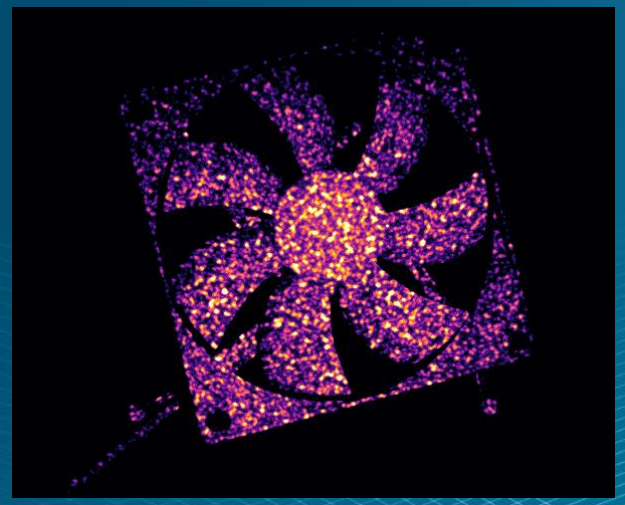

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Oldenburger 3D-Tage, 31.01.–01.02.2024

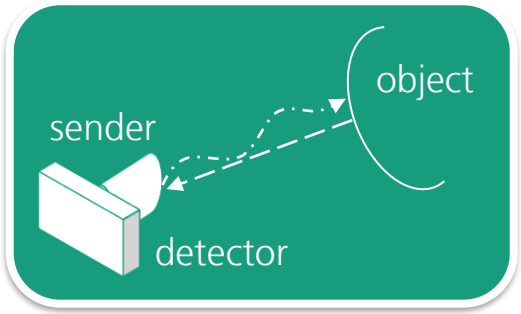
Thermal single-shot 3D shape measurement of transparent objects with projected spatial-statistical pattern

Henri Speck, Martin Landmann, Andreas Breitbarth,
Stefan Heist, Peter Kühmstedt, and Gunther Notni

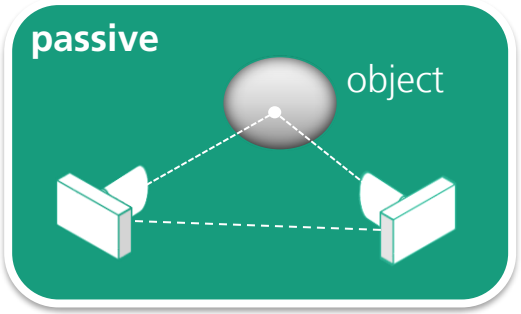
3D Measurement Techniques

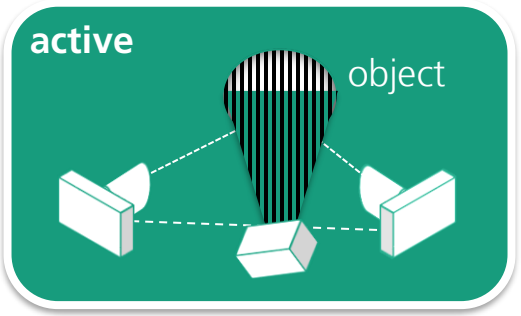
State-of-The-Art Optical Methods

time of flight



triangulation



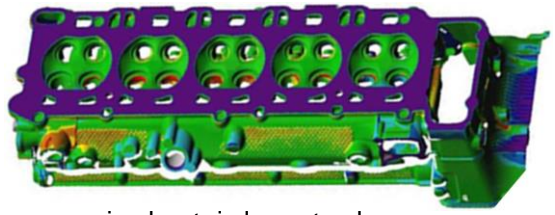


cultural heritage

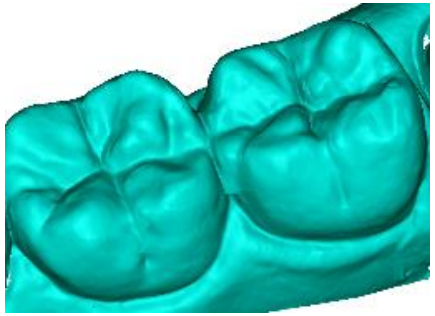
security and forensics

3D sensor network
for patient monitoring

diffuse reflection



industrial metrology



medical engineering

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Why Do We Need Thermal 3D Measurements?

3D Measurement of Transparent Objects

3D surface model

conventional VIS 3D sensor

plastic cap measurable
diffuse reflection

transparent glass *not* measurable
~~diffuse reflection~~

thermal 3D sensor

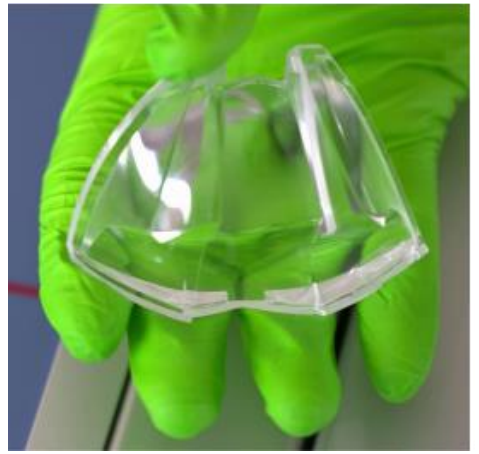
measurement time
t_{meas} = 4 s

motivation

developing a **single-shot high-speed** 3D sensor for **uncooperative** surfaces

Why Do We Need Thermal 3D Measurements?

