Impact of Thermal and Environmental Conditions on the Kinect Sensor

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Motivation

- Using the Kinect as a range sensor is very popular
- Many calibration approaches exist to increase the quality of the range data
- The RGB-Sensor is often involved in the calibration process

Problem: Depth and RGB sensor are both sensitive to thermal and environmental changes

Consequence: Disregarding this problem can lead to invalid calibration results and range measurements

Goal: Analyze the thermal and environmental influence and derive simple rules to reduce/avoid errors

Overview

- Motivation
- Pretests: Thermal influence on optical camera systems
- Experimental setup
- Thermal and environmental influences on distance measurements
  - Practical rules for error reduction
- Summary

Pretests: Thermal influence on optical camera systems

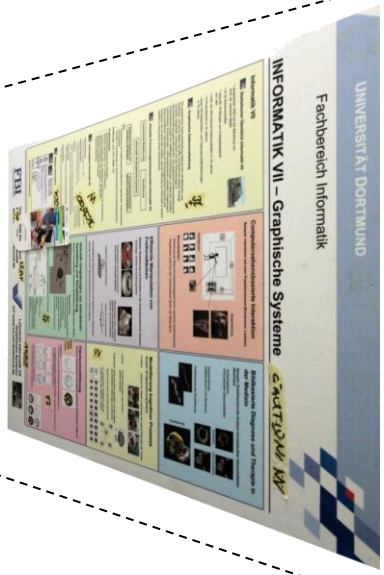
Kinect warm-up phase

warm state

fan off

time

Mounted fan



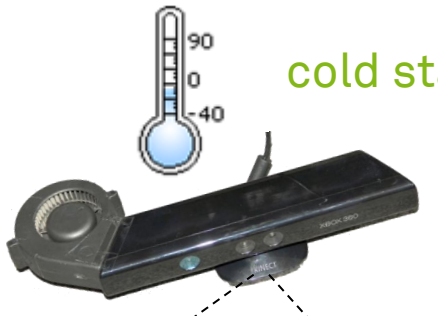
Texture-rich poster

Pretests: Thermal influence on optical camera systems

Kinect warm-up phase

warm state

Kinect cool down phase



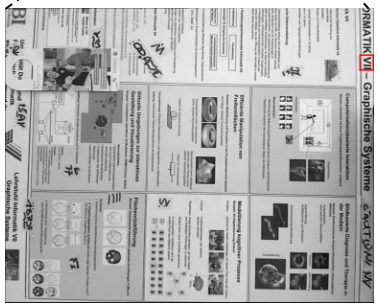
cold state

fan off

fan on

time

RGB Camera



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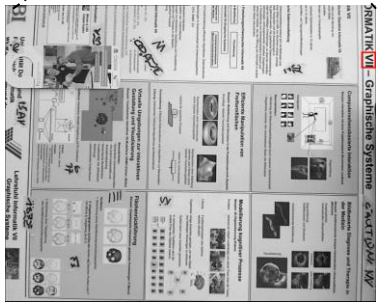
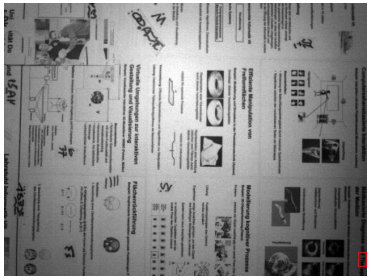


IR Camera



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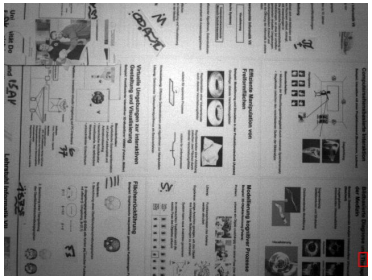
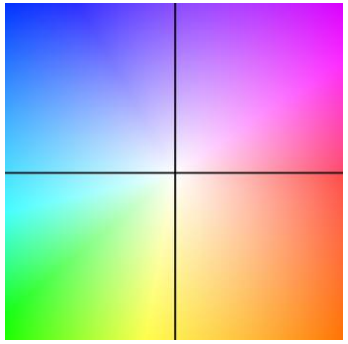


