From Research to Industry: Development of a High-Resolution Measurement System for Mirrored Heliostats in Series Production

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CONCENTRATING SOLAR POWER SERVICES
DLR Deutsches Zentrum für Luft- und Raumfahrt
German Aerospace Center
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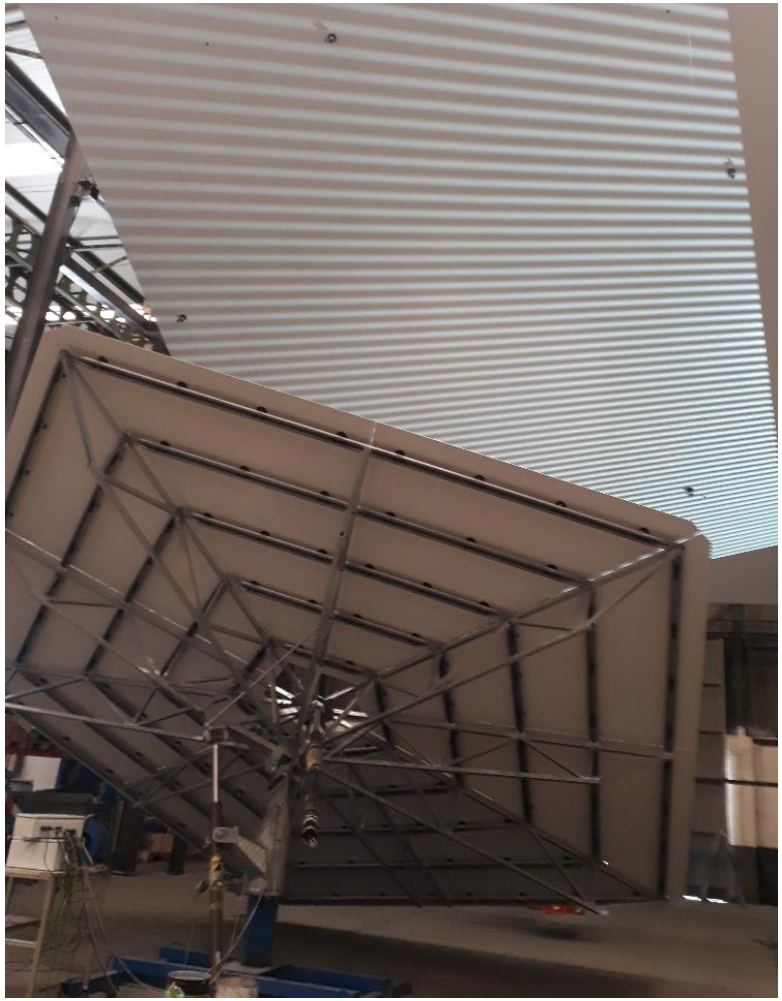
Agenda

- Introduction to Deflectometry
- Measurement System
  - Status Quo & Last Developments
  - Test Applications
  - Validation
  - Industrial Application
- Summary & Outlook



Introduction

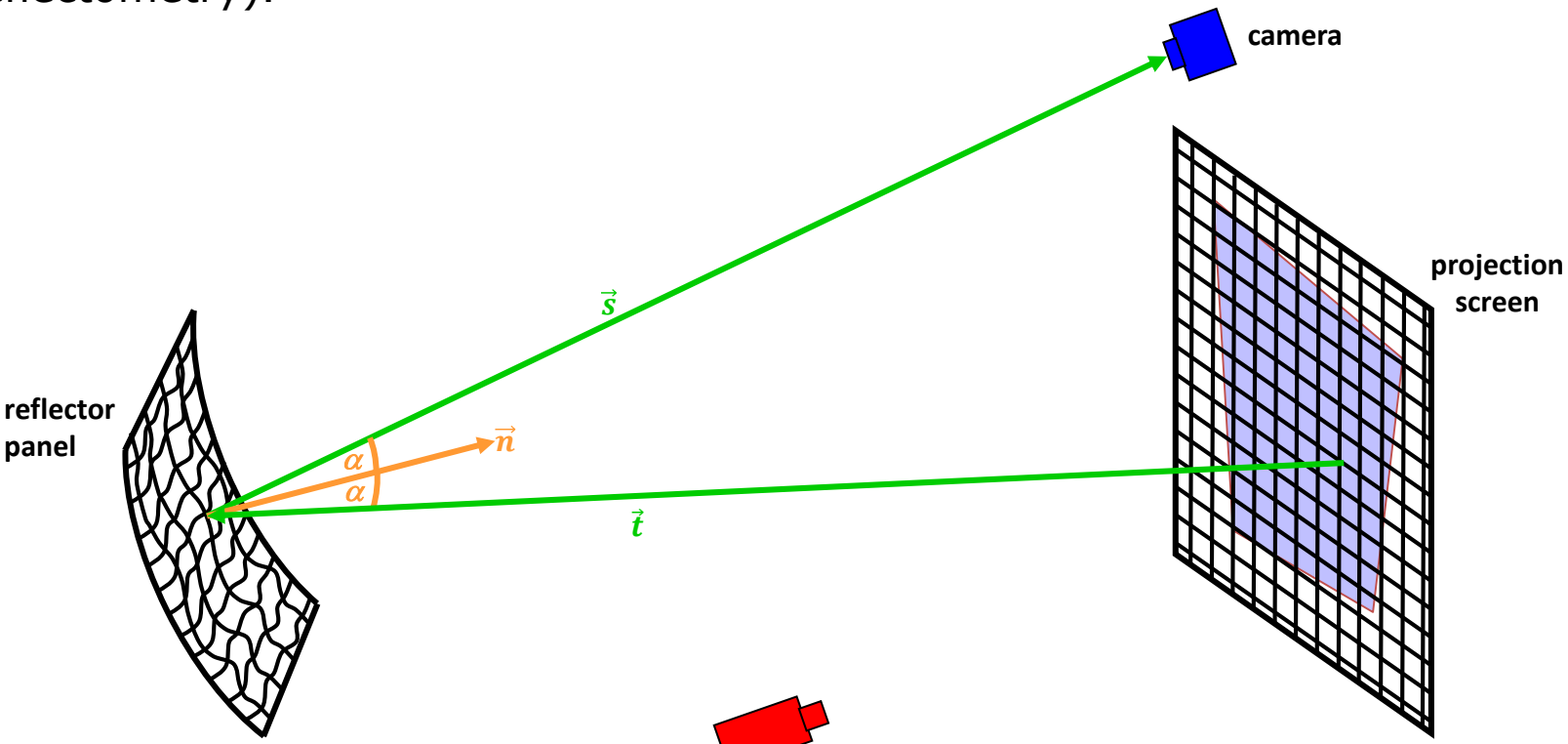
High quality in shape of concentrating solar mirror panels is crucial for good optical performance of the solar field.

