PG 2011

The 19th Pacific Conference on Computer Graphics and Applications
(Pacific Graphics 2011) will be held on September 21 to 23, 2011 in Kaohsiung, Taiwan.

Exposure Fusion for Time-Of-Flight Imaging

Uwe Hahne, Marc Alexa

Technische Universität Berlin

Depth imaging

[Audi]

Applications

[Shotton2011]

Depth imaging

[Microsoft]

[PMDTec]

Devices

[PTGrey]

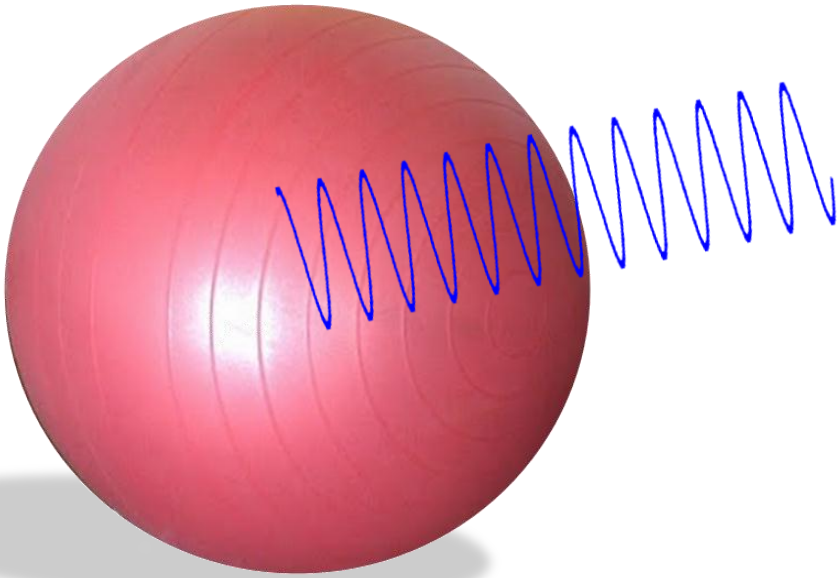
General problem

Our results

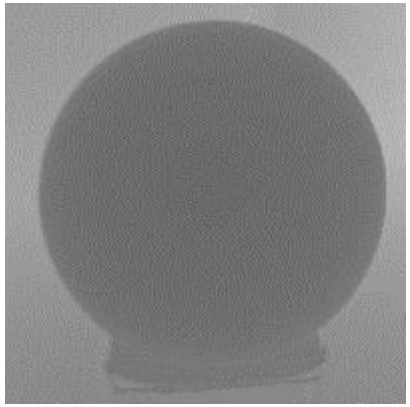
Contribution

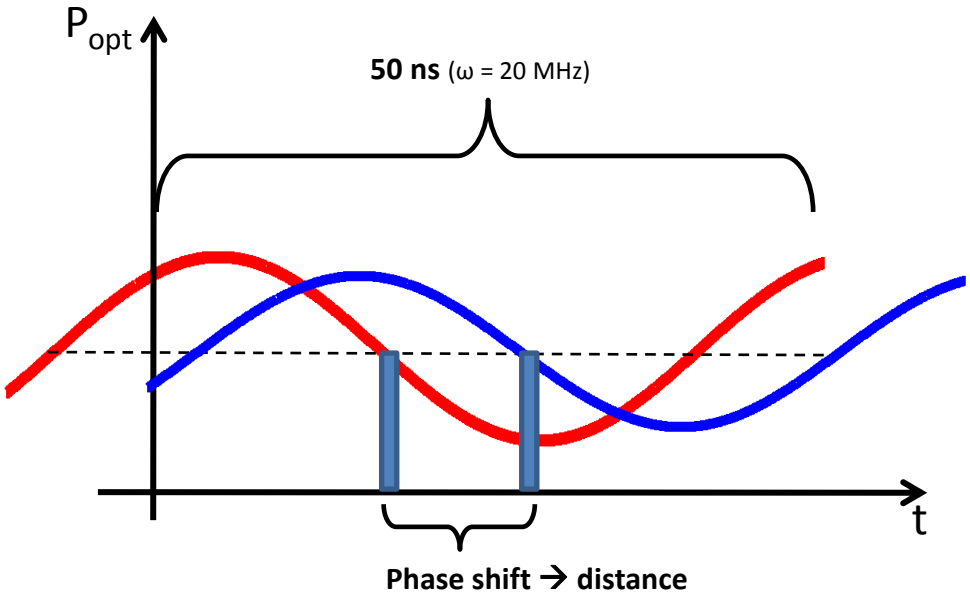
+ No calibration
+ Real-time capable
+ Error reduction

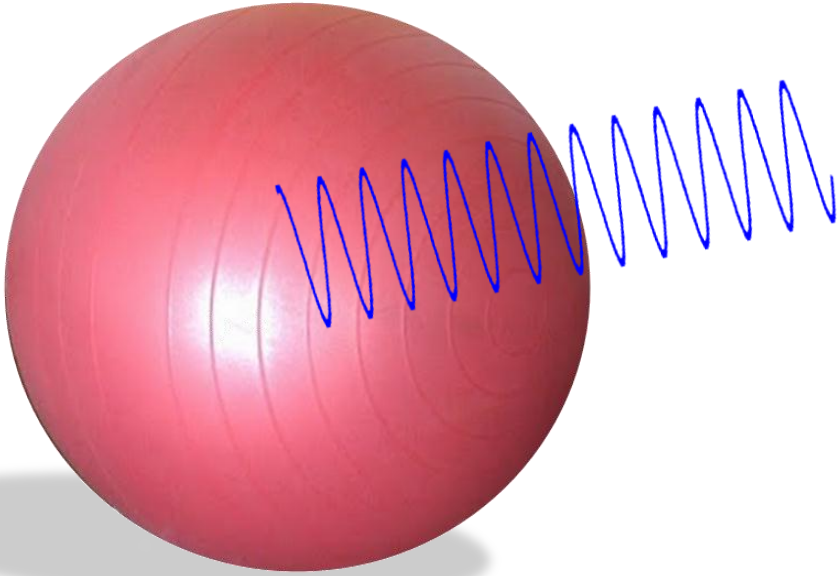
- Only for time-of-flight imaging...



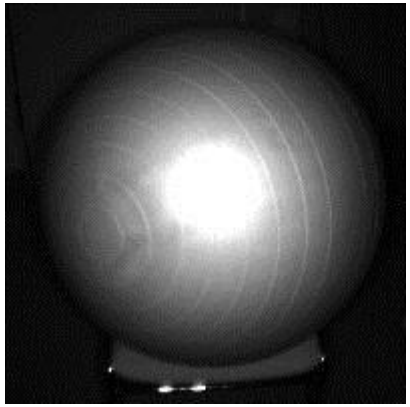
[PMDTec]

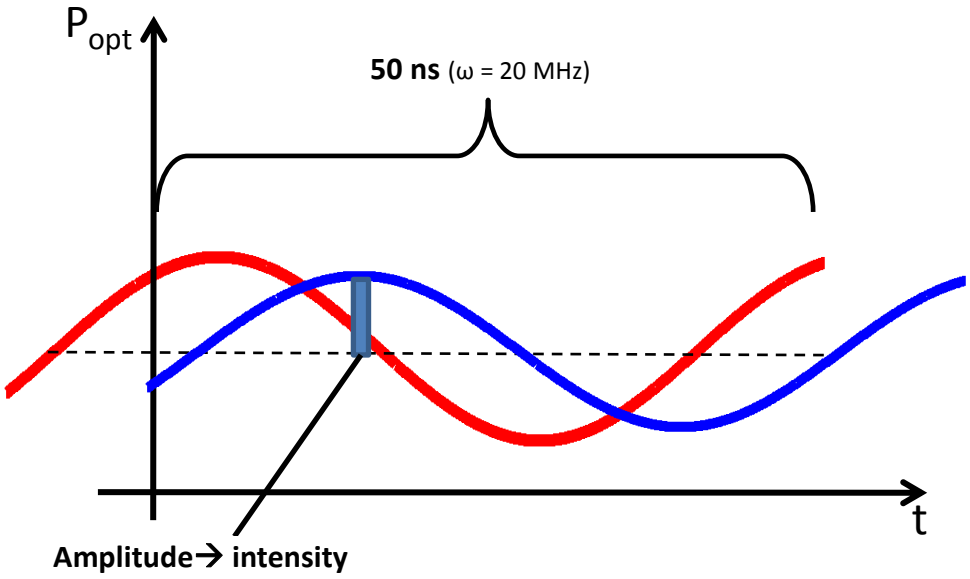


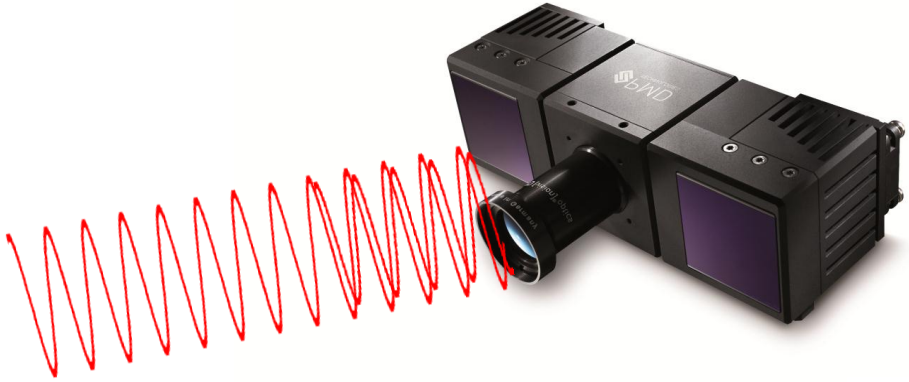




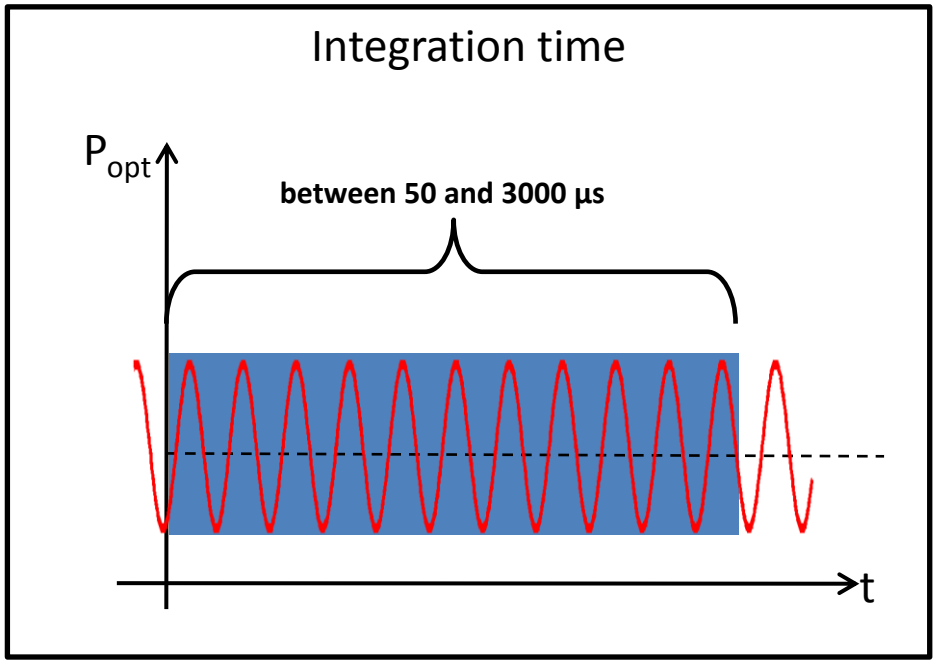
[PMDTec]



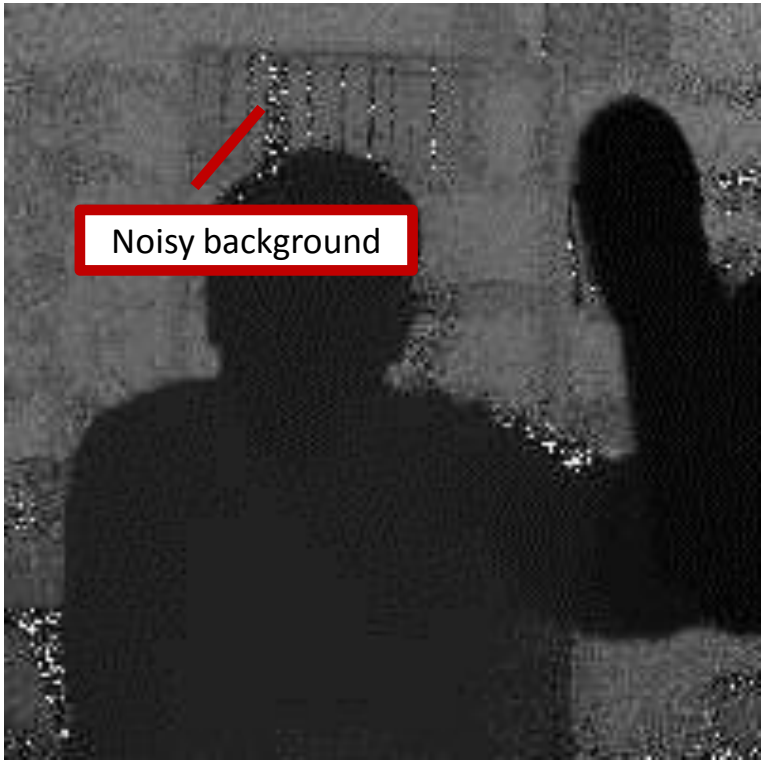




[PMDTec]