Pretests: Thermal influence on optical camera systems

- Use optical flow approach to visualize the movement within the image
- Color coding of the movement:
  - Hue indicated direction
  - Saturation indicates magnitude



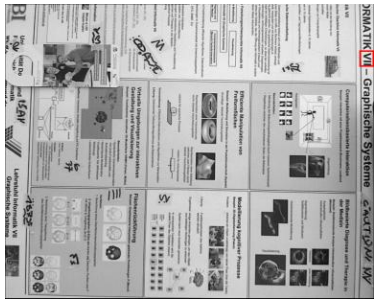
White color:

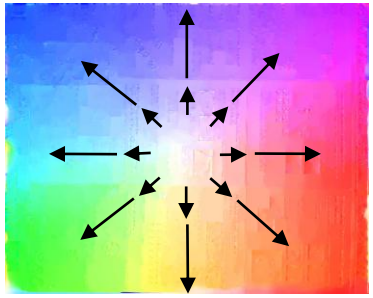
no movement

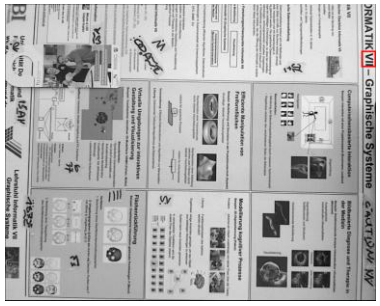
Bruhn A., Weickert J., Schnoerr C.: Lucas/Kanade meets Horn/Schunk: combining local and global optical flow methods.

warm state ← cold state

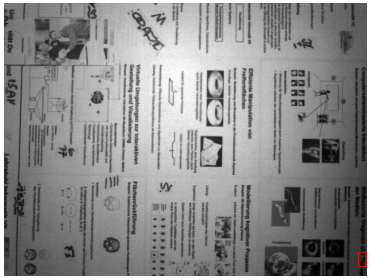
RGB Camera

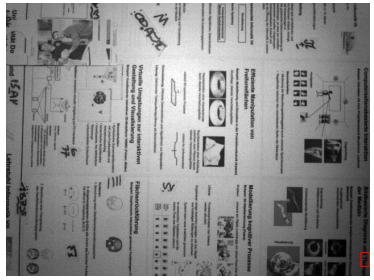






IR Camera





Pretests: Thermal influence on optical camera systems

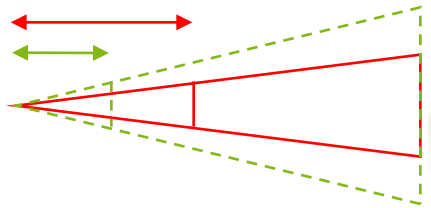
Observation:

Movements during the cold to warm transition are similar to a zoom-in effect

⇨ Perform camera calibration in both heat states

Parameter	f_x	f_y	c_x	c_y	p_1	p_2	p_3	q_1	q_2	Error
RGB										
Cold	1041.60	1043.29	356.70	520.56	0.18314	-0.51989	0.45196	0.00012	0.00122	0.07146
Warm	1046.25	1048.14	356.87	523.67	0.19178	-0.55455	0.50113	0.00069	0.00144	0.06770
Difference	4.65	4.85	0.17	3.10	0.00864	-0.03466	0.04917	0.00057	0.00022	-0.00376
IR										
Cold	586.02	586.78	321.27	239.21	-0.10137	0.46481	-0.6413	-0.00112	-0.00009	0.02704
Warm	587.14	588.04	322.70	238.15	-0.11278	0.5179	-0.71455	-0.00213	-0.00013	0.02438
Difference	1.12	1.25	1.43	-1.06	-0.01141	0.05309	-0.07325	-0.00101	-0.00004	-0.00266