Quality check methods	Resolution	Accuracy	Meas. time	Requirements	Contact/-less
Deflectometry (a.k.a. fringe reflection technique)	high	high	short	accurate positioning	contactless
Photogrammetry (PG)	medium	high	medium	target stickers	contactless
Laser reflection scanners	medium	low	short	diffuse paint	contactless
Coordinate measuring machines	low	high	long	movement of prism or arm	contact
Laser Radar	high	high	long		contactless

Deflectometry is especially suited for this task as it measures directly the relevant surface slopes and combines **short measurement time, high accuracy and high resolution**. In the last years it therefore became more and more a standard and is widely used in industrial quality control and R&D laboratories.

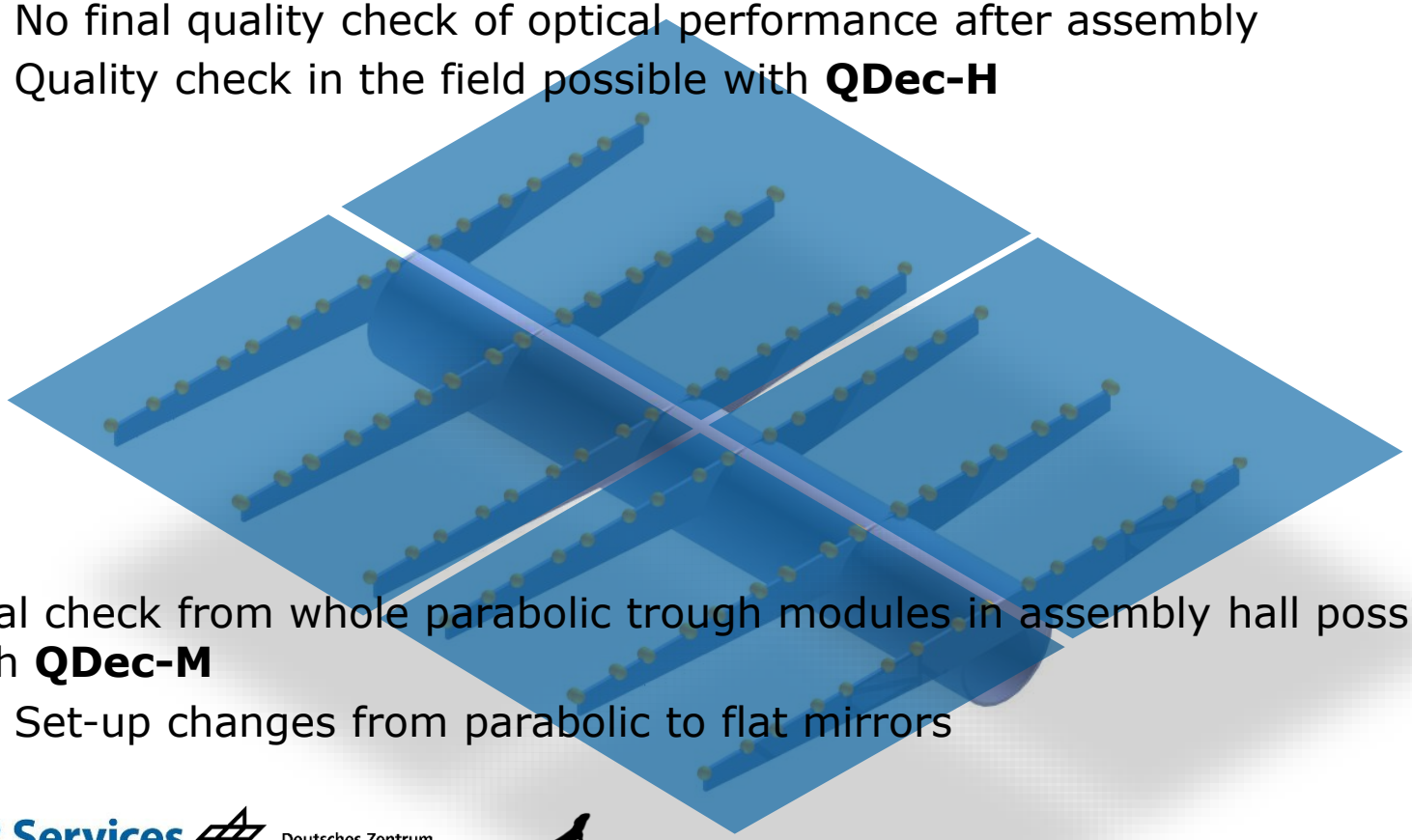
Measurement principle

QDec provides high resolution and high precision measurements of the shape deviations of curved or flat reflector panels for a **wide range of geometries**. It uses a non-contact optical measurement and digital image processing technique based on the deflectometric measurement principle (Deflectometry).