3D Measurement of Transparent Objects



Outline

motivation

thermal 3D measurement methods

simulation results single-shot

measurement example

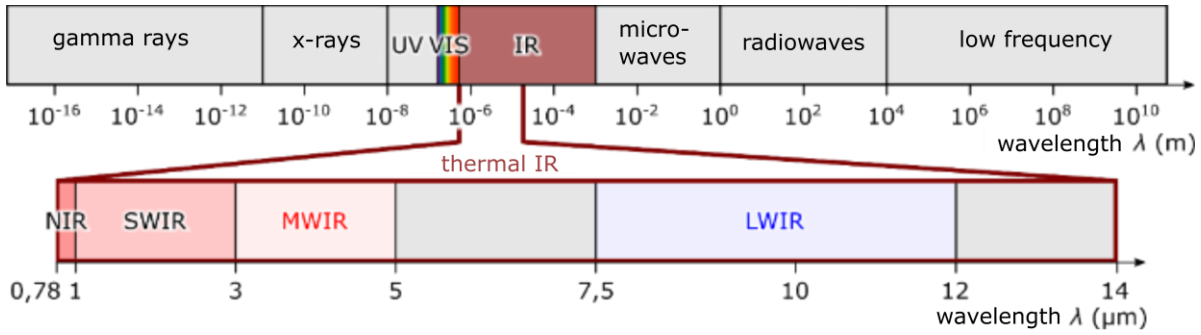
summary and outlook

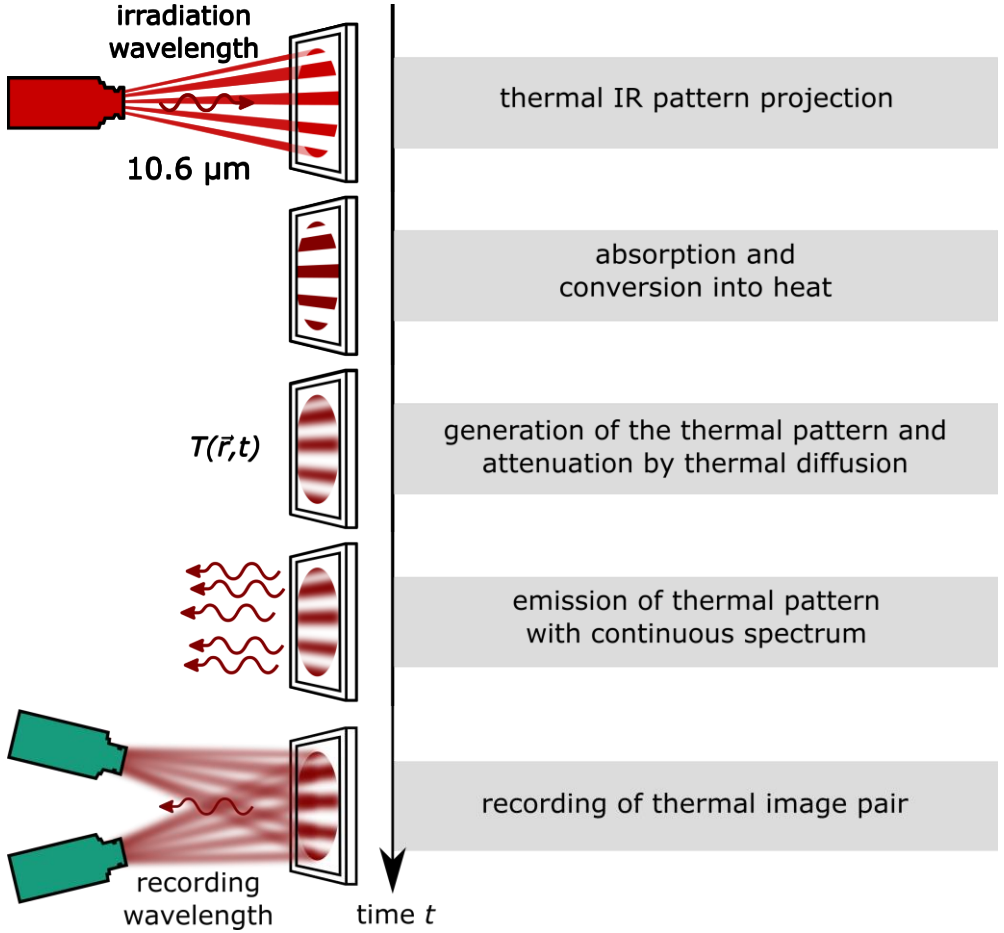
Measurement Principle: Thermal 3D Measurement

Projection and Reemission of Thermal Infrared Patterns

pattern projection in VIS (diffuse reflection)

projection and reemission **in thermal IR**





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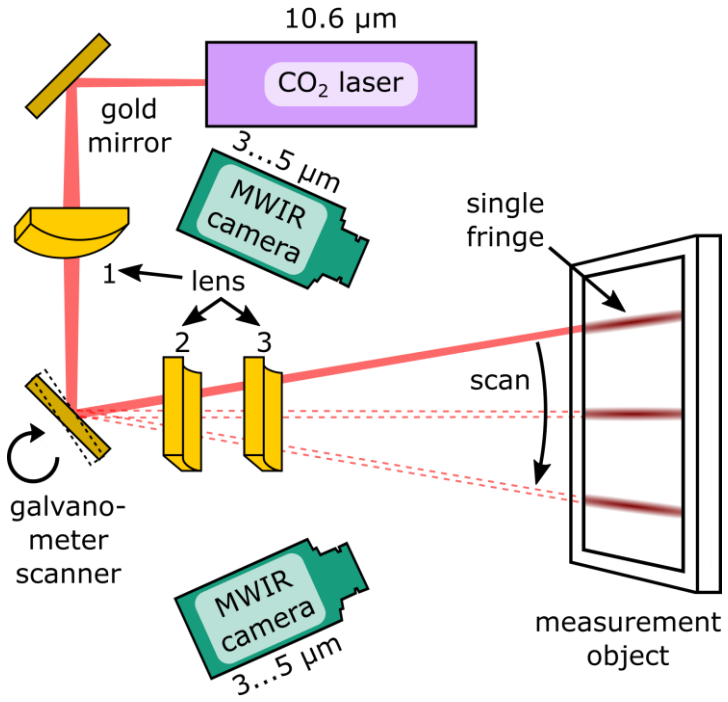
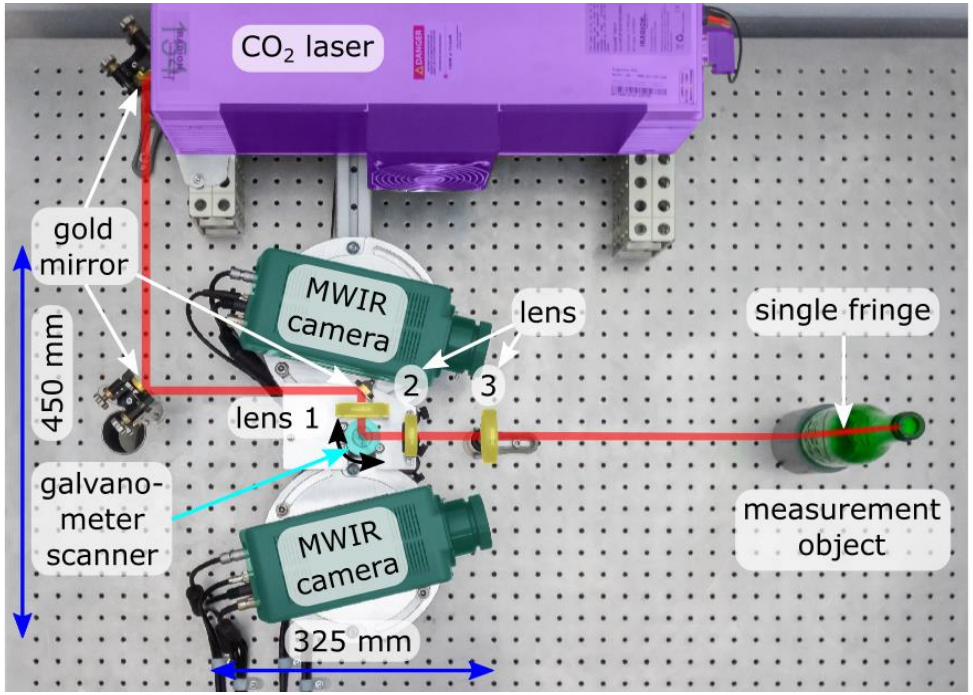
Realizations of Thermal 3D Sensors