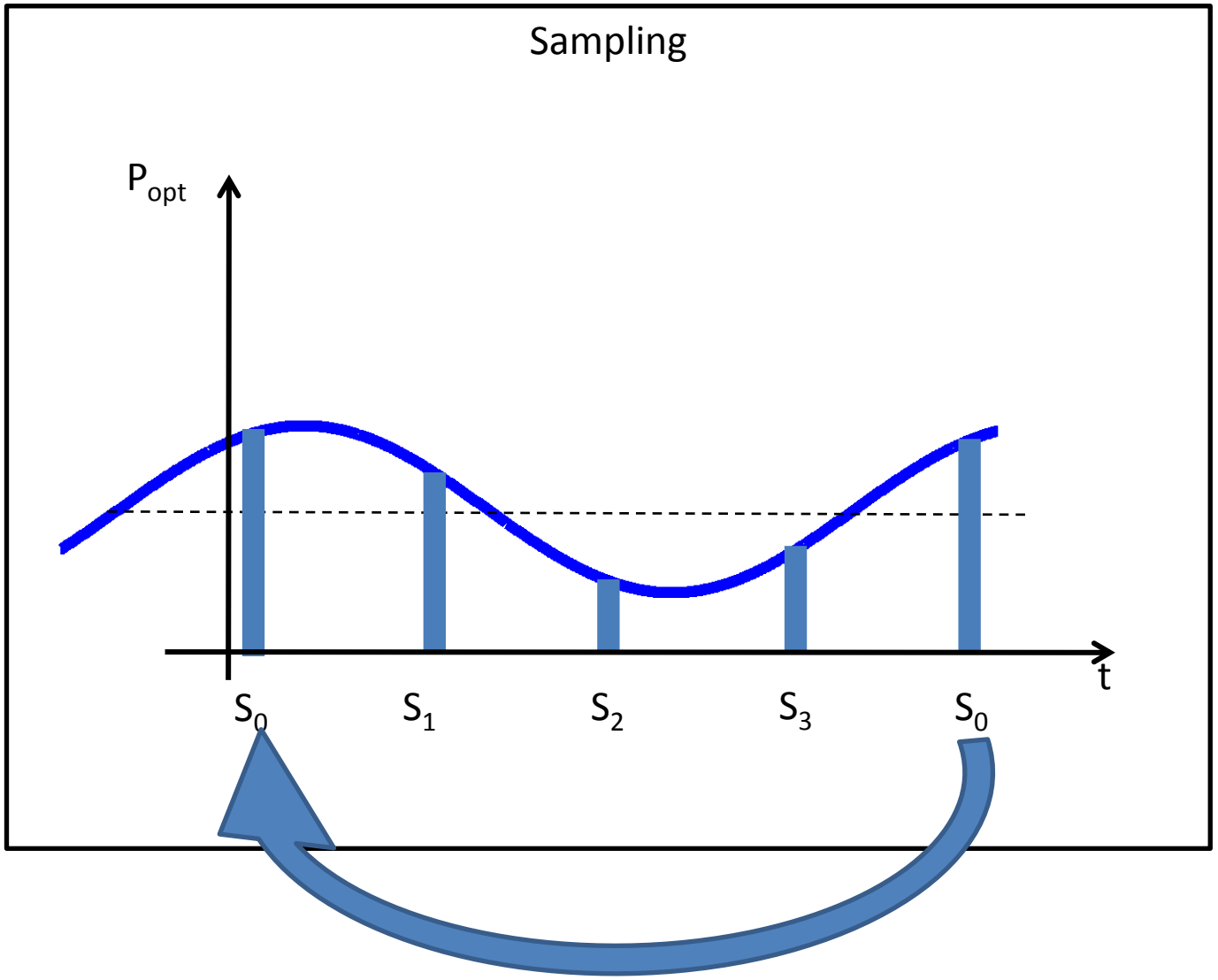


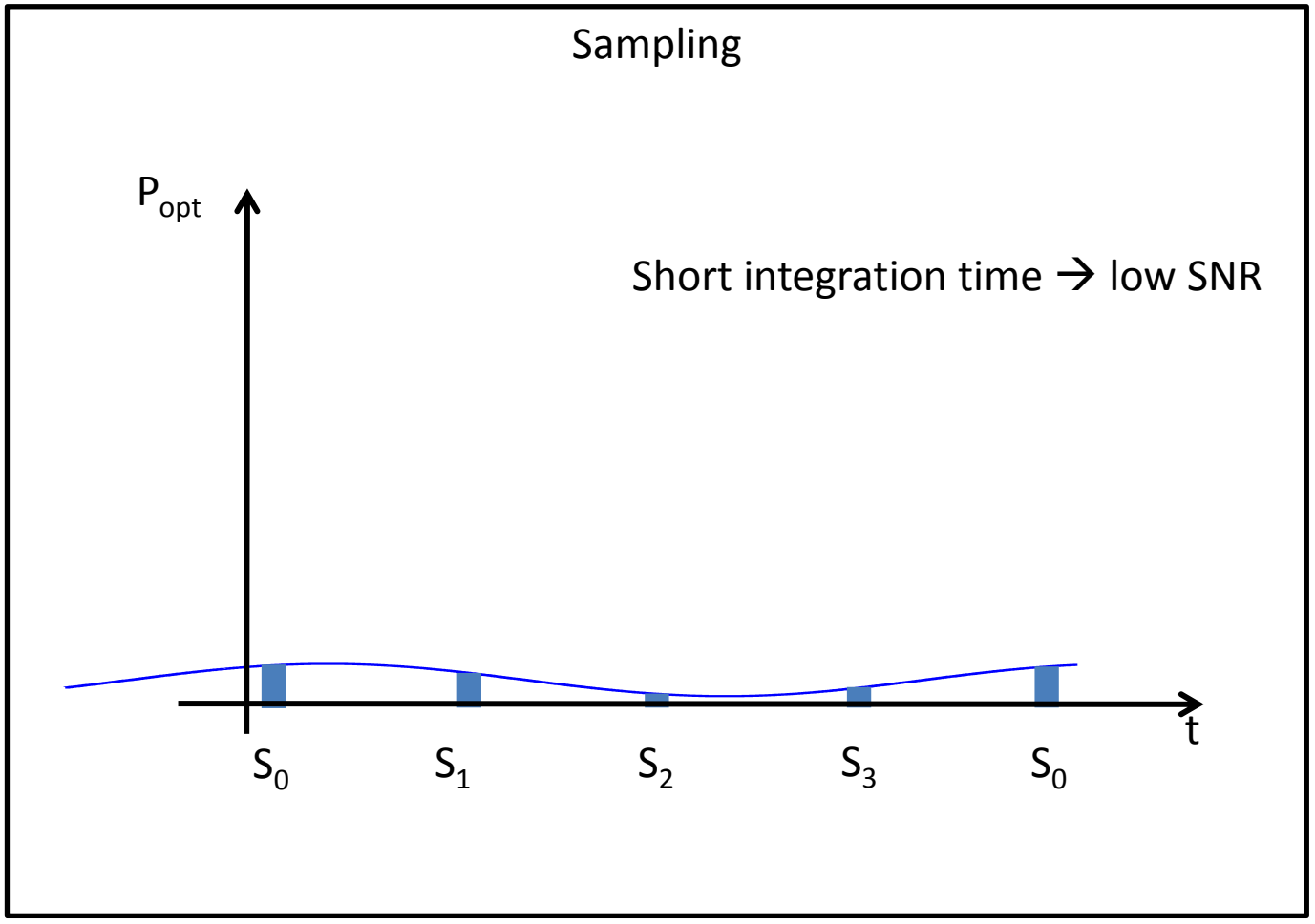
Problem

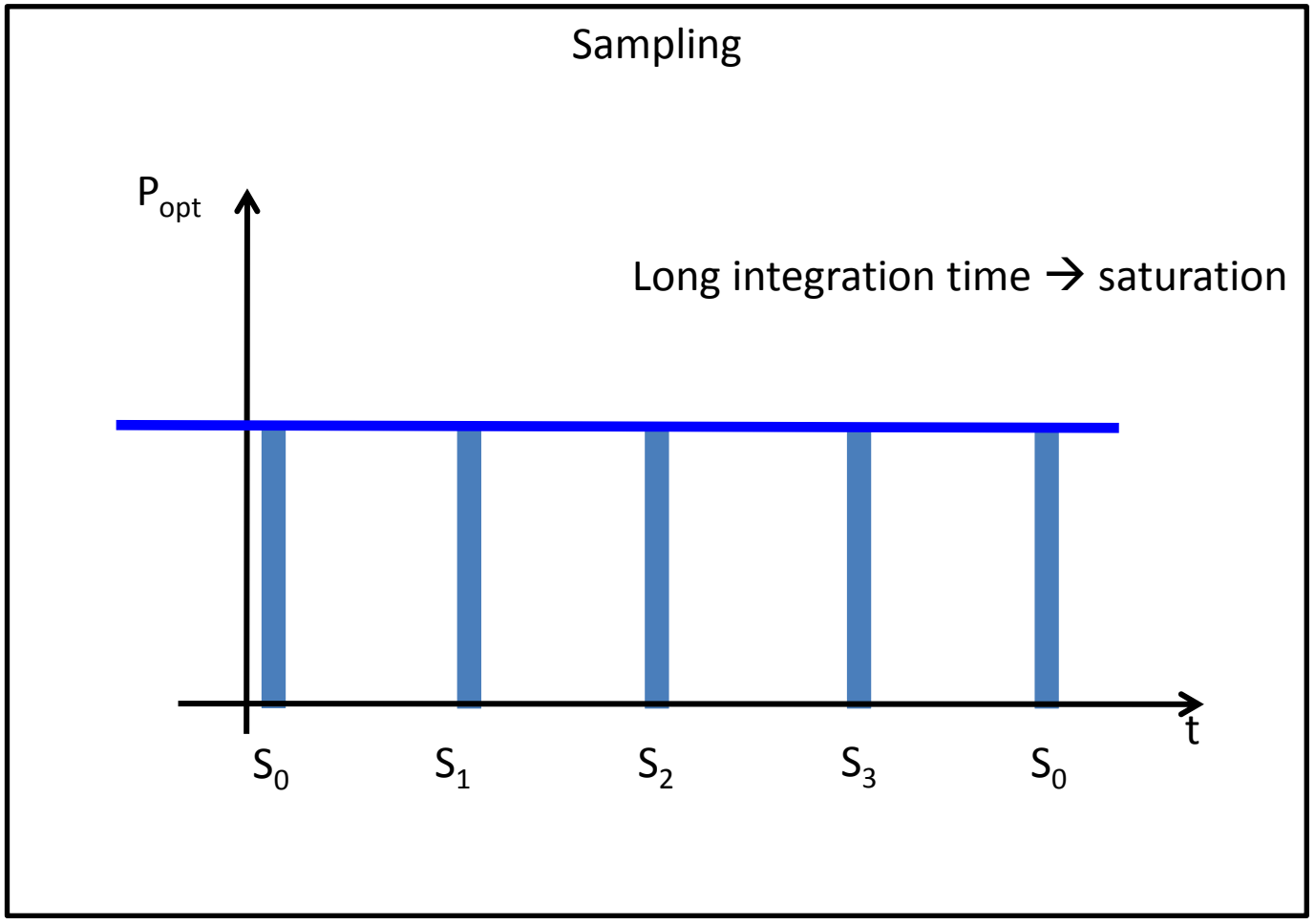


Short integration time (50 µs)

Long integration time (1250 µs)


Sampling
P_{opt}
t
S_0
S_1
S_2
S_3
S_0


Sampling
P_{opt}
Short integration time → low SNR
t
S_0
S_1
S_2
S_3
S_0


Sampling
P_{opt}
Long integration time → saturation
t
S_0
S_1
S_2
S_3
S_0

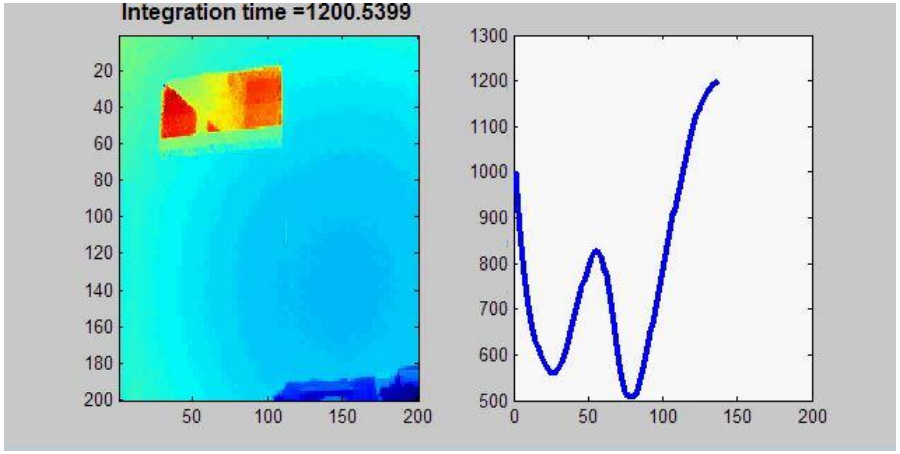
What is the optimal integration time?

