

Stereo Imaging with Rotating Line Cameras

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THE GENERAL

STEREO IMAGING MODEL

Stereo image pair: captured image values on a pair of Jordan surfaces, potential positions of corresponding positions form **epipolar curves** which are Jordan curves.

Stereo image analysis: not identical with stereoscopic viewing, the existence of parameterized epipolar curves suffices to enable stereo image analysis.

A pair of images is **stereoscopic viewable** iff it possesses standard epipolar geometry.

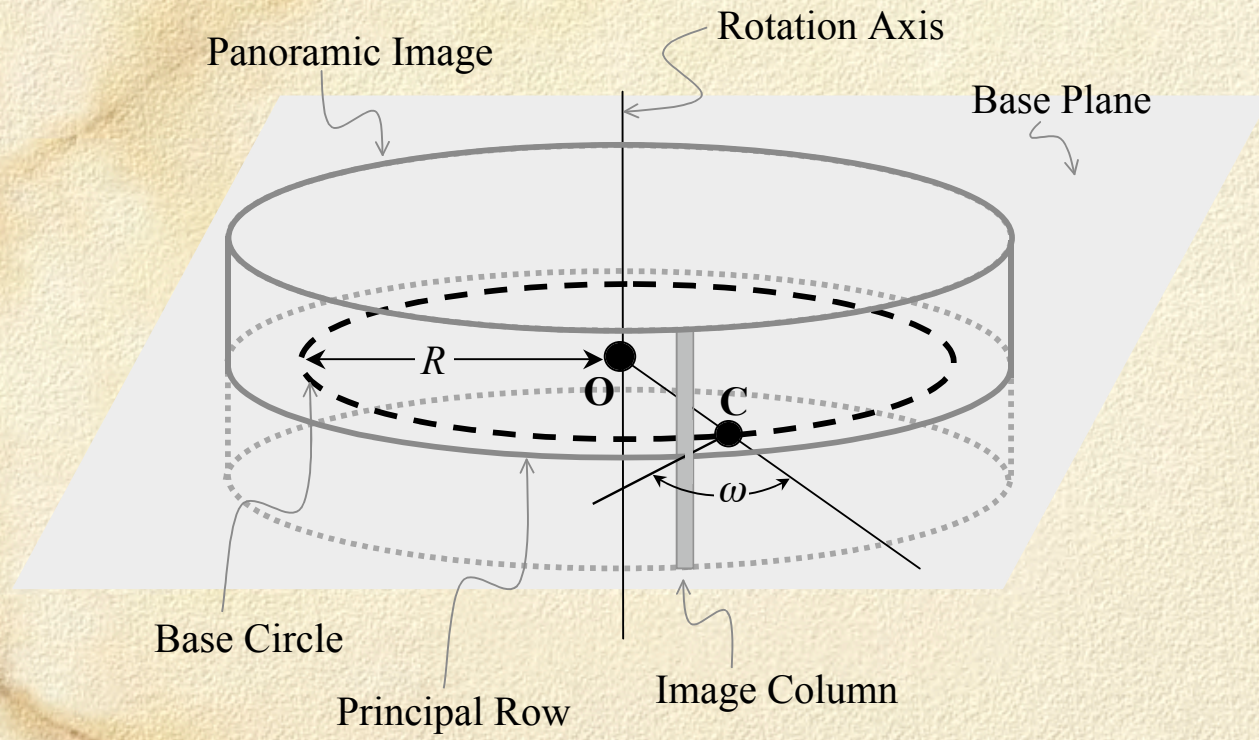
Contents of talk

Stereo image pairs captured by rotating line cameras
Which satisfy our epipolar **curve** constraint

How to evaluate the **quality** of such stereo pairs (stereo acuity,
density of samples in space etc.)?

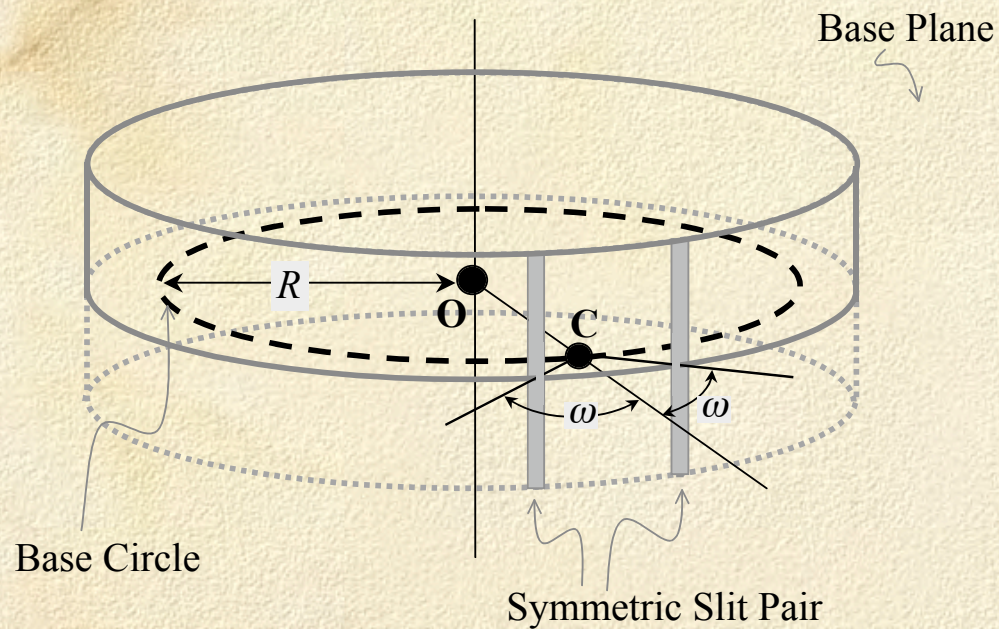
Analysis of **epipolar geometry** by parameterization of
epipolar curves.

rotating line cameras



single-line
cylindrical
panorama

MULTIPLE SENSOR LINES


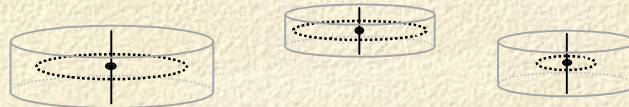
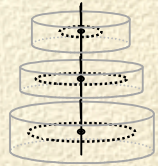
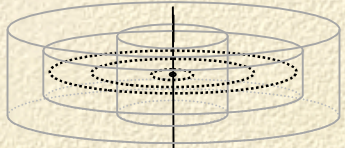
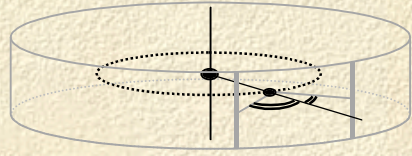


stereo
panoramas



polycentric
panoramas

CYLINDRICAL PANORAMIC PAIRS

Polycentric Panoramas	 The diagram shows three cylindrical panoramic units. The first and third units are upright with their axes of rotation at the center of their bases. The second unit is tilted at an angle, with its axis of rotation also at the center of its base. Each unit has a vertical axis and a horizontal axis of rotation, and a dotted line representing the panoramic arc.
Parallel-axis Panoramas (e.g. leveled panoramas)	 The diagram shows three cylindrical panoramic units. Each unit has its axis of rotation at the center of its base, but the axes are parallel to each other and not necessarily vertical. The units are shown at different orientations, illustrating how they can be leveled.
Co-axis Panoramas	 The diagram shows three cylindrical panoramic units stacked vertically. All three units share a single common vertical axis of rotation passing through the center of each unit's base.
Concentric Panoramas	 The diagram shows three cylindrical panoramic units of different diameters stacked vertically. They all share a single common vertical axis of rotation that passes through the center of each unit's base.
Symmetric Panoramas	 The diagram shows a single large cylindrical panoramic unit. It features a vertical axis of rotation and a horizontal axis of rotation. A small figure is shown sitting on a platform inside the cylinder, looking outwards, illustrating the symmetric panoramic view.