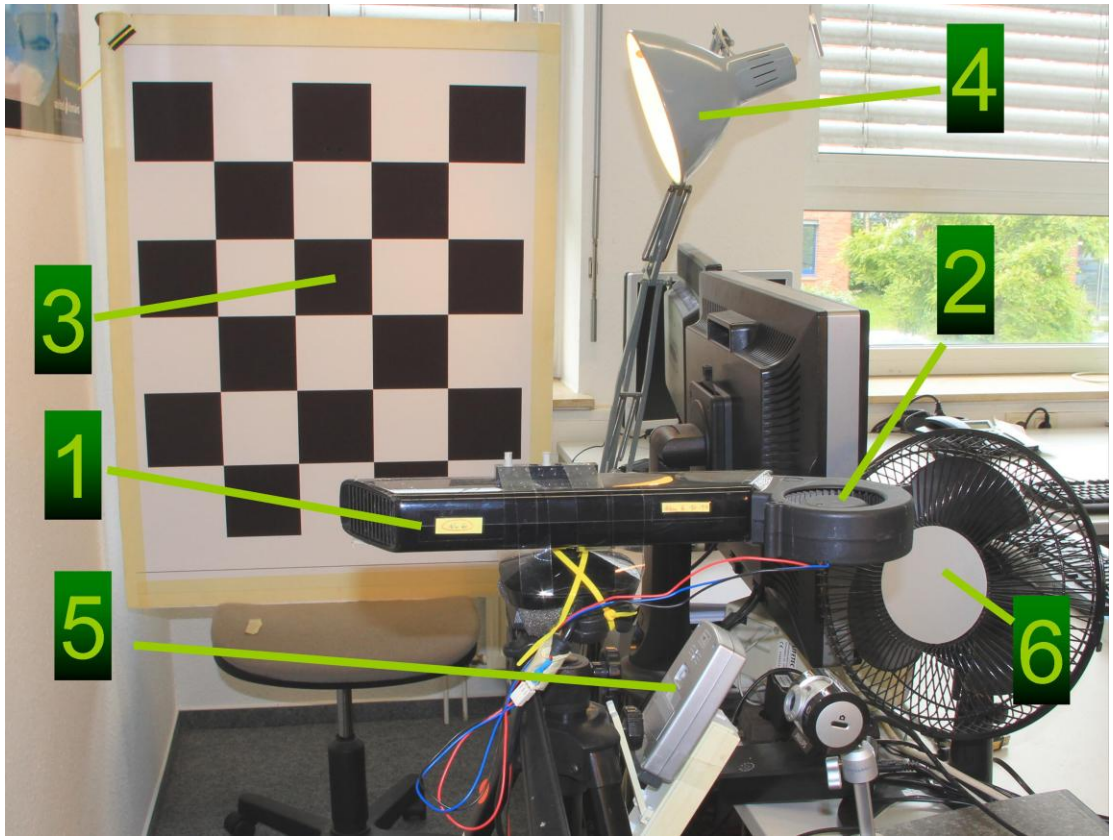
- Larger focal lenght in the warm state
- Confirms the observed zoom-in effect

