University of Applied Sciences and Arts Northwestern Switzerland
School of Architecture, Civil Engineering and Geomatics

3D Imagery for Infrastructure Management

Mobile Mapping meets the Cloud

56th Photogrammetric Week

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Source: autodesk.com

Motivation

A functioning technical infrastructure

- **foundation** of a modern society
- **major challenge** in maintaining and udpating

Enormous economical value of technical infrastructure

Swiss NRP 54 "sustainable development of the built environment" (Schalcher et al., 2011)

- **cost of rebuilding**
  - 1.5 times GDP, or approx. **100'000 € per person** (at 2008 prices)
- **yearly cost for maintaining and updating**
  - 3.5% of the GDP, or approx. **2'100 € per person**

Schalcher, H.-R. et al., 2011. Was kostet das Bauwerk Schweiz in Zukunft und wer bezahlt dafür? Fokusstudie NFP 54. vdf, Zürich

Source: autodesk.com

Motivation

Digitisation of infrastructure assets

- often referred to as “Infrastructure 4.0”,
- key role in future infrastructure management

Infrastructure and traffic corridors

- largest part of public infrastructure is located **along traffic corridors**
- **mobile mapping technologies** & digital realities are ideally suited

Infrastructure 4.0: for domain experts NOT only for geospatial experts

- digital realities enable numerous measurement and inspection tasks
- make a large part of costly and potentially dangerous fieldwork obsolete
- **solutions need to be VERY intuitive and user friendly**

Agenda

Introduction

Geospatial 3D Imagery

Acquisition Systems

Georeferencing and Depth Extraction

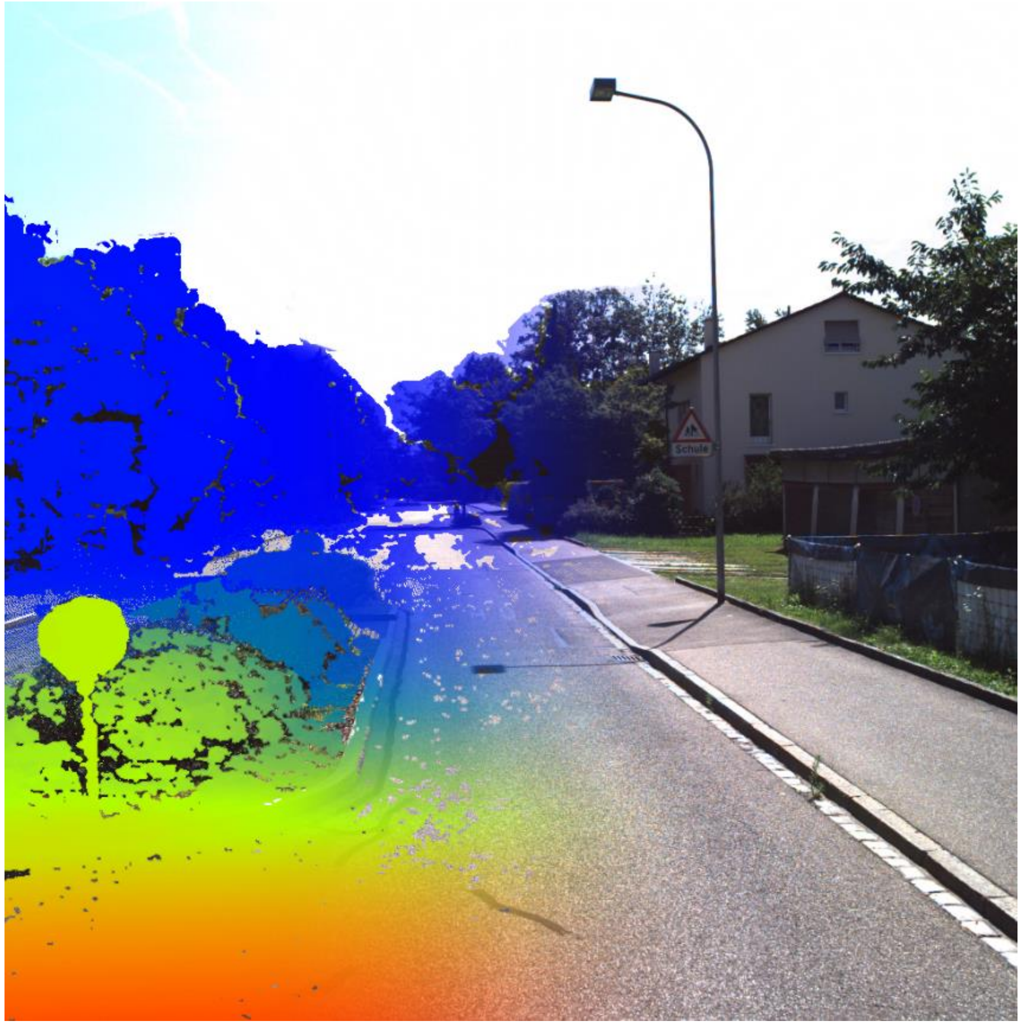
Performance Evaluation

3D Image Cloud Services: Functionality and Applications

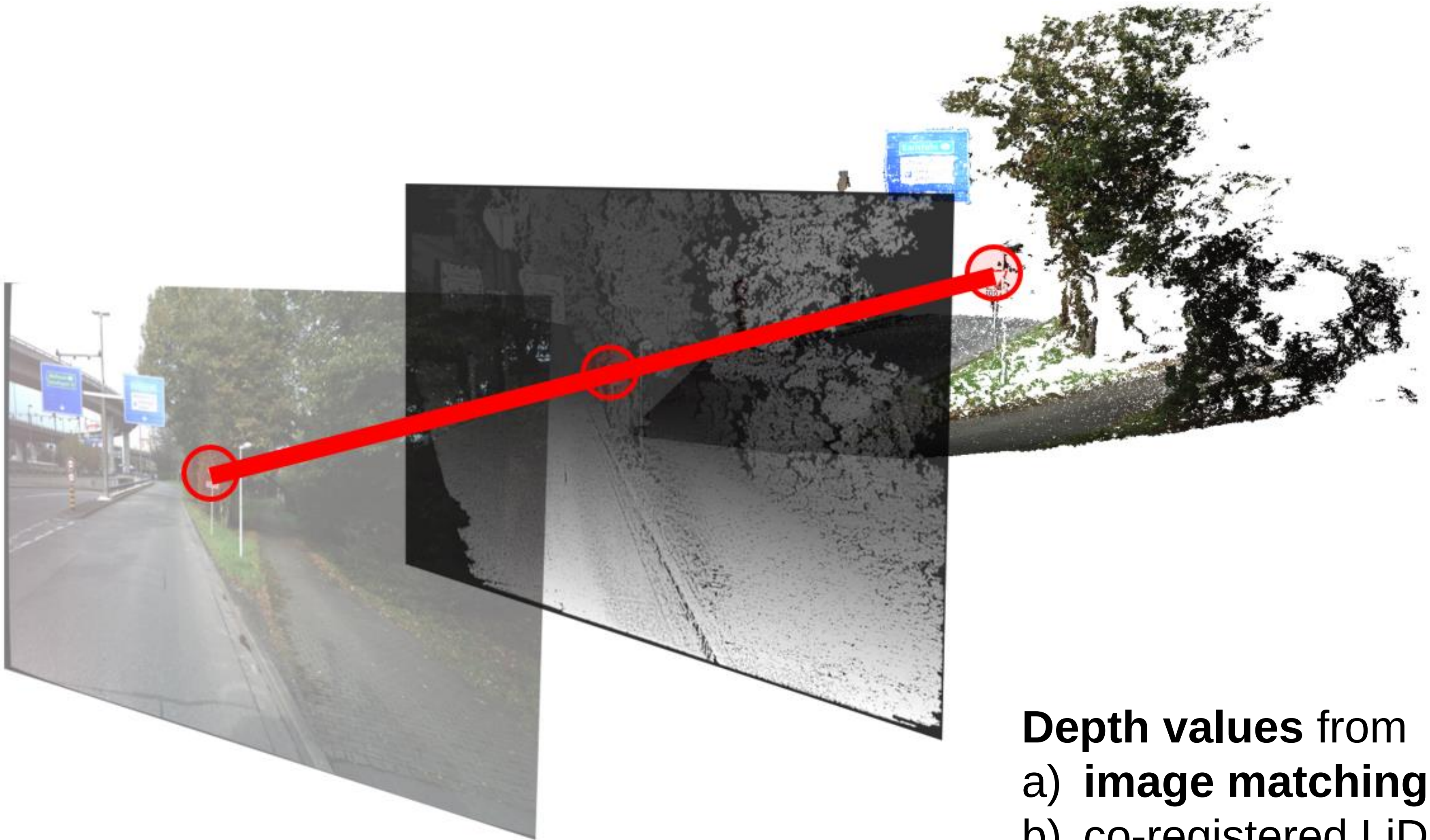
Conclusion and Outlook

3D Imagery

- **metric imagery** with depth value for each pixel
- more than **RGB-D imagery** (multispectral, thermal etc.)
- **simple interpretation** as with 2D images but full **3D functionality**
- integration into: **3D image spaces** and cloud services
- supports relative and absolute **3D measurements**, **digitisation** and **augmentation**



