Calibration and Validation of Phase One Aerial Cameras

Richard Ladstädter, Karlheinz Gutjahr,
Roland Perko, Helmut Woschitz[1]

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[1] Graz University of Technology

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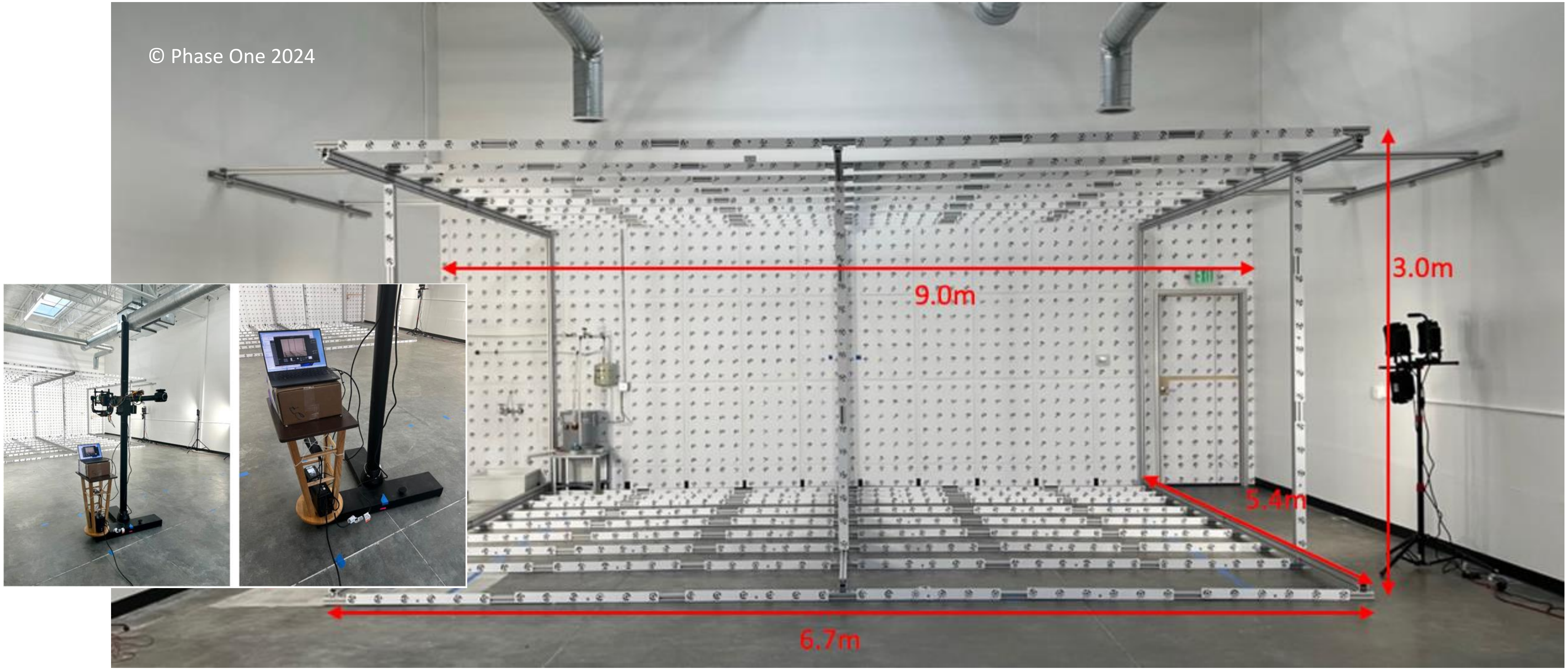
Content

Motivation

- Phase One A/S installed an updated lab calibration workflow in late 2023
- New calibration facilities build in Denver, USA and Saku, Japan
- A specific approach is used:
  - Coded markers are used (~2000)
  - Markers have not been surveyed, 3D structure of the test field made of aluminum
  - Labs are not temperature stabilized. Positions of the markers will slightly change with temperture changes which is fully accepted
  - A high redundant image data set is used (~180 images)
  - Lenses from 50mm up to 150mm are used, stopped down to F22 for lab calibration
- JR has reviewed this workflow and investigated on validation methods

Phase One Calibration Facility in Denver



Lab Calibration Review

(a) Theoretical considerations & findings

- Control points (CP) are **not needed** for camera calibration (cf. e.g. Luhmann text book on Close Range Photogrammetry)
- Approximate 3D coordinates are sufficient to fix the datum in a free network adjustment
- The scale of the lab coordinates has no influence on the calibration parameters (this has also been tested empirically by scaling of the 3D coordinates by 10%)
- Variation of the camera position (in X and Y) and viewing direction (phi & kappa angle) is very important to de-correlate parameters and to gain accuracy (this is possible in the Phase One calibration labs due to the room size)
- Missing CP reduce redundancy but this can be compensated by more (image) measurements

Lab Calibration Review

(b) Investigating a Phase One calibration project from the Denver Lab

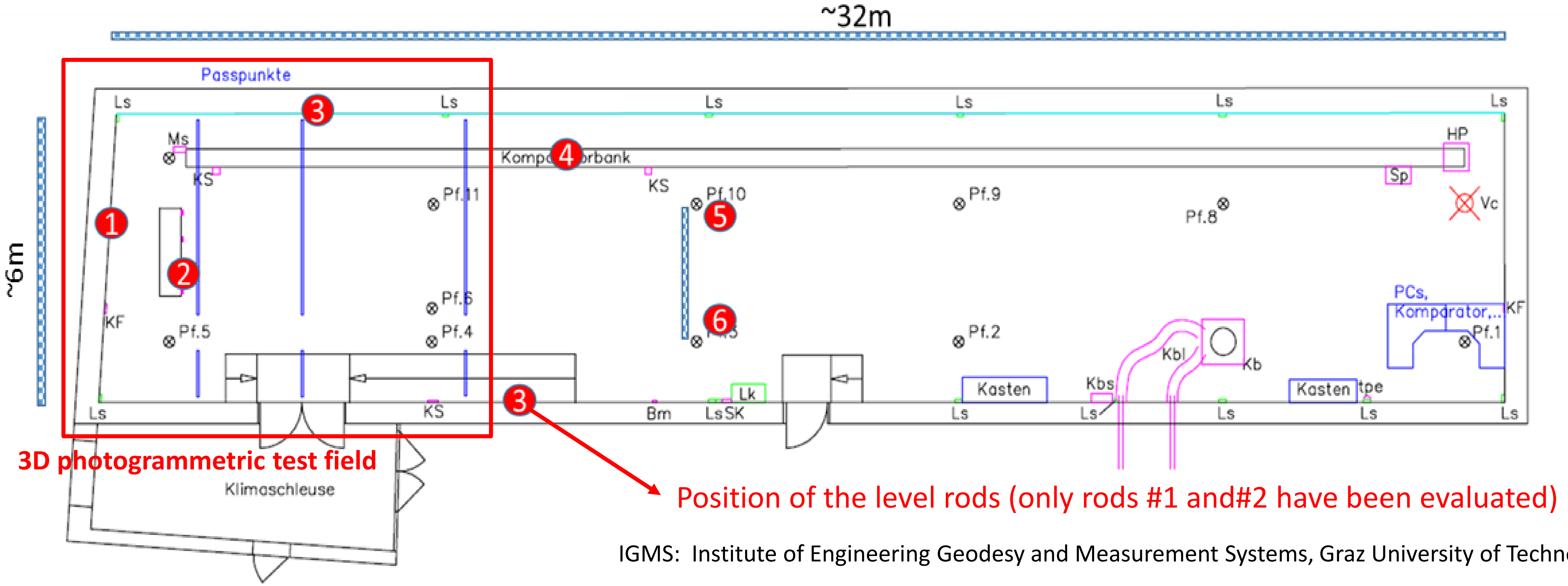
- Camera model: iXM-RS150F camera with 150mm lens
- Image measurements have been provided for analysis at JR
- Data set has been reduced from 180images / 130488 2D points to 44 images / 32001 2D points
- Evaluation done with the **Ph**otogrammetric **B**undle **A**djustment Tool (PhoBA) from JR
- Identical additional parameters used for distortion modelling (Brown-Conradi, 7 parameters)
- Direct comparison of calibration parameters → identical results

