted mounting/welding
- Lower costs for FOS ➔ higher installation density can be realized
- Potential for the use of distributed FOS (DFOS)
- Acquisition of (additional) environmental data is necessary (e.g., tide)
  → influence on the deformation behavior of the quay wall

Literature

Barnefske, E., Ohlendieck, J. & Sternberg, H. (2020). Modellierung der Deformation eines Stahlträgers durch indirekte Dehnungsmessungen. In: *Tagungsband GeoMonitoring 2020*. Gerke, M. & Riedel, B. (eds.), TU Braunschweig, pp. 93-103.

Schwieger, V. & Zhang, L. (2019). Qualität in der Ingenieurgeodäsie – Begriffe und Modellierung. In: DVW e. V. (ed.). Qualität

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Multi-sensor system: Integration of FOS

- Idea: change of inclination angle
  ➔ strain of the surface
- Derived observation: **strain**
- Fiber Bragg Grating (**FBG**) : Change of refraction index
  → (Total) Reflection of a certain wavelength
- Observations: Influence of temperature and strain → acquisition of temperature