

Scalable geometric calibration for multi-view camera arrays

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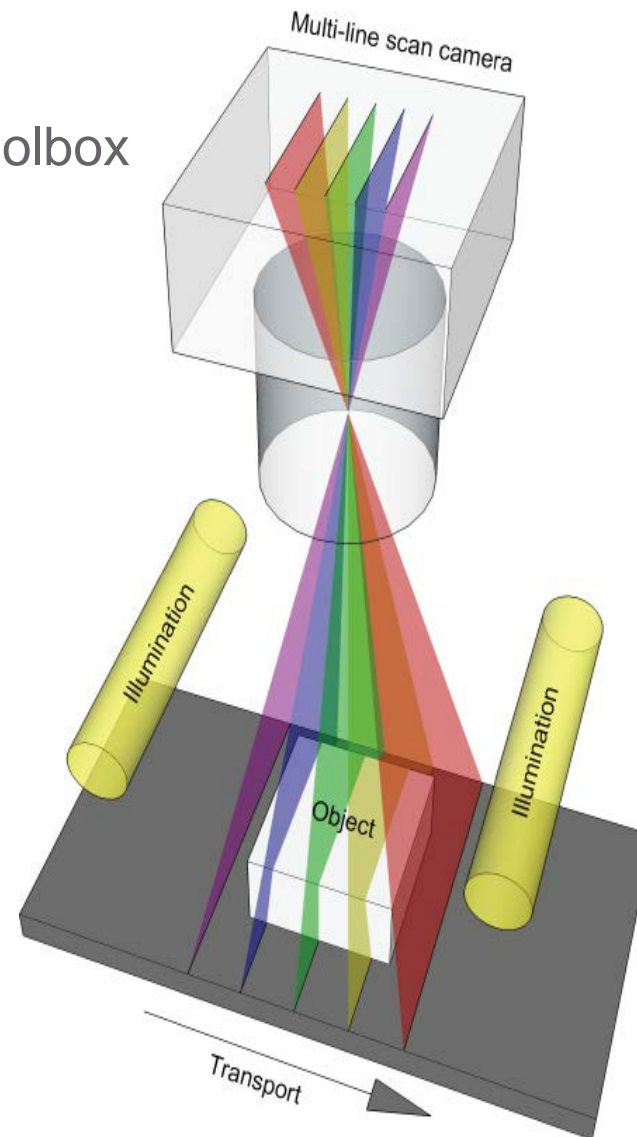
Intelligent Vision Systems

