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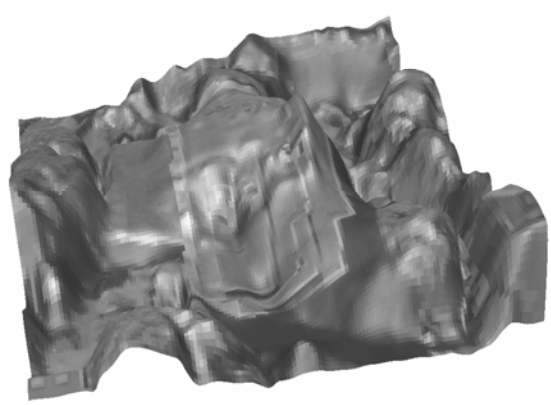
Comeback of Digital Image Matching

Photogrammetric Week 2009

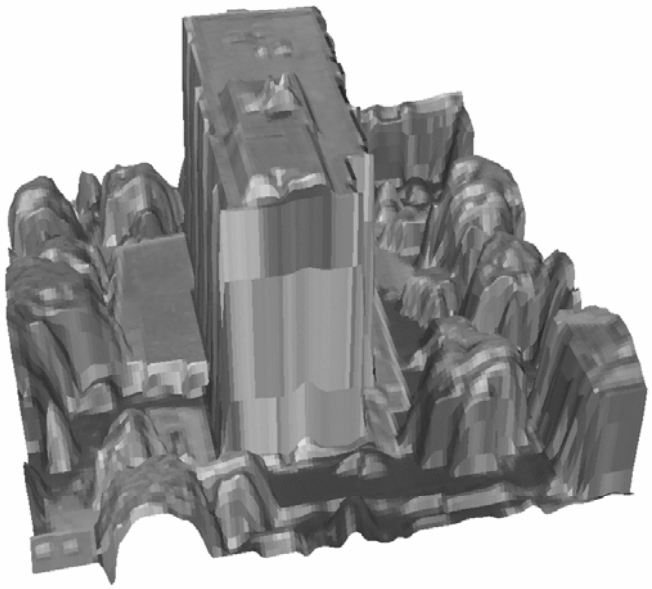
Universität Stuttgart

Comeback of Digital Image Matching
Digital Image Matching vs. Airborne LiDAR

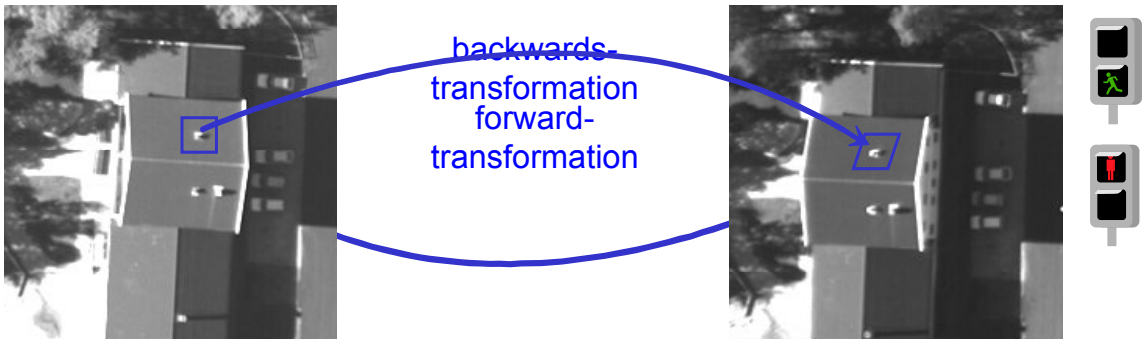
- 3D surface reconstruction from stereo image matching
  - Established approach in open terrain (?)
- Problems due to missing surface texture, occlusions ..
  - Shadow, overexposure, homogenous surfaces, built-up areas



- Airborne LiDAR
  - 3D point clouds from run-time measurement of refleceted laser pulses

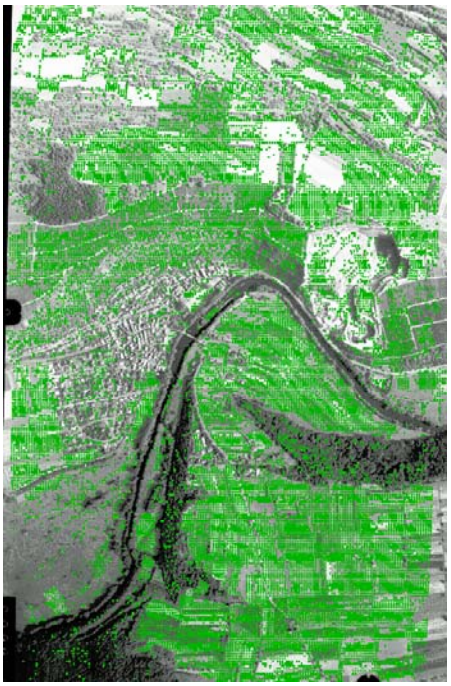


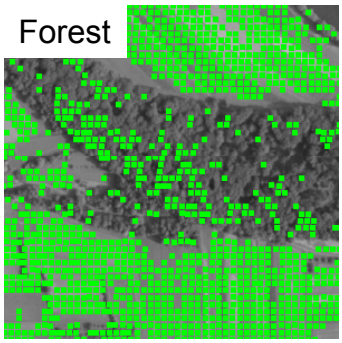
Test of image matching quality: Consistency from forward- backward-matching

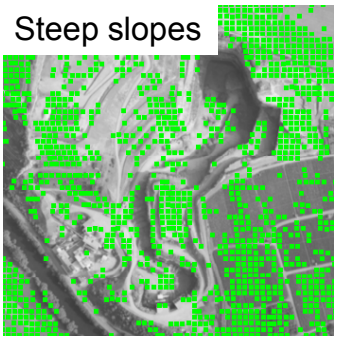


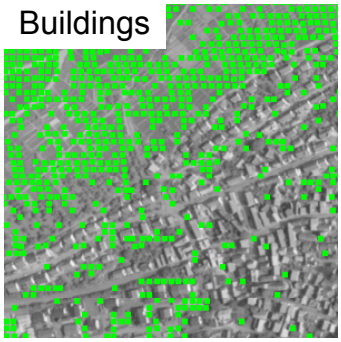
- Consistency of matching result from backwards transformation of search window to starting point
  - Hited starting point
  - Missed starting point

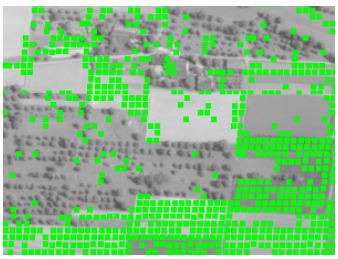
Quality from forward- backward-matching: Phowo Tutorial 1999











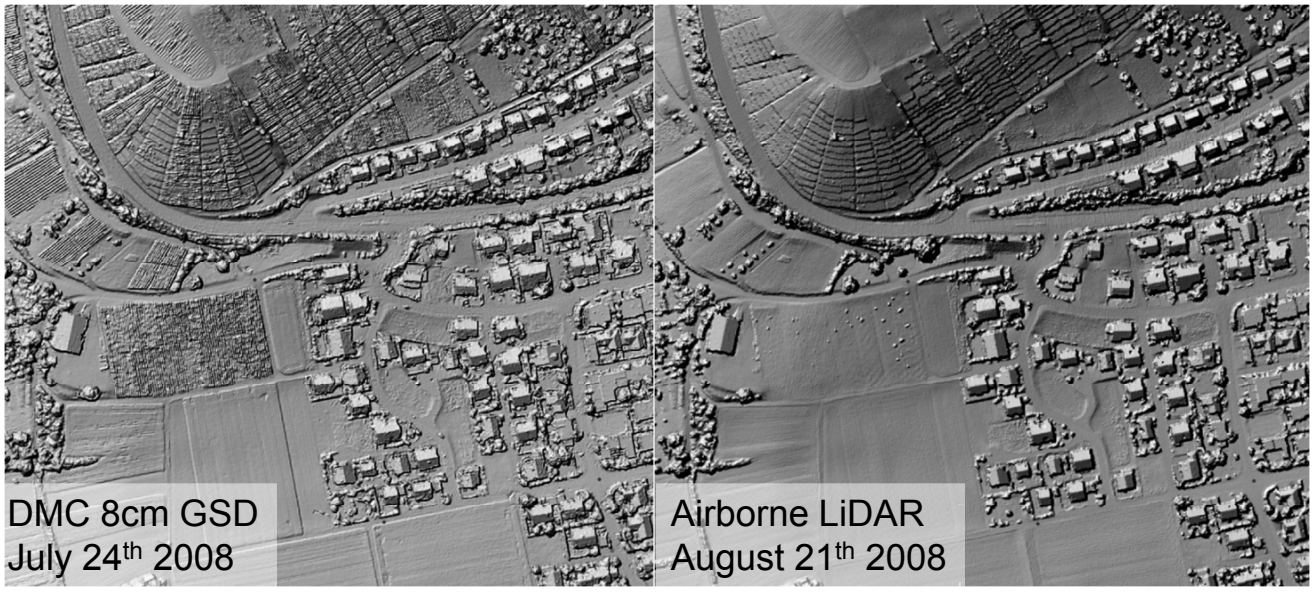
- Success rate of 50% of point transfer for scanned RMK images
- Clearly defeated by airborne LiDAR