Duality: 3D Imagery vs. Coloured 3D Point Clouds

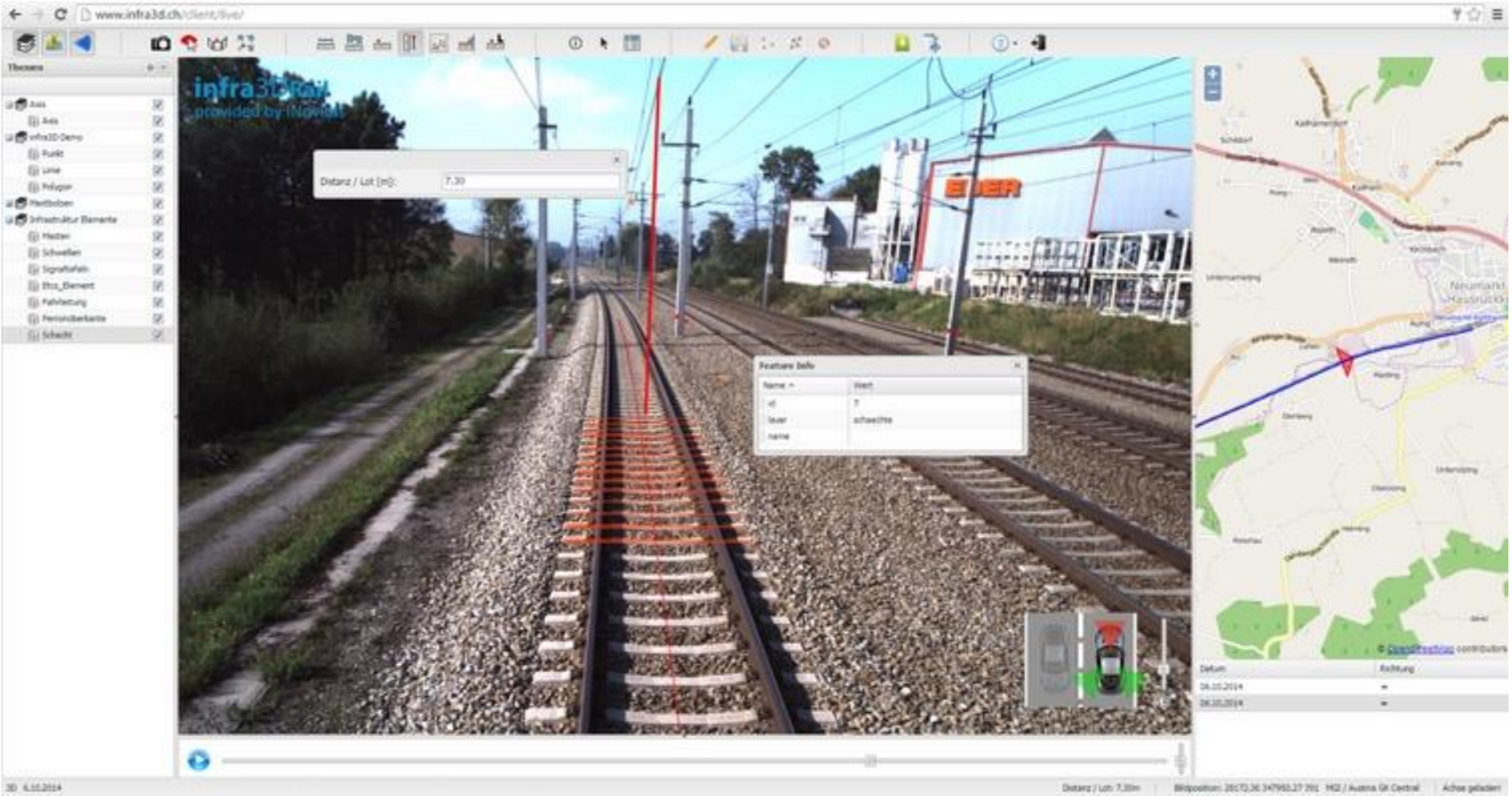


Depth values from
a) **image matching** or
b) co-registered LiDAR

Point Cloud vs. 3D Image: Interpretation and Context

Acquisition of 3D Imagery: Multiview and Panoramic Stereo

Exploitation of 3D Imagery: Web-based and mobile Cloud Services



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Mobile Mapping System: Multiview Stereo Research Platform

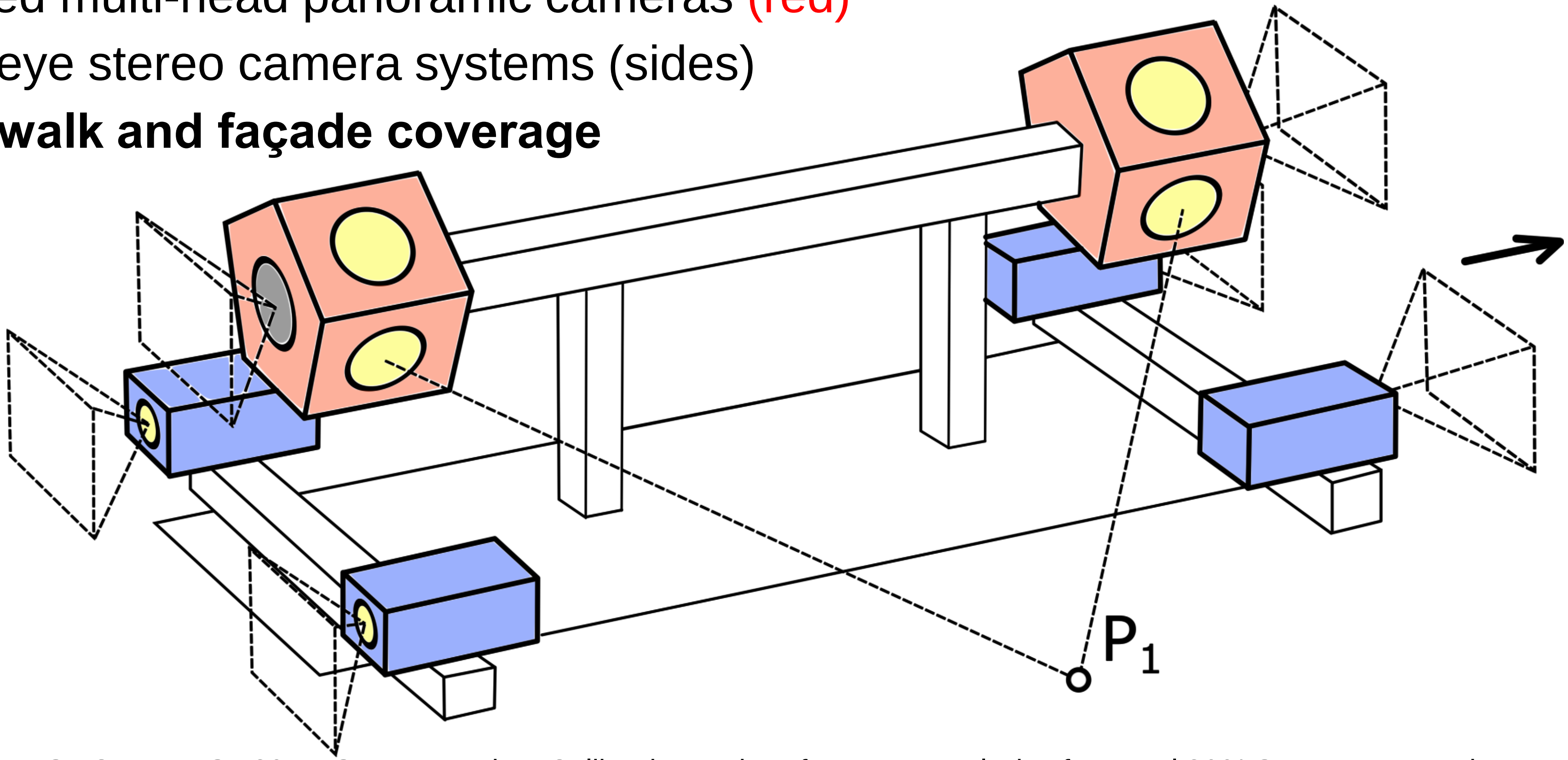
- **Inertial Navigation System:** NovAtel SPAN
  2D 10 mm, height 15 mm, Φ Θ 0.005°, Ψ 0.008°

