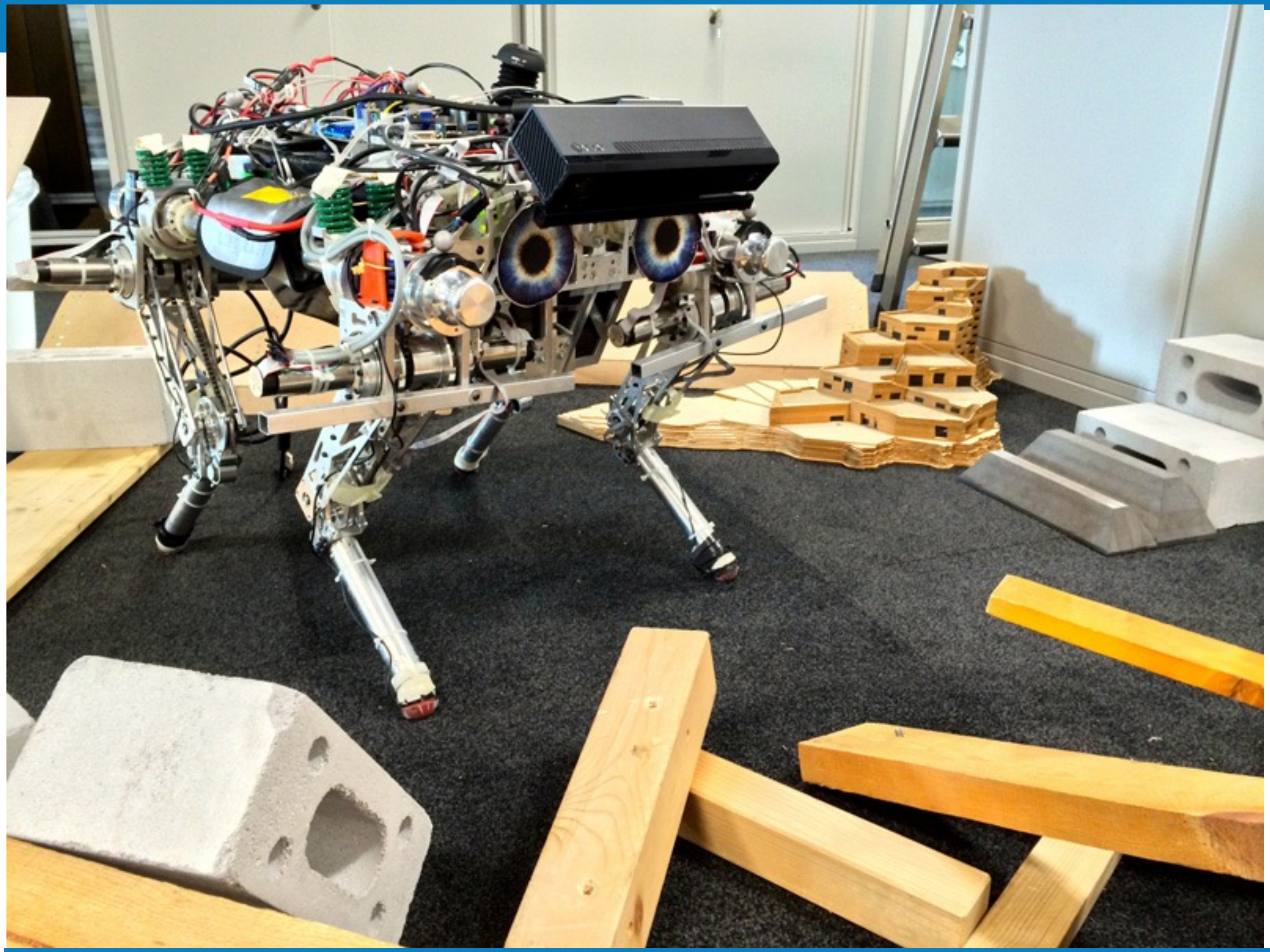


Source: heise.de

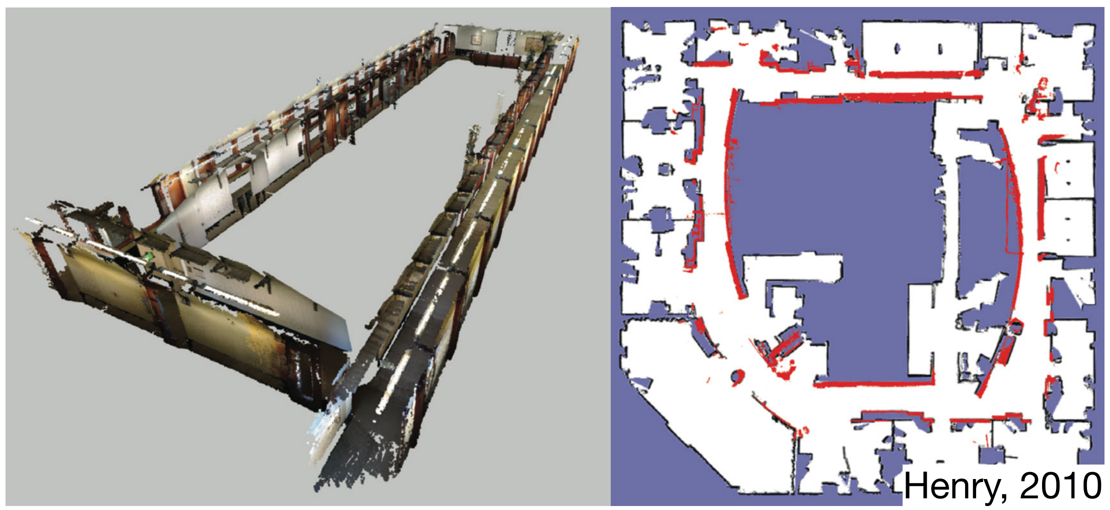
Kinect v2 for Mobile Robot Navigation

Evaluation and Modeling

Péter Fankhauser
Michael Bloesch, Diego Rodriguez,
Ralf Kaestner, Marco Hutter, Roland Siegwart