Existing approaches

1. Adaptation (May2006)

- Updating the integration time based on data from previous frames.

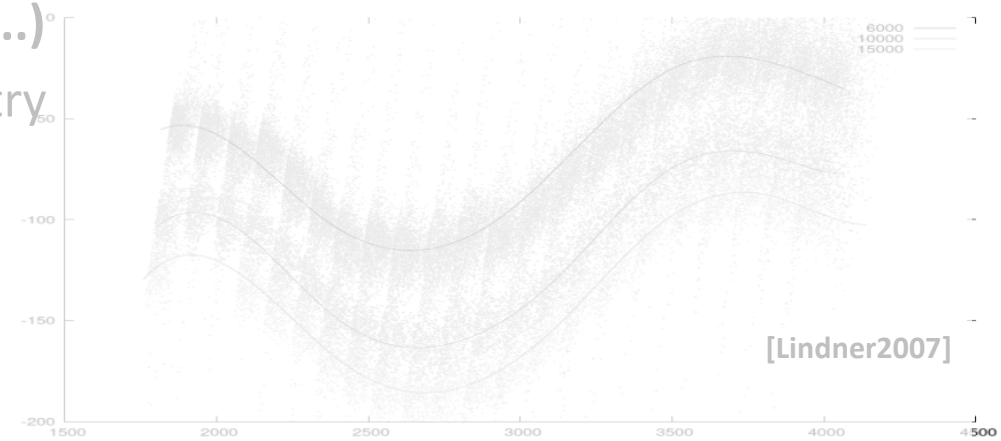
→*Only a global solution*



2. Calibration (Lindner, Schiller, Kolb,...)

- Capture samples of known geometry and correct the measurements.

→ *Laborious and device specific*



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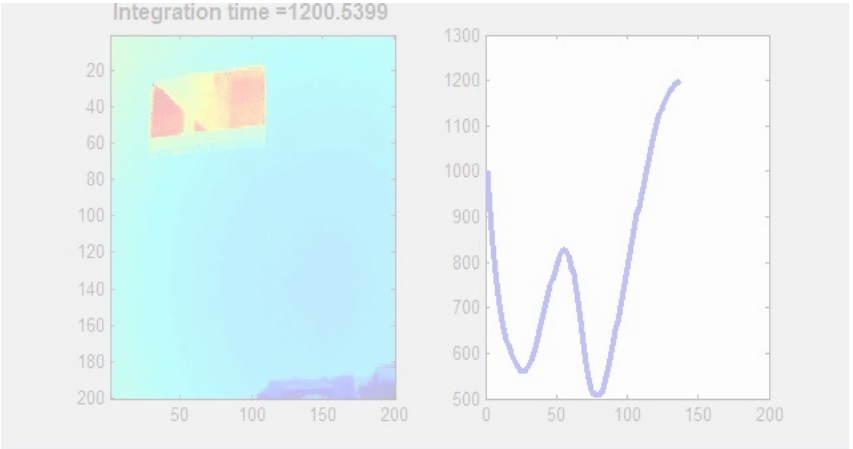

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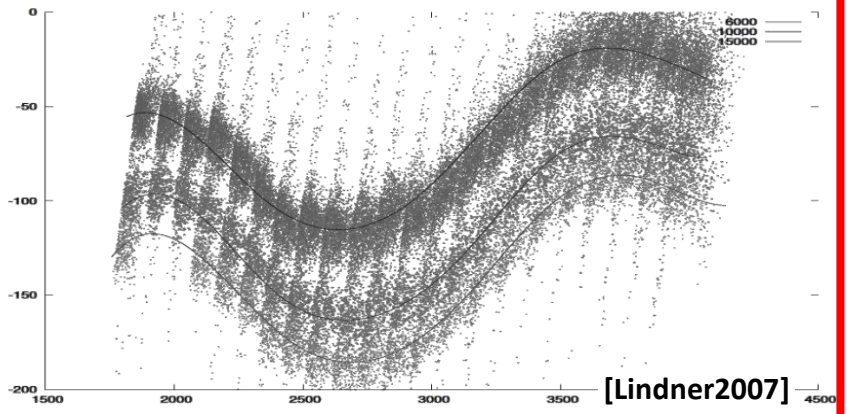


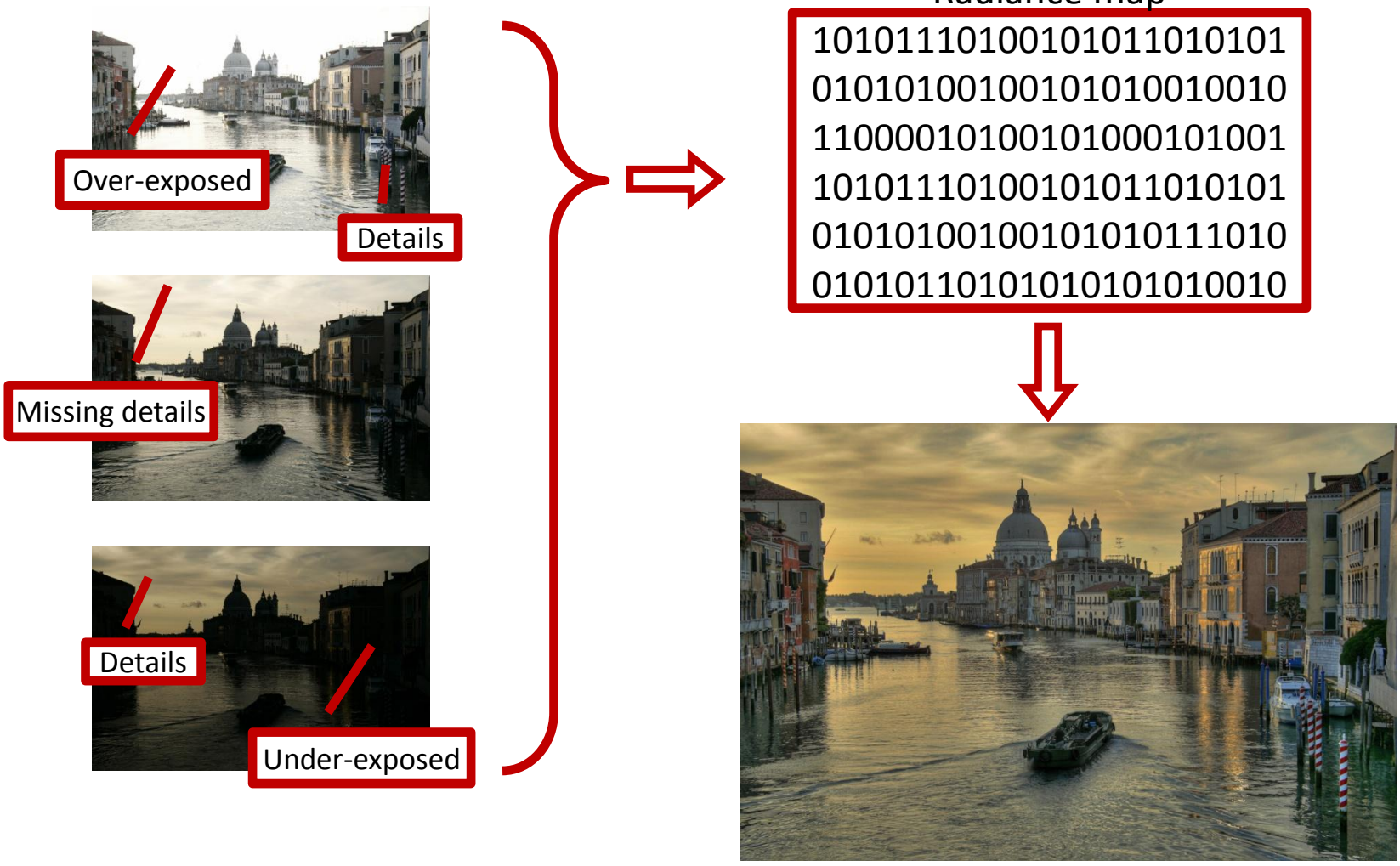
[Lindner2007]

Our approach

How is this problem solved in photography?

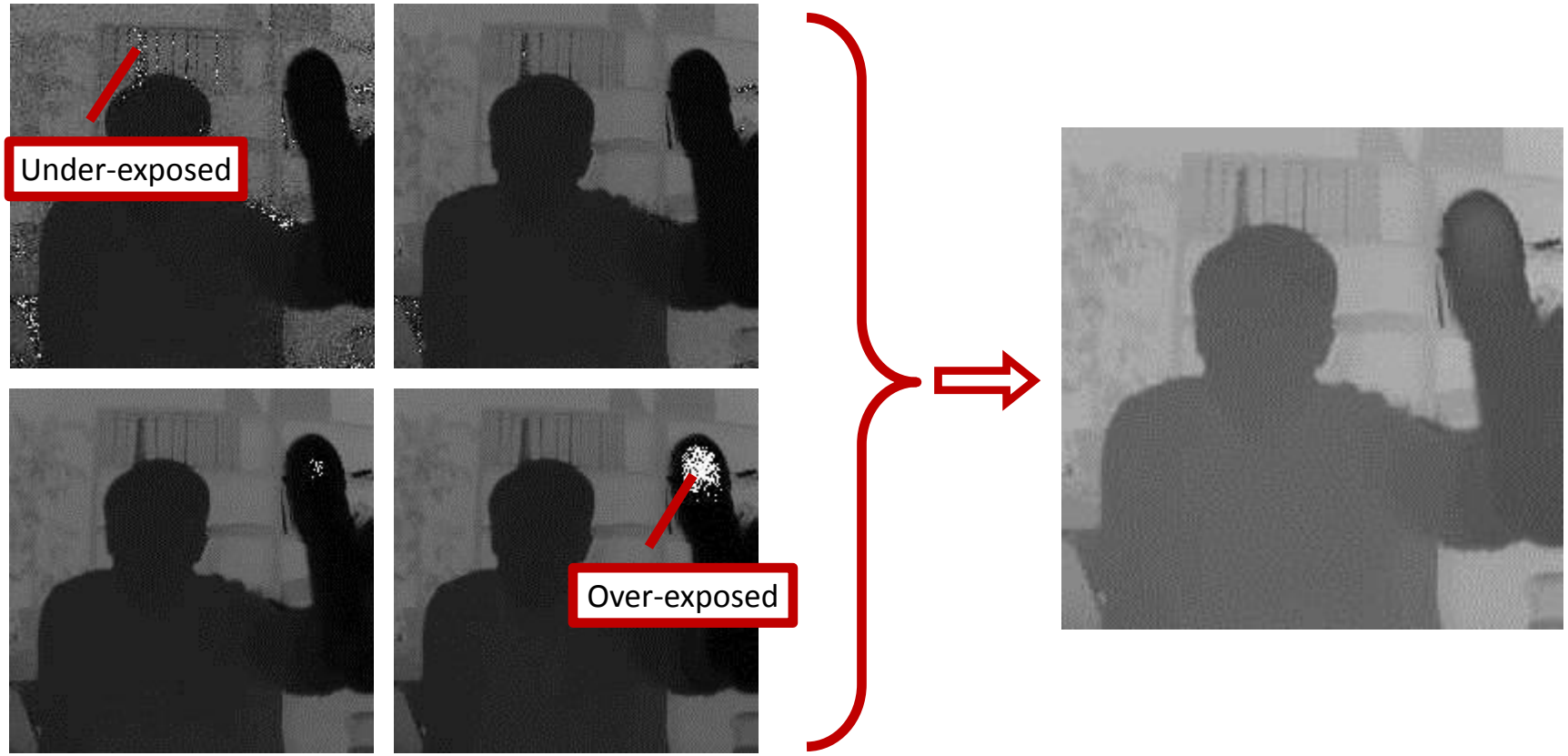
→ High Dynamic Range (HDR) Imaging

HDR imaging



[Images are courtesy of Jacques Joffre]