Comeback of Digital Image Matching (2009)

- Automatic image based DSM generation – the DGPF test on digital airborne camera performance

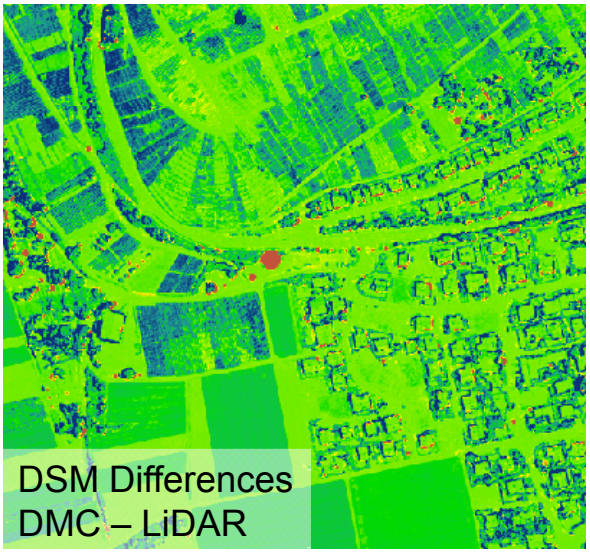
DSM from image matching
(DGPF test, 2009)

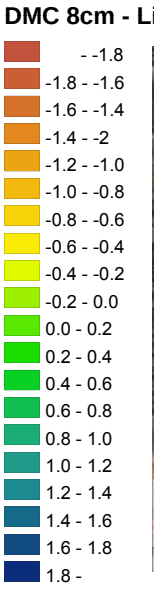
3D Surface Reconstruction
Digital Image Matching vs. Airborne LiDAR



- Reasonable results from both techniques
- Main differences at vegetation due to growth and measurement principle

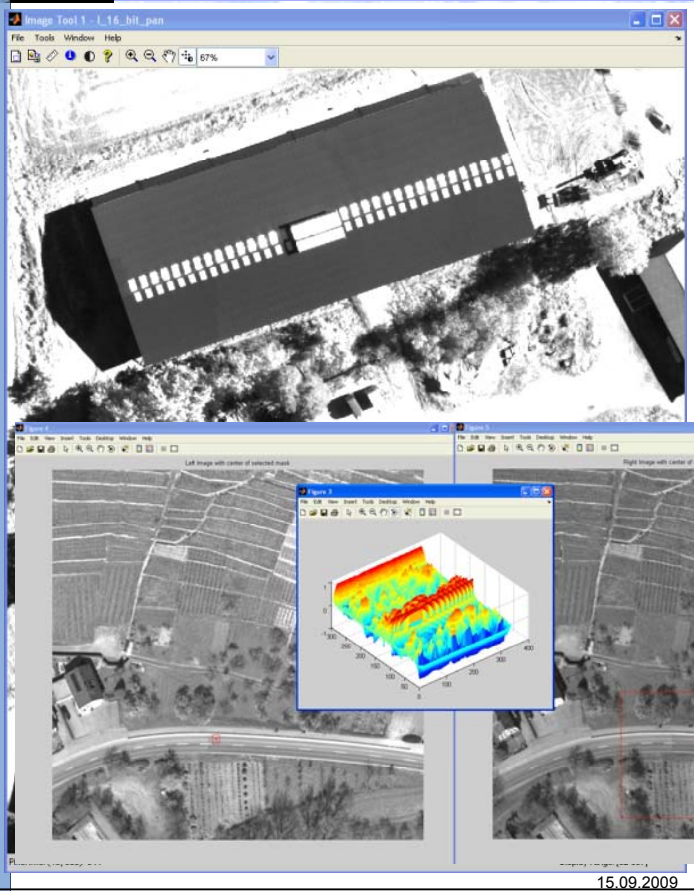
3D Surface Reconstruction
Digital Image Matching vs. Airborne LiDAR





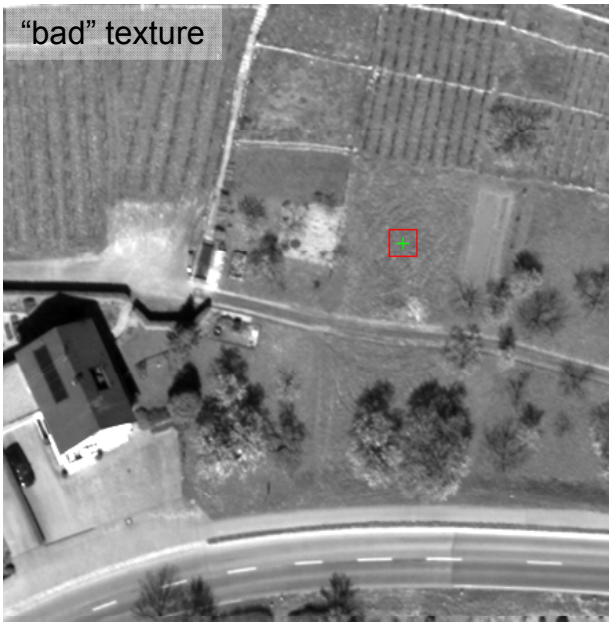
- Reasonable results from both techniques
- Main differences at vegetation due to growth and measurement principle
  - Vineyard, maize, single trees

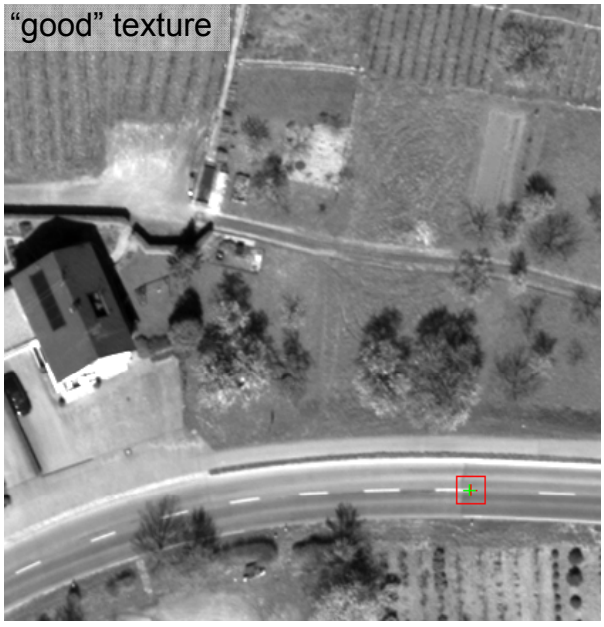
Improvement of matching performance: Enhanced image quality



- Improved dynamic and signal-to-noise-ratio of aerial images even for difficult illumination conditions
- Improved matching performance even for standard algorithms
  - Correlation (lecture Digital Image Processing)

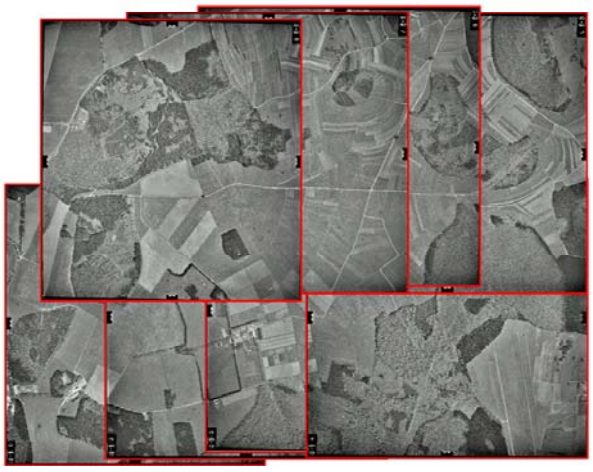
Accuracy performance of point transfer Least-Squares-Image-Matching

