Stereo Imaging with Rotating Line Cameras

Reinhard Klette
Auckland, New Zealand

Fay Huang and Shou Kang Wei
Taipei, Taiwan

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.

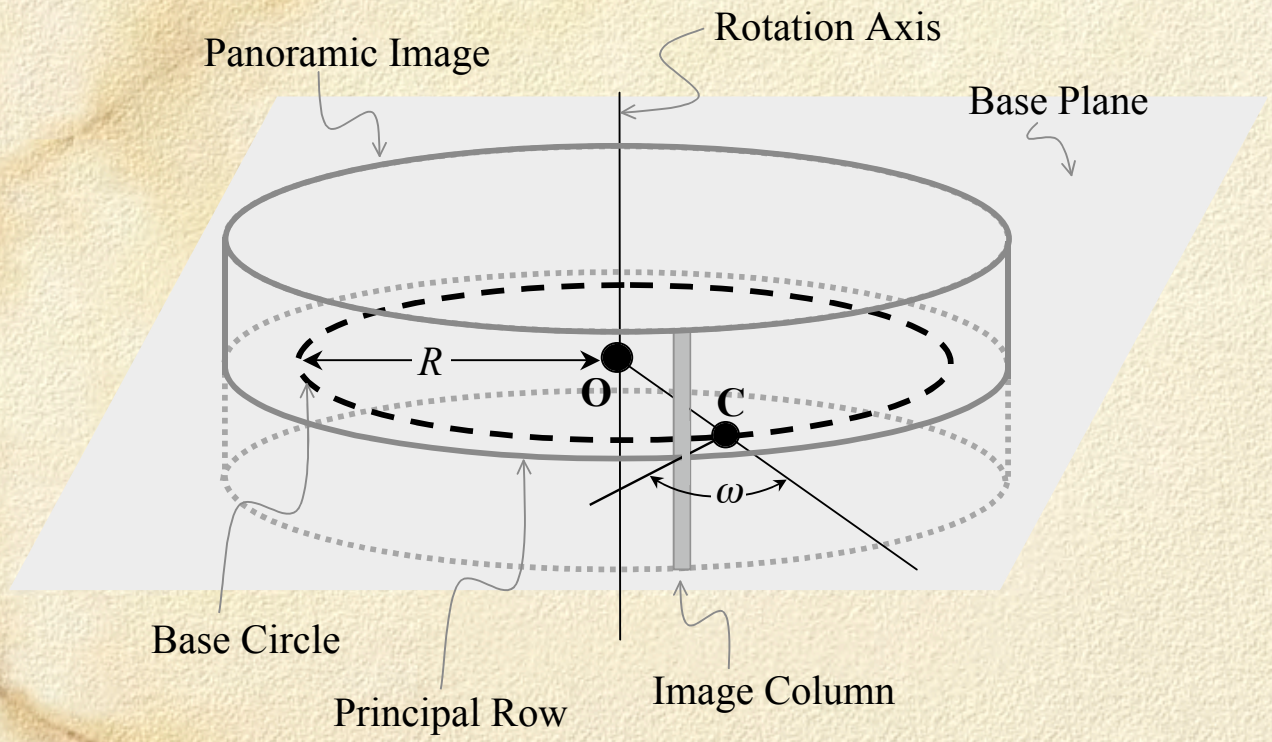
Contents of talk

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.)?

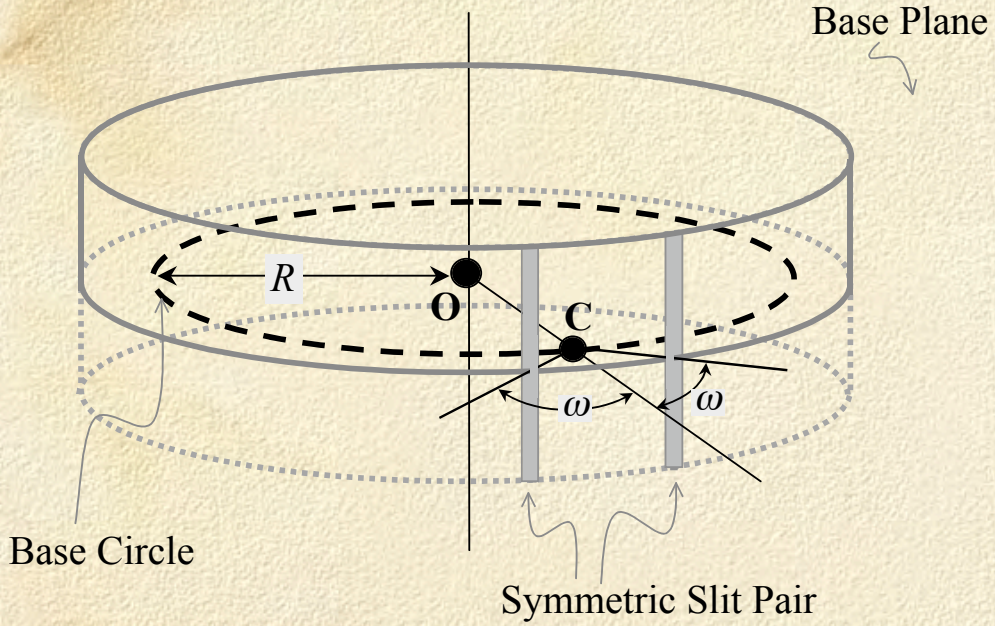
Analysis of **epipolar geometry** by parameterization of epipolar curves.

rotating line cameras



single-line cylindrical panorama

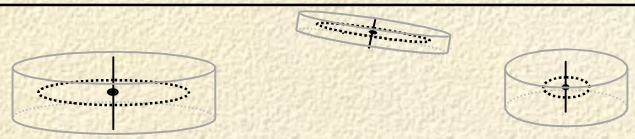
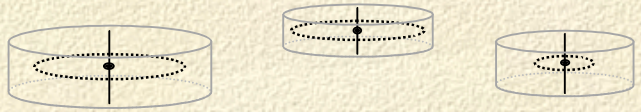
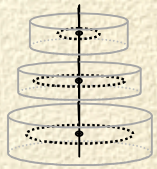
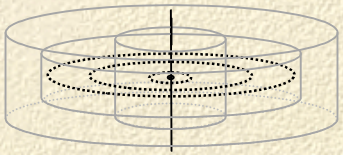
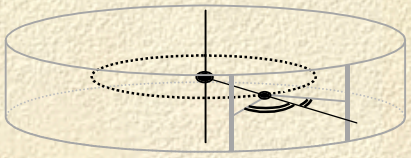
MULTIPLE SENSOR LINES



stereo panoramas

polycentric panoramas

CYLINDRICAL PANORAMIC PAIRS

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

DEPTH CALCULATION

in a symmetric pair of panoramas

angular disparity $\theta = \frac{2\pi d}{W_P}$ with $0° < \theta < 180°$ and $0 < d < \frac{W_P}{2}$