DEPTH CALCULATION

in a symmetric pair of panoramas

angular disparity $\theta = \frac{2\pi d}{W_p}$ with $0^\circ < \theta < 180^\circ$ and $0 < d < \frac{W_p}{2}$

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

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

CCD SINGLE-LINE CAMERAS

EyeScan M2 Metric 2000

10,200 pixels in one line

360 degree rotation >>>

3.5 Giga Byte

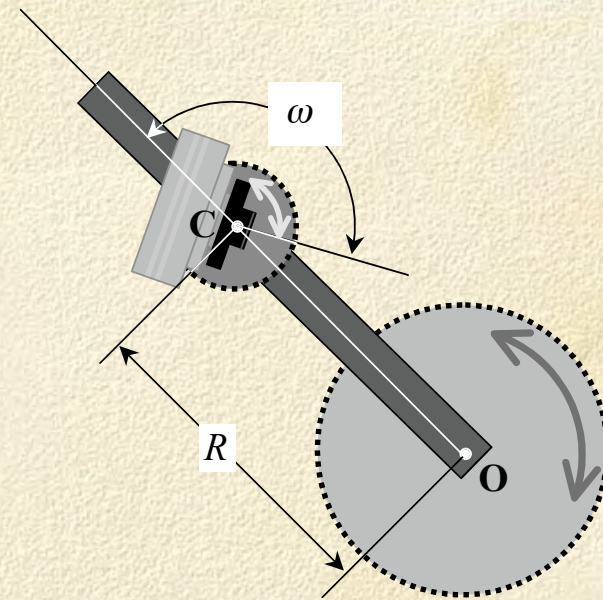


co-axis panoramas

DLR at Auckland 2001



symmetric and concentric panoramas



Experiments with EyeScan
at Auckland

2002

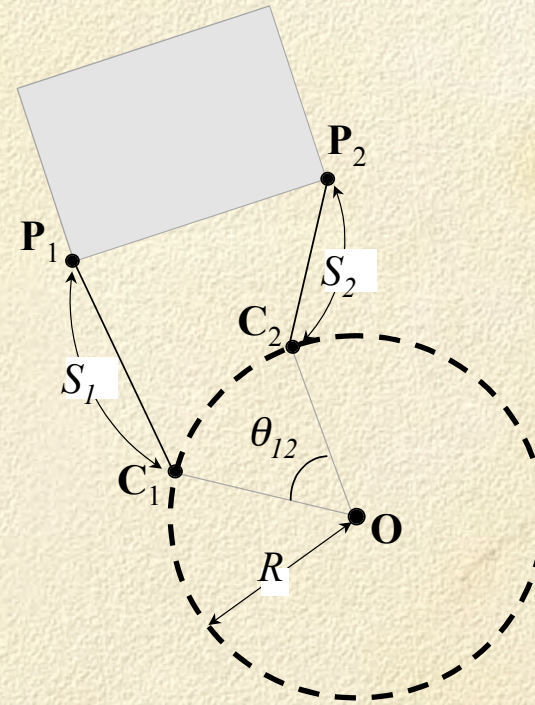
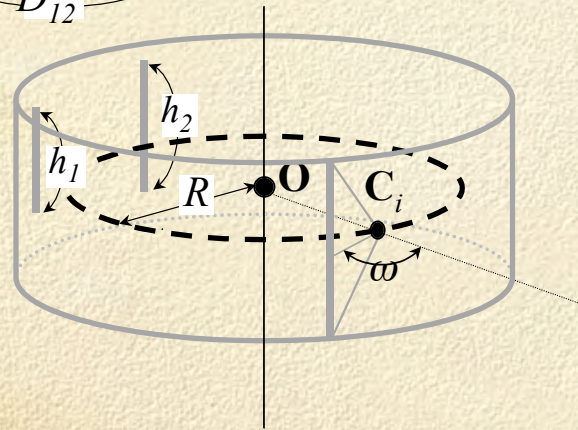
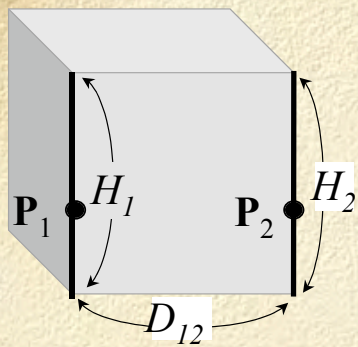
CAMERA CALIBRATION

- Parameters: f , v_c (principal row), R , and ω
- On-site methods: point based, image correspondence, **new:**

Two-step approach: 1st (f , v_c); 2nd (R , ω)

Two parallel-line based approaches:
parallelism or orthogonality

≥ 3 PARALLEL LINE SEGMENTS

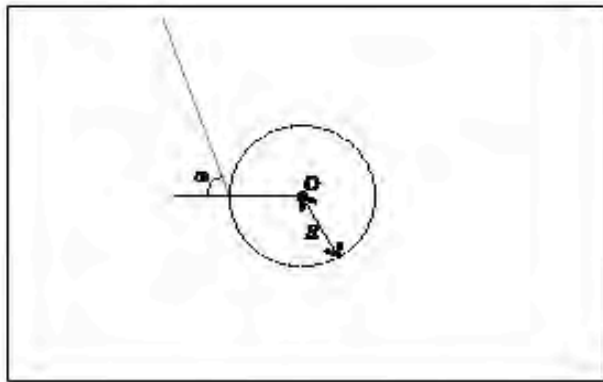


stereo samples

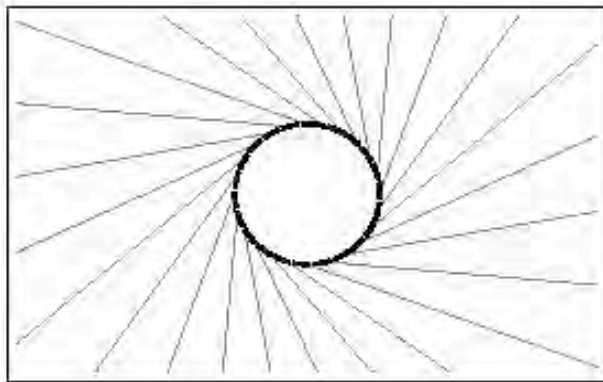
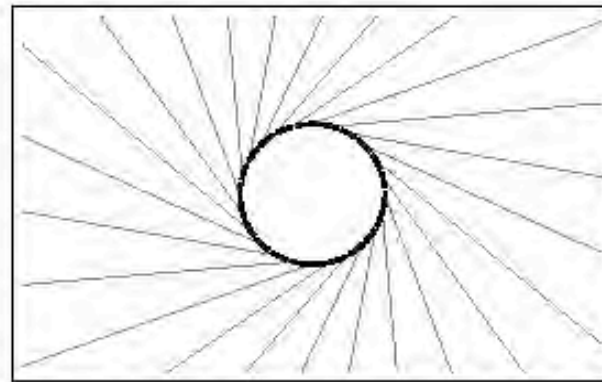
SPATIAL SAMPLING

How is the 3D space sampled by a pair of stereo panoramas?

