Wide-Angle Image Acquisition, Analysis and Visualisation

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Ralf Reulke, Herbert Jahn, ... ----- German Aerospace Centre

design and application of
spaceborne and airborne scanners

methods and algorithms for
stereo analysis and 3D **visualisations**

Georgy Gimel'farb, Reinhard Klette, ...

Contents of Talk

- Multi-line and single-line CCD cameras
- Camera calibration
- Registration of airborne and panoramic images
- Epipolar geometry
- Stereo matching
- Visualisation
- Conclusions

2001 **Example of wide-angle view -** ***Auckland*** (h=3000m, GSD=1m)

First techniques for capturing an aerial view

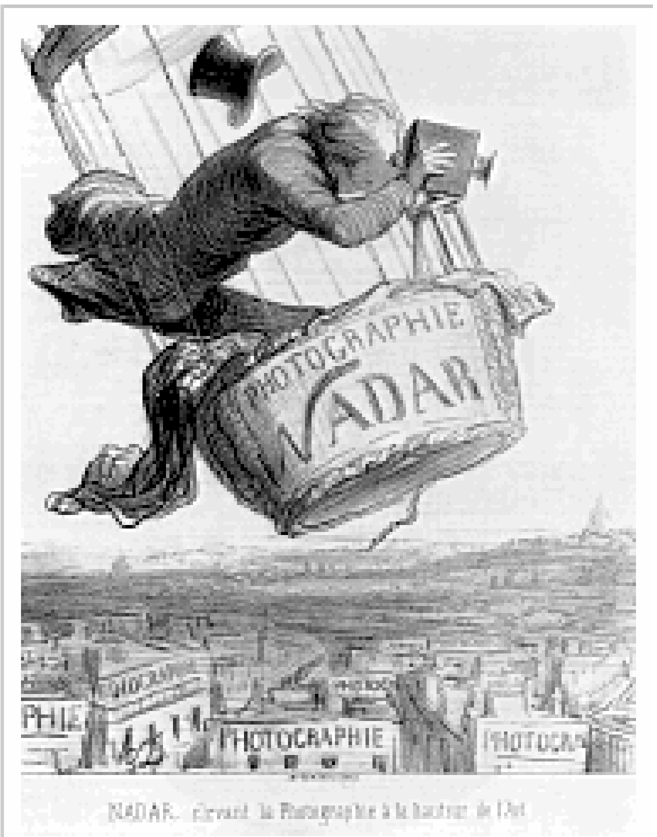
construct one from the principles of perspective

1500 Jacopo de Barbari - *Vista deVenecia*

1878 B. McQuillan - *Bird's Eye View from the Bay looking southwest. San Francisco*

The balloon provided a platform for the first aerial photographs

1858 Felix Tournachon (*nom de plume* Nadar)



- *the first aerial photograph over the Bievre Valley*

1860 **James Wallace Black -** *Boston from a captive balloon, October 13, 1860.*