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

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

CCD SINGLE-LINE CAMERAS

EyeScan M2 Metric 2000

10,200 pixels in one line

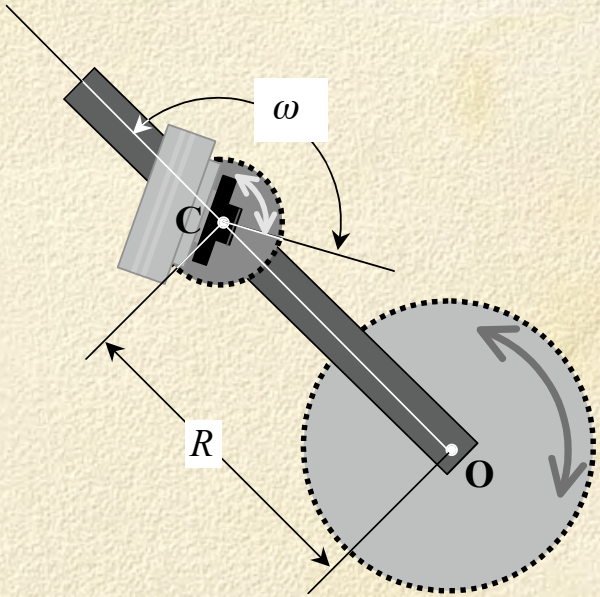
360 degree rotation >>>

3.5 Giga Byte

DLR at Auckland 2001

co-axis panoramas

symmetric and concentric panoramas



Experiments with EyeScan
at Auckland

2002

CAMERA CALIBRATION

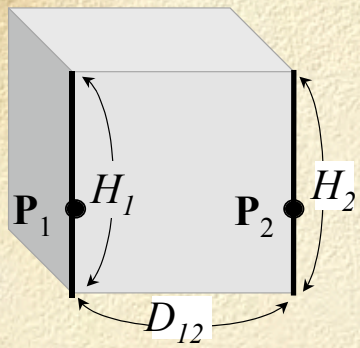
- Parameters: f, v_c (principal row), R, and ω

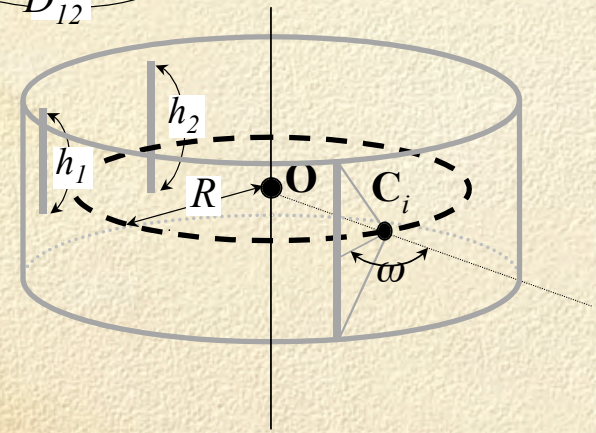
- On-site methods: point based, image correspondence, **new**:

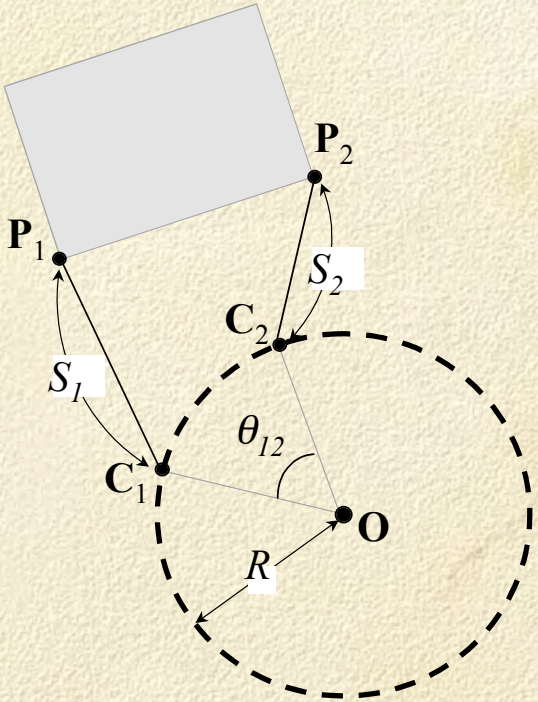
  Two-step approach: 1st (f, v_c); 2nd (R, ω)