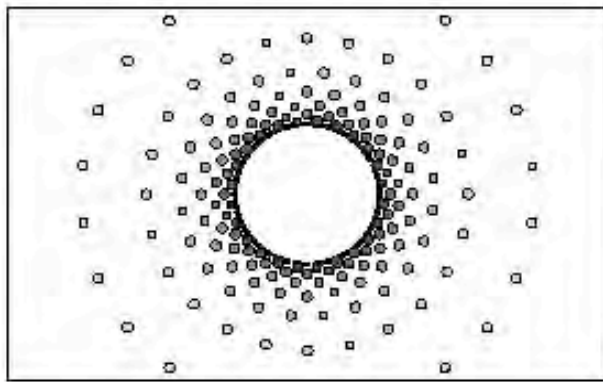
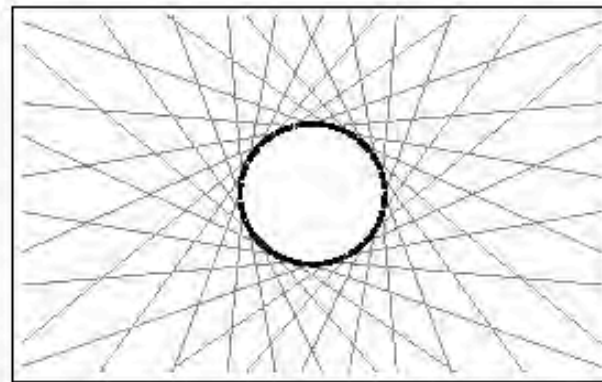
- Sampling resolution
- Sampling distribution
- Sample distances



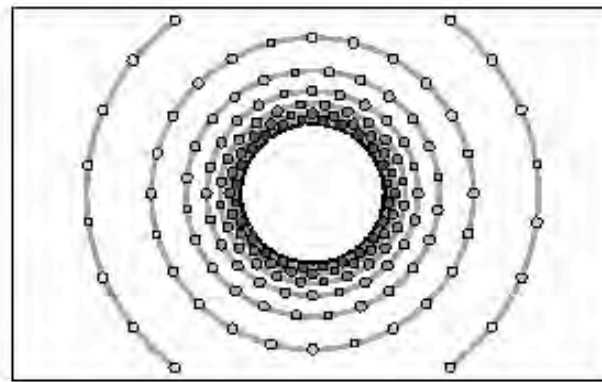
(A)

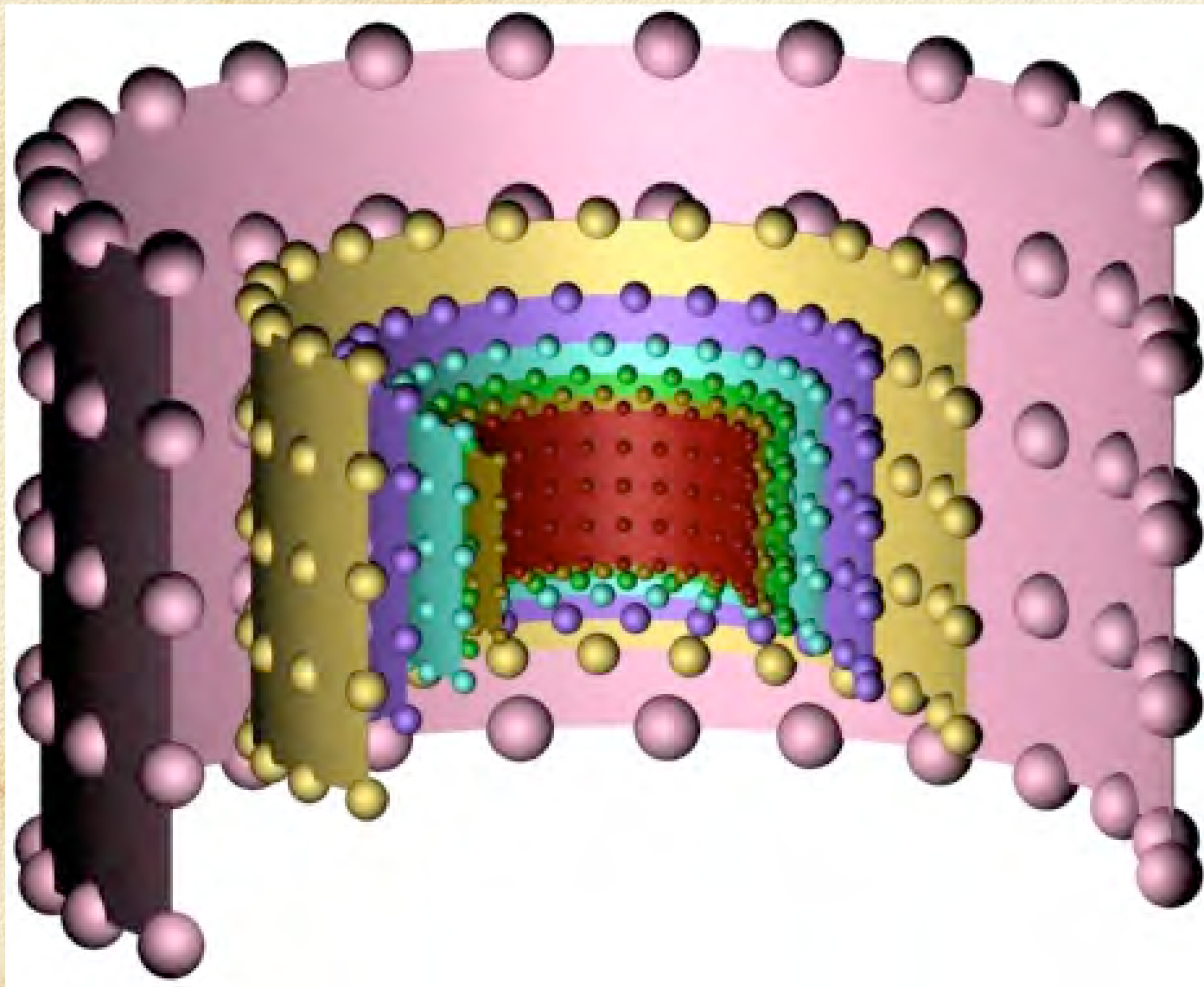


(C)



(E)





TOTAL NUMBER OF SAMPLES

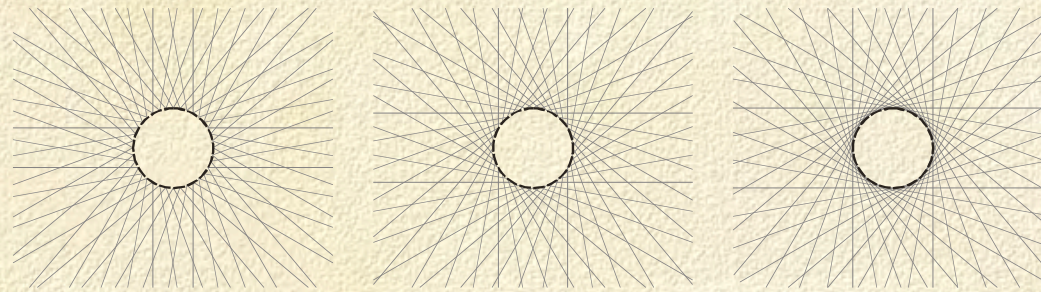
- The total number of spatial samples of a symmetric pair of stereo panoramas is equal to

$$(2W_p - 1) \times H_p \times \left\lfloor \frac{\omega W_p}{\pi} \right\rfloor$$

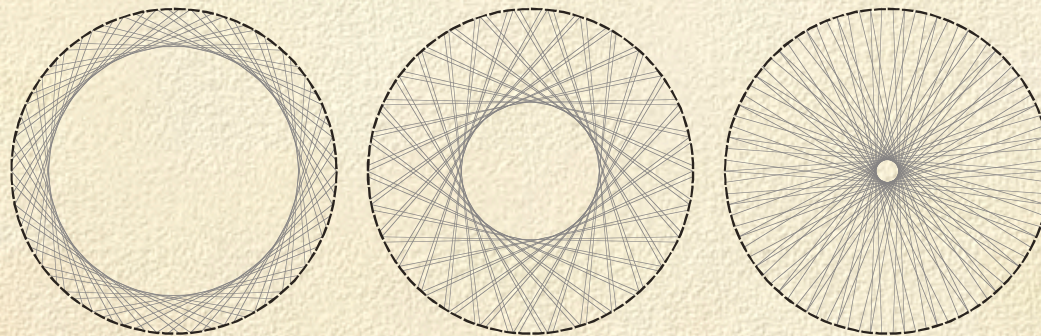
where W and H are image width and height in pixels, and the value of ω is between 0° to 180° exclusively.