MWIR 3D Sensor: Sequential Fringe Projection

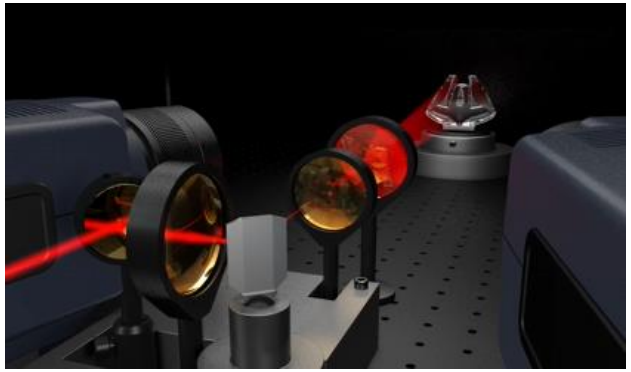
schematic sensor setup



top view of the laboratory setup



animation



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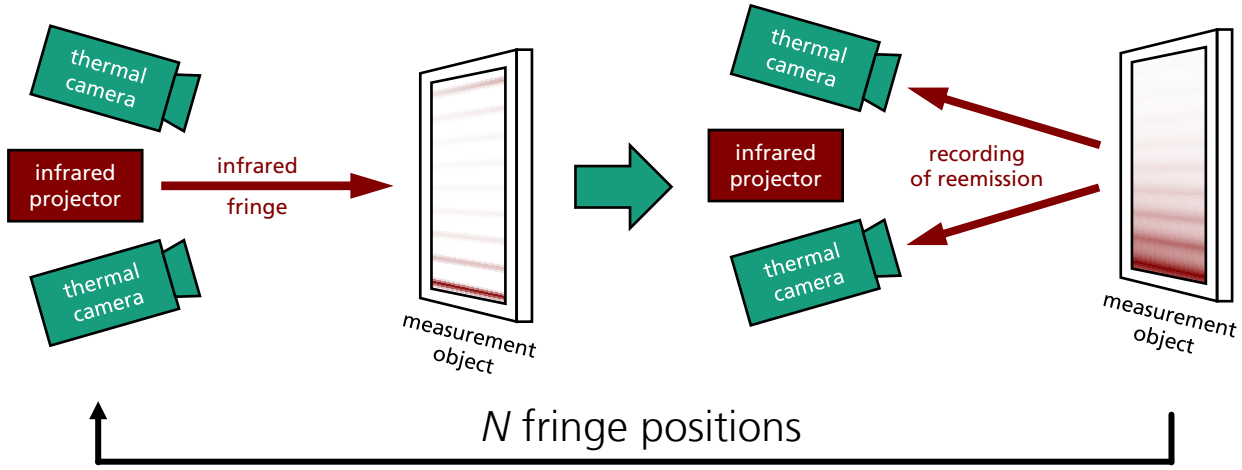
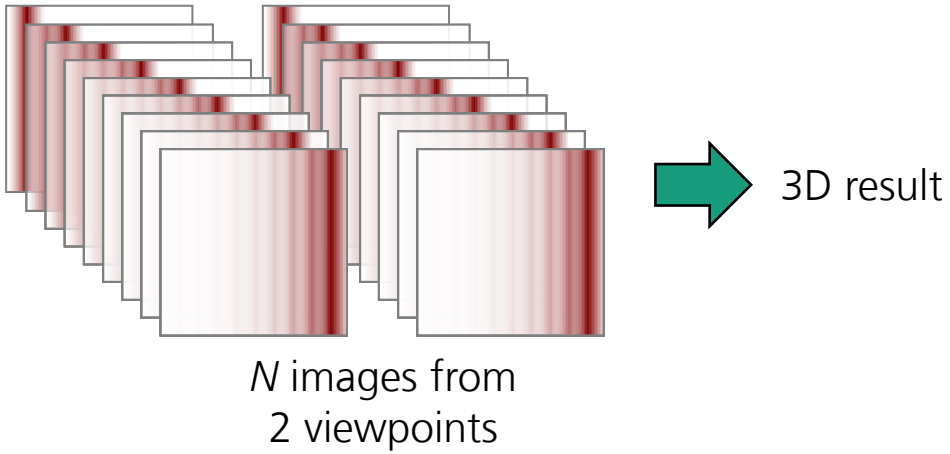
Measurement Principle: Thermal 3D Measurement

Projection and Reemission of Thermal Infrared Patterns

projection wavelength: ~~VIS~~ → thermal IR
detection wavelength: ~~VIS~~ → thermal IR

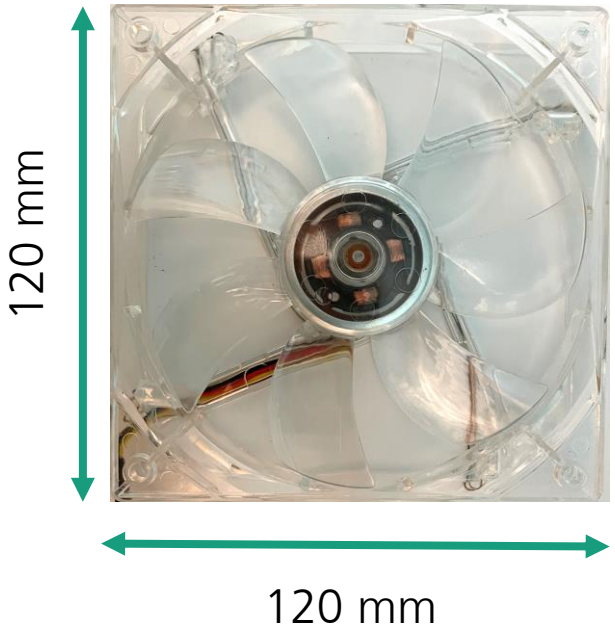




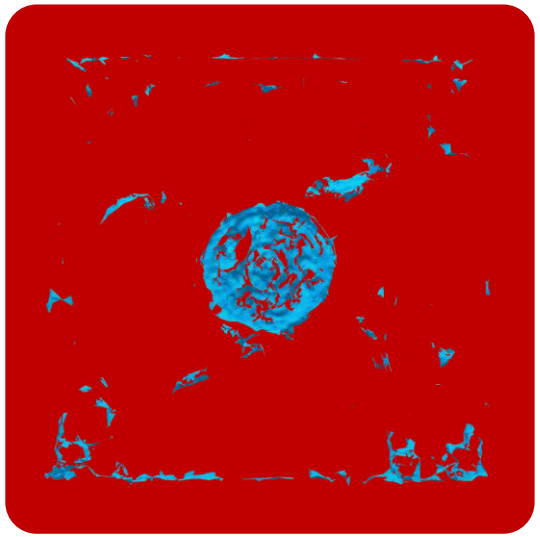
Realizations of Thermal 3D Sensors

Measurement Example: Fan (not moved)

