Towards specifying and optimizing 3D point cloud quality based on UAV-borne image data acquired by citizen scientists

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Citizen Science and Earth Observation

Paramount goal: To understand processes and relationships on earth for making wise decisions
→ Data must be collected to generate information

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Citizen Science and Earth Observation

Integrative Earth Observation

Motivation

Application of UAV data

- Agriculture: Precision Farming
- Forestry: Evaluation of forest areas, fire monitoring, vegetation monitoring, species identification, volume calculations and silviculture
- Archeology and Architecture: 3D Surveying and Mapping
- Physiogeographic applications: monitoring tasks, erosion mapping, volume calculation, volcano monitoring, coastal surveillance, geological analyzes
- Urban areas: road mapping, cadastral mapping, thermal analysis
- Traffic monitoring
- Crisis management: images for early impact assessment and rescue planning
- (3D) Reference data generation for satellite based analyses

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Motivation

Application of UAV data

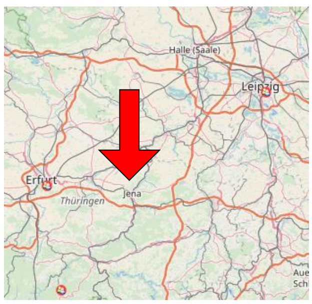
- Up-to-date 3D reference information hardly available
- Acquisition of such data causes high efforts (labour and/or equipment)

- Low cost drones have potential to supplement need for 3D data
- Several issues need to be solved to foster trust and acceptance in this kind of data by the scientific community and administrative bodies (in particular if data acquired by citizens)
- Issue with the potentially highest priority: quality of the 3D point clouds

Experimental data

Testsite Jenaer Forst

- 2 km to the West of Jena, Germany
- Flat terrain, dimensions: 800 m x 350 m
- Various land cover: e.g. forest, buildings, grassland, paved and gravel roads, water surfaces



Pointcloud based on DJI Mavic Pro Model 2018 (Citizen Pilot)

Experimental data

UAV Campaign

UAV data

- 7 UAVs/9 camera systems (professional to toy level)
- Optimal acquisition conditions on 01.11.2018: diffuse light, no wind
- Flight altitude: 100 m over ground
- Image overlap 75% along and across track nominal
- Exposure time < 1/320 s to prevent motion blur

Reference data

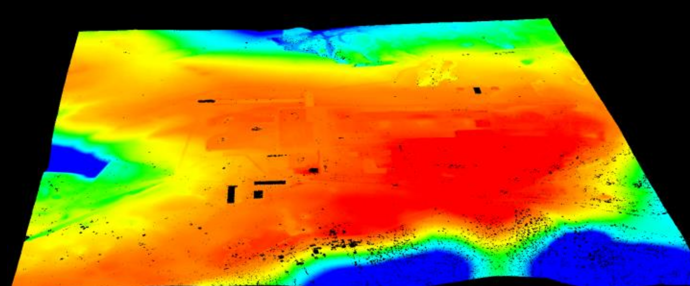
- LiDAR data (2014), 13.5 points/m²
- 8 GCPs surveyed with RTK GNSS

Experimental data

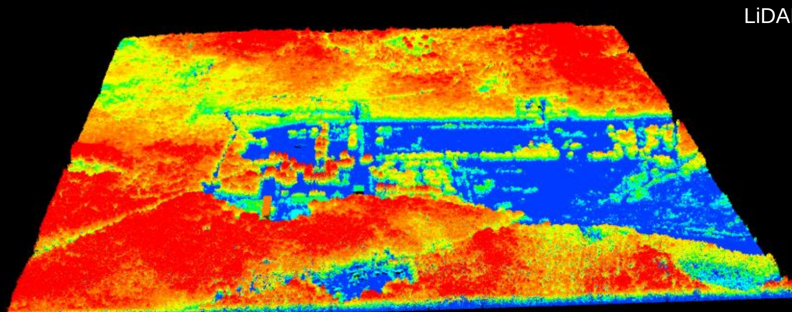
Reference targets

- Position of 8 GCPs (teflon panels, 50 cm x 50 cm) measured with survey grade equipment (Stonex S9 GNSS RTK) – average of 5 measurements per GCP (before and after campaign), RMSE < 2 cm
- Distance to nearest SAPOS base station (reference station "Jena 2") 5.4 km