- R has no impact onto the total number of spatial samples.
 - The total number of spatial samples increases as ω increases.
-

OUTWARD AND INWARD

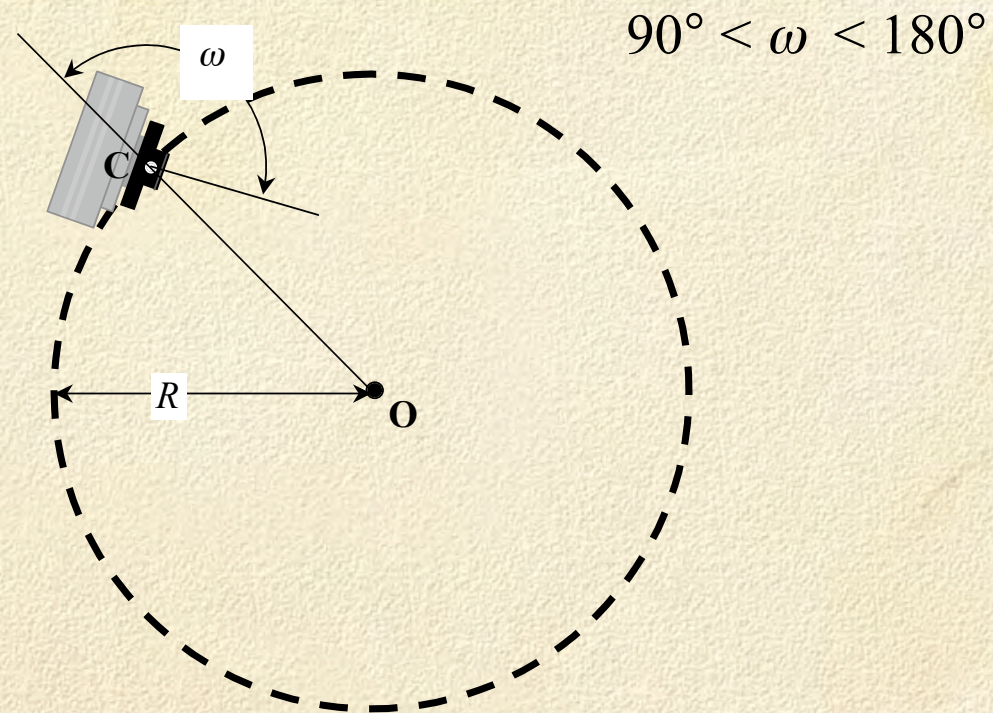


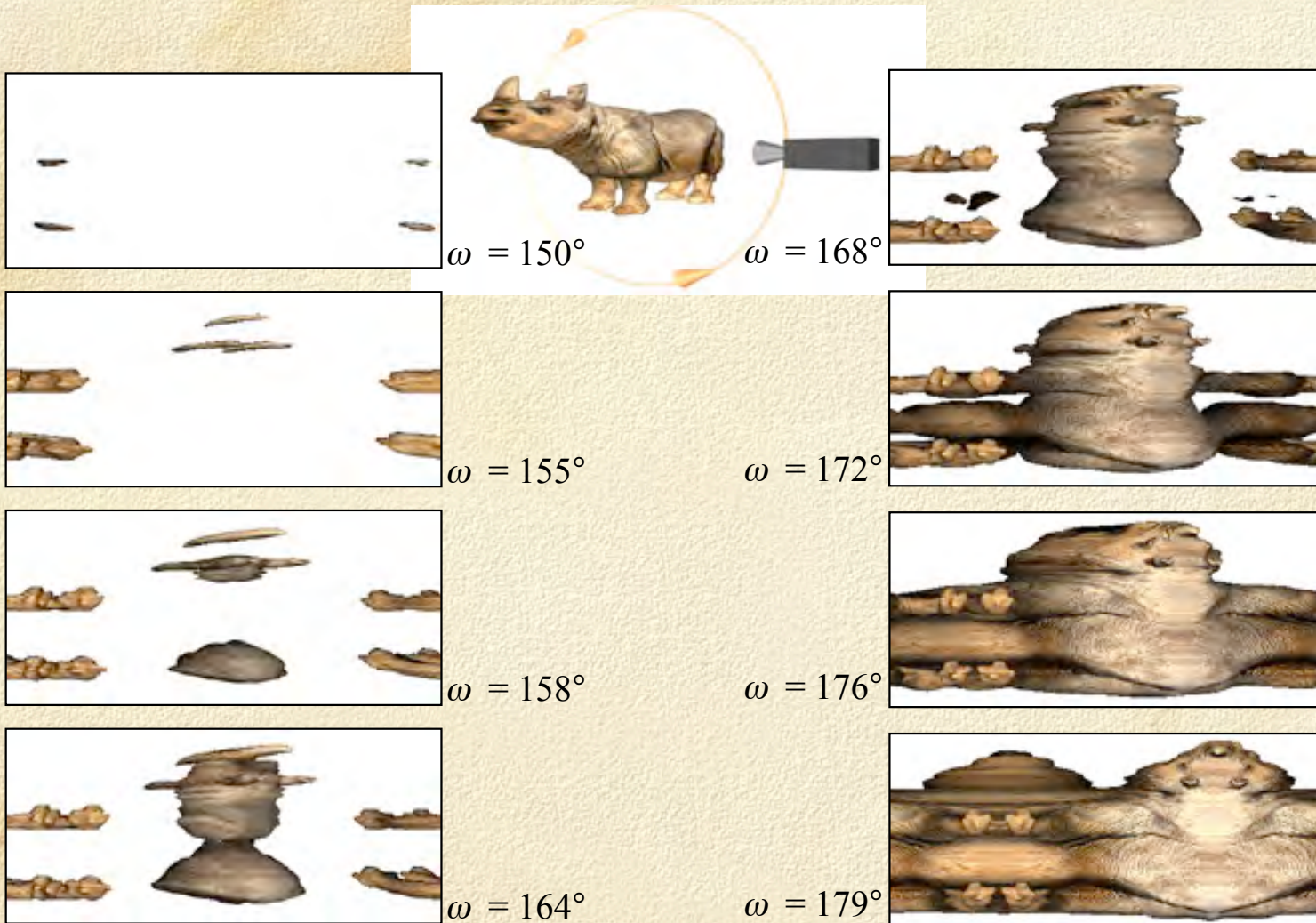
$\omega =$ 30° 60° 90°



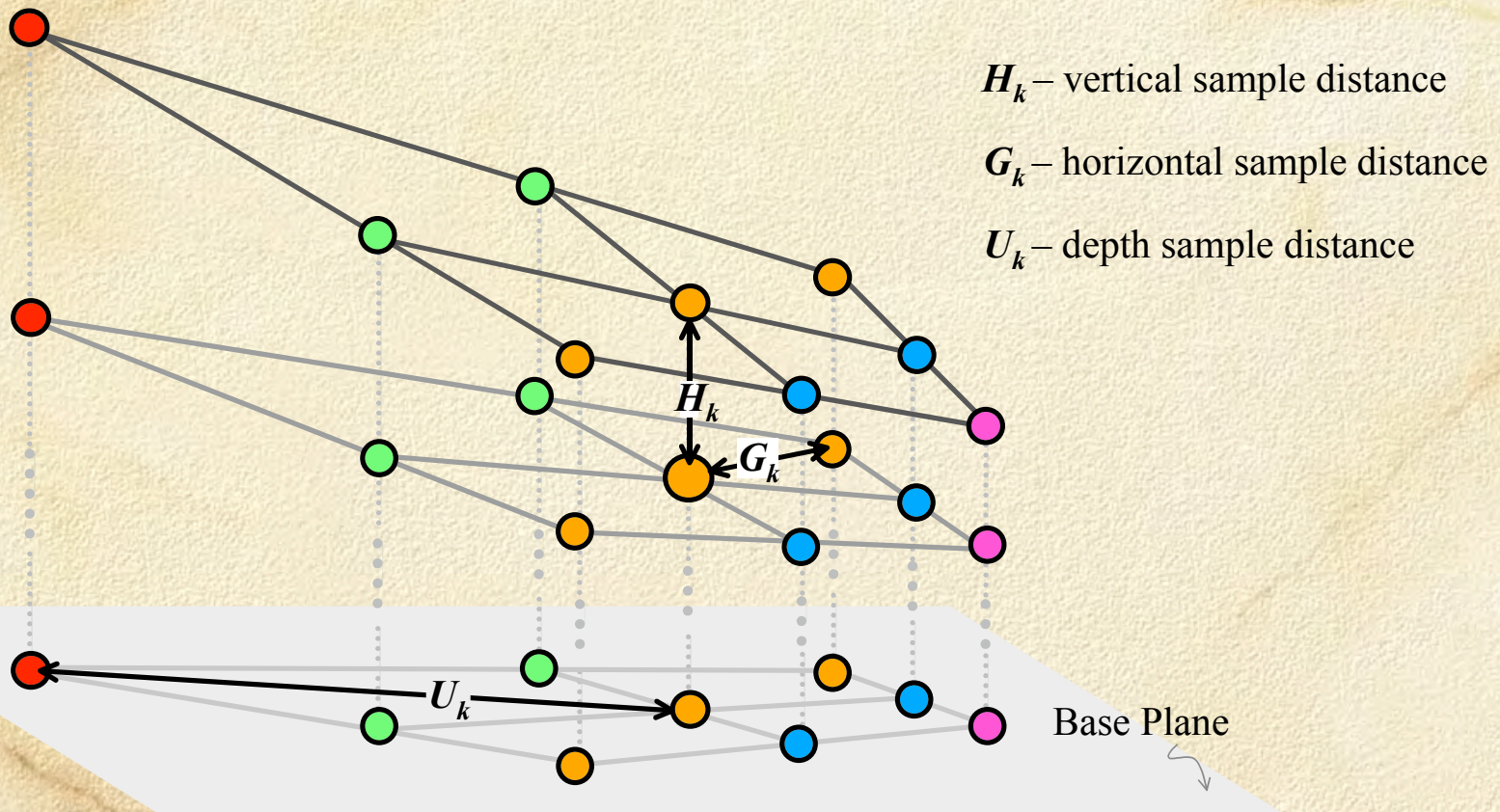
$\omega =$ 130° 155° 175°

INWARD CASE

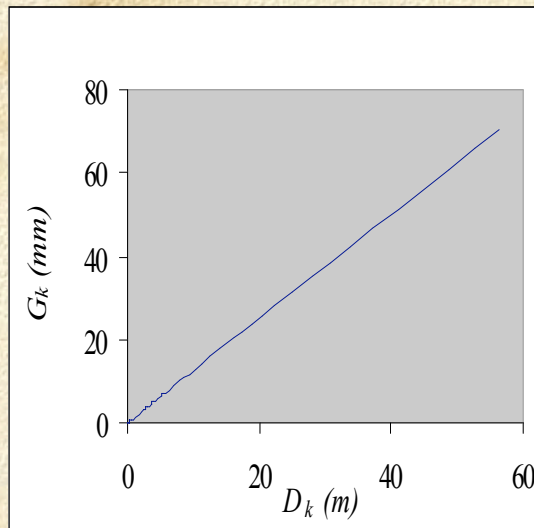




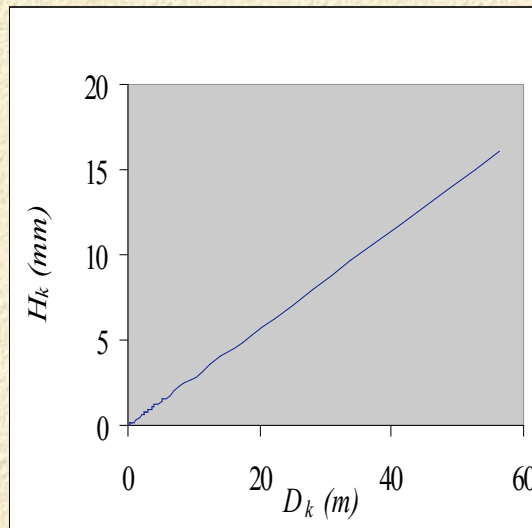
NEAREST SAMPLE DISTANCES



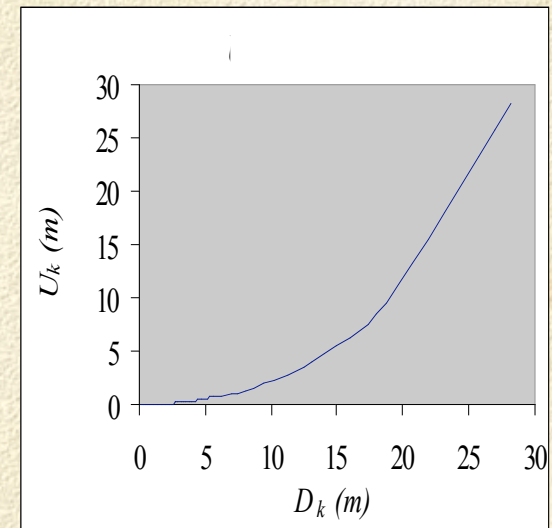
SAMPLE DISTANCES VS. DEPTH