- **Cameras**

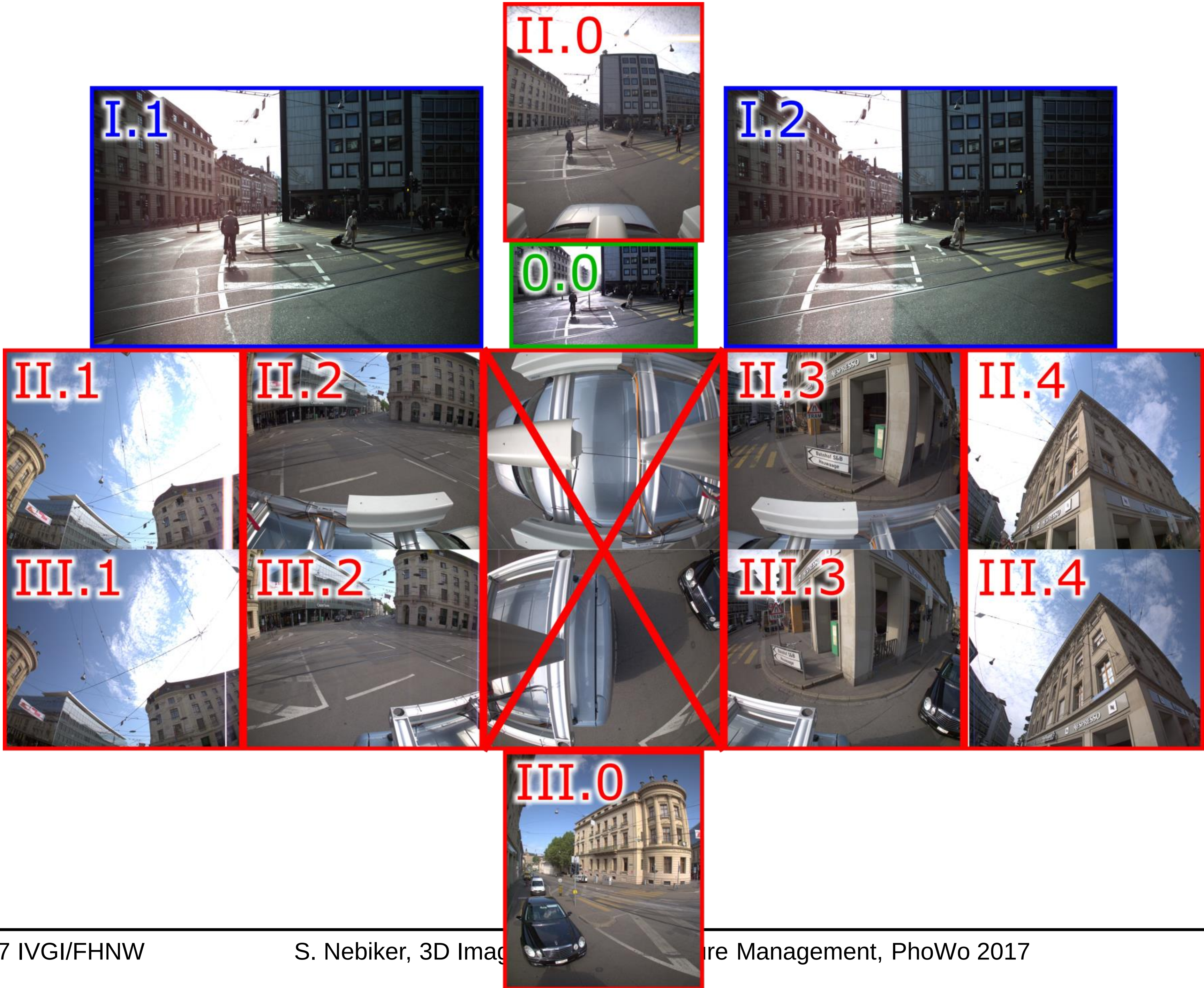
Sensor size	**11 MP**	2 MP
Pixel pitch	9 µm	7.4 µm
Focal length	21 mm	8 mm
Field of view	81° x 60°	83° x 53°
Radiom. Res.	12 bit	12 bit
Stereo base	**905 mm**	779 & 949 mm

New 360° Stereo Panoramic Camera System

- Wide-angle pinhole stereo camera systems (front / back)
  → **road infrastructure coverage**
- Two tilted multi-head panoramic cameras (red)
  = 4 fisheye stereo camera systems (sides)
  → **sidewalk and façade coverage**

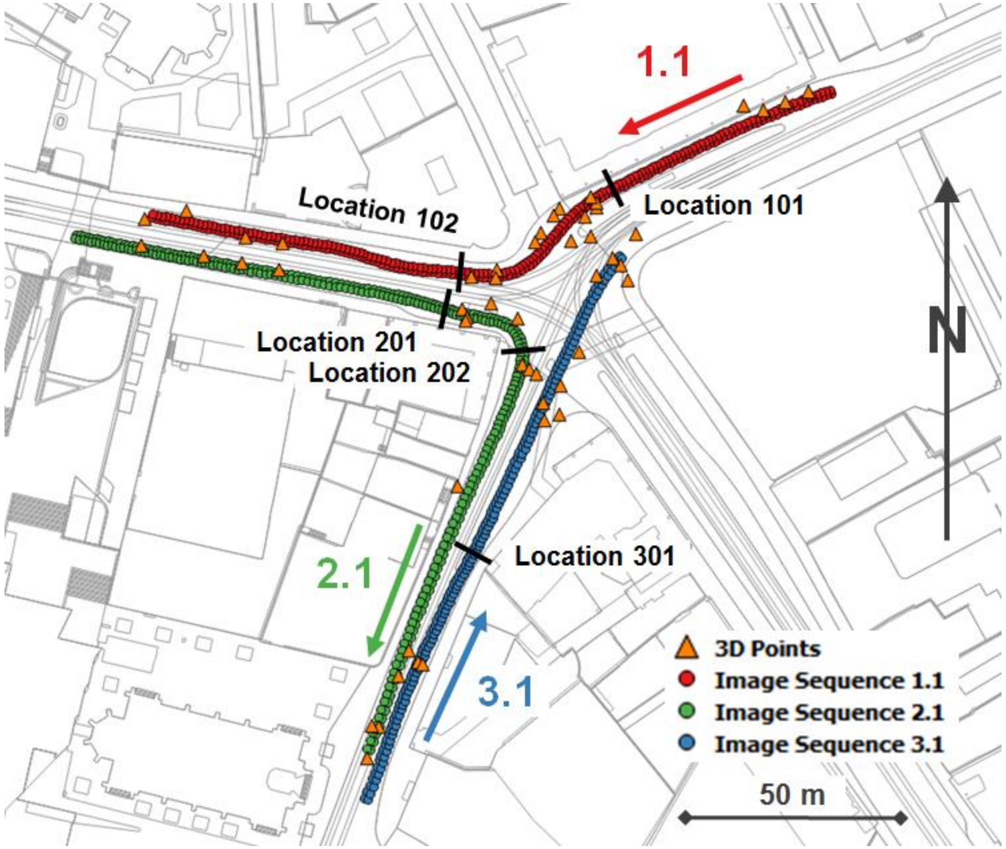


Blaser, S., Nebiker, S., Cavegn, S., 2017. System Design, Calibration and Performance Analysis of a Novel 360° Stereo Panoramic Mobile Mapping System. ISPRS Ann. Photogramm. Remote Sens. Spat. Inf. Sci. IV-1/W1, 207–213.