Vienna, Austria

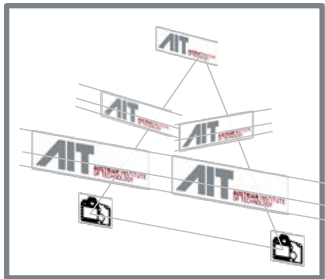
www.ait.ac.at

Motivation

Inline Multi-line scan calibration toolbox

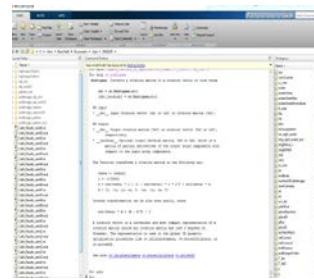


Overview



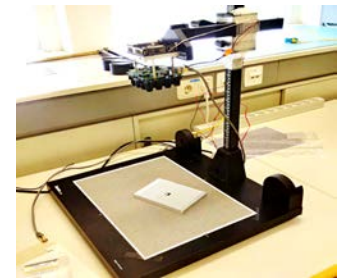
Introduction

Calibration, Rectification



AIT
Calibration
Toolbox

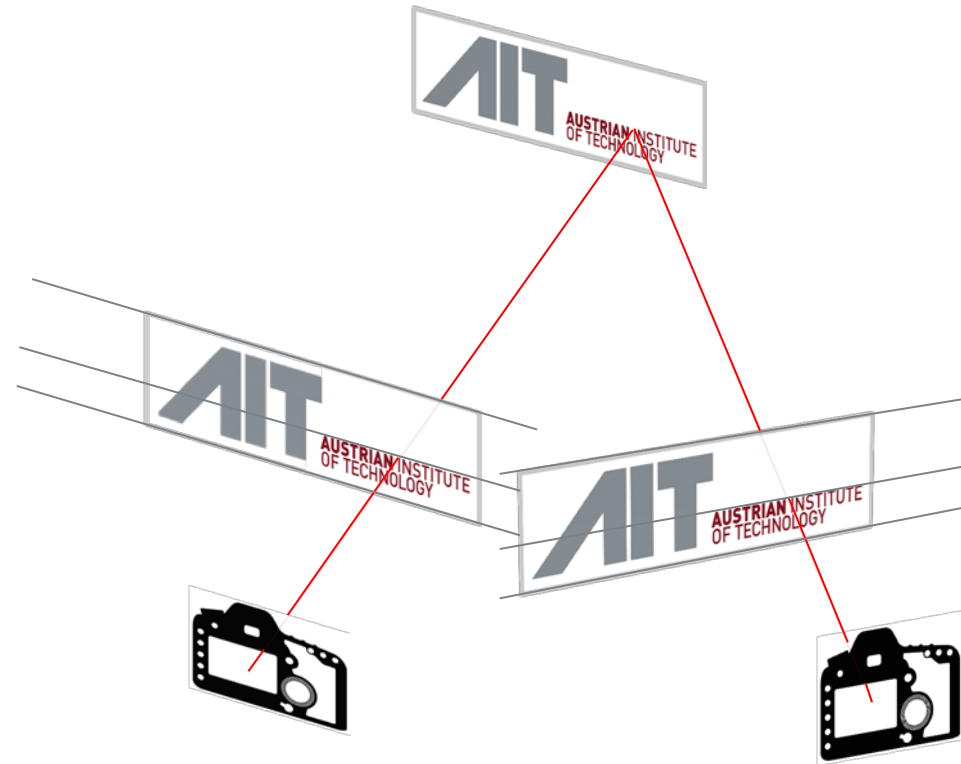
Camera Array



Applications

3D Stereo

Calibration

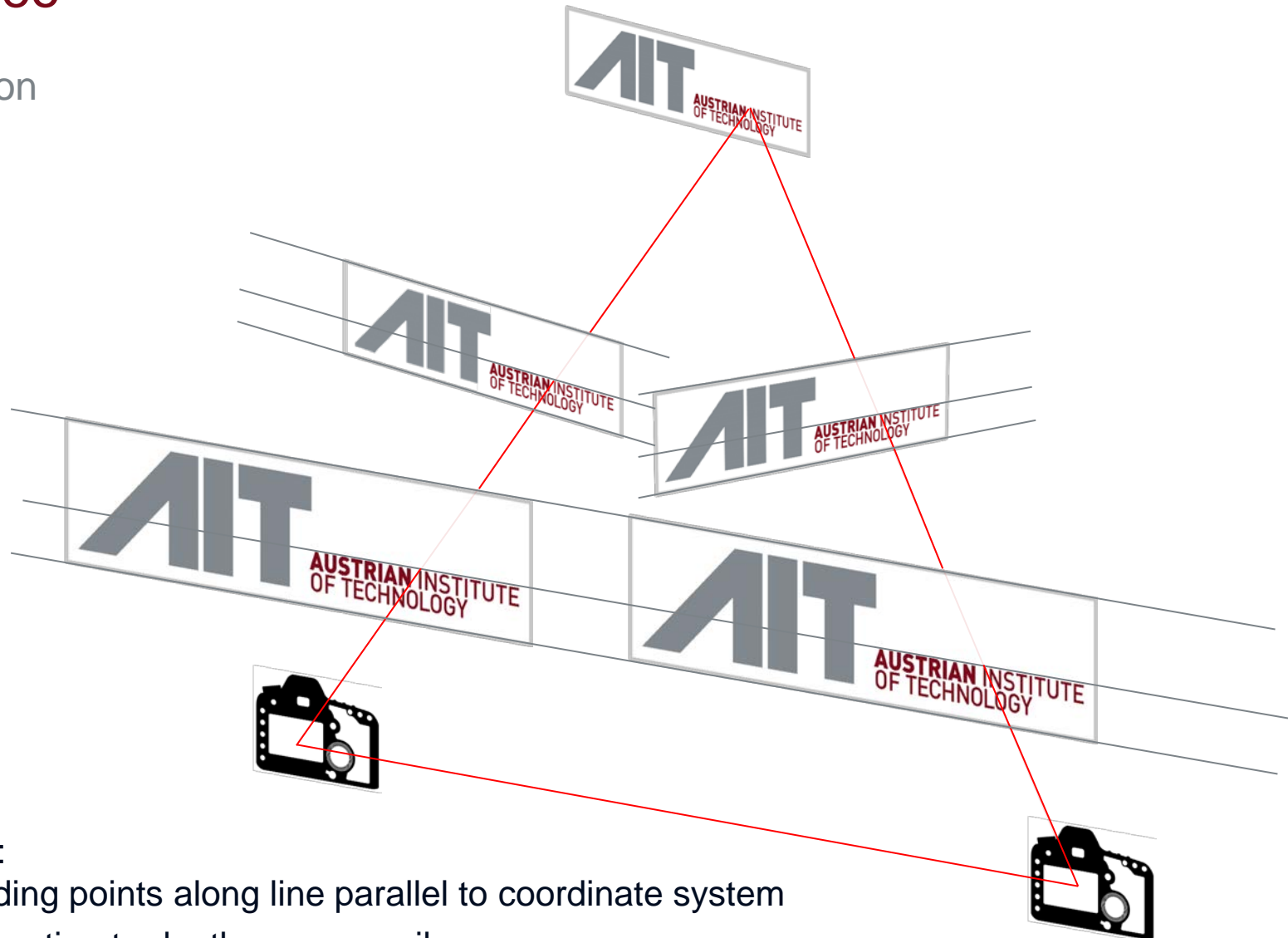


Calibration:

know the **positions**, **rotations**, focal lengths, distortions of all cameras

3D Stereo

Rectification

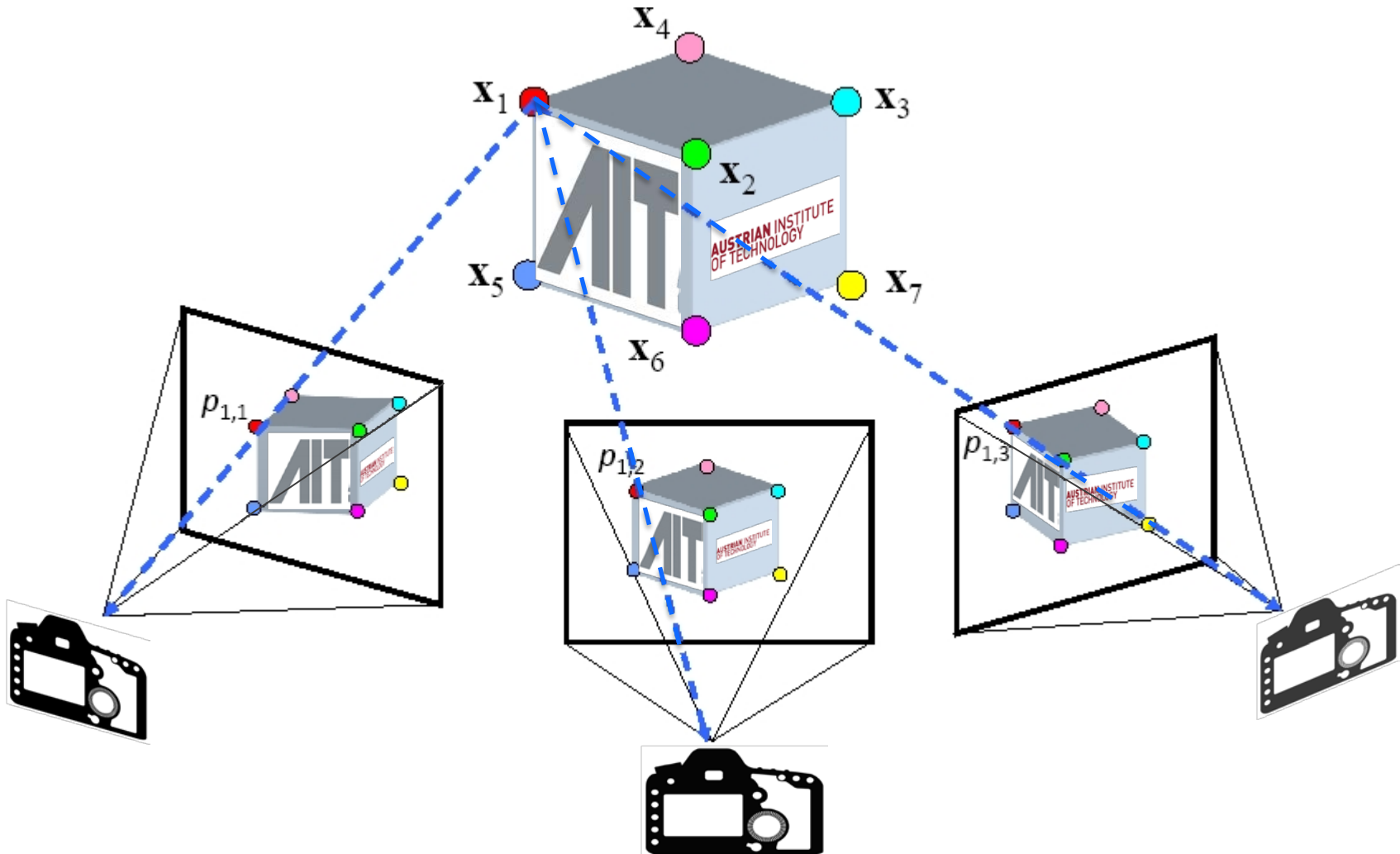


Motivation:

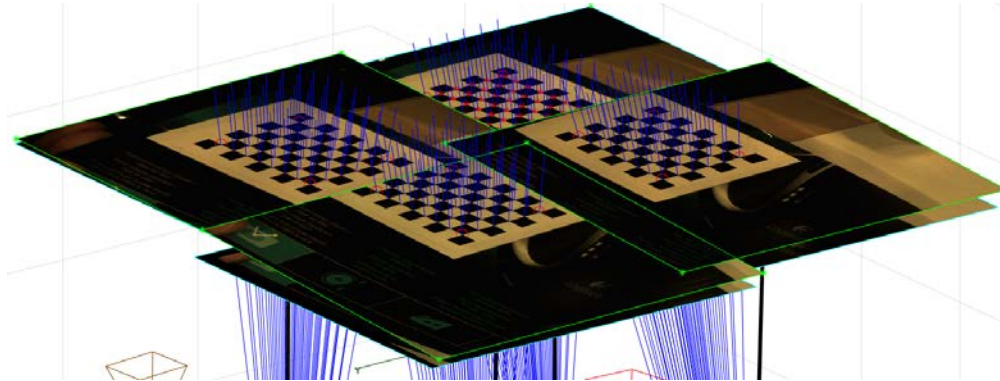
corresponding points along line parallel to coordinate system