Status Quo & Last Developments

- Status Quo
  - Structure and Mirror are measured separately, then assembled
  - No final quality check of optical performance after assembly
  - Quality check in the field possible with **QDec-H**

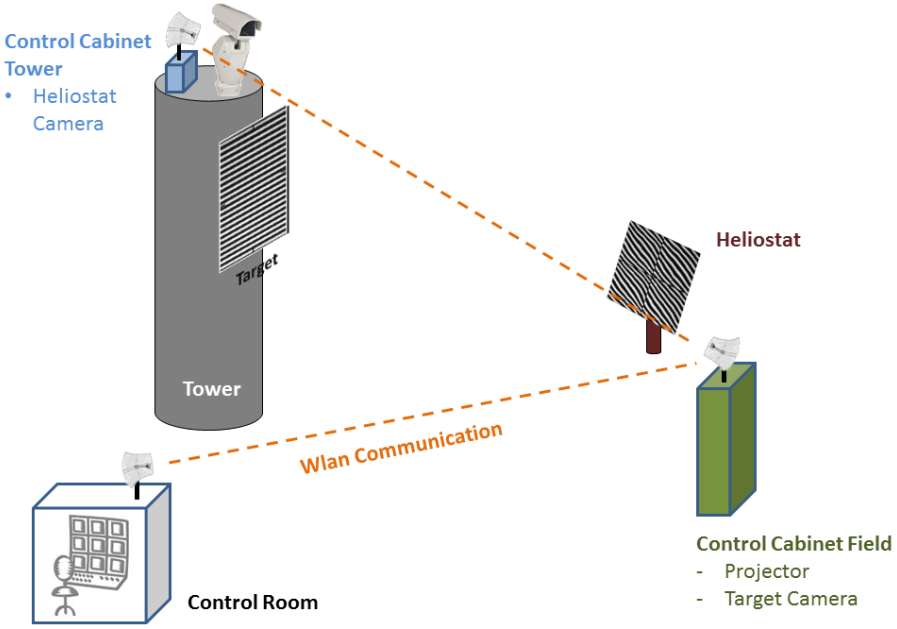


- Final check from whole parabolic trough modules in assembly hall possible with **QDec-M**
  - Set-up changes from parabolic to flat mirrors

QDec-H (heliostats)

Automatic deflectometric measurement of heliostats

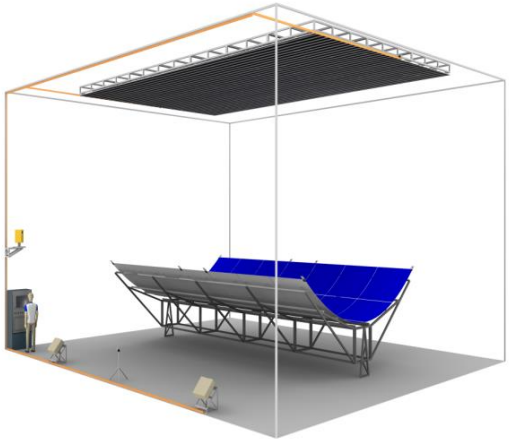
- Works only in darkness (during night)
- 1 camera with long distance to heliostat = high accuracy
- Total measurement time: ~ 2 minutes per heliostat

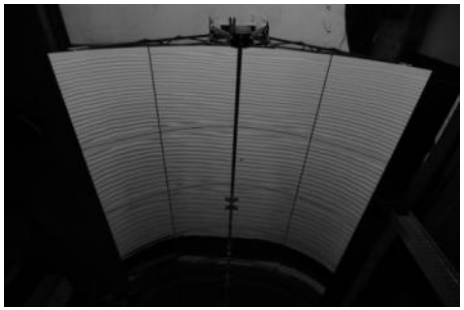


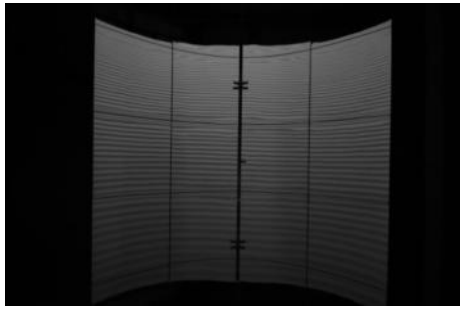
QDec-M (concentrator modules)

Automatic deflectometric measurement of parabolic trough modules at the end of the assembly line

- Multiple camera and projector measurement
- Joining of results in uncritical uncurved direction
- Automatic determination of module position with remote controlled total station with each measurement
- Total measurement time: ~ 7 minutes