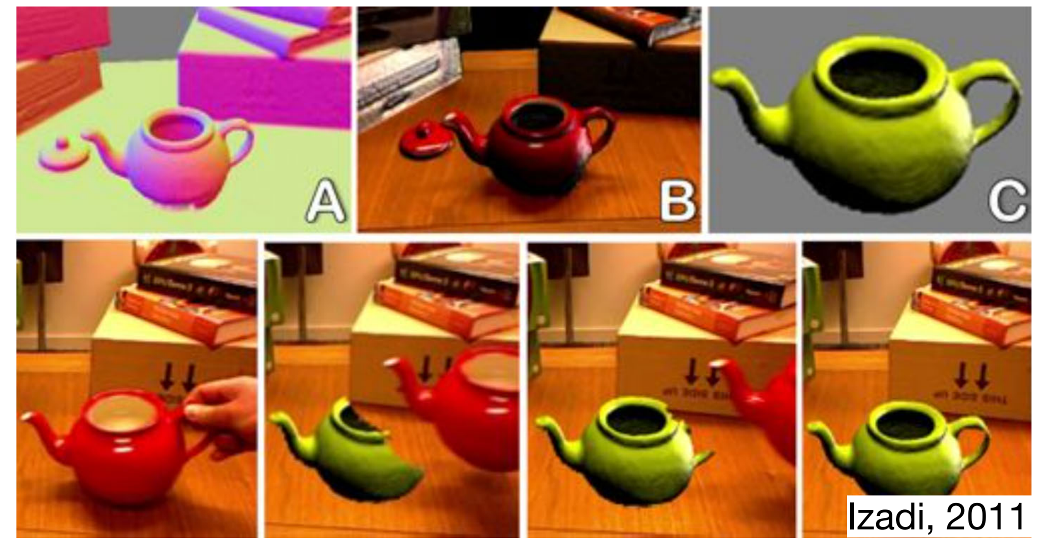
Microsoft Kinect

High quality, low-cost depth sensor



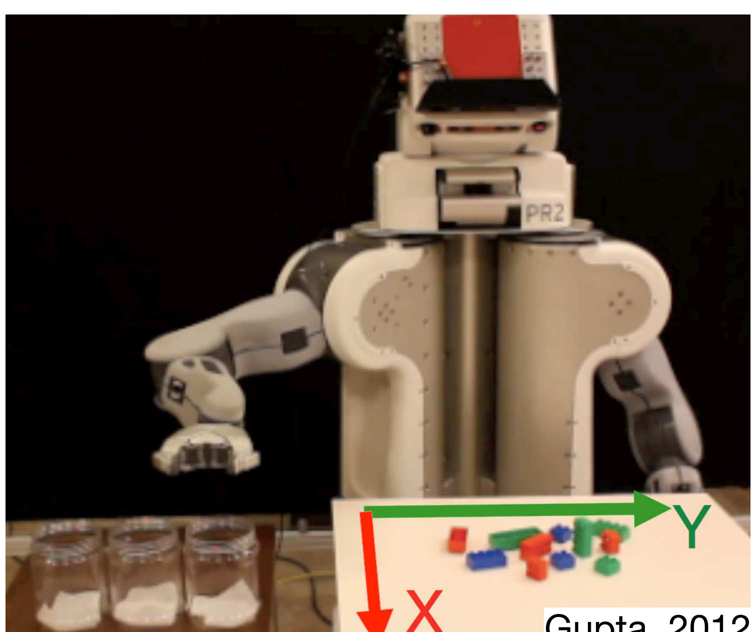
Henry, 2010

Localization & Mapping



Izadi, 2011

Object Reconstruction & Recognition



Gupta, 2012

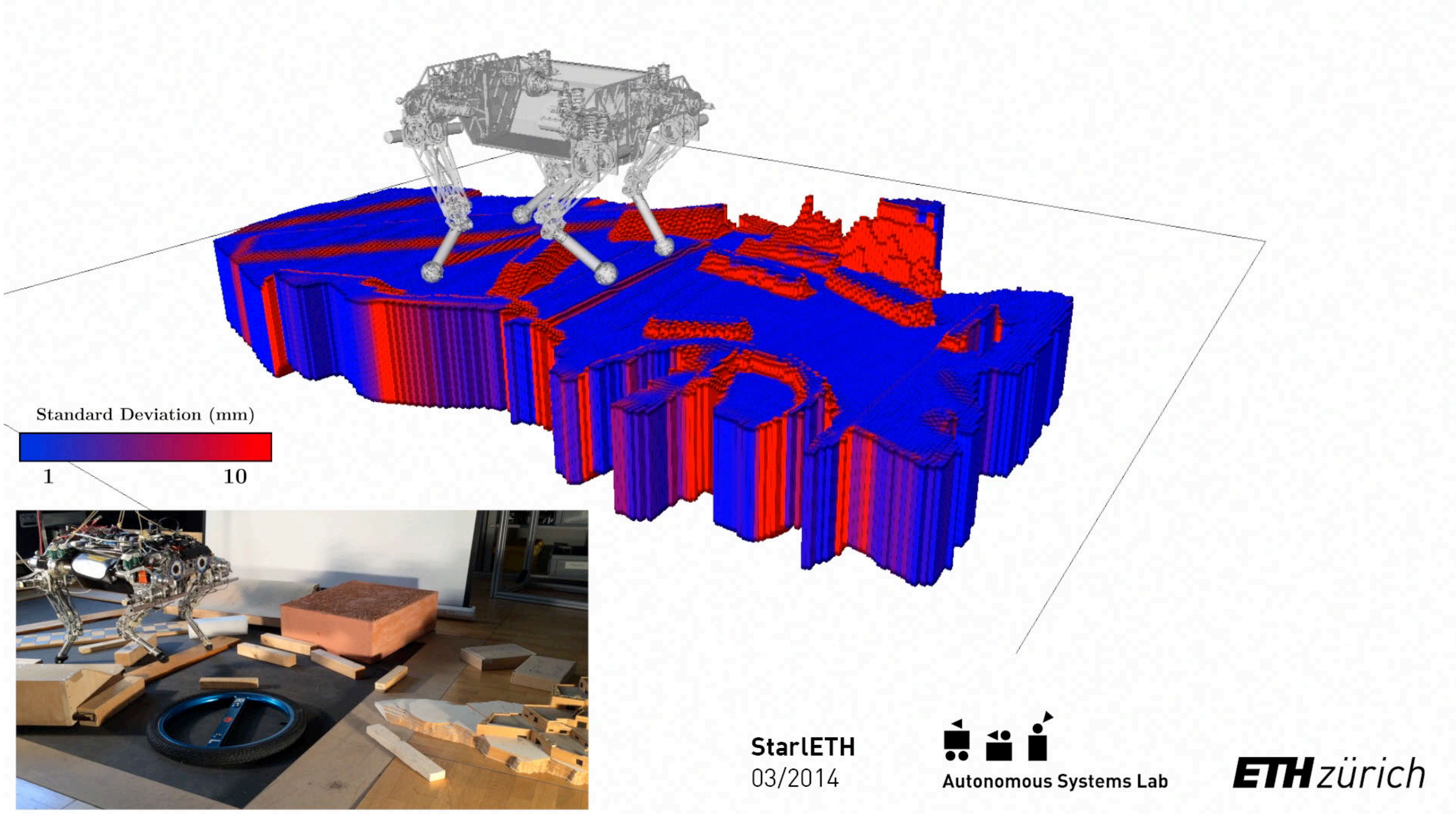
Manipulation

Flacco, 2012

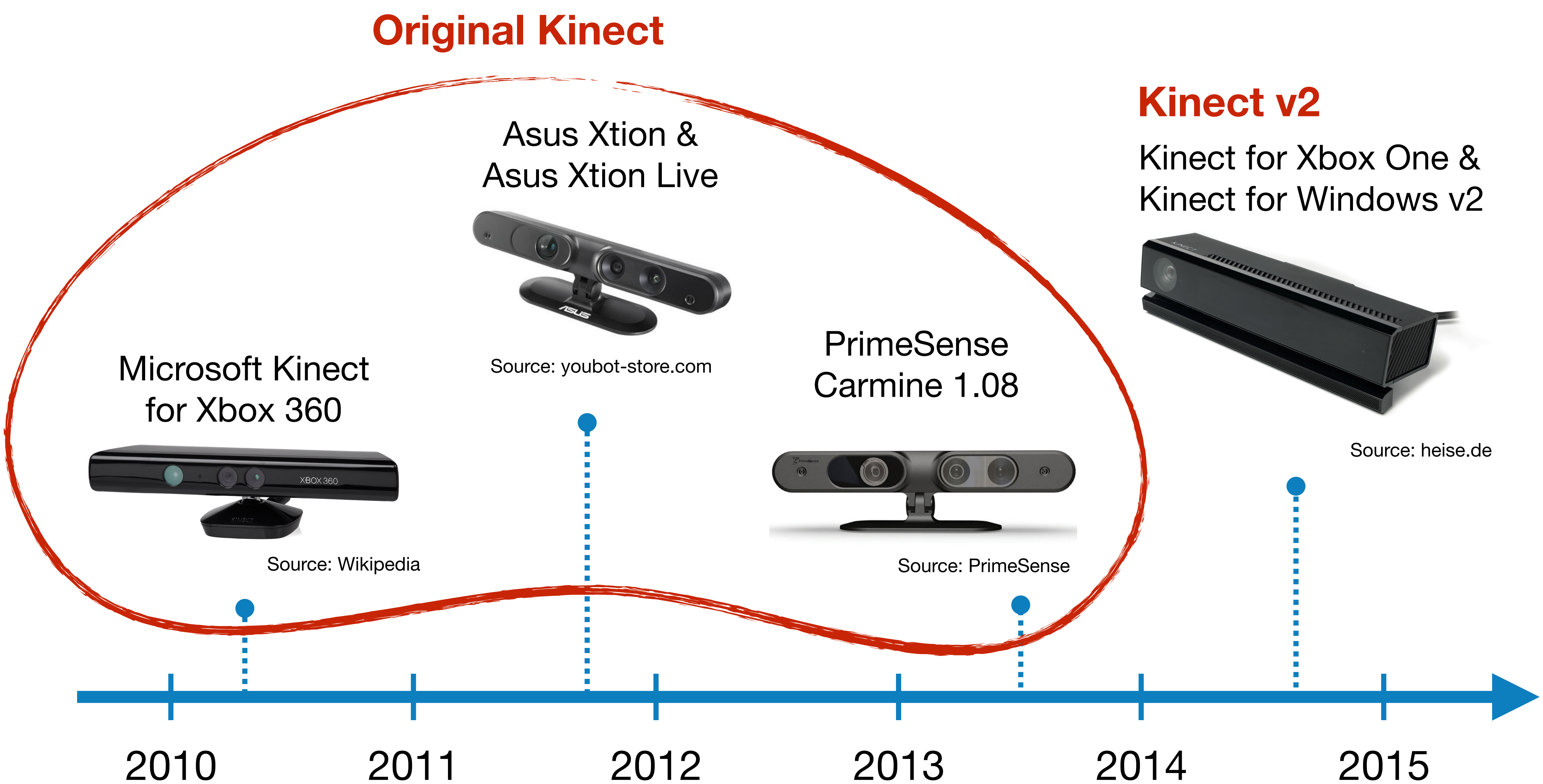
Human Robot Interaction

Robot-Centric Elevation Mapping

P. Fankhauser, M. Bloesch, C. Gehring, M. Hutter, and R. Siegwart, "**Robot-centric elevation mapping with uncertainty estimates"**, in Climbing and Walking Robots (CLAWAR), 2014.



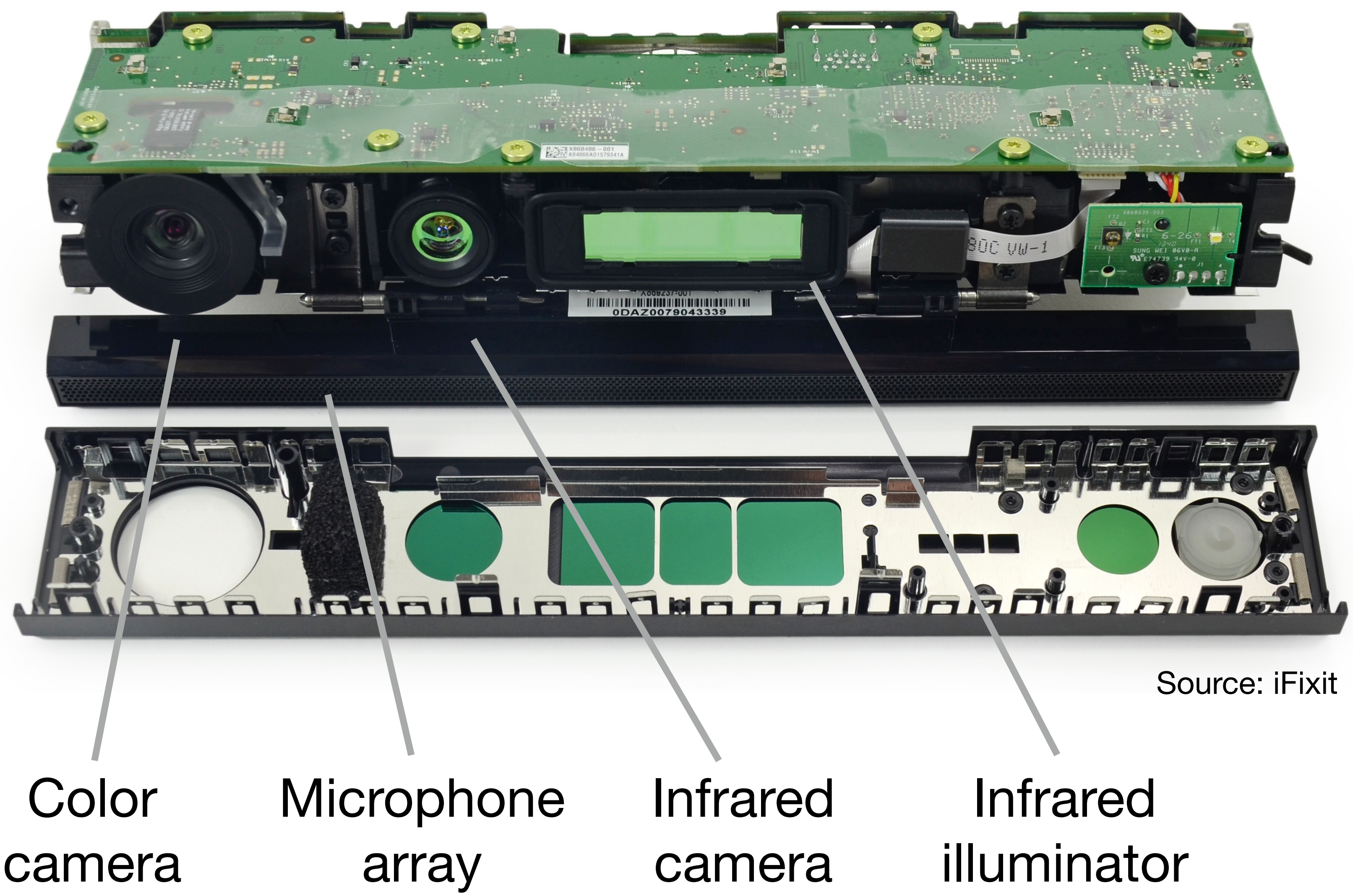
The Kinect Family



Overview

- Kinect v2 Overview
- Noise Modeling
  - Indoor
  - Overcast
  - Sunlight
- Short Range Evaluation
- Comparison