In order to estimate depths more easily

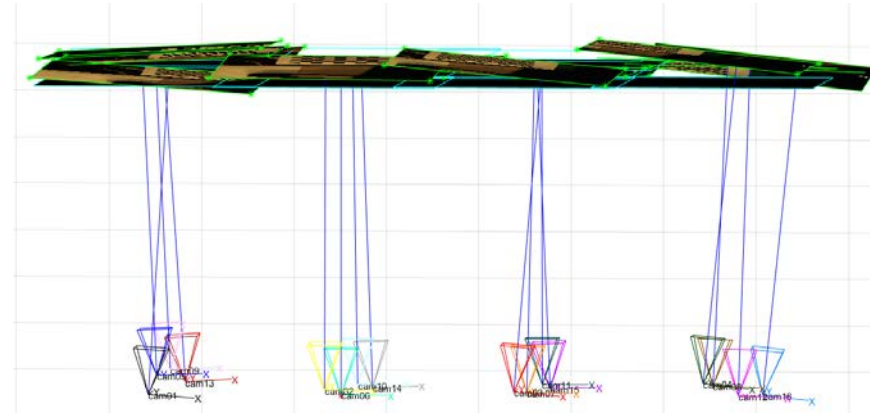
Multiview Stereo for depths estimation



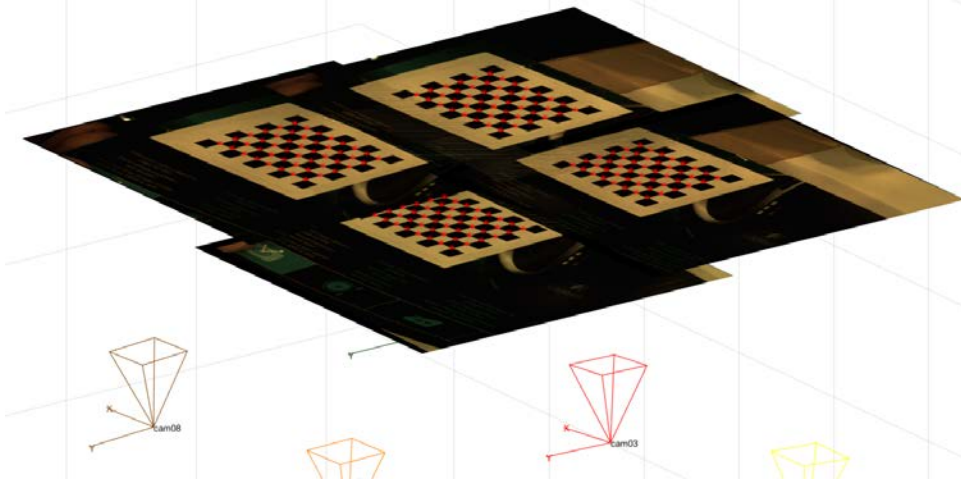
Rectification through reprojection



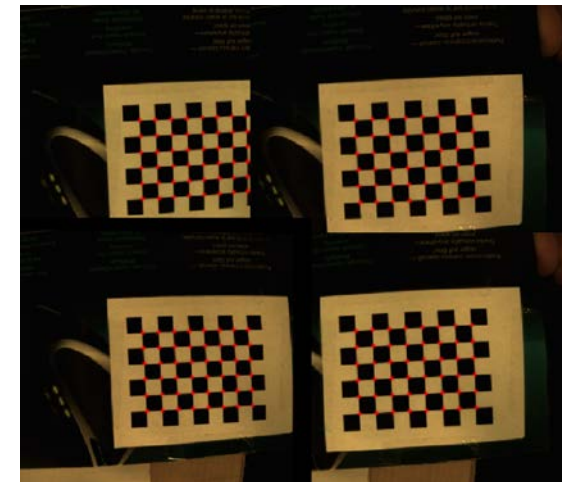
Images in original image planes



Original planes view from front

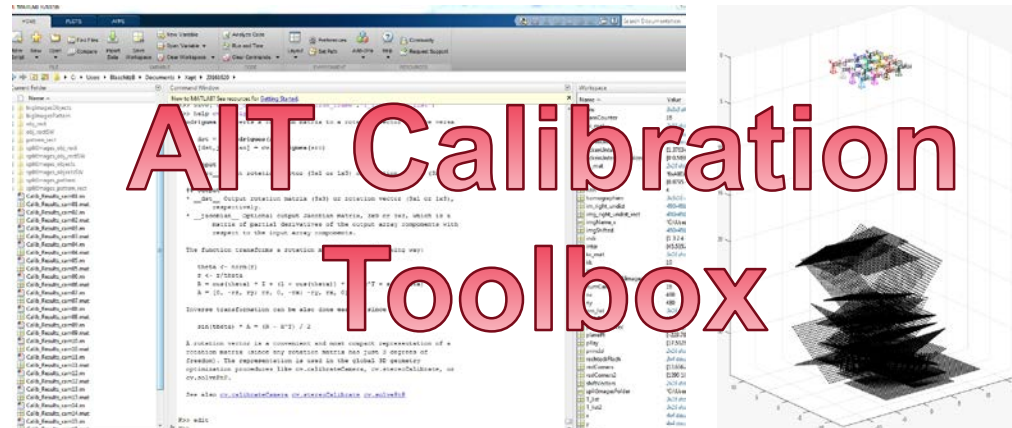


Images reprojected to common plane



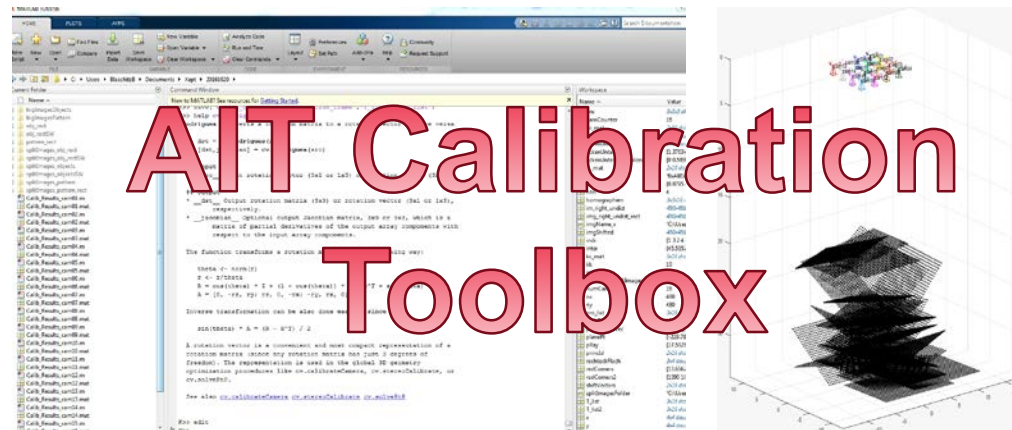
Top view of rectified images

AIT calibration toolbox



- We developed an toolbox that can turn any multi-view camera array into a **multiview stereo camera system**, resp. into a **light field camera**, which is well suited for capturing **depth information**.
- The toolbox allows for determination of all **intrinsic** (*focal lengths, principal points, distortions*) and **extrinsic** (*positions and rotations*) of cameras w.r.t. each other and w.r.t. the input checkerboard patterns) camera parameters, which enables us to undistort and rectify the images.

AIT calibration toolbox



- The software has been realized in **Matlab**, images provided through standard interfaces.
- The calibration itself depends on the *Complete Camera Calibration Toolbox for Matlab* by Jean-Yves Bouguet, see http://www.vision.caltech.edu/bouguetj/calib_doc/ and uses some routines of the [OpenCV] Toolbox, <http://code.opencv.org/>

Camera calibration model

- David Claus, Andrew W. Fitzgibbon: *A Rational Function Lens Distortion Model for General Cameras*. CVPR (1) 2005: 213-219

$$x' = x/z$$

$$y' = y/z$$

$$x'' = x' \frac{1+k_1 r^2+k_2 r^4+k_3 r^6}{1+k_4 r^2+k_5 r^4+k_6 r^6} + 2p_1 x' y' + p_2 (r^2 + 2x'^2)$$

$$y'' = y' \frac{1+k_1 r^2+k_2 r^4+k_3 r^6}{1+k_4 r^2+k_5 r^4+k_6 r^6} + p_1 (r^2 + 2y'^2) + 2p_2 x' y'$$

$$\text{where } r^2 = x'^2 + y'^2$$

$$u = f_x * x'' + c_x$$

$$v = f_y * y'' + c_y$$

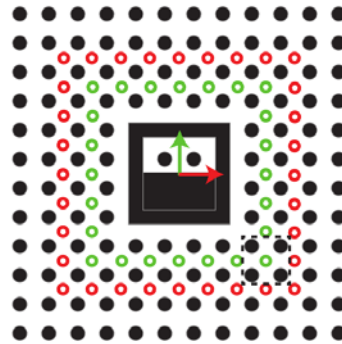
- Intrinsic camera model has 12 degrees of freedom
 - 2 focal lengths (f_x, f_y)
 - 2 principal point coordinates (c_x, c_y)
 - 6 radial distortion parameters ($k_1, k_2, k_3, k_4, k_5, k_6$)
 - 2 tangential distortion coefficients (p_1, p_2)

Details of the implementation

Our contribution

- Use of the improved **calibration target by ICG of TU Graz**

Ferstl, D., Reinbacher, C., Riegler, G., R  ther, M., & Bischof, H. Learning Depth Calibration of Time-of-Flight Cameras.
https://github.com/RobVisLab/camera_calibration



- A true multi view calibration instead of a pairwise stereo calibration, which means **bundle adjustment through optimization.**

Cf. *Bundle adjustment gone public* by Manolis I.A. Lourakis at PRCV 2012, see <http://users.ics.forth.gr/~Iourakis/sba/>

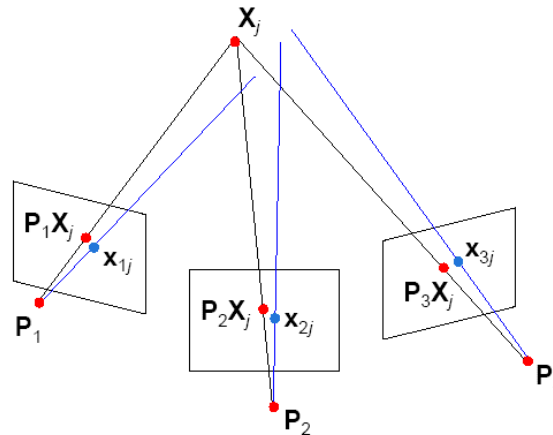
- Row-wise resp. column-wise epipolar images rectification, which allows for an exact depth measurement for a multiview image (not only stereo).

Details of the implementation

Bundle Adjustment

- Is a non-linear method for refining extrinsic and intrinsic camera parameters, as well as the structure of the scene
- Means minimizing the reprojection error