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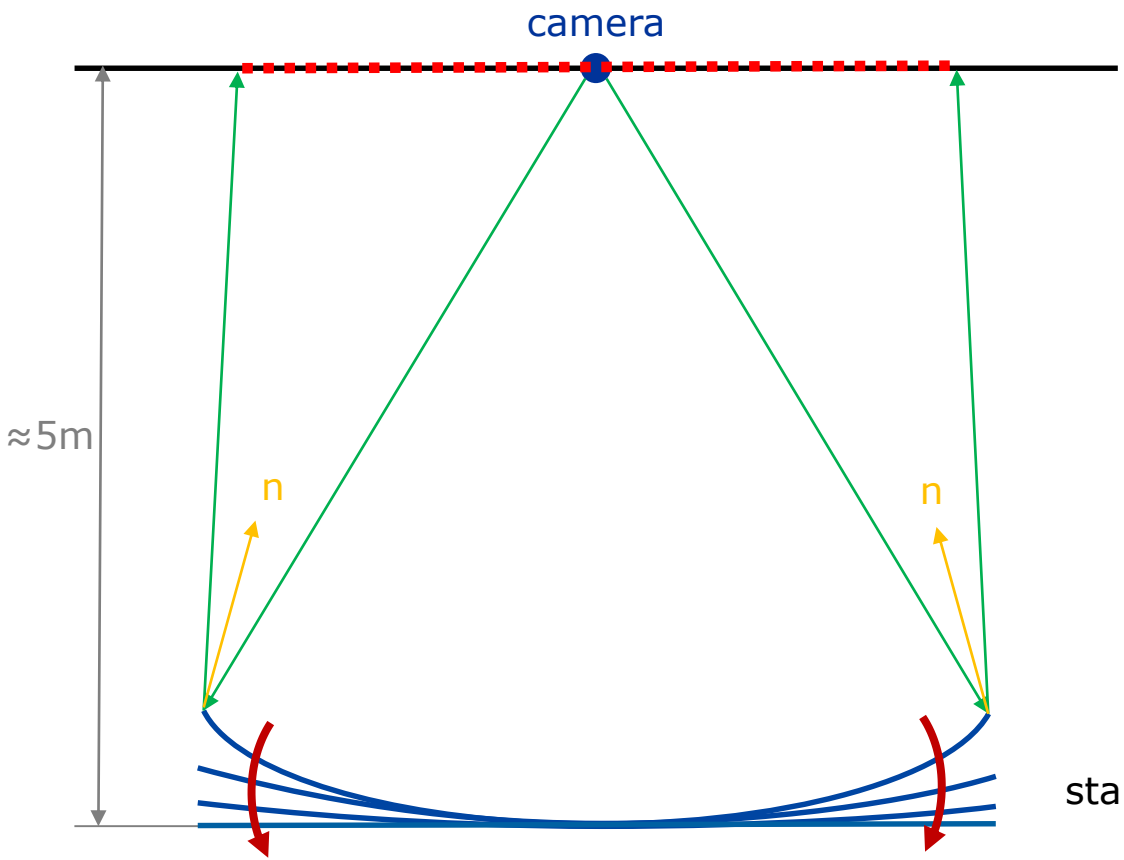
Development - Parabolic to Flat

Simplified ray paths for parabolic trough geometry:



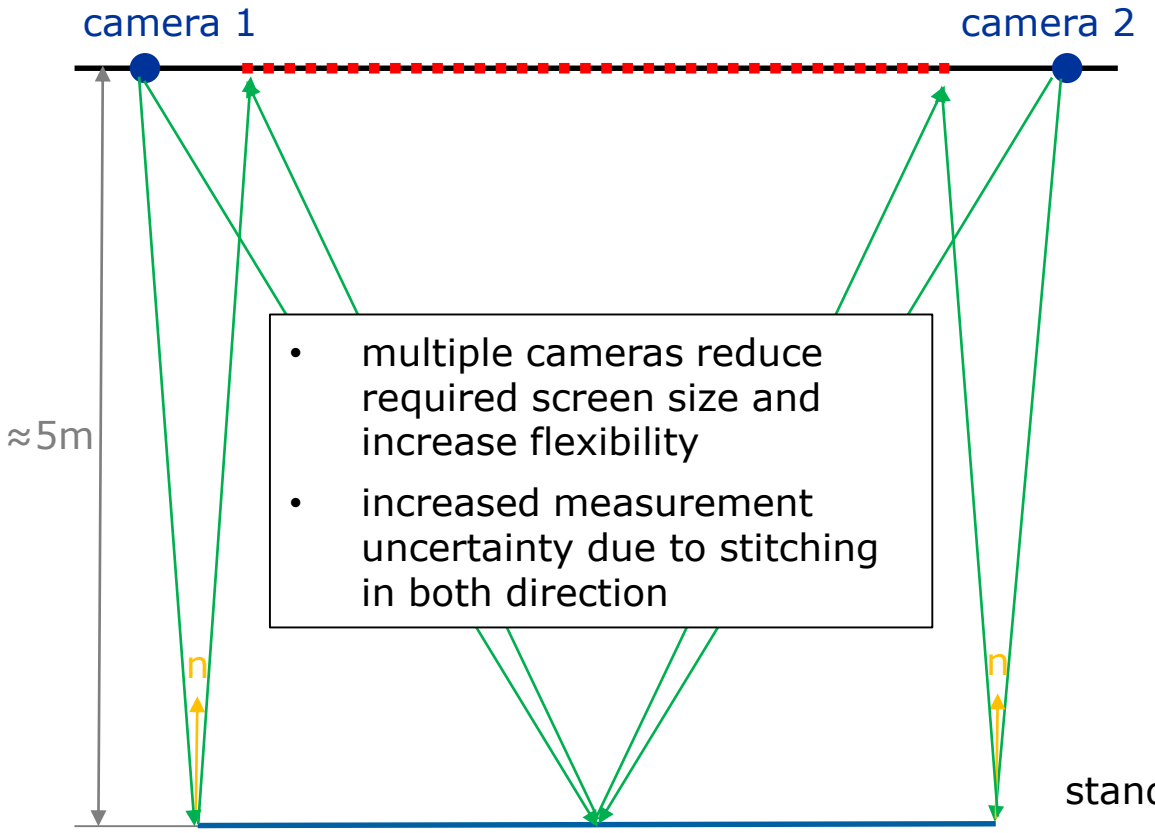
screen plane

(red: minimum screen size)

standard trough

Development - Parabolic to Flat

Simplified ray paths for heliostat geometry:

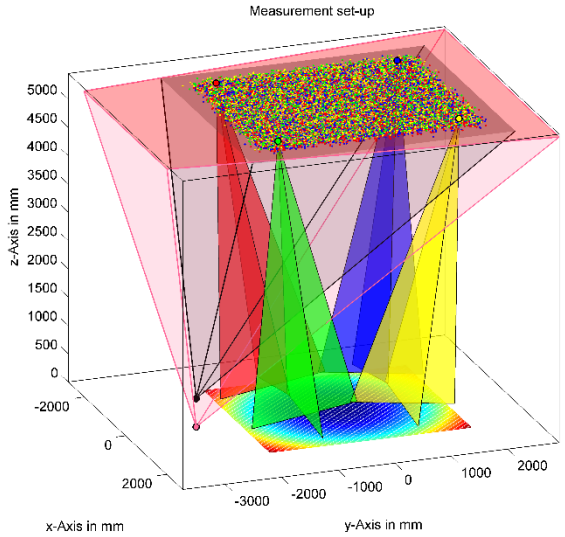


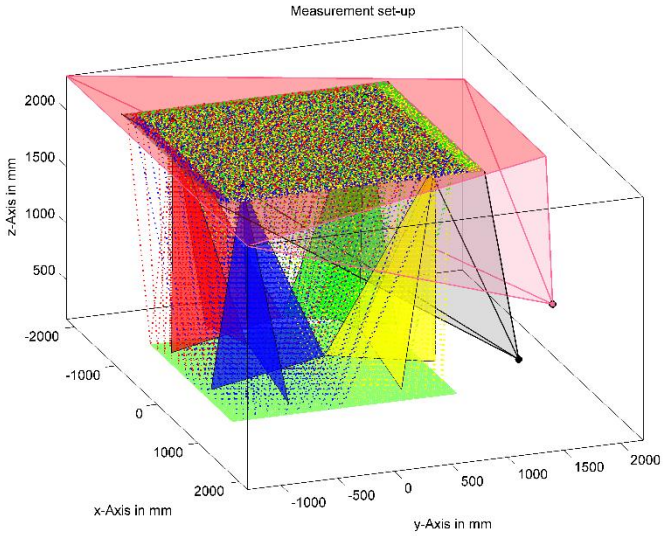
Test Applications

R&D projects „HelFer" and „TERRA"

	HelFer	TERRA
Heliostat size	3 m x 4 m	2 m x 2 m
Screen height	5 m	2.2 m
Calibration	Total Station + PG	PG

4 Cameras inserted in the screen
Optics calculated for an overlapping of pictures about 10%





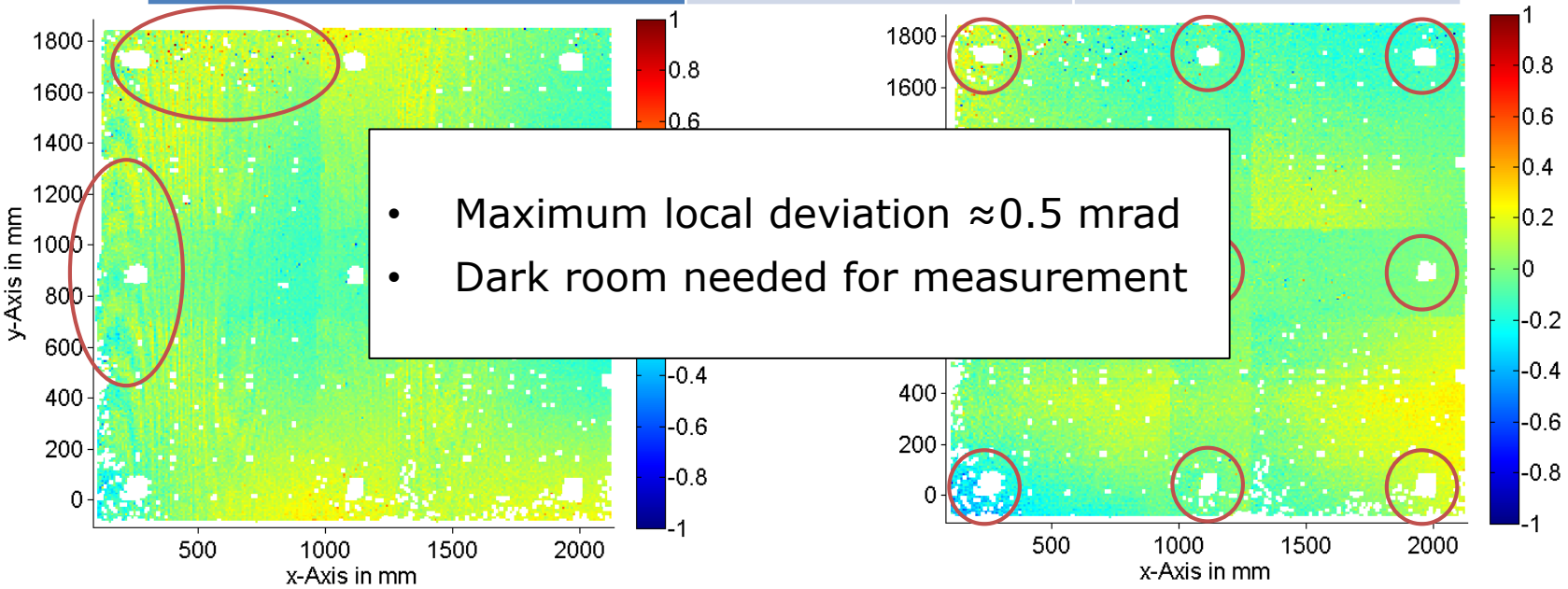
Validation
Water surface

- Water surface is used as a perfectly plane reference object
- Size equals heliostat surface
- Results can be used as calibration correction per camera
- The measured local slope deviations have an **RMS value of <0.2 mrad** and are well within the expected local uncertainties

