Combinations of Range Data and Panoramic Images

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350 Megapixel 380 degrees panoramic image

[view from the top of Auckland's harbor bridge, 2002;
PhD projects by Shou-kang Wei, Fay Huang, Karsten Scheibe]

Zooming in by factor 2

Zooming in by factor 4

Zooming in by factor 8

Zooming in by factor 16

Zooming in by factor 32

Zooming in by factor 64

Zooming in by factor 128

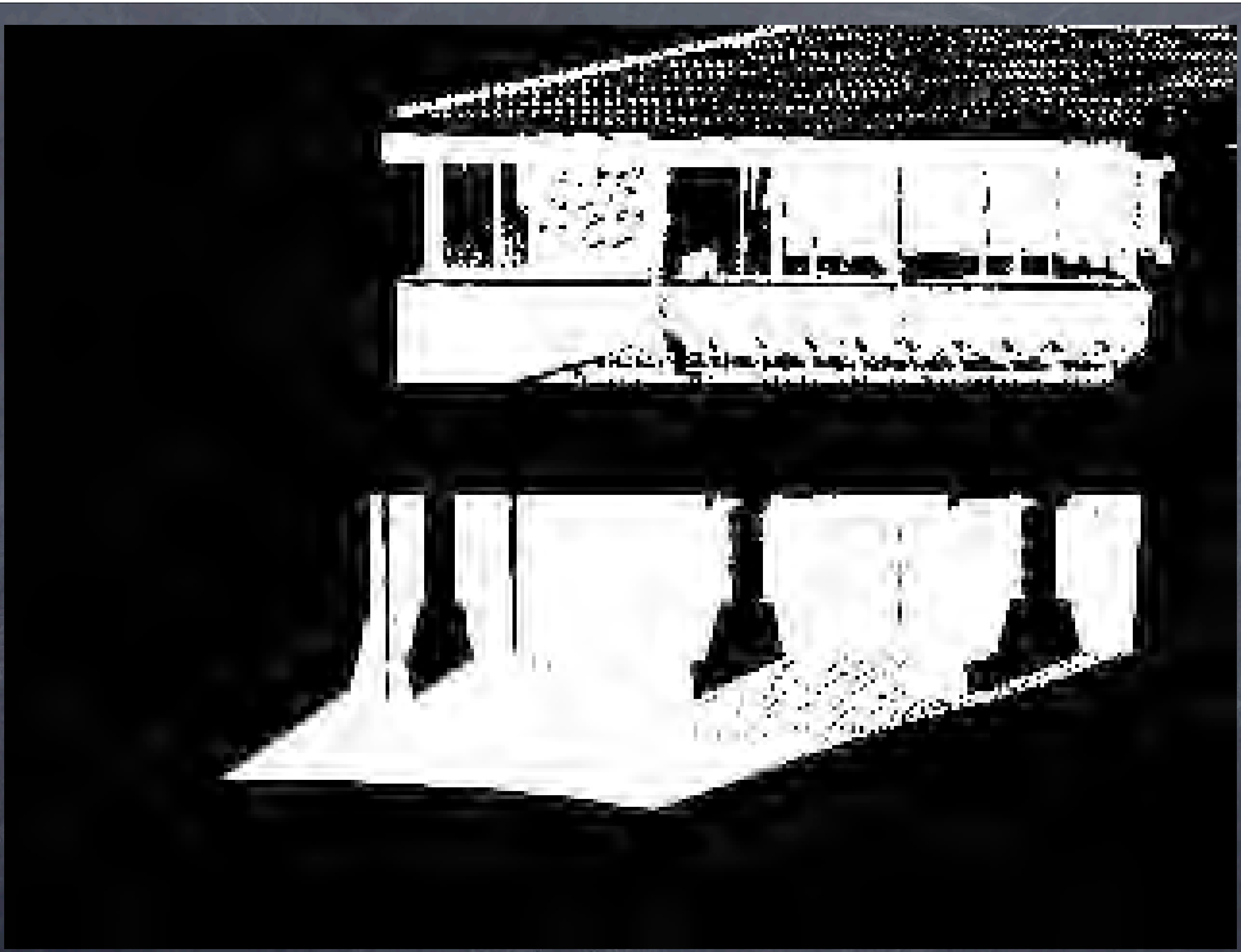
How to visualize 350 Megapixel images ?

How to use them for 3D scene modeling?

More tools available for this task?

Actually: for example --- laser scanners

[here: graduate project by Xin Zhang at CITR, Auckland]



raw distance data: millions of 3D points from one viewpoint distance data ---- from laser range finder

+

texture ---- from panoramic images

- allow multiple viewpoints
- panoramic images are of higher resolution than LRF scans

Outline of Talk

- (1) Sensors: LRF and Rotating line cameras
- (2) Stereo with rotating line cameras
- (3) Optimized camera parameters
- (4) Calibration of sensors
- (5) Unification of multiple scans
- (6) Textured surfaces
- (7) Conclusions

(1) Brief Intro of the Sensors

DLR Berlin-Adlershof: design and production of airborne sensors
(including alternative applications)

Original Laboratory
Set-Up for the Ruby Laser

first laser range finder (LRF): it used ruby lasers and was demonstrated less than a year after the laser's discovery in 1960 at Hughes (time-of-flight LRFs)

Phase-difference LRFs allow to measure very accurate range values as well as intensity (gray) values. A scene is illuminated point by point, and time-of-flight and phase differences are measured for light that is reflected from surfaces. Combining such an LRF with a (rotating) deflection mirror also allows to measure horizontal and vertical angles.

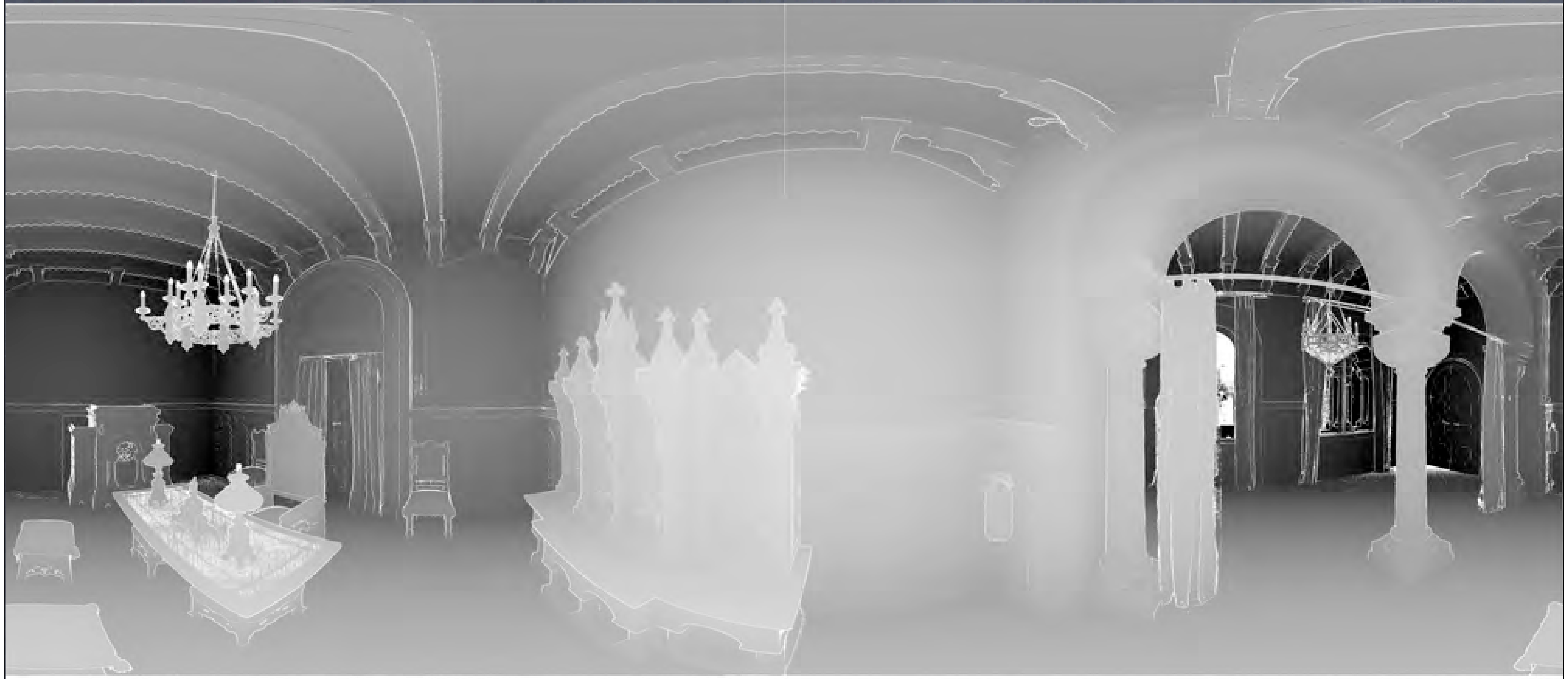
Example: LARA 53500 of Zoller und Fröhlich, Germany

company data

	LARA 25200	LARA 53500
Distance up to ...	25.2m	53.5m
Error in range data	< 3mm	< 5 mm
Data acquisition rate	< 625 Kpx/s	< 500 Kpx/s
Laser output power	22 mW	32mW
Laser wavelength	780 nm	780 nm
Beam divergence	0.22 mrad	0.22 mrad
Laser safety class	3R (DIN EN 60825-1)	3R (DIN EN 60825-1)
Field of view vertical	310°	310°
Field of view horizontal	360°	360°

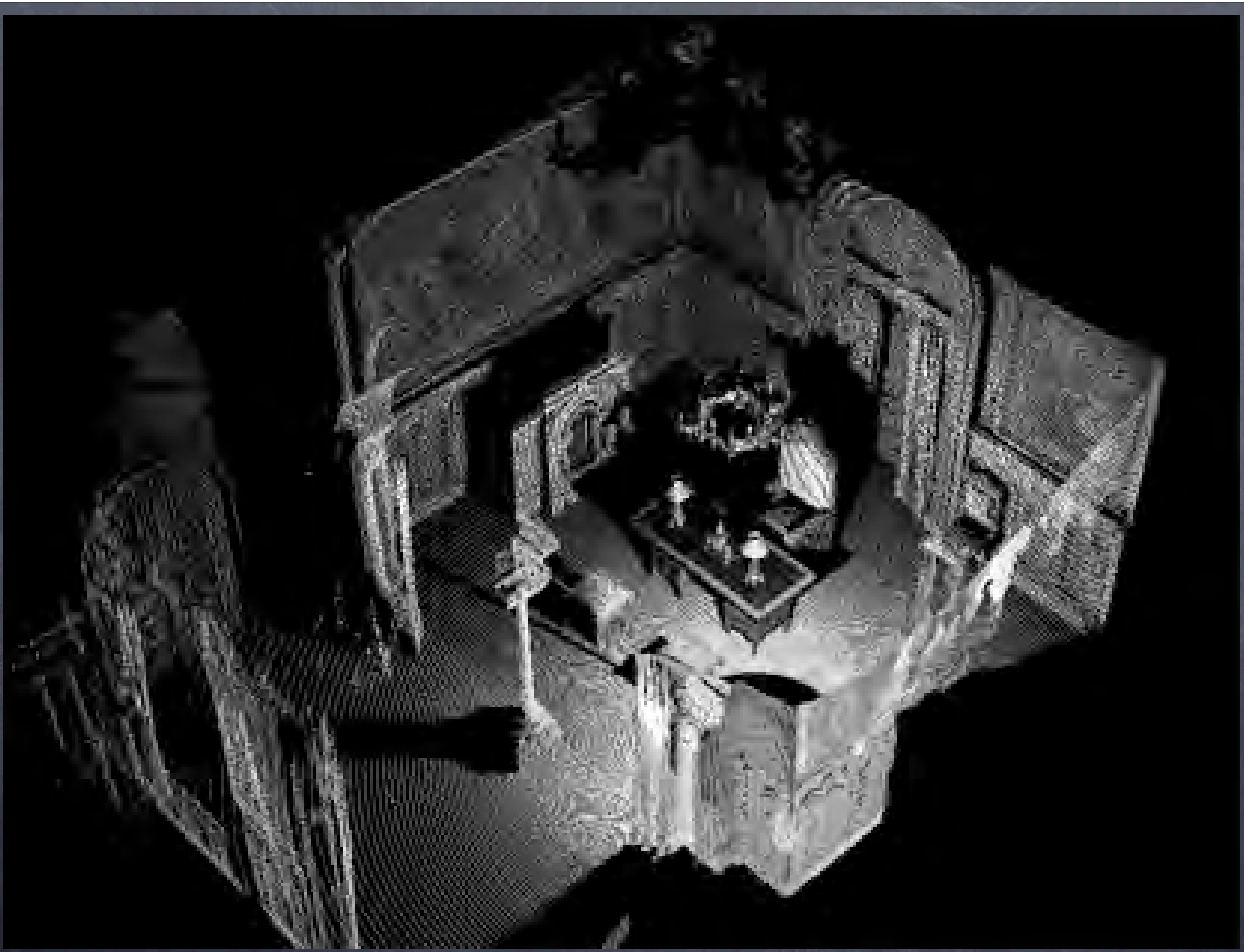
Intensity data

[Office of King Ludwig, Neuschwanstein]