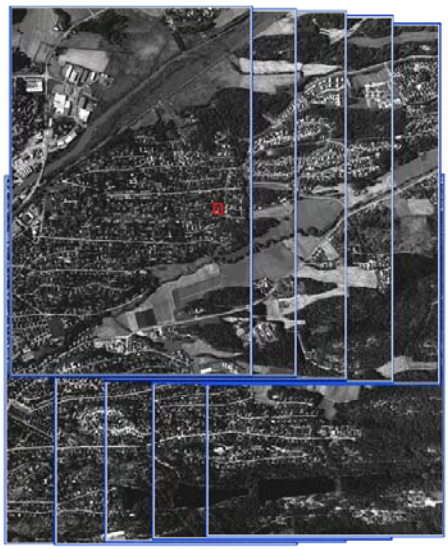




- Standard deviation from least-squares matching σ_x = 0.39 pel, σ_y = 0.36 pel σ_x = 0.04, σ_y = 0.01
- Differences forward-backward-matching Δx =0.28, Δy =-0.35 Δx =0.008, Δy =0.0004

Improvement of matching performance: Multiple overlapping image blocks

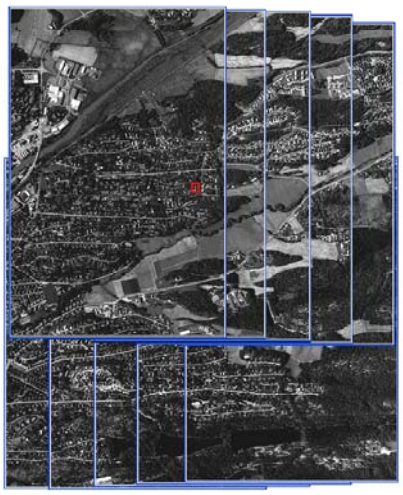


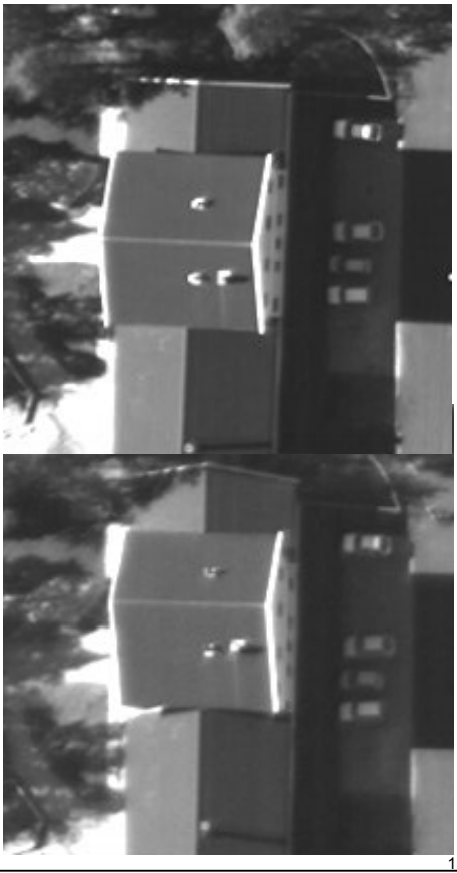


- Standard overlaps of (analog) image flight
  - 60% along-
  - 20% across track
- Large overlaps of (digital) image flight
  - 80% along-
  - 60% cross track

Multiple overlapping image blocks

- Coverage 80% in-flight and 60% across-flight
- Each object point visible in 10 images
  - 2 image strips with 5 images each





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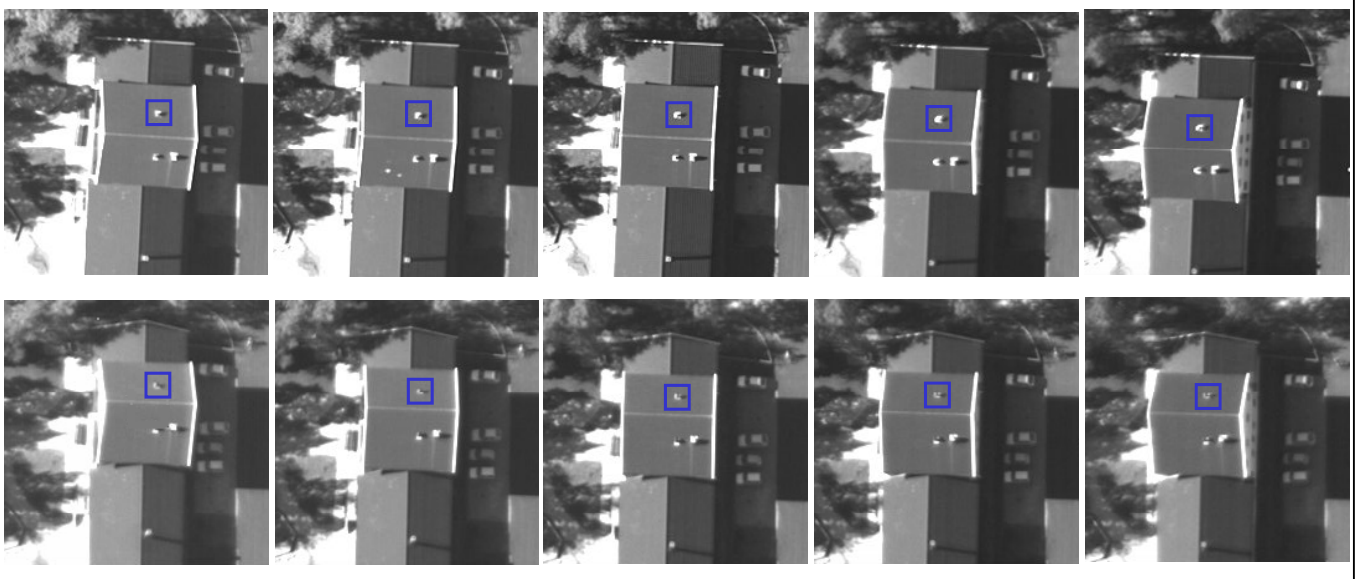
Dense matching using multiple-overlaps



- Evaluate all possible stereo combinations
- Generate dense 3D point clouds from automatic stereo matching

$$\binom{k}{r} = \frac{k!}{r!(k-r)!} = \binom{10}{2} = 45$$

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Advantage of multiple stereo configurations (I): Different base orientations

- Stereo partners available
  - in-flight
  - across-flight
- Optimal stereo configuration available for each gradient direction
  - Support dense matching using epipolar lines from aerial triangulation

Advantage of multiple stereo configurations (II): Different base lengths

Image 1

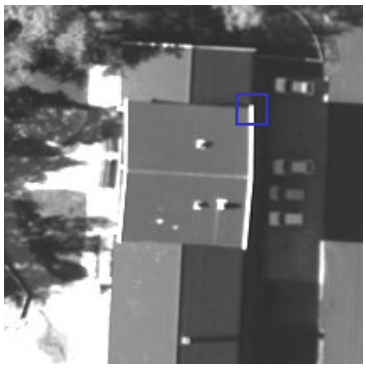
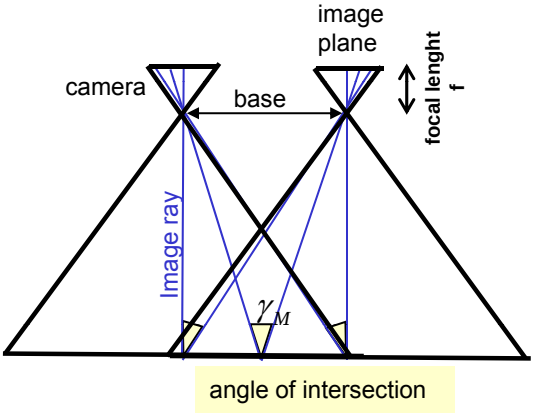


Image 2

Image 5

- Large image base (1-5)
  - Good accuracy for spatial intersection
  - Great image differences
- Small image base (1-2)
  - Simplified automatic matching due to small image differences
  - Reduced accuracy for spatial intersection



angle of intersection

DGPF project: Performance of automatic DSM generation from digital airborne cameras-