Validation

Water surface

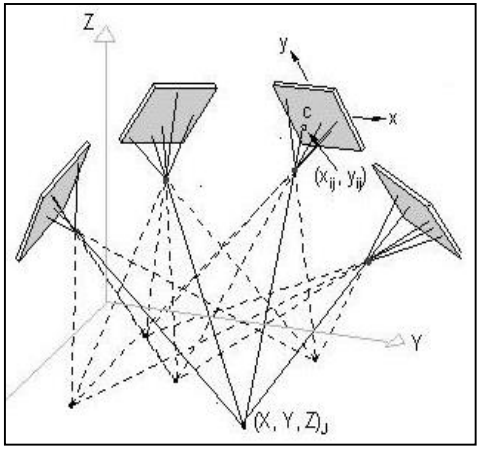
	HelFer	TERRA
Heliostat size	3 m x 4 m	2 m x 2 m
Screen height	5 m	2.2 m
Calibration	Total Station + PG	PG
SDx Watersurface (RMS)	0.12	0.12
SDy Watersurface (RMS)	0.16	0.11



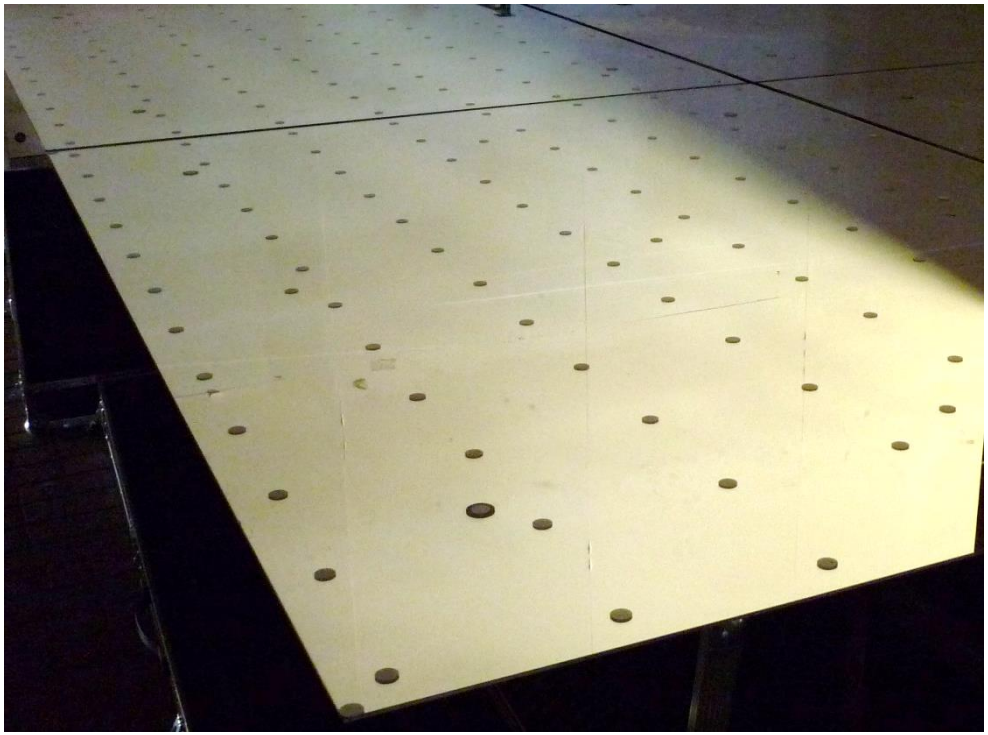
- Maximum local deviation ≈0.5 mrad
- Dark room needed for measurement

Comparison to Photogrammetry

Measurement principle



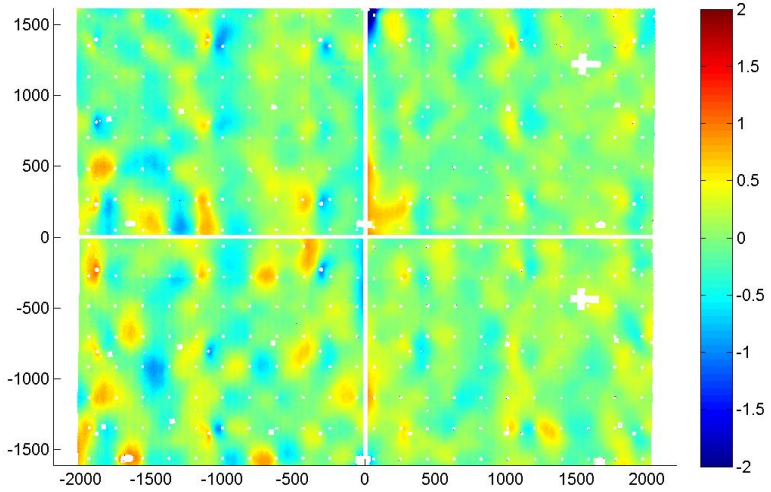
Measurement set-up

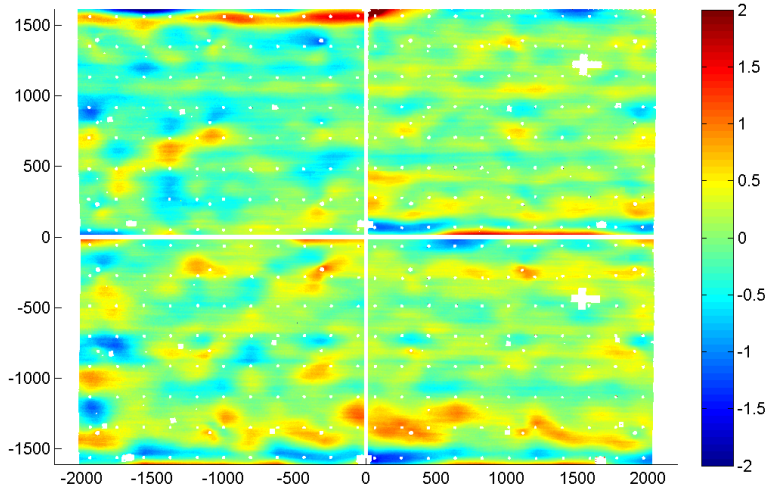


- Attachment of ~80 retro-reflective PG targets per mirror panel (270-380 for complete module)
- Camera measurement manually