Horizontal sample distance
vs.
Depth



Vertical sample distance
vs.
Depth

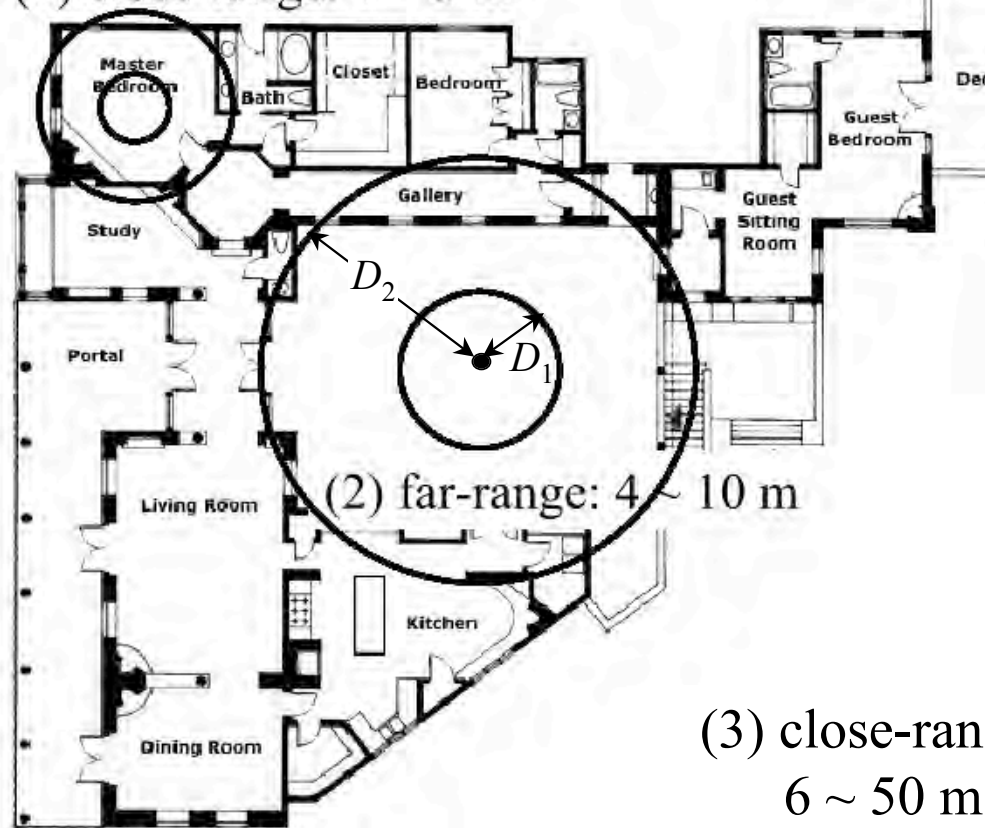


Depth sample distance
vs.
Depth

scene model

SCENE RANGE OF INTEREST

(1) close-range: 1 ~ 3 m

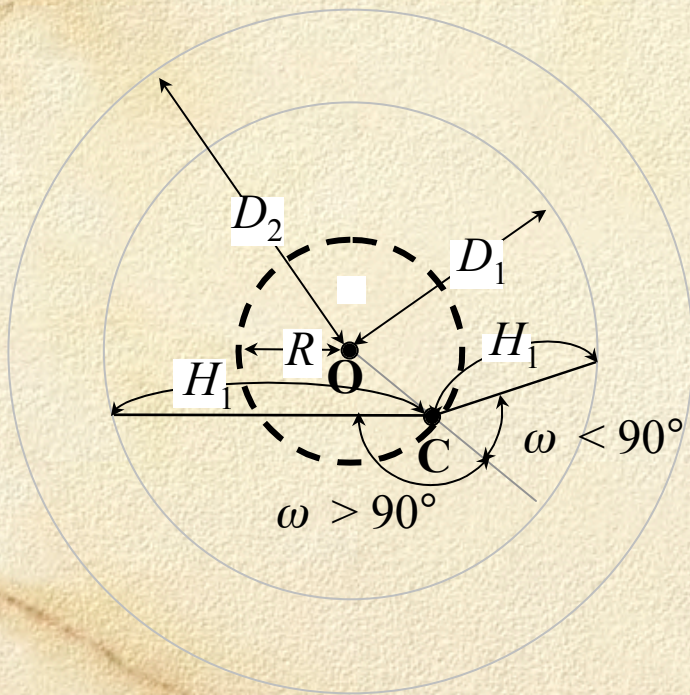


Albert Park, Auckland

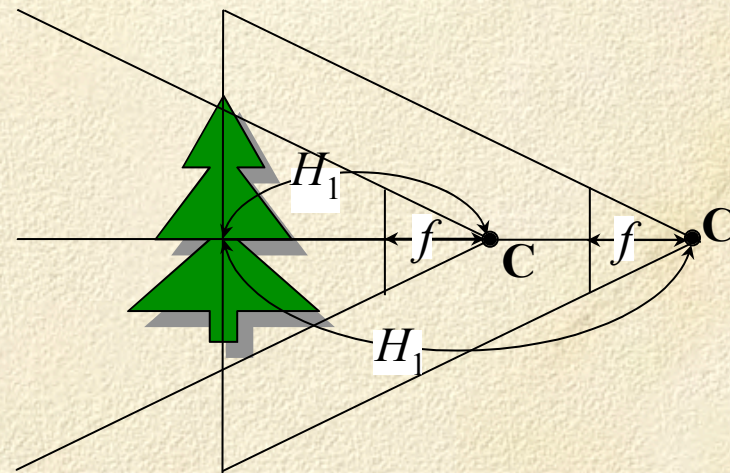


(3) close-range outdoor:
6 ~ 50 m

VERTICAL VIEW COMPOSITION

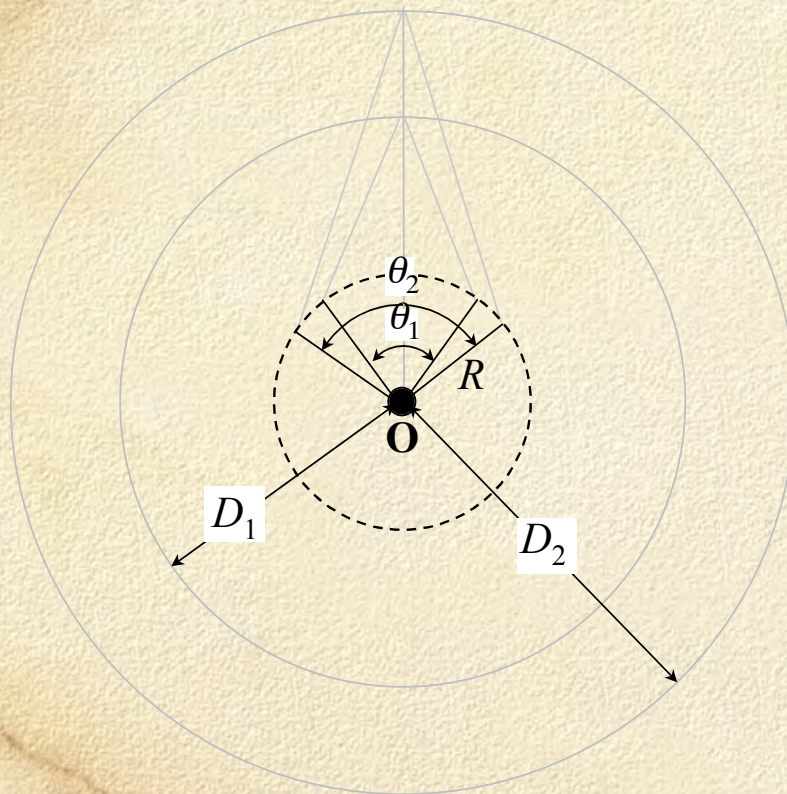


Side View



viewer model

STEREO ACUITY



= the cardinality of potential disparities

= the number of depth levels in the defined scene range, given by

$$\theta_w = \theta_2 - \theta_1$$

and the width W of the panoramic image

QUALITY CONTROL FOR STEREO PANORAMAS

- Quality criteria: **stereo acuity**, **scene composition** and avoid **dipodia** (stereo acuity larger than upper disparity limit of human vision)
 - Procedures should ensure:
efficiency, accessibility, portability, and affordability
 - **Aim**: on-site determination of values of R and ω
-

AVOIDANCE OF DIPODIA

Model the indented viewing conditions.