Kinect v2
Sensor Components



Source: iFixit

Kinect v2

Sample Images

RGB

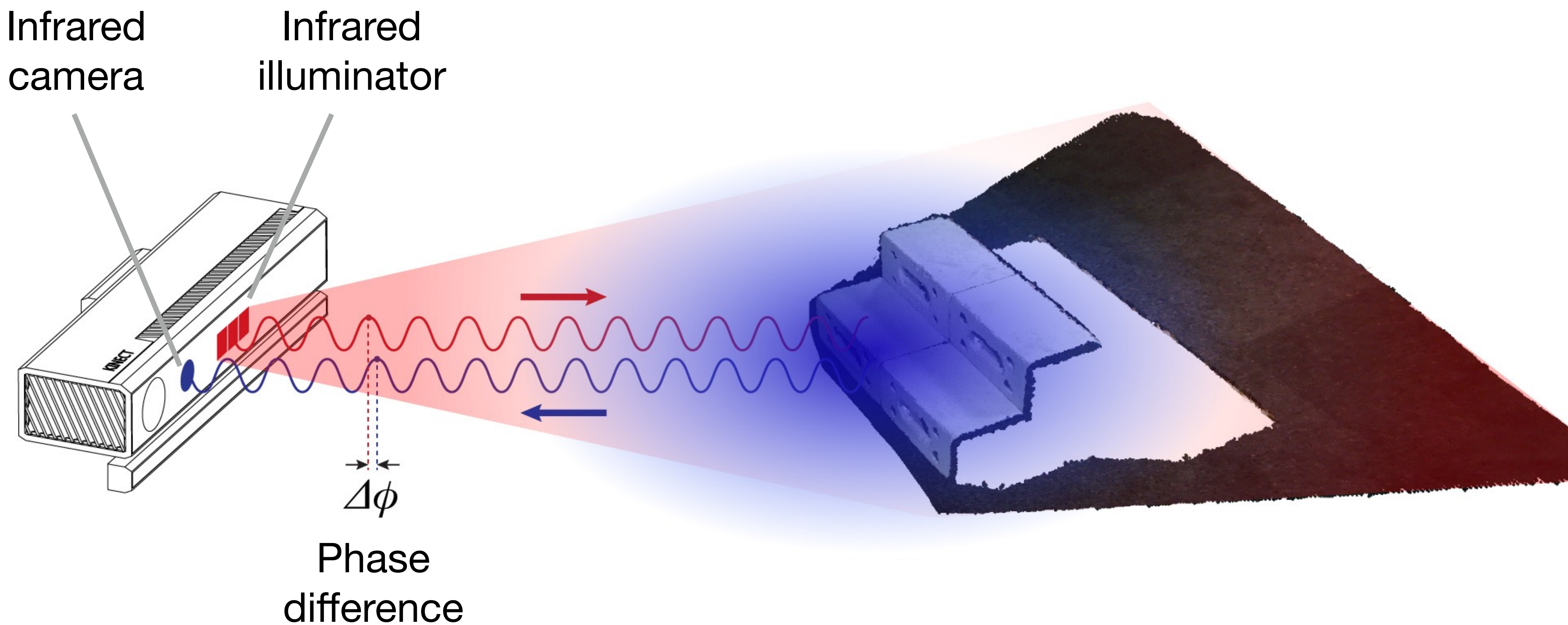
Infrared

with active IR illumination

Depth

Source: XboxViewTV

Kinect v2
Time of Flight (ToF) Measurement Principle



Original Kinect
Structured Light Measurement Principle

Source: Wikipedia

Source: PrimeSense

Source: hackengineer.com

Kinect v2
Depth Camera Specifications

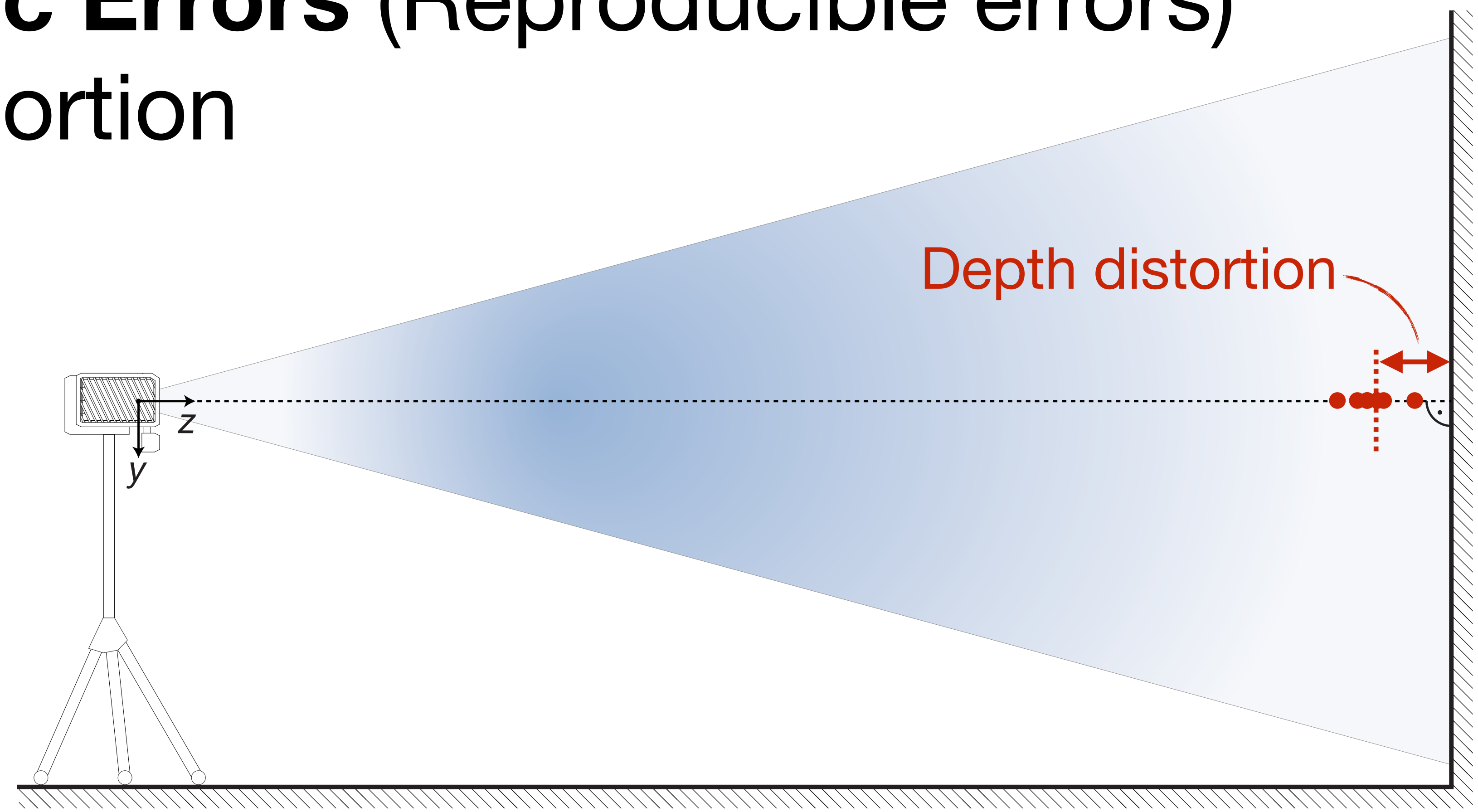
	Original Kinect: PrimeSense Carmine 1.08	Kinect v2
Measurement Principle	Structured Light	Time-of-Flight
Resolution	320 × 240 px	512 × 424 px
Field of view (h × v)	58° × 45°	71° × 60°
Operating range	0.8–3.5 m	0.5–4.5 m
Frame rate	30 Hz	30 Hz
Dimensions (w × d × h)	180 × 35 × 25 mm	249 × 66 × 67 mm
Mass	160 g	970 g
Power usage	2.25 W	~15 W