Depth imaging



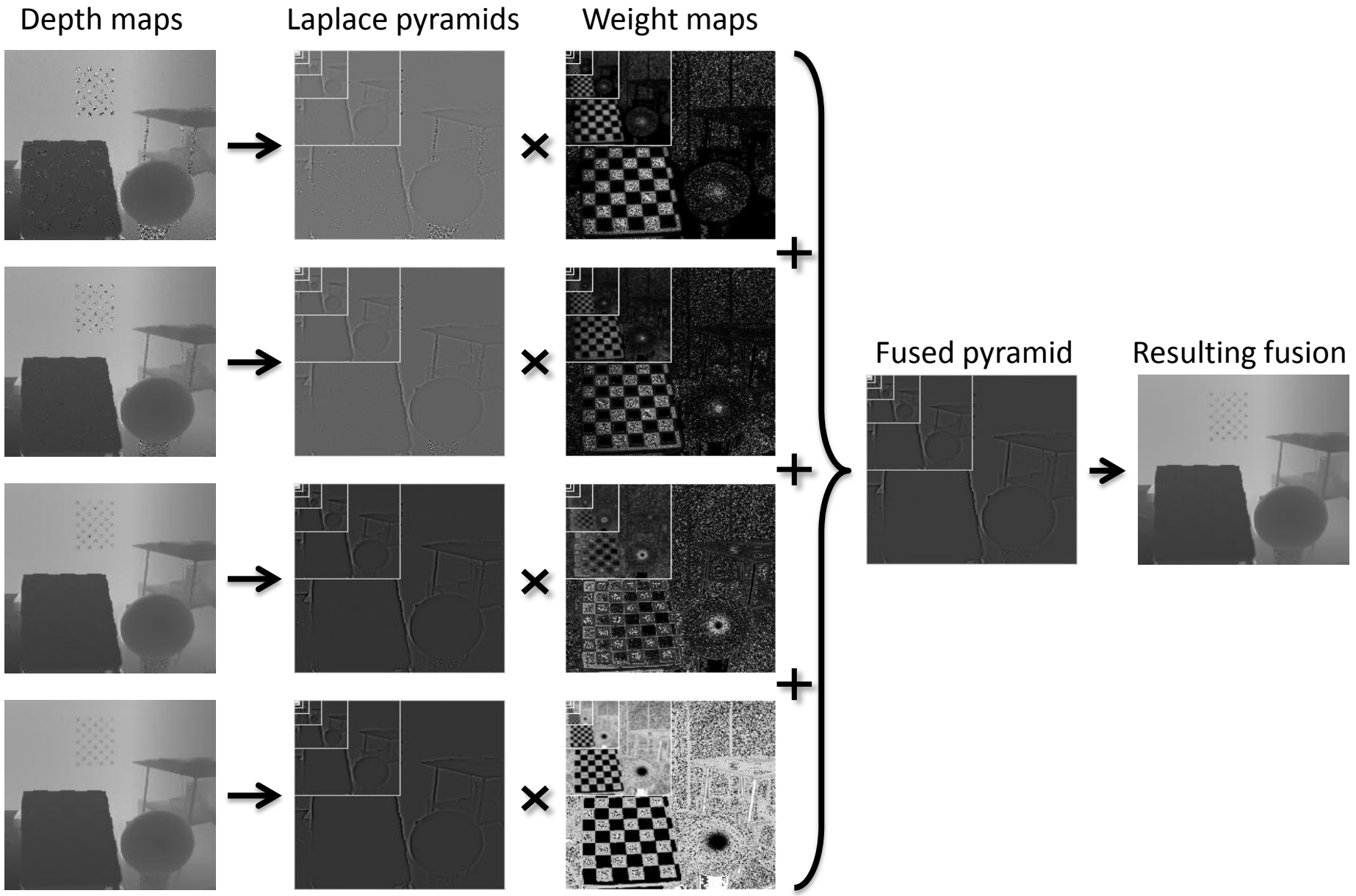
Algorithm

1. Capture a series of depth images with varying integration times.

2. Compute weights using quality measures.

3. Fuse images together as affine combination of weighted depth maps.

Process overview

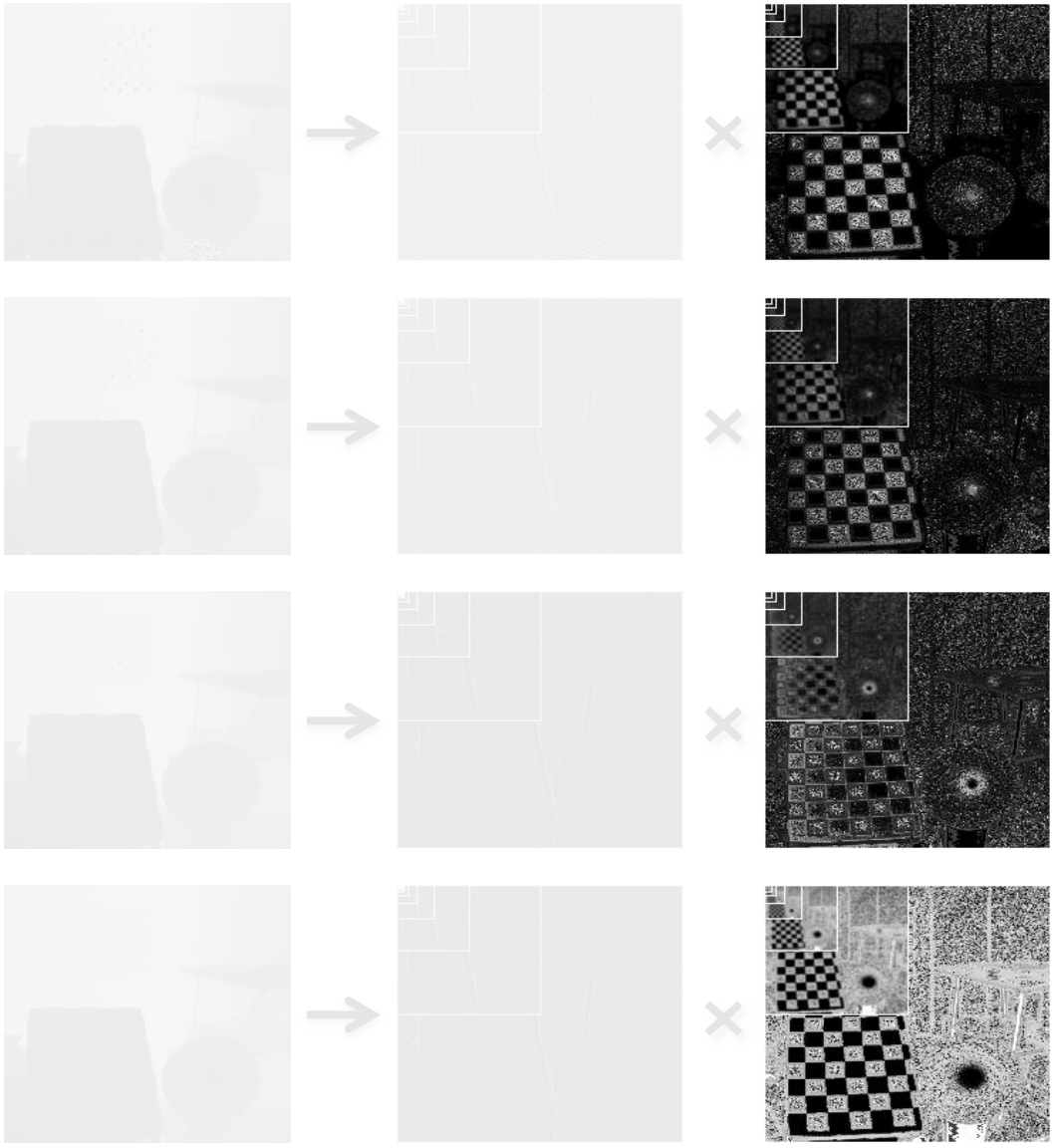


Process overview

Depth maps

Laplace pyramids

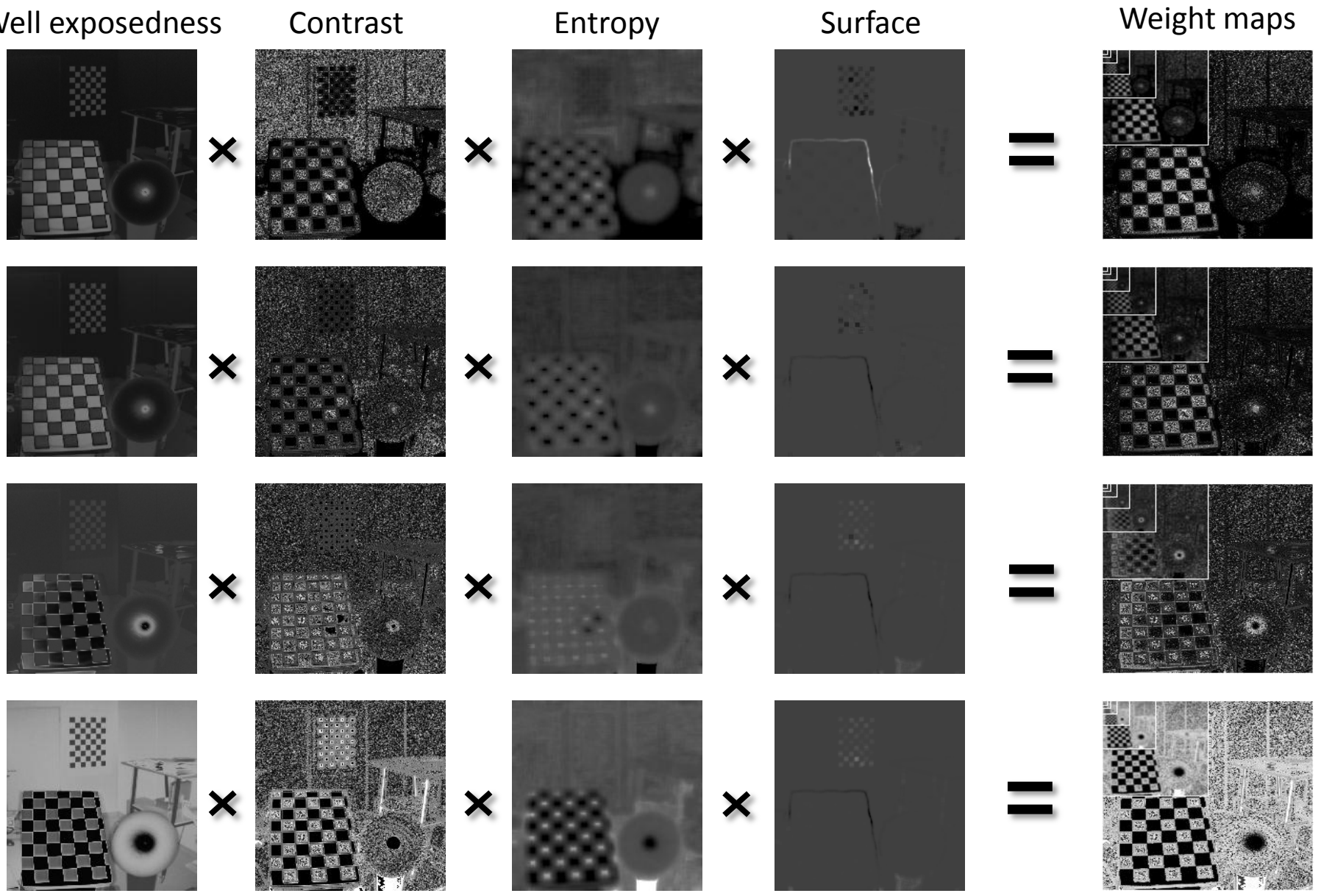
Weight maps



Fused pyramid

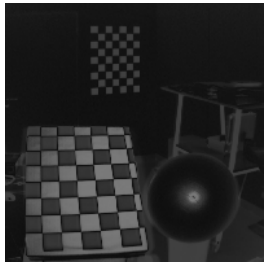
Resulting fusion

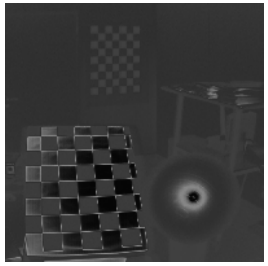
Quality measures



Quality measures

Well exposedness





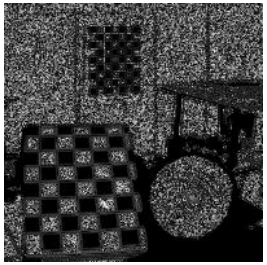
$$W_{ij} = e^{\frac{-(A_{ij}-\alpha)^2}{2\sigma^2}}$$

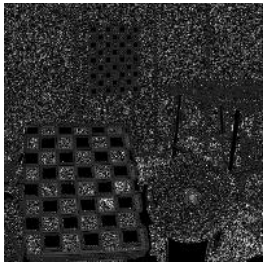
Emphasizes those pixels where the amplitude is in a “well” range and hence removes over- and underexposure.