Validation

Comparison to Photogrammetry





	Facet 1	Facet 2	Facet 3	Facet 4
DF-PG SDx (std):	0.31	0.21	0.28	0.24
DF-PG SDy (std):	0.36	0.33	0.37	0.31
DF-PG SDx (mean):	0.01	0.04	-0.06	-0.00
DF-PG SDy (mean):	0.05	0.10	-0.11	0.04

- No systematic error
- Low mean differences per facet
- Higher std of local differences due to the waviness of panels under resolution of PG

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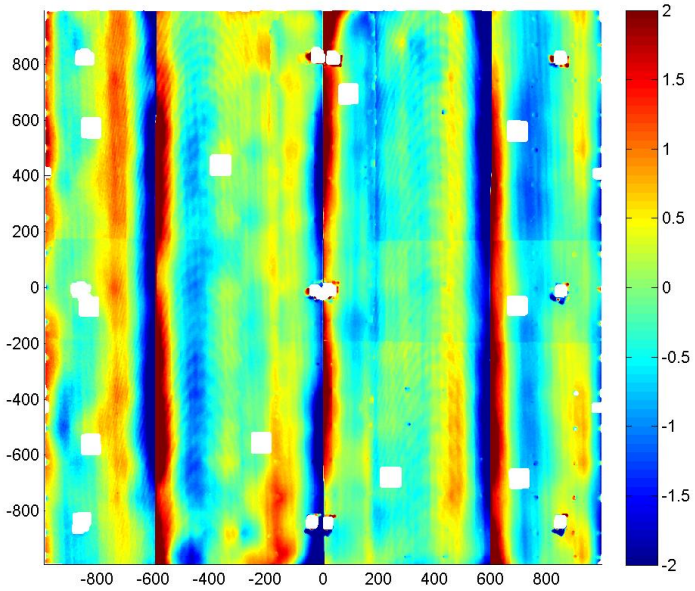
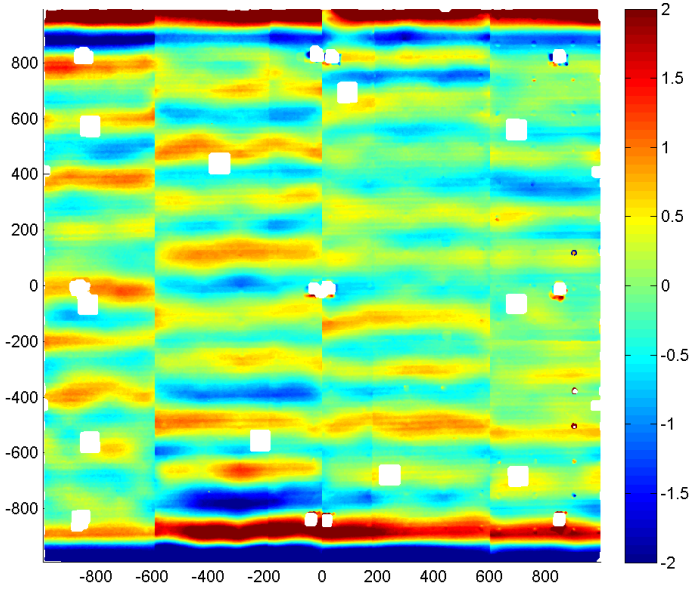
Validation

Comparison to Photogrammetry





	Facet 1	Facet 2	Facet 3	Facet 4
DF-PG SDx (std):	0.84	0.81	0.80	0.77
DF-PG SDy (std):	0.93	1.09	0.87	0.82
DF-PG SDx (mean):	-0.03	-0.05	-0.13	-0.01
DF-PG SDy (mean):	0.11	0.02	0.03	0.03

- No systematic error
- High local differences due to high waviness of panels below resolution of PG
- borders were not included in photogrammetric measurement grid

Repeatability Study

To check measurement repeatability the same module was measured over the period of a day to see influence of temperature (Δ 5.5°C) especially on structure expansion.

12 independent measurements were compared for local differences

- Very low std (0.03 mrad) and mean (0.1 mrad) values indicate **high repeatability**

Illumination Study

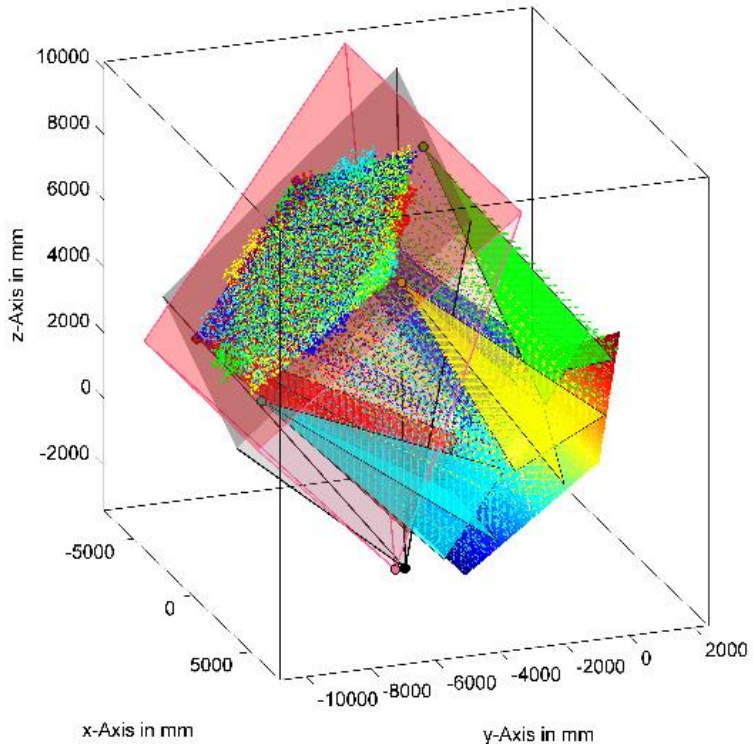
Combination of dust loads and external lighting conditions can lead to failures in stripe detection and evaluation.