LiDAR Data acquired in 2014, average point density 13.5 points/m², RMSE Z < 0.08 m



LiDAR DTM



LiDAR nDSM

Supplier: Thuringian land surveying office

Feldkampagne mit 8 Drohnen und 10 Kamerasystemen am 31.10.2018 & 01.11.2018

Processing

- Delineation of orthomosaics and dense point clouds [high] (Agisoft Metashape 1.5.1)
- Each UAV datasets was processed three times:
  1.) Using on-board GNSS data only, 2.) Using the 3 exterior GCPs only, 3.) using all 8 GCPs
- No manipulation of original image data

Orthomosaic

Dense point cloud

UAV Data – Visual Analysis

AscTec Falcon 8 – Sony ILCE-7R 55 mm

AscTec Falcon 8 – Sony ILCE-7R 35 mm

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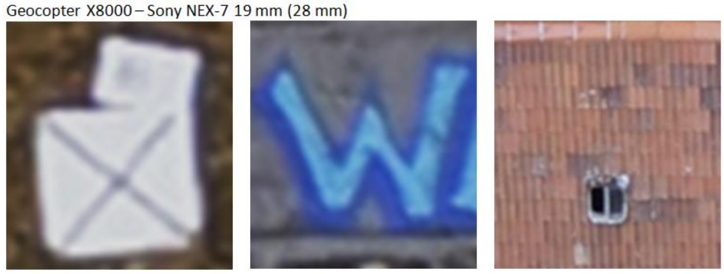
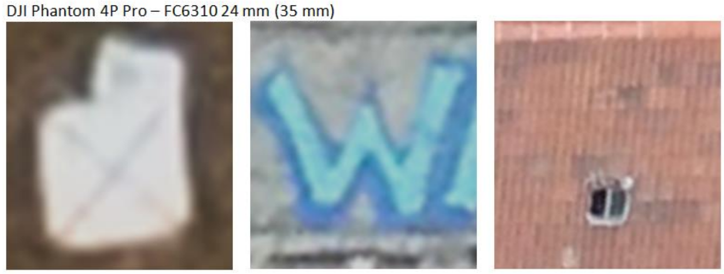
UAV Data – Visual Analysis

Geocopter X8000 – Sony NEX-7 19 mm (28 mm)



DJI Phantom 4P Pro – FC6310 24 mm (35 mm)



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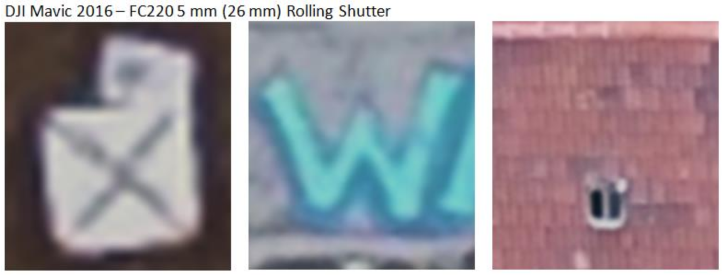
UAV Data – Visual Analysis

DJI Mavic 2016 – FC220 5 mm (26 mm) Rolling Shutter



DJI Mavic Pro 2018 – Hasselblad L1D-20c 10 mm (28 mm) Rolling Shutter

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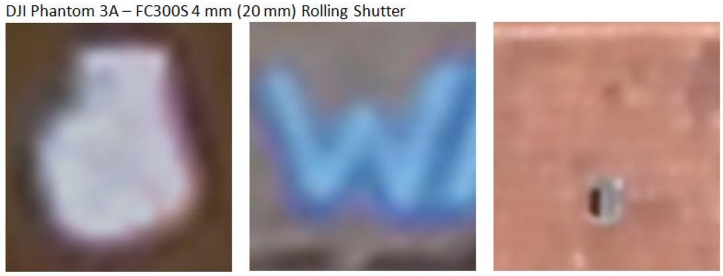
UAV Data – Visual Analysis