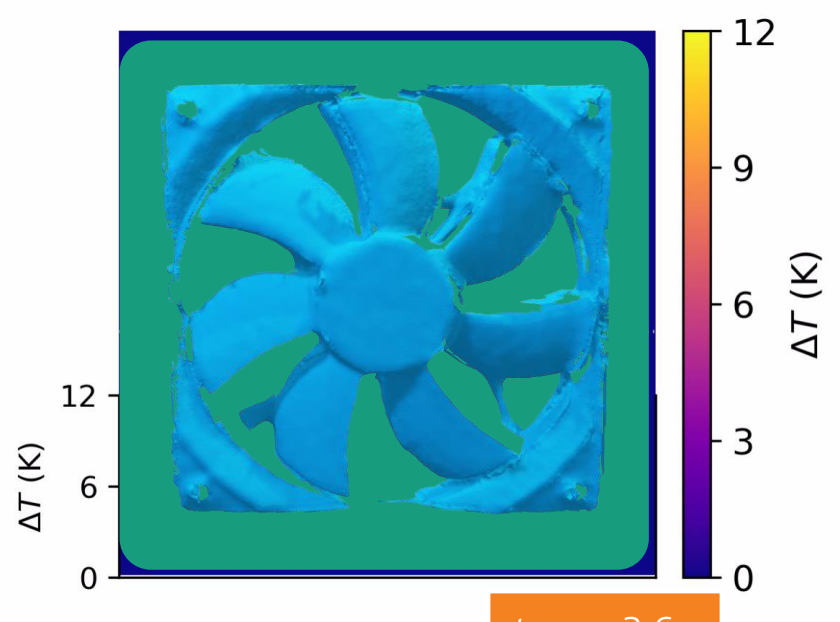
RGB-photo



conventional VIS 3D sensor



sequential IR fringe projection



t_{meas} = 3.6 s
N > 100

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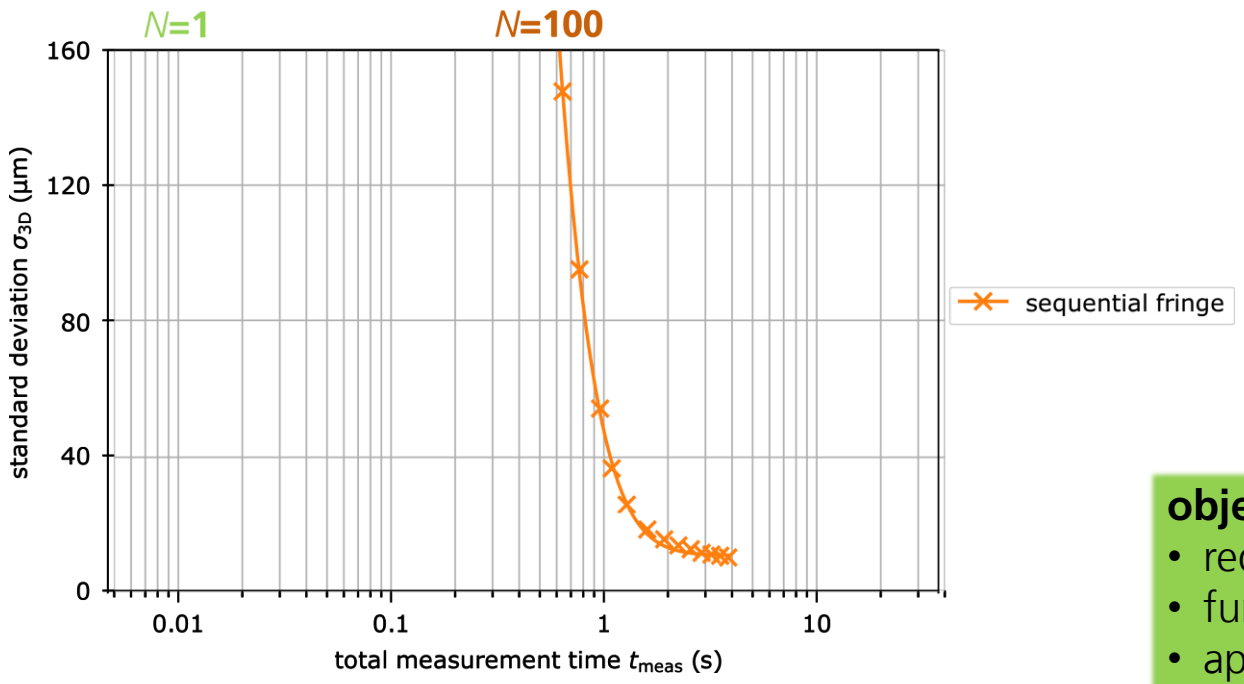
Development Progress from Sequential Fringe Protection to Single Shot

sensor performance



measurement time > 1 s

→ **too long** for in-line quality control or dynamic processes

number of images are the limiting factor

objective:

- reduction of measurement time to ~**10 ms**
- further reduction of influence of **thermal diffusion**
- application for **robot handling, in-line quality control** or **dynamic processes**

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Thermal Single-Shot Approach

Spatial-Statistical Thermal Point Pattern

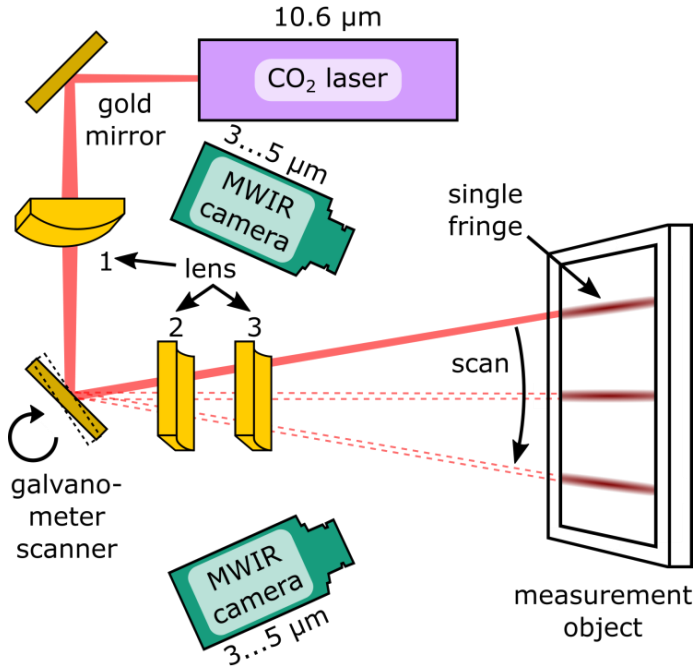
diffuse reflection in NIR

Intel RealSense
structured light sensor
850 nm

Apple Face ID
structured light sensor
940 nm

adaption

absorption and reemission in thermal IR



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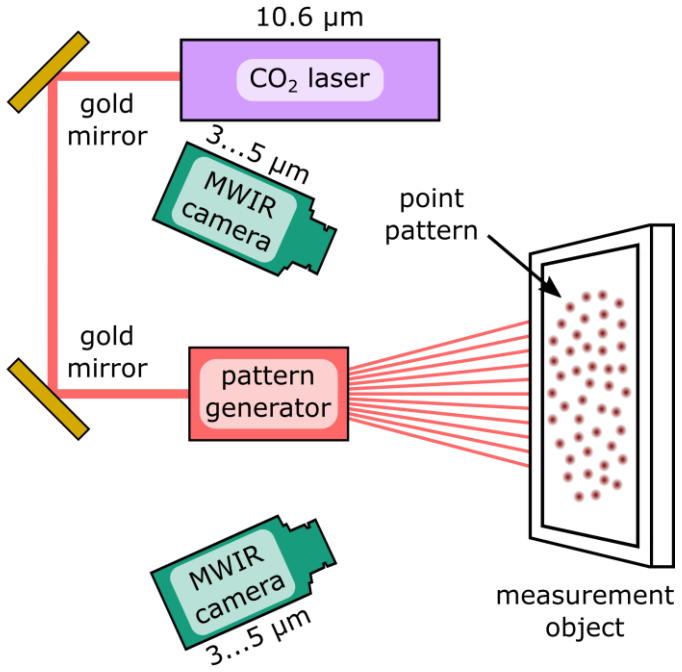

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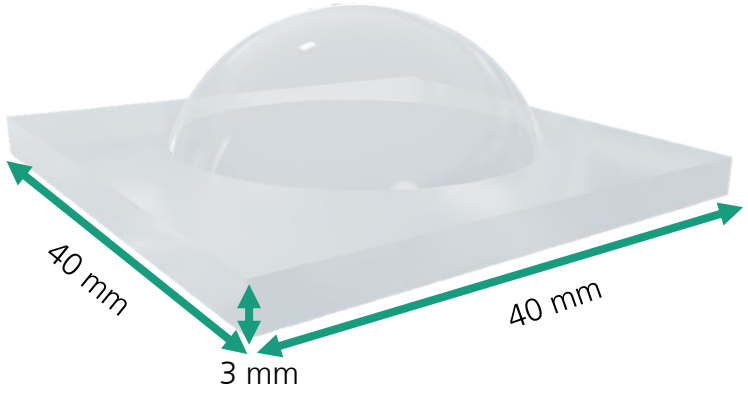
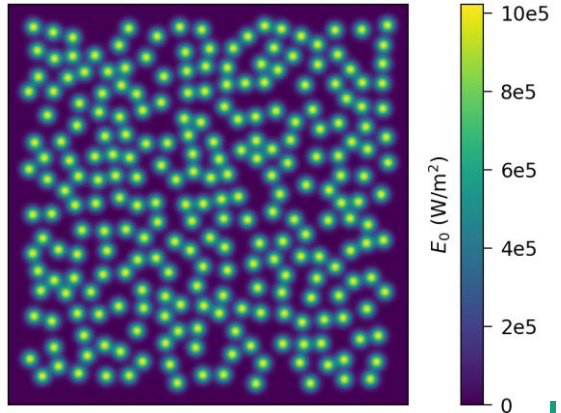
Thermal Single-Shot Approach