  Two parallel-line based approaches:
  parallelism or orthogonality

≥3 Parallel Line Segments





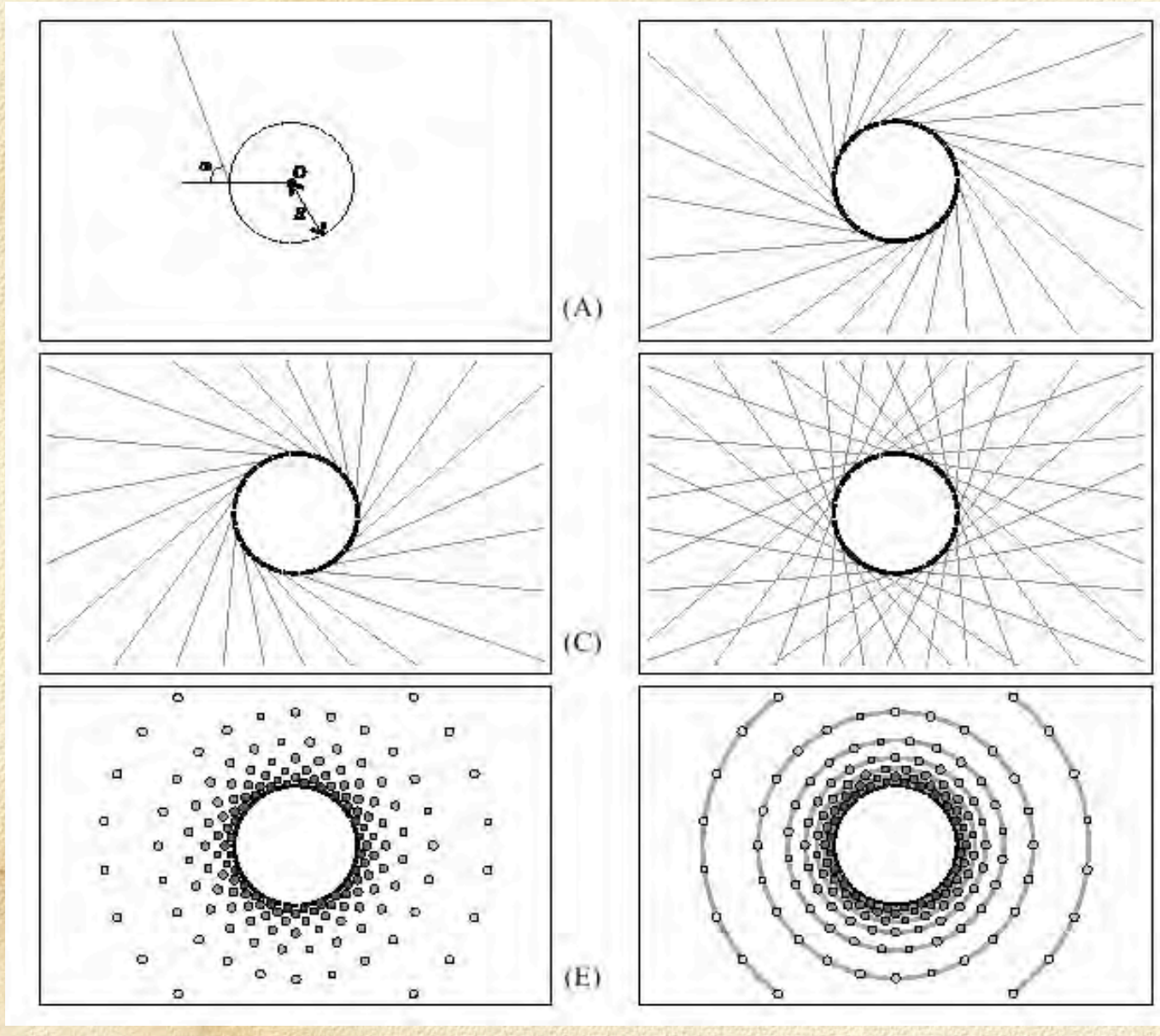


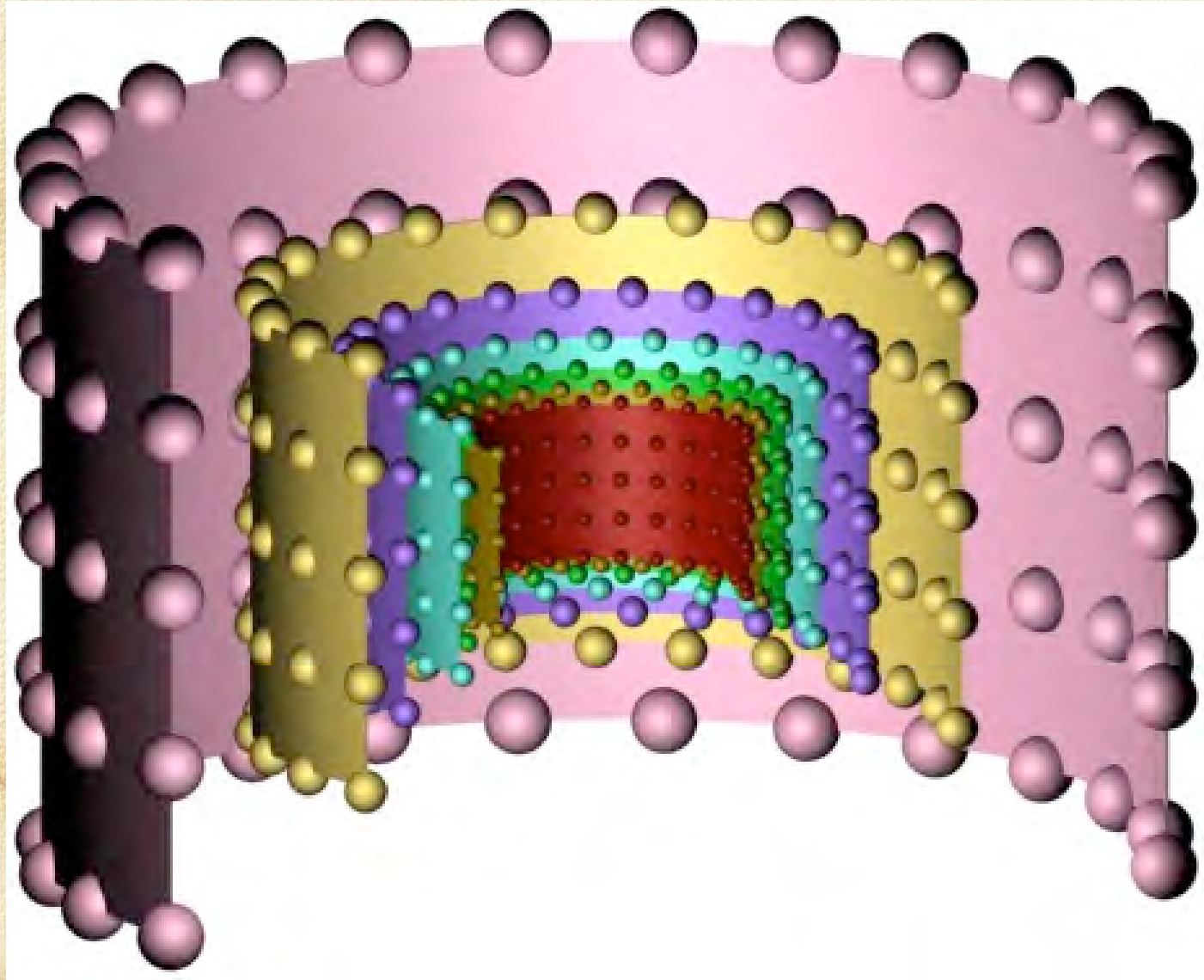
stereo samples

SPATIAL SAMPLING

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

- Sampling resolution
- Sampling distribution
- Sample distances


a
O
R
(A)
(C)
(E)



TOTAL NUMBER OF SAMPLES

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

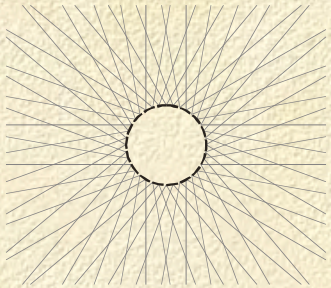
$$(2W_p - 1) \times H_p \times \left\lfloor \frac{\omega W_p}{\pi} \right\rfloor$$

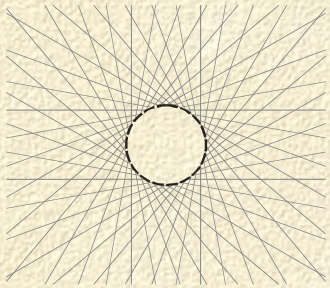
where *W* and *H* are image width and height in pixels, and the value of ω is between 0° to 180° exclusively.

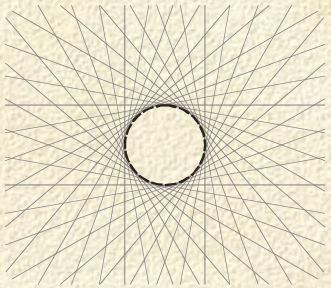
- *R* has no impact onto the total number of spatial samples.

- The total number of spatial samples increases as ω increases.