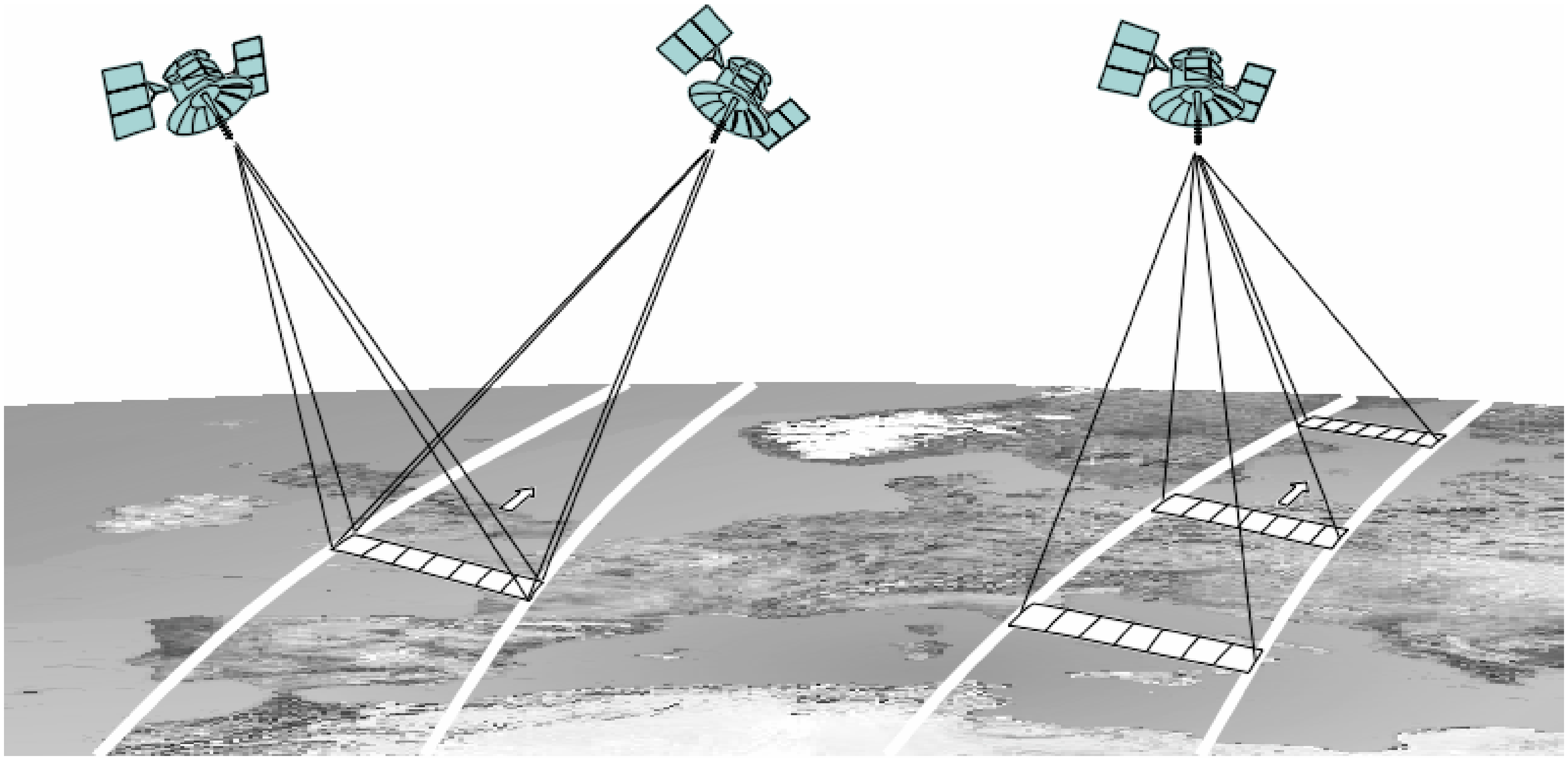
2000 Interactive aerial maps with panoramic images