II.0
I.1
I.2
0.0
II.1
II.2
II.3
II.4
III.1
III.2
III.3
III.4
III.0

Test Site and Data

- City centre of Basel, Switzerland
- Very challenging environment for GNSS positioning
- Image data capturing interval: approx. 1m (full image set)



Cavegn et al. (2015)

Cavegn, S., Haala, N., Nebiker, S., Rothermel, M., Zwölfer, T., 2015. Evaluation of Matching Strategies for Image-based Mobile Mapping. ISPRS Ann. Photogramm. Remote Sens. Spat. Inf. Sci. II-3/W5, 361–368.

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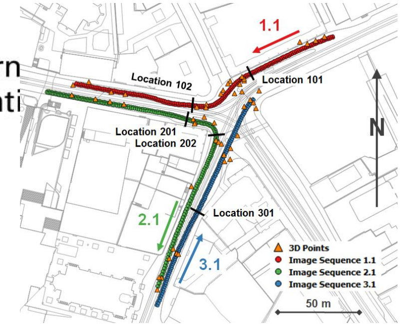
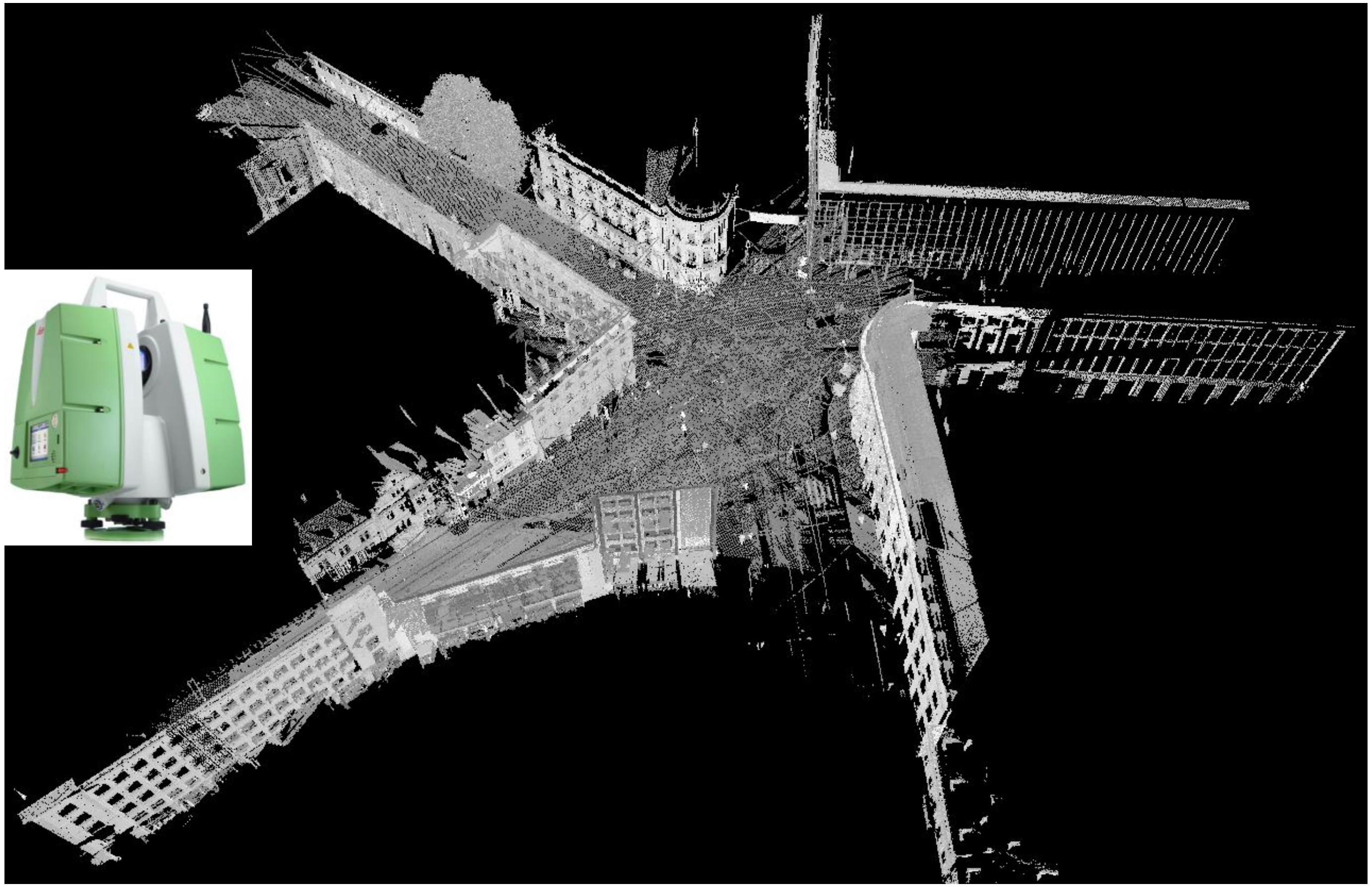


Test Campaign in July 2014

Reference Data

- 4 TLS scans with Leica P20
- 3D accuracy of TLS points 1-2 cm
- 70 GCP with Total Station Leica MS50
- 3D accuracy of GCP < 1 cm



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Georeferencing Strategies and Results

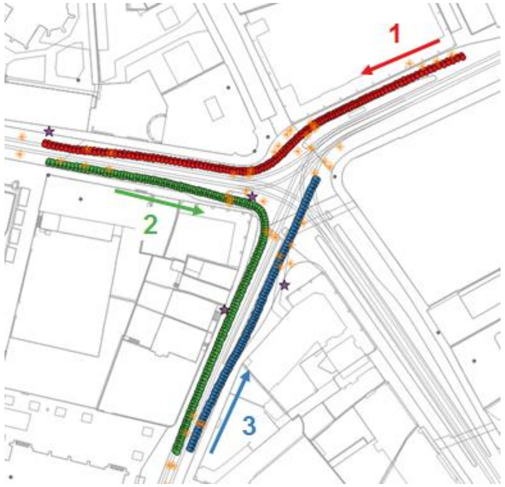
Direct Georeferencing

- NovAtel Inertial Explorer, tightly coupled, multi-pass directions, smoothed
- Lever arm and misalignment as well as relative orientation parameters between cameras from calibration process

Image-based Georeferencing

- Bundle adjustment
- Agisoft PhotoScan, approx. 20 GCP per sequence, forward stereo only
- Overall reprojection error 0.42-0.89 pixel,
  tie points 0.15-0.21 pixel, ground control points (GCP) 0.81-1.08 pixel

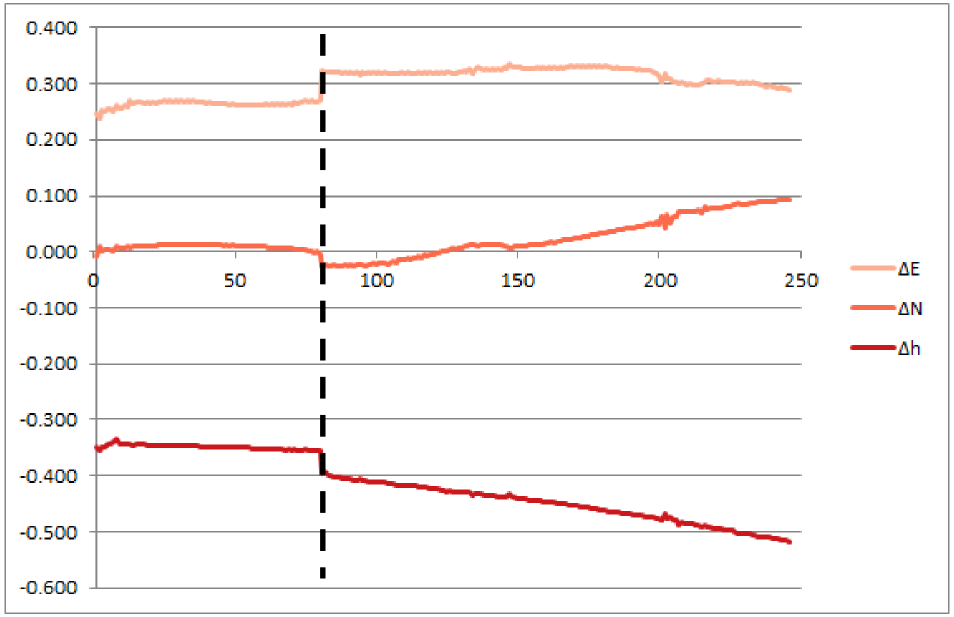
Comparison of Direct vs. Image-based Georeferencing Accuracy