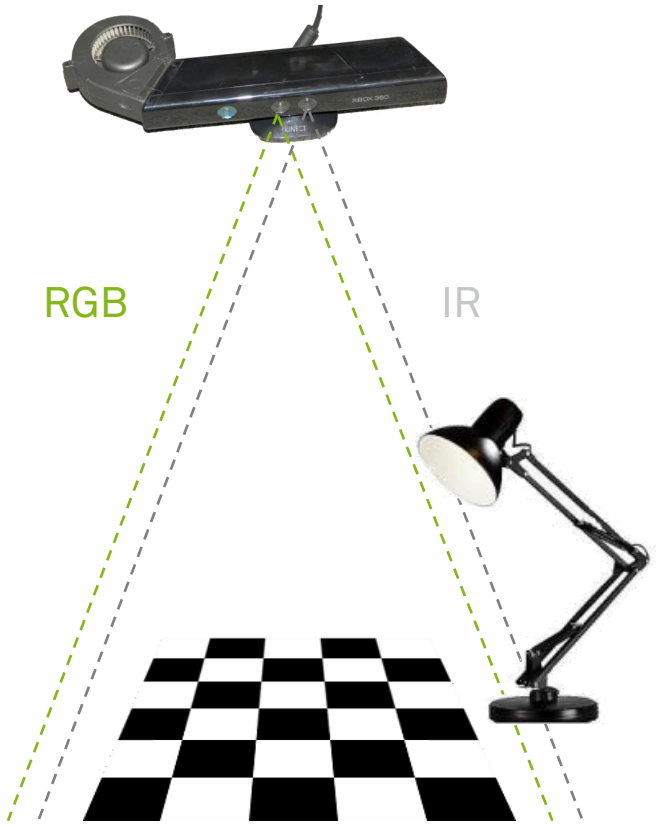


☑ Rule 1: Camera calibration and subsequent measurements should be performed at the same thermal conditions

Experimental Setup

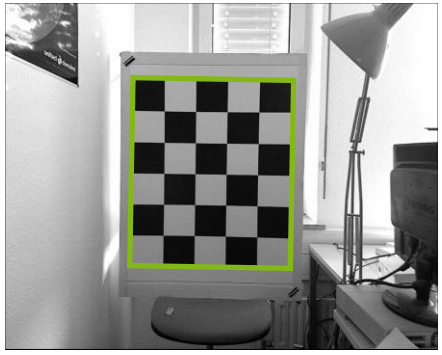
1) Kinect
2) Mounted fan
3) Checkerboard 1.2mx0.8m
4) Light source
5) Temperatur sensor
6) Table fan



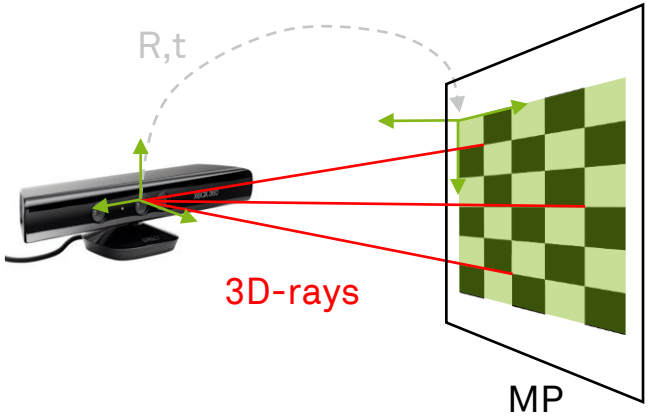


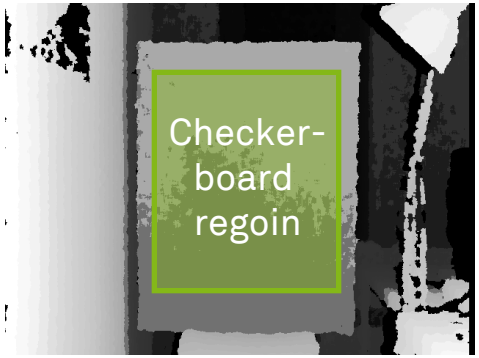
Experimental Setup: Distance measurement methods

- Detect checkerboard region within the RGB-camera image and extract corners
- Generate planar checkerboard model plane (MP) and calculate the homography
- Determine 3D position and rotation from homography
- Calculate mean distances to the checkerboard in two ways:
  - Mean distance of intersection points of rays with the model plane (MP)
  - Mean depth value within the checkerboard reagion in the depth image