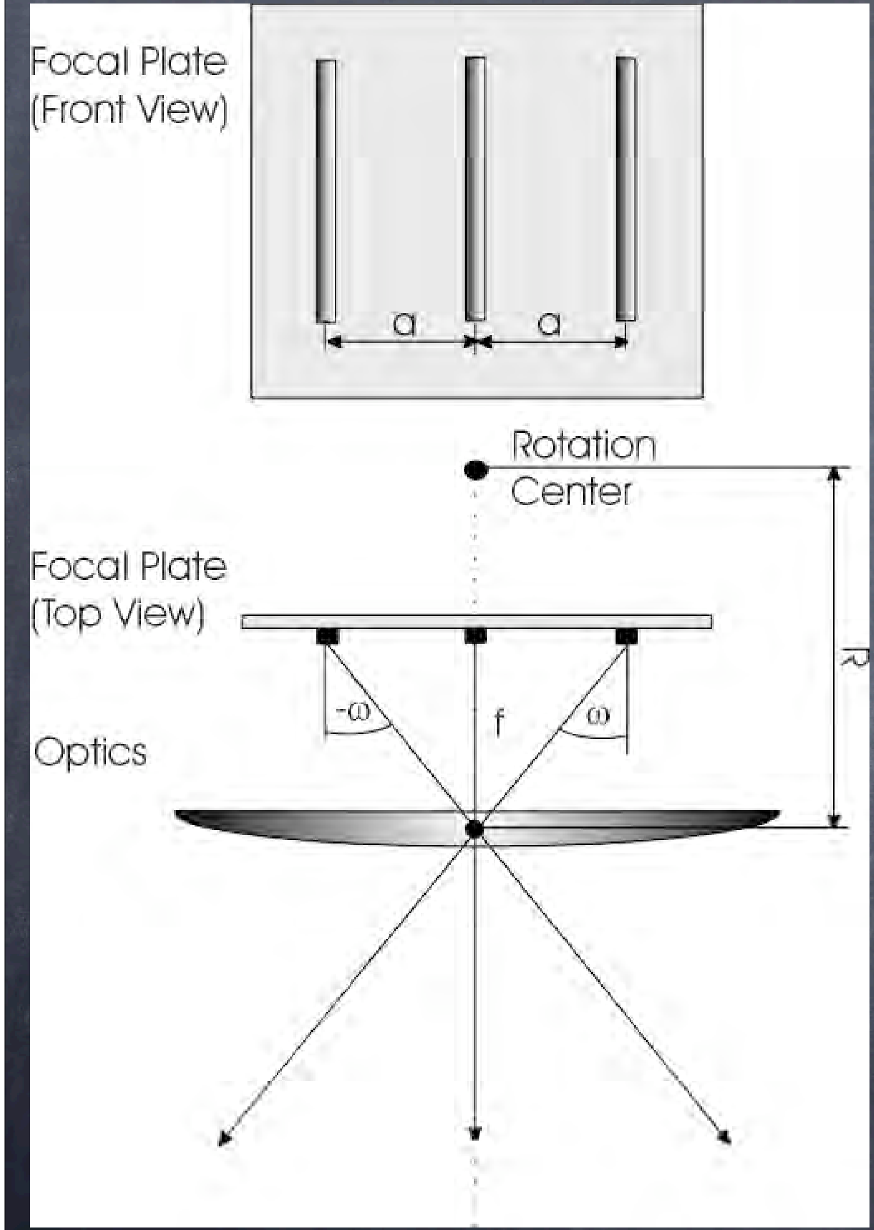


Range data (same LRF scan)

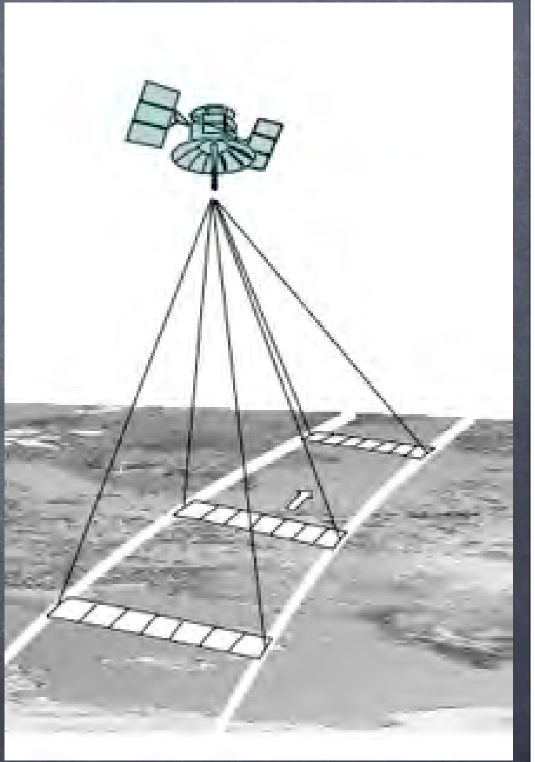
[Office of King Ludwig, Neuschwanstein]



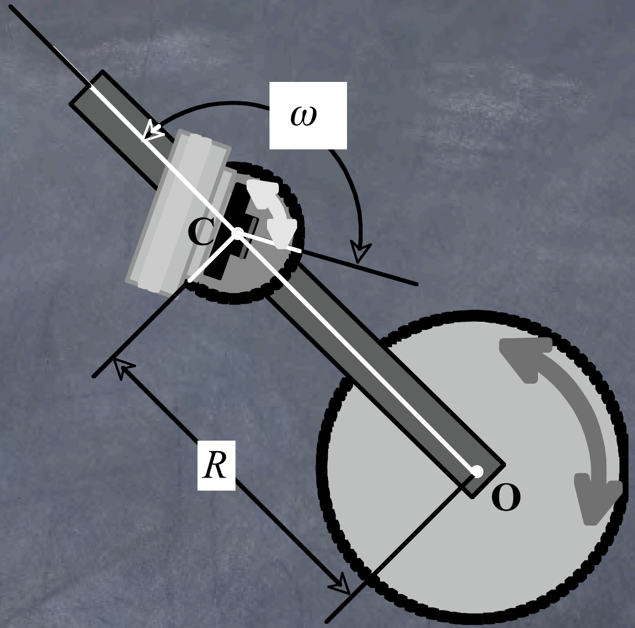
Cloud of 3D points and their gray values



CCD line cameras designed and build at DLR for space missions



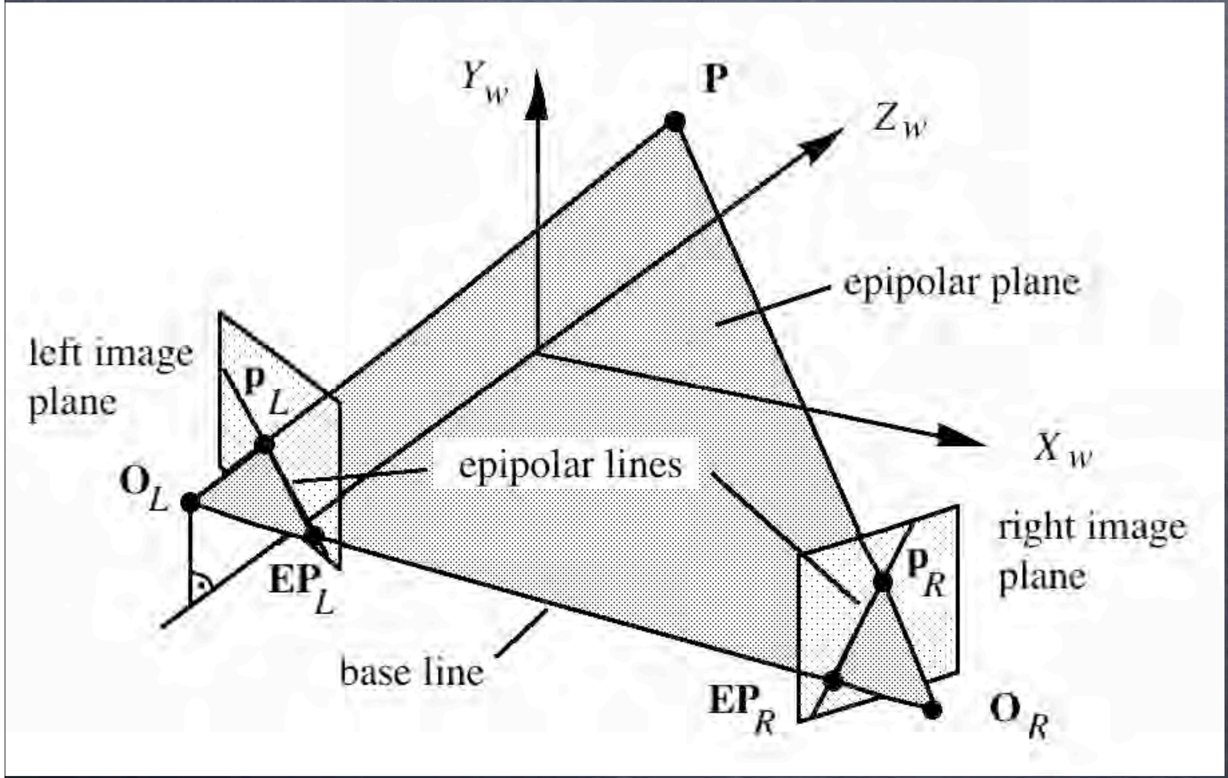
used for panoramic images (rotation)



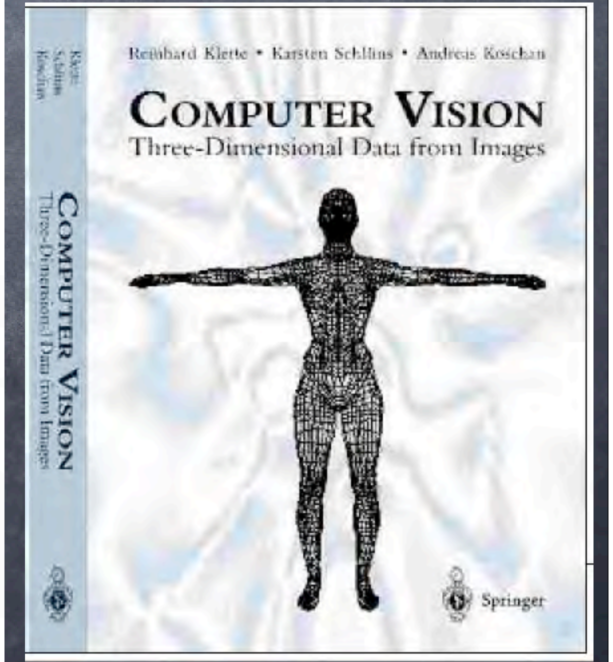
Stereo options proposed by CITR, joint experiments in Auckland 2002

(2) Stereo with Rotating Line Cameras

Stereo with pinhole cameras: well-studied subject



see (e.g.)