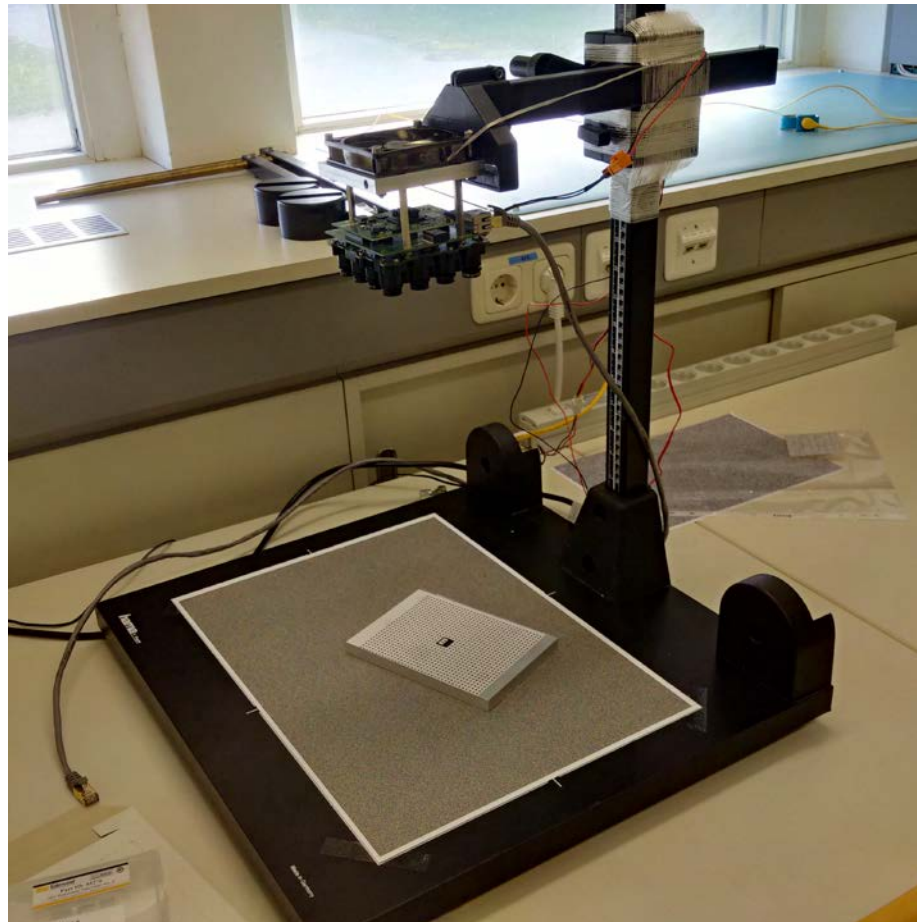
$$\gg E(P, X) = \sum_i \sum_j \text{dist}(x_{ij}, P_i X_j)^2$$



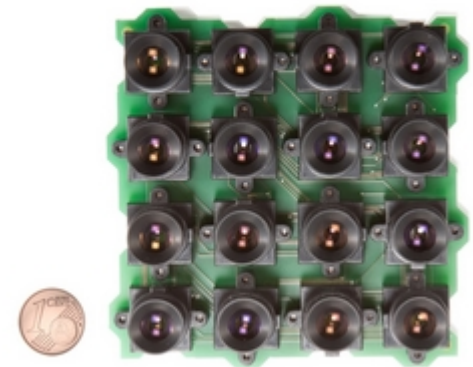
C.f. Fergus, Rob., Computer Vision Spring 2014, <http://cs.nyu.edu/~fergus/teaching/vision/>