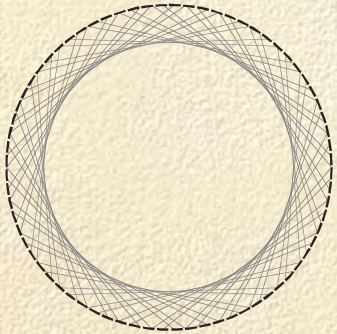
OUTWARD AND INWARD

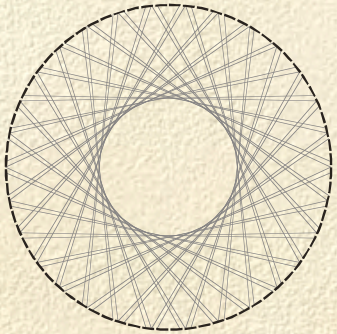


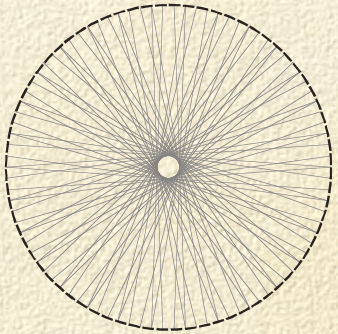




ω = 30° 60° 90°

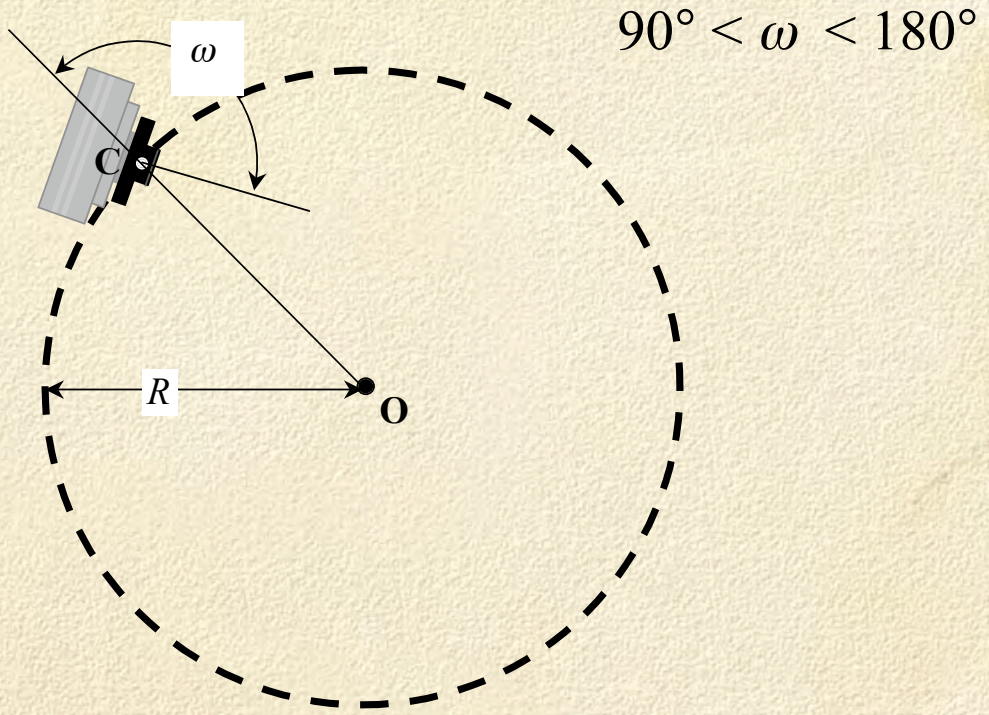


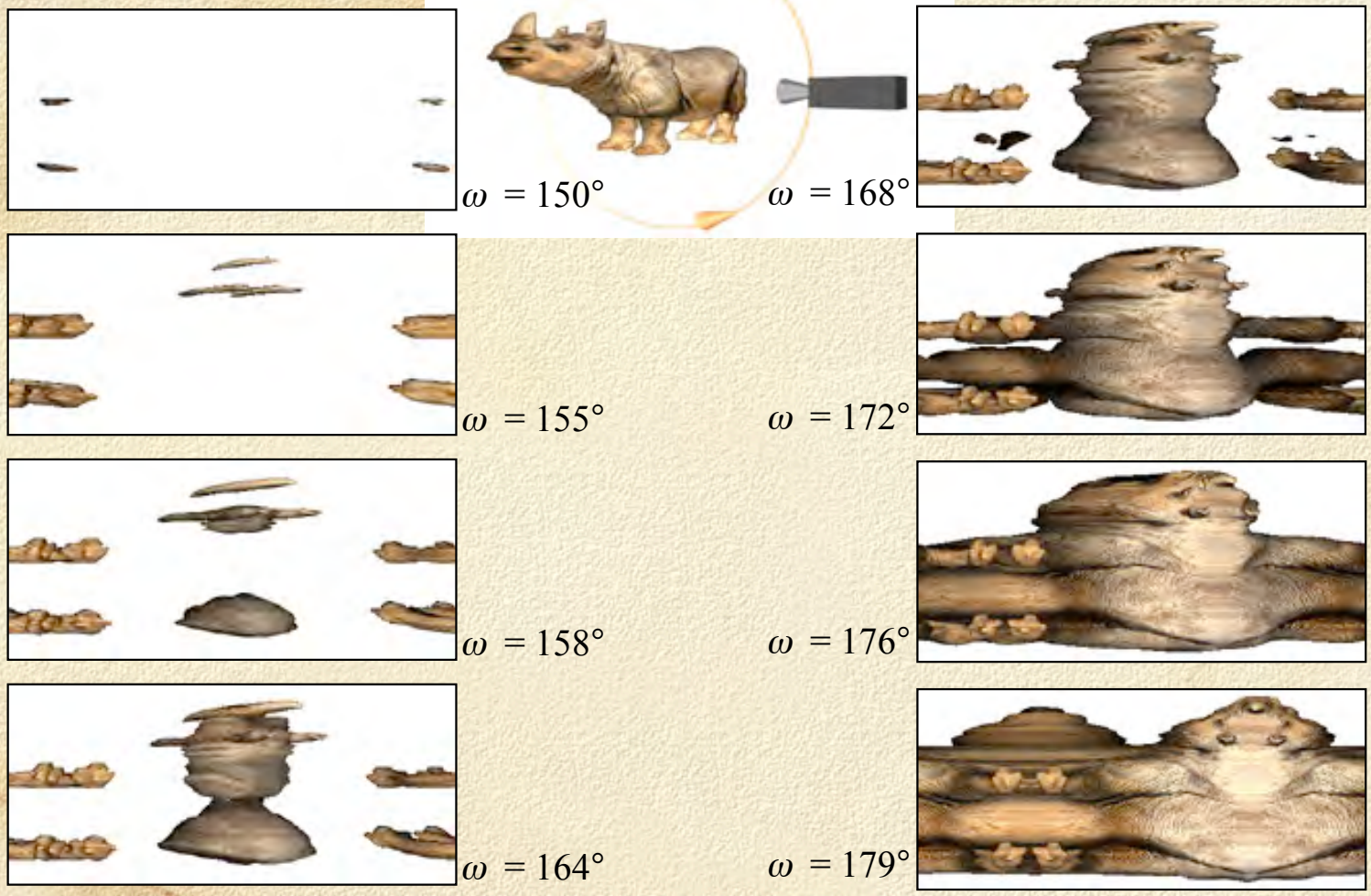




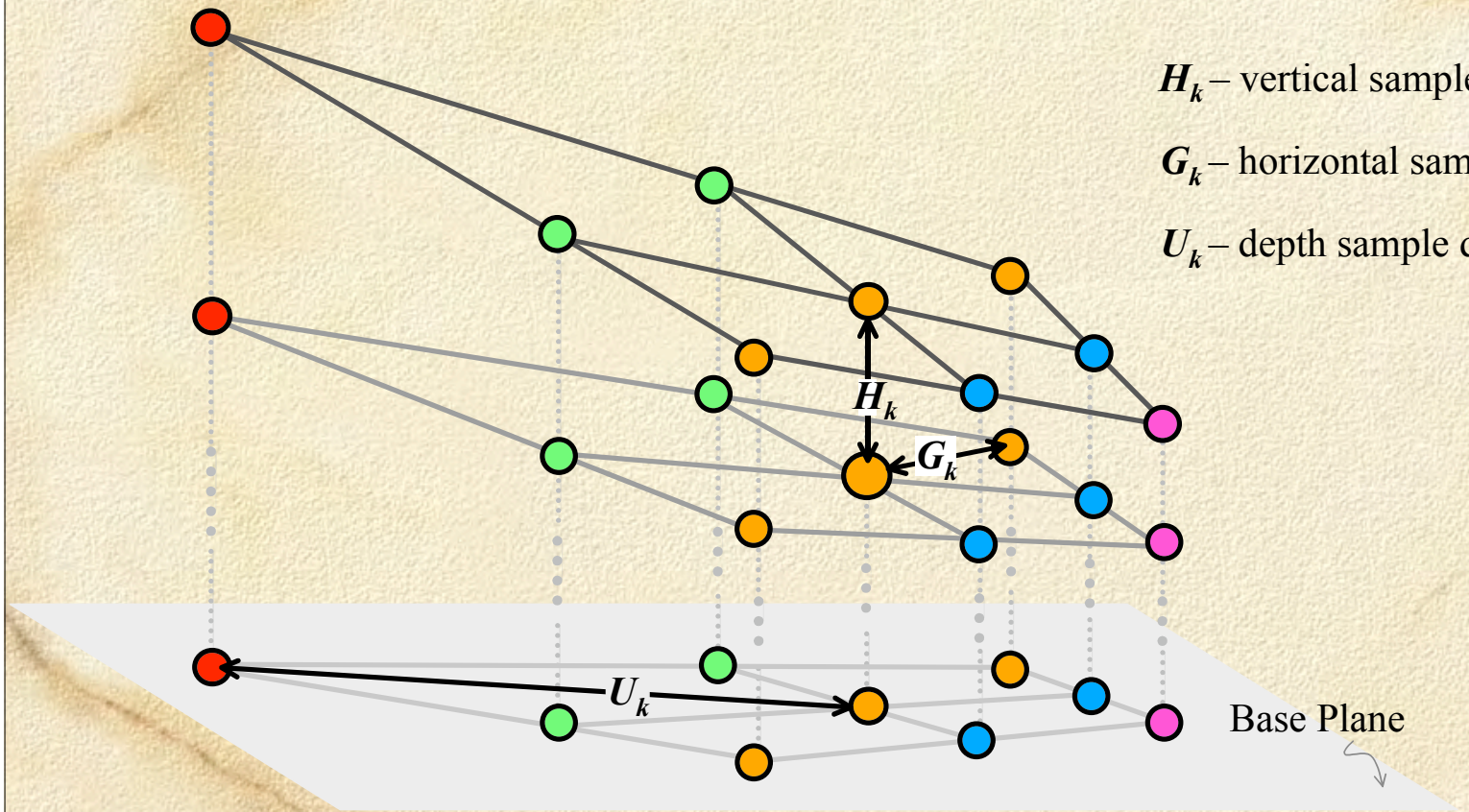
ω = 130° 155° 175°

INWARD CASE




ω = 150°
ω = 155°
ω = 158°
ω = 164°
ω = 168°
ω = 172°
ω = 176°