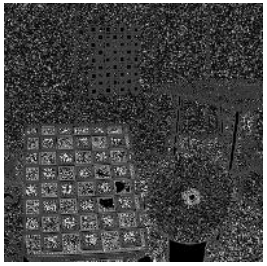
[Mertens2007]

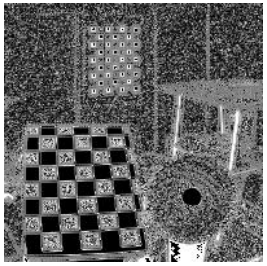
Quality measures

Contrast









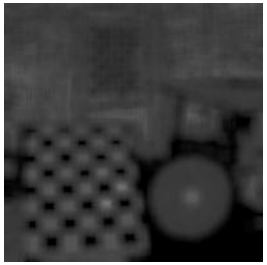
$$M_C = \|\Delta A\|$$

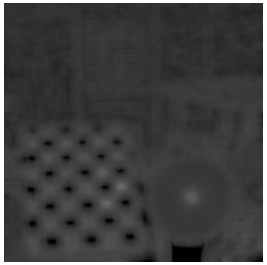
Good contrast in the amplitude image indicates absence of flying pixels.

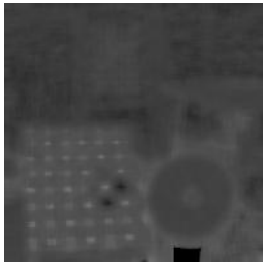
[Mertens2007]

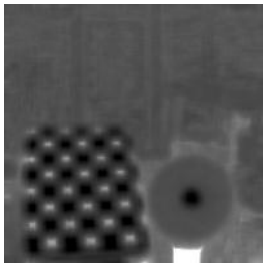
Quality measures

Entropy









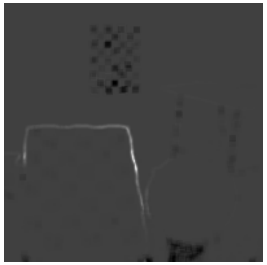
$$\mathbf{E_{ij}} = -\sum \mathbf{p(A_{ij})log_2(p(A_{ij}))}$$

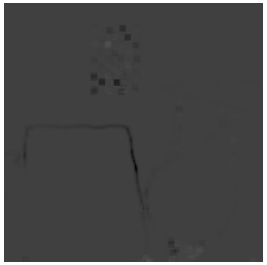
The entropy is a measure for the amount of information.

[Goshtasby2005]

Quality measures

Surface





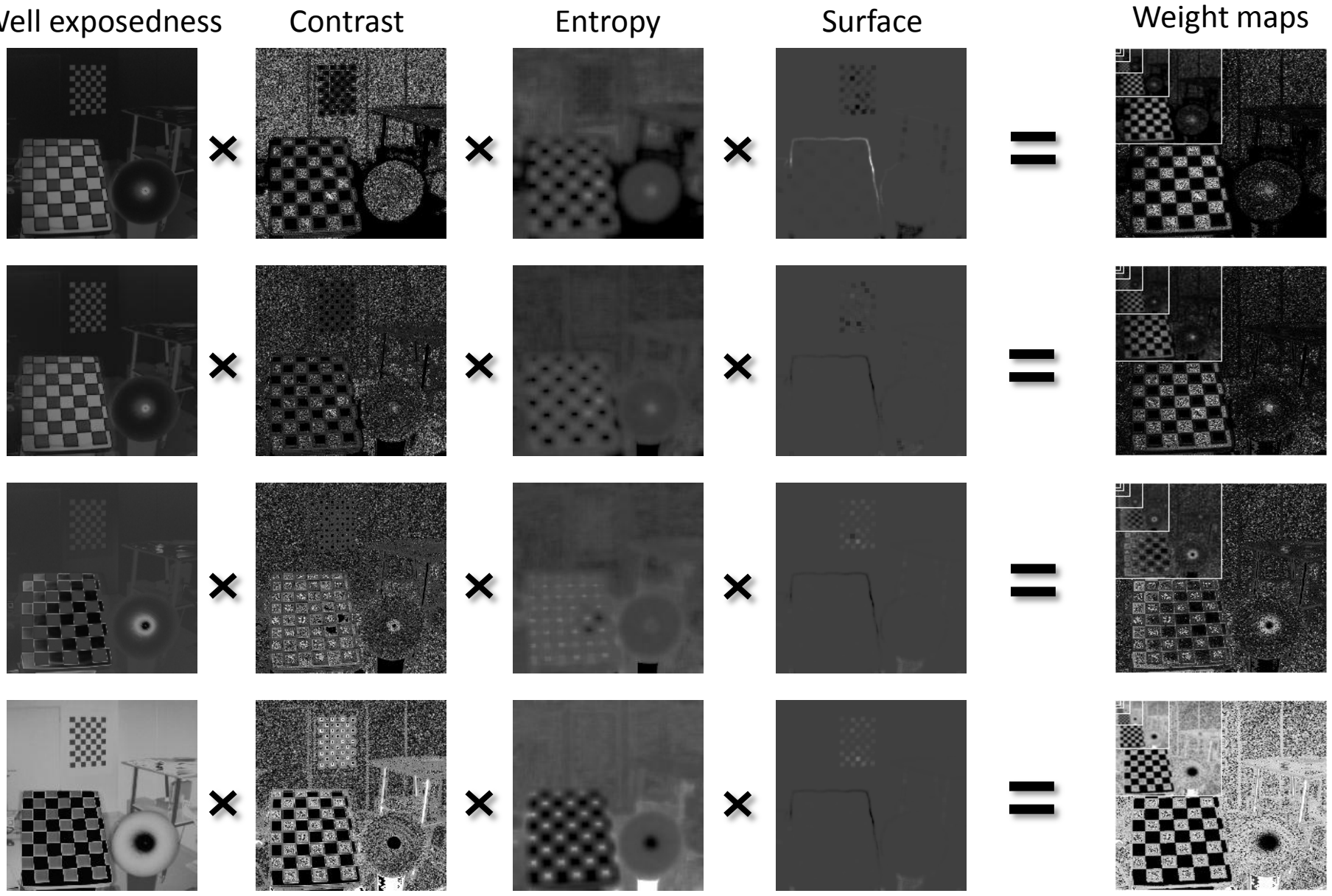
$$M_S = 1 - \frac{(\sigma - \mu^2)}{max(\sigma - \mu^2)}$$

σ = Gaussian blurred squared depth map
μ = Gaussian blurred depth map

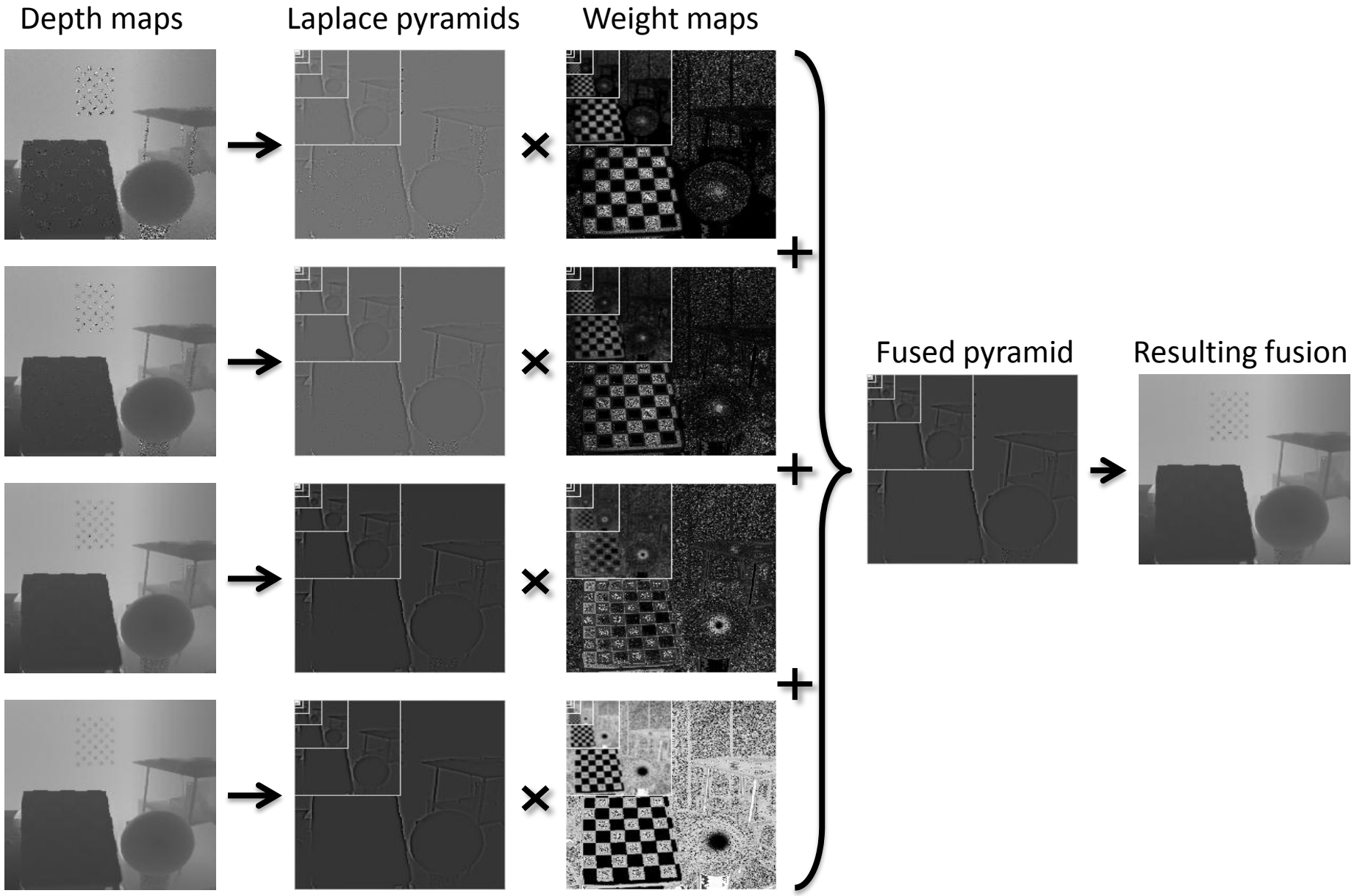
A measure for surface smoothness which indicates less noise.

[Malpica2009]

Quality measures



Process overview



Evaluation

Depth map quality

- What is the reference?

Reference

We compared our results to single exposures with the integration time t’.

The integration time t’ is the global optimum found by the method from [May2006].

We use N = 4 exposures (i = 0..N-1) with integration times $t_i = 2^{i-\frac{N}{2}} t'$.

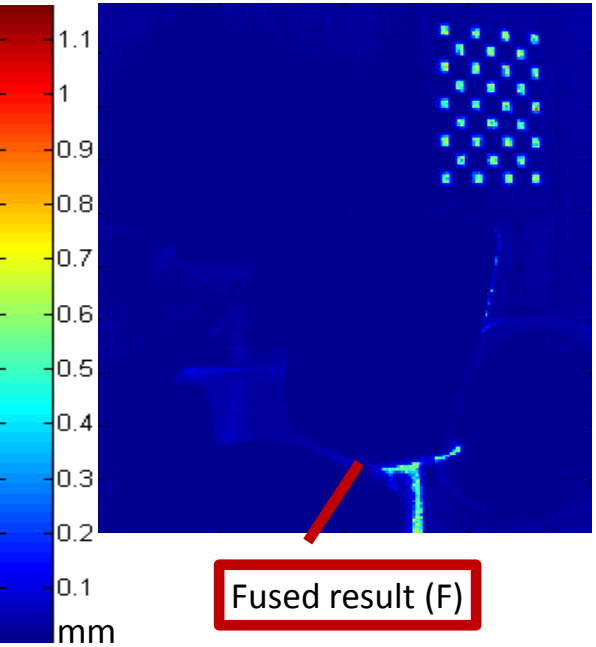
Evaluation

Depth map quality

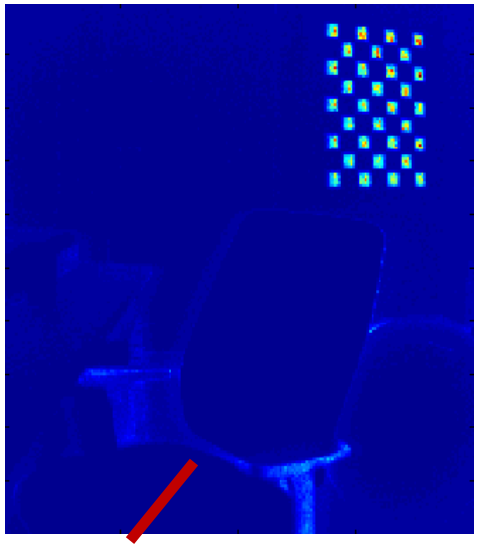
- What is the reference?
- What does quality mean?
  - Less temporal noise → Stability over time test

Stability over time

Capture a static image over time and determine the standard deviation for each pixel.