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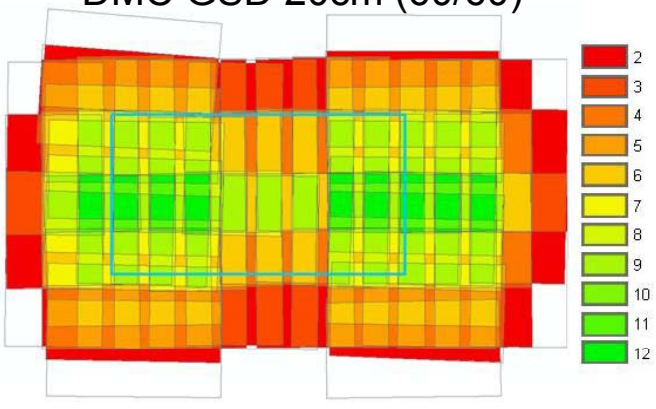
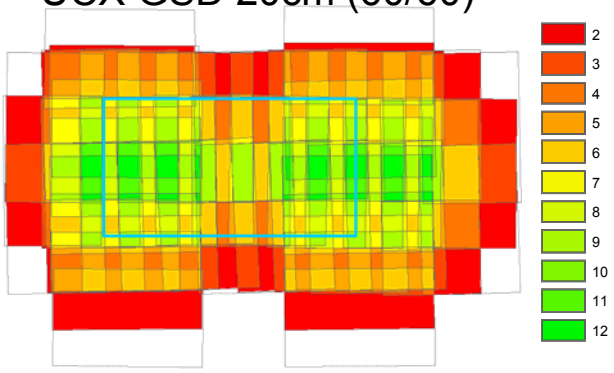
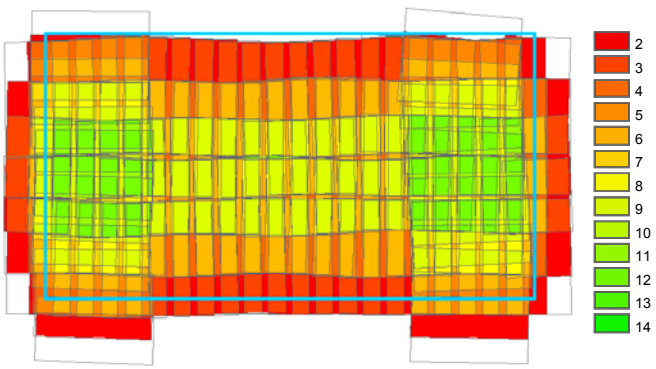
DGPF project: Exemplary overlap for GSD 20cm/8cm DMC & UCX

DMC GSD 20cm (60/60)

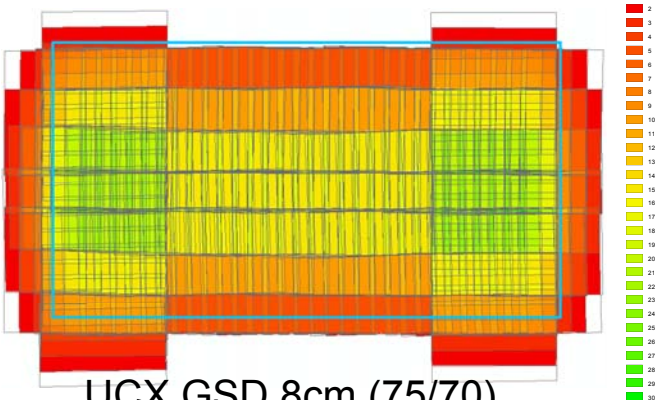


UCX GSD 20cm (60/60)





DMC GSD 8cm (60/63)



UCX GSD 8cm (75/70)

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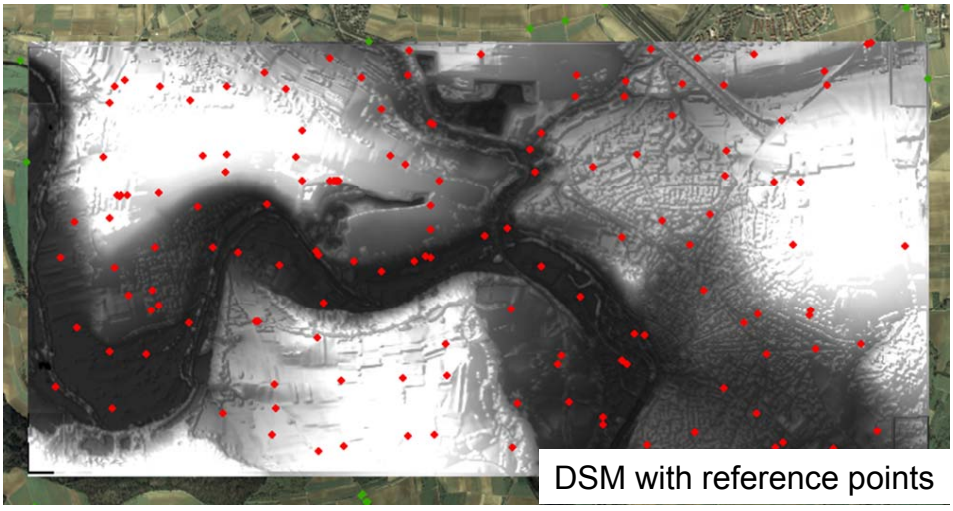
Performance of automatic DSM generation from digital airborne cameras- the DGPF project

System	System provider	Flyer	Date of flight(s)
DMC	Intergraph/ZI	RWE Power	24.7.08 + 6.8.08
ADS 40, SH52	Leica Geosyst.	Leica Geosyst.	6.8.08
JAS-150	JenaOptronik	RWE Power	9.9.08
Ultracam-X	Vexcel Imaging	bsf Swissphoto	11.9.08
RMK-Top15	Zeiss	RWE Power	24.7.08 + 6.8.08
quattro DigiCAM, 4-Head	IGI	Geoplana	6.8.08
AIC-x1, 1-Head	Rolleimetric	Alpha Luftbild	11.9.08
AIC-x4, 4(3)-Head	Rolleimetric	Vulcan Air	19.9.08
DLR 3K-Camera	DLR Munich	DLR Munich	15.7.08
AISA+ hyper-spectral (with DMC parallel)	Specim/FH Anhalt	RWE Power	2.7.08
ROSIS hyper-spectral	DLR Munich	DLR Munich	15.7.08
ALS 50 LiDAR	Leica Geosyst.	Leica Geosyst.	21.8.08

DSM raster accuracy: Comparison to reference points

- DSM generated by MATCH-T DSM
  - 25cm grid width for 8cm GSD
  - 50cm grid width for 20cm GSD
- Compute RMS-values from differences at available GPS reference points



DSM with reference points

DSM raster accuracy: Comparison to reference points

	Sensor	RMS [cm]	Mean [cm]	Δ Max/Min [cm]		Elim. Points
LiDAR-reference	ALS 50	3.4	-1.1	6.4	-11.0	3
GSD 8cm Raster 0.2m	DMC	3.9	-0.8	21.1	-0.9	2
	Ultracam-X	4.2	-1.4	11.7	-10.8	0
	DigiCAM	5.3	-1.1	15.5	-15.7	1
	RMK	5.2	2.4	15.6	-19.9	2
GSD 20 cm Raster 0.5m	DMC	15.7	-9.3	36.9	-30.5	1
	DigiCAM	10.1	-0.1	27.1	-30.5	1
	Ultracam-X	7.6	0.7	21.3	-17.9	1
	RMK	9.9	1.4	31.8	-25.9	2

- Potential gross DSM errors due to
  - Point occlusions
  - Other errors
- Improve comparability
  - Eliminate points $|\Delta Z| > 3 \cdot RMS$
- DSM-raster accuracy
  - 8cm GSD: 4.4cm RMS
    - already limited by available reference accuracy
  - 20cm GSD: 11.1cm RMS

DSM accuracy: Influencing factors

- Image Geometry
  - Investigated by separate group within DGPF-test
  - Phowo-Presentation Michael Cramer
    - Generation and application of „absolute orientation“ for DSM generation
- Topography and texture of object surfaces
  - Evaluation of different areas
    - Planar surfaces (paved areas, sport fields)
    - Built-up areas
    - Agricultural areas
- Multi-Image-Matching software
  - Evaluate different software packages
    - MATCH-T DSM
    - SAT-PP
    - NGATE
- Elevation data generation - Image matching, interpolation, filtering
  - Evaluate different products
    - Interpolated DSM raster
    - 3D point clouds