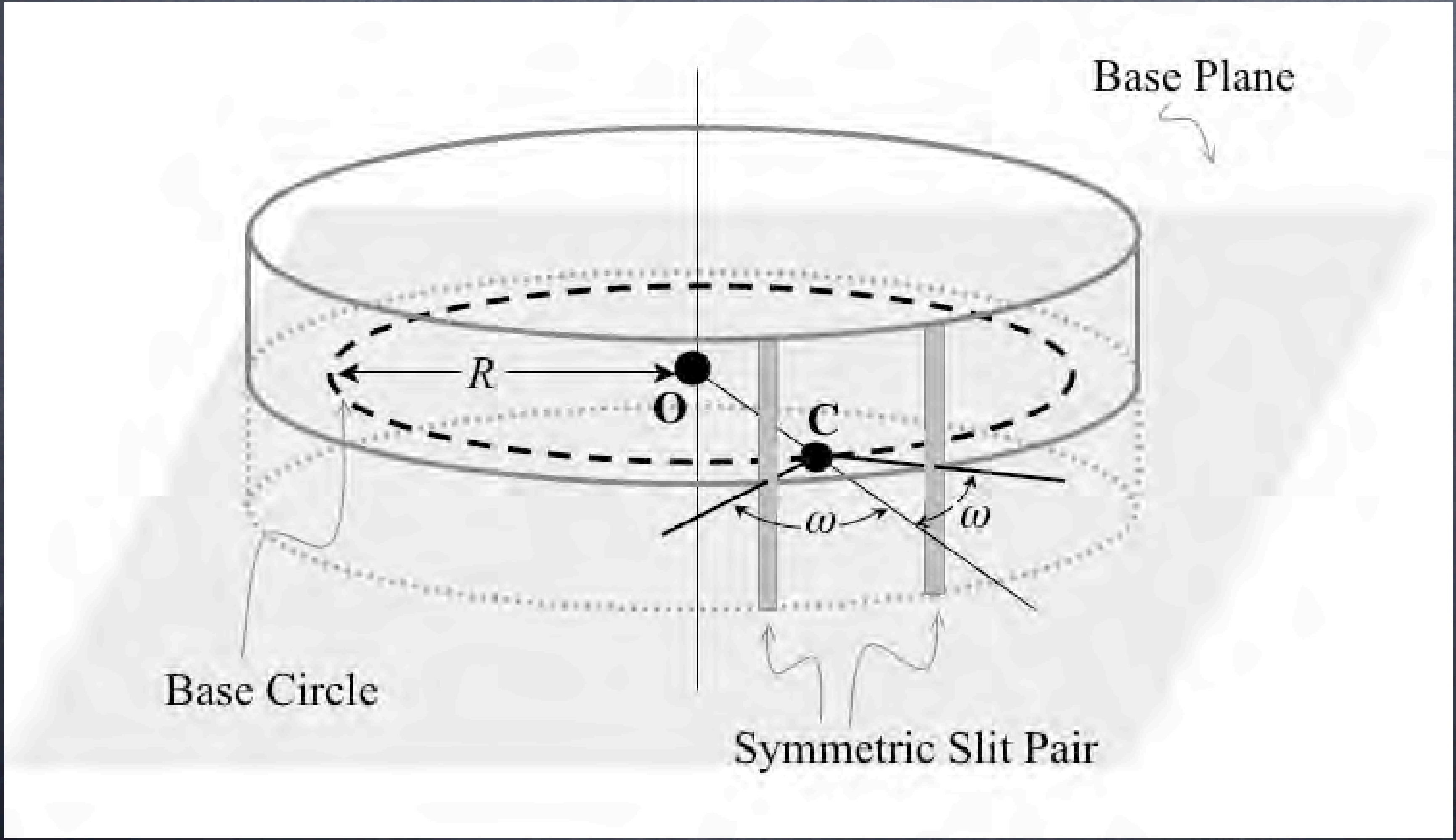

Reinhard Klette • Karsten Schlüns • Andreas Koschan

COMPUTER VISION

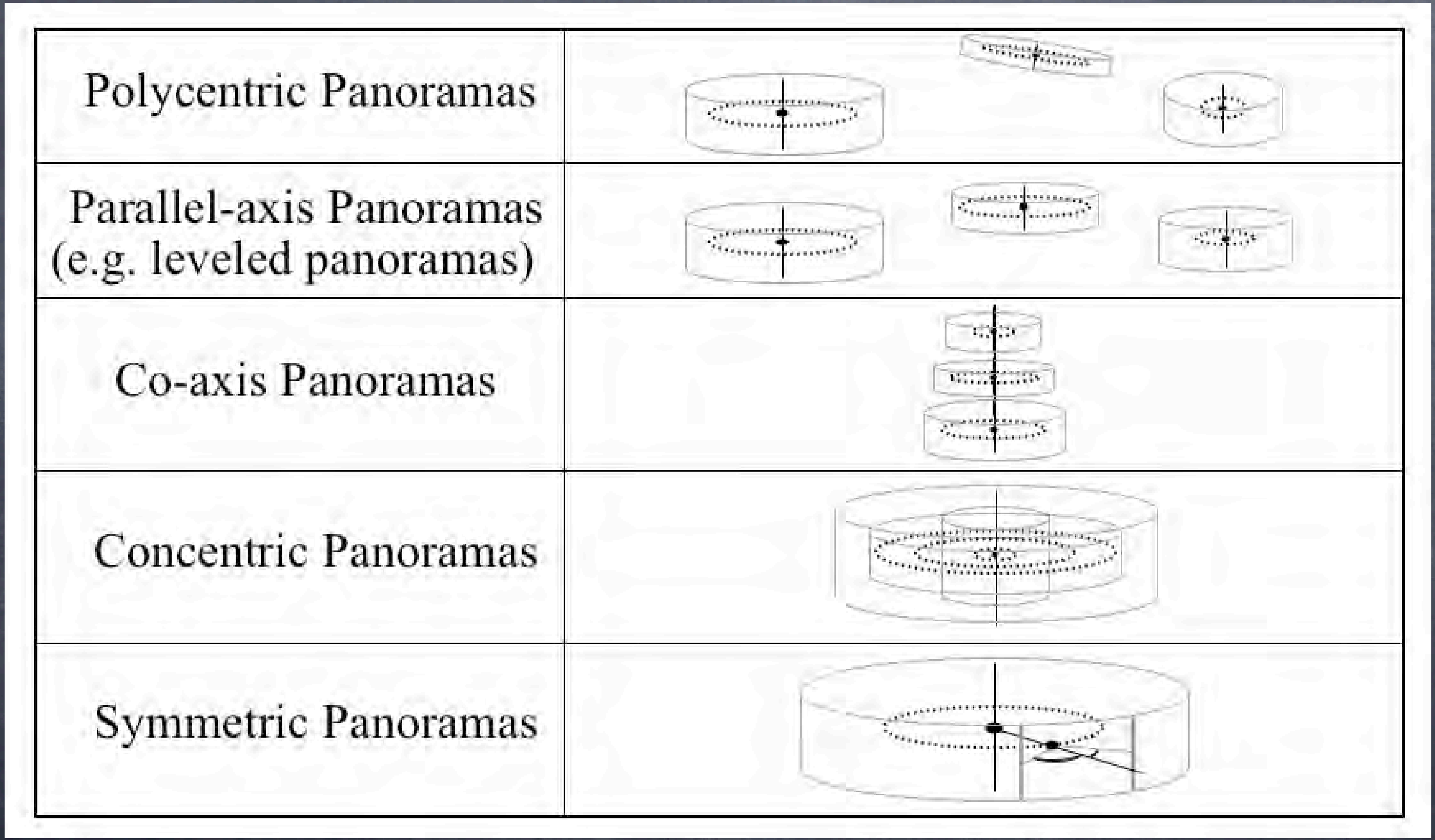
Three-Dimensional Data from Images

Springer

Stereo with rotating line cameras:
for example two CCD lines with different viewing angles ω



More options in general:



Polycentric Panoramas	
Parallel-axis Panoramas (e.g. leveled panoramas)	
Co-axis Panoramas	
Concentric Panoramas	
Symmetric Panoramas	

different view points, rotation radius' R, or viewing angles ω

Depth calculation in a symmetric pair of panoramic images:

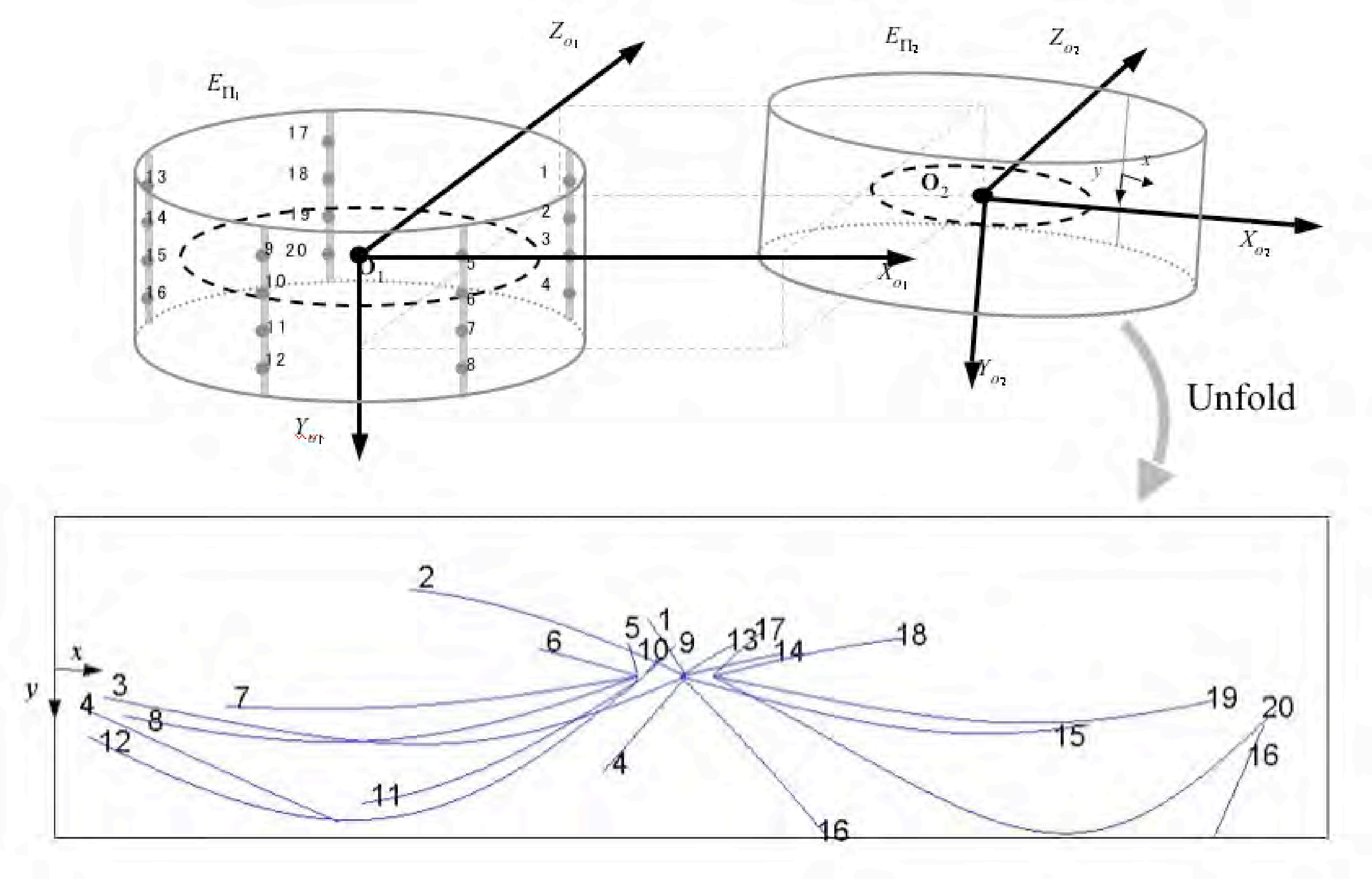
disparity d with $0 < d < \frac{W}{2}$

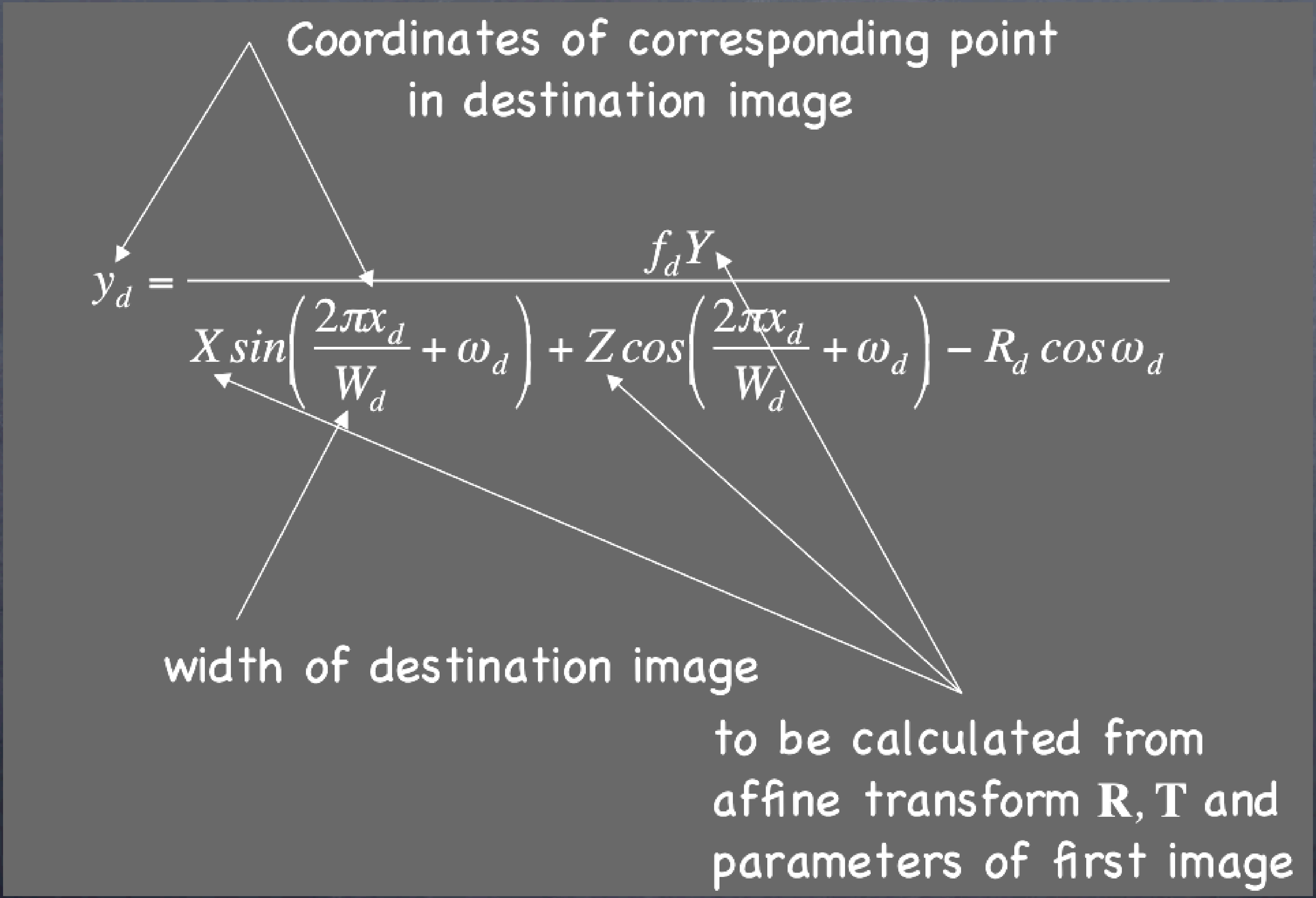
or angular disparity $\theta = \frac{2\pi d}{\mathrm{W}}$ with $0^\circ < d < 180^\circ$

then depth (or distance)

$$D = \frac{R\sin\omega}{\sin\left(\omega - \frac{d\pi}{W}\right)} = \frac{R\sin\omega}{\sin\left(\omega - \frac{\theta}{2}\right)}$$