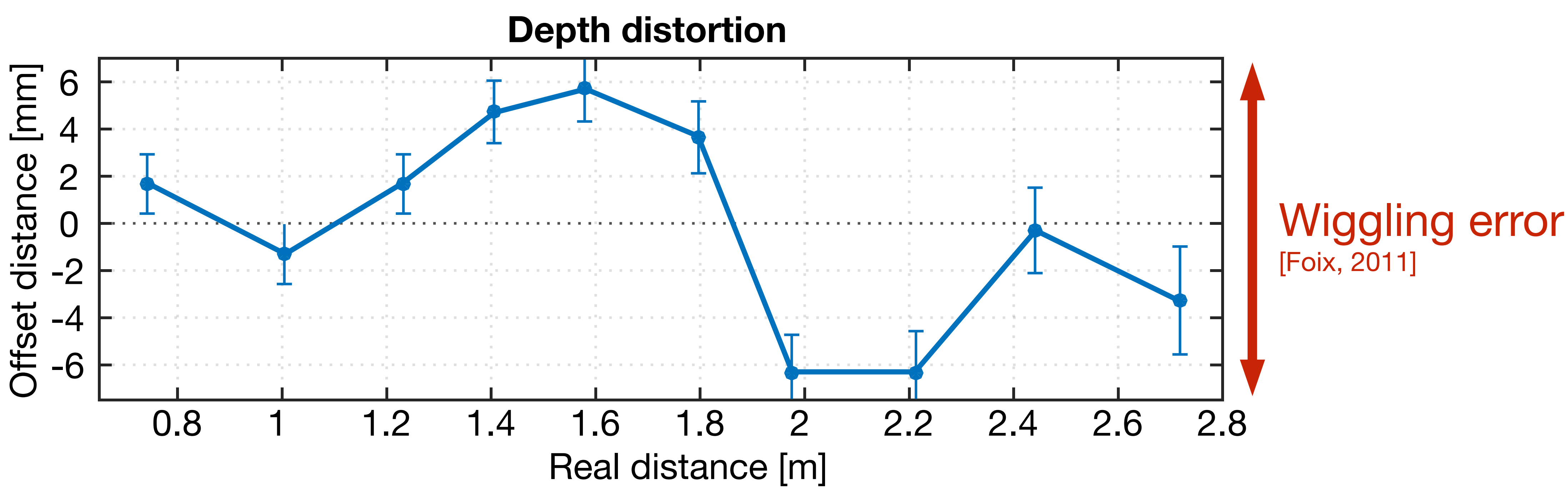
Systematic Errors
Calibration

Wiedemeyer, 2015

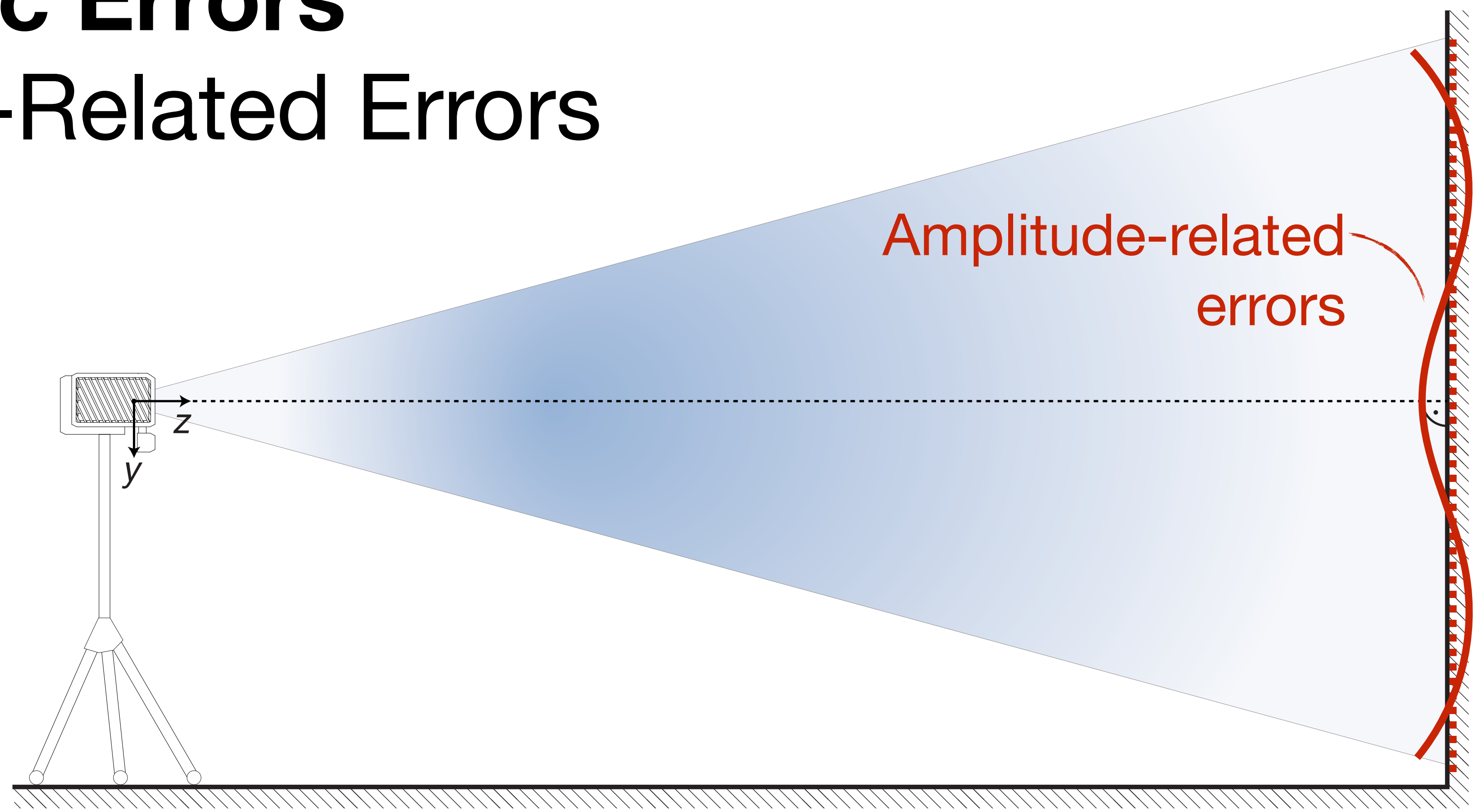
- Intrinsics calibration of the IR camera
- OpenCV calibration
- Warm up time 20 min

Systematic Errors (Reproducible errors)
Depth Distortion

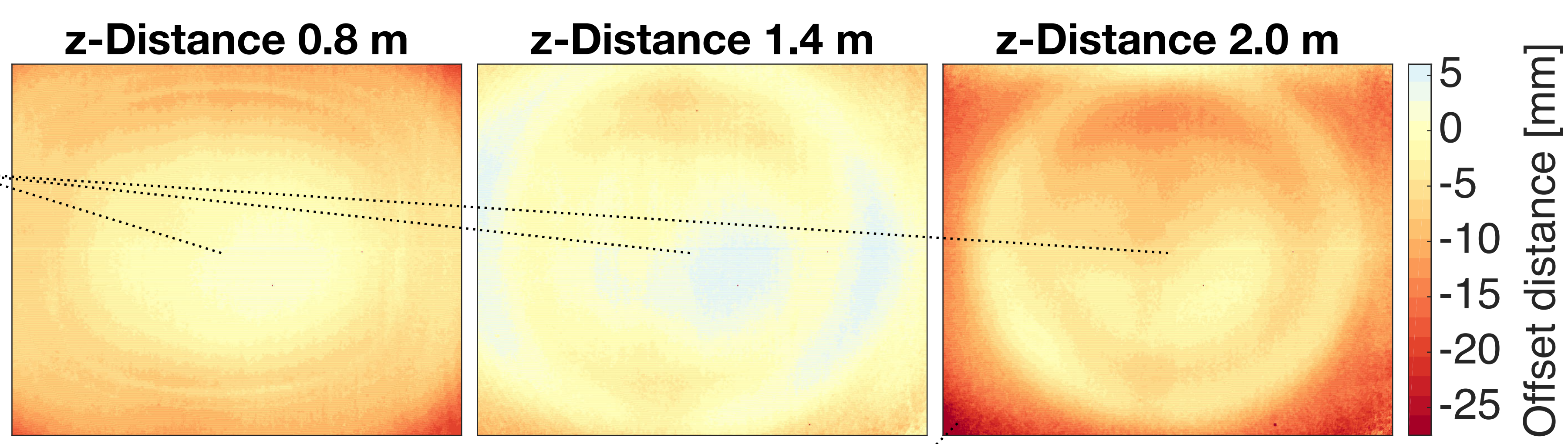




Systematic Errors
Amplitude-Related Errors

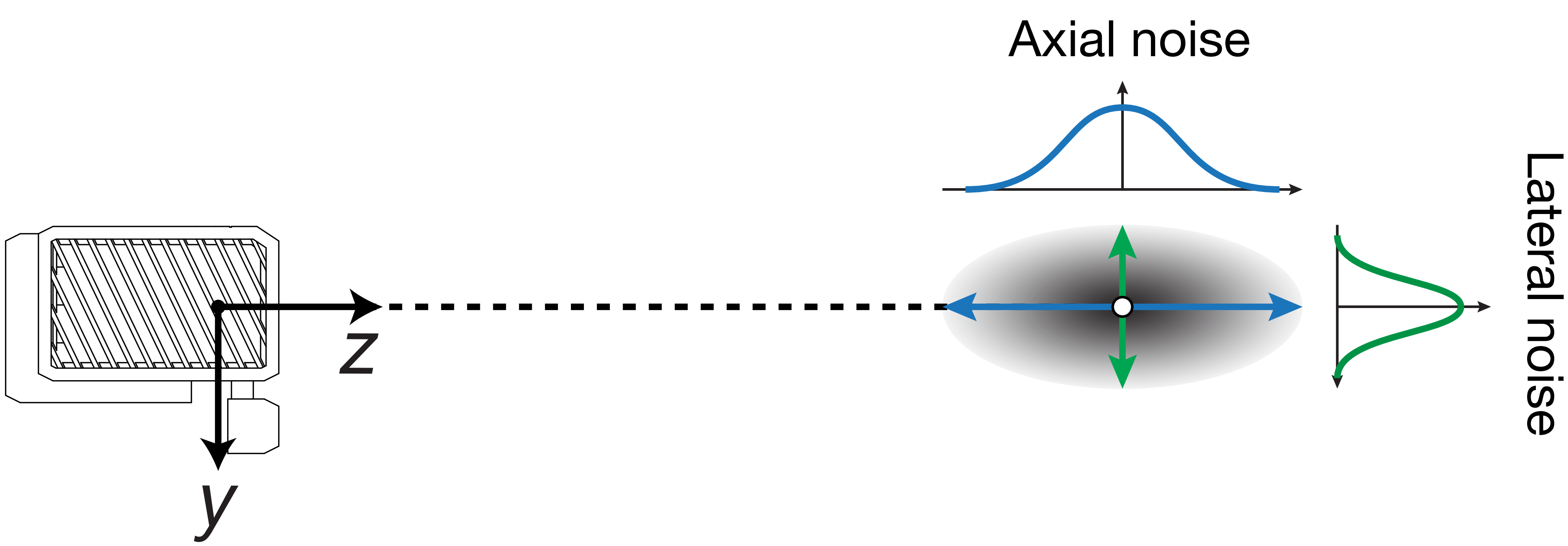


Error ±6 mm at centers



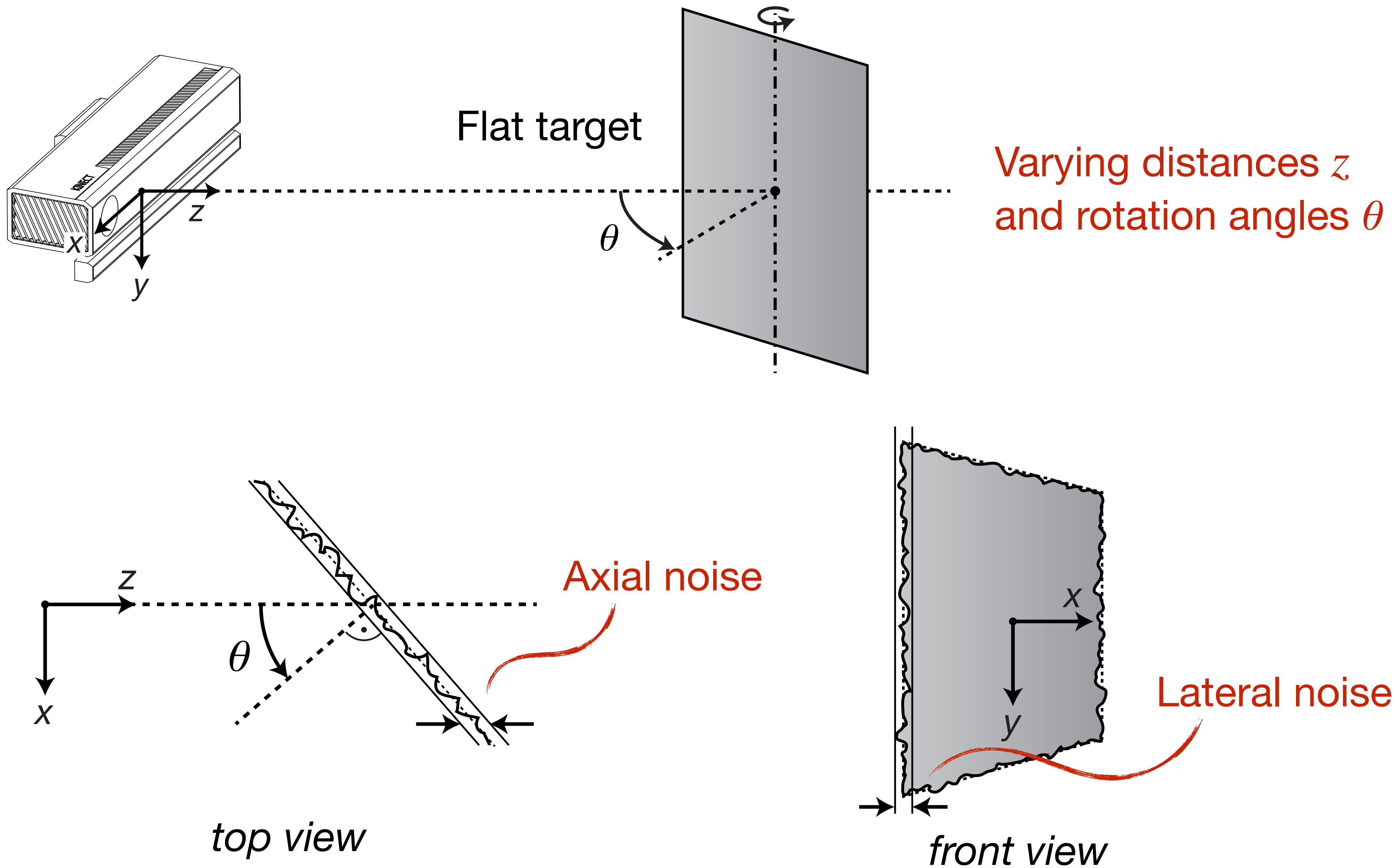
Error up to 30 mm at edge

Noise Modeling
Overview



Nguyen, C. V., Izadi, S., & Lovell, D., “**Modeling Kinect Sensor Noise for Improved 3D Reconstruction and Tracking**”, in International Conference on 3D Imaging, Modeling, Processing, Visualization and Transmission, 2012.