Klette-Gimel'farb-Reulke

Berlin 2000

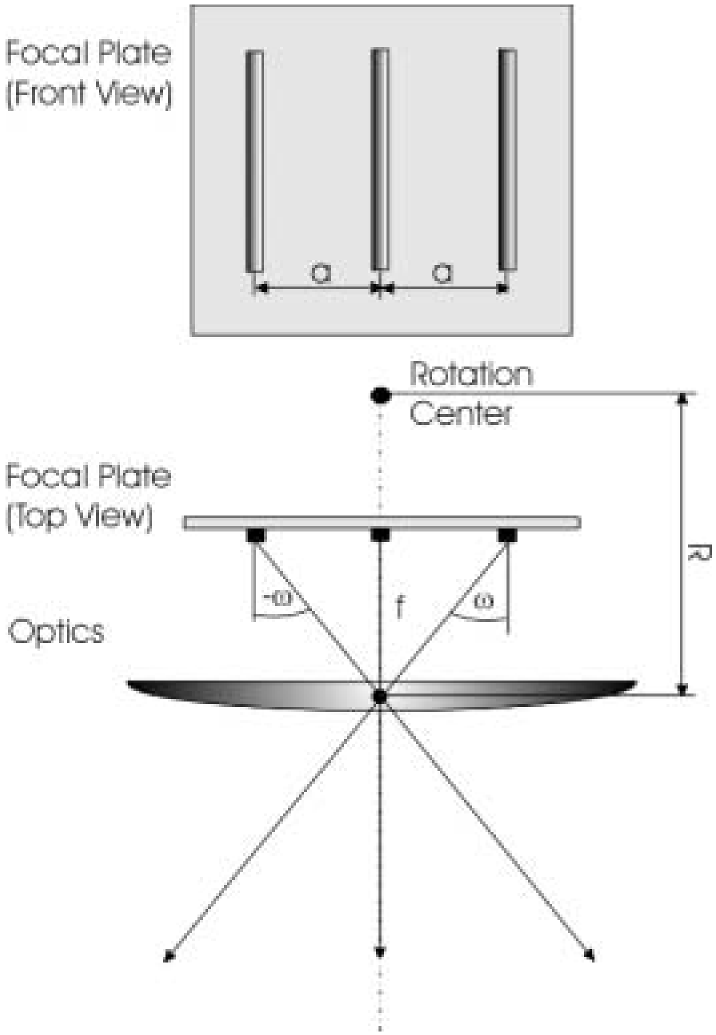
Klette-Gimel'farb-Reulke

CCD Multi-Line Cameras



pushbroom principle for spaceborne cameras

1986 *across-track* (SPOT) *along-track* (MOMS) 1994



model of a three-line camera

1998

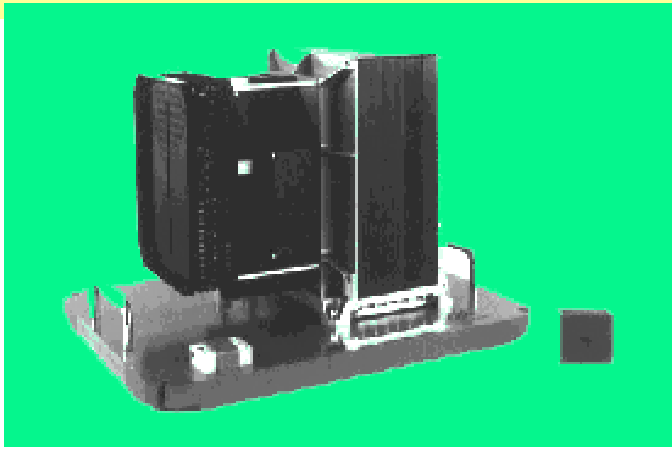
WAAC

(*Wide Angle Airborne Camera*)