Epipolar curves (for detecting corresponding pixels):





Coordinates of corresponding point in destination image

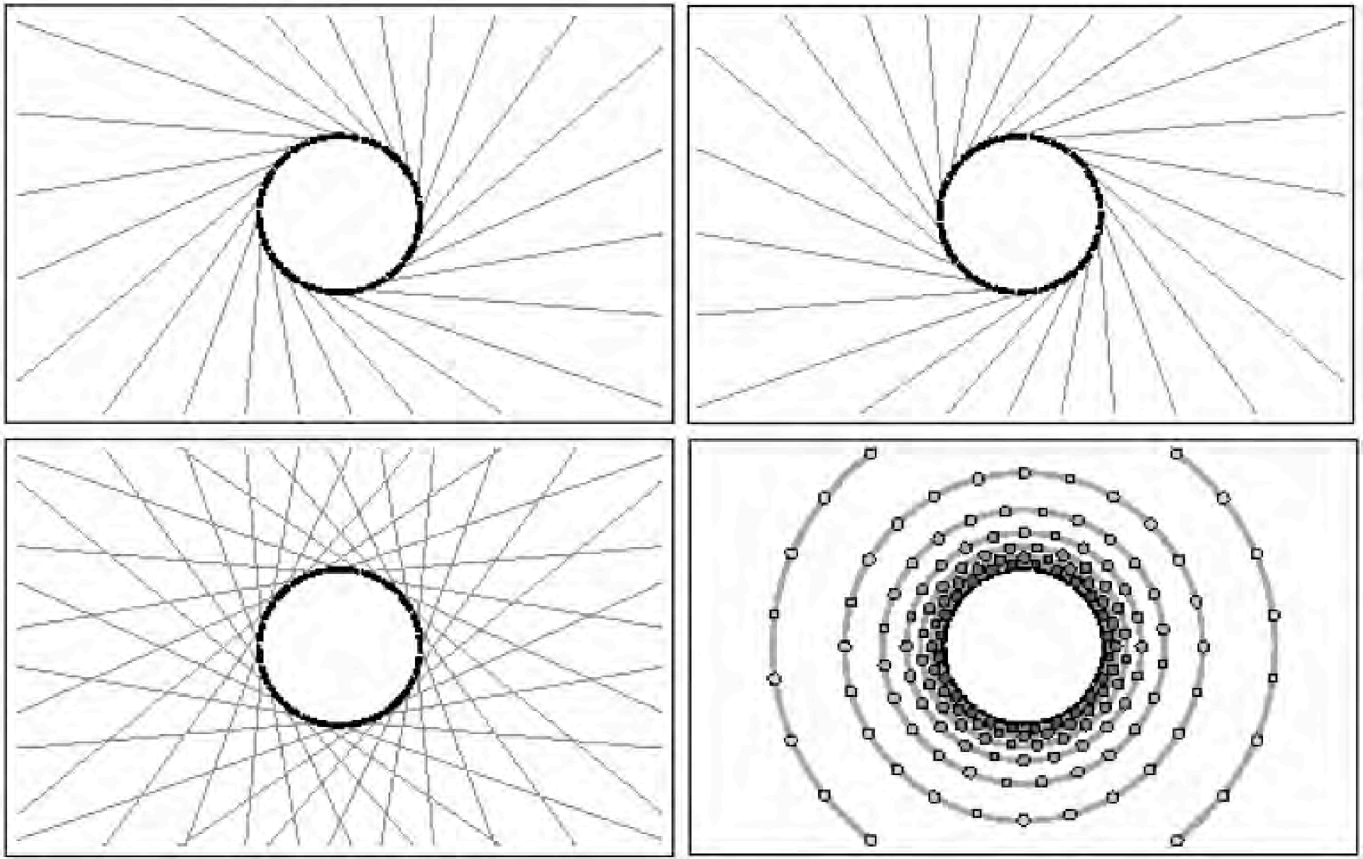
$$y_d = \frac{f_d Y}{X\,sin\left(\frac{2\pi x_d}{W_d}+\omega_d\right)+Z\,cos\left(\frac{2\pi x_d}{W_d}+\omega_d\right)-R_d\,cos\,\omega_d}$$

width of destination image

to be calculated from affine transform $\mathbf{R}, \mathbf{T}$ and parameters of first image

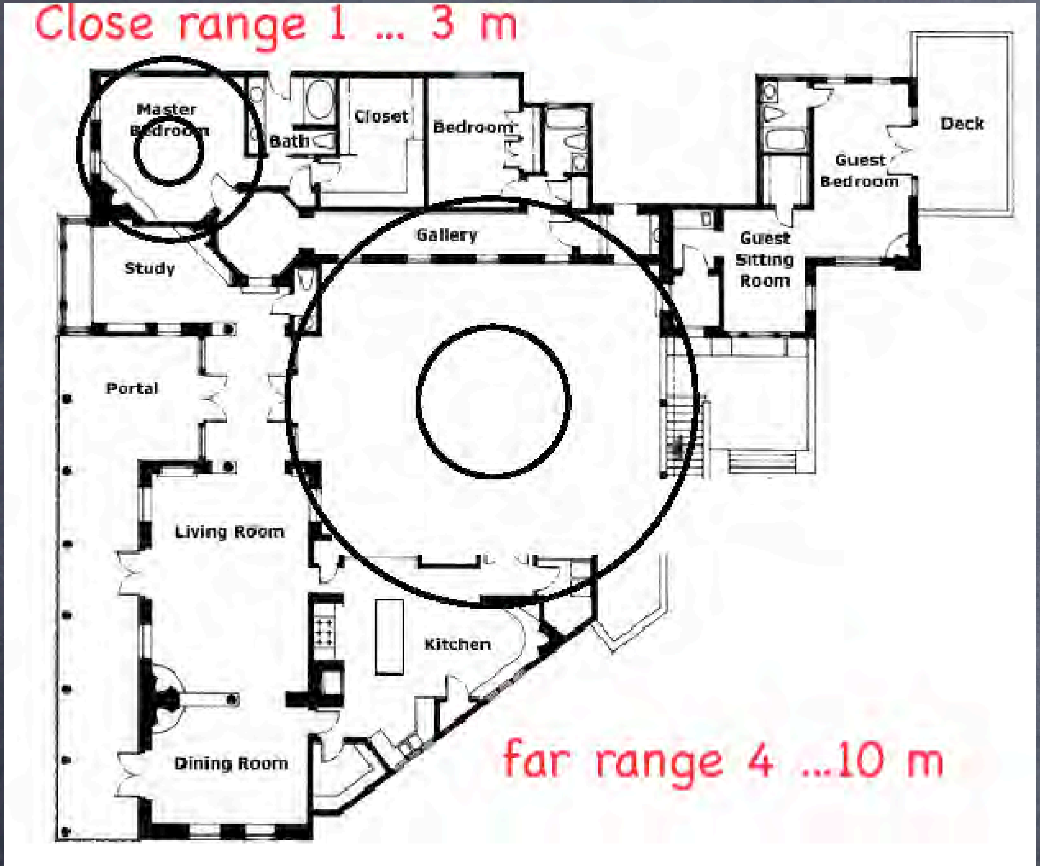
[F. Huang, S.-K. Wei, R. Klette, ICCV 2001]

(3) Optimized Camera Parameters

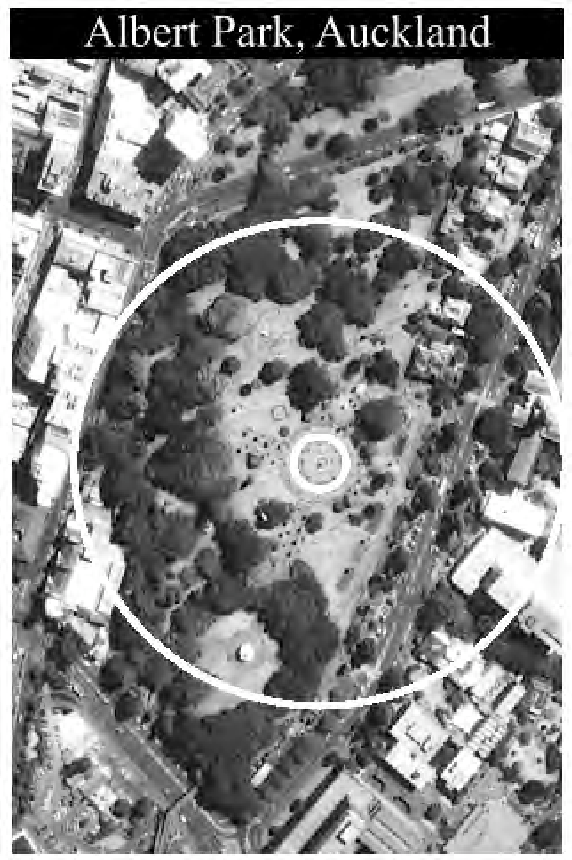


potential samples
of a symmetric panorama

Scene model indoor:

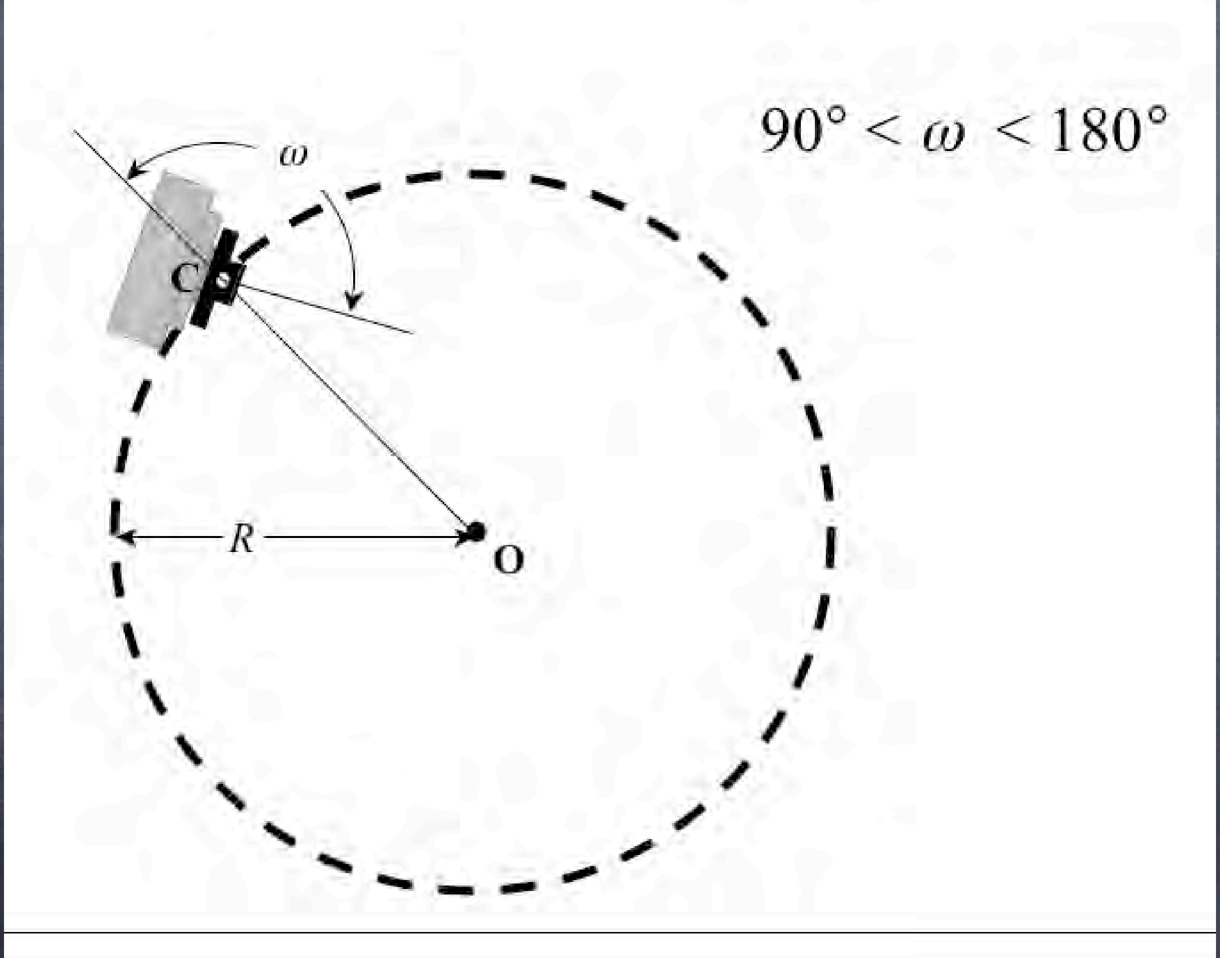

Close range 1 ... 3 m

far range 4 ...10 m


Albert Park, Auckland

Close range outdoor 6 ... 50 m

Inward case:

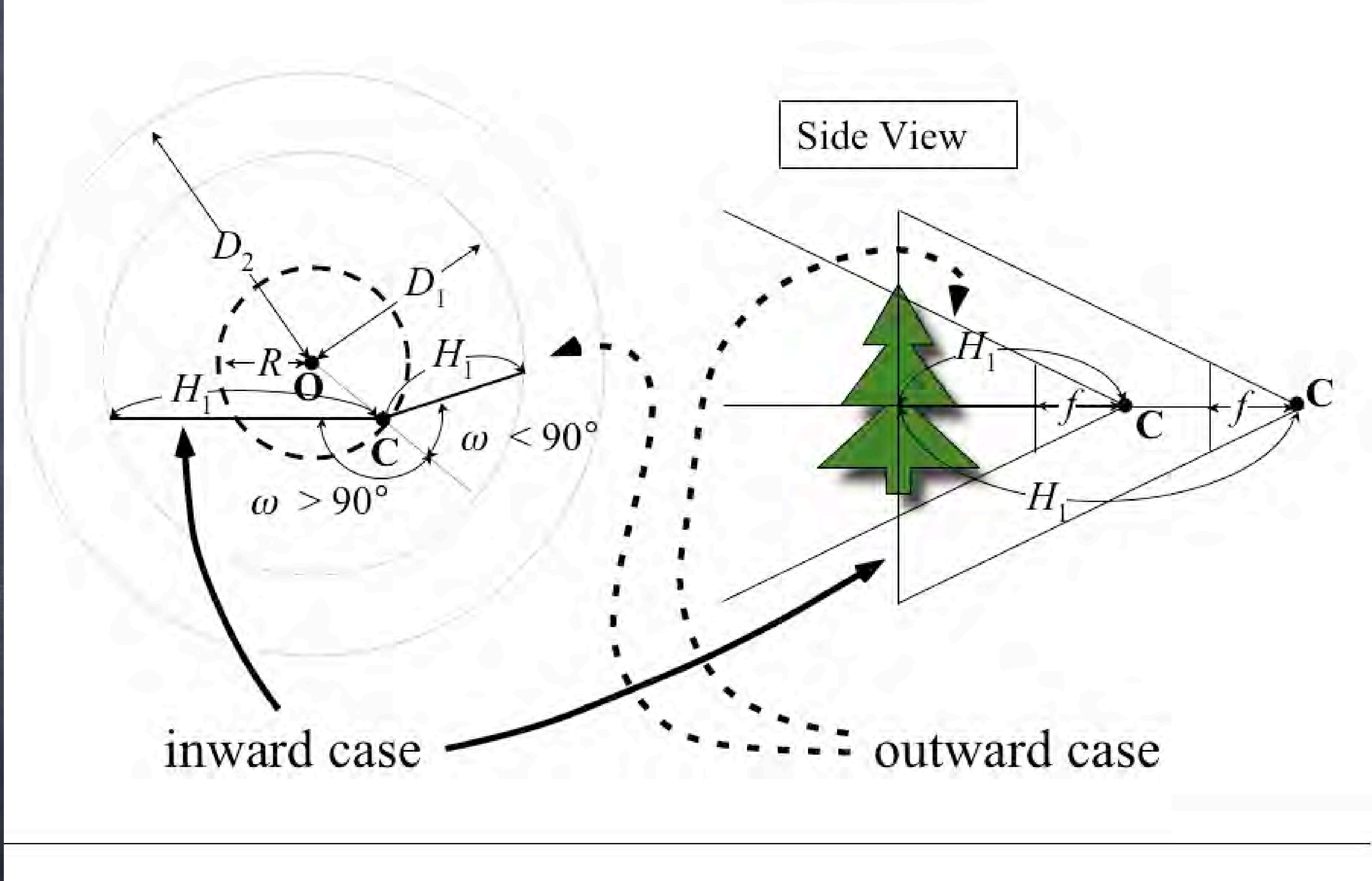


Given: width W of a panoramic image to be captured, and model about stereo viewing

Goal: avoid dipodia by allowing only a maximum disparity of θ_w (use 0.03 times viewing distance)

Optimization problem for symmetric panoramas (i.e., those which are stereo viewable): Calculate R and ω such that number of samples in scene space between D_1 and D_2 is maximized, and angular disparity is always less or equal θ_w.

Three parameters for modeling a scene:



D_1, D_2 and H_1

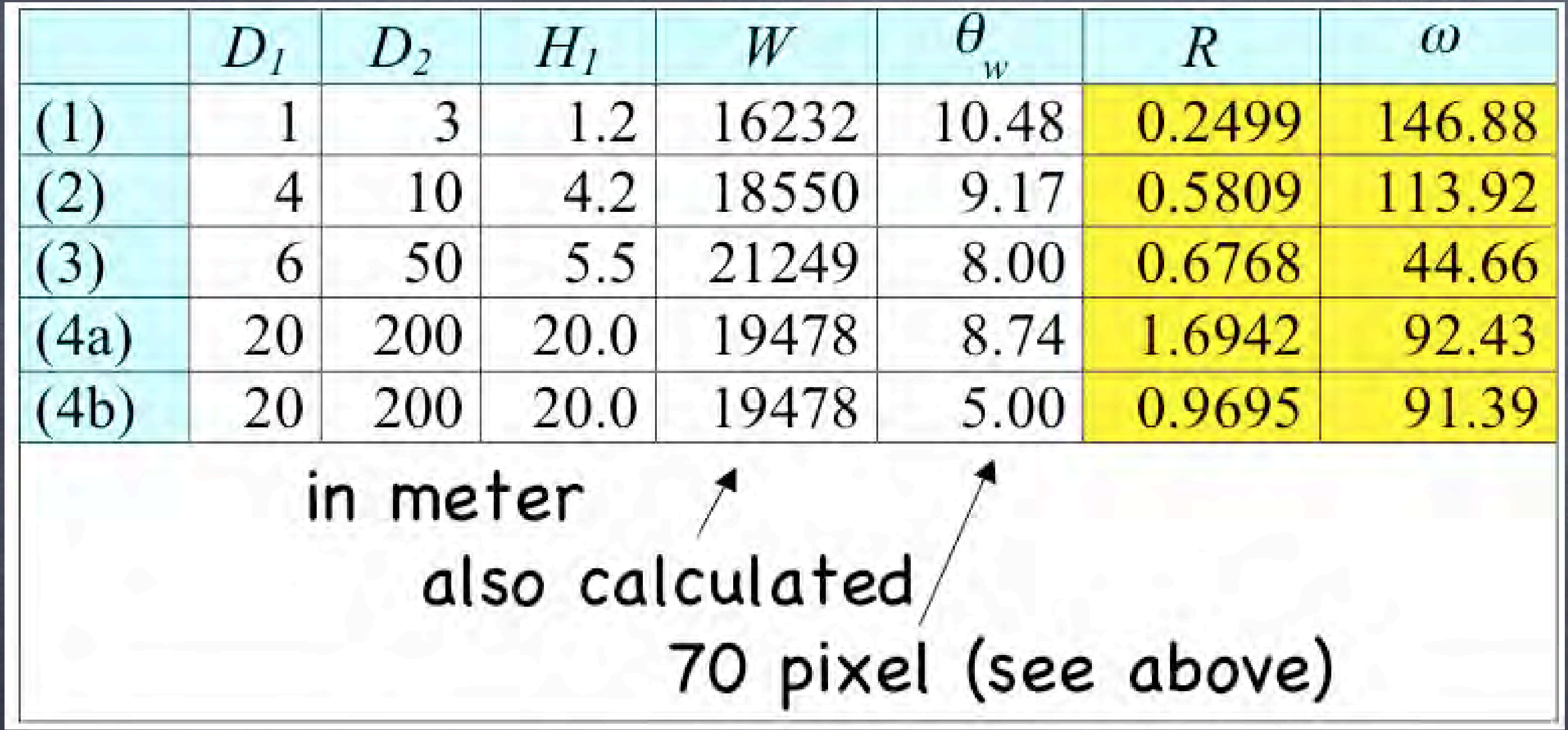
Unique (!) solution:

$$R = \sqrt{D_1^2 + H_1^2 + 2D_1H_1\frac{D_1 - D_2\cos\left(\frac{\theta_w}{2}\right)}{\sqrt{D_1^2 + D_2^2 - 2D_1D_2\cos\left(\frac{\theta_w}{2}\right)}}}$$

$$\omega = \arccos\left(\frac{D_1^2 - H_1^2 - R^2}{2H_1R}\right)$$

The total number of potential samples of a symmetric panorama is $\left\lfloor \frac{\omega W}{\pi} \right\rfloor (2W-1)H$

where H is the number of pixels in each column (the height). Note: no influence of R



	D_1	D_2	H_1	W	θ_w	R	ω
(1)	1	3	1.2	16232	10.48	0.2499	146.88
(2)	4	10	4.2	18550	9.17	0.5809	113.92
(3)	6	50	5.5	21249	8.00	0.6768	44.66
(4a)	20	200	20.0	19478	8.74	1.6942	92.43
(4b)	20	200	20.0	19478	5.00	0.9695	91.39

in meter

also calculated

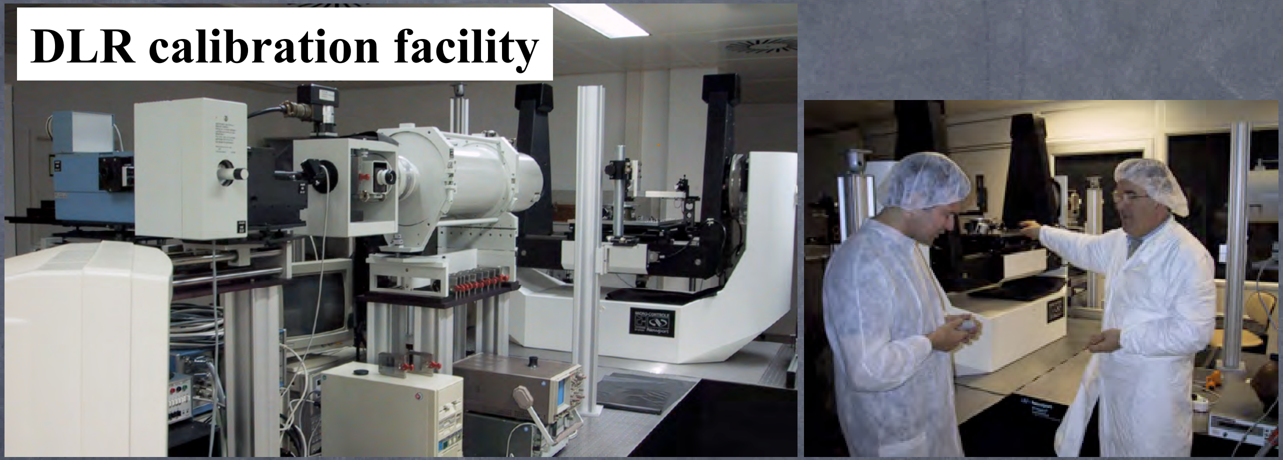
70 pixel (see above)

CITR (Auckland): anaglyphic panorama, 350 Megapixel: two panoramic images of 10,000 x 35,000 pixels each combined into one stereo viewable panoramic image

[Shou-kang Wei, Fay Huang, ... 2002, DLR and CITR]

(4) Calibration of Sensors

a. production-site calibration of camera



b. calibration before capturing data

b.1 intrinsic parameters R, ω , ... of camera

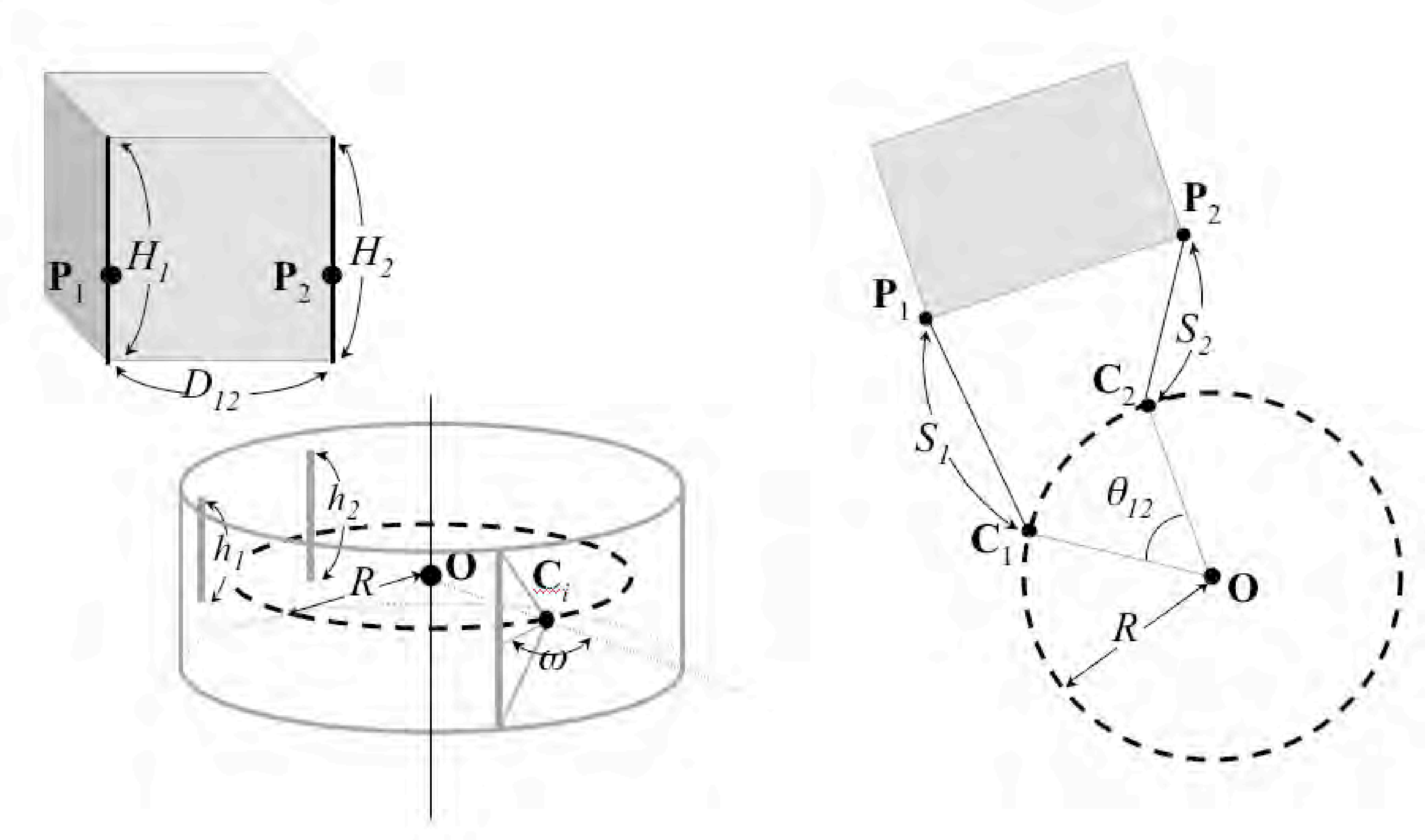
b.2 extrinsic parameters (affine transforms) for camera and range finder