Lab Calibration Review

(c) Performing lab calibration experiments at TU Graz

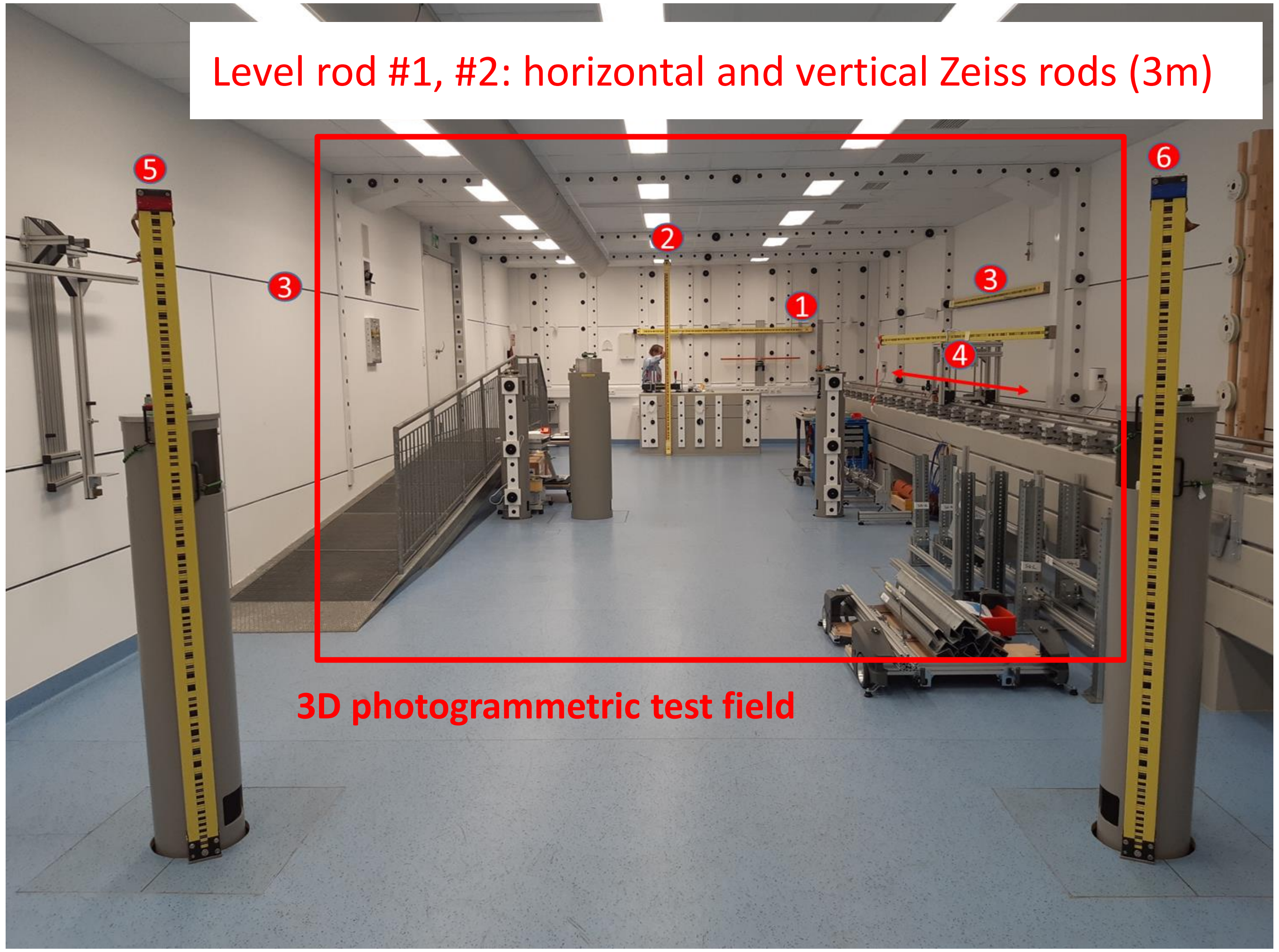
- Camera models: iXM-RS150F reference cameras with 50mm and 150mm lens
- A limited number of calibration images (36 / 52) has been taken at distances from 7m to 30m
- Camera have been rotated 4x by 90deg at each position
- Aperture has been switched between F22 to F5.6 for all images
- Measurement lab has a stable temperature (20°C)
- 3D test field consists of ~250 circular markers with precisely known (surveyed) 3D coordinates
- Evaluation has been done using JR software tools (RSG and PhoBA)
- Measurement lab has been equipped temporarily with Zeiss (and Leica) level rods (3m)