Simulation Workflow

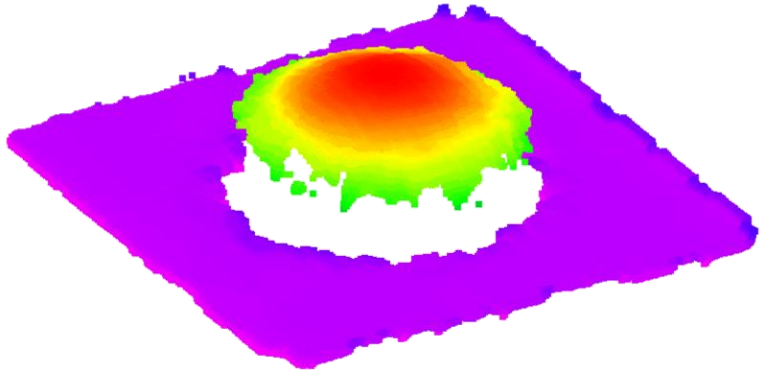
CAD model borosilicate glass



irradiance distribution

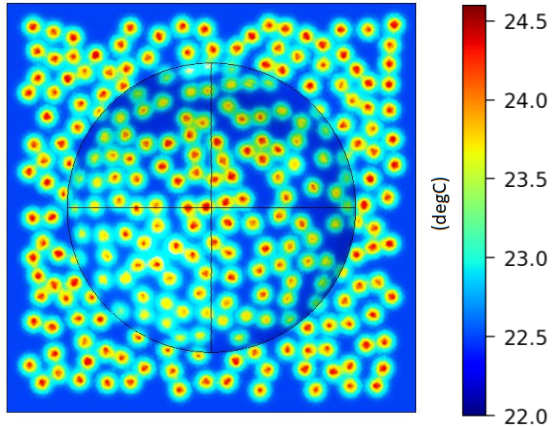


3D result

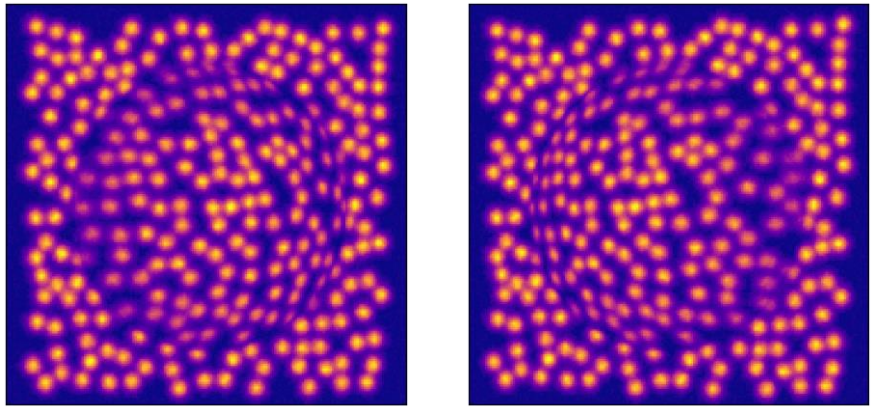


spatial cross-correlation

temperature distribution



camera pictures



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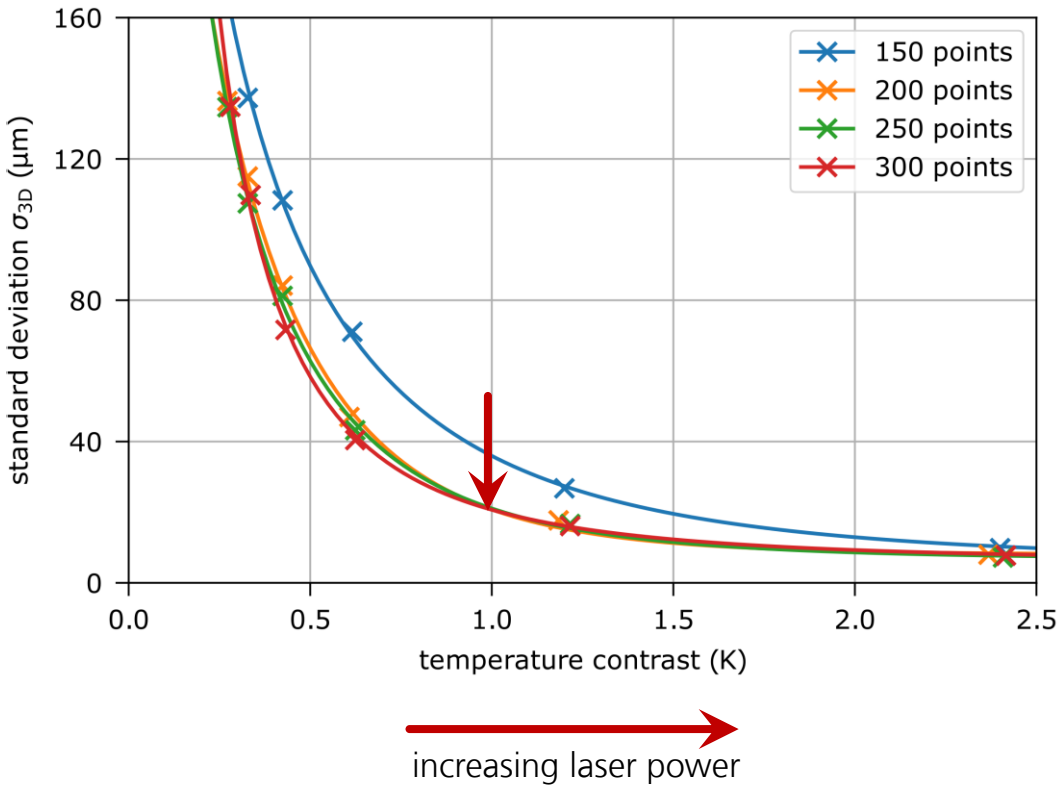
Thermal Single-Shot Approach

