ACCURACY ANALYSIS FOR AUTOMATIC ORIENTATION OF A TUMBLING OBLIQUE VIEWING SENSOR SYSTEM

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Mission Background (SMAP)

- in 2006 the first UAS project started at University of Applied Sciences Wildau **SMAP** *(Smart Aerial Photogrammetry System)*

- aim was to demonstrate that small UAS are capable to carrying a calibrated aerial camera

- the project finished, but showed that the carrier aircraft and sensor was not the ideal platform for this kind of mission

- Main disadvantages:
  - vibrations
  - limited access to the camera system
  - addition payload of 7 kg (too heavy)
  - full system < 25kg

First step development (UAS)

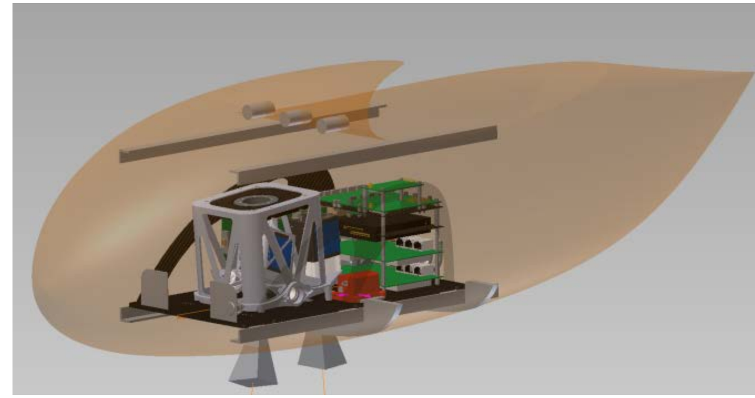
- especially a new carrier aircraft designed for multi role measurement tasks
- UAS ATISS (*Autonomous Flying Testbed for Integrated Sensor Systems*) was designed as an internal university project in spring 2007
- **SALSA-** project (*Smart Airborne Laser Scanner)* in 2009 was the first try to use ATISS in an official project
- the aim was to combine a laser scanner with an aerial oblique camera within the ATISS payload limits of 10 kg

Second step development (Sensor)

- conventional methods of taking oblique images could not be adapted
- Consequence: developed the MACS-TumbleCam
- challenge/ requirements:
    - professional oblique camera system
    - limits of 5 kg Payload
    - autonomy GPS, power
    - compact volume

THE SALSA PROJECT HIGH-END AERIAL 3D CAMERA

W. Rüther-Kindel a, *, J. Brauchle b



MACS TumbleCam - camera specification

Imaging sensors	2x RGB CCD, 3296 x 2472 pixels each, 5.5 µm pixel size
Geometric resolution	~2 cm @ 100m height (above ground)
Radiometric resolution	12 bit raw image
Focal length	35 mm each
Image rate	5 Hz max.
Arrangement	1x nadir + 1x oblique with tilt angle of ~30 deg and arbitrary rotation
Actuator tumbling camera	Rotational stage, 34µrad encoder resolution
IMU	Postprocessed L1/L2 GNSS + MEMS AHRS

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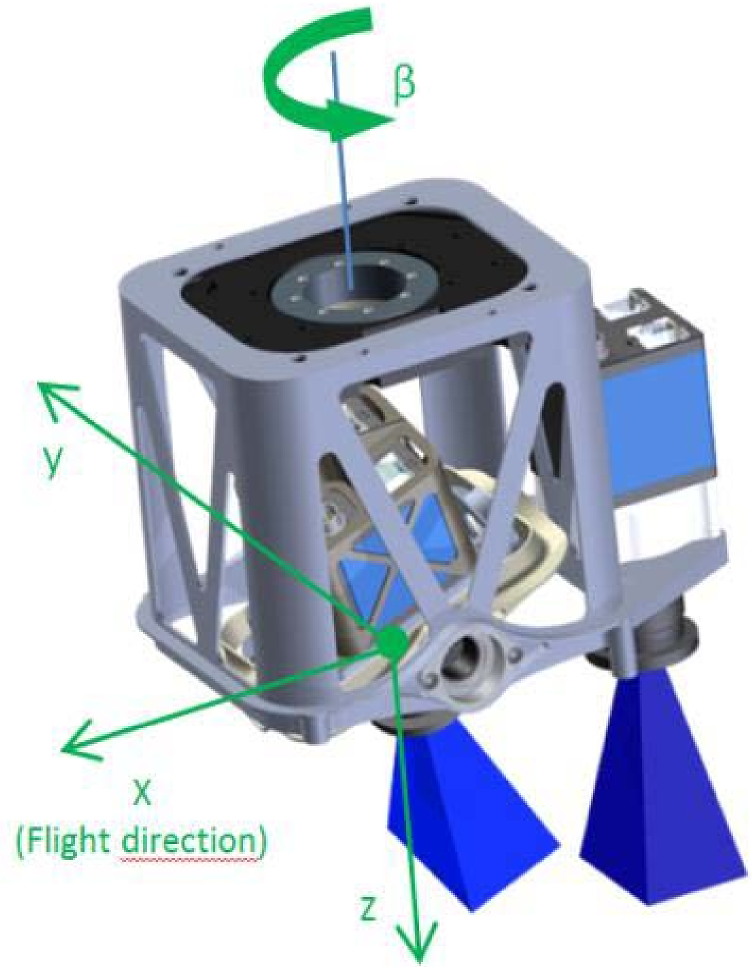
MACS TumbleCam - concept