ω = 179°

NEAREST SAMPLE DISTANCES

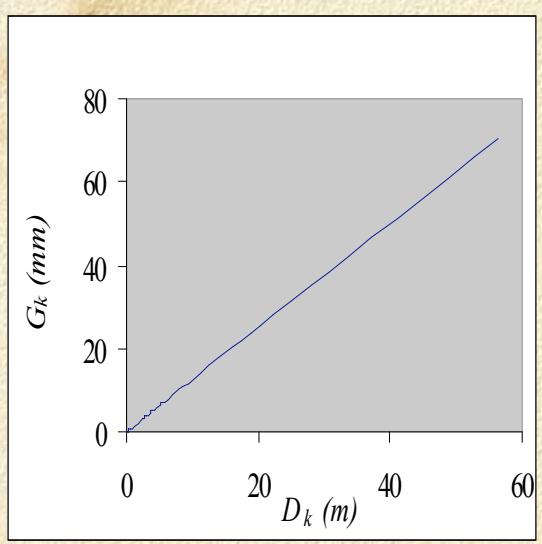


H_k – vertical sample distance

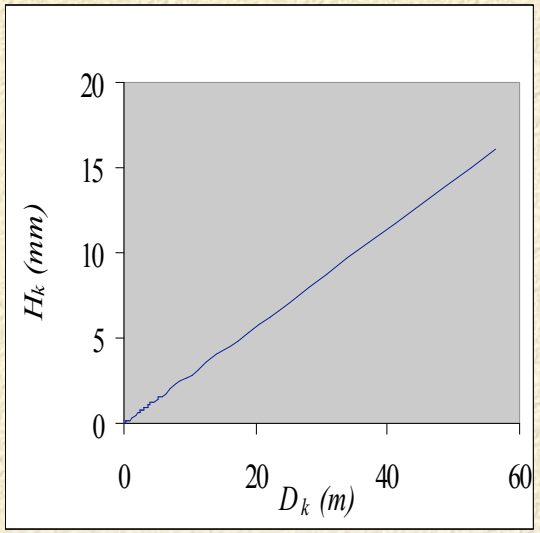
G_k – horizontal sample distance

U_k – depth sample distance

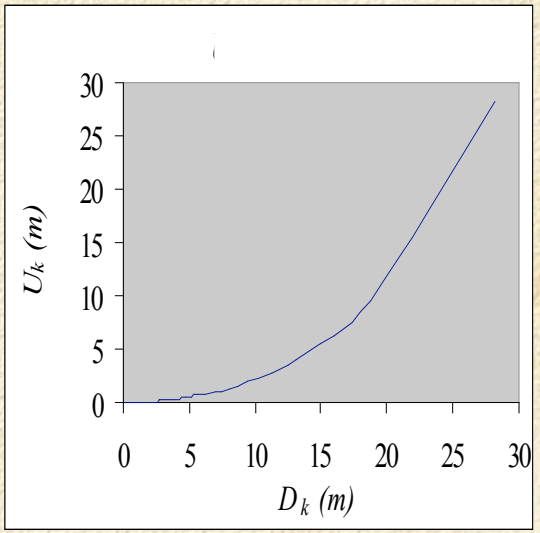
SAMPLE DISTANCES VS. DEPTH



Horizontal sample distance
vs.
Depth



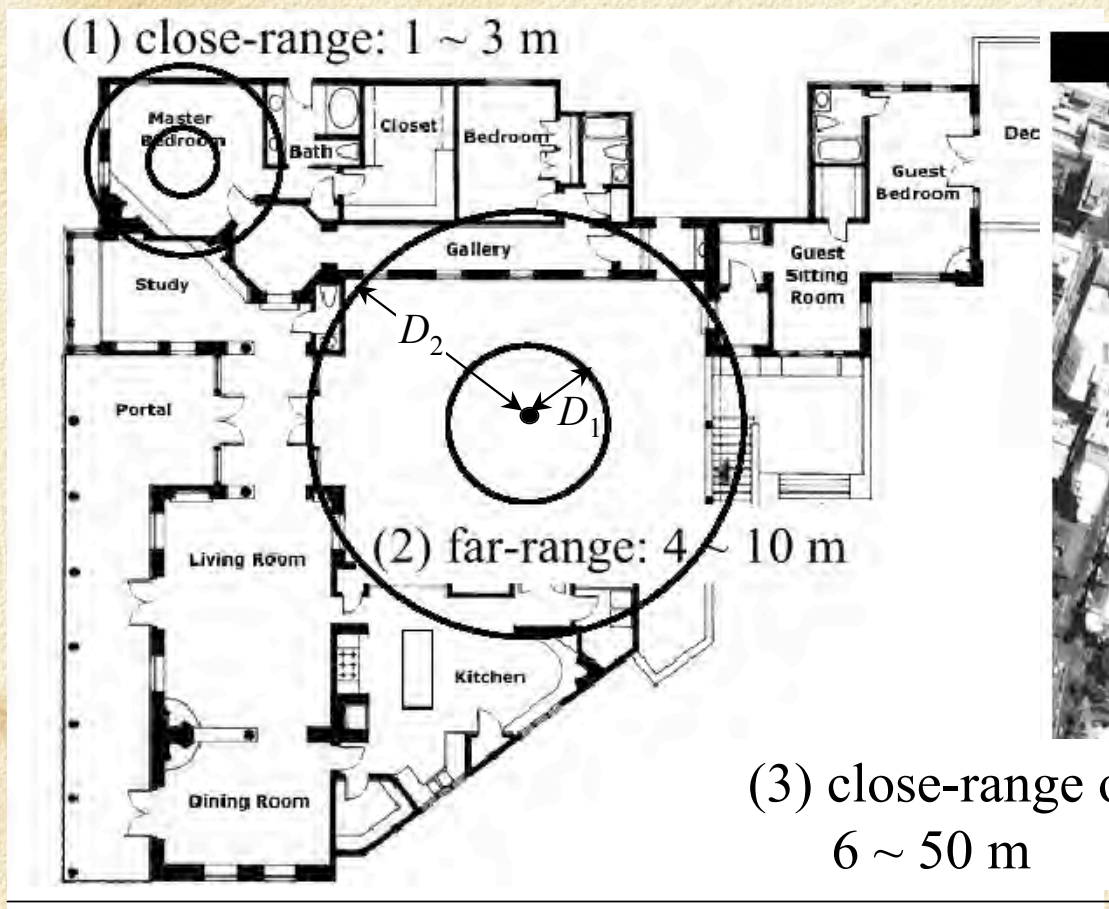
Vertical sample distance
vs.
Depth