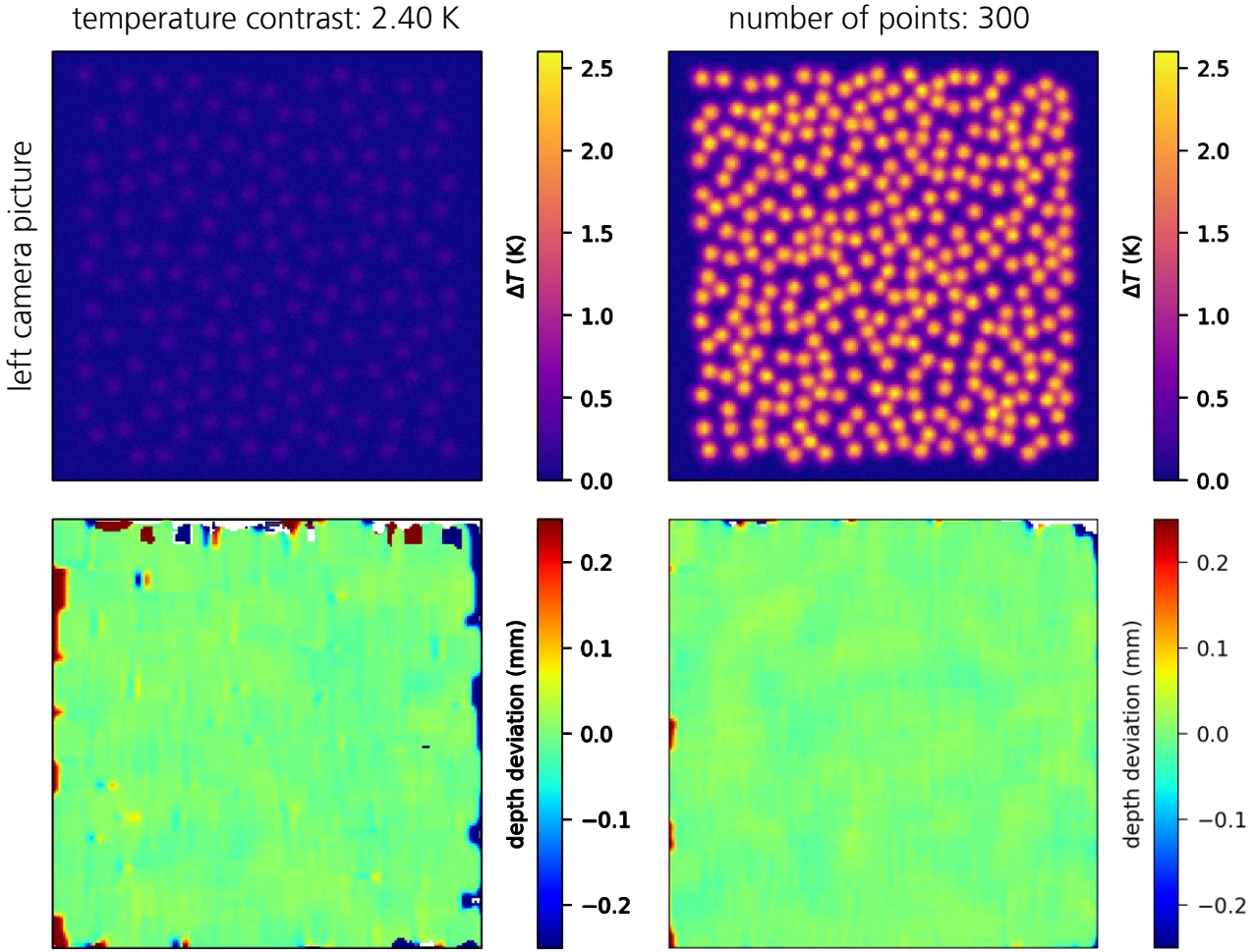
Simulation Results: Borosilicate Plane

CAD model
borosilicate plane



increasing laser power

temperature contrast: ~ 1 K
number of points: ~ 200



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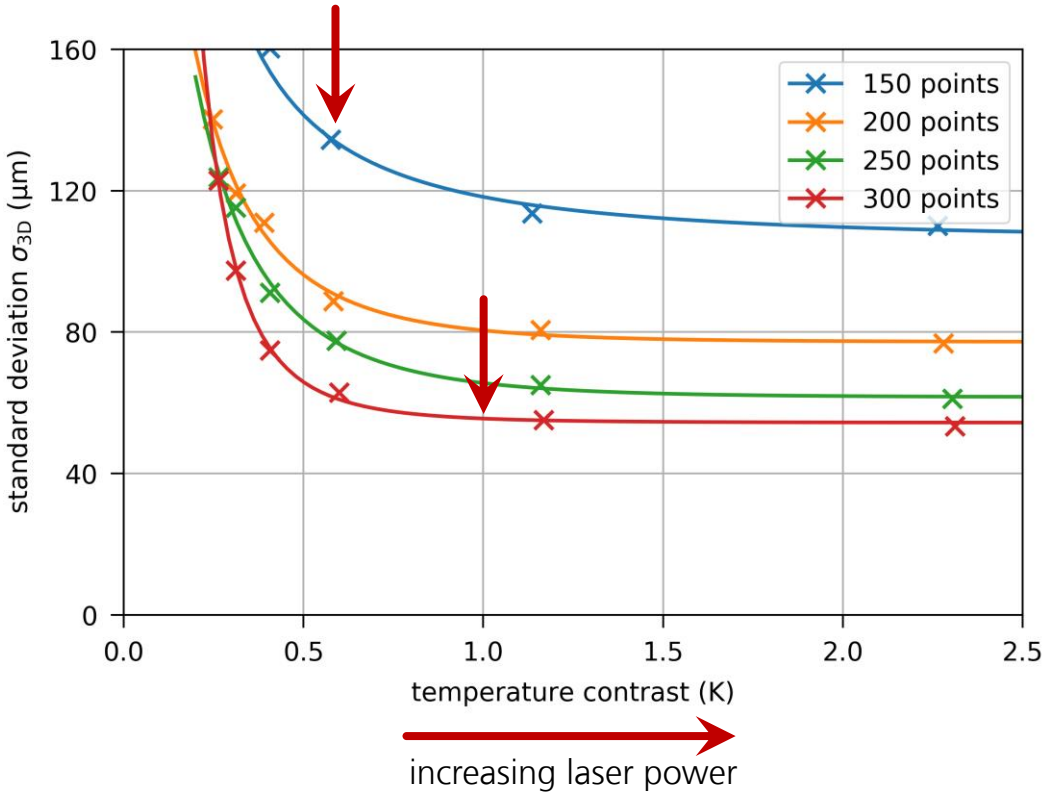
Thermal Single-Shot Approach