IGMS measurement lab at TU Graz, Austria

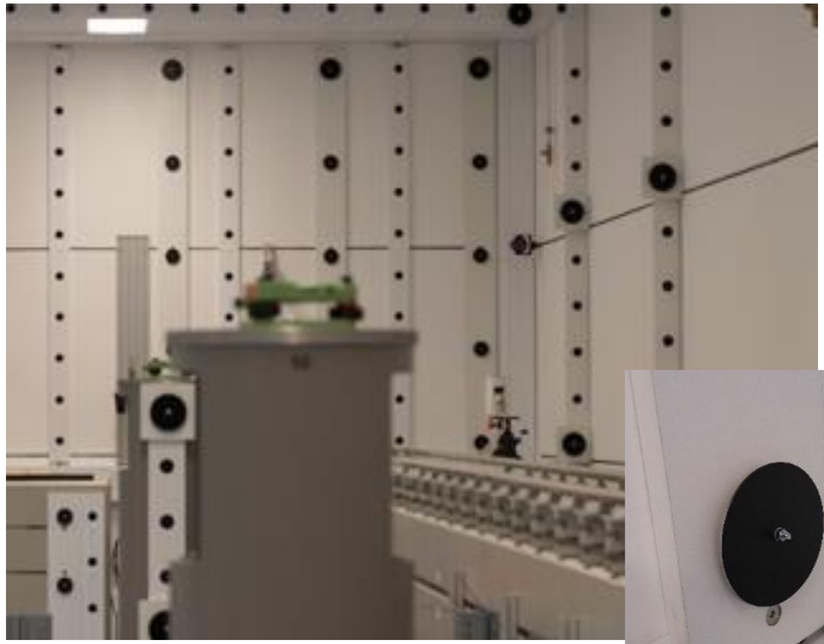


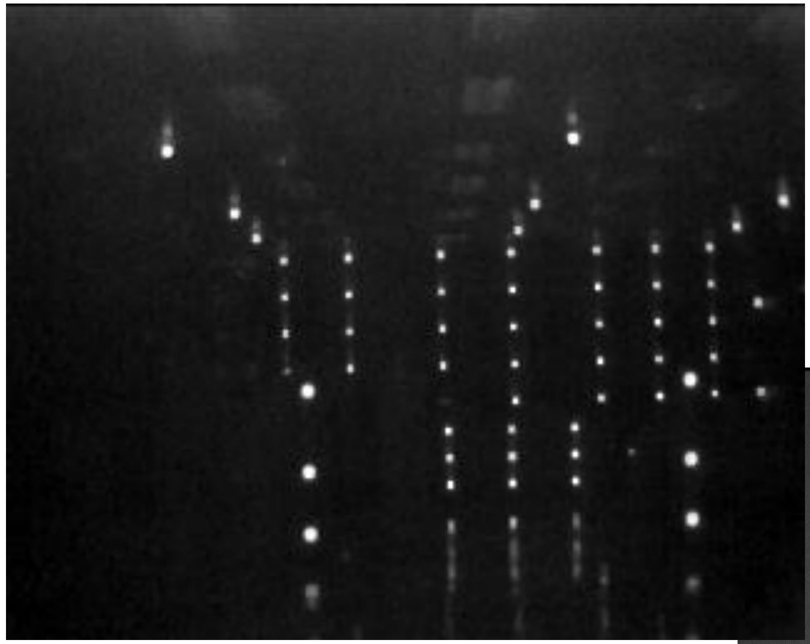
IGMS: Institute of Engineering Geodesy and Measurement Systems, Graz University of Technology, Austria

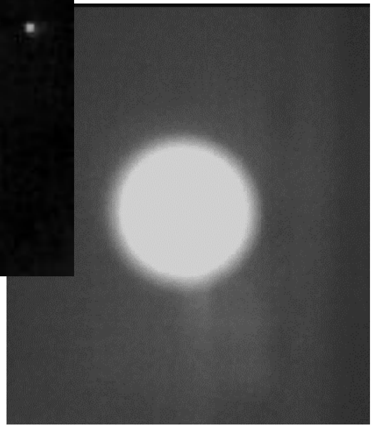
IGMS measurement lab at TU Graz, Austria

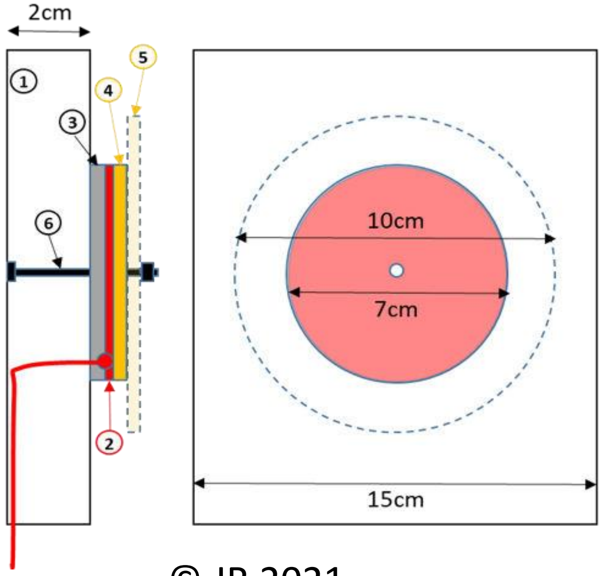


Excursion: Thermal-photogrammetric Targets









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The IGMS lab has been equipped with 65 special markers electrically heated from the backside (designed by JR)
→ perfect visible in near infrared (thermal) cameras
→ successfully used for combined RGB & TIR camera calibration