Noise Modeling
Experimental Setup

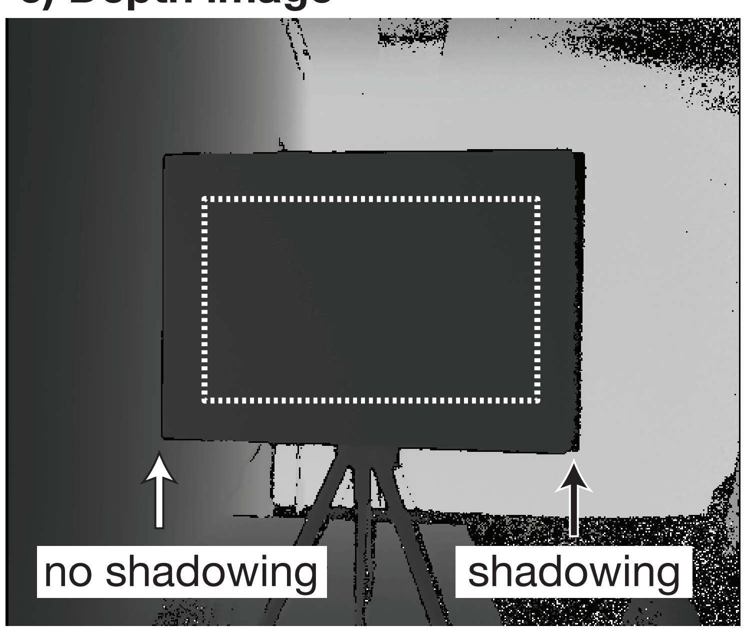


Noise Modeling
Experimental Setup

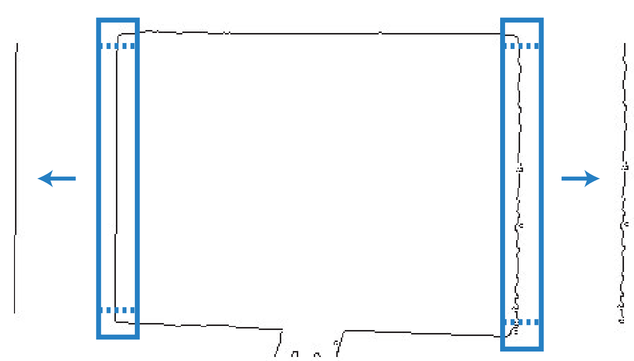
a) Color image

b) Infrared image

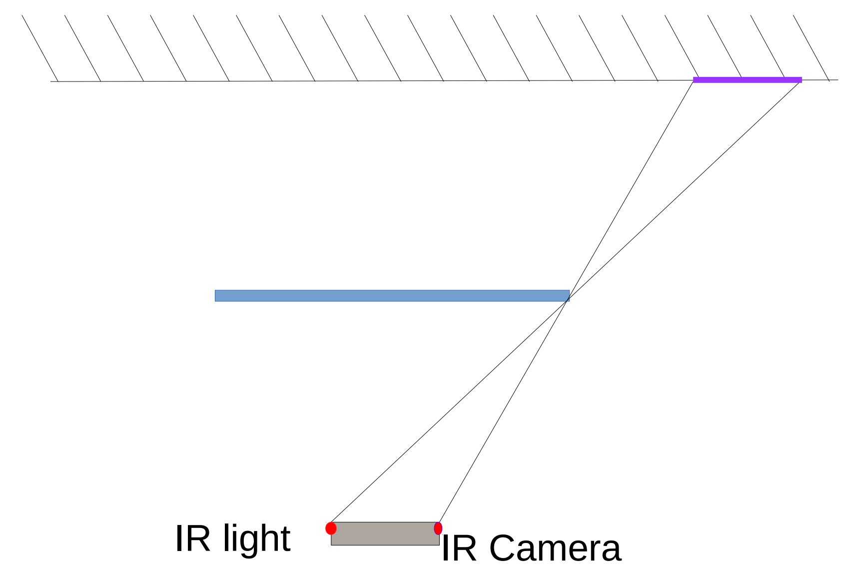
c) Depth image



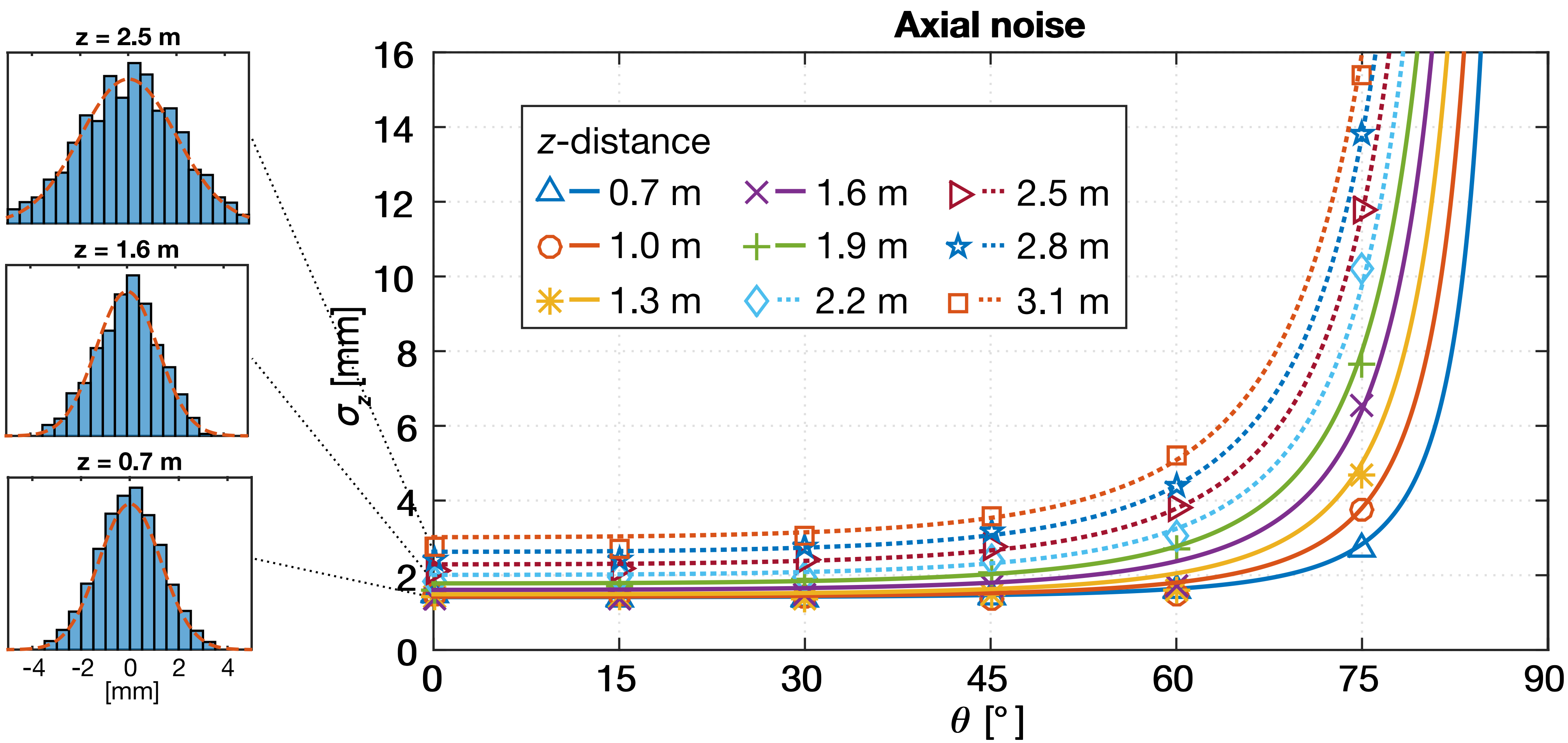
d) Extraction of lateral noise



no shadowing shadowing

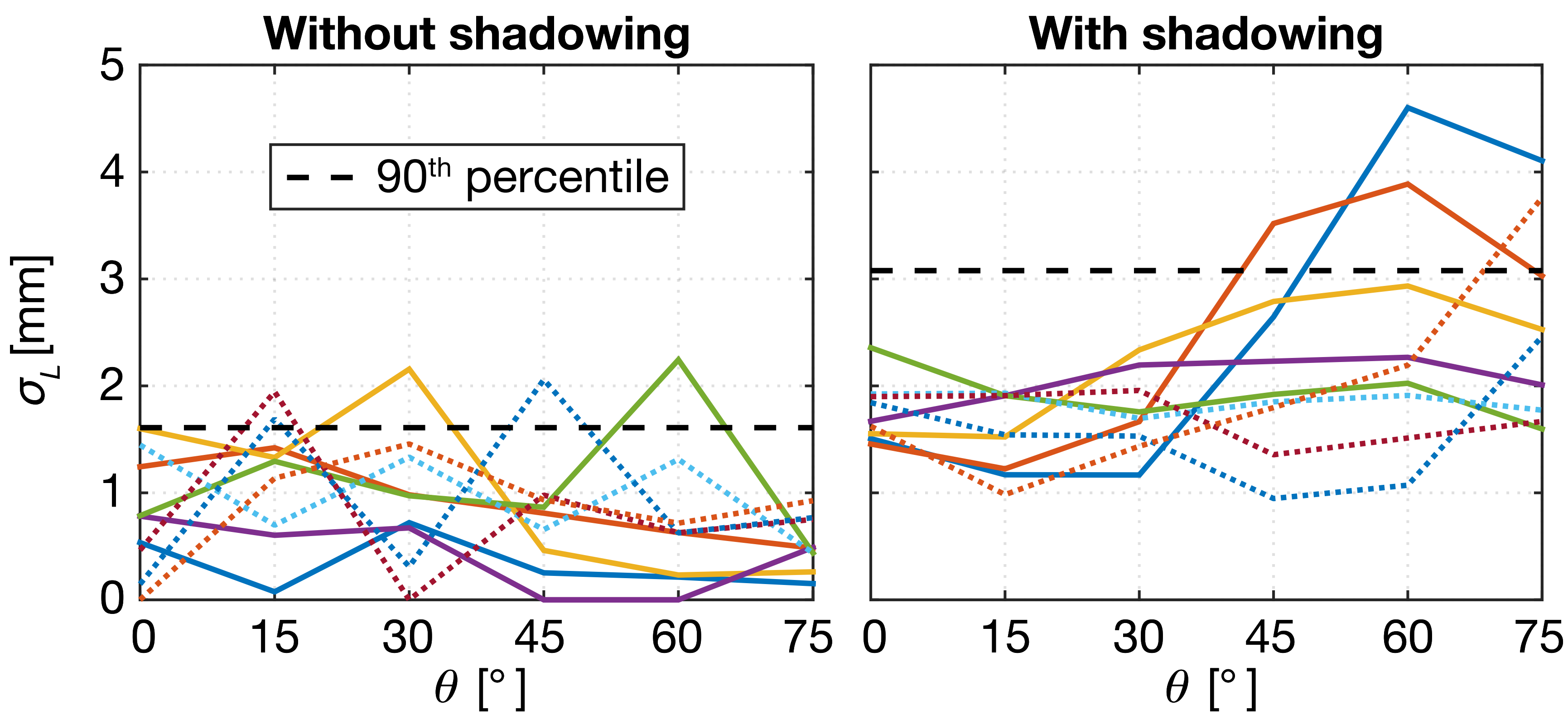


Noise Modeling
Axial Noise Model



Normal distribution approximation		**RMSE**
Indoor	$\sigma_z(z,\theta)[\mathrm{mm}] = 1.5 - 0.5z + 0.3z^2 + 0.1z^{\frac{3}{2}} \dfrac{\theta^2}{(\frac{\pi}{2}-\theta)^2}$	0.0002 mm