- new approach to catch multiple perspectives by only one camera is given by the tumbling (wobbling) sensor
- camera is biaxial gimbal-mounted
- ability to describe a circular path which is the only left degree of freedom (ß - piezo motor)
- mathematic definable and direct relation between the two camera systems (nadir and tumbling), through the two joints and the radius



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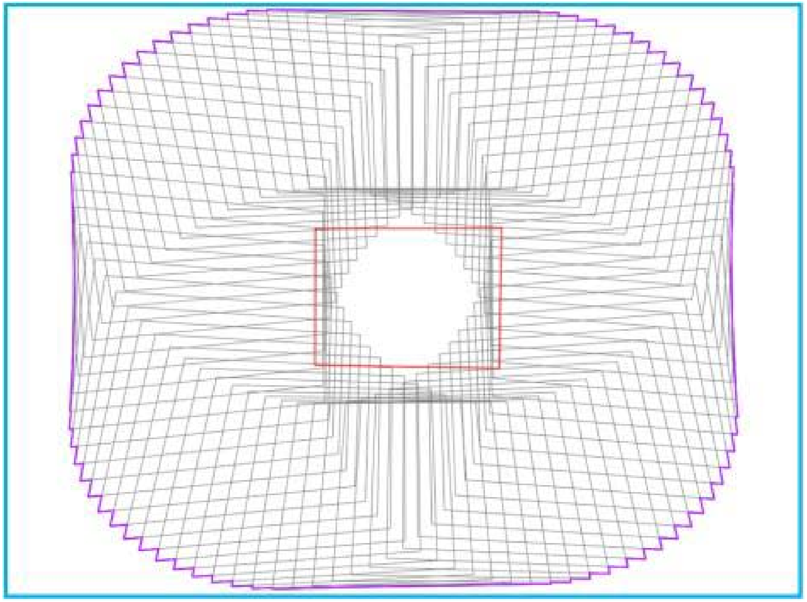
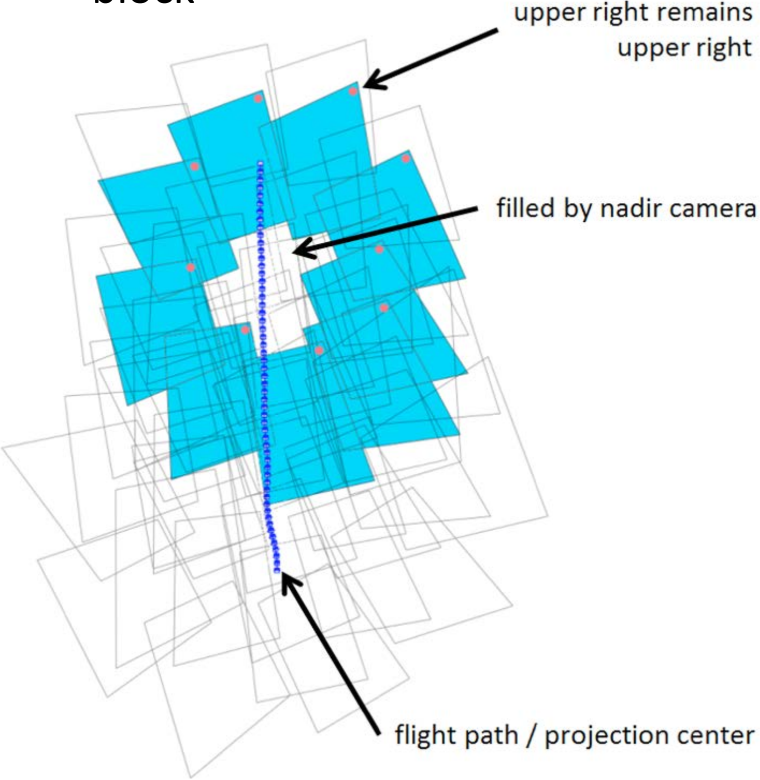
MACS TumbleCam - concept