Avg. 3D Deviations

- 1: 520 mm
- 2: 93 mm
- 3: 81 mm

1



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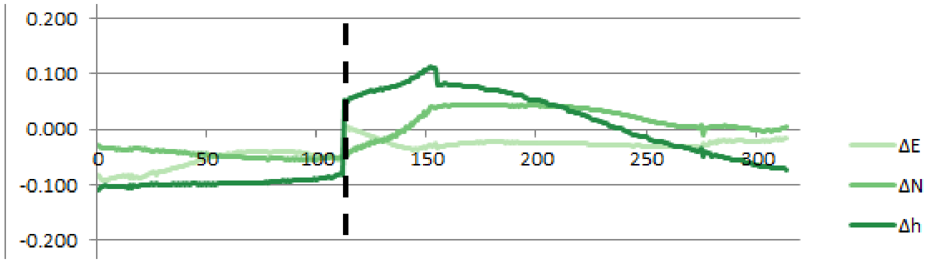

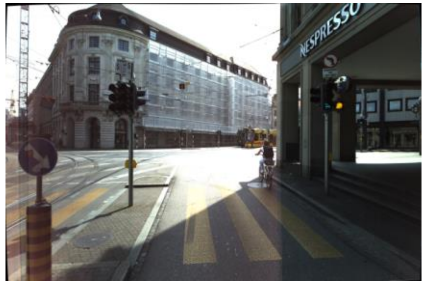

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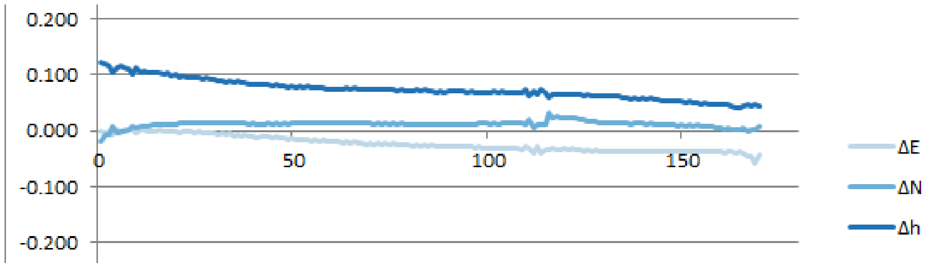
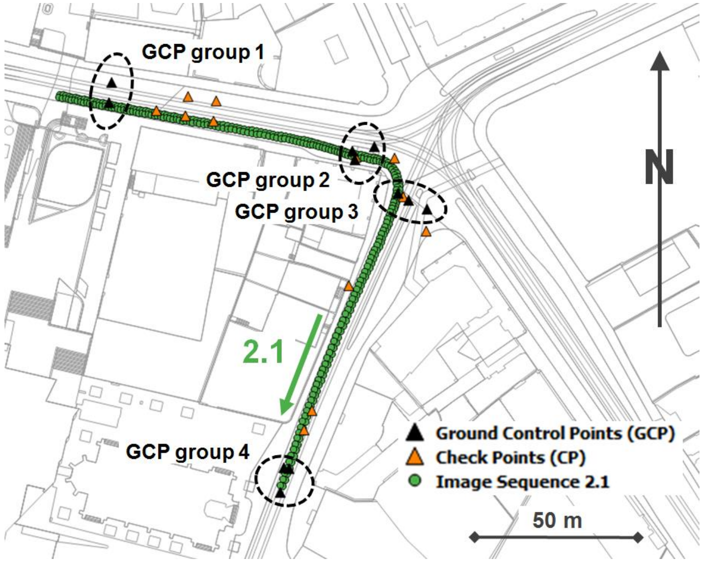


Cavegn, S., Nebiker, S., Haala, N., 2016. A Systematic Comparison of Direct and Image-based Georeferencing in Challenging Urban Areas. ISPRS - Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci. XLI-B1, 529–536.

Direct and Image-Based Georeferencing – Comparison with Check Points

- Groups: 2/3/4 ground control points (GCP)
- Scenario 1: one GCP group at each end of a segment
- Scenario 2: two additional GCP groups close to the corresponding sharp curve



Sequence	CP count	Direct	Image-based 2 GCP groups		Image-based 4 GCP groups	
		Δ3D [mm]	Δ3D [mm]	Impr. factor	Δ3D [mm]	Impr. factor
1.0	15	555	137	4.1	27	20.4
1.1	11	168	42	4.0	21	8.0
1.2	11	774	121	6.4	26	29.4
2.0	11	131	76	1.7	48	2.7
2.1	12	593	432	1.4	73	8.1
2.2	11	813	425	1.9	36	22.5
3.0	8	174	42	4.2		
3.1	10	64	30	2.1		
3.2	10	568	53	10.8		
Mean		427	151	2.8	39	11.1

Matching Strategies and Results (Cavegn et al. 2015)

⇒ Dense image matching for street-level mobile mapping imagery

Implementation of a dense multi-view stereo matching pipeline…

- Software **SURE** originally developed to provide 3D point clouds or DEM from **standard airborne** and **close range terrestrial** image blocks
- Mobile mapping scenarios typically include stereo configurations with **camera motion** predominantly **in viewing direction**

➢ Adaptation of existing processing pipeline

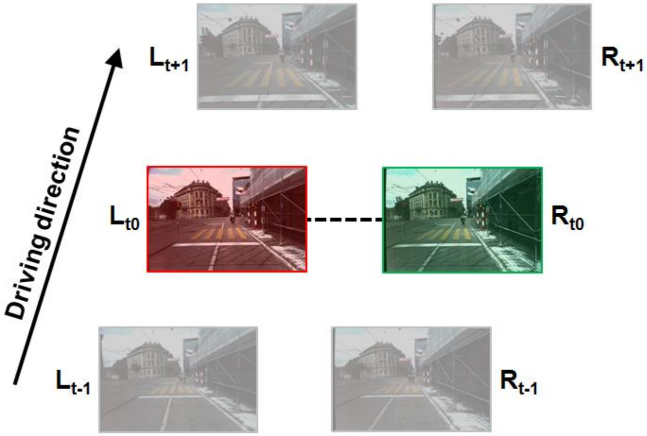
Evaluation of matching strategies…

…for **image sequences** captured by a **stereovision-based mobile mapping system**

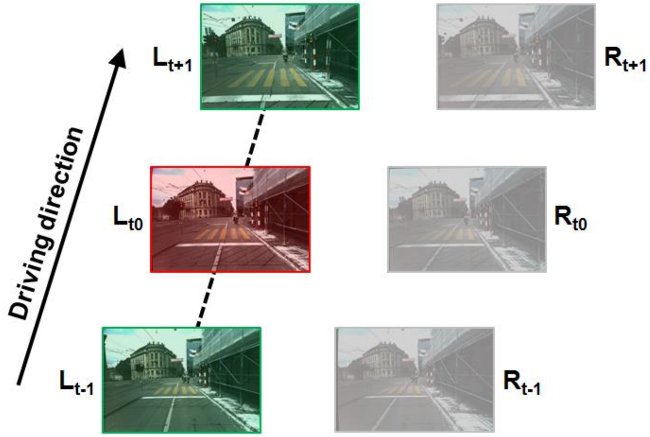
Cavegn, S., Haala, N., Nebiker, S., Rothermel, M., Zwölfer, T., 2015. Evaluation of Matching Strategies for Image-based Mobile Mapping. ISPRS Ann. Photogramm. Remote Sens. Spat. Inf. Sci. II-3/W5, 361–368.