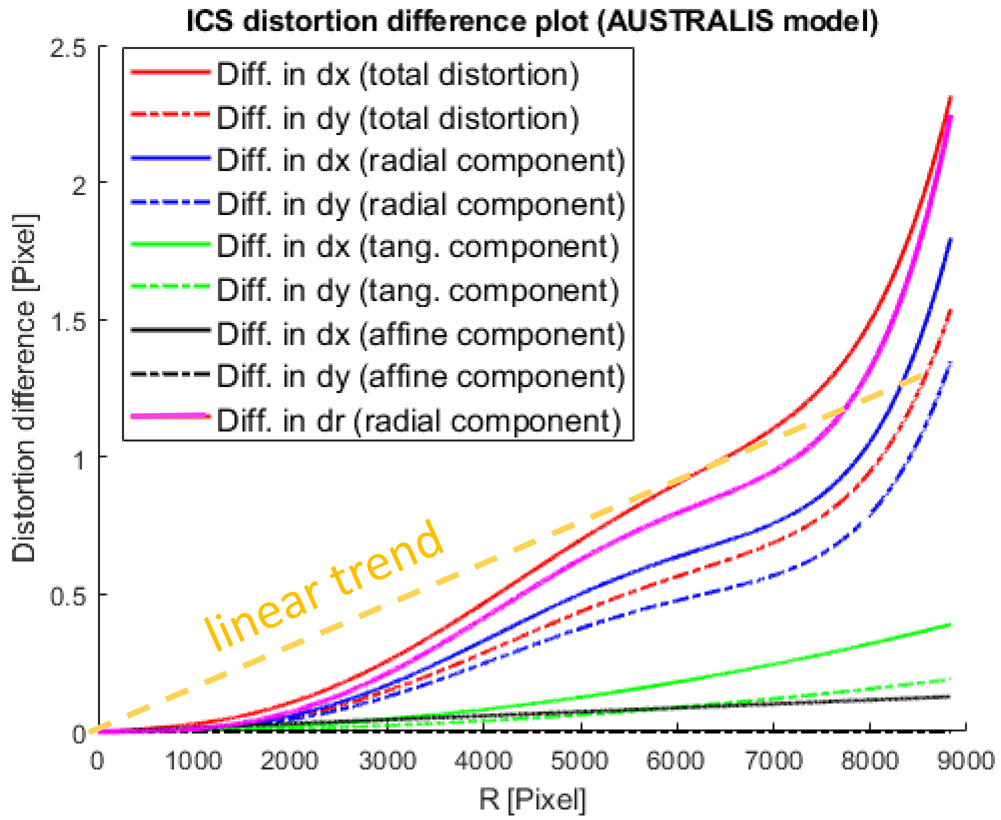
Lab Calibration Review

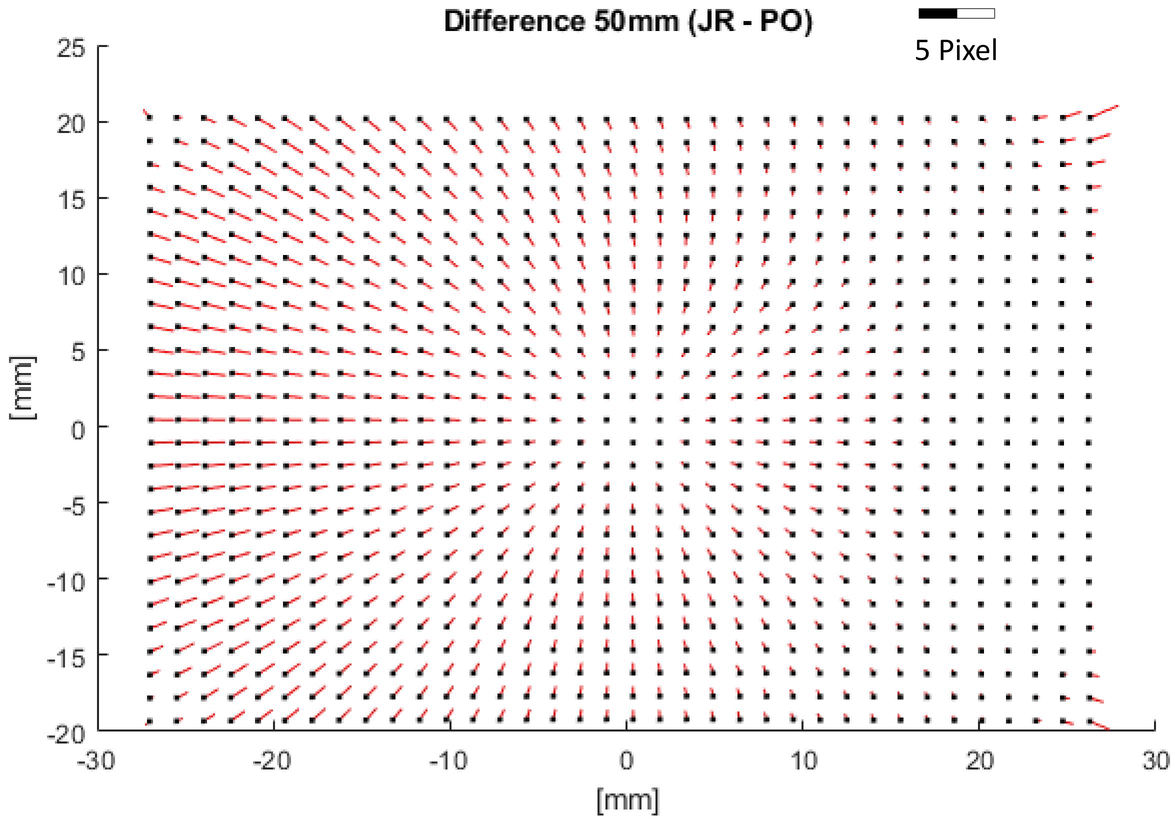
Result: Comparison of calibration parameters (50mm lens @ F22)

Parameter	PhaseOne	JR	Unit	Correlation coefficients (JR)									
Principle distance c	51.5406 +/- 0.0001	51.5503 +/- 0.0006	[mm]	100	0	0	-57	53	-47	0	0	-30	-2
Principle point x0	0.2127 +/- 0.0001	0.2041 +/- 0.0021	[mm]		100	8	-1	0	-1	96	8	-1	-1
Principle point y0	0.0115 +/- 0.0001	0.0170 +/- 0.0017	[mm]			100	0	-1	0	8	92	-1	0
Radial K1	1.6e-05 +/- 2.3e-09	1.7e-05 +/- 7.2e-08	[mm^{-2}]				100	-96	89	-1	0	4	-1
Radial K2	-5.7e-09 +/- 4.8e-12	-6.9e-09 +/- 1.8e-10	[mm^{-4}]					100	-98	0	-1	0	4
Radial K3	9.9e-13 +/- 3.2e-15	1.7e-12 +/- 1.3e-13	[mm^{-6}]						100	-1	0	6	-2
Tangential P1	2.7e-07 +/- 3.5e-09	8.3e-07 +/- 2.9e-07	[mm^{-1}]							100	7	0	-1
Tangential P2	-2.7e-07 +/- 2.8e-09	-2.0e-07 +/- 2.4e-07	[mm^{-1}]								100	-1	0
Affine B1	1.2e-05 +/- 8.3e-08	2.2e-05 +/- 5.0e-06	[ ]									100	-1
Affine B2	-6.6e-06 +/- 8.2e-08	3.8e-06 +/- 5.1e-06	[ ]										100

Lab Calibration Review

Result: Comparison of calibration parameters (50mm lens @ F22)