Noise Modeling
Lateral Noise Model

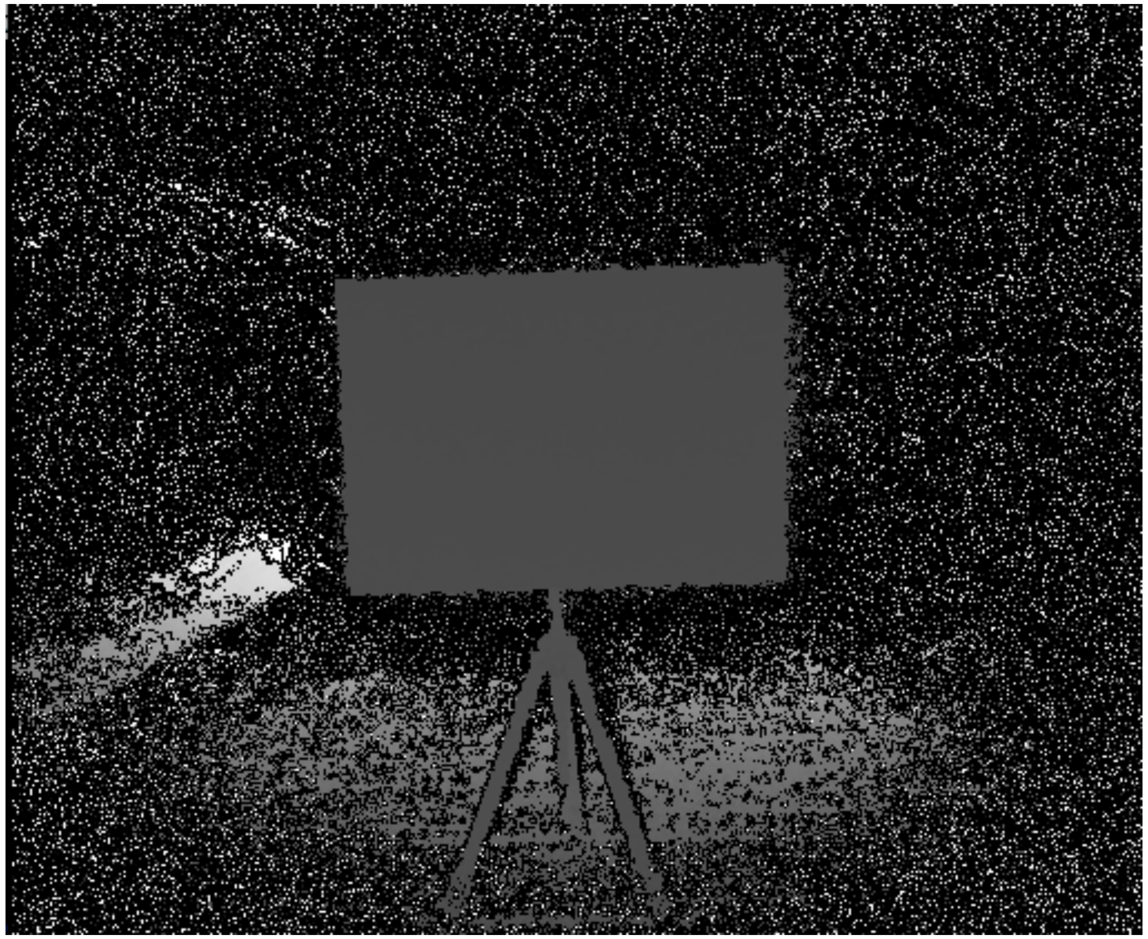


90th percentile:

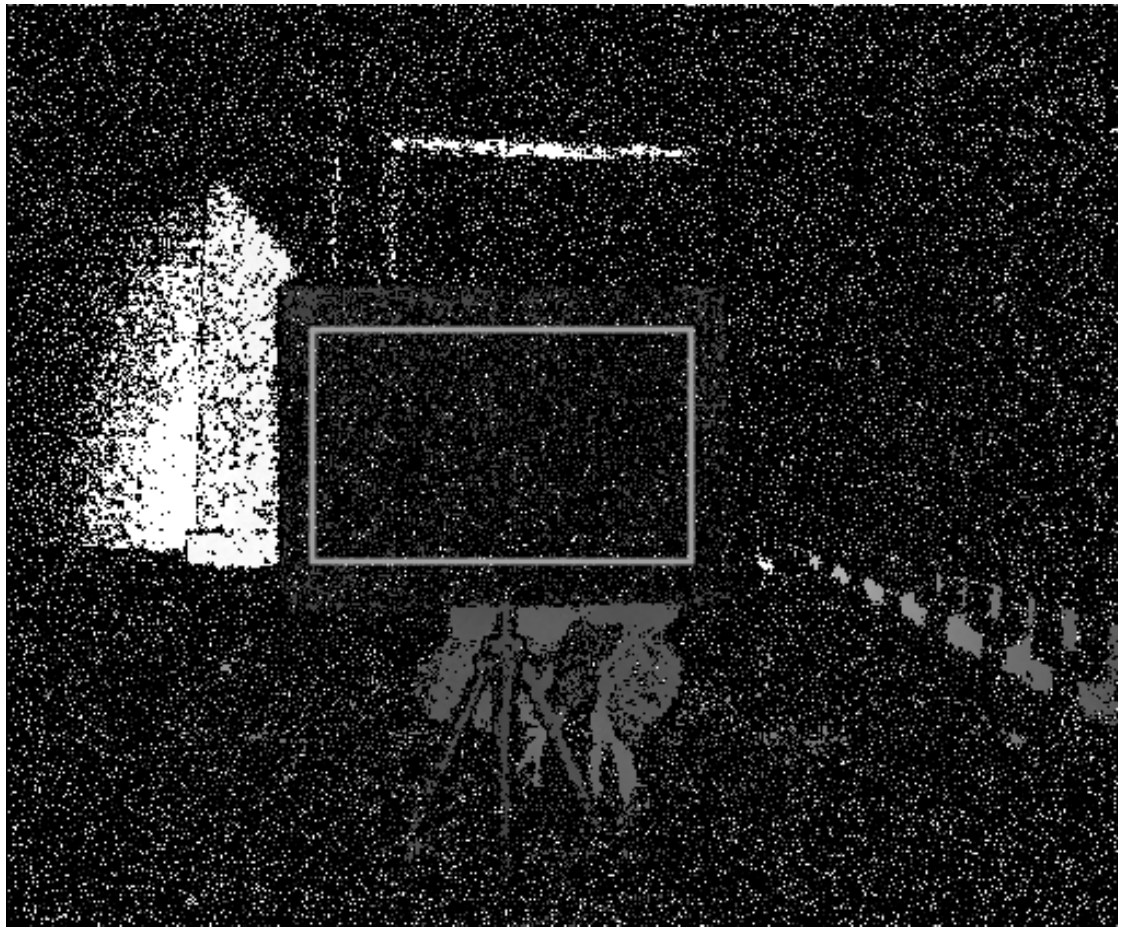
Indoor	$\sigma_L = 1.6\,\mathrm{mm}$	$\sigma_L = 3.1\,\mathrm{mm}$
Overcast	$\sigma_L = 6.8\,\mathrm{mm}$	$\sigma_L = 6.8\,\mathrm{mm}$

Noise Modeling
Outdoor Data Quality

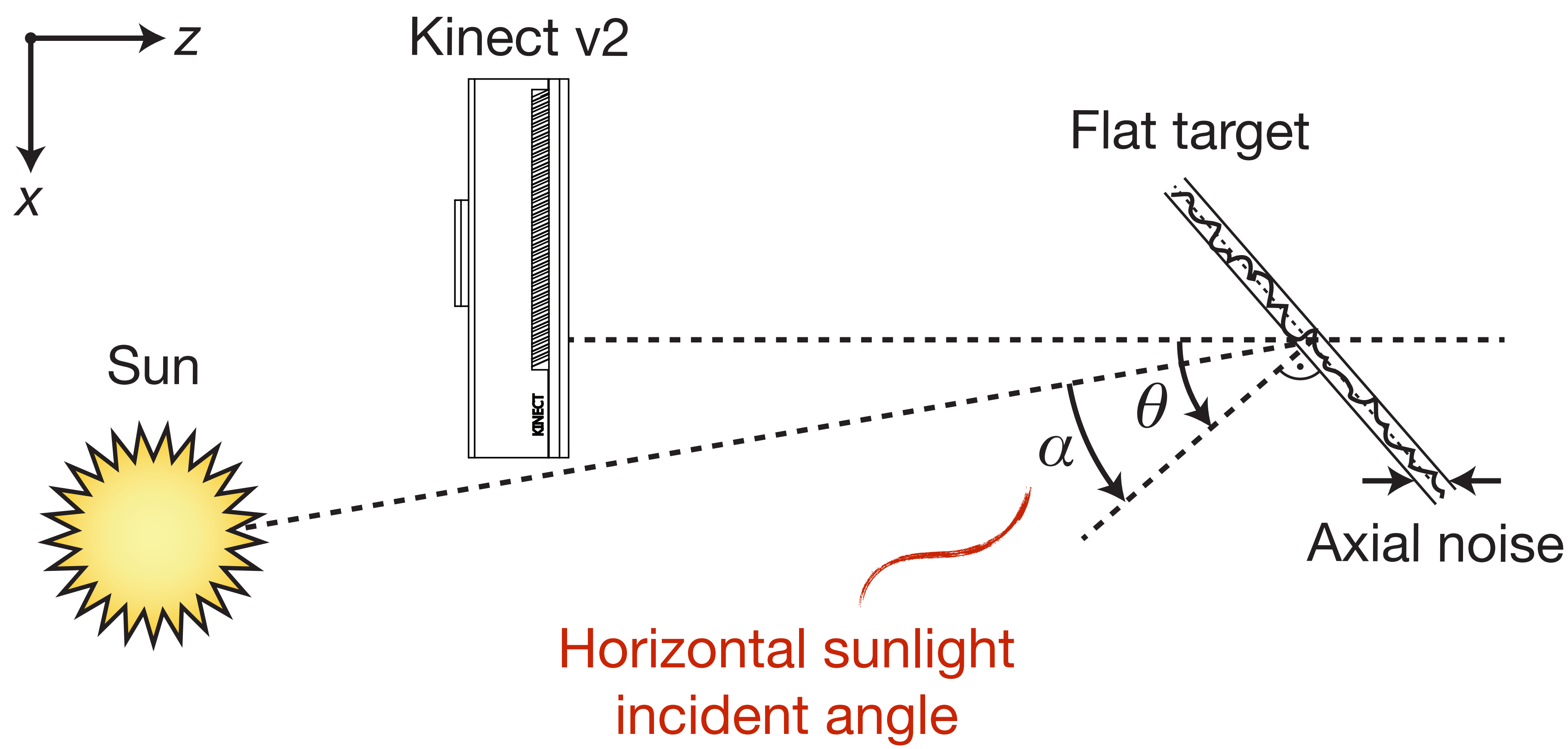
Overcast (1–12 kLux)