Fused result (F)



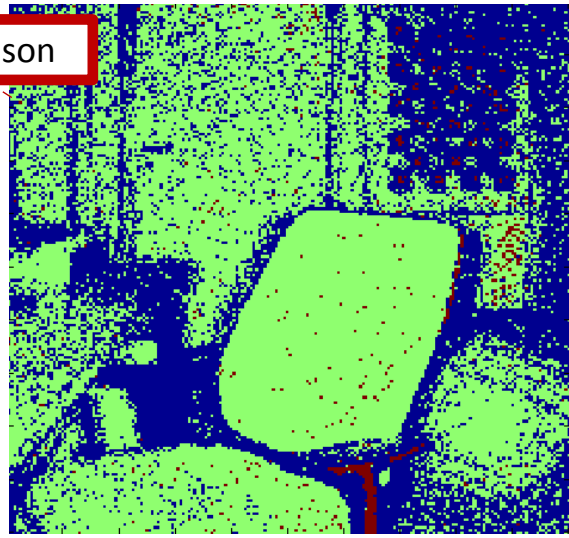
Single exposure (S)

Comparison

F > S

F < S

F ≈ S



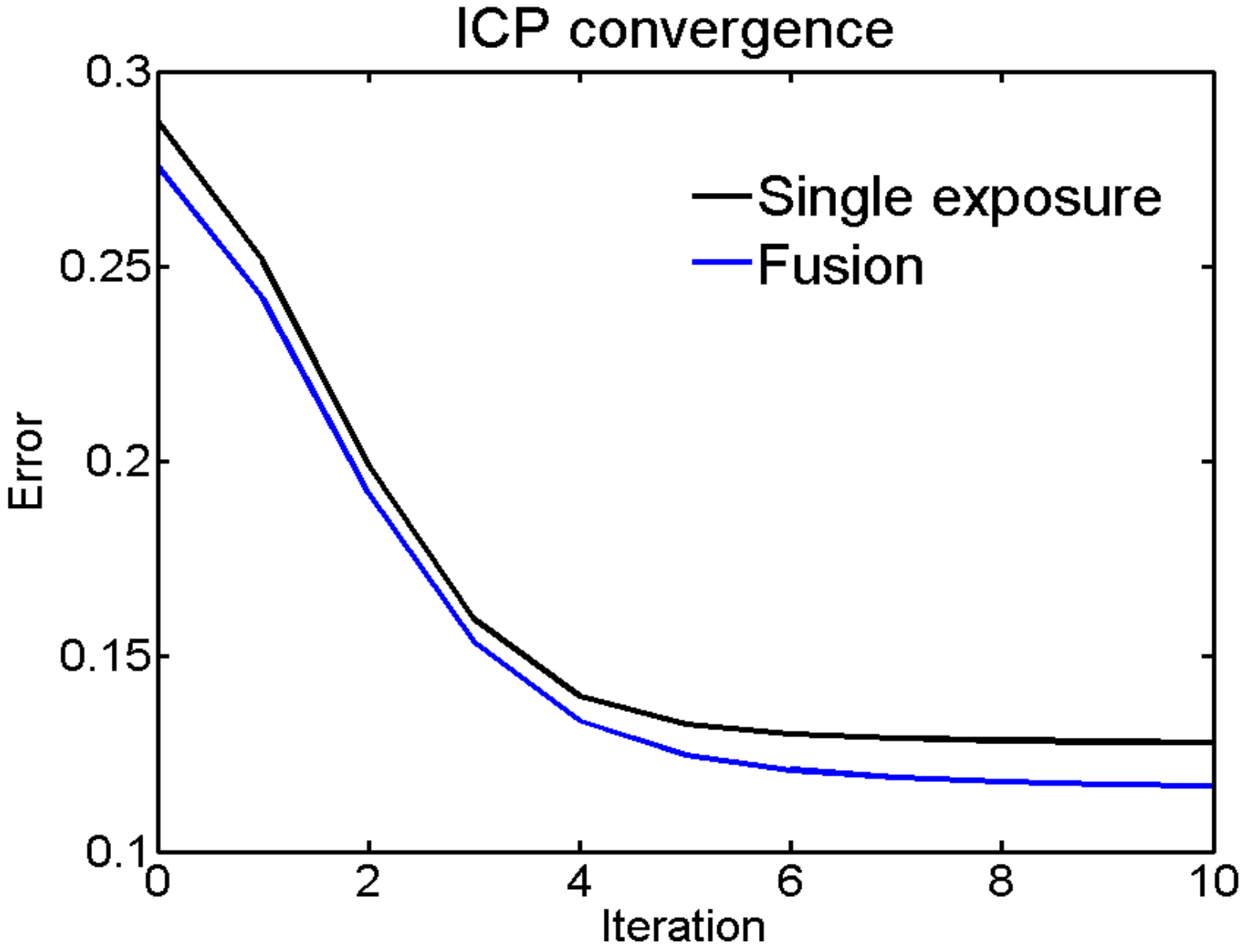
Overall reduction of mean standard deviation by 25%.

Evaluation

Depth map quality

- What is the reference?
- What does quality mean?
  - Less temporal noise → Stability over time test
  - Better processing results → Run ICP and compute 3D reconstruction error

3D reconstruction

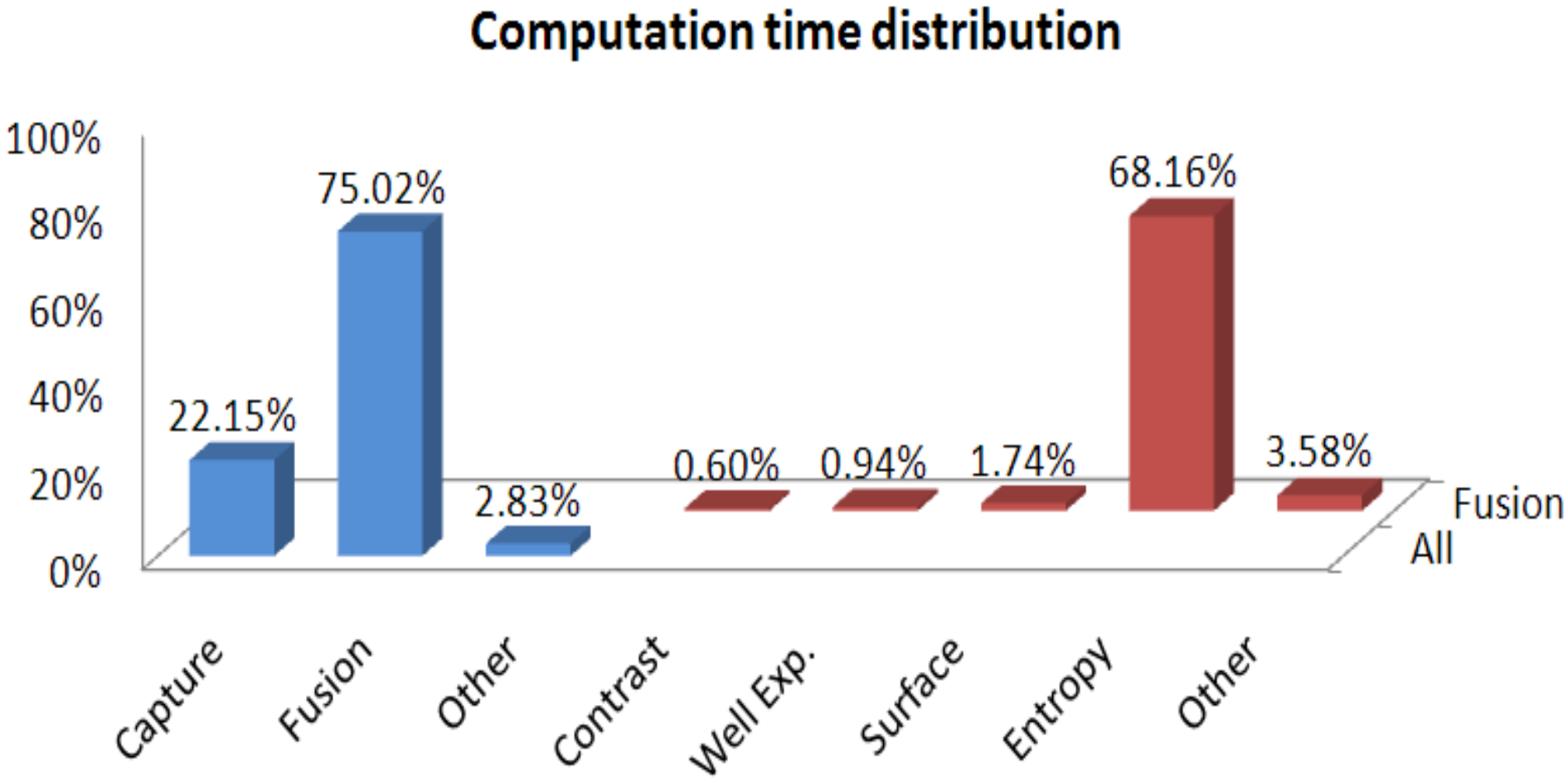


Evaluation

Depth map quality

- What does quality mean?
  - Less temporal noise → Stability over time test
  - Better processing results → Run ICP and compute 3D reconstruction error
- Impact of each quality measure
  - Computation times

Computation



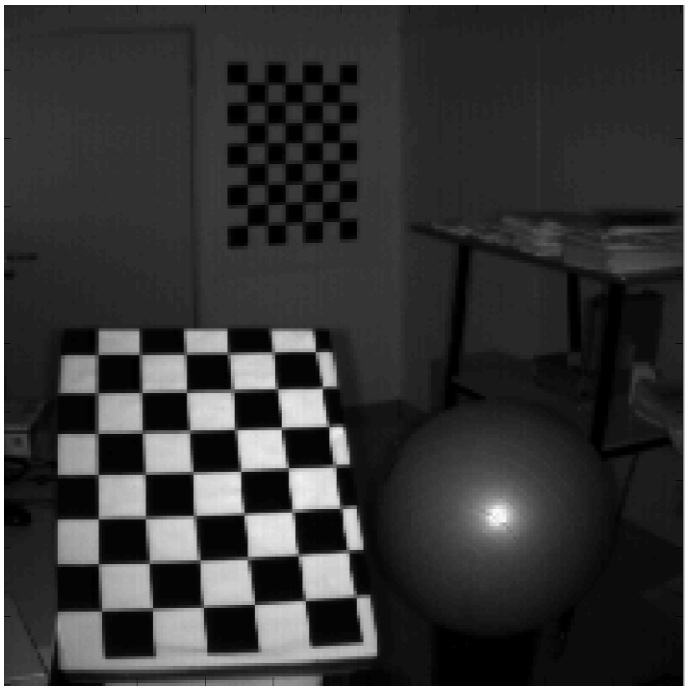
Evaluation

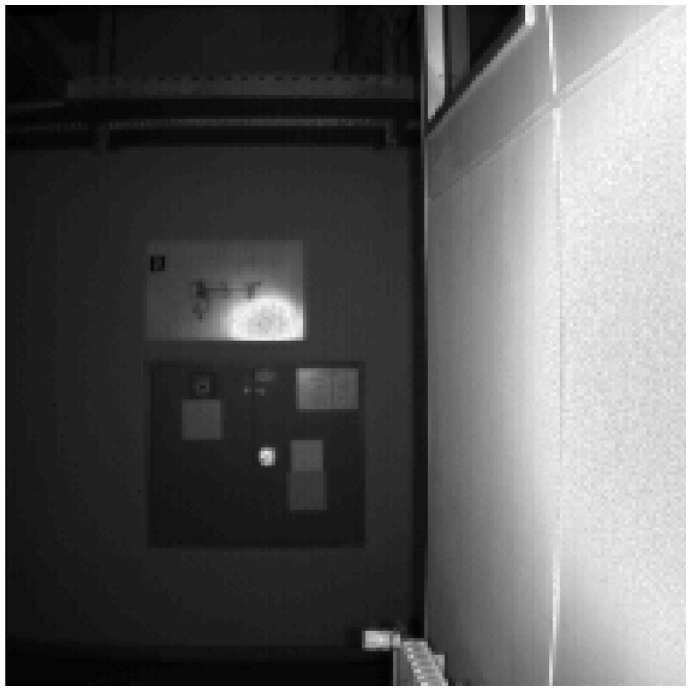
Depth map quality

- What does quality mean?
  - Less temporal noise → Stability over time test
  - Better processing results → Run ICP and compute 3D reconstruction error
- Impact of each quality measure
  - Computation times
  - Precision → Plane fit in planar regions