1m GSD (ground sample distance) at 3000m

3 lines: backward, nadir, forward

each line 5k pixel, gray values only

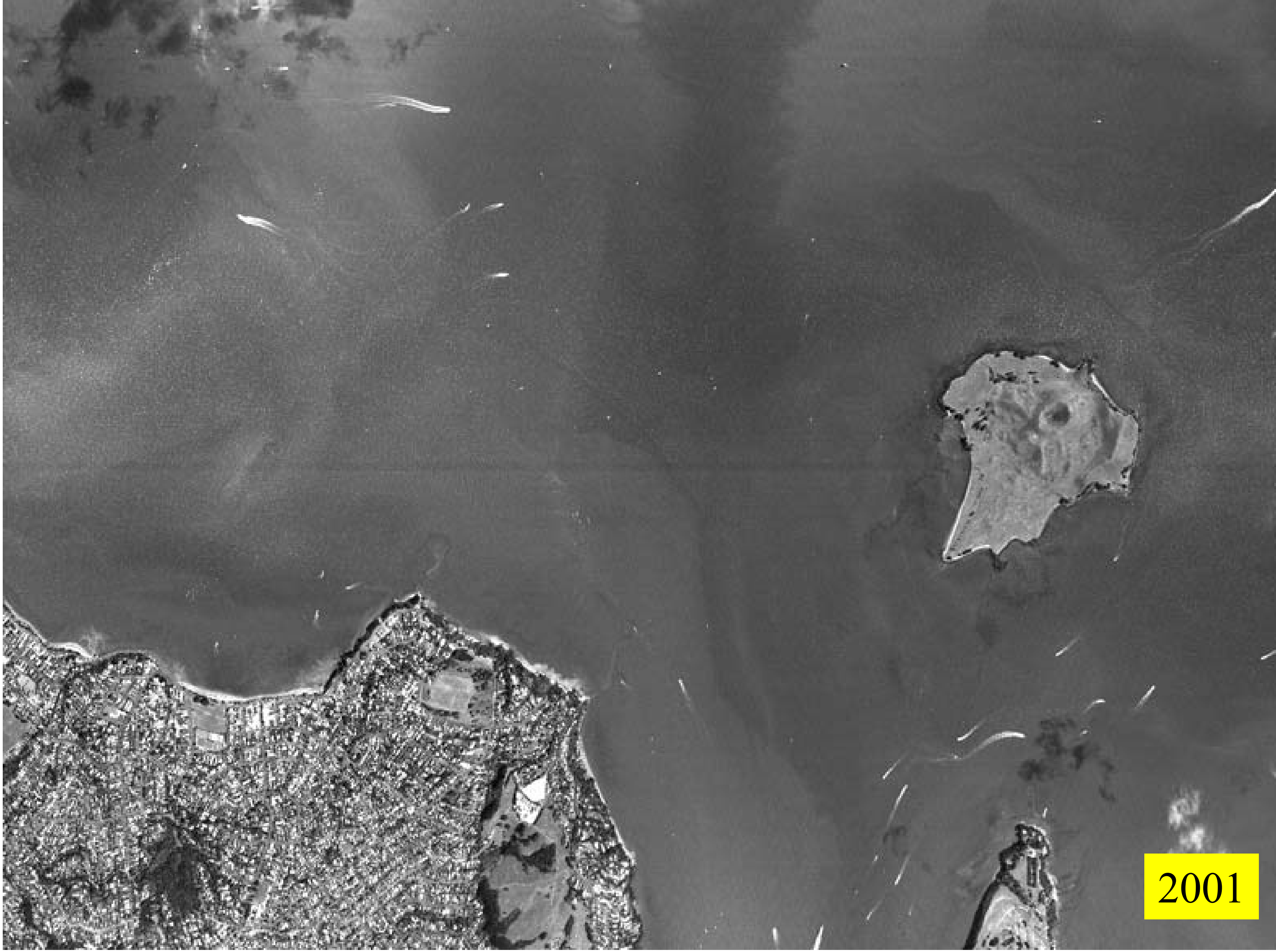


WAAC flight campaign in Auckland 2001