Preparing for capturing data

indoor:
Drottingholm, Sweden

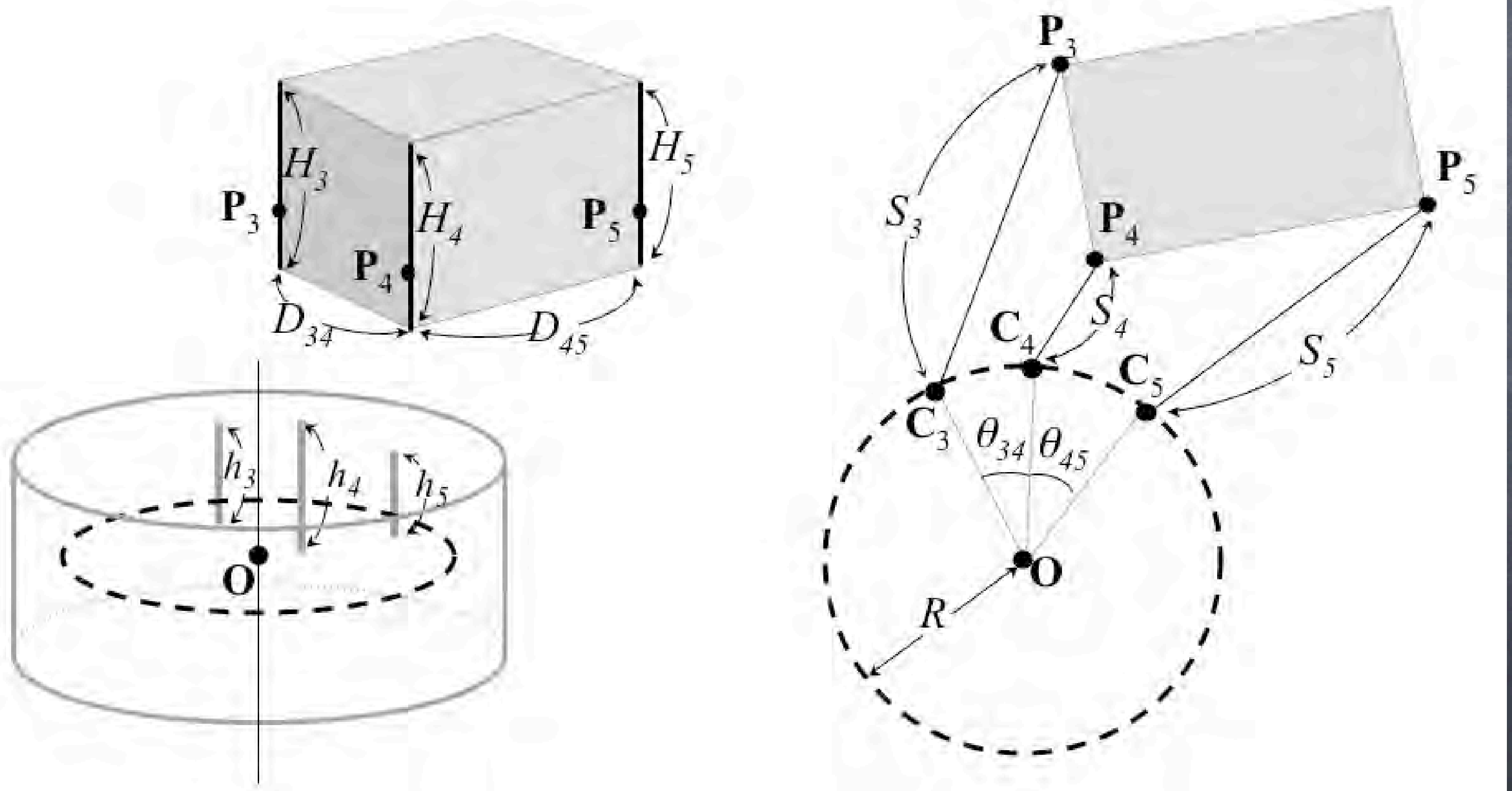
outdoor:
Wörlitz, Germany

Method 1 for calibrating R and ω

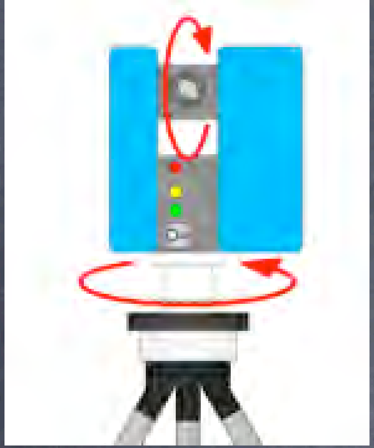


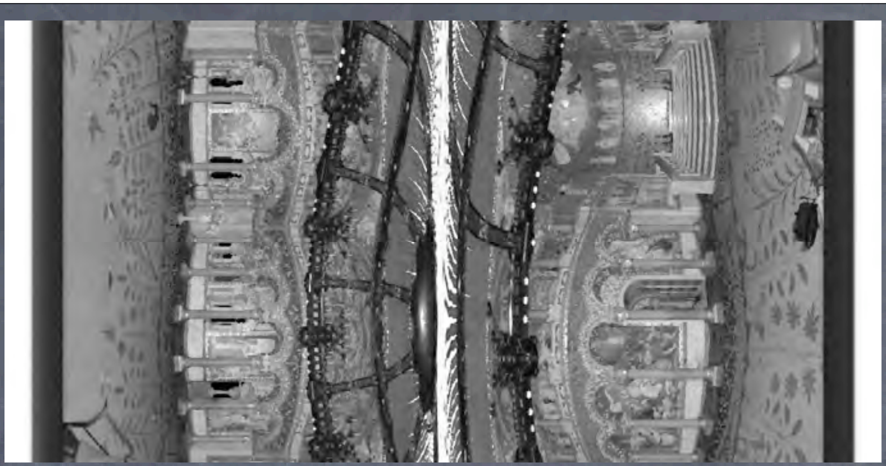
at least three parallel line segments in the scene

Method 2 for calibrating R and ω



at least one triple of orthogonal line segments





uncalibrated LRF data

$\vartheta = j \cdot \Delta\vartheta$

$\varphi = i \cdot \Delta\varphi$

Calibration: (1) local polar coordinates
(2) world coordinates (affine transform)

local coordinates of camera data:

$j \cdot \delta$

$\varphi = i \cdot \Delta\varphi$

Polar coordinates as well!
(due to similarity of sensor geometry)
IMU (inertial measuring unit) allows
to identify φ with error ≤ $\frac{1}{1000}^{\circ}$

Calibration: (1) local polar coordinates
(2) world coordinates (affine transform)