RGB-camera





Depth image

Thermal and environmental influences on distance measurements:

1) Kinect Power-On

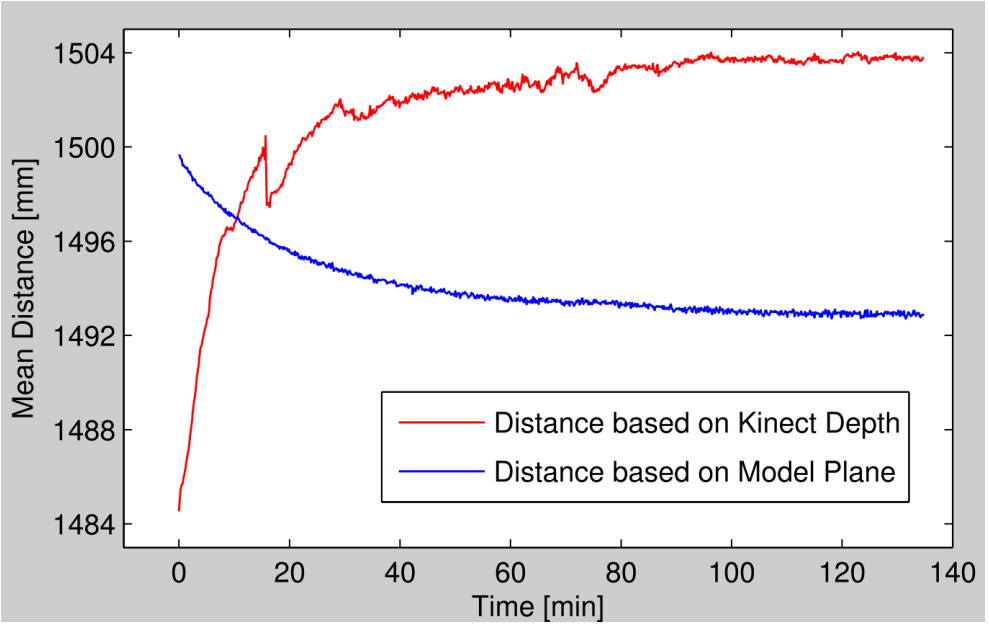
Tracking both distances during the first 135 minutes (warm-up phase)

Conditions

- Static scene (no movements)
- No fan activity
- Room temperature at 27.7°C

Distance Changes

- Model Plane: -6.9 mm (~0.5%)
- Kinect Depth: 19.4mm (~1.3%)
- 90% of overall change reached after 60 minutes (Model Plane) and 41 minutes (Kinect Depth)



☑ Rule 2: A warm-up time of up to 60 minutes is necessary to reach stable measurements

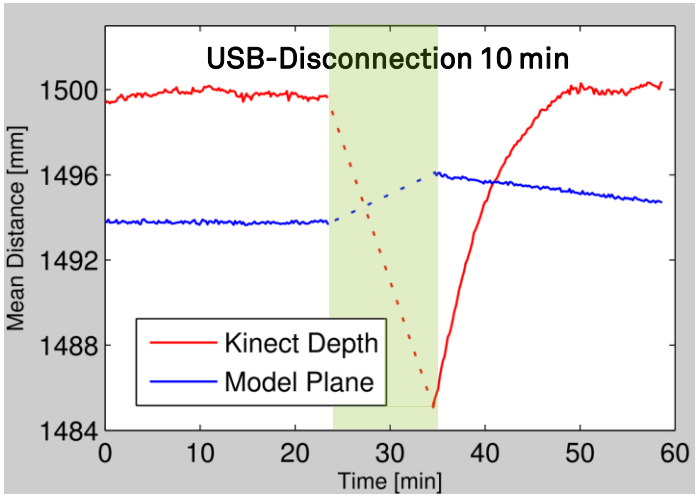
2) Kinect after Stand-By and USB-Disconnection