Accuracy of 3D point clouds: Test at planar areas

Test site sports field

ALS50 LiDAR reference colour coded height

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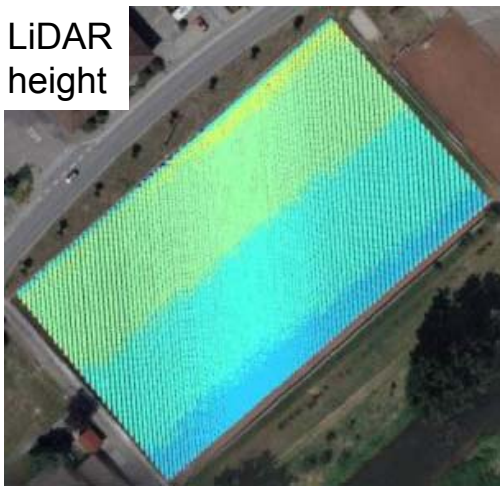
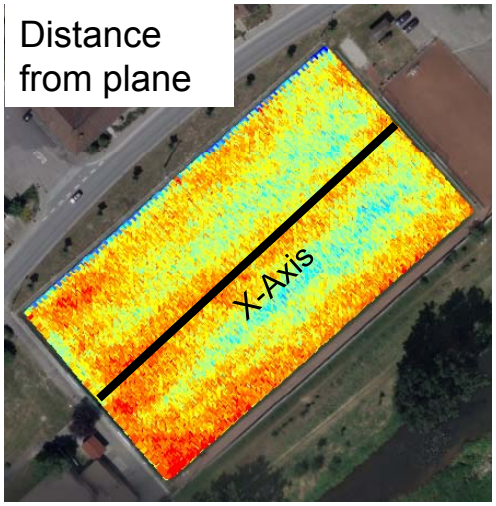
Analysis of 3D point clouds in flat areas

Example LiDAR (ALS50) performance

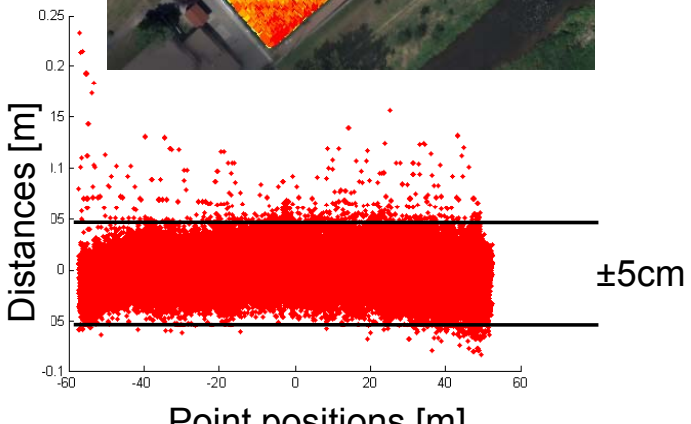
LiDAR height



Distance from plane



- Adjusted plane from 3D point cloud
- Analysis of distances from plane
  - RMS = 1.92 cm
  - Point density = 8.25 Pts/m²



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Analysis of 3D point clouds in flat areas
Multi-Image-Matching

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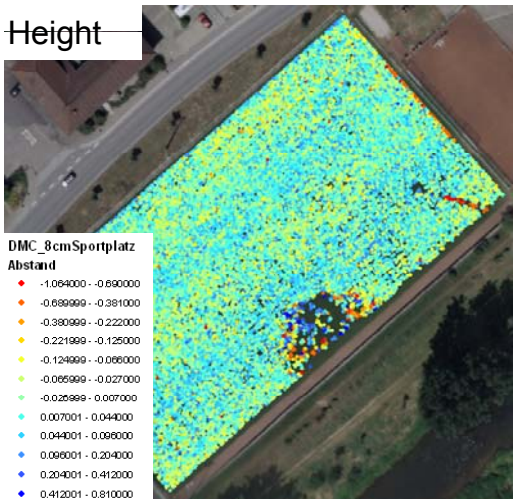
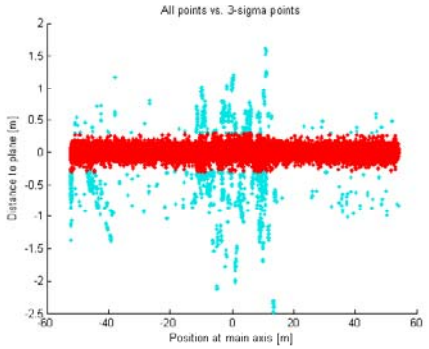
Height



DMC 8cm

Matched points and gross errors

- Analysis influenced by gross errors from matching
  - Moving objects
  - Moving shadows
- Eliminate gross error before further analysis
  - Compute standard deviation from all points
  - Eliminate points with distance > 3□Std.dev.



Distance 3D points to plane (Dist >3 □ Std.Dev.) marked

Analysis of 3D point clouds
Sports field Rosswag 8cm GSD

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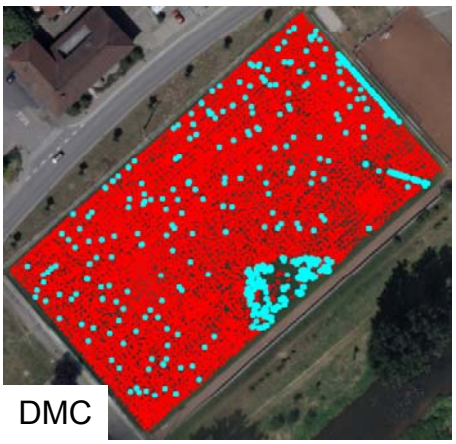
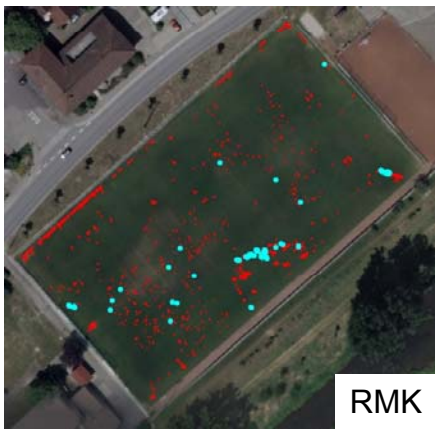
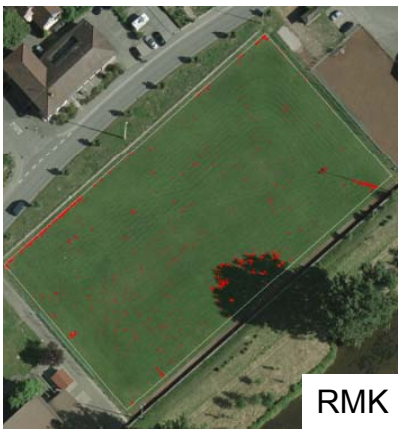


DMC



RMK



RMK

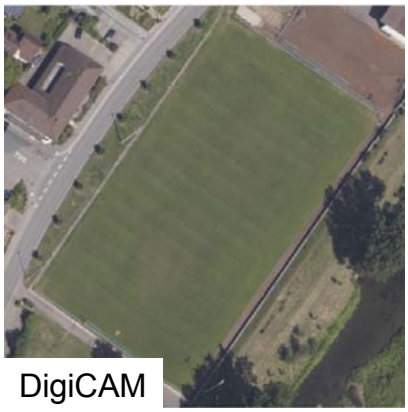
DMC

- DMC and RMK images recorded simultaneously, double hole flight allows for direct comparison
  - DMC
    - RMS = 5.2 cm
    - Point density = 19.7 Pts/m^2
  - RMK
    - RMS= 17.2 cm
    - Point density = 0.8 Pts/m^2
- Significant quality increase due to digital imagery

Digital image data
Sports field Rosswag 8cm GSD

DMC

Ultracam-X



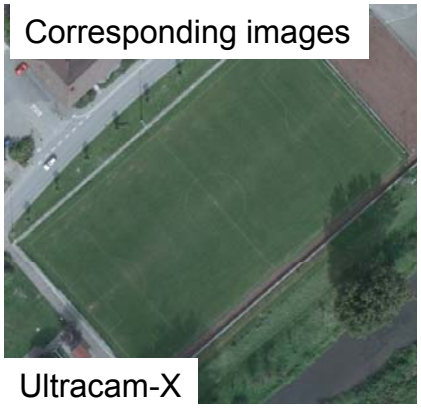
DigiCAM

	DMC	Ultracam-X	DigiCAM
Day of Flight:	July 24	September 11	August 6
Local time:	~10:00h	~12:00h	~12:00h