DLR

CITR

NZ Aerial Mapping Ltd



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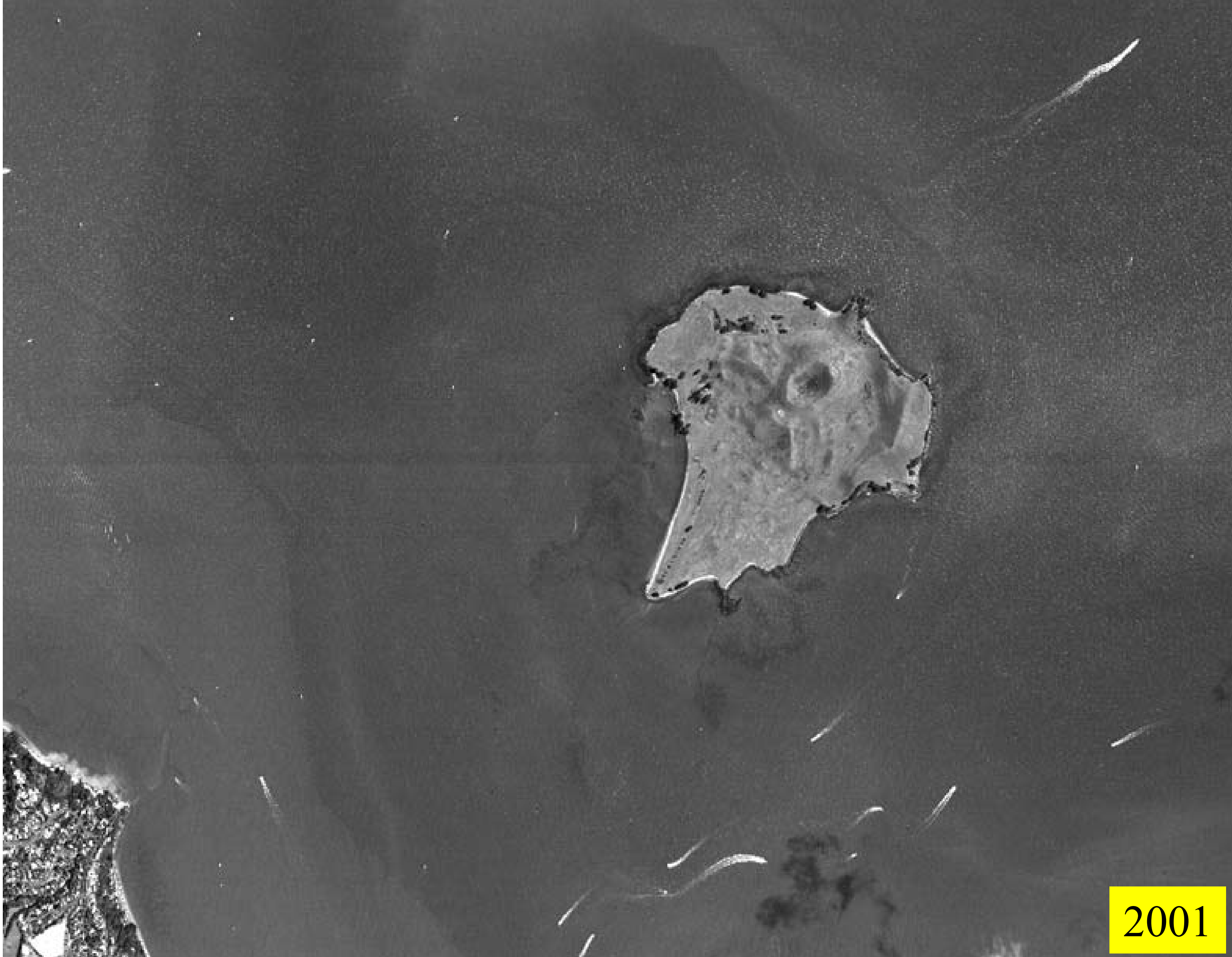
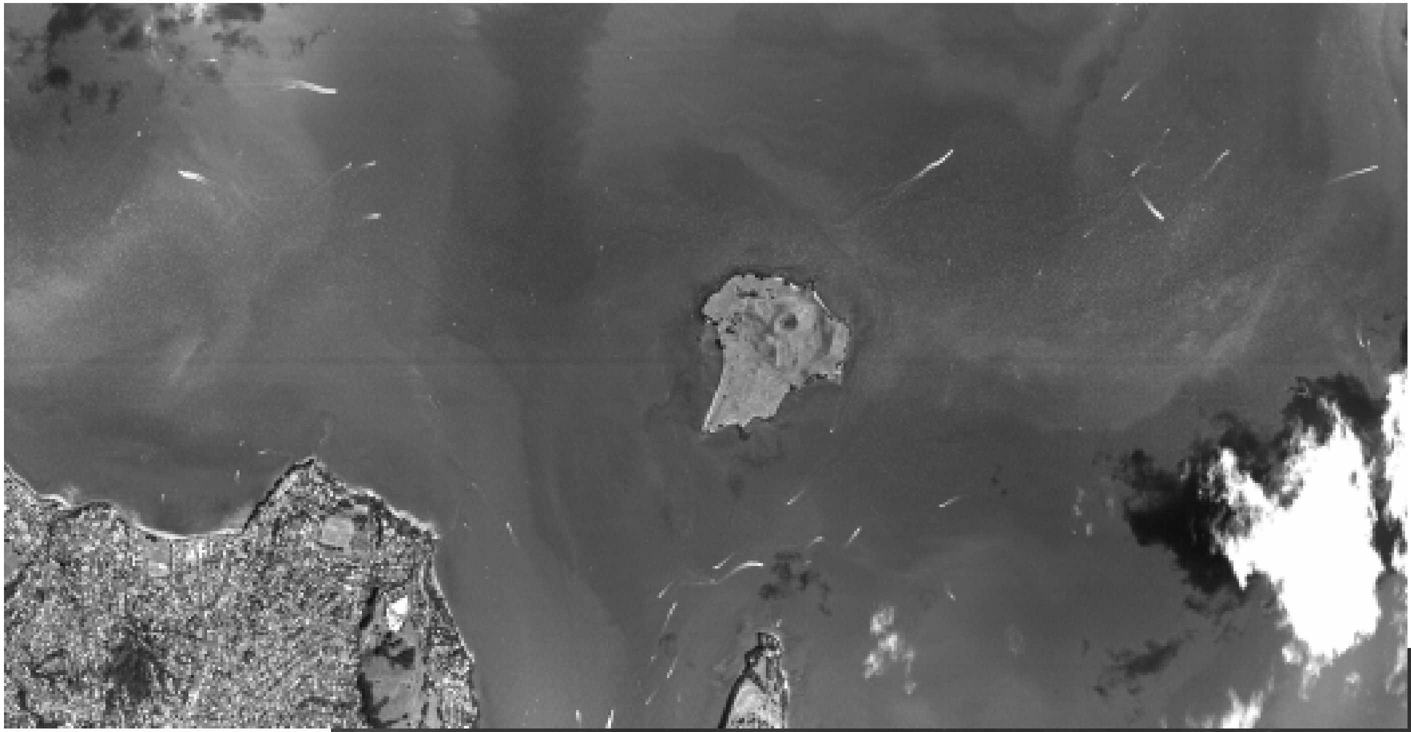