Sony alpha 5100 12 mm (18 mm)

DJI Phantom 3A – FC300S 4 mm (20 mm) Rolling Shutter



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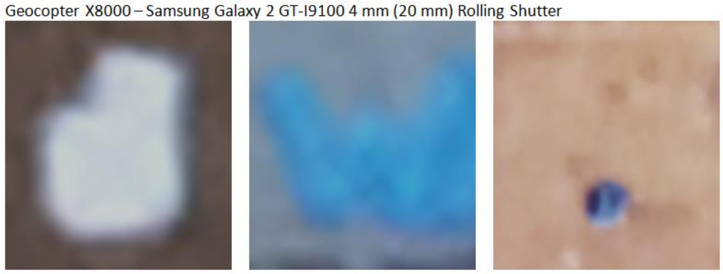
UAV Data – Visual Analysis

Geocopter X8000 – Samsung Galaxy 2 GT-I9100 4 mm (20 mm) Rolling Shutter



Data selection

Image quality according to Metashape Software
min – med – max

AscTec Falcon 8 – Sony ILCE-7R 35 mm

0.689 – 0.864 – 0.921

DJI Phantom 4P Pro – FC6310 24 mm (35 mm)

0.829 – 0.875 – 0.908

DJI Mavic 2016 – FC220 5 mm (26 mm) Rolling Shutter

0.825 – 0.888 – 0.938

Processing

Camera, Data and Product parameters

	Sony 7 R 35 mm	DJI Phantom 4P Pro	DJI Mavic 2016
# camera pixels	7360 x 4912	5472 x 3648	4000 x 3000
# images acquired	516	200	380
# images aligned	516	189	359
# points	667,158,869	177,342,850	160,768,494
# points per m²	2216	664	480
Ground resolution	1.47 cm	2.45 cm	2.98 cm
Pixel spacing orthomosaic	1.5 cm	3 cm	3 cm
Total processing time	ca. 30 h	ca. 4.5 h	ca. 6.5 h

House with damaged roof

Ortho-mosaic of test site Phantom 4 Pro

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3D point cloud showing details of damaged roof – Sony 7R

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3D point cloud showing details of damaged roof – DJI Phantom 4 Pro

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3D point cloud showing details of damaged roof – DJI Mavic 2016

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Parked cars of campaign team – Sony 7R

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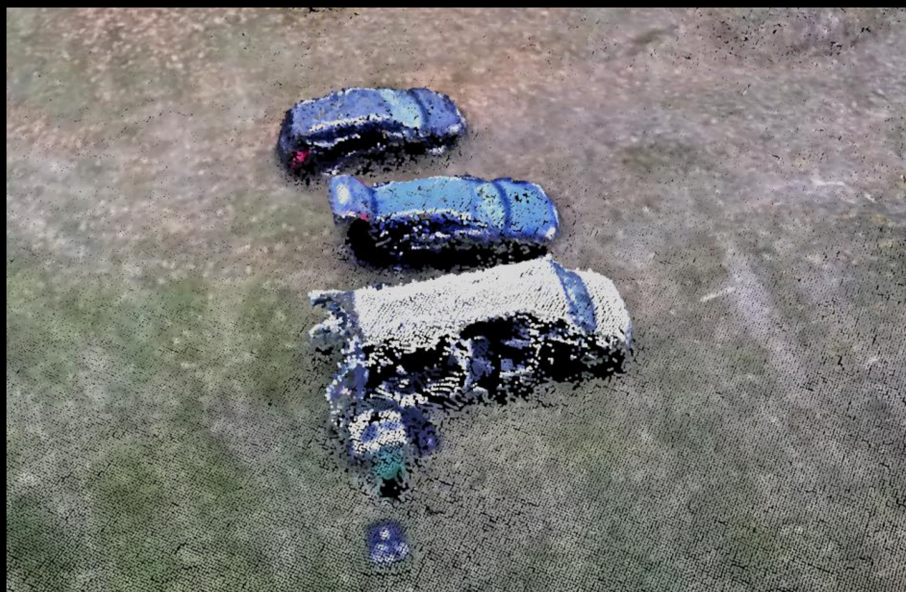