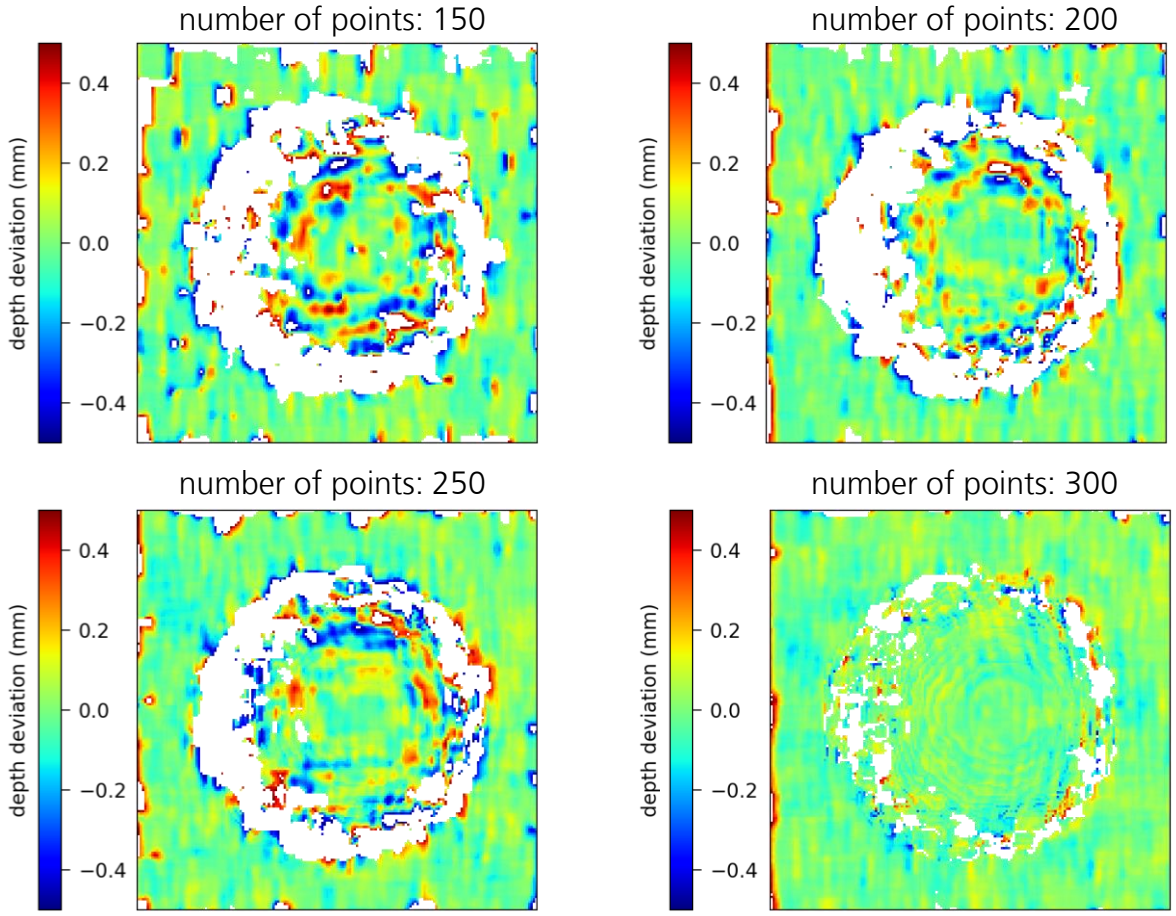
Simulation Results: Sphere



temperature contrast: ~ 1 K
number of points: ~ 300

reference

CAD model
borosilicate sphere



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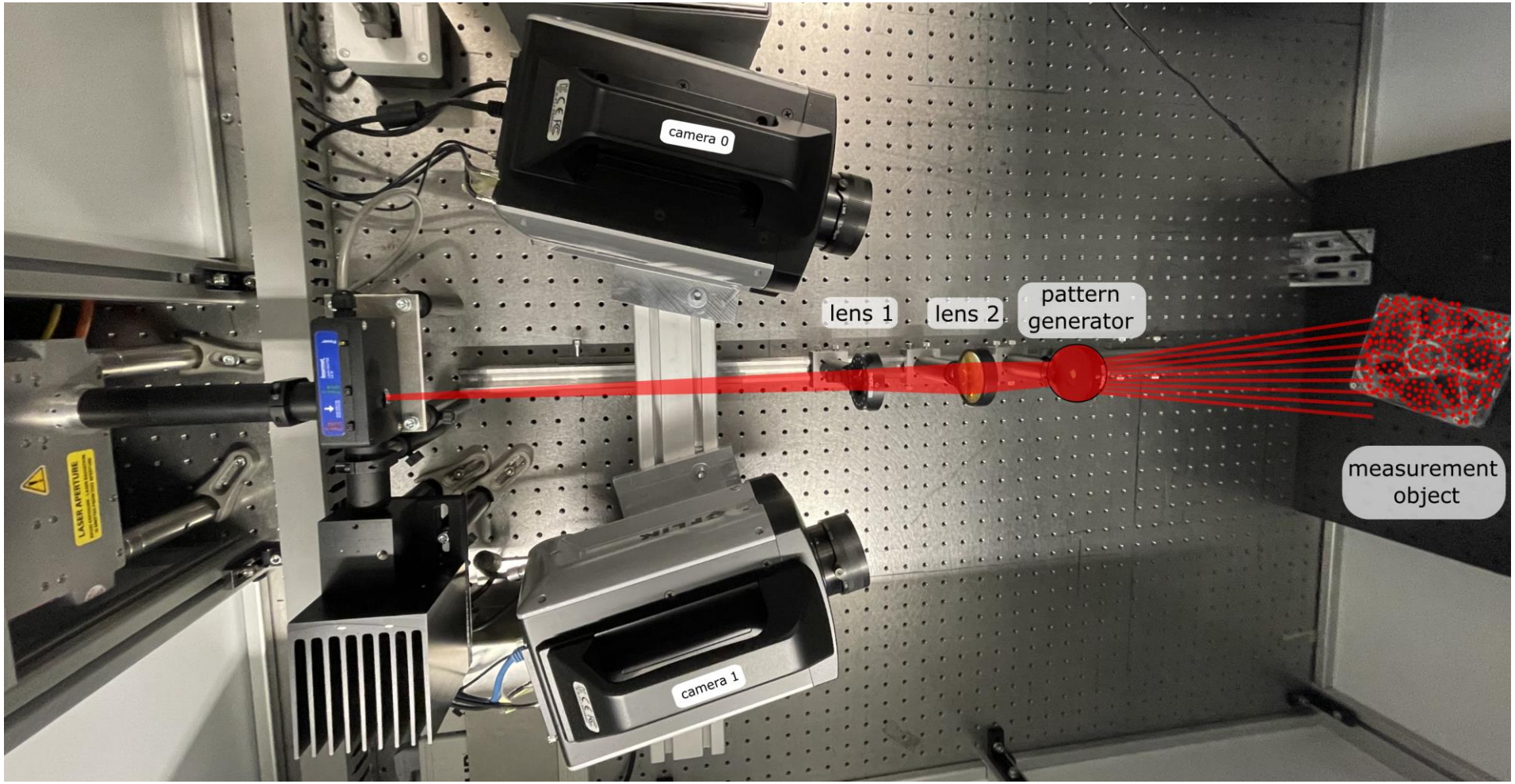
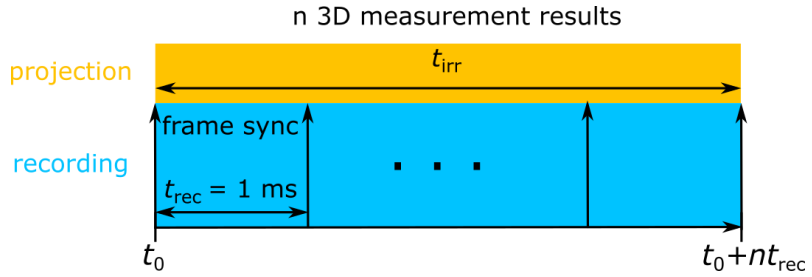
Realization of Thermal 3D Single Shot Sensor

Experimental Setup

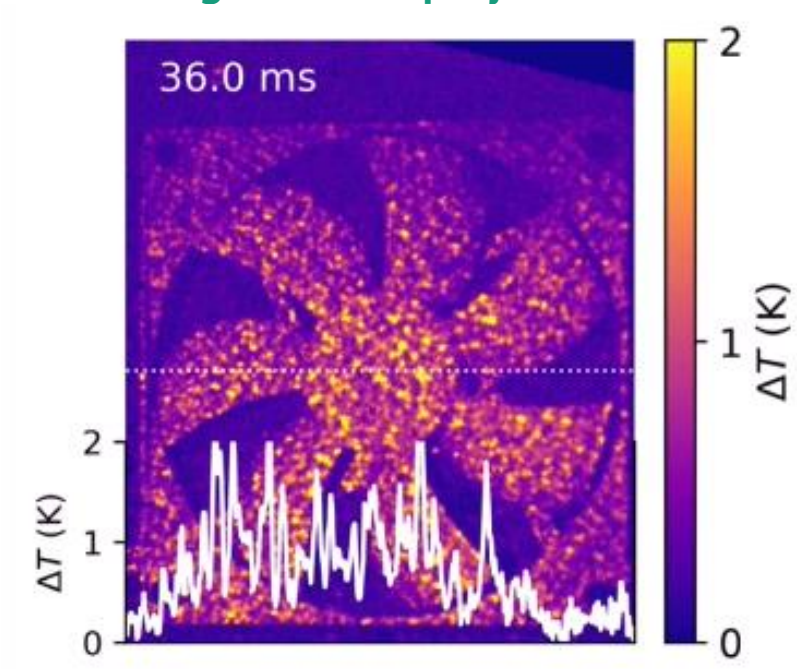


Realization of Thermal 3D Single Shot Sensor

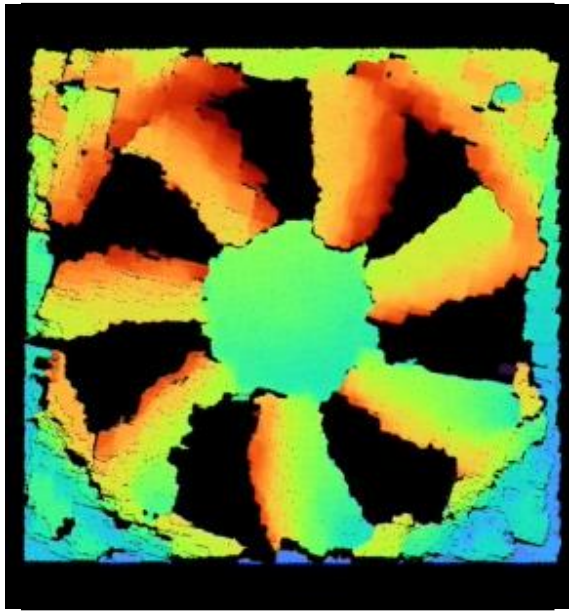
Measurement Example: Fan (not moved)