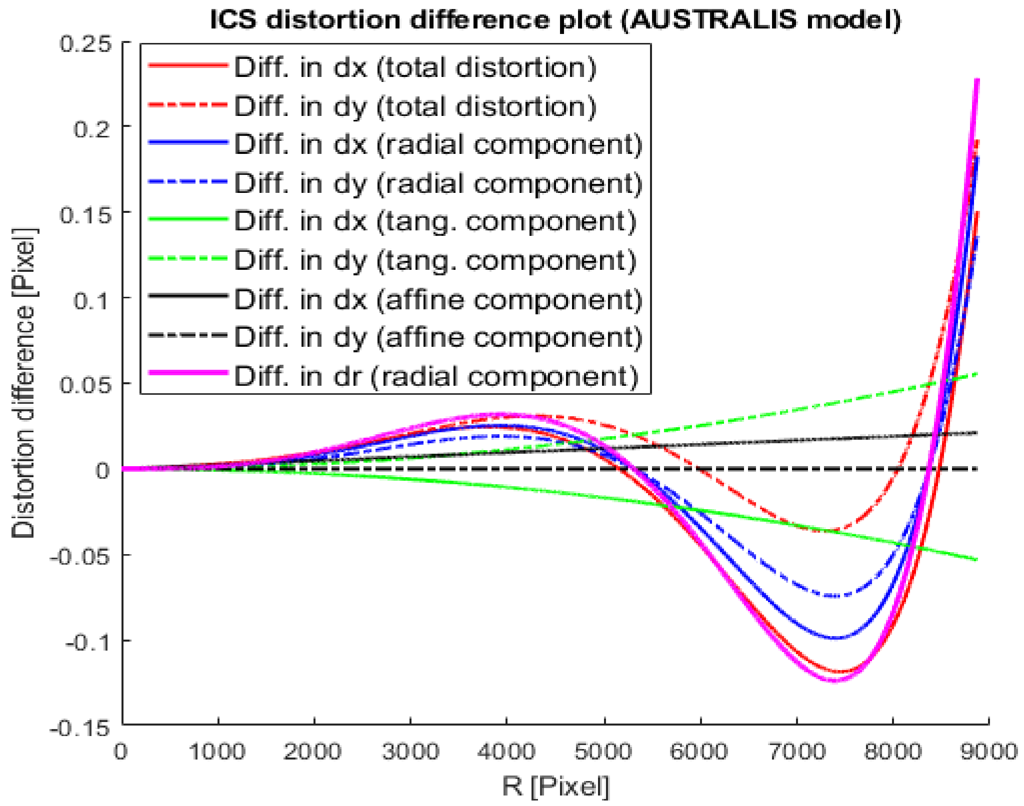
Lab Calibration Review

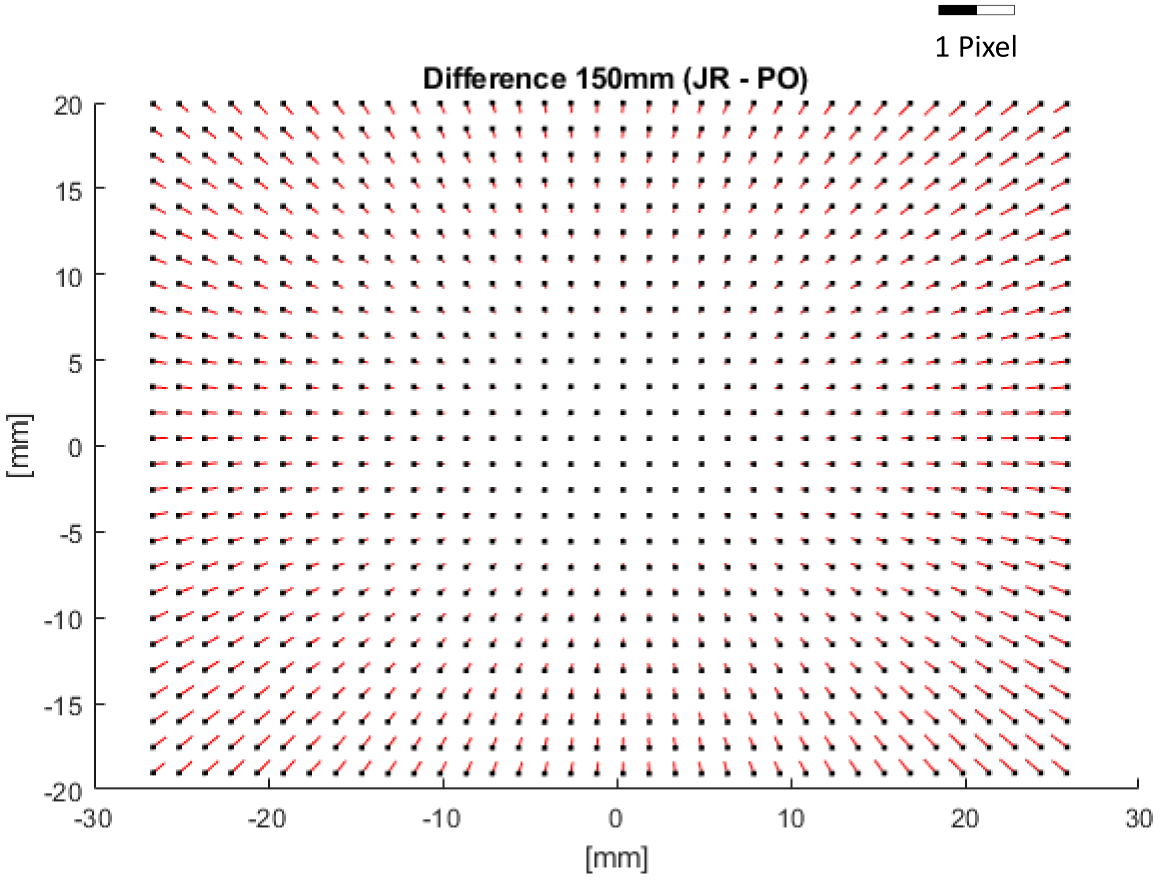
Result: Comparison of calibration parameters (150mm lens @ F22)

Parameter	PhaseOne	JR	Unit	Correlation coefficients (JR)									
Principle distance c	146.321 ±0.0005	146.339 ±0.0055	[mm]	100	-1	-1	-15	12	-10	-1	-1	-7	0
Principle point x0	0.0907 ±0.0002	0.0933 ±0.0081	[mm]		100	8	0	-1	0	96	-1	-1	0
Principle point y0	-0.0628 ±0.0002	-0.0640 ±0.0062	[mm]			100	-1	0	-1	-1	90	-1	-1
Radial K1	-2.9e-06 ±1.8e-09	-2.8e-06 ±5.3e-08	[mm^{-2}]				100	-95	87	0	-1	4	0
Radial K2	-1.1e-09 ±4.1e-12	-1.5e-09 ±1.1e-10	[mm^{-4}]					100	-98	-1	0	-7	-1
Radial K3	7.8e-13 ±2.7e-15	1.0e-12 ±7.8e-14	[mm^{-6}]						100	0	-1	6	0
Tangential P1	2.7e-07 ±5.9e-09	1.1e-07 ±1.3e-07	[mm^{-1}]							100	-1	-1	0
Tangential P2	1.5e-06 ±4.7e-09	1.7e-06 ±1.0e-07	[mm^{-1}]								100	-1	-1
Affine B1	-2.3e-05 ±8.5e-08	-1.6e-05 ±2.5e-06	[ ]									100	-1
Affine B2	1.0e-06 ±8.4e-08	-6.1e-06 ±2.5e-06	[ ]										100

Lab Calibration Review

Result: Comparison of calibration parameters (150mm lens @ F22)





Calibration vs. Validation

Definitions:

- **Calibration** and **Validation** are different and independent tasks!
- **Calibration:**
  - Compares measurements of a device with a given standard
  - Calculates corrections to be applied to the readings
- **Validation:**
  - Assessment of the measurement accuracy of a (calibrated) device
  - Check if a device has been correctly calibrated (or is still calibrated after some time)