Note: c2 & c4 require polar rectification for in-sequence stereo matching
e.g. Pollefeys et al. (1999)

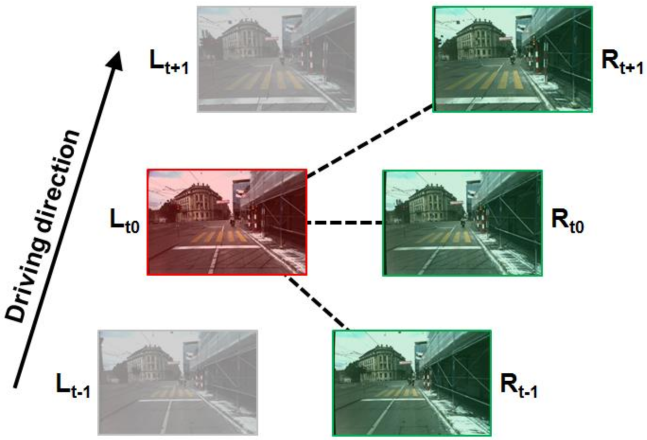
Matching Configurations



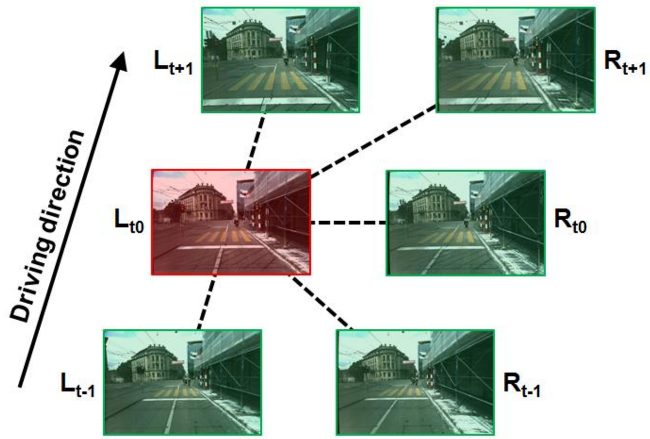
Configuration c1



Configuration c2

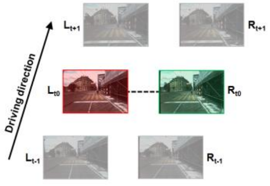


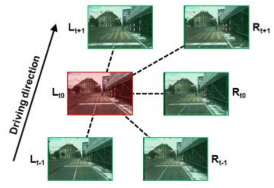
Configuration c3

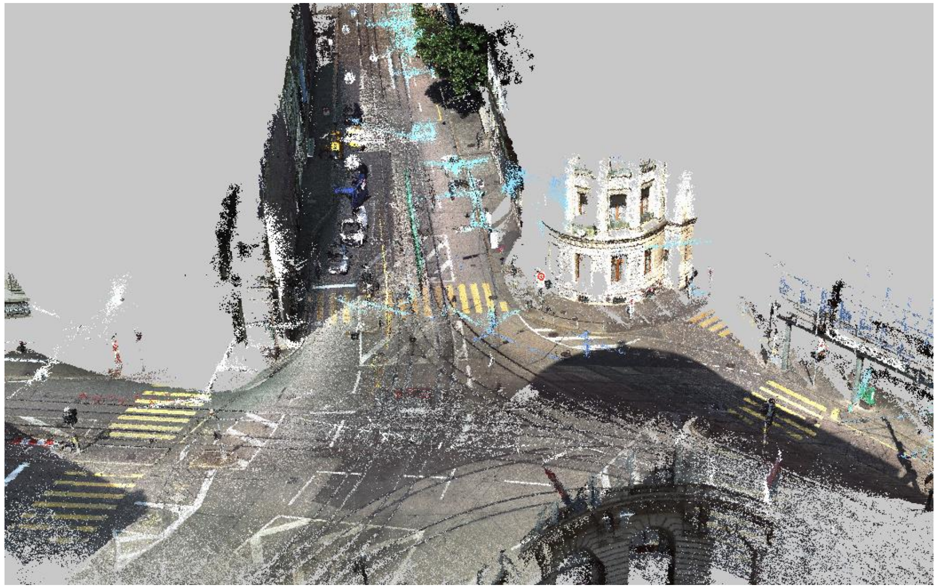


Configuration c4

Accuracy and Completeness

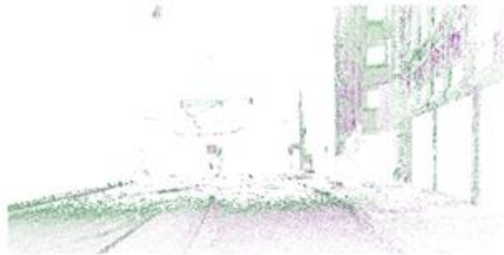






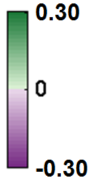
Fused c1-TLS

RMSE: 147 mm, Mean: 23 mm



Fused c4-TLS

RMSE: 165 mm, Mean: 27 mm



Cavegn, S., Haala, N., Nebiker, S., Rothermel, M., Zwölfer, T., 2015. Evaluation of Matching Strategies for Image-based Mobile Mapping. ISPRS Ann. Photogramm. Remote Sens. Spat. Inf. Sci. II-3/W5, 361–368.