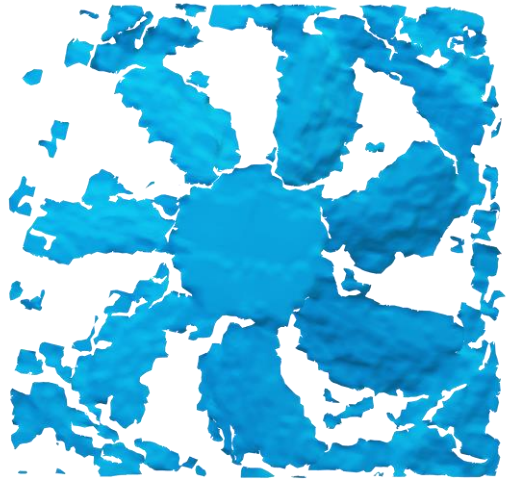
single shot IR projection



3D point cloud



3D surface model



t_{rec} = 1 ms t_{irr} = 10 ms

t_{rec} = 1 ms t_{irr} = 36 ms

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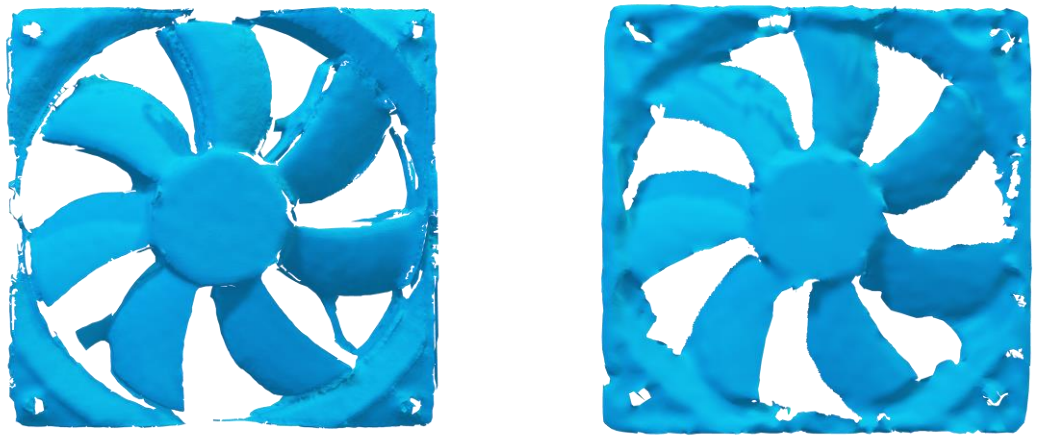
Summary & Outlook

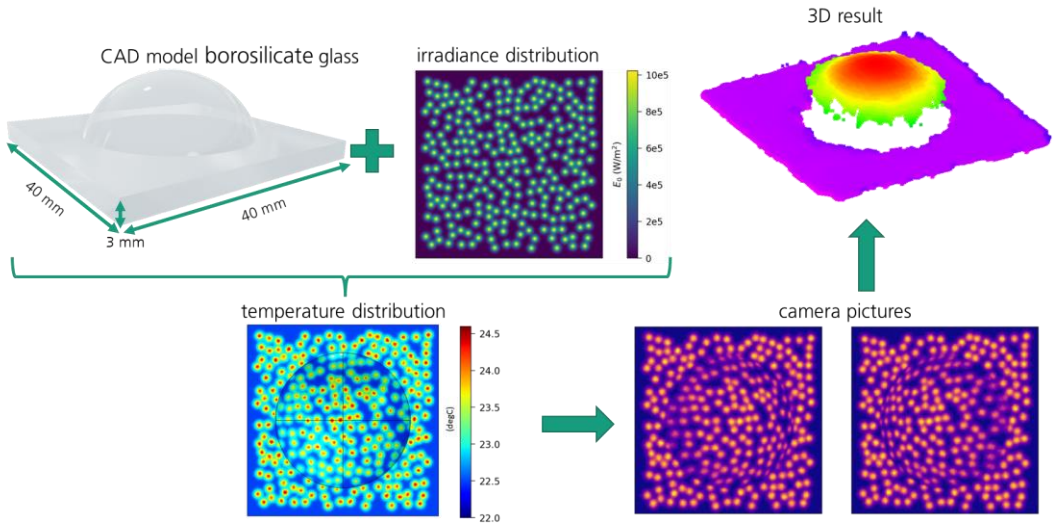
Conclusion

- **Results:**
  - successful thermal 3D measurements for transparent objects
  - build up simulation tool for thermal single-shot 3D measurement
    - temperature contrast of about 1 K
    - point density of about 300 points per 40 × 40 mm²
  - realization of experimental setup
  - single-shot measurement of a transparent, plastic fan with a repetition rate of 1 ms per 3D results



measurement time
t_{meas} = 3.6 s

record time
t_{rec} = 0.001 s



This work has been funded by the Federal Ministry of Education and Research (BMBF) within the project "MAKIR" under Grant No. 03RU1U151A.

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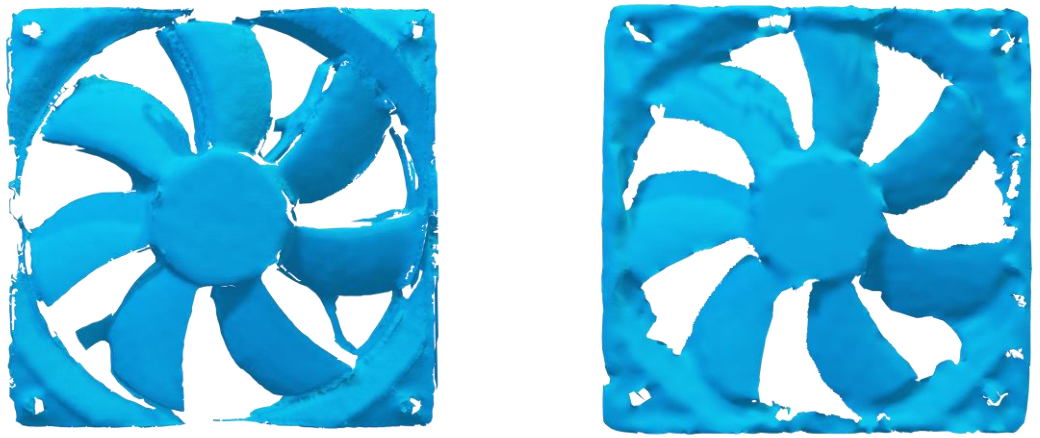
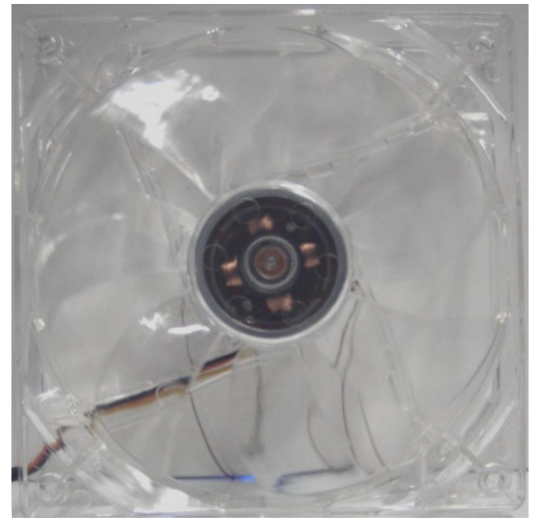
- **Outlook:**
  - experimental realization of a dynamic scene



measurement time t_{meas} = 3.6 s → **record time** t_{rec} = 0.001 s



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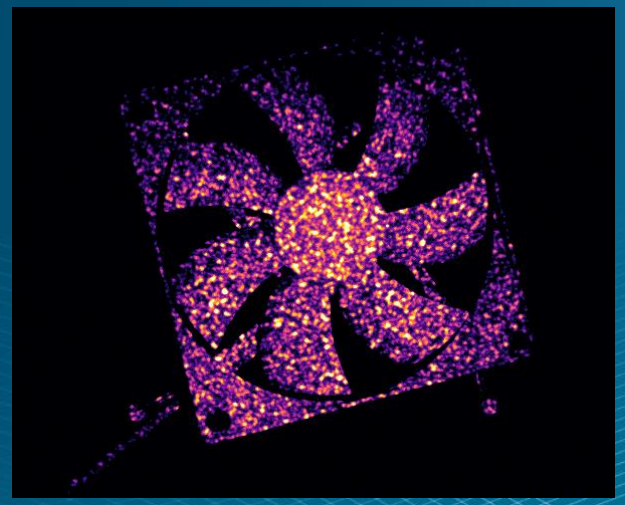

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