Lab Validation Experiment

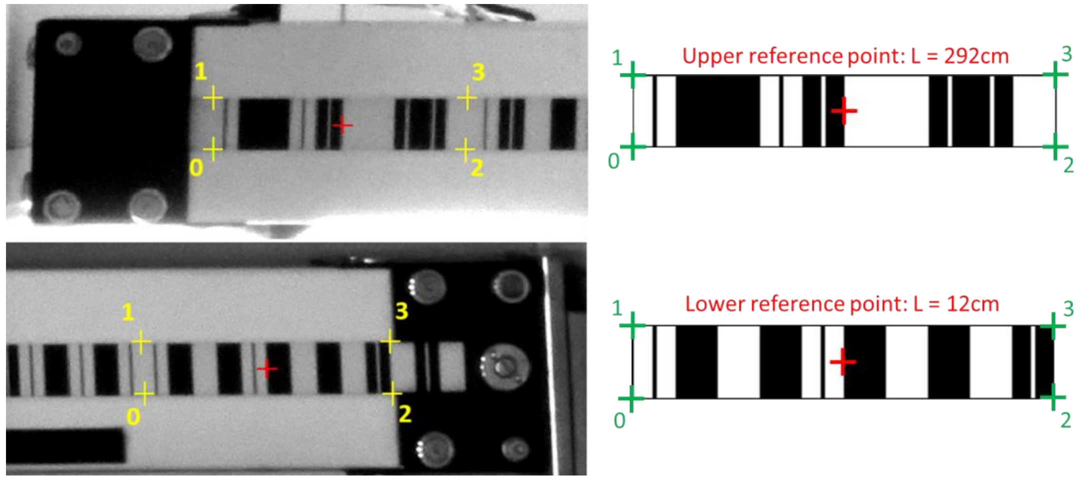
Developing a new lab validation method

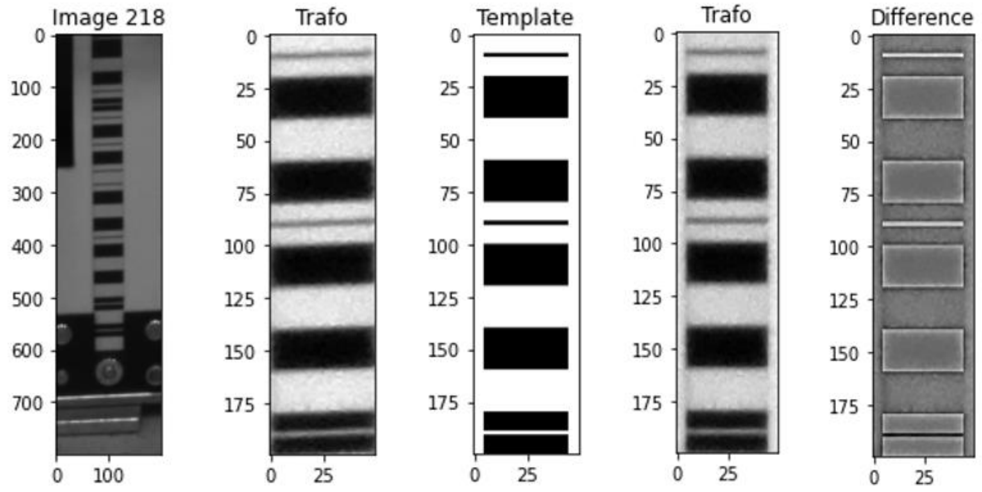
- Standardized methods exist for close range camera systems (e.g. acceptance tests defined by ISO 10360-13:2021)
    - 3D length deviations are used to assess the measurement accuracy
- Disadvantages:
    - Special calibrated test bodies are needed
    - To achieve homogenious 3D reconstruction accuracy, a photogrammetric network „around“ the test body needs to be realized (not feasible in calibration labs with given space limitations)
- Our new approach:
    - We use standard geodetic equipment (calibrated level rods) and Least Squares Matching
    - We avoid 3D reconstruction by correcting for image scale to calculate 3D lengths

Lab Validation Experiment

Least Squares Image Matching (LSM) of Zeiss bar code

- Bar code on the Zeiss level rods are very accurately aligned to a cm scale (10ppm corresponding to 0.03mm @ 3m length)
- Synthetic LSM templates are generated for the upper/lower part (10cm long)
- Reference points are defined at the center of the templates at L=12cm and L=292cm (resulting in a 2800mm reference length)
- Matching accuracy of +/- 0.05 pixels can be achieved using LSM with projective parameters