- footprints of Vertical/Nadir and Tumble System



- as a result of linear flight path the rotating oblique image footprints become a spiral, coherent image block



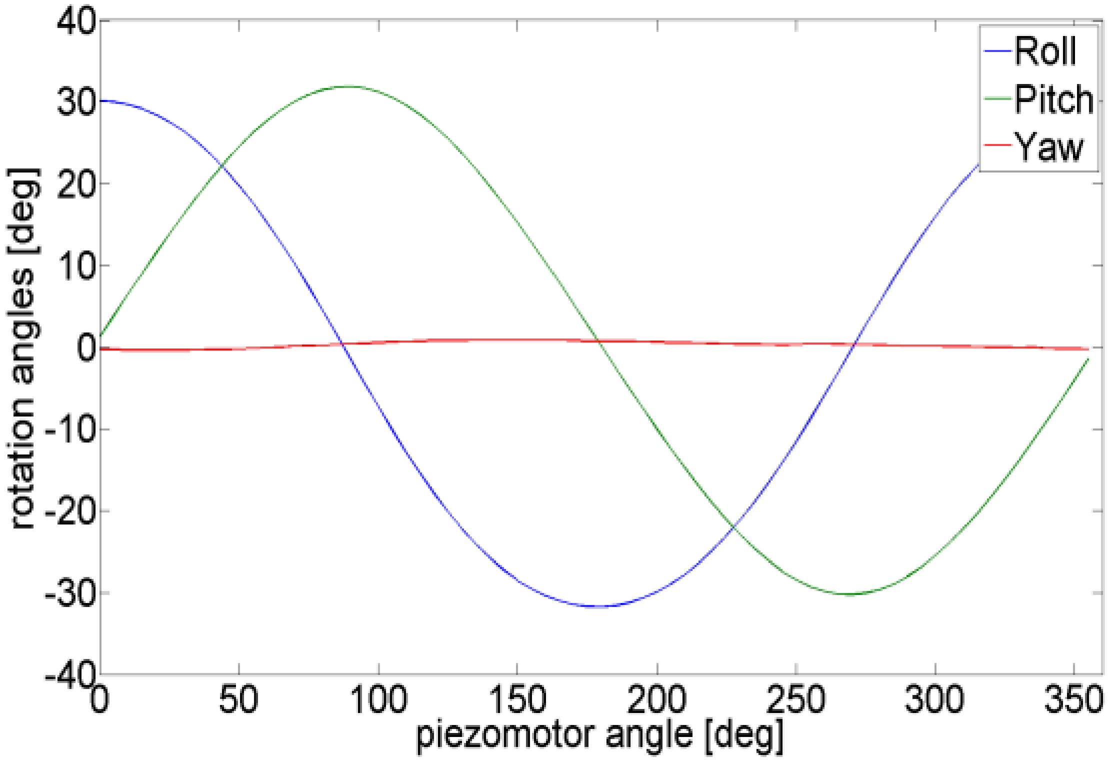
MACS TumbleCam - concept

Photogrammetric challenge

- A reference orientation method will be evaluated for image data orientation
- tumbling camera head (ObliqueCam) should be oriented though its geometrical relation to VerticalCam
- The movement of the ObliqueCam in relation to the VerticalCam can be described as a rotation based on the angular position of the piezo motor and the modelling of the kinematic chain
- the deviations of the motion must be measured and described mathematically