- Examine changes due to interruptions of the on-line state (streaming data)
- Constant environmental conditions (temperatur 26.9 °C, no fan, no air draft)
- Warm-up phase before entering each interruption phase

Stand-By: No data stream, connection to USB and power supply

USB-Disconnection: Comparable to power disconnection

Type \ Interruption		2 min	5 min	10 min	15 min	10 h
Stand-By	MP [mm]	-	-	-	0.7	1.7
	Depth [mm]	-	-	-	-3.1	-6.0
USB-Discon-nection	MP [mm]	0.3	1.2	2.4	-	-
	Depth [mm]	-6.1	-10.4	-14.7	-	-

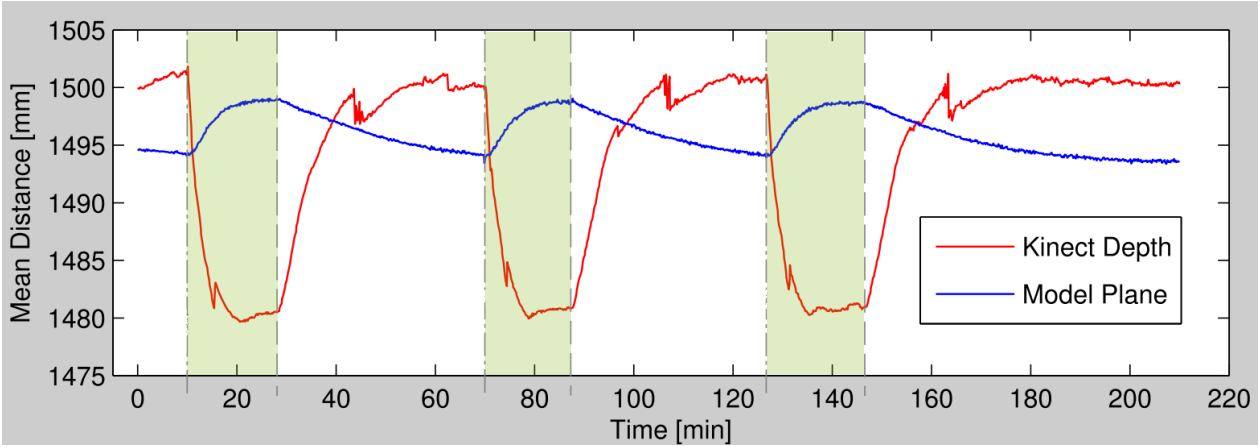


☑ Rule 3: Try to keep the Kinect always in the on-line mode. If this is not possible, leaving it in the stand-by mode is the best alternative.

3) Fan Cooling and Air Draft

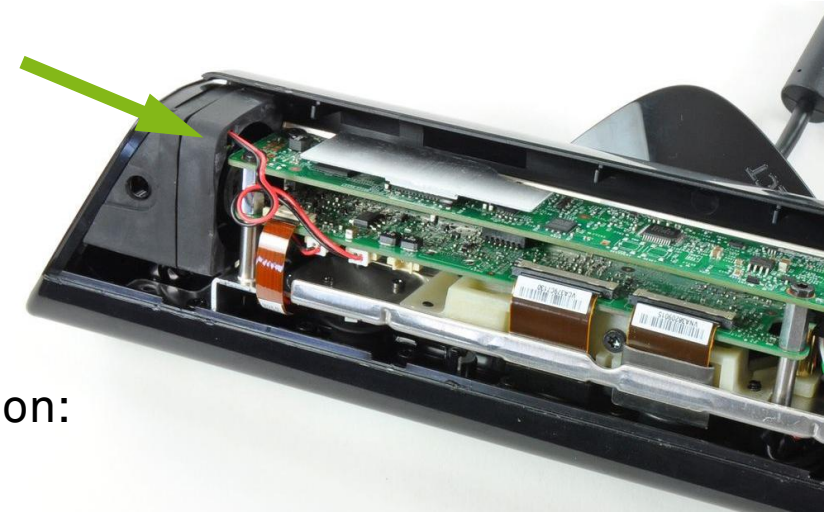
Experiment 1: Mounted Fan

- Static scene and constant room temperature (27.5 °C)
- Alternating between phases with and without fan cooling
- Tracking distances in three repetitions of the experiment