Applications of our toolbox

Camera array



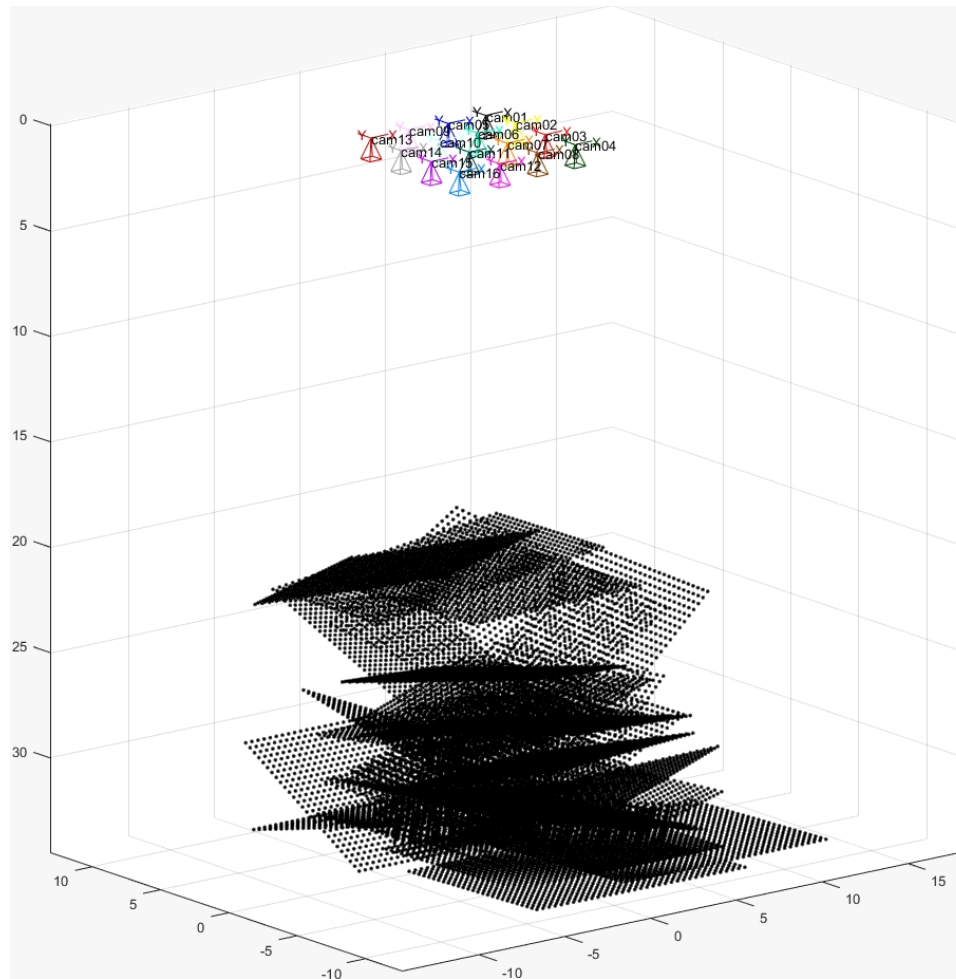
EYE-SECT XA



For all camera-related questions,
please refer to <http://xapt-gmbh.de/>

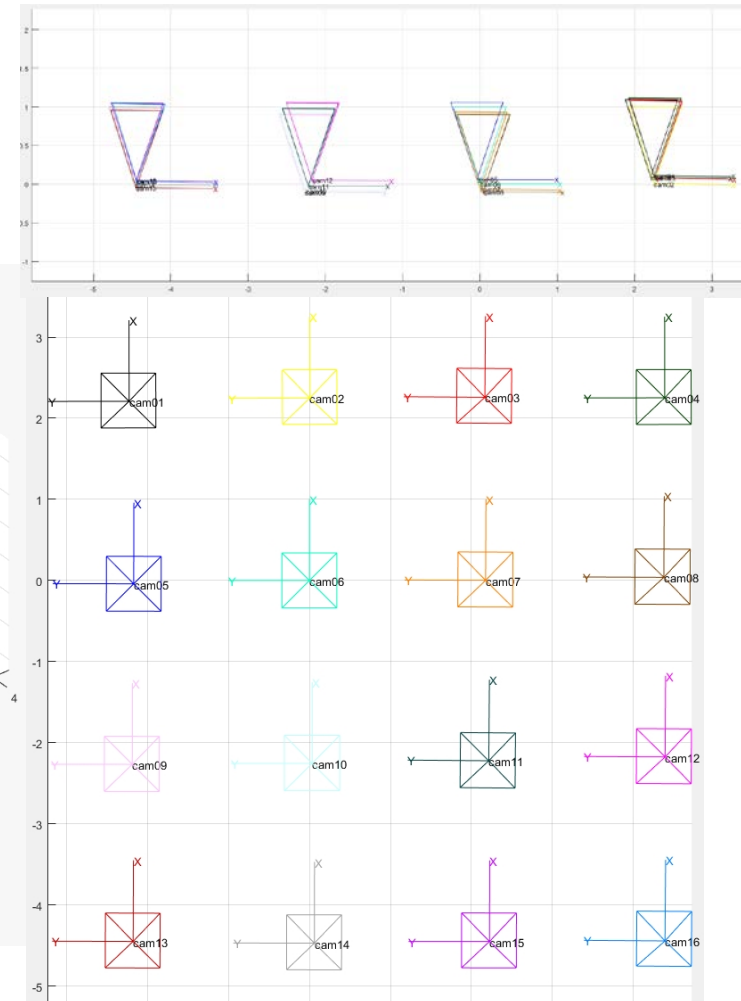
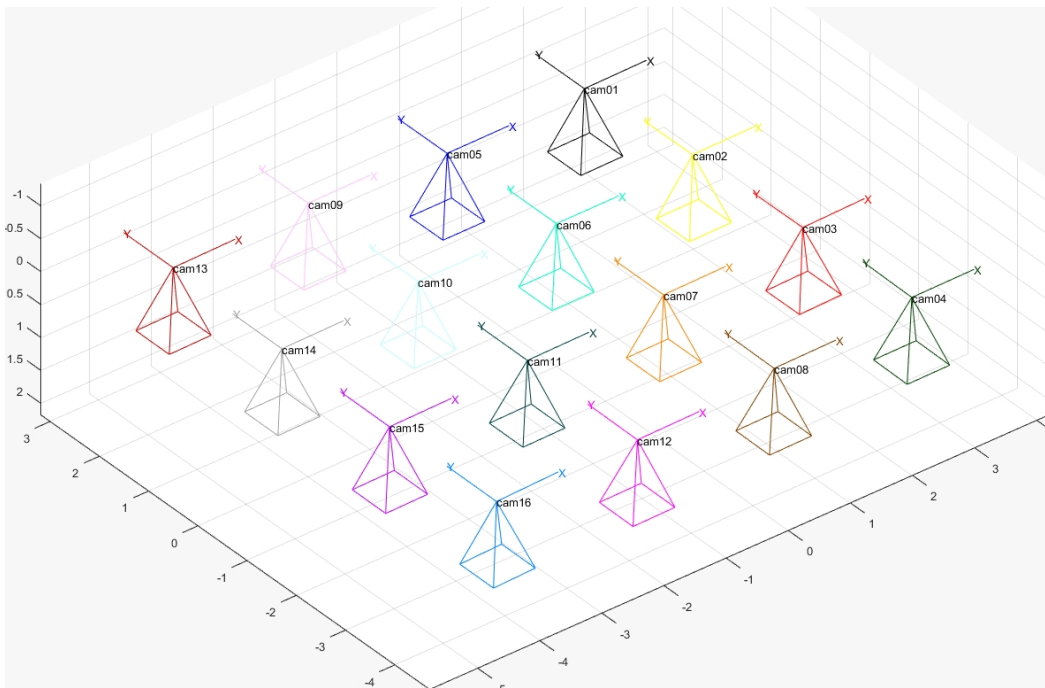
Applications of our toolbox

Camera array with pattern positions



Output of the calibration

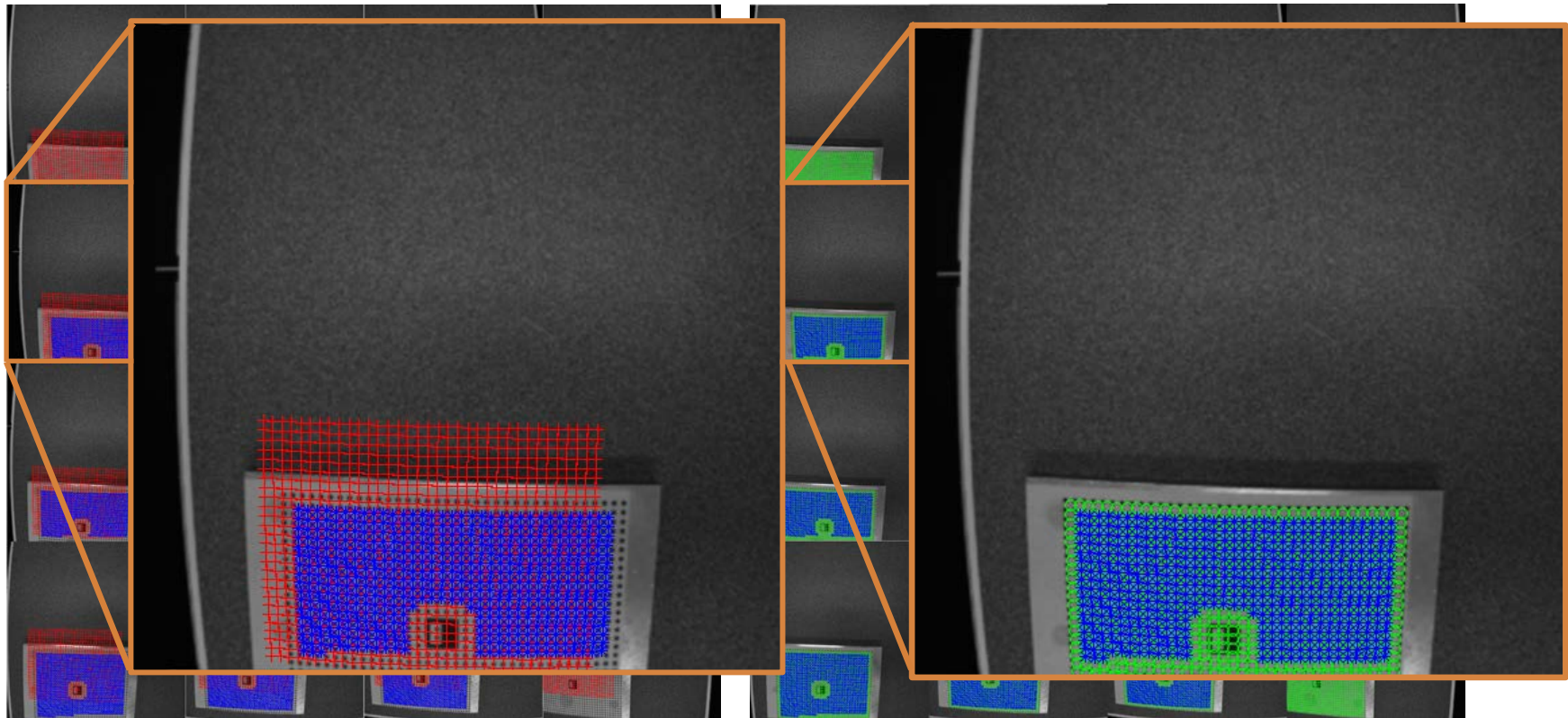
Camera Positions



cam01	cam02	cam03	cam04	cam05	cam06	cam07	cam08	cam09	cam10	cam11	cam12	cam13	cam14	cam15	cam16
22,172	22,363	22,144	22,125	-0,233	0	-0,159	0,149	-22,873	-22,586	-22,415	-22,06	-44,85	-44,824	-44,723	-45,386
22,171	0,235	-21,542	-43,62	21,721	0	-21,778	-43,761	22,022	-0,142	-21,961	-43,964	22,094	-0,003	-22,069	-43,516
0,329	-0,772	-0,104	-0,173	0,141	0	0,009	-0,113	-0,773	-0,286	0,357	1,213	-0,61	0,593	0,99	1,197