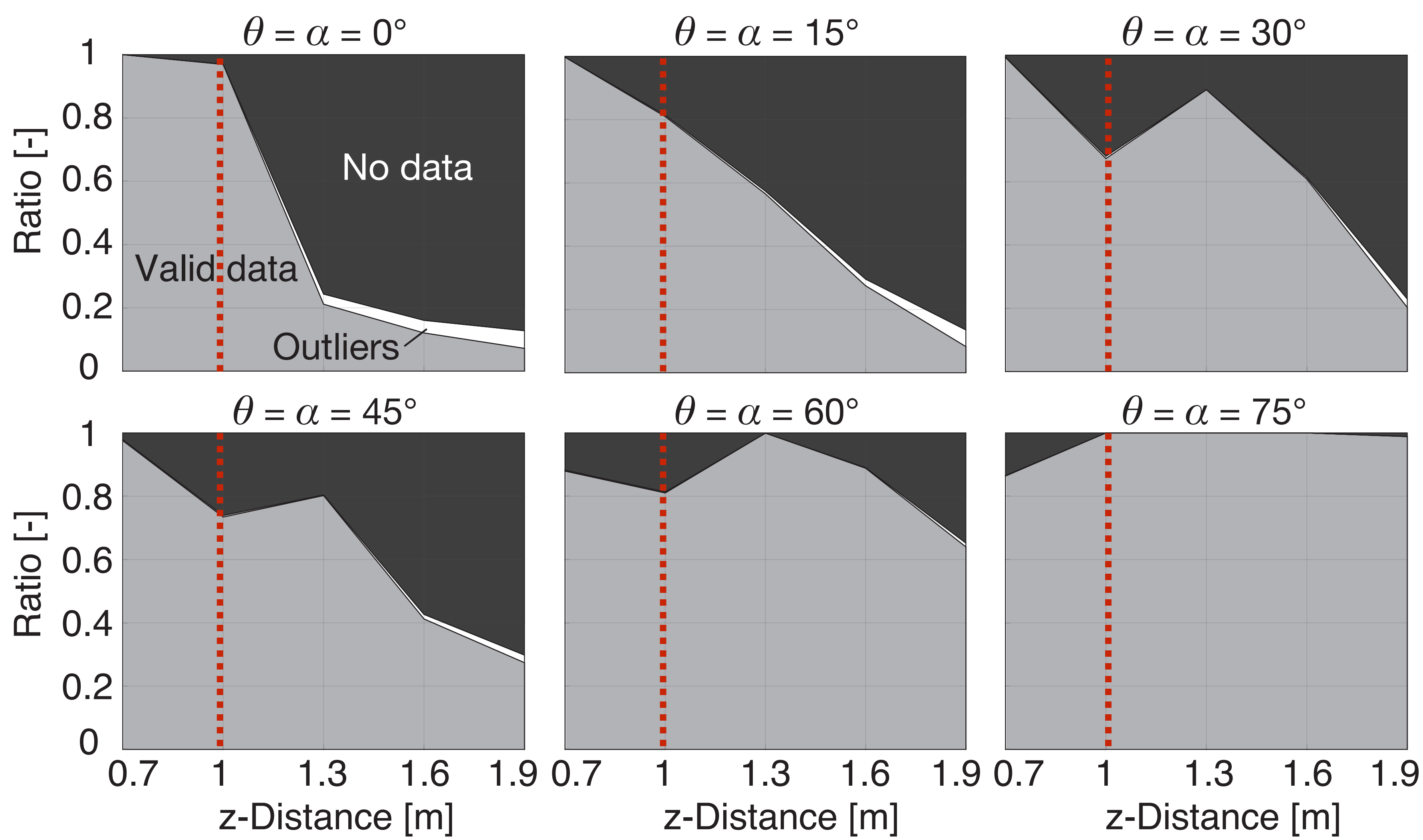
Direct sunlight (85–95 kLux)



Noise Modeling
Experimental Setup Outdoor

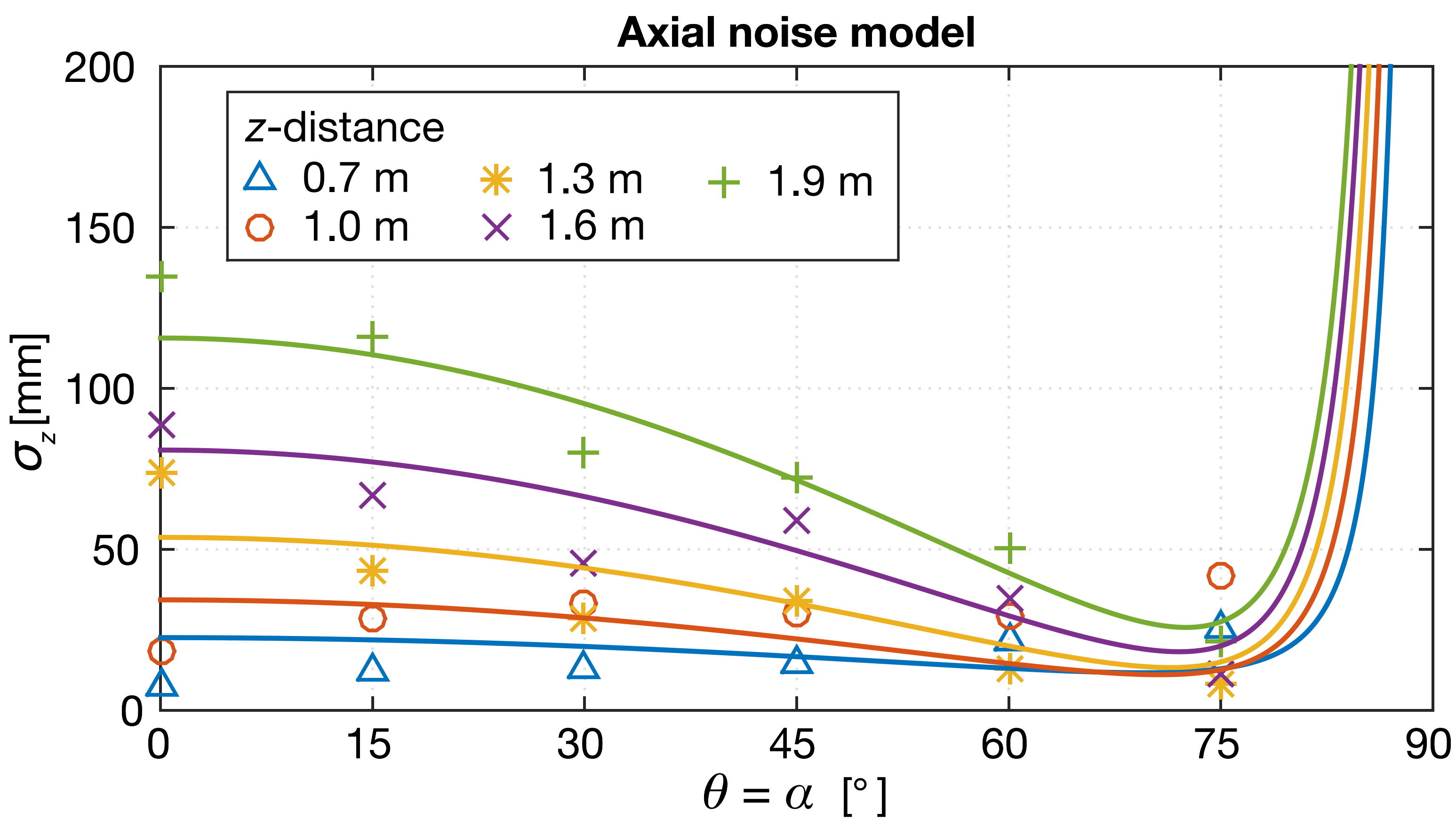


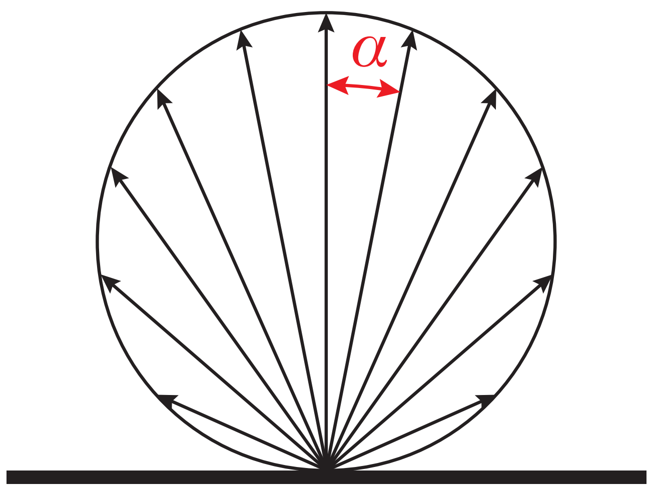
Noise Modeling
Direct Sunlight Data Quality



- ➡ More direct incidence angle (e.g. $\alpha = 0°$) leads to degradation of data.
- ➡ Reliable data up to distance z = ~1 m for all incidence angles α.