	Cool down phase	Warm-up phase	Impact of ventilation on distance measurement
Model Plane	18 min	60 min	5.7 mm
Kinect Depth	10 min	33 min	-22.8 mm

3) Fan Cooling and Air Draft



Experiment 2: Kinect‘s internal Fan

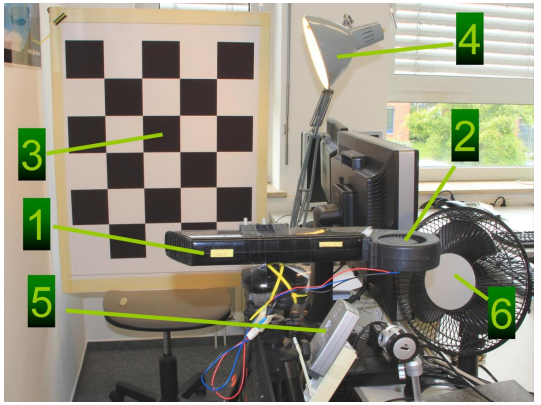
- Small and silent fan (less powerpull)
- Activation at room temperature of ~30°C
- Observed impact on distances after activation:
  - Model Plane: 2.4 mm
  - Kinect Depth: -12.2 mm

Experiment 3: Air Draft

- No control of real air draft
  ➔ Simulation with a table fan
- Activation for only 10 seconds in a distance of 30 cm (3 repititions):
  - Model Plane: insignificant
  - Kinect Depth: -3.2, -3.1 and -3.2 mm

☑ Rule 4: Try to avoid air draft while using the Kinect in the warm state.

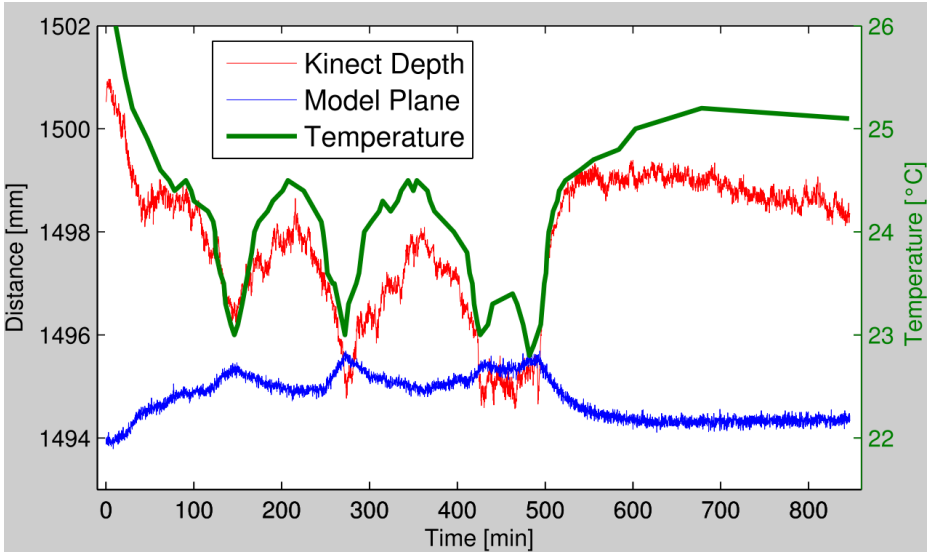
Variations in temperature



Experiment 1: Natural temperature fluctuations

- Closed door and window before starting (26.2°C)
- Window was opened at start of experiment (morning)
- Avoidance of air draft (closed door, blinded window)
- Weather (mix of sun and rain) causes natural indoor temperatur variations
- Window was closed at minute 497 (evening)
- Correlations:
  - Temperature and MP: negative
  - Temperature and depth: positive