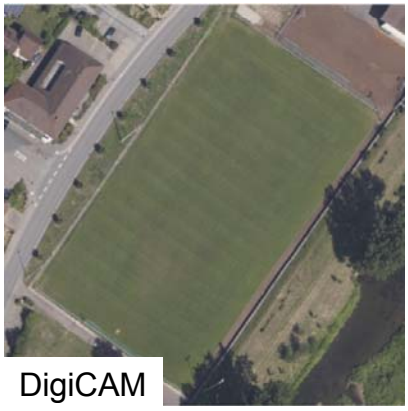
Point clouds (original and filtered)
Sports field Rosswag 8cm GSD

DMC

Corresponding images

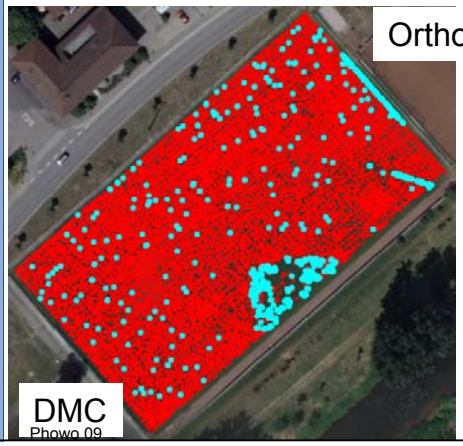


Ultracam-X

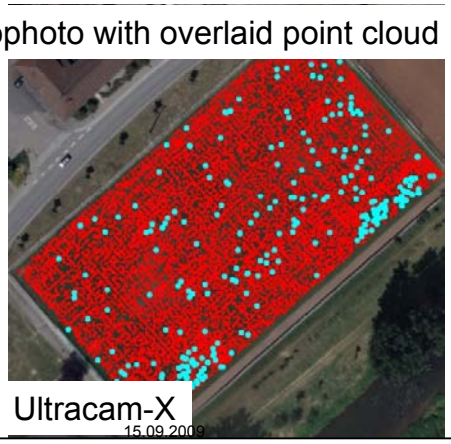


DigiCAM

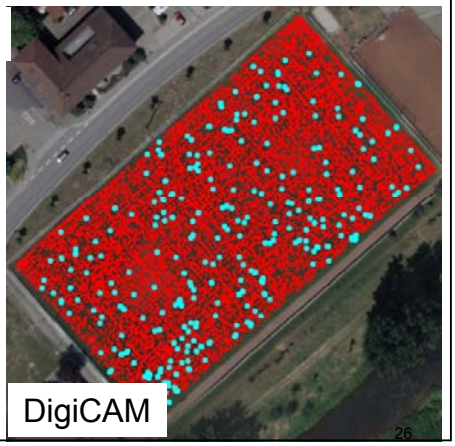
Orthophoto with overlaid point cloud



DMC



Ultracam-X



DigiCAM

Accuracy of 3D point clouds
Sports field Rosswag - GSD 8cm

Sensor	STD w/o gross errors [cm]	STD [cm]	Elim.Pts. [%]	Density Pts./m²
DMC 8cm	5,2	9,7	1,3	19,67
UCX 8cm	6,8	8,0	0,4	19,04
DigiCAM 8cm	10,2	11,2	0,7	20,83
RMK 8cm	17,2	27,3	3,2	0,77
ALS50	1,8	1,9	0,5	8,25

7,4 cm	**Mean (only from digital cameras)**	**19,85 Pts/m²**

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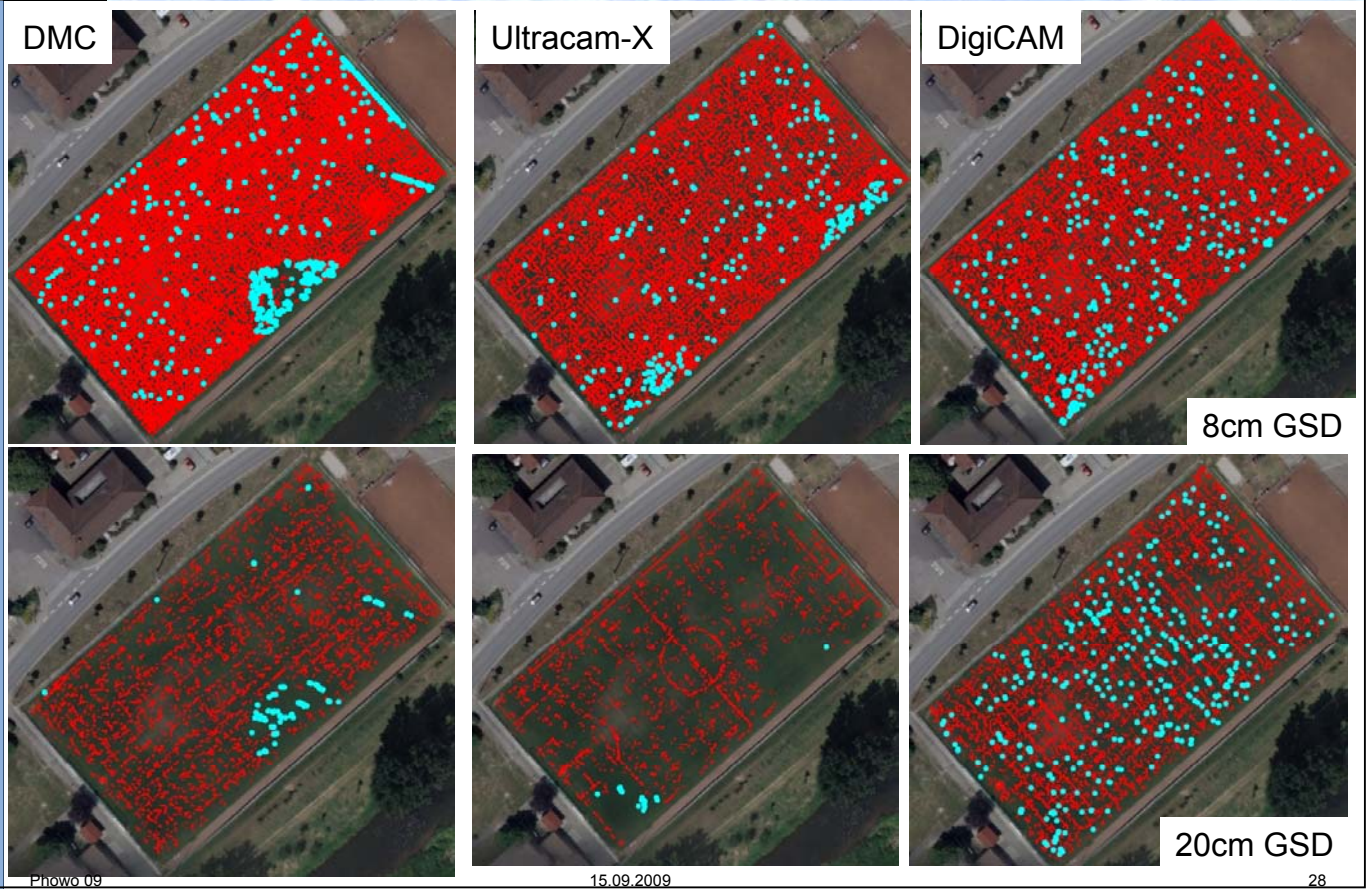
Influence of GSD on DSM generation



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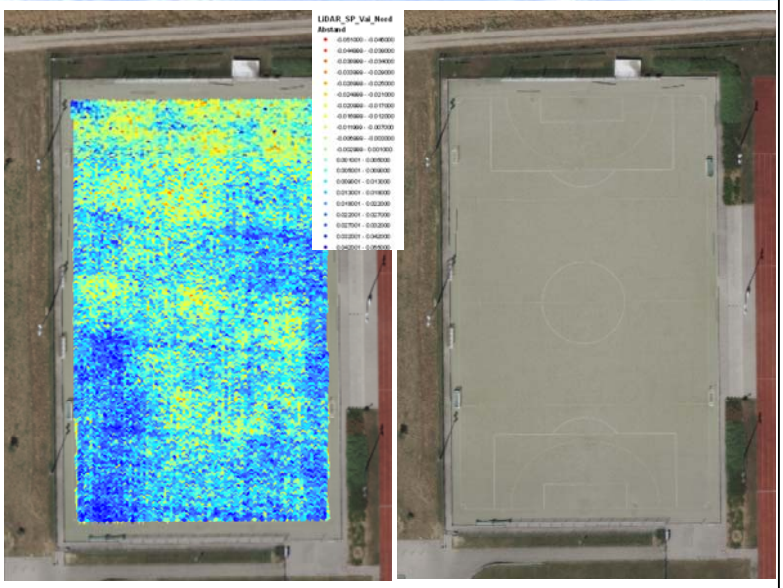
Accuracy of 3D point clouds
Sports field Rosswag - GSD 20cm