Planar regions

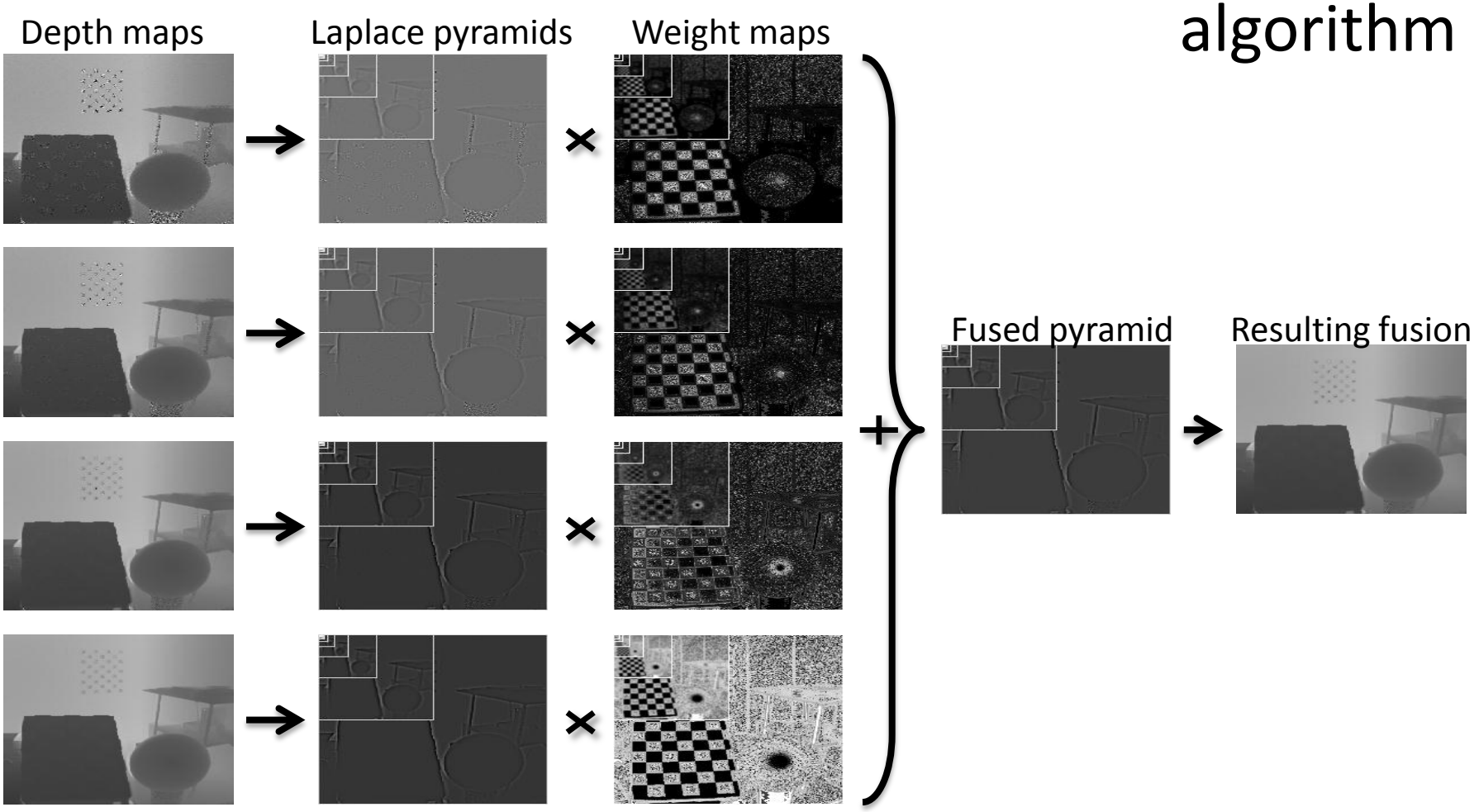
We captured test scenes with planar regions.





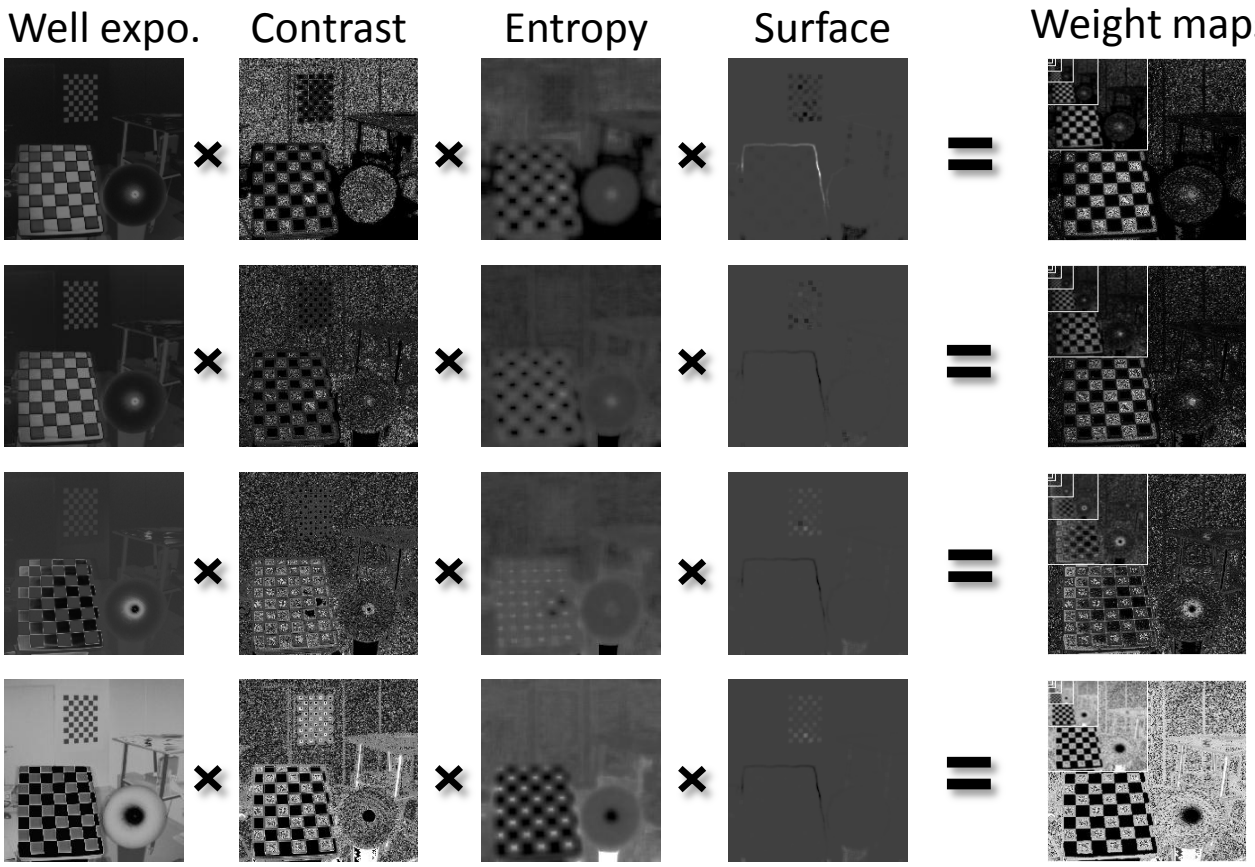
Planar regions

We ran our fusion algorithm ...



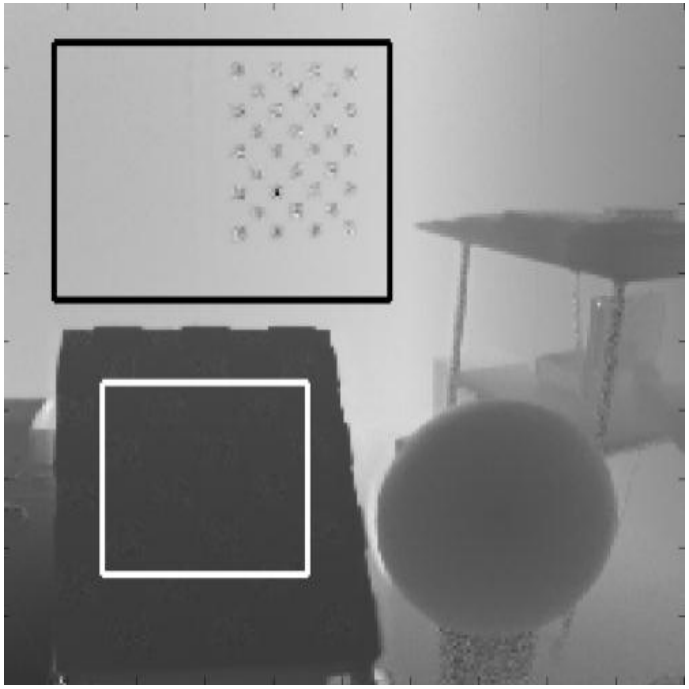
Planar regions

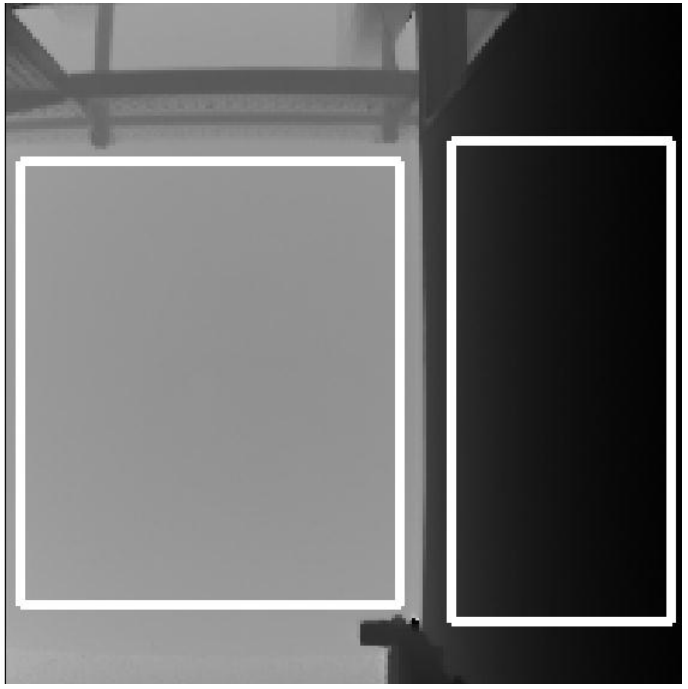
...and compared the fusion results of all combinations of quality measures.



Planar regions

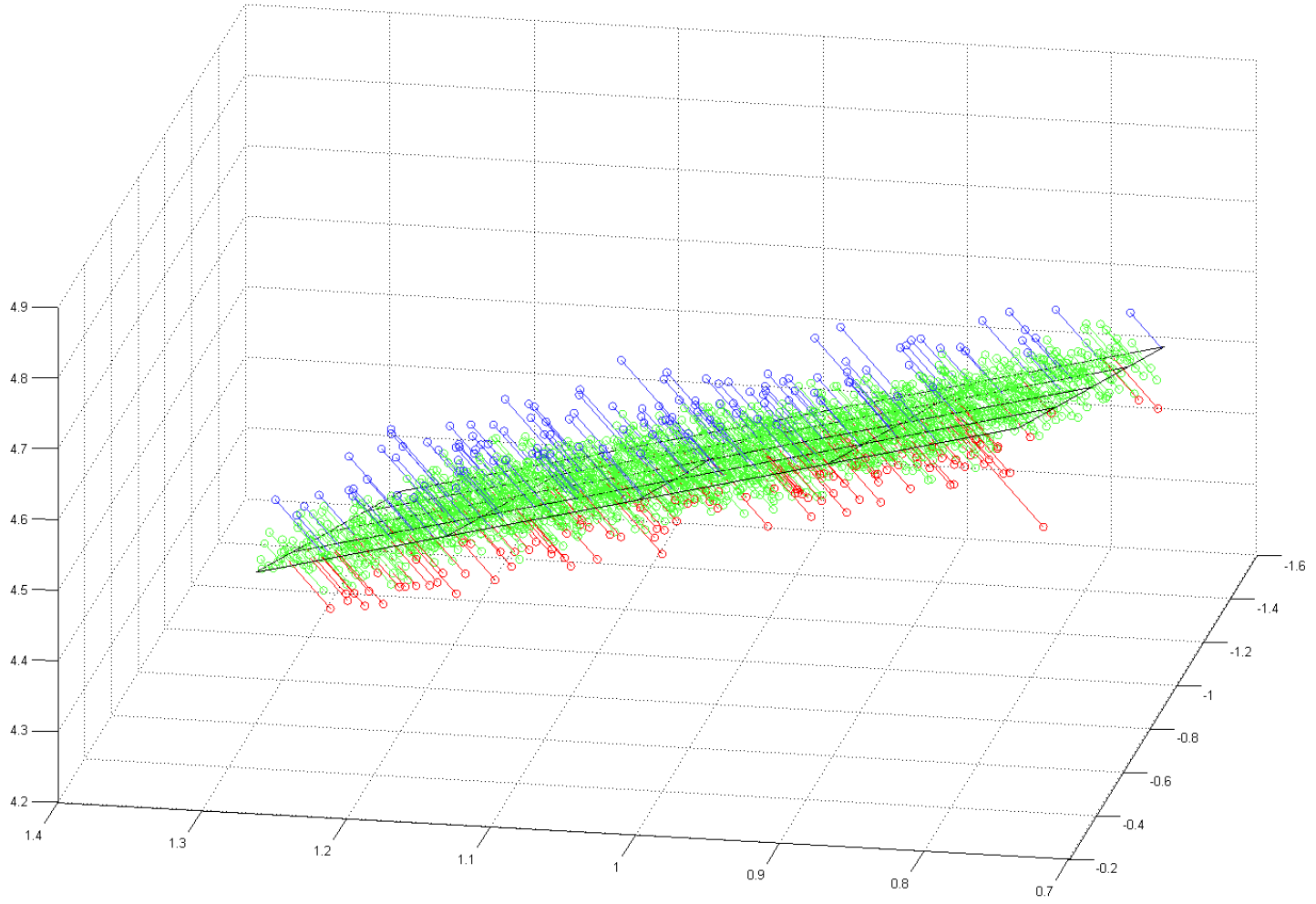
We identified planar regions...