Parked cars of campaign team – DJI Mavic 2016

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Parked cars of campaign team – DJI Phantom 4 Pro

Results

Absolute location accuracy

Results

Absolute location accuracy

Sony R7 - on board GNSS only for processing

	Error X [m]	Error Y [m]	Error Z [m]
GCP#2	2.453	-0.333	-2.022
GCP#3	1.207	-0.809	0.541
GCP#1	1.456	-2.196	0.658
GCP#4	0.702	-1.469	1.425
GCP#5	0.552	-2.993	0.986
GCP#8	-0.887	-1.411	1.092
GCP#6	-1.159	-4.414	-1.521
GCP#7	-2.172	-2.954	-1.075
RMSE	**1.467**	**2.422**	**1.249**

Central doming effect due to insufficient camera calibration

Results

Absolute location accuracy

Sony R7 - on board GNSS plus 3 GCPs for processing

	Error X [m]	Error Y [m]	Error Z [m]
GCP#1	0.035	0.021	-0.887
GCP#3	0.017	0.011	-0.744
GCP#4	-0.004	0.021	-1.007
GCP#5	-0.001	0.026	-0.963
GCP#8	0.064	-0.016	-0.765
RMSE	**0.033**	**0.019**	**0.879**

Central bowling effect due overcompensation of distortion parameters

Results

Absolute location accuracy

RMSE for all models

	Error X [m]	Error Y [m]	Error Z [m]
Sony R7 – GNSS	1.467	2.422	1.249
Sony R7 – GNSS + 3 GCPs *	0.033	0.019	0.879
Sony R7 – GNSS + 8 GCPs	0.020	0.009	0.004
Phantom P4 – GNSS	3.569	1.021	17.633
Phantom P4 – GNSS + 3 GCPs *	0.124	0.531	0.719
Phantom P4 – GNSS + 8 GCPs	0.004	0.004	0.009
Mavic 2016 – GNSS	1.245	0.982	18.879
Mavic 2016 – GNSS + 3 GCPs *	0.175	0.455	0.620
Mavic 2016 – GNSS + 8 GCPs	0.002	0.002	0.005

Results

Absolute location accuracy

RMSE for all models

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Issue with altitude readings of DJI drones (solvable)

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Results

Absolute location accuracy

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* Improved camera calibration using 8 GCPs results in lower location errors (XYZ < 0.2 m)

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Results Relative Height Accuracy (relevant for nDSM)

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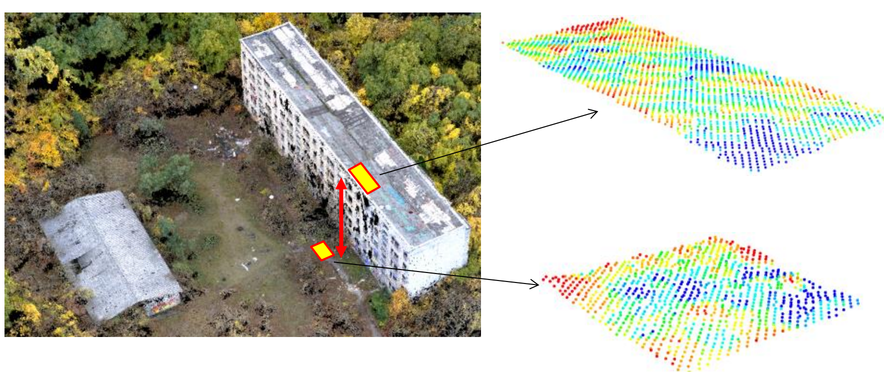
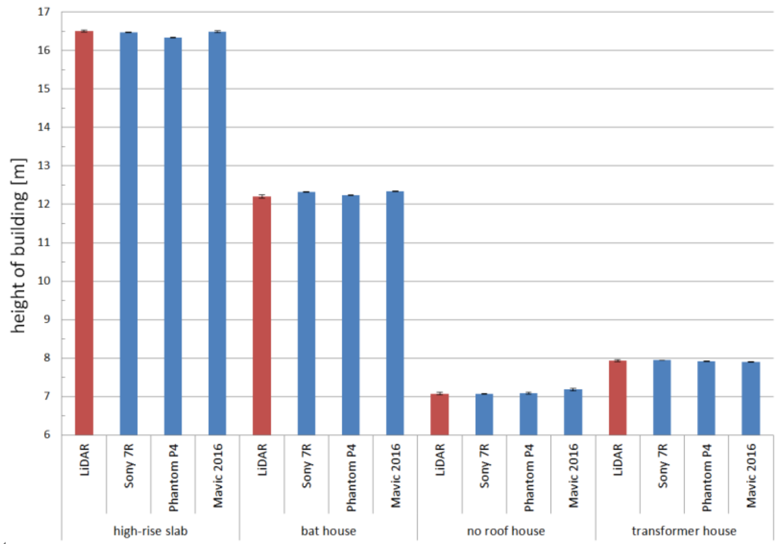