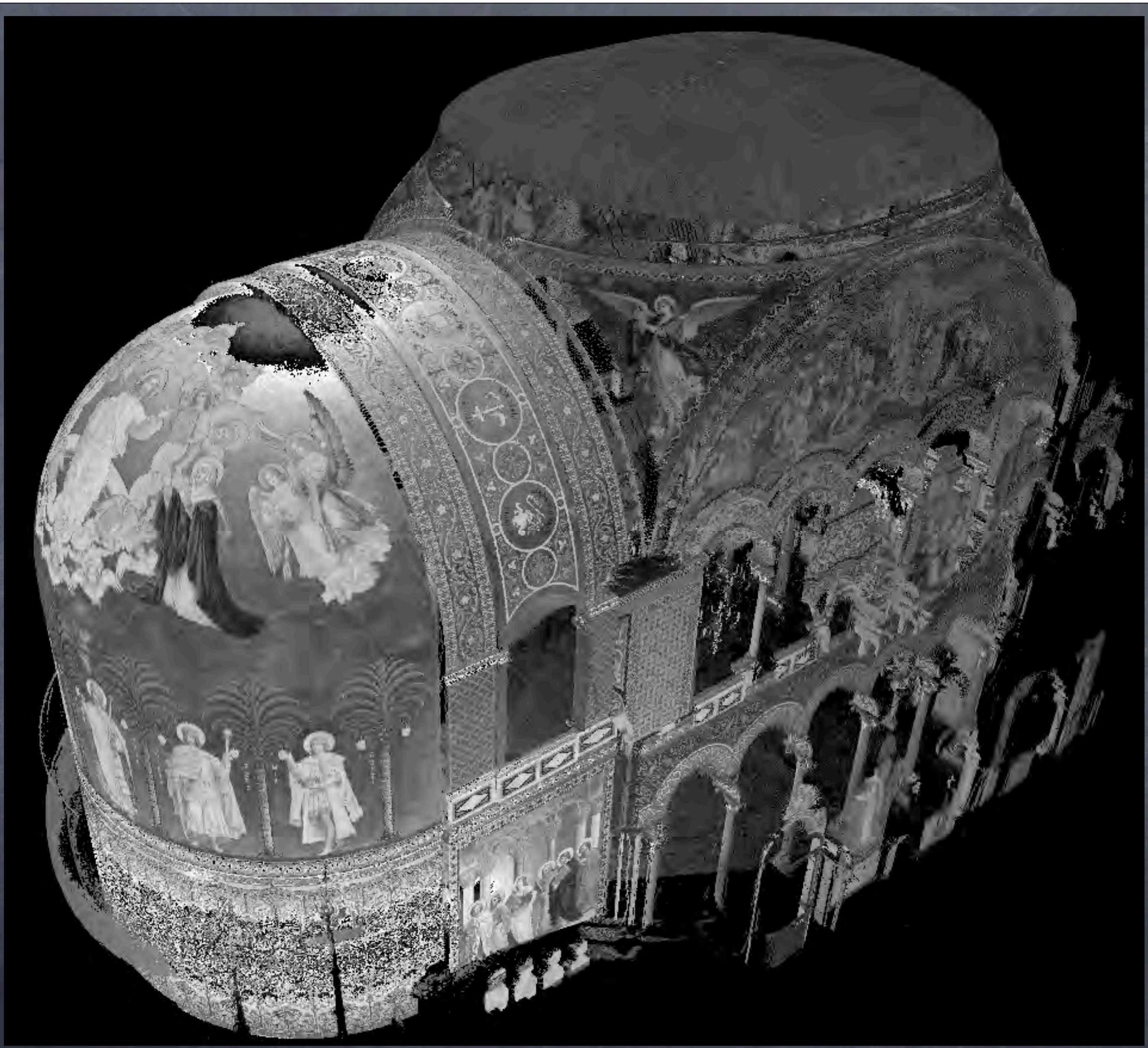
(5) Unification of Multiple Scans

Least-square error approach for calibration of affine transforms

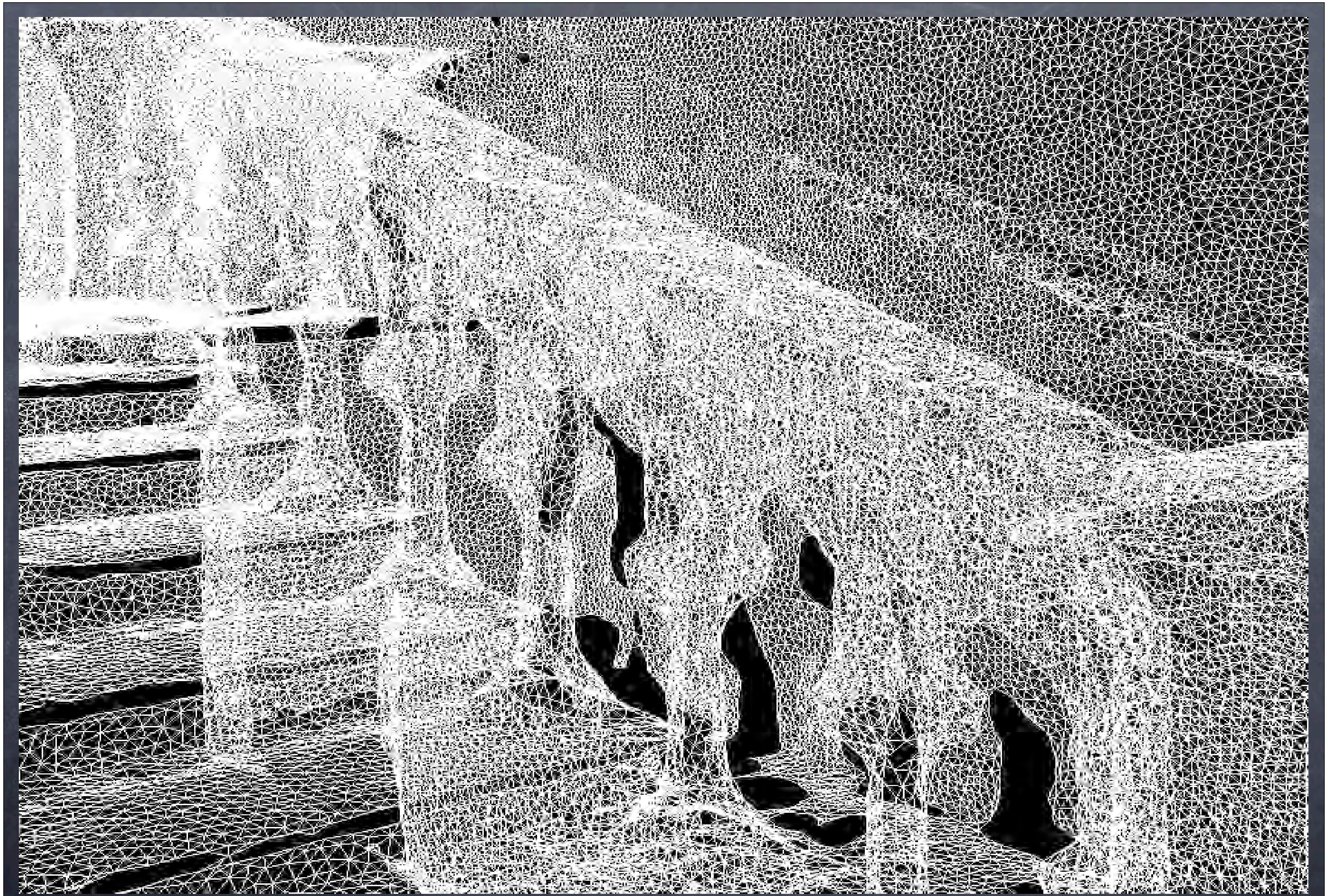
(see conference article for details)

workflow

a. all range data (and camera data) in same world coordinate system
b. triangulation of range data for each view point
c. unification and simplification of triangulations
d. geometric correction of unified triangulations



Point cloud (multiple viewpoints) in world coordinates



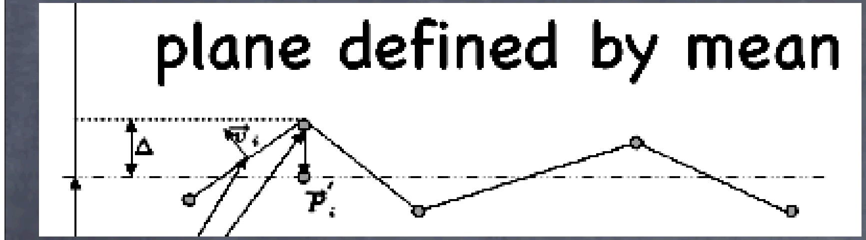
Small detail of triangulated point cloud

Digital surface model (DSM) by triangulation:

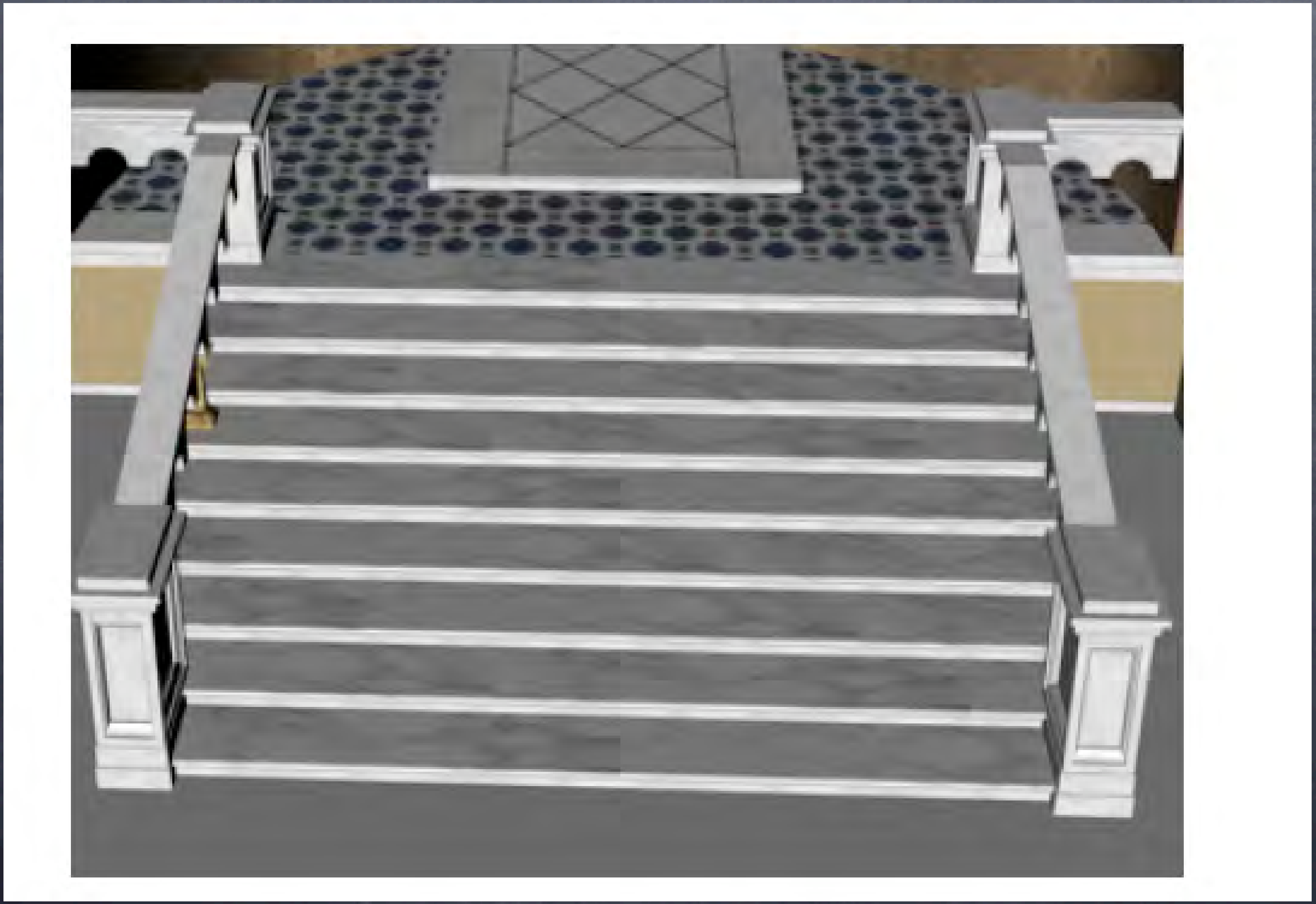
[T. Bodenmüller, DLR Berlin]

a. thinning of points (”density check”)
b. approximation of normals based on local surface approximation
c. point insertion depending on normals and density
d. estimation of Euclidean neighborhoods
e. projection of neighborhoods into tangential planes
f. local Delaunay triangulation creates DSM

Detection of planar surface patches, edges, …

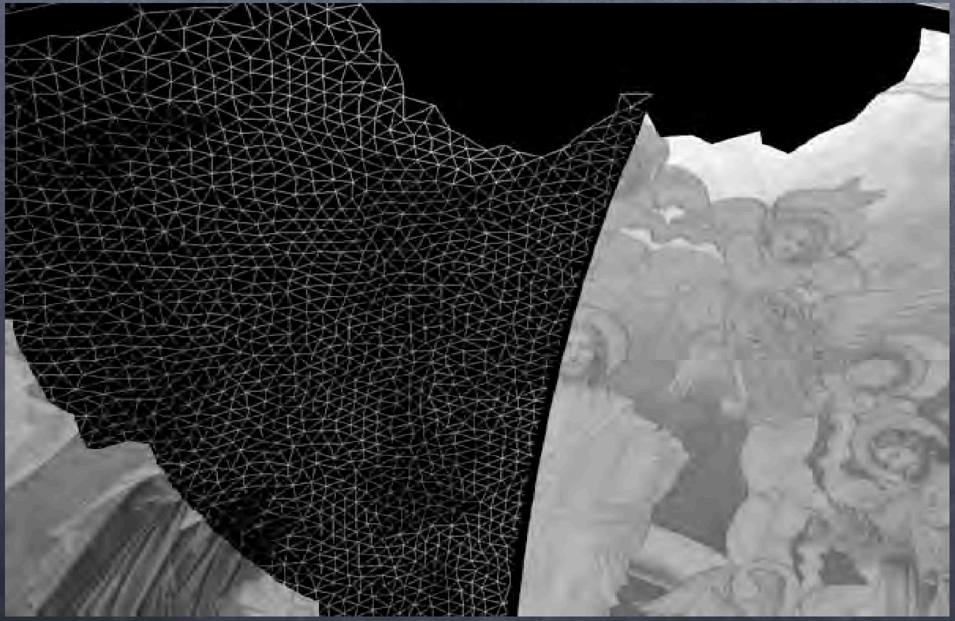


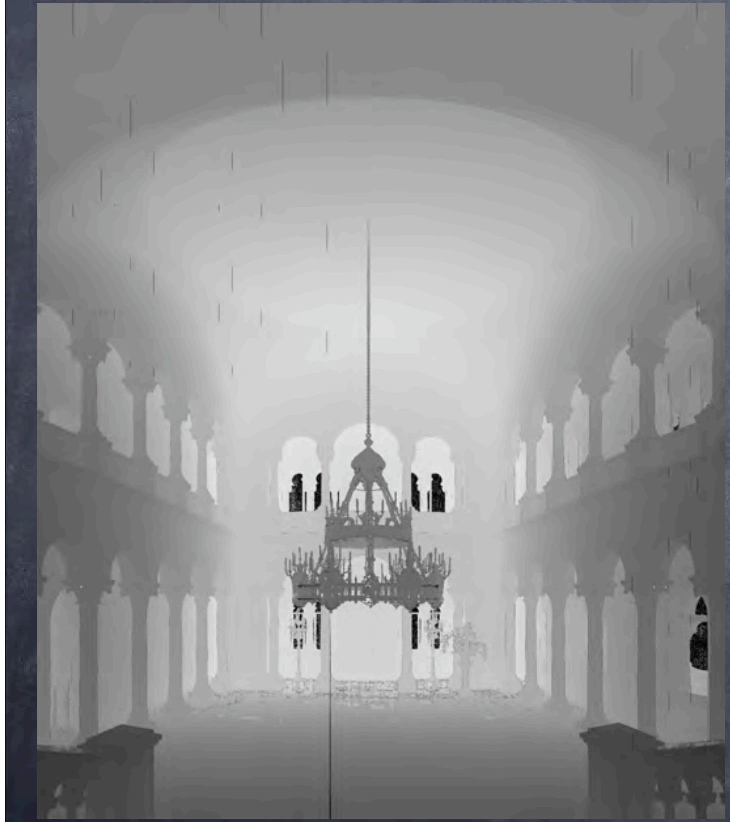
[C. Sparchholz, K. Scheibe et al., 2005]