Sensor	STD w/o gross errors [cm]	STD [cm]	Elim.Pts. [%]	Density Pts./m²
DMC 20cm	17,2	25,4	1,1	2,71
UCX 20cm	22,6	34,2	0,4	1,62
DigiCAM 20cm	34,1	48,2	2,5	2,64
RMK 20cm	60,6	66,2	0,7	0,31
ALS50	1,8	1,9	0,5	8,25

24,6 cm	**Mean (only from digital cameras)**	**2,32 Pts./m²**

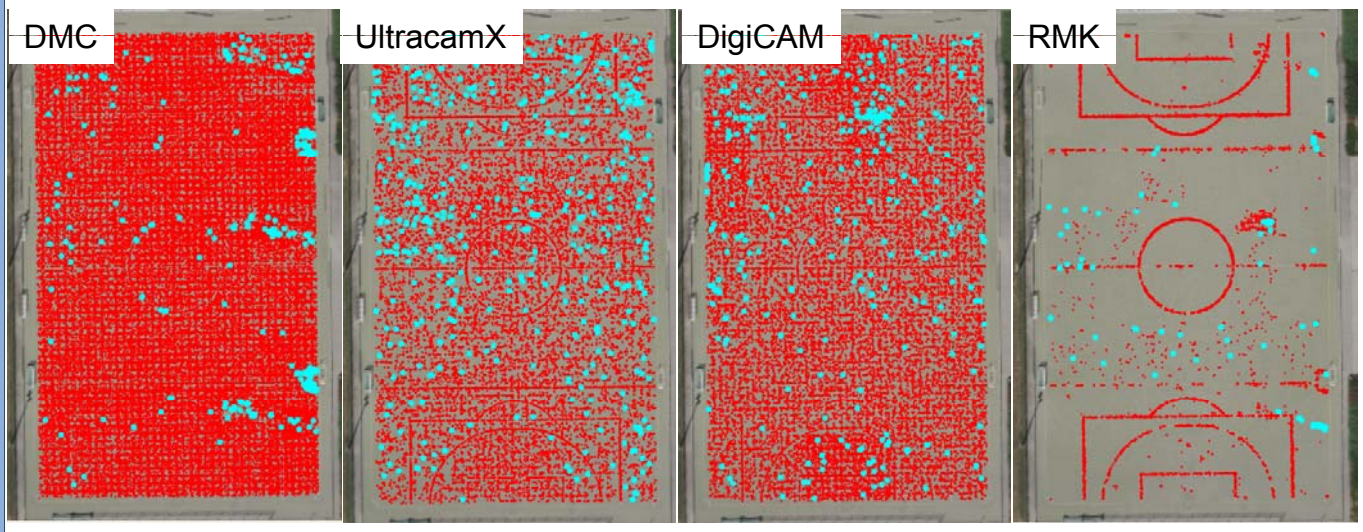
Alternative area
Sports field Vaihingen/Nord

UltracamX



- Sports field Rosswag
  - Grass
    - σ_{Filt_LiDAR}=1.83cm
  - Change of surface structure due to cutting and marking
- Sports field Vaihingen Nord
  - Artificial turf
    - σ_{Filt_LiDAR}=1.47cm
  - Only limited image texture

Sports field Vaihingen/Nord
GSD 8cm



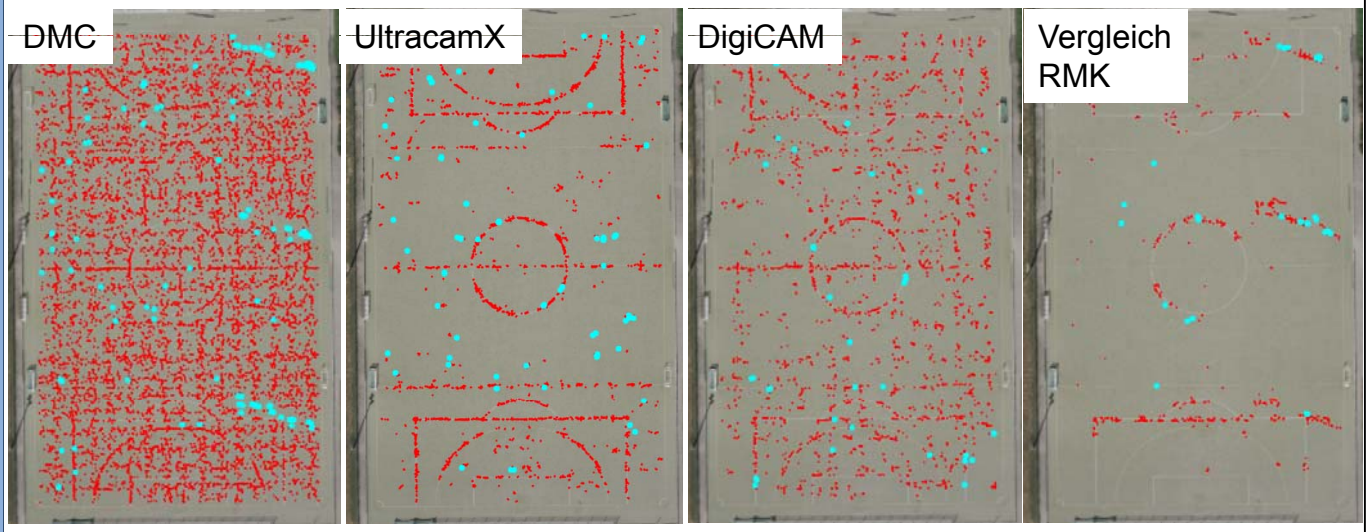
- Despite limited texture suitable point density at GSD 8cm
- Partially greater differences to point density at 20cm GSD

Accuracy of 3D point clouds
Sports field Vaihingen/Nord - GSD 8cm

Sensor	STD w/o gross errors [cm]	STD [cm]	Elim.Pts. [%]	Density Pts./m²
DMC 8cm	3,2	5,9	0,5	22,3
UCX 8cm	7,1	7,5	0,7	16,0
DigiCAM 8cm	6,2	7,0	0,5	22,7
RMK 8cm	6,9	19,9	0,6	5,7
ALS50	1,5	1,5	0,3	11,6

5,5 cm	**Mean (only from digital cameras)**	**20,3 Pts/m²**

Sports field Vaihingen/Nord
GSD 20cm



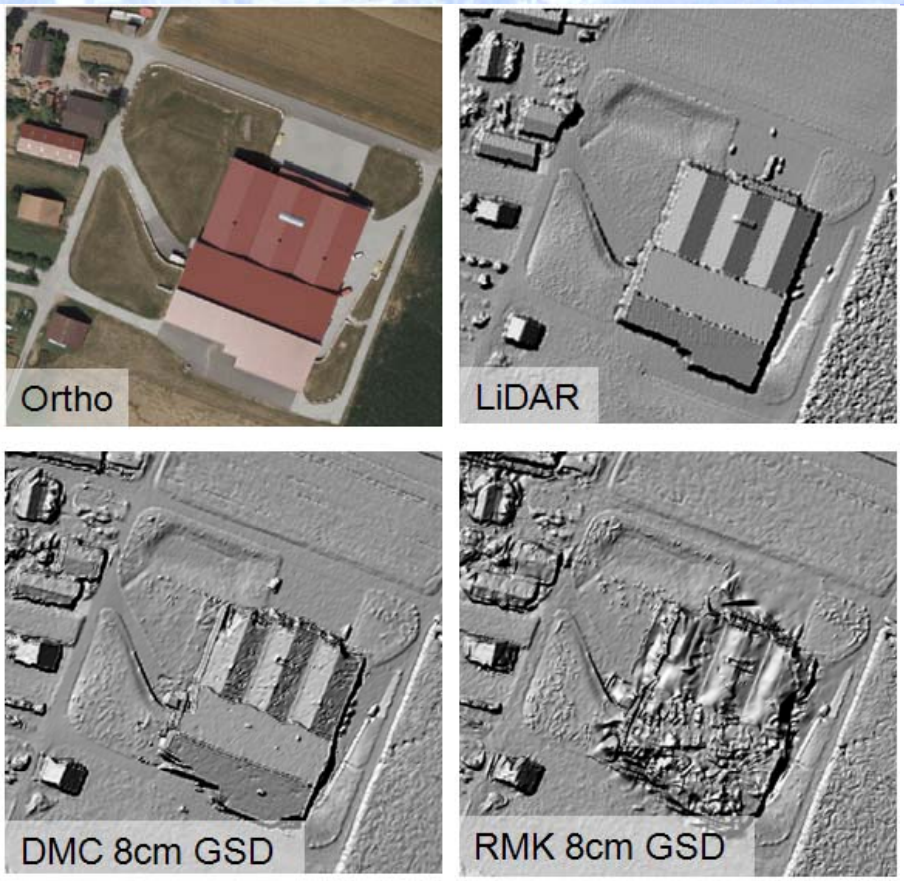
- Despite limited texture suitable point density at GSD 8cm
- Partially greater differences to point density at 20cm GSD