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Performance Evaluation

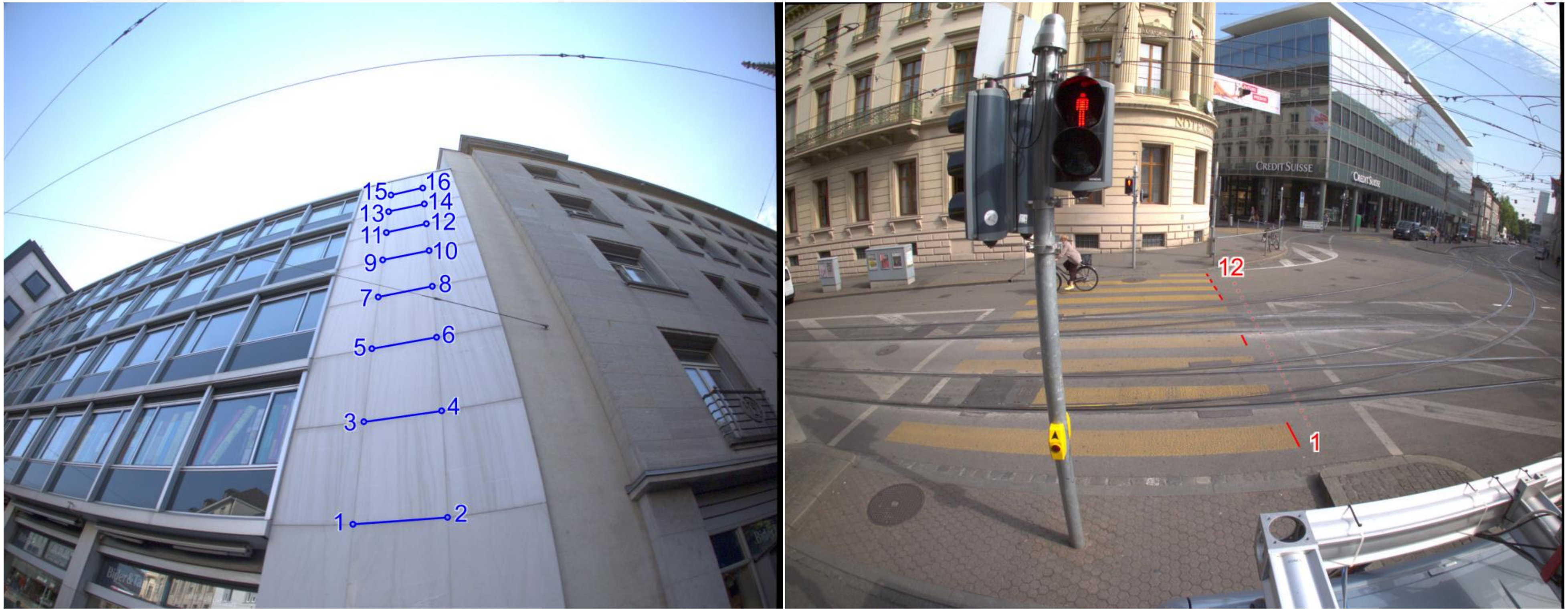
– Relative 3D Measurement Accuracies

– Absolute 3D Measurement Accuracies

3D Image Cloud Services: Functionality and Applications

Conclusion and Outlook

Performance Evaluation – Reference Data



Reference points and distances for the accuracy analysis

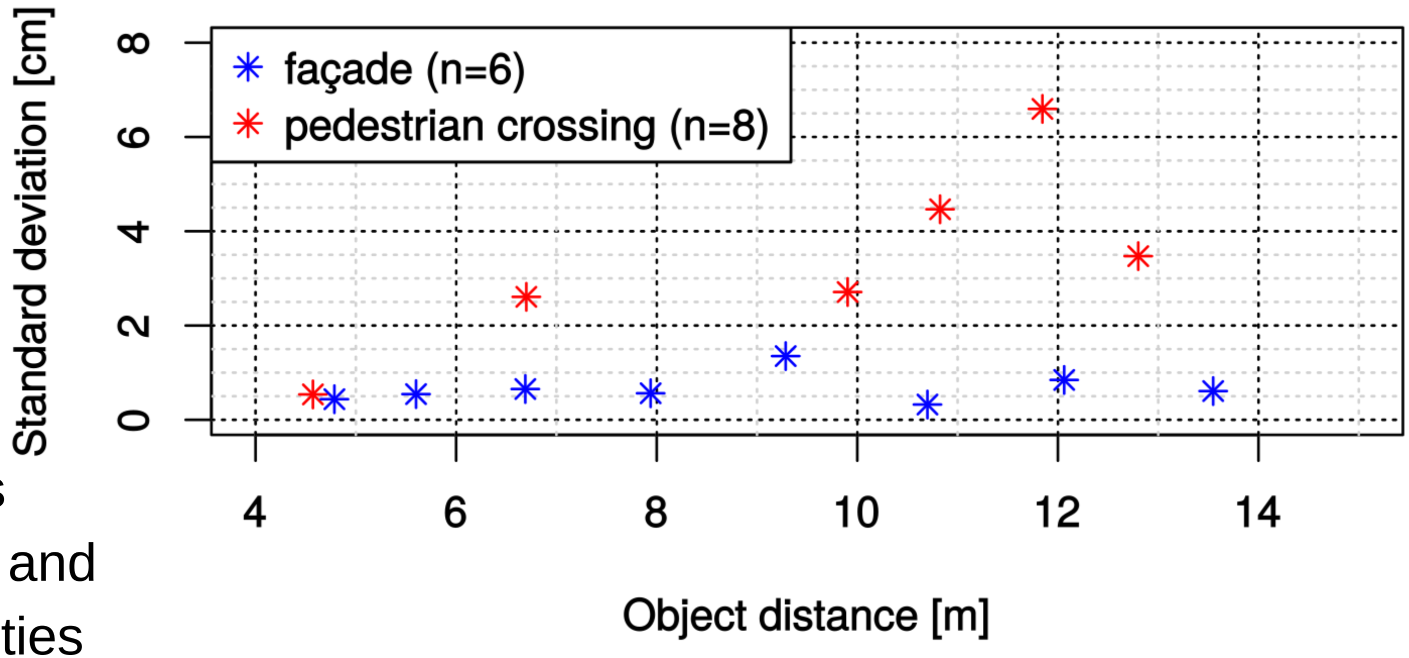
– architectural use case (left), road infrastructure use case (right)

– points determined using a total station

Blaser, S., Nebiker, S., Cavegn, S., 2017. System Design, Calibration and Performance Analysis of a Novel 360° Stereo Panoramic Mobile Mapping System. ISPRS Ann. Photogramm. Remote Sens. Spat. Inf. Sci. IV-1/W1, 207–213.

Relative Accuracy (360° Panoramic Stereo System)

- Comparison of **image-based 3D distance measurements** with reference 3D distances
- SD façade: **0.5 – 1.5 cm**
- SD pedestrian crossing: **0.5 – 6.5 cm**
- Affected by uncertainties of IO and RO calibration and point definition uncertainties

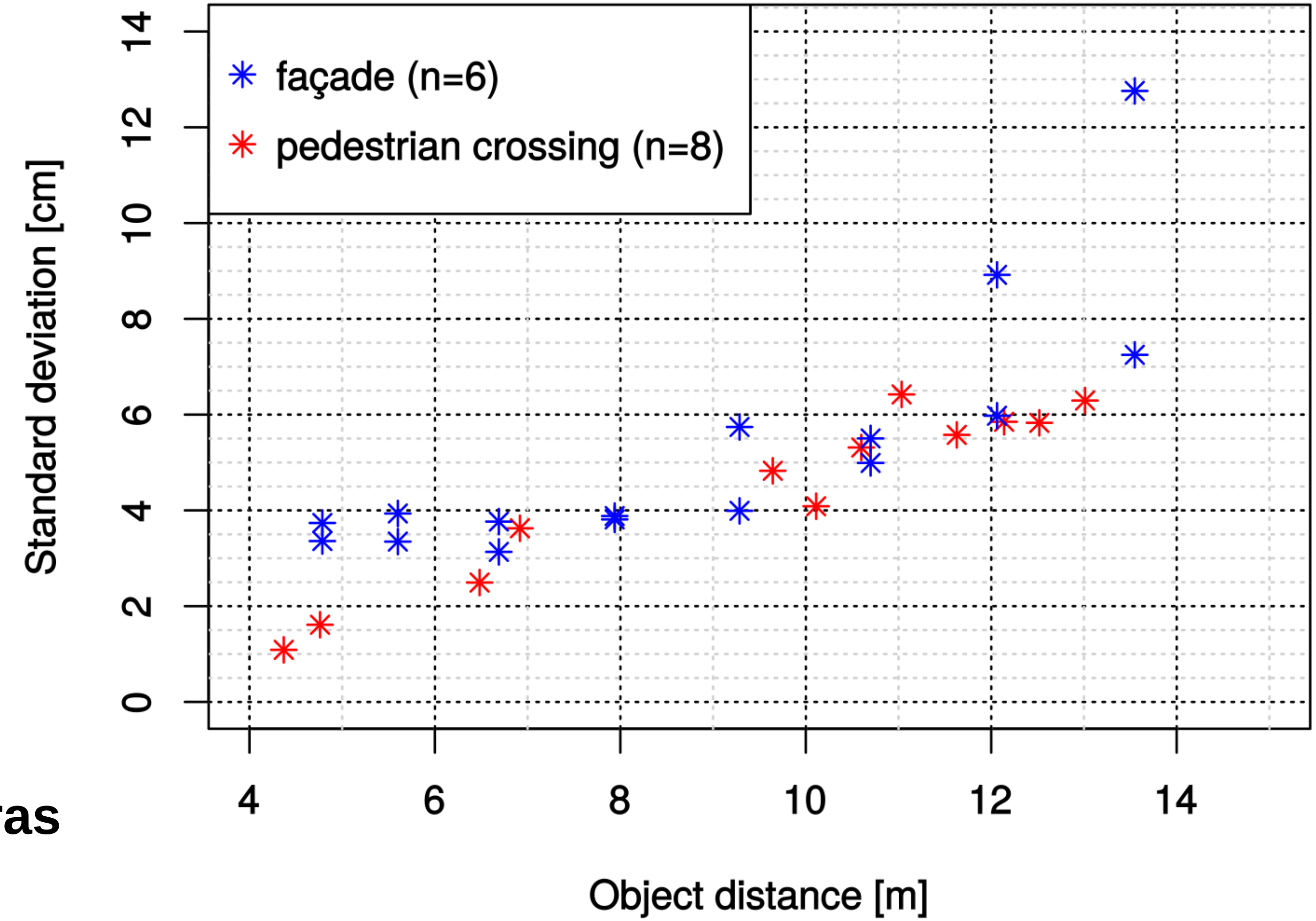


- Errors in viewing direction require further attention => point definition …

Blaser, S., Nebiker, S., Cavegn, S., 2017. System Design, Calibration and Performance Analysis of a Novel 360° Stereo Panoramic Mobile Mapping System. ISPRS Ann. Photogramm. Remote Sens. Spat. Inf. Sci. IV-1/W1, 207–213.

Absolute Accuracy (360° Panoramic Stereo System)

- Comparison of **image-based 3D point measurements** with reference 3D points
- SD façade: **3.5 – 13.0 cm**
- SD pedestrian crossing: **1.0 – 6.5 cm**
- Additionally affected by trajectory error
- **Accuracies** ~ equal to **perspective stereo cameras** (Burkhard et al., 2012)



Burkhard, J. et al., 2012. Stereovision Mobile Mapping: System Design and Performance Evaluation, in: ISPRS - International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. Melbourne, pp. 453–458.