Depth sample distance
vs.
Depth

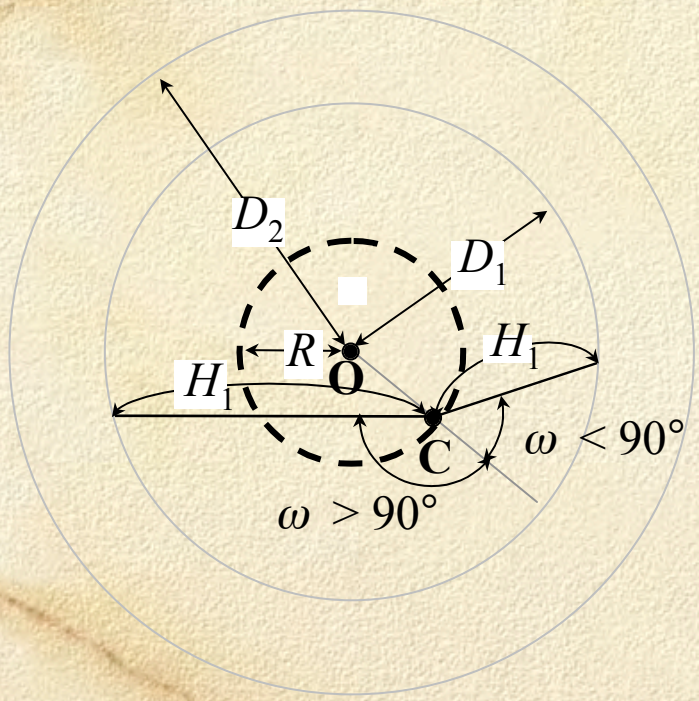
scene model

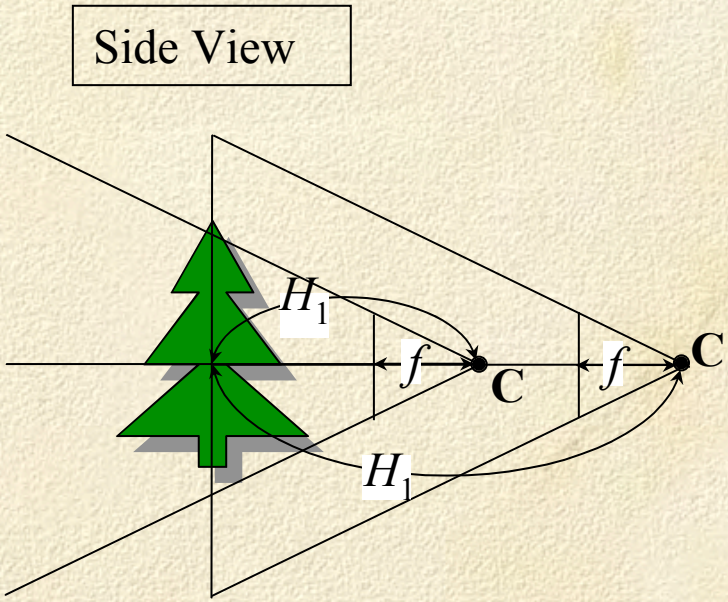
SCENE RANGE OF INTEREST



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

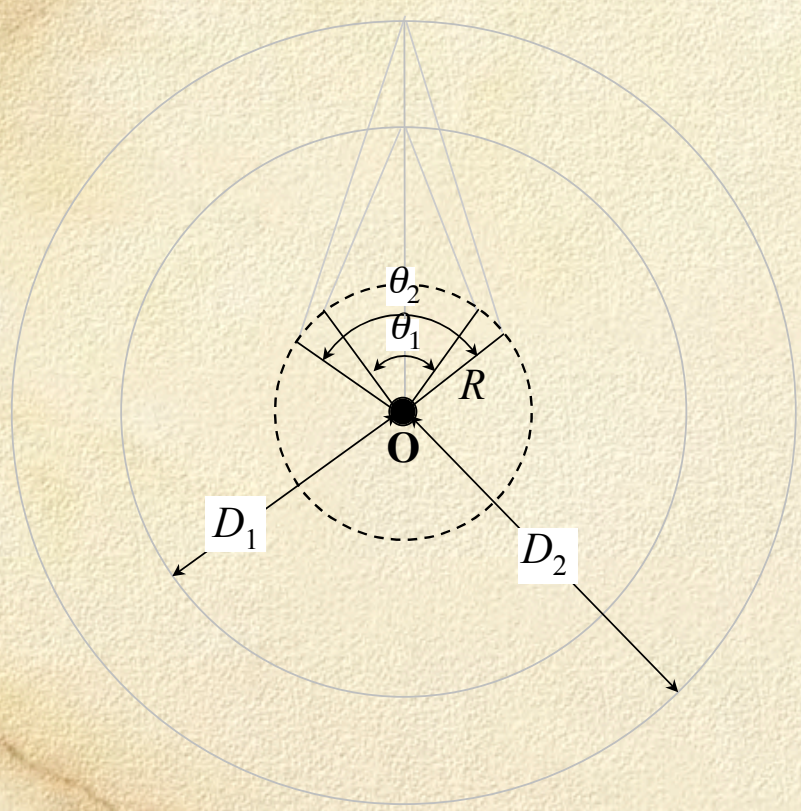
VERTICAL VIEW COMPOSITION





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 × 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