Determination of the theoretical motion model

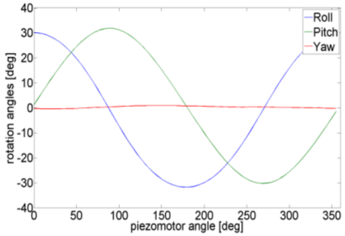
$$\varphi(\beta) = \sin(\beta) * \gamma$$
$$\theta(\beta) = \cos(\beta) * \gamma$$
$$\psi = 0$$



Depends:

- valid only if the projection center is also the center of rotation of this tumbling camera head (only theoretically)
- construction quality of the kinematic chain
- elasticity of the kinematic chain
- uncertainties of the angle encoder of the piezo motor

Theoretical motion model of tumbling ObliqueCam



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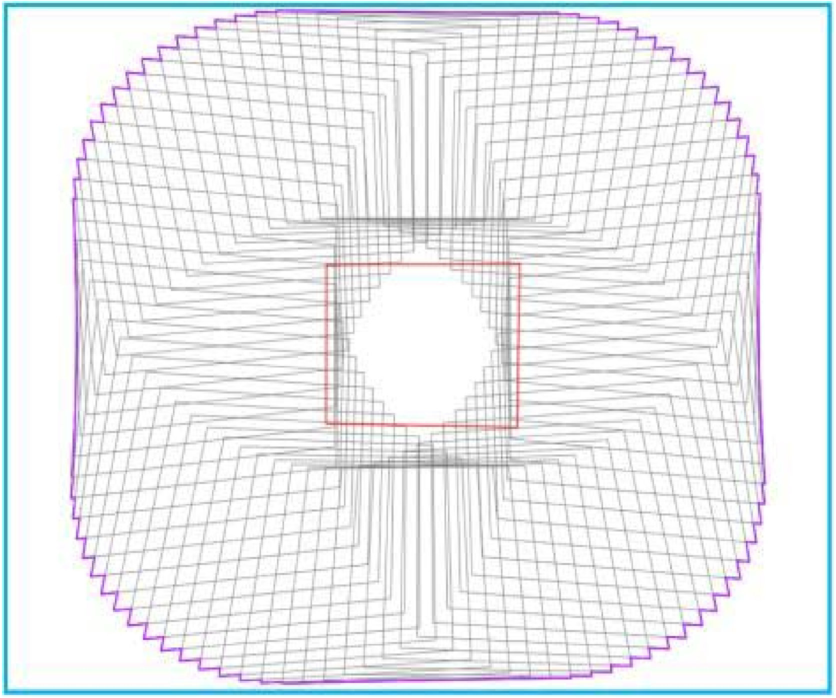
Determination of the motion model

- To determine the deviation between the theoretical model and the actual characteristics of the system
- experimental installation was set up in front of a test field.
- additional wide-angle camera head was used as reference and control camera
- geometric reconstruction of rotation of the ObliqueCam in relation to the VerticalCam → projective reconstruction

Determination of the motion model

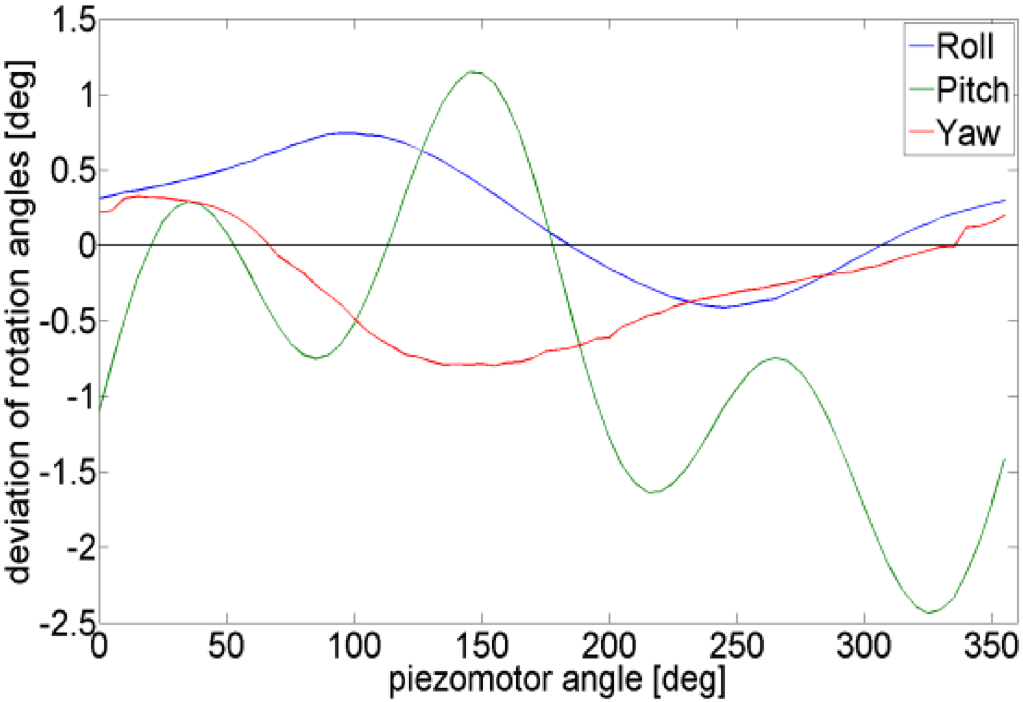
Correct reconstruction depends on a stable set-up:

- detect a potential mutual movement due to vibrations or instabilities in the experimental set-up
- analyzing the block matching during the series of measurements
- transformation between the wide-angle RefCam and VertCam should be constant



Determination of the motion model

- Five series of measurements Full Circle
- 5323 image point measurements
- the influence of the construction quality and stiffness of the kinematic chain
- number and position of the graph's turning points even reveal the presence of two joints.
- constant portions of the deviation
- which indicate a constant rotation between the two camera heads



Axis	Δmax [deg]	Δmean [deg]	NegErr [deg]	PosErr [deg]	Misal. [deg]
Roll	0.0030	0.0009	-0.413	0.746	0.1665
Pitch	0.0019	0.0007	-2.437	1.147	-0.6450
Yaw	0.0089	0.0027	-0.799	0.240	-0.2790

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Corrected motion model of tumbling ObliqueCam

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Results

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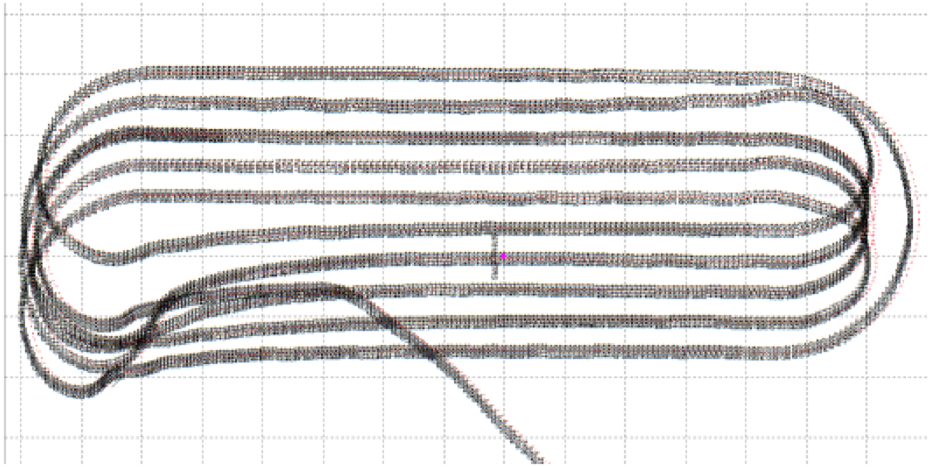
Validation and exemplary use of the enhanced motion model



- test area near Hammelburg
- 1000 m long and 300 m wide
- 10 flight lines in 15-20 min

- conventional orientation of 726 nadir images, GSD = 5cm
- 6 GCP,
- extensive set of reference data (Laser pointcloud, GPS etc.)