Example: 17" screen, 1024 x 768 pixels
viewing at 40 cm
frontal position

upper disparity limit: about $d = 70$ pixels

$0.03 \times$ viewing distance

UNIQUE SOLUTION FOR *optimal* CAMERA PARAMETERS

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

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

EXAMPLES

	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

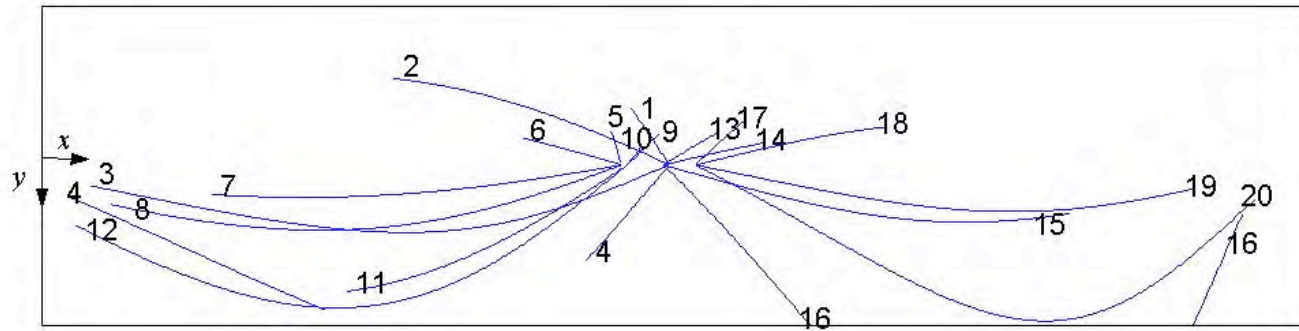
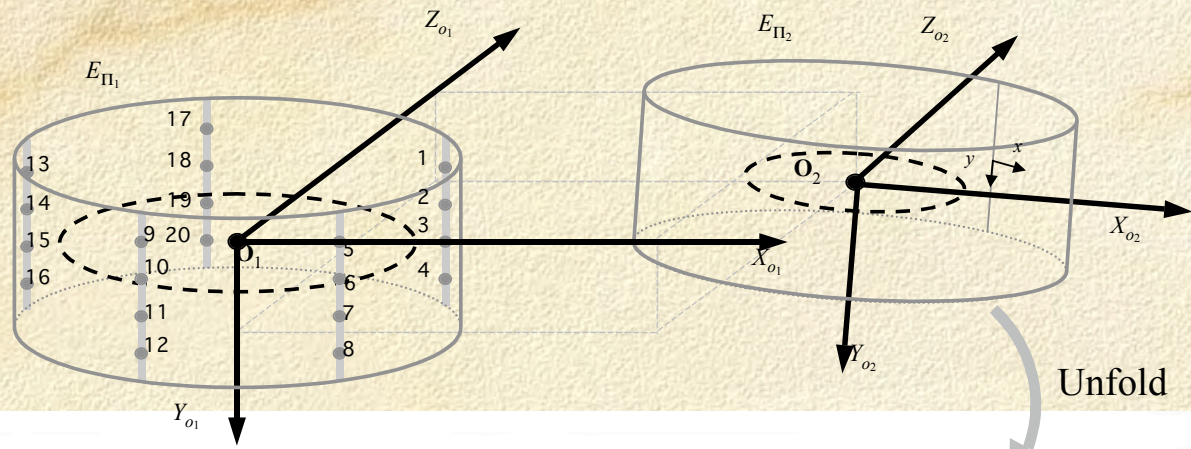
in meter

also calculated

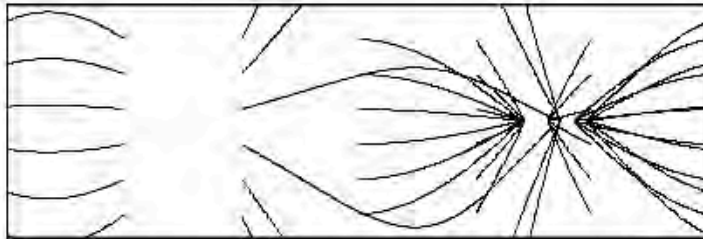
70 pixel (see above)



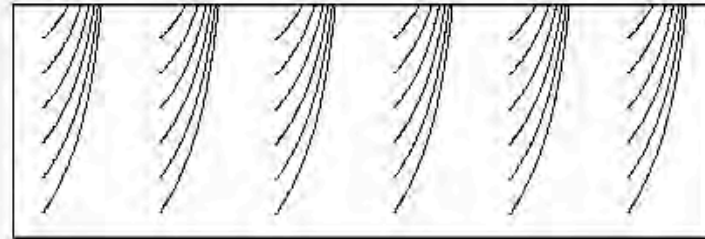
epipolar curves



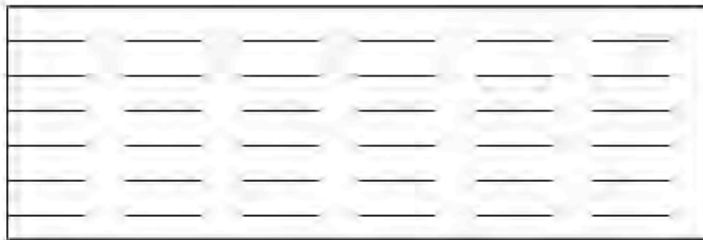
EPIPOLAR CURVE SKETCHES



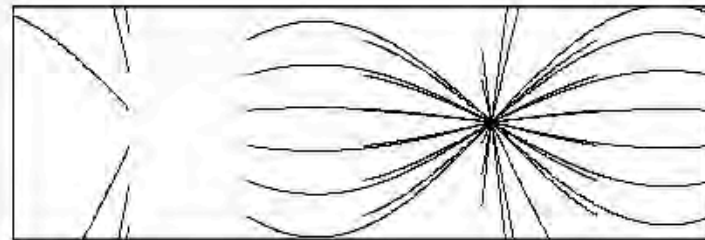
Levelled



Co-axis



Symmetric (stereo)