Output of the calibration

Reprojection Errors

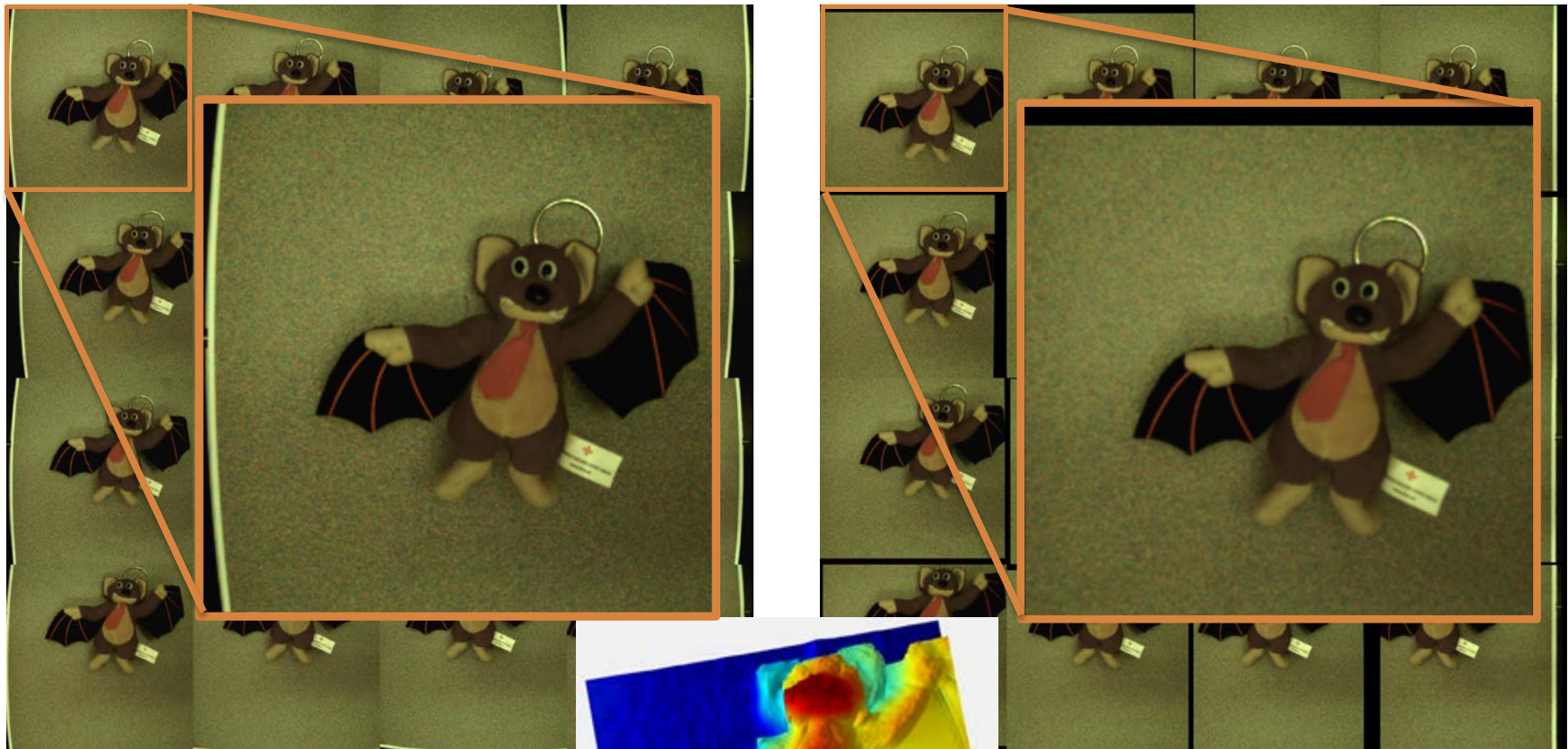


Reprojection **before** optimization

Reprojection **after** optimization

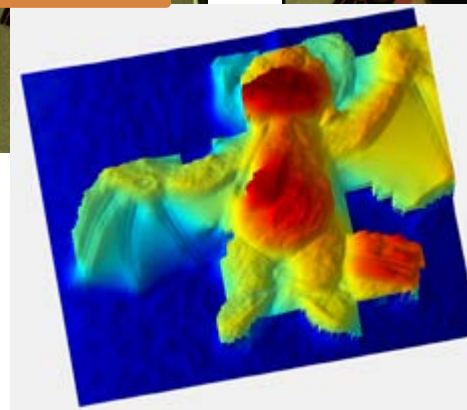
After optimization, the **average reprojection error** across all images is 0.3508 ± 0.2592 pixels.