Accuracy of 3D point clouds
Sports field Vaihingen/Nord - GSD 20cm

Sensor	STD w/o gross errors [cm]	STD [cm]	Elim.Pts. [%]	Density Pts./m²
DMC 20cm	10,5	15,1	1,1	2,7
UCX 20cm	11,6	13,2	1,7	1,2
DigiCAM 20cm	20,7	22,1	1,0	1,4
RMK 20cm	35,3	44,0	1,5	0,3
ALS50	1,5	1,5	0,3	11,6

14,3 cm	**Mean (only from digital cameras)**	**1,8 Pts/m²**

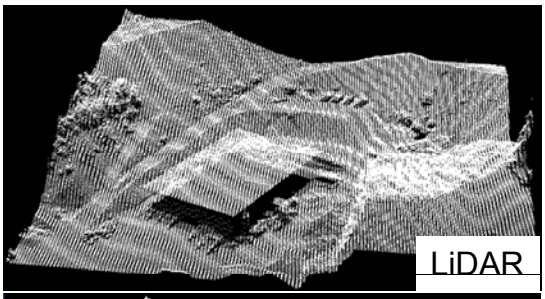
Comeback of Digital Image Matching



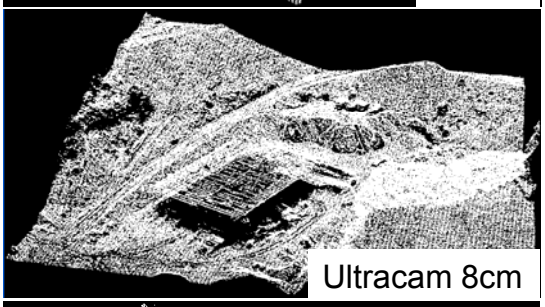
Comeback of Digital Image Matching

- Tremendous improvement 3D data capture from image matching due to use of digital camera systems
  - DMC, Ultracam-X, DigiCAM
- Relative accuracies of matched 3D points with respect to approximating plane
  - 1.6cm LiDAR
  - 6.5cm @ 8cm GSD
  - 19.5cm @ 20cm GSD
- Accuracy of filtered DSM-Raster (signalized points at paved areas)
  - 4.4cm @ 8cm GSD
  - 11.1cm @ 20cm GSD
    - DSM-Raster accuracy mainly defined by preceding bundle block accuracy

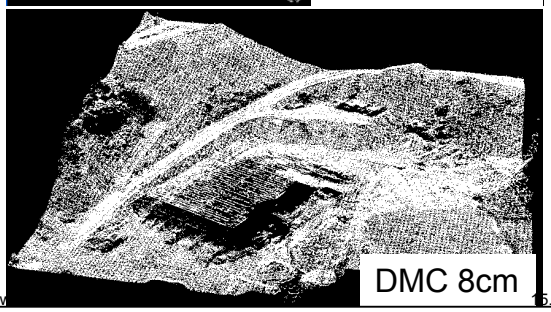
Digital Image Matching vs. Airborne LiDAR
Usability of point 3D clouds



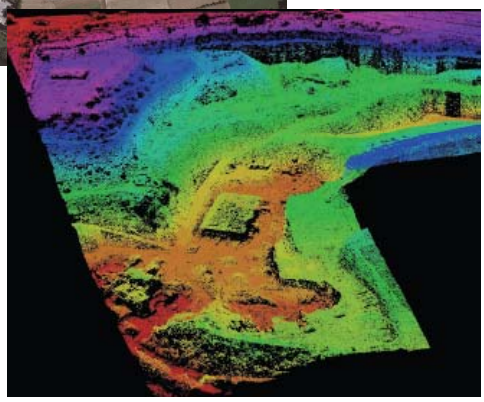
LiDAR



Ultracam 8cm



DMC 8cm



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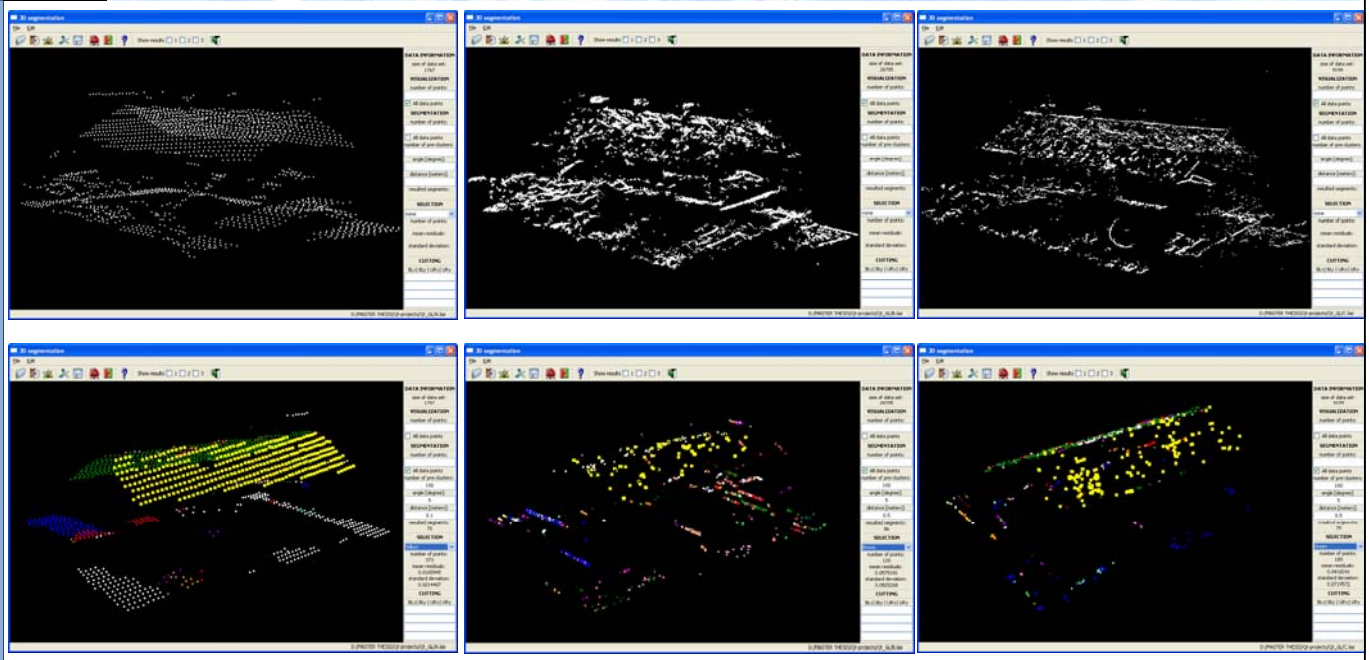
Usability of point 3D clouds:
Segmentation by region growing



LiDAR | UCX with 8 cm GSD | DMC with 8 cm GSD

- Regular distribution and quality of LiDAR points more suitable to standard segmentation algorithms
- Adapt existing algorithms

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Comeback of Digital Image Matching

- Tremendous improvement 3D data capture from image matching due to use of digital camera systems
- Point density and accuracy from high resolution and largely overlapping images moves towards LiDAR data quality
  - Improving LiDAR quality, applications like full-waveform for vegetation analysis …
- Heterogeneity of geometric 3D point quality has to be taken into account for further processing
  - Will become important anyway
    - “zoo of photogrammetric systems”
    - “Crowd source images”