Single-center

LEVELLED PANORAMAS

same height and parallel rotation axes

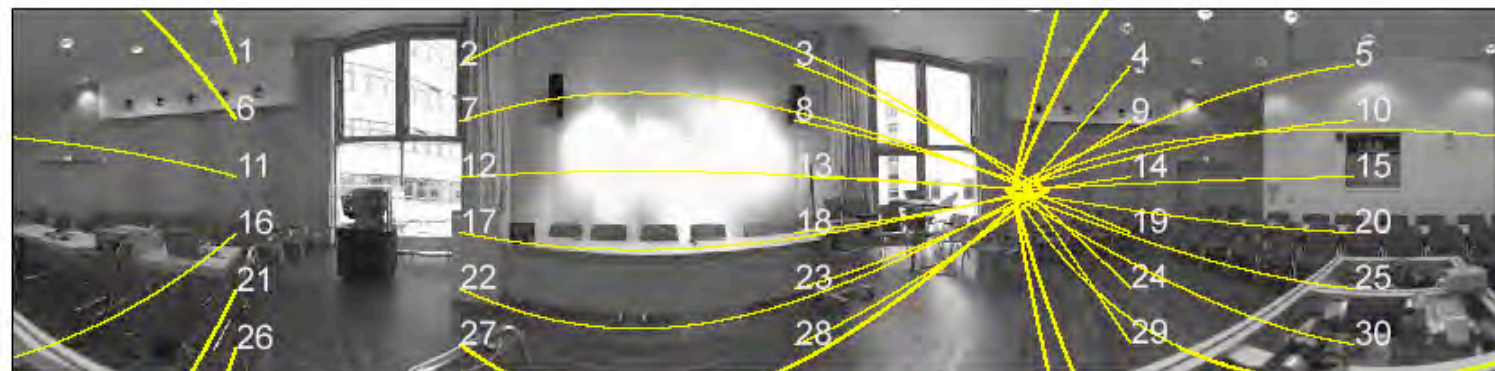
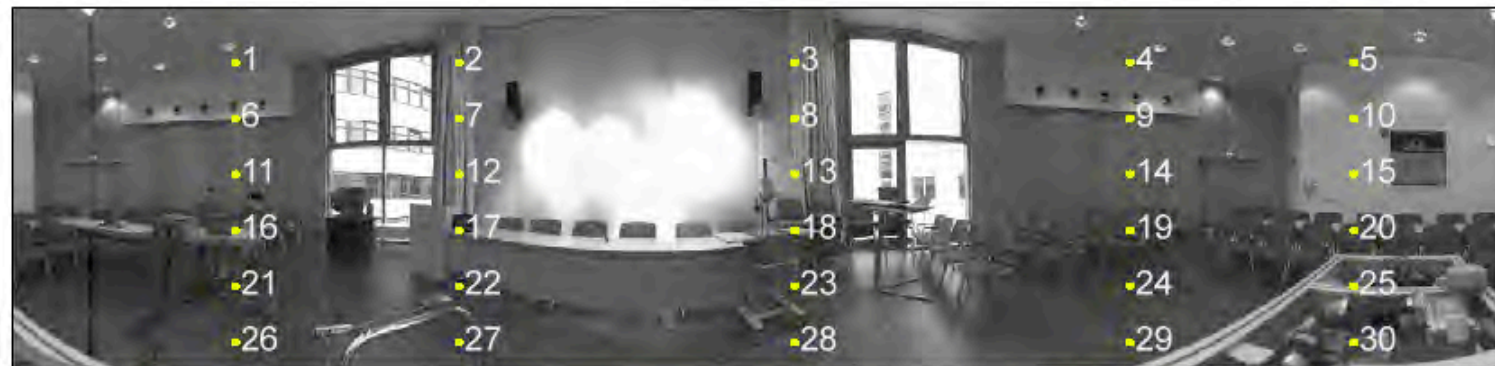
different R 's

different ω 's

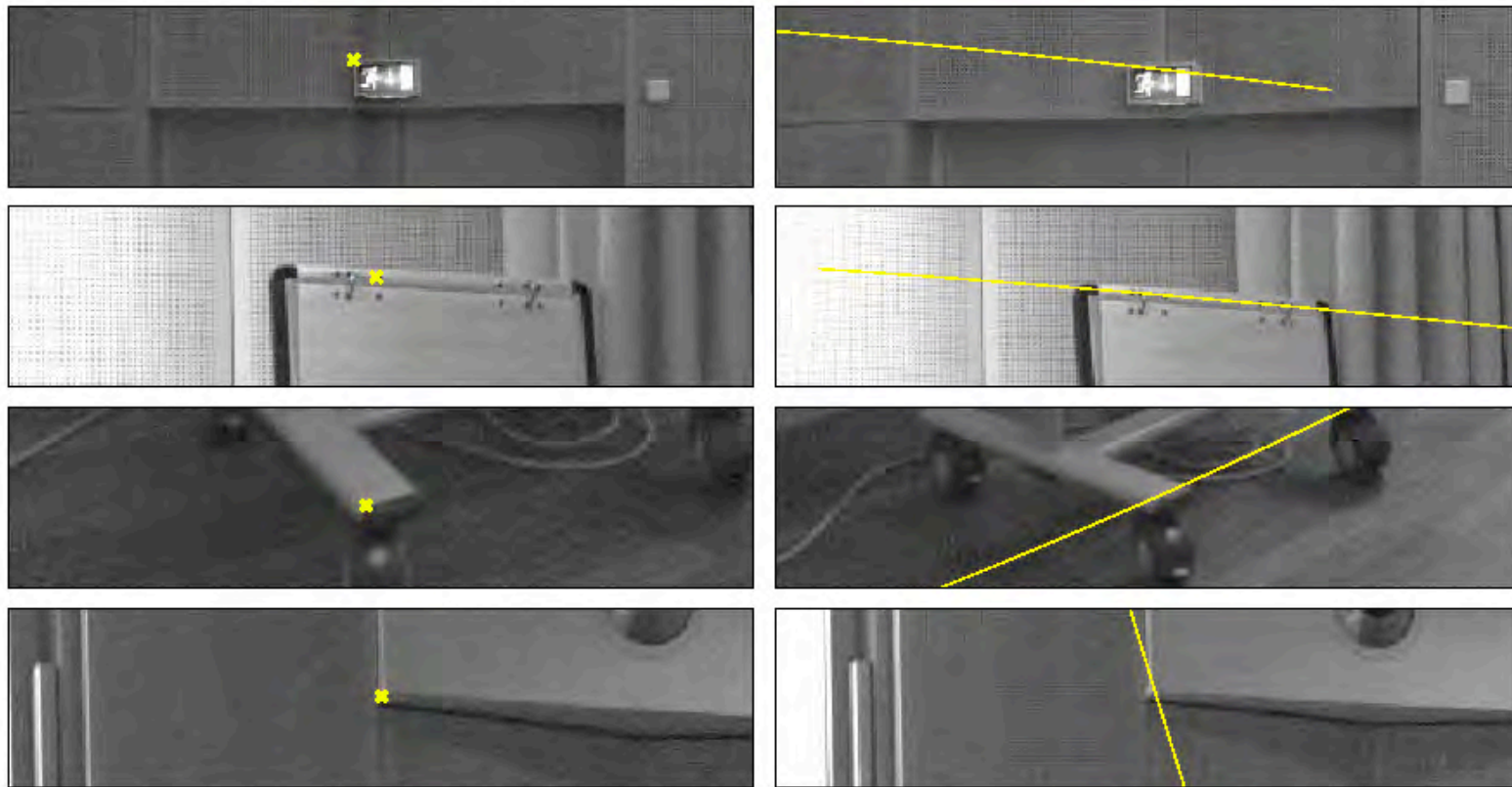
different f 's

$$y_d = y \cdot \left(\frac{f_d}{f} \right) \cdot \left(\frac{R_d \sin \omega_d - R \sin \left(\frac{2\pi x_d}{W_d} - \frac{2\pi x}{W} + \omega_d \right) - t_x \cos \left(\frac{2\pi x_d}{W_d} + \omega_d \right) + t_z \sin \left(\frac{2\pi x_d}{W_d} + \omega_d \right)}{-R \sin \omega - R_d \sin \left(\frac{2\pi x_d}{W_d} - \frac{2\pi x}{W} - \omega \right) - t_x \cos \left(\frac{2\pi x}{W} + \omega \right) + t_z \sin \left(\frac{2\pi x}{W} + \omega \right)} \right)$$

EXAMPLE: LEVELLED PANORAMAS



CLOSE UPS



conclusions

RESULTS

- **General model:** unifies existing geometric models of panoramic cameras into a single and more general representation.
 - An **on-site panoramic camera calibration method** using parallelism or orthogonality constraints.
 - The off-axis distance **R** has **no impact** onto the total number of samples.
 - The **solution** of the camera parameter problem (stereo acuity and scene composition) is **unique**.
 - **General epipolar curve equations** for arbitrary pairs of polycentric panoramas.
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