Definition of reference planes for four buildings (one top, one bottom)
Averaging Z-value of all points (computation of std), # points > 350 for UAV data
Computation of ΔZ

Results Relative Height Accuracy (relevant for nDSM)



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Results Dispersion of Z (noise) over smooth and planar surfaces

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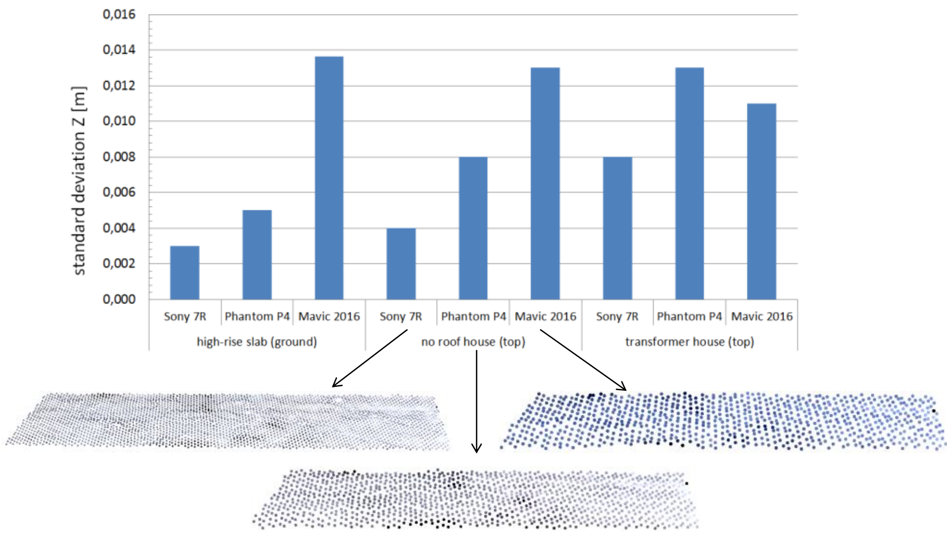
Dispersion of Z (noise) over smooth and planar surfaces



Summary of preliminary results

- Low cost UAV image data can be used for orthomosaic and point cloud generation
- Without GCPs 2D (XY) geolocation accuracy was better than 5 m (for low cost UAVs)
- Without GCPs Z offset of model was close to 20 m (for low cost UAVs)
- 3 GCPs were not sufficient for sound camera calibration (flat terrain, single scale nadir images)
- Delineated relative heights (building heights) in good agreement with LiDAR (ΔZ < 10 cm) → generation of precise nDSM feasible
- Small σ (< 1.4 cm) of Z values over smooth and planar surfaces for all cameras – low cost cameras show larger σ

Outlook – Ongoing Work

- Elaboration of camera calibration scheme suited for CS (external pre-calibration/self calibration using suited image data)
- Analysis of remaining data
- Overall extension of analysis, e.g.:
  - Cross comparison of different UAV datasets incl. LiDAR data
  - Computation of difference DSMs (same UAV dataset but processed using 3 and 8 GCPs)
  - Analysis of point density over various surfaces
  - Analysis of dispersion of Z (noise) over various surfaces
  - Analysis of 3D edge preservation at buildings

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