- High dust loads (just 30% reflectivity) are acceptable if dark room is used
- With constant ambient light (~100 lux), medium dust load (50 % reflec.) is acceptable
- Dynamic light reflexes on mirror and screen have to be avoided during picture taking

Industrial Application

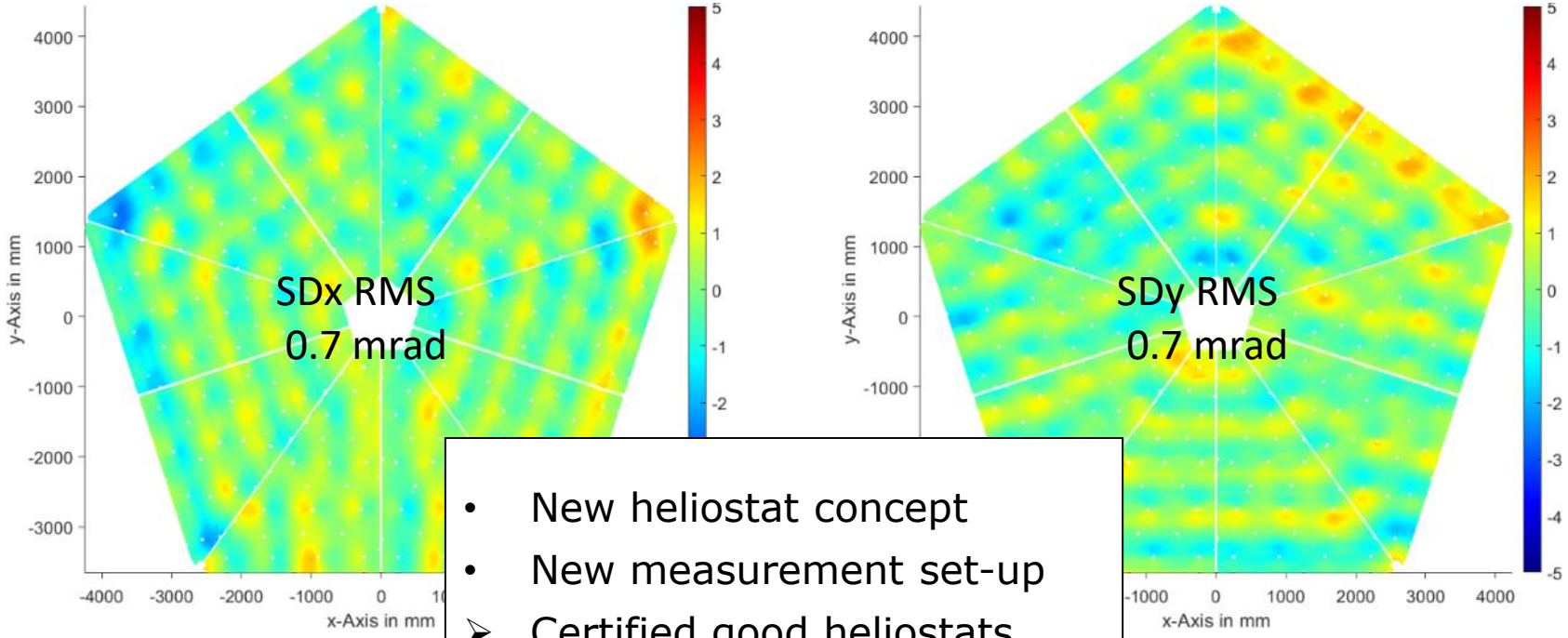
QA for Stellio Heliostat

- New concept of shaping the heliostat's mirrored surface in a jig
- Mirror panels are glued to the supporting structure
  - Higher allowance in structure tolerances
  - Final check advisable
- Pentagonal shape required 5 cameras to equalize picture taking
- Specially angled, moveable screen developed to measure in average operating angle
- Automatic determination of module position with remote-controlled laser tracker in each measurement



Industrial Application

Example result of a deflectometric measurement with QDec-M-Helio in x and y direction in mrad



- New heliostat concept
- New measurement set-up
- ➢ Certified good heliostats

Summary & Outlook

- The new developed measurement system (called "QDec-M-Helio") is able to automatically measure a complete mirrored heliostat module
- Key system features are:
  - high resolution (about 1 million points)
  - high accuracy (< 0.2 mrad globally)
  - short measurement and evaluation time (in total <5 minutes)
  - very high repeatability (< 0.1 mrad locally)
- The system was validated and uncertainties are within the expected range from:
  - local uncertainties in slope < 0.5 mrad RMS
  - global uncertainties in SDx/SDy < 0.2 mrad
- This makes the measurement system a valuable tool for:
  - final geometric quality control of heliostat modules in series production
  - continuous optimization of concentrator optical quality and prototype development
  - reduction of costs and risks by ensuring and increasing solar field performance

Thank you for your attention.

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