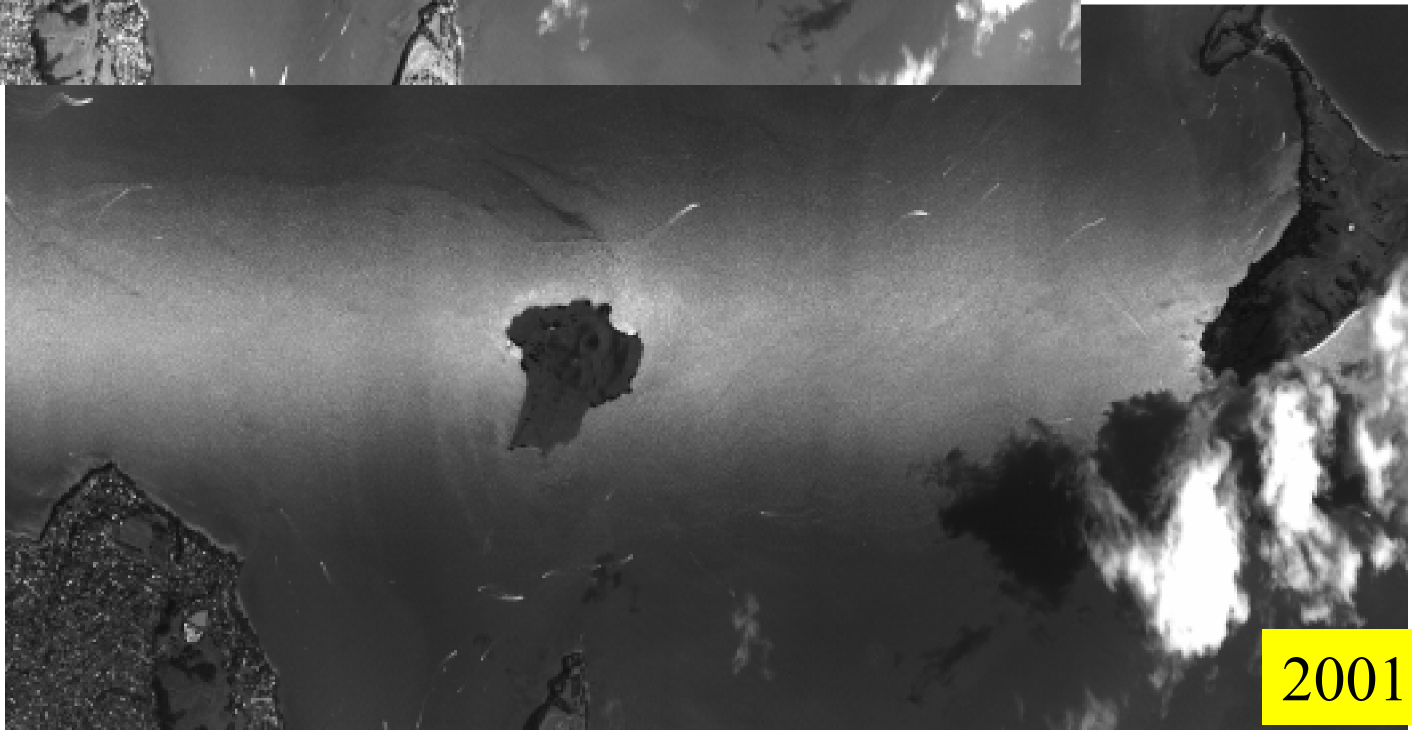
Klette-Gimel'farb-Reulke

2001

Klette-Gimel'farb-Reulke



Nadir Image



Backward Image

2001

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1997

1. REGISTRATION

Problems of **panoramas** by **mosaicing** (image stitching):