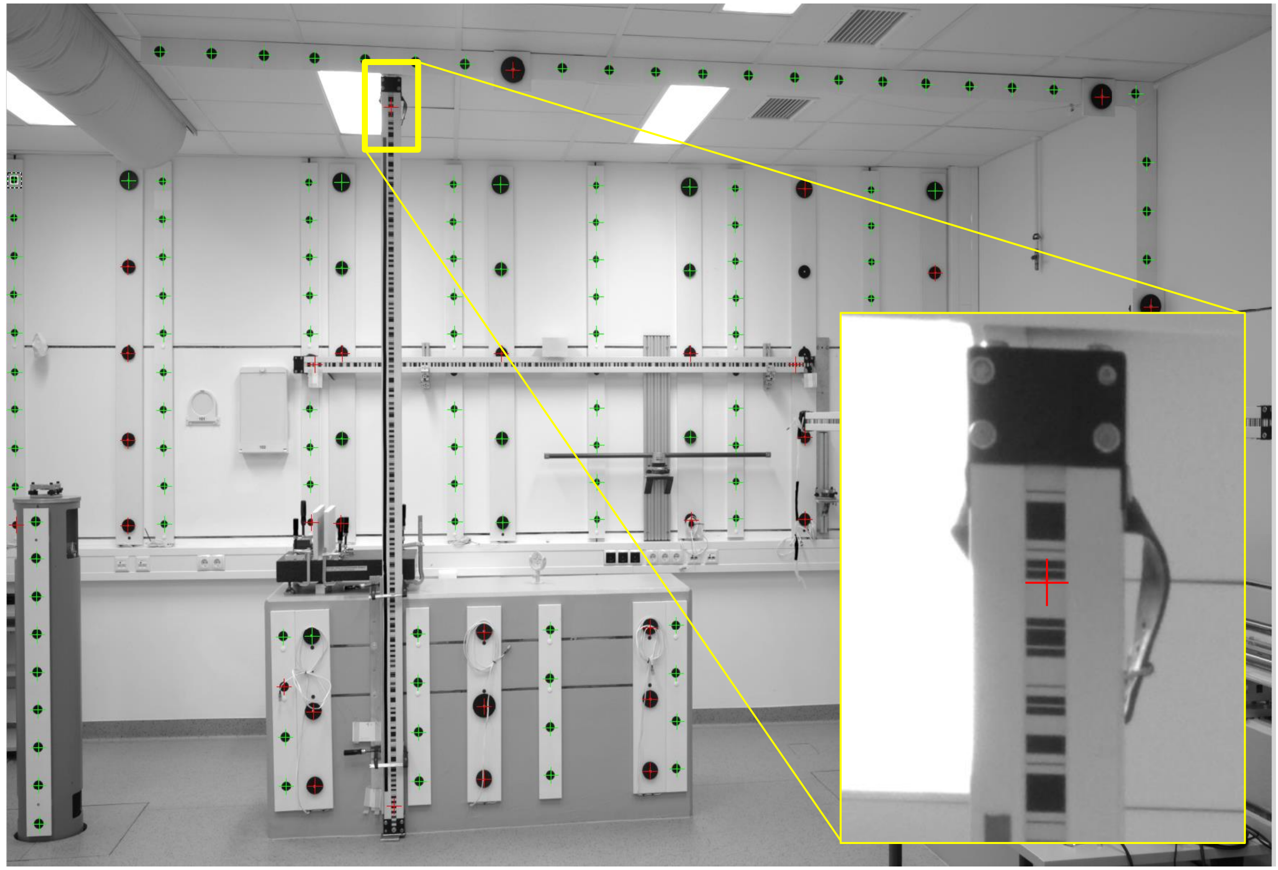




Lab Validation Experiment

Measurement of a horizontal and vertical level rod

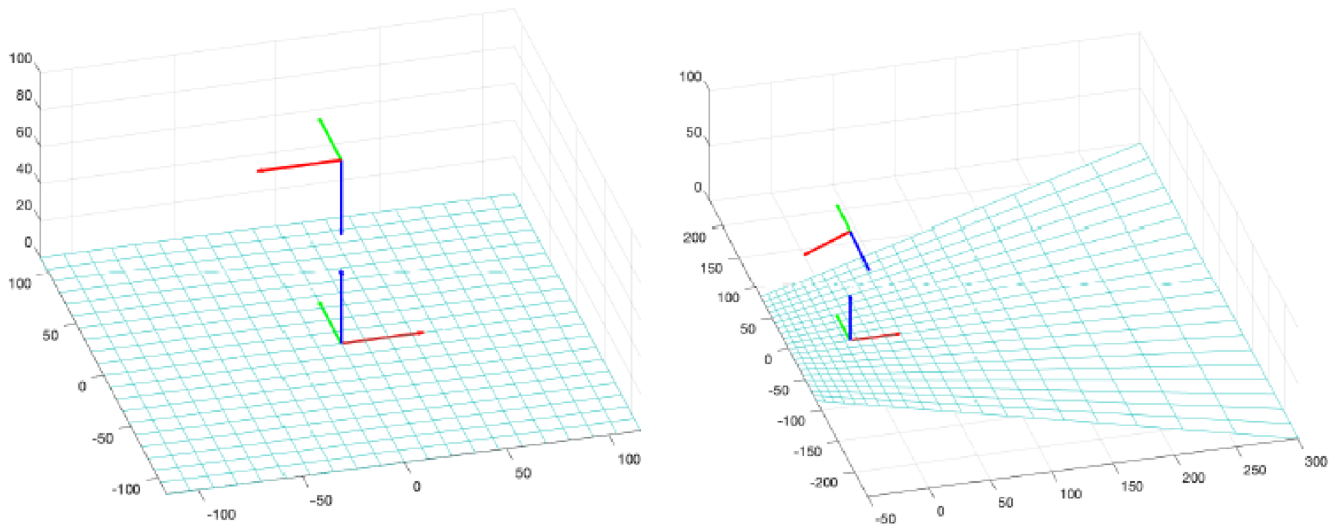
- In the first 16 calibration images, two level rods have been measured using LSM
- This includes images at distances from 5m to 11m, kappa angles 0, 90, 180, 270 deg and phi angle variation of > +/- 20 deg
- Reference points are corrected for principle point offset and distortion
- Local scale corrections need to be applied along the depicted line to convert the 2D image length into a 3D length



Lab Validation Experiment

Local image scale correction

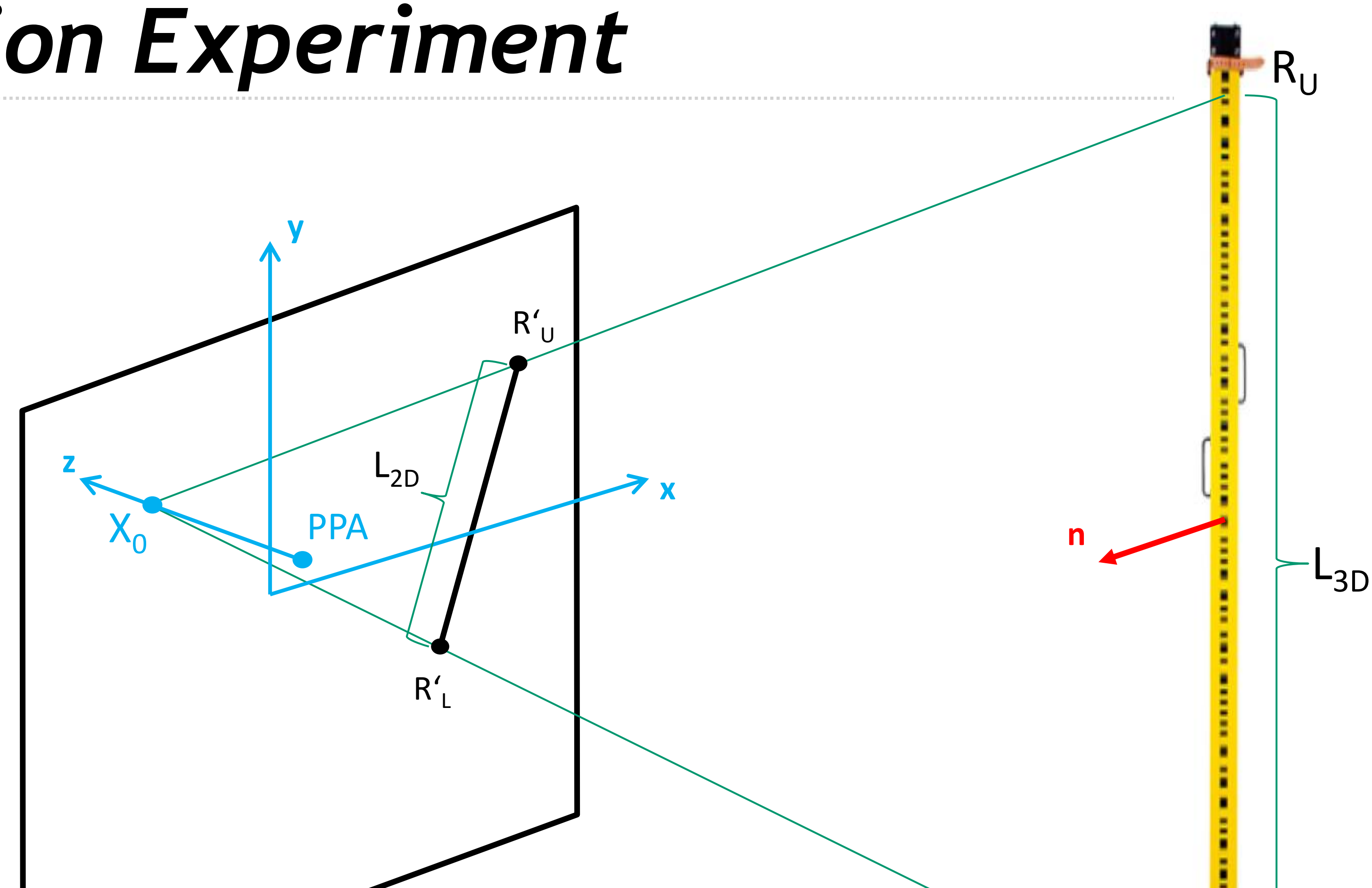
- If the image plane is exactly parallel to a reference plane in object space, the image scale is constant over the whole image: $m_x = m_y = c/H$
- Otherwise the image scale is different in x,y-direction and has to be calulated for every image position:
  - $m_x = f(x, y, H, omega, phi, kappa)$
  - $m_y = g(x, y, H, omega, phi, kappa)$
- Formulas are given in Maset & Fusiello, 2024