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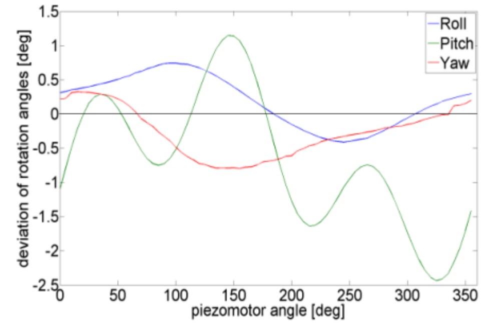
Results of bundle adjustment (nadir images)

RMS L1/L2 GNSS observations		RMS AHRS observations	
x	0.070 [m]	Omega	0.07 [grd]
y	0.083 [m]	Phi	0.06 [grd]
z	0.071 [m]	Kappa	0.11 [grd]

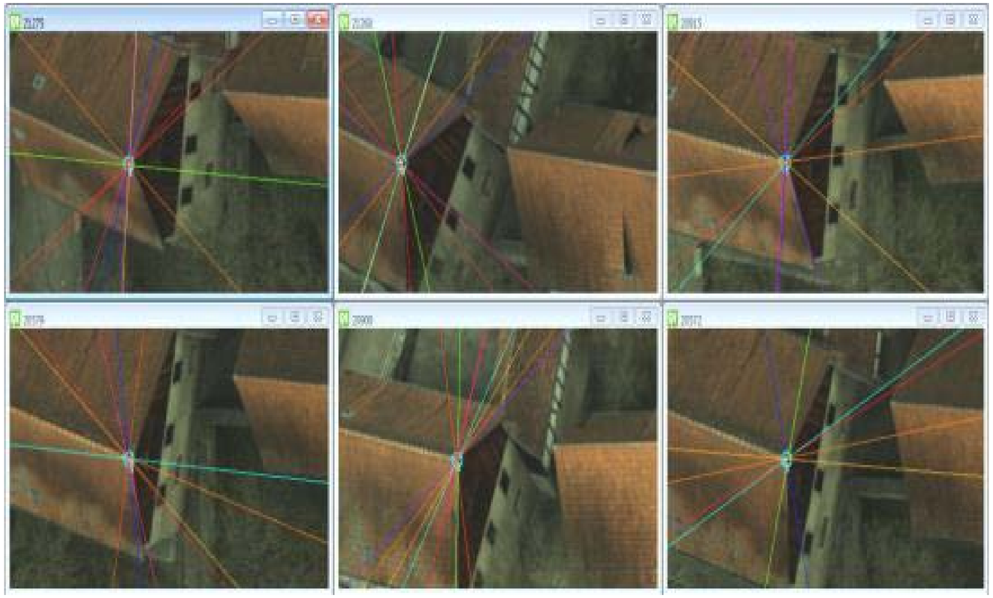
	Omega [deg]	**Phi [deg]**	**Kappa [deg]**
Misalign. IMU to VertCam	-0.5919	0.0325	0.1091
Mean stddev. rotation	3.7/1000	3.8/1000	1.2/1000
	X [m]	**Y [m]**	**Z [m]**
Mean stddev translation	0.012	0.013	0.021
Mean stddev. controlpoints	0.031	0.030	0.053

Results of tumbling oblique viewing system



- accuracy in the actual flight campaign depends on the quality of the vertical aero triangulation
- In contrast to the vertical image data set, oblique images cover a wider area with the same aperture angle
- identical homologous points are visible on oblique images from up to seven flight lines

PointID	Epipolar error using all images[px]	Epipolar error using adjacent images [px]
1	1.272	0.295
2	1.556	0.198
3	1.658	0.352
4	1.457	0.312
5	1.246	0.254
6	1.483	0.272
Mean	**1.446**	**0.281**



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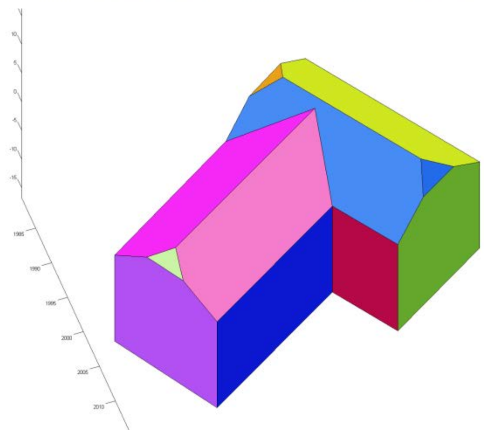
Results of tumbling oblique viewing system



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CONCLUSION

Transformation parameters between the images of the two camera heads of the MACS-TumbleCam were successfully determined

parameters can be used for the calculation of highly accurate approximations for the exterior orientation

Oriented images of Obique Cam can directly be used for texturizing

In further studies, the derivation of true 3D information using the MACS-TumbleCam must be examined

ACKNOWLEDGMENT

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Thanks

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