Temp. influence	Min	Max	Diff.	mm/°C
Temperature [°C]	22.8	26.2	3.40	-
Kinect Depth[mm]	1494.57	1500.96	6.39	1.88
Model Plane[mm]	1493.79	1495.69	1.90	-0.56



☑ Rule 5: Try to keep the environmental temperature stable.

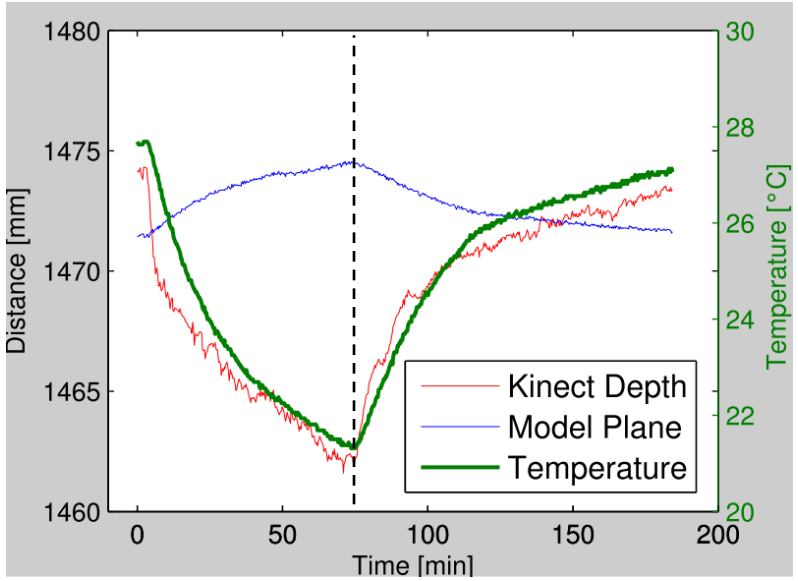
Variations in temperature

Experiment 2: Controlled room cooling / heating

- Static scene, comparable to previous tests
- Temperatur sensor directly at Kinect‘s ventilation slot
- Temperatures at the beginning: Sensor: 27.1°C , Room: 22.0°C
- Cold outdoor temperatures (11°C)
- Open window: minute 5-75 (room cool down)
- Closed window: minute 75-185 (room warm-up)

Correlation to temperature:

- Kinect Depth: 0.9685
- Model Plane: -0.9960



Temp. influence	Min	Max	Diff.	mm/°C
Temperature [°C]	21.31	27.69	6.38	-
Kinect Depth[mm]	1461.60	1474.32	12.72	1.99
Model Plane[mm]	1471.39	1474.56	3.17	-0.50

Summary and future work

- Sensitivity of the Kinect sensor to
  - Temperature (~ 2mm per 1 °C)
  - Air draft (~3mm in 10 s)
  - Working interruptions (~15mm in 10 min)
- Several experiments to evaluate the environmental influence
- Practical rules to reduce errors during
  - Calibration phase
  - Measurement phase
- Future work
  - Temperature dependent correction function

Practical rules for error reduction

- ☑ Rule 1: Camera calibration and subsequent measurements should be performed at the same thermal conditions.
- ☑ Rule 2: A warm-up time of up to 60 minutes is necessary to reach stable measurements.
- ☑ Rule 3: Try to keep the Kinect always in the on-line mode. If this is not possible, leaving it in the stand-by mode is the best alternative.
- ☑ Rule 4: Try to avoid air draft while using the Kinect in the warm state.
- ☑ Rule 5: Try to keep the environmental temperature stable.

Thank you very much

for your attention