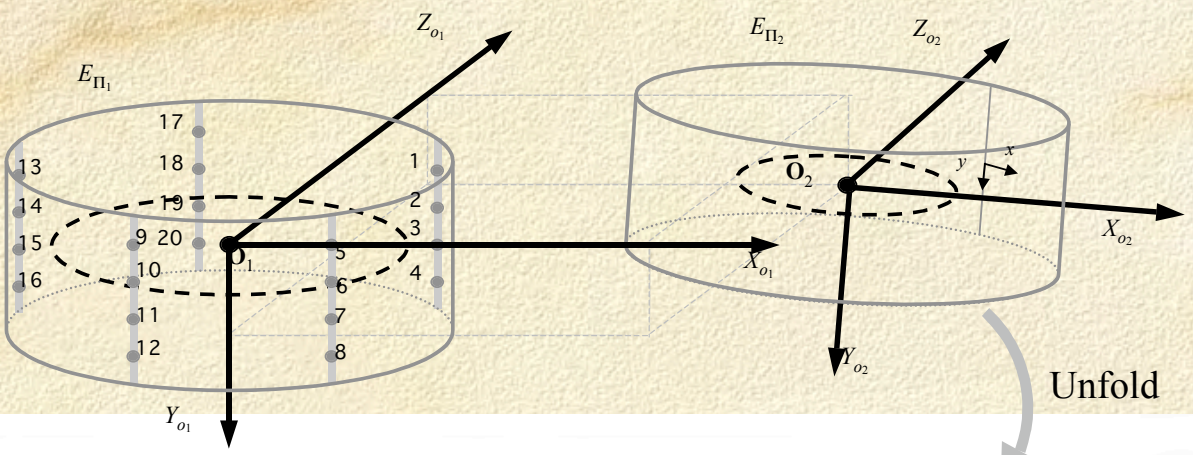
	D_1	D_2	H_1	W	θ_w	R	ω
(1)	1	3	1.2	16232	10.48	0.2499	146.88
(2)	4	10	4.2	18550	9.17	0.5809	113.92
(3)	6	50	5.5	21249	8.00	0.6768	44.66
(4a)	20	200	20.0	19478	8.74	1.6942	92.43
(4b)	20	200	20.0	19478	5.00	0.9695	91.39

in meter

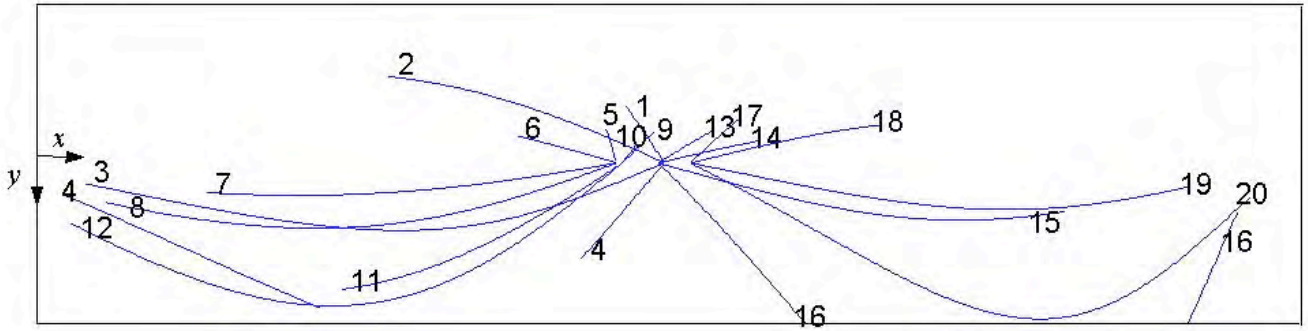
also calculated

70 pixel (see above)

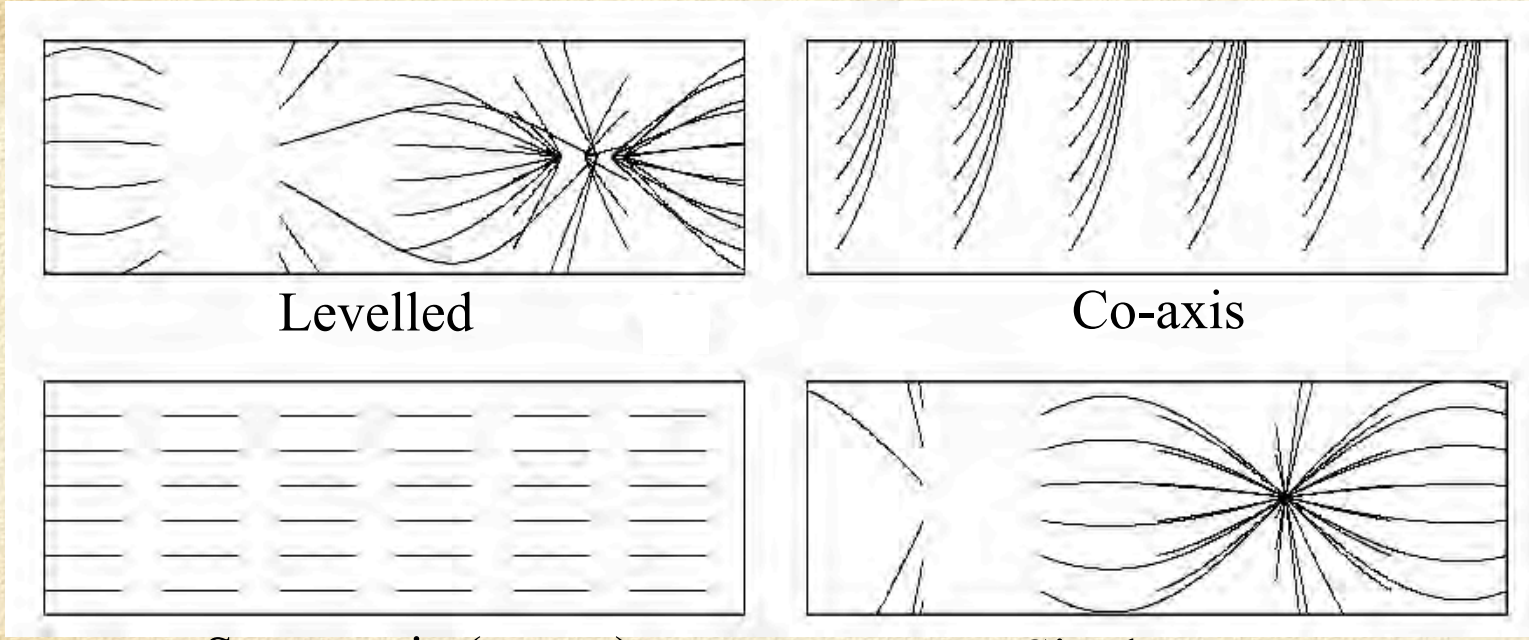
epipolar curves


Z_{o_1}
E_{Π_1}
17
18
19
13
14
15
16
9 20
10
11
12
1
2
3
5
4
6
7
8
O_1
Y_{o_1}
E_{Π_2}
Z_{o_2}
O_2
y
x
X_{o_1}
X_{o_2}
Y_{o_2}

Unfold


x
y
2
6
5
1
10
9
13
17
14
18
3
4
7
8
12
11
4
19
20
15
16
16

EPIPOLAR CURVE SKETCHES



Levelled

Co-axis

Symmetric (stereo)