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Functionality of 3D Image Cloud Services (I)

3D Measurements

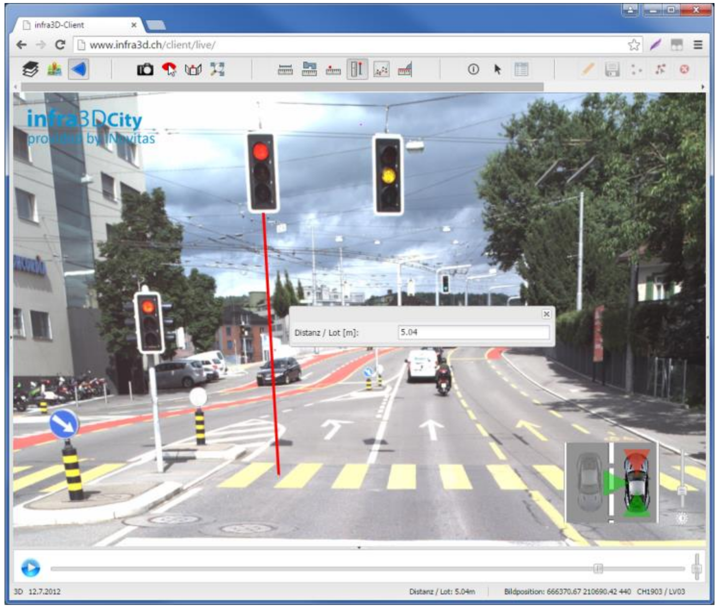
- distances, areas, height differences, clearance heights etc.

3D Digitizing

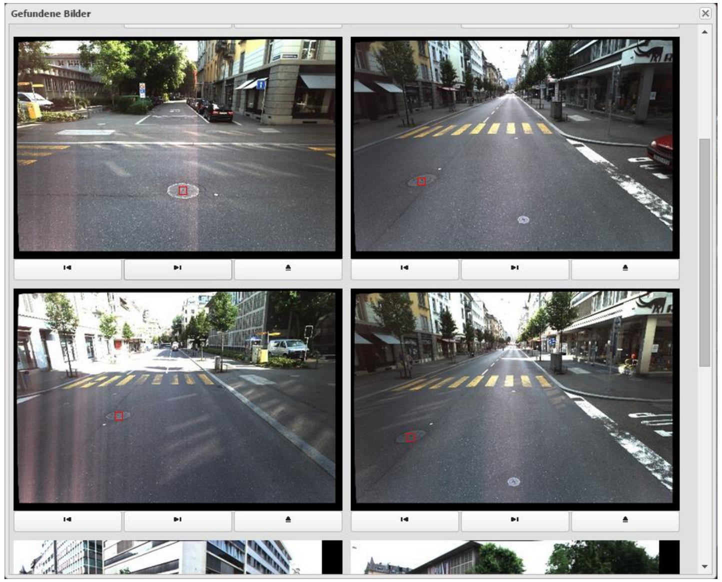
- capturing of visible objects, e.g. gulleys, inlets, road markings, surface type, damages etc.

Augmentation

- accurate real-time overlays of existing or projected objects or infrastructure elements
- georeferenced annotations



Functionality of 3D Image Cloud Services (II)



Spatial-temporal Search Functionality

- efficient spatio-temporal search of 3D images containing a specific point or object
- basis for accurate and reliable multi-image measurements and change analysis

Staking-out / GIS-to-Field

- using mobile clients (tablets, smartphones etc.)
- in the future: 3D smartphones & AR glasses

Automatic Information Extraction

- 3d imagery ideally suited for object detection and extraction using **deep learning**

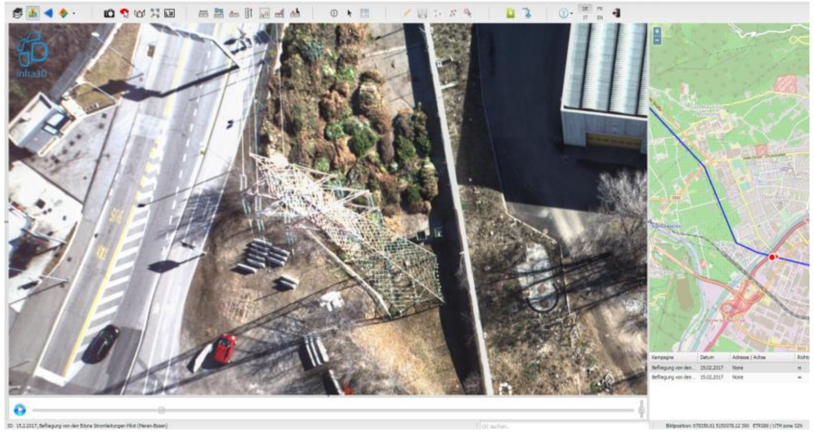
Automatic Derivation of Reality-based 3D City Models

(Bachelor Thesis Ackermann & Studer, 2016)

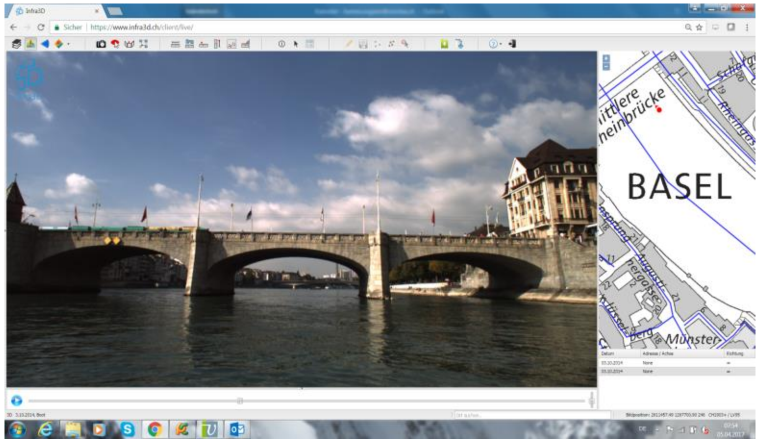
Selected Infrastructure Applications – Streetlevel, Aerial, Water, Rail …

Utilities cadastres (Ingesa Oberland AG)

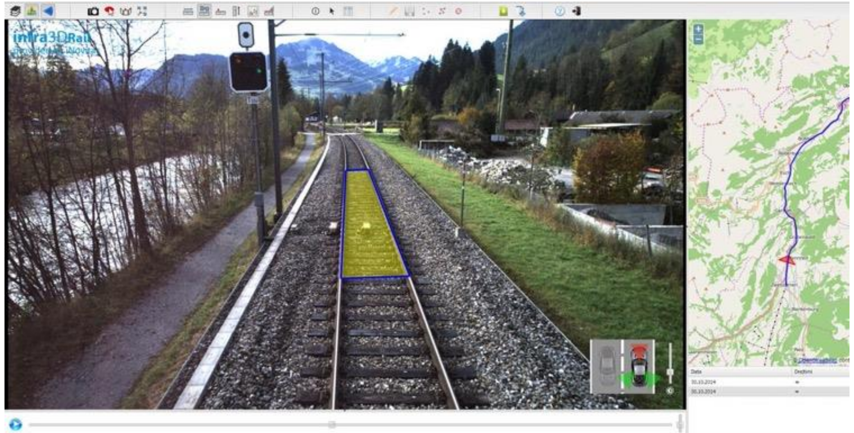
Electricity / power lines (Meran / Bozen)



River shores & bridges (State of Basel)



Rail traffic infrastructure (BLS)



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Conclusion

3D imagery & cloud services for infrastructure management

- **Paradigm change**
  - field visits / field work ➔ office / digital realities
  - field surveyors ➔ infrastructure domain experts
    (fewer ‘surveyors’ needed for simple / traditional field tasks)
- **Strengths of 3D imagery over (coloured) 3D point clouds**
  - spatial and temporal coherence of radiometric and depth information
    - WYSIWIG
  - intuitive virtual measurements tasks (points, edges, surfaces)
- **Wide spectrum of functionality and applications**

Outlook

Image-based Georeferencing

- exploitation of (calibrated) multi-view camera configurations

Automated Information Extraction

- application of Machine Learning and **Deep Learning** to additional tasks
- beyond anonymization etc. – towards high-end scene understanding
- ➢ we are at the very beginning!

Indoor Mapping and Building Information Management (BIM)

- LiDAR SLAM and advanced image-based georeferencing
- for highly accurate and robust georeferencing of indoor 3D image spaces

A (3D) picture says more than thousand words …

Questions?

Contact: **Stephan Nebiker, stephan.nebiker@fhnw.ch, @snebiker**

Interested in our technology? **www.inovitas.ch**

Interested in our related Working Groups?

ISPRS ICWG I/IV Robotics for Mapping and Modelling
Twitter: @robmap_isprs

DGPF Arbeitskreis Sensoren & Plattformen / Mobile Mapping
http://www.dgpf.de/aks.html