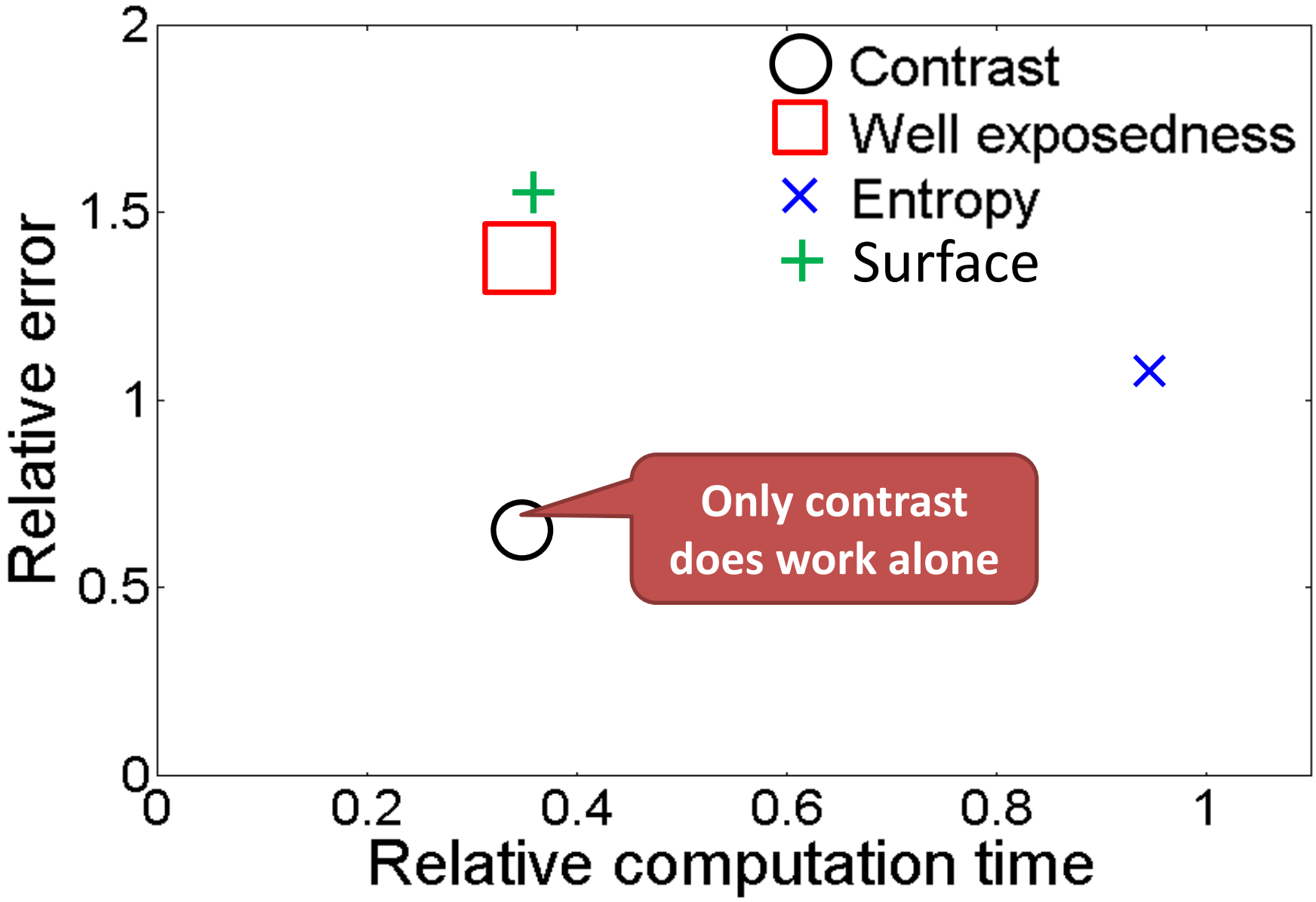


Planar regions

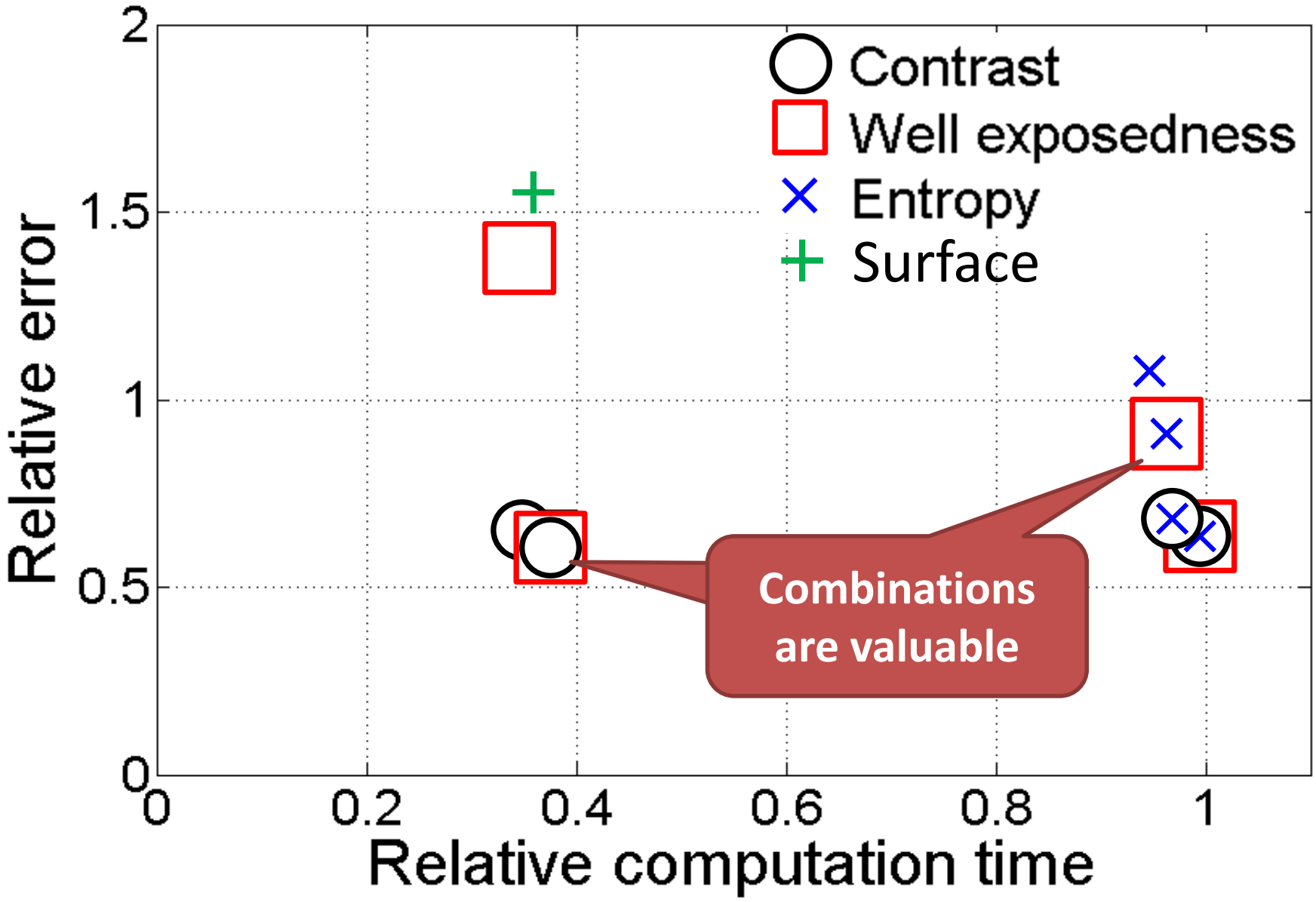
...and fitted planes into the 3D data.



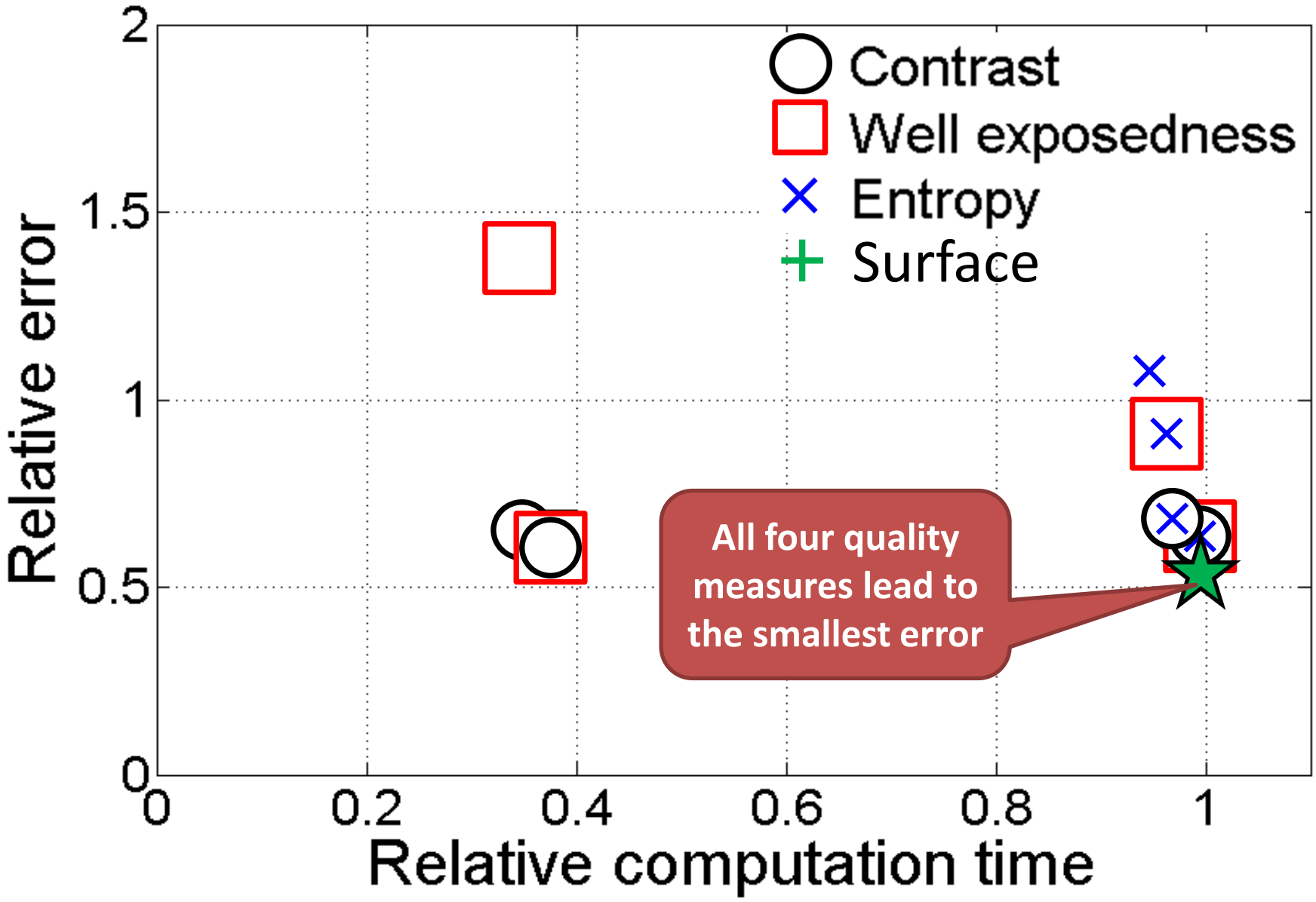
Planar regions



Planar regions



Planar regions



Conclusion

A new method for time-of-flight imaging:

+ No calibration

+ Real-time capable

+ Reduced error

Thank you

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