Xapt – Example for 3D Reconstruction



Original Images

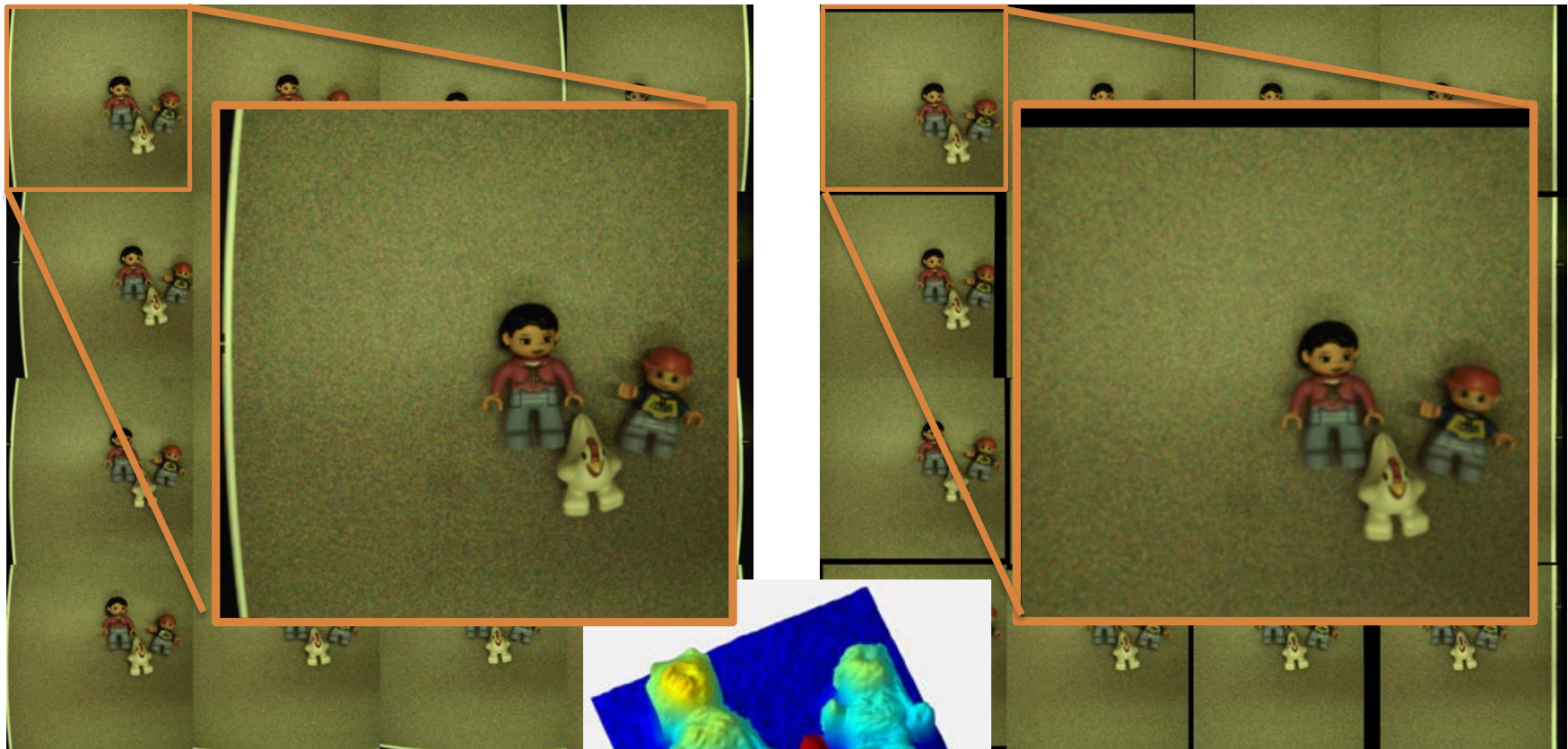
Rectified Images



Depth map

A. Shekhovtsov, Ch. Reinbacher, G. Graber and Th. Pock. "Solving Dense Image Matching in Real-Time using Discrete-Continuous Optimization." 21st Computer Vision Winter Workshop, 2016.

Xapt – Example for 3D Reconstruction

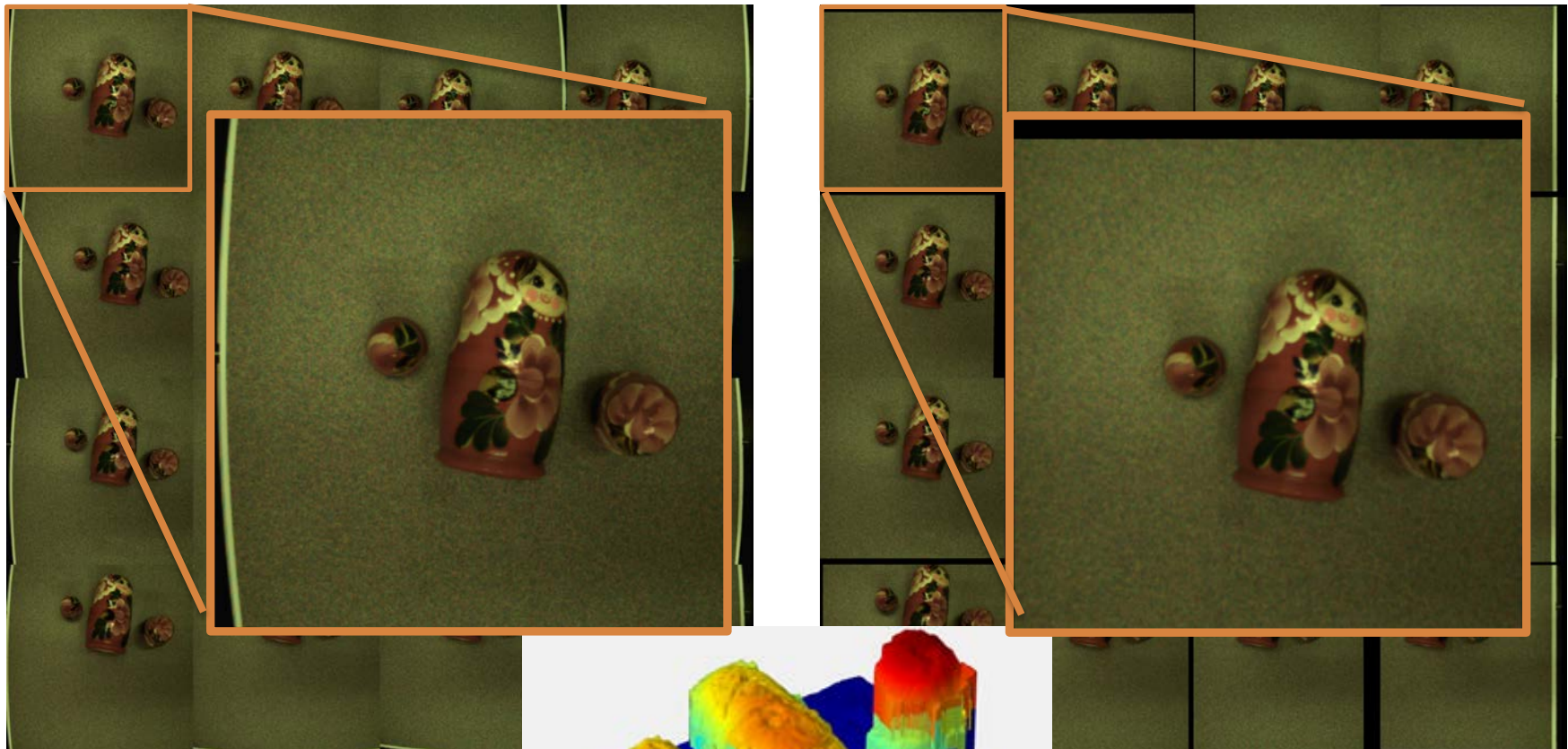


Original Images

Rectified Images

Depth map

Xapt – Example for 3D Reconstruction



Original Images

Rectified Images

Depth map

Summary

AIT Calibration Toolbox



- turns any multi-view camera array into a **light field camera**.
- has been realized in **Matlab**, only dependencies to free libraries.
- uses non-linear **optimization** to minimize **reprojection error**.
- allows for an **exact depth measurement** for a multiview image through epipolar images rectification.

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your ingenious partner

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