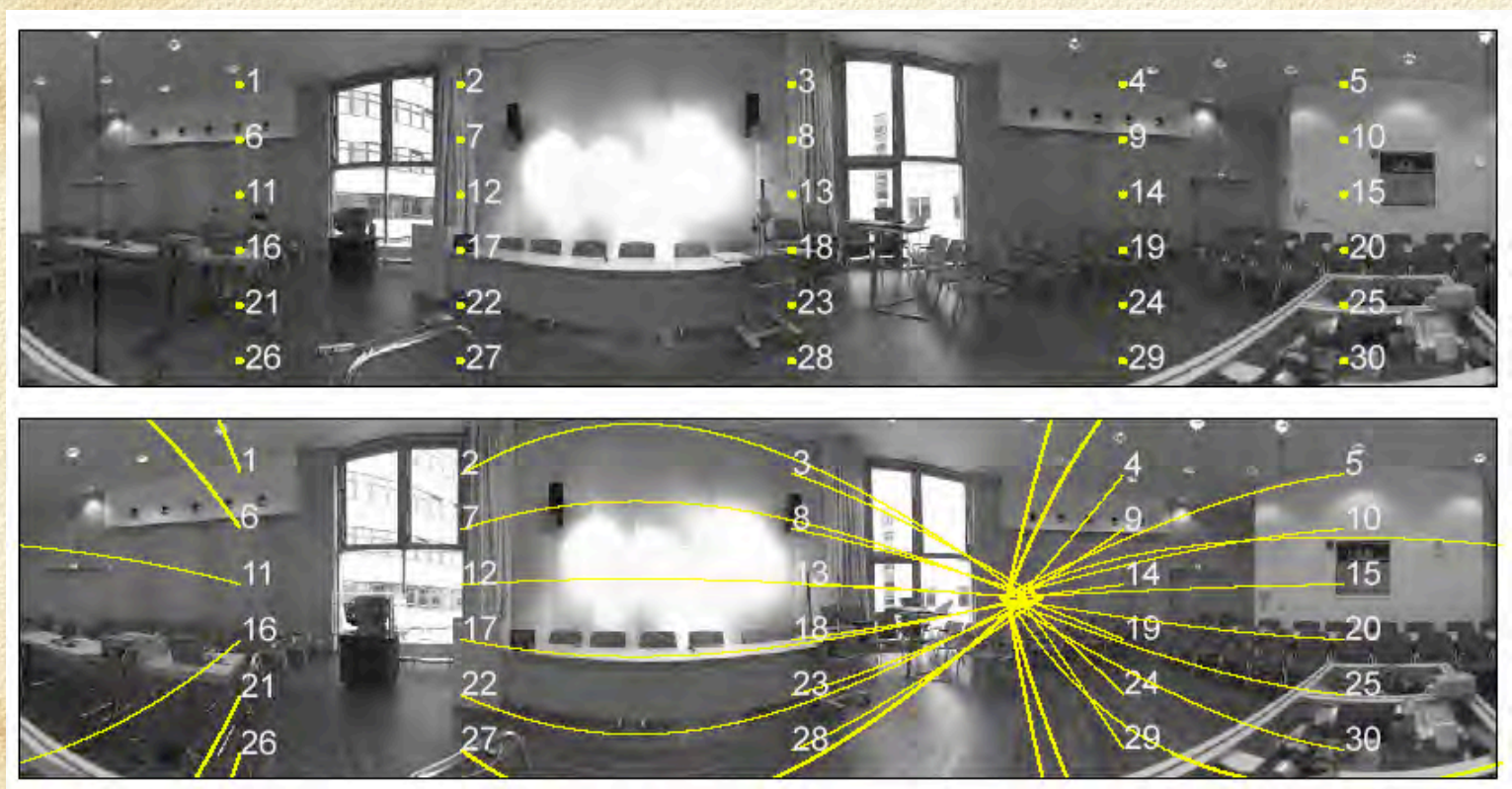
Single-center

LEVELLED PANORAMAS

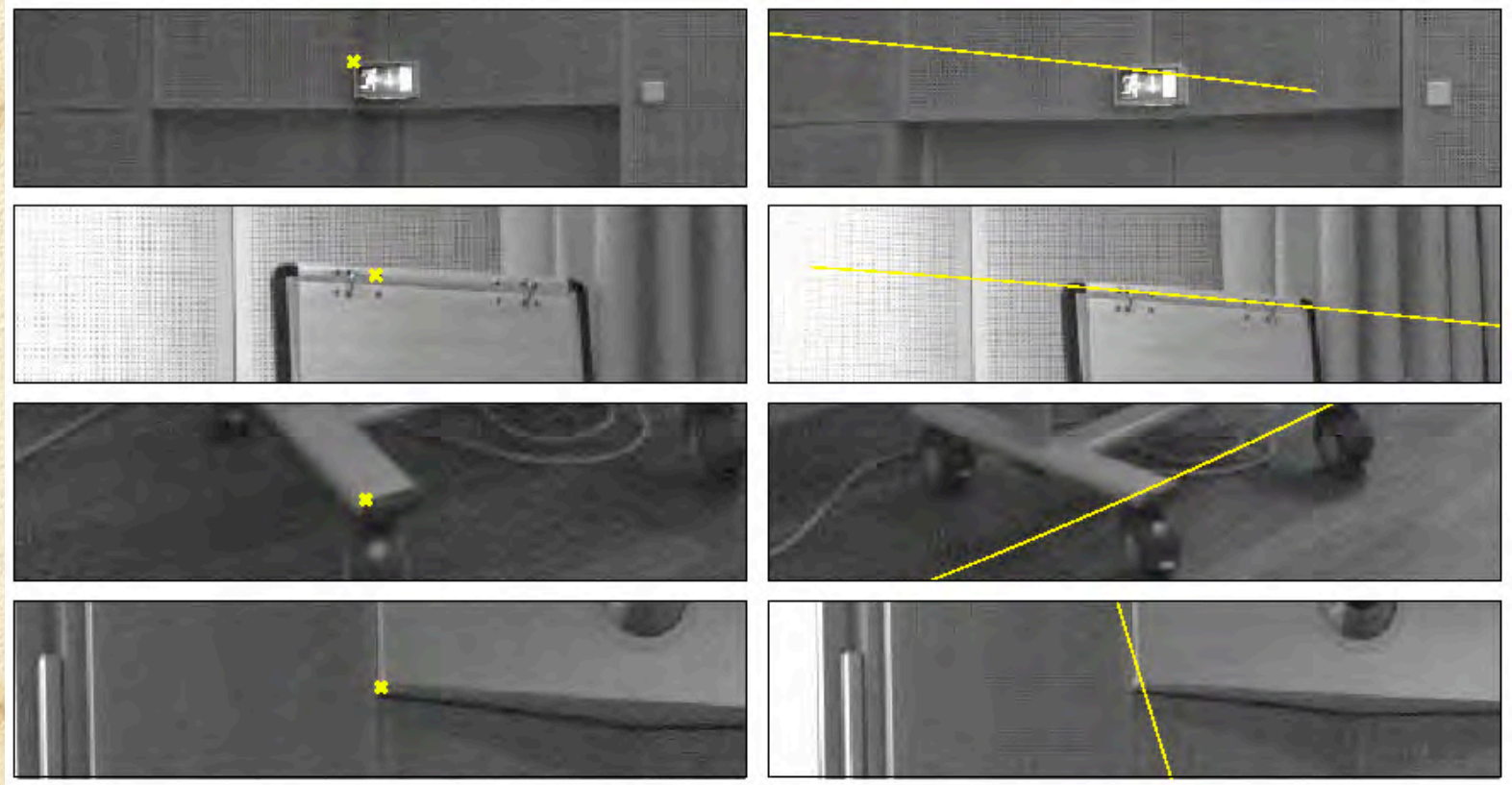
same height and parallel rotation axes
different R ' s
different ω ' s
different f ' s

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

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.