Noise Modeling
Direct Sunlight Noise Model





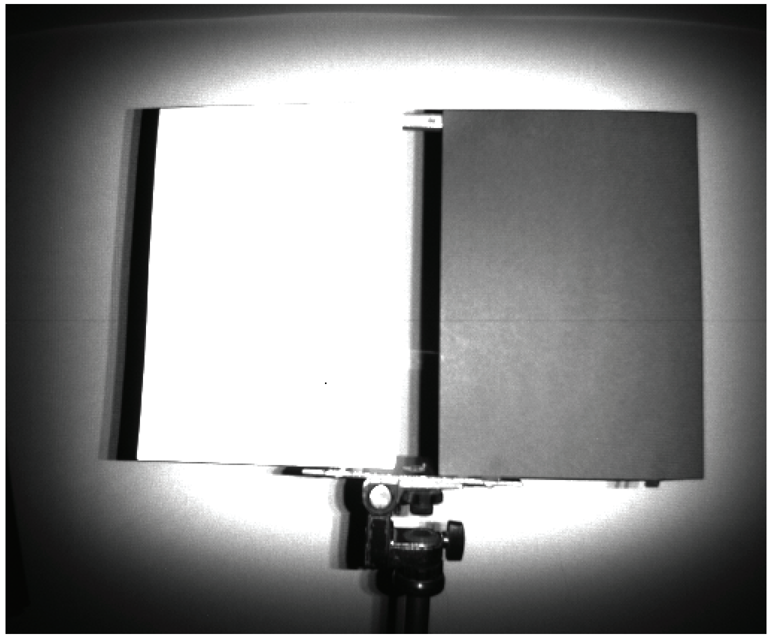
Normal distribution approximation

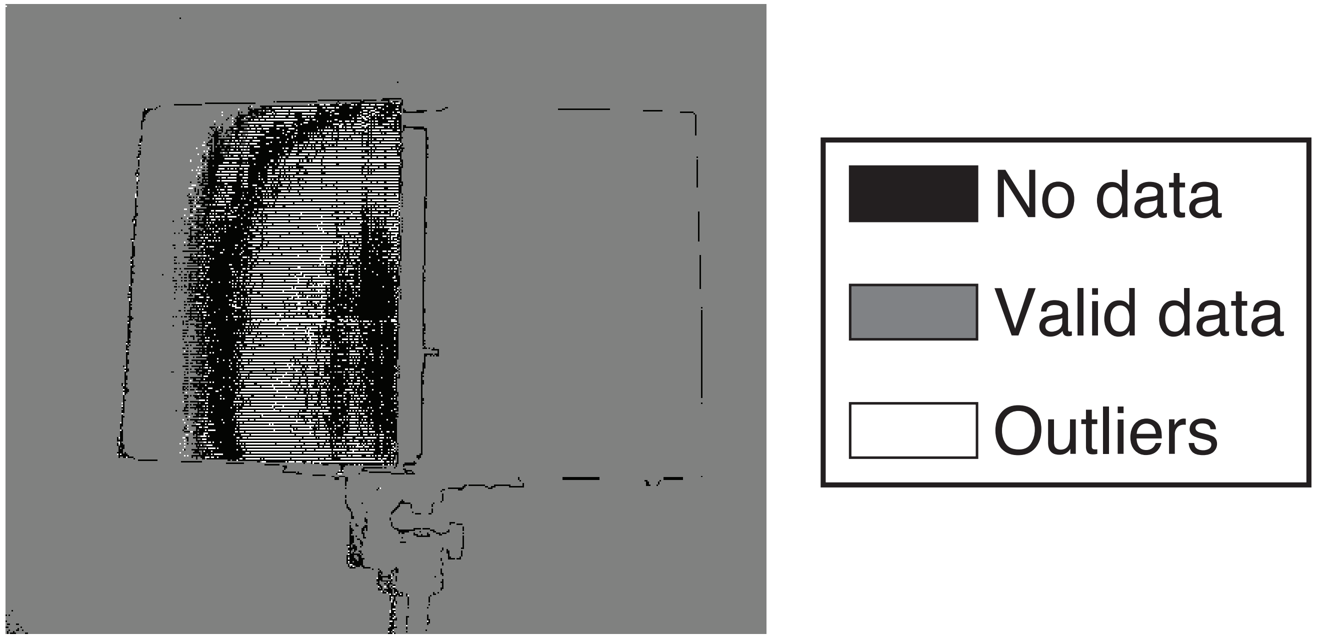
$$\sigma_z(z, \theta, \alpha)[\mathrm{mm}] = 28 - 38z + 2.0z^2 + 0.3z^{\frac{3}{2}} \frac{\theta^2}{(\frac{\pi}{2} - \theta)^2} + 42z^2 \cos\alpha$$

RMSE

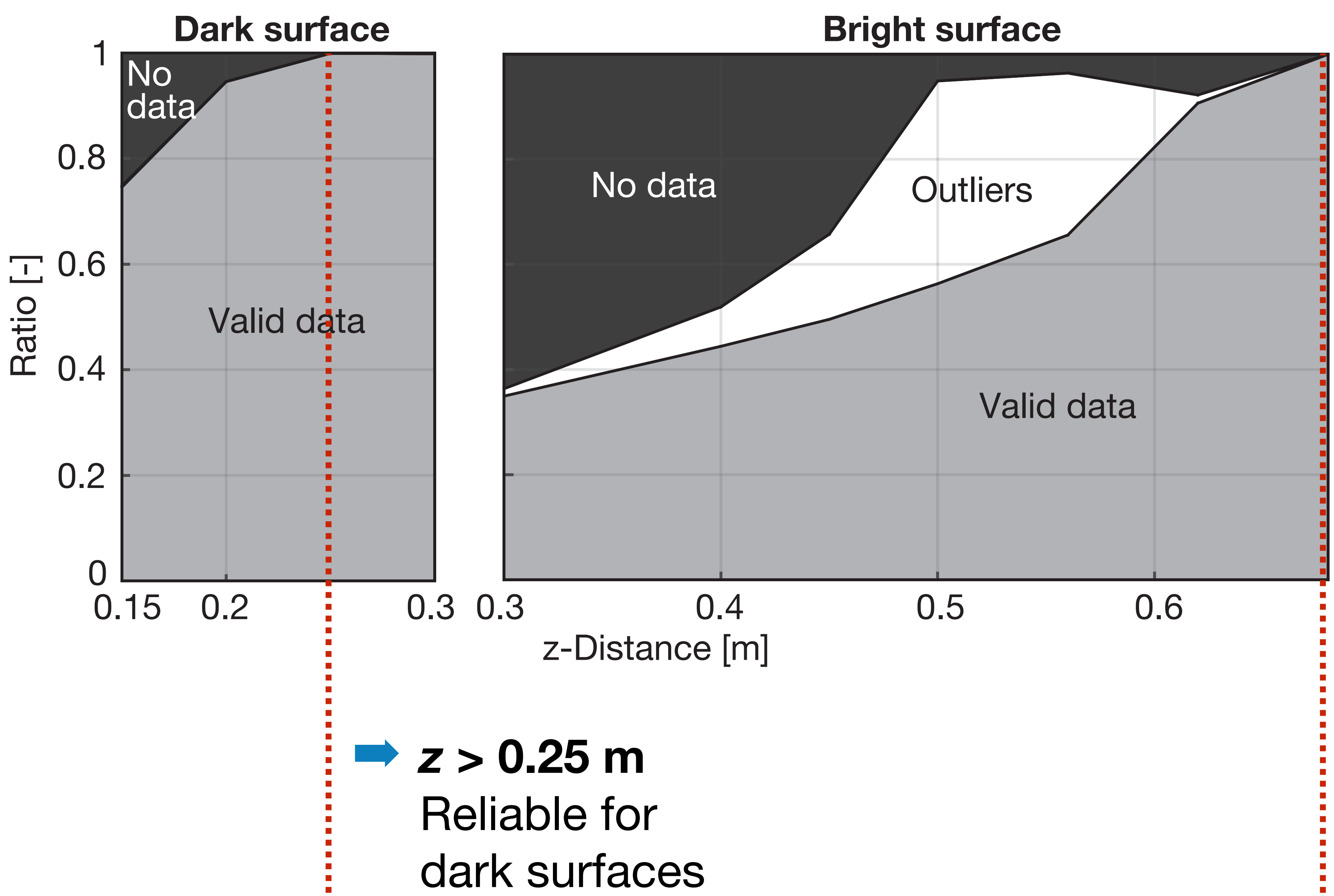
4.4 mm

Short Range Evaluation
Example





Short Range Evaluation
Analysis



➡ ***z* > 0.25 m**
Reliable for dark surfaces

➡ ***z* > 0.7 m**
Reliable for bright surfaces

Numerical Comparison

		Original Kinect	Kinect v2		
A: $z = 1.0$ m, $\alpha = \theta = 45°$ **B:** $z = 2.8$ m, $\alpha = \theta = 10°$		**Indoors**	**Indoors**	**Overcast**	**Sunlight**
Axial noise	**A**	2.0 mm	1.4 mm	3.2 mm	22 mm
	B	12 mm	2.5 mm	7.6 mm	–
Lateral noise	**A**	1.4 mm	1.6 / 3.1 mm	6.8 mm	–
	B	3.9 mm	1.6 / 3.1 mm	6.8 mm	–
Valid data	**A**	–	100%	100%	73%
	B	–	100%	100%	0%

- ➡ **Axial noise:** Significantly less noise for Kinect v2, especially at larger distances (configuration B)
- ➡ **Later noise:** Similar performance
- ➡ **Overcast:** Up to 2–3× amplification of noise
- ➡ **Sunlight:** Highly depending on distance and sunlight incidence angle, increase of noise by ca. order of magnitude

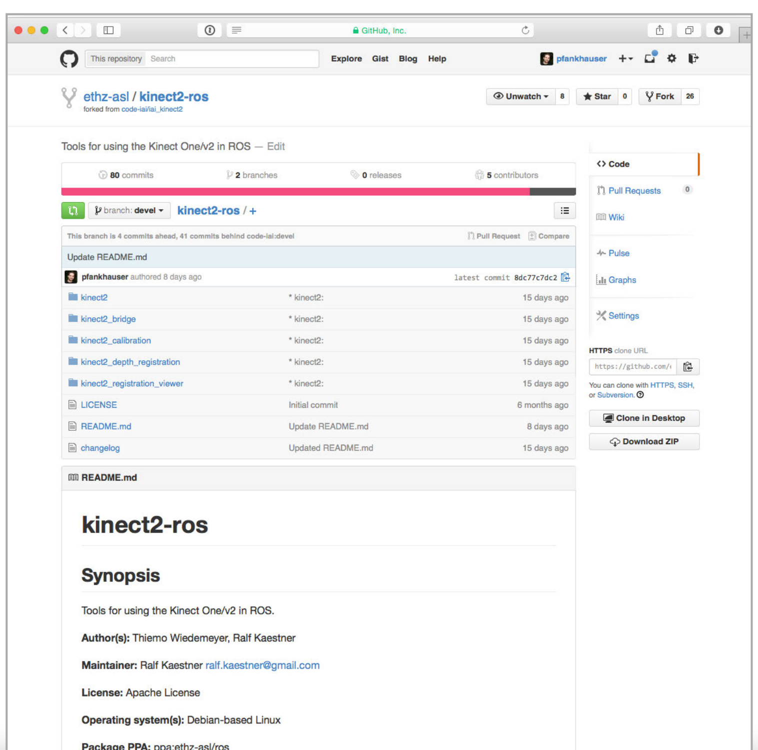
Summary

+ **Robust depth measurements** even in textureless or poorly lit scenes
+ **Vast amount of dense data** (6.5 mio. points/s)
+ **Improvement for outdoor/sunlight scenes**
+ **Competitive price** (~200 USD)

! **Bigger size**, **higher mass** (1 kg), and **increased power consumption** (15 W)
! **Minimal range can be dangerous** with close obstacles
! **Presence of outliers** in non-ideal conditions requires robust post processing

Future Work

- Switching between noise models (based on light intensity sensor?)
- Detection of sun incidence angle
- Extended calibration



Kinect v2 Driver
Package based installation for ROS
https://github.com/ethz-asl/kinect2-ros

```
sudo apt-get install ros-indigo-kinect2
```

Software based on:
T. Wiedemeyer, “IAI Kinect2,” https://github.com/code-iai/iai_kinect2, Institute for Artificial Intelligence, University Bremen, 2014 – 2015, accessed July 29, 2015.