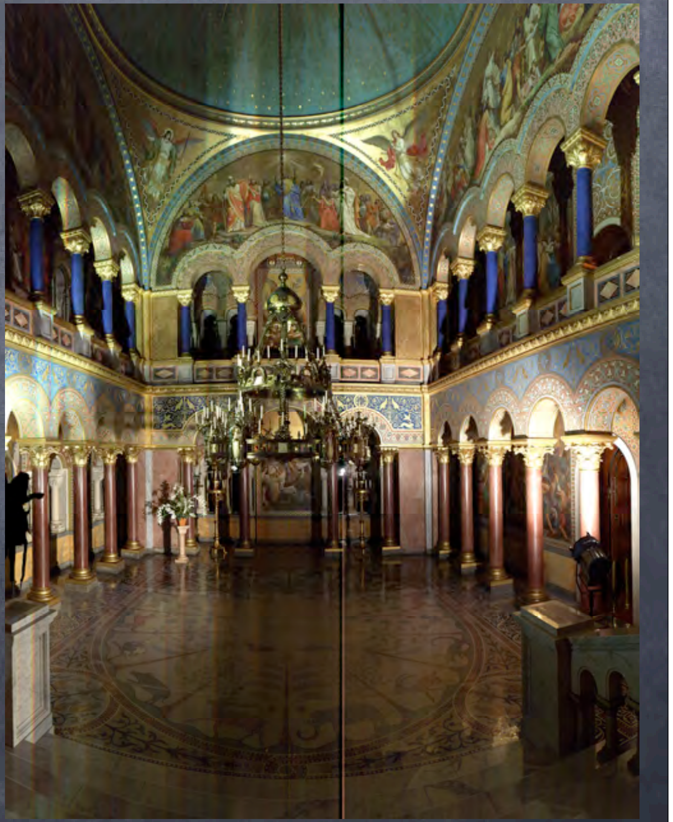


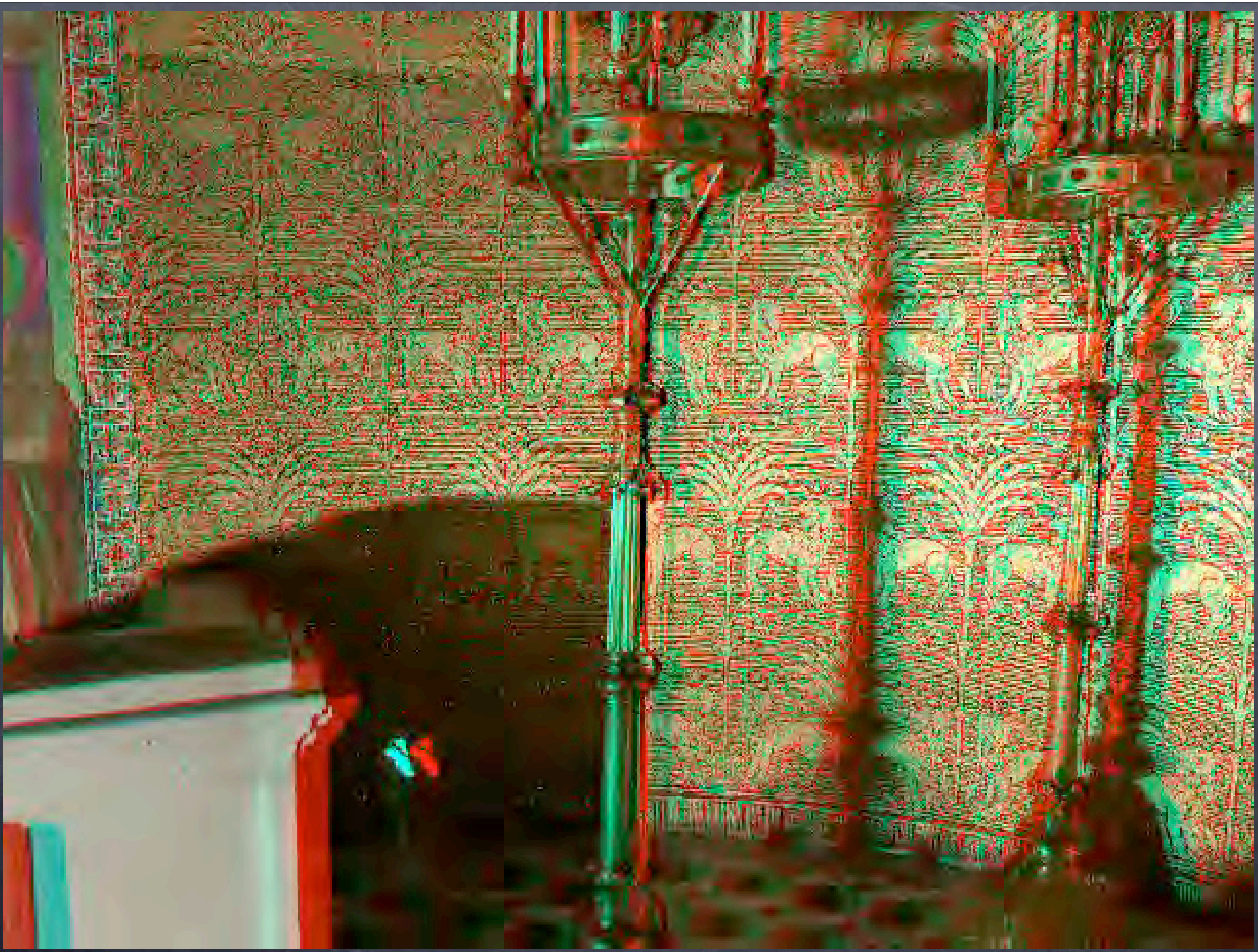
(6) Textured Surfaces

Spatial density of range data less than spatial density of camera data:
texture triangles by camera data









Low-resolution anaglyphic visualization (Neuschwanstein)

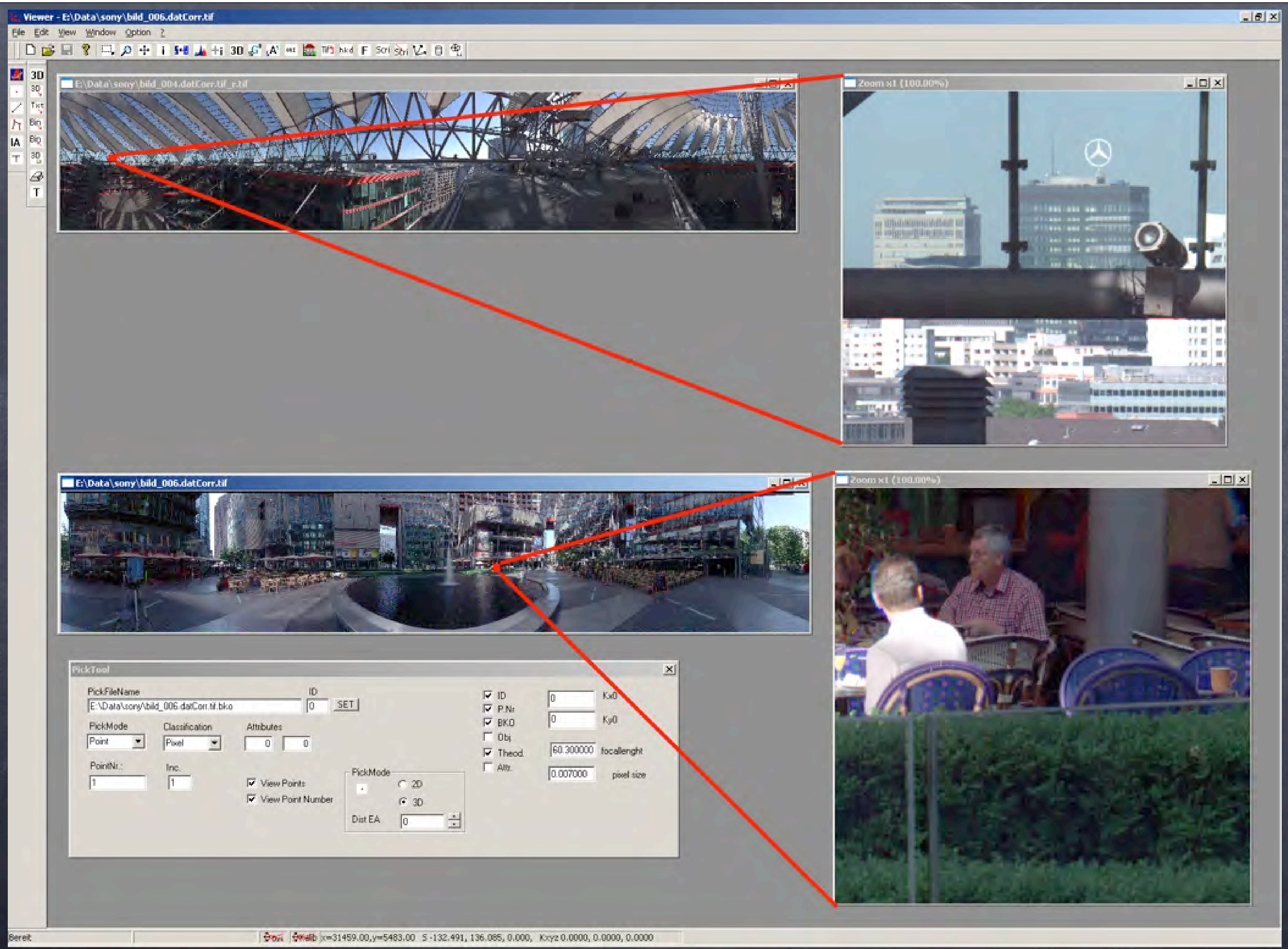
Separated surface parts with textures

[C. Sparchholz, K. Scheibe
et al., 2005]

(7) Conclusions

Described projects go to the limits of available computer technology (memory, speed)

Open problems: Reduction of influence of lighting effects, elimination of shadows, filtering of range data, visualization of high-resolution images ... rendered surfaces, and many more



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PickMode: Point

Classification: Pixel

Attributes: 0 0

PointNr.: 1

Inc.: 1

☑ View Points

☑ View Point Number

PickMode: ○ 2D ● 3D

Dist EA: 0

☑ ID

☑ P.Nr

☑ BKO

☐ Obj.

☑ Theod.

☐ Attr.

Kx0: 0

Ky0: 0

focallenght: 60.300000

pixel size: 0.007000

Bereit

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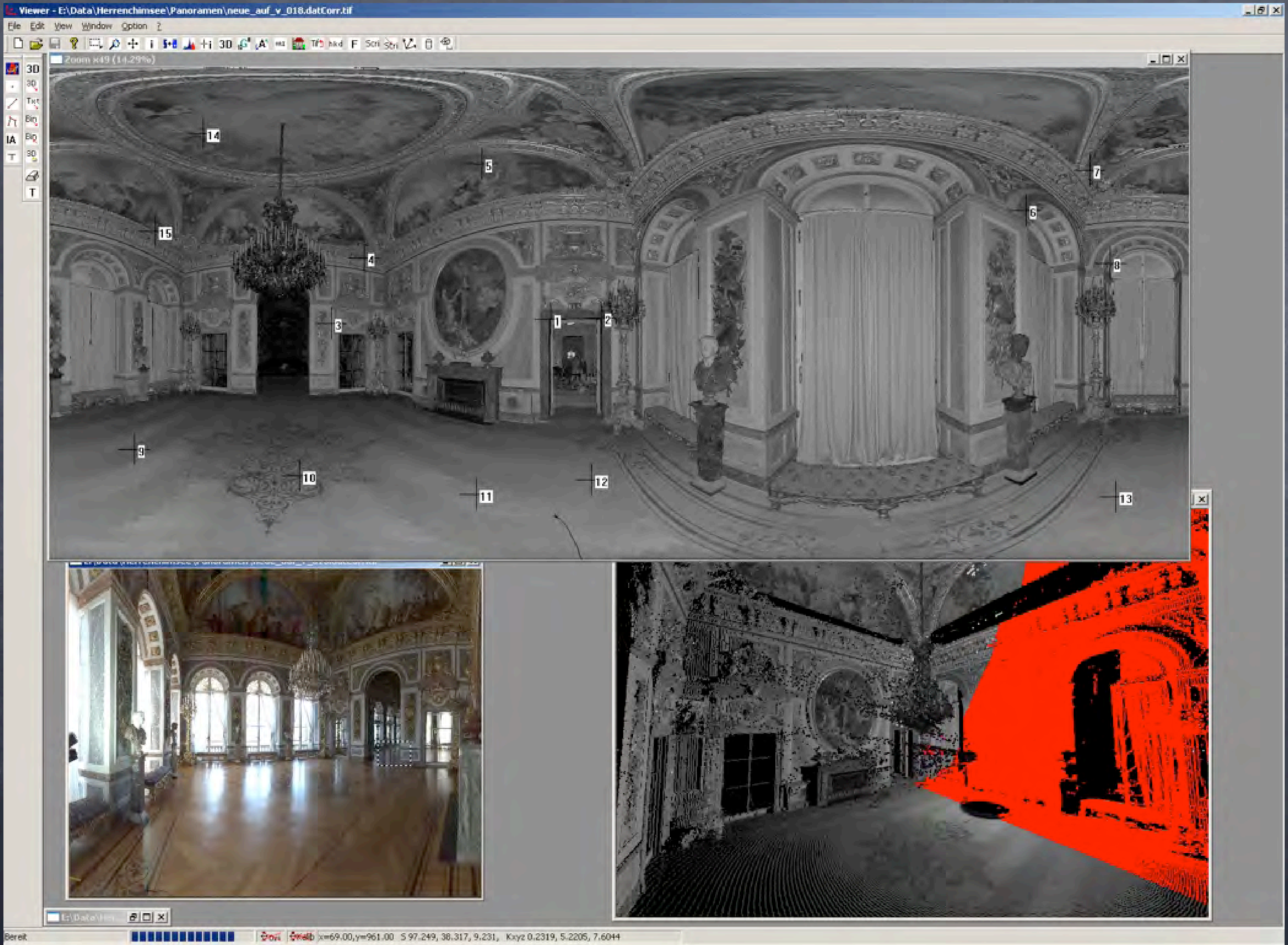
Data, but visualization problems (Sony Center)



Viewer - E:\Data\Herrenchimsee\Panoramen\neue_auf_v_018.datCorr.tif

Bereit

x=69.00,y=961.00 S 97.249, 38.317, 9.231, Kxyz 0.2319, 5.2205, 7.6044

Applied studies are crucial (Herrenchiemsee)

An animation (HRSC, DLR) illustrating further fusion of multiple sensor data

The End