Lab Validation Experiment

Local image scale correction

- The scale on the level rod defines the „ground plane“ with normal vector ***n*** being the *Z*-direction and *Y* being aligned with the (vertical) rod
- Reference points R_U and R_L are measured in the image and define a straight line between image points R'_U and R'_L with length L_{2D}
- Position X_0 and (outer) orientation of the image are precisely known (taken from the calibration project)
- To calculate L_{3D} from L_{2D} we need to calculate the local image scale m_s along the line



$$L_{2D} = \int_{\bar{x}_1}^{\bar{x}_2} ds \cong \sum_{i=1}^{n} \Delta s_i(x,y)$$

$$L_{3D} = \int_{\bar{x}_1}^{\bar{x}_2} m_S \cdot ds = \int_{\bar{X}_1}^{\bar{X}_2} dS(dx,dy) \cong \sum_{i=1}^{n} \Delta S_i(x,y)$$

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Lab Validation Experiment

Results (horizontal and vertical level rod)

- Tables are listing the results from the validation measurements:
  - H: distance between camera and level rod (= difference in *Z*-value)
  - $m_s(R_U)$ and $m_s(R_L)$: local image scales for the start- and endpoint
  - L_{2D}: length of the image line
  - L_{3D}: calculated 3D length
- Mean L_M and standard deviation sL_M is calulated
- L_M can be compared with the „true“ (calibrated) 3D length (2800.029 mm): $E = L_C – L_M =$ -0.122mm
- A relative accuracy sL_M/L_M of ~1:23.000 has been achieved

Img#	H [m]	$m_S(R_U)$ [ ]	$m_S(R_L)$ [ ]	L_{2D} [mm]	L_{3D} [mm]
1	7.131	132.534	143.075	20.336	2800.333
2	7.132	132.505	143.090	20.336	2800.221
3	7.131	132.454	143.121	20.339	2800.287
4	7.131	132.443	143.118	20.339	2800.155
10	7.145	115.591	144.960	21.631	2799.980
12	7.146	115.643	144.974	21.625	2800.074
13	11.009	214.160	206.511	13.315	2800.145
14	11.008	214.143	206.594	13.313	2800.204
15	11.008	214.082	206.580	13.316	2800.227
16	11.008	214.166	206.368	13.319	2800.130

Img#	H	$m_S(R_U)$	$m_S(R_L)$	L_{2D}	L_{3D} [mm]
					2800.190
					2800.158
					2800.241
					2800.057
					2800.059
					2800.460
					2800.174
					2800.212
10	5.464	99.895	95.426	28.677	2799.905
12	5.464	99.964	95.367	28.679	2800.163
13	9.330	173.129	185.570	15.622	2800.100
14	9.330	173.137	185.563	15.622	2800.077
15	9.330	172.997	185.583	15.627	2799.977
16	9.330	173.068	185.579	15.624	2799.986

Level rod	L_M [mm]	sL_M [mm]	E [mm]	sL_M/L_M [ ]
Horizontal	2800.126	±0.13	-0.097	1: 21.538
Vertical	2800.176	±0.10	-0.147	1: 28.000
Mean	**2800.151**	**±0.12**	**-0.122**	**1:23.333**

Conclusions & Outlook

Lab calibration

- The PhaseOne lab calibration workflow (using a 3D test field without GCP‘s) has been reviewed in detail
- The new calibration facilities, image aquisition strategy and software tools allow to derive high quality calibration results
  - The use of balanced radial parameters is recommended (maximum distortion and correlation to principle distance could be reduced)
- Saisonal temperature differences in the labs will not affect the correctness of the calibration parameters but need to be considered in a temperature correction model during flight time
- Using F22 for calibration not only supports image sharpeness (especially for the 150mm lens) but also supresses optical abberation caused by open aperture (F5.6) and short distances (~10m)
- Remark: Lab calibration is not standardized, manufacturers use different approaches and issue their own calibration „certificates“

Conclusions & Outlook

Lab validation

- A new method based on geodetic level rods, Least-Squares-Matching and computation of the 3D length without photogrammetric reconstruction has been developed
- A first experiment in the IGMS lab gives reasonable results which could be improved:
  - Better illumination of the level rods to achieve high matching accuracy also at longer distances
  - Precise measurement of the position/orientation of the level rods in the lab system
  - Higher number of images (measurements)
  - More level rods could be used in (more) different orientations
- Calibration and validation should be more strictly seperated than in this experiment
- Lab validation is considered to be useful to verify lab calibration quality but cannot replace (in-situ) field validation of complex multi-camera systems (flight over a dedicated test field)

Thank you for your attention!

JOANNEUM RESEARCH
Forschungsgesellschaft mbH

DIGITAL
Institute Digital Technologies

Steyrergasse 17
8010 Graz

Phone:. +43 316 876-5000
digital@joanneum.at

www.joanneum.at/digital

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Standards

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- ISO 10360-13-2021 (Geometrical product specification (GPS)-Acceptance and reverification for coordinate measuring systems, 52 p.)
- ISO/TS 19159-1-2014 (Geographic information - Calibration and validation of remote sensing imagery sensors and data - part 1: optical sensors, 100 p.)
- VDI/VDE Richtline 26334 Blatt 1 / 2002 (Optische 3D Messsysteme, 10 p.)