- low-pass effect due to merging
- geometric distortions (“straight lines not straight”)

2. MERGING

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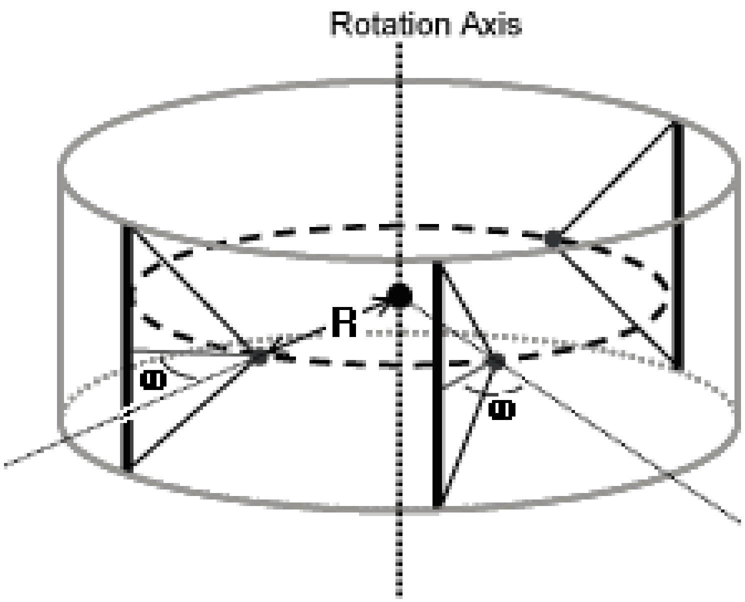
CCD Single-Line Cameras



model of single-line camera

EyeScan M2 Metric 2000

10,200 pixels in one line

360 degree rotation >>>

3.5 Giga Byte

2001

Panoramic Image with EyeScan

capturing time: 3 min

16-18 February 2001: Conference “**Robot Vision**”

Auckland, CITR Tamaki

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February 1995

first panoramic image taken with a line camera (WAOSS/HRSC)
-
view from the roof of Dornier / Germany

May1995

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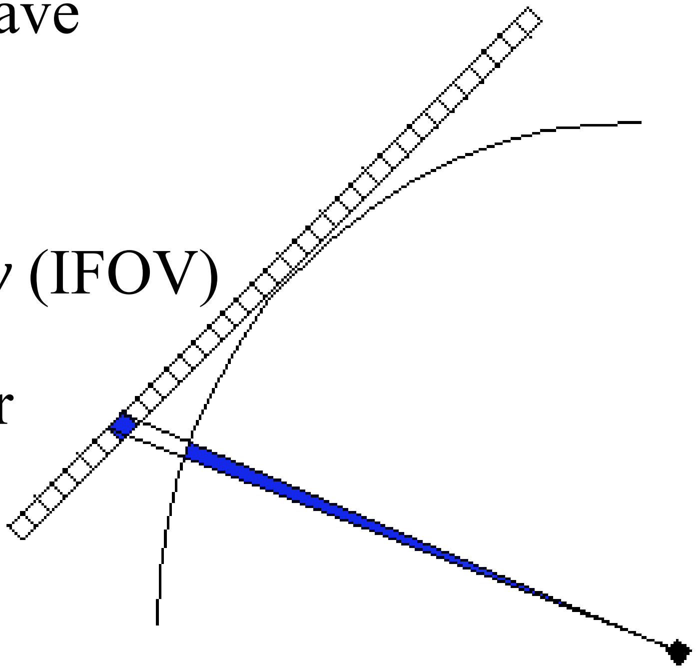
Camera Calibration

high resolution CCD-line cameras have

- a **large** *field of view* (FOV) and
- a **small** *instantaneous field of view* (IFOV)

results in high-accuracy demands for

- *geometric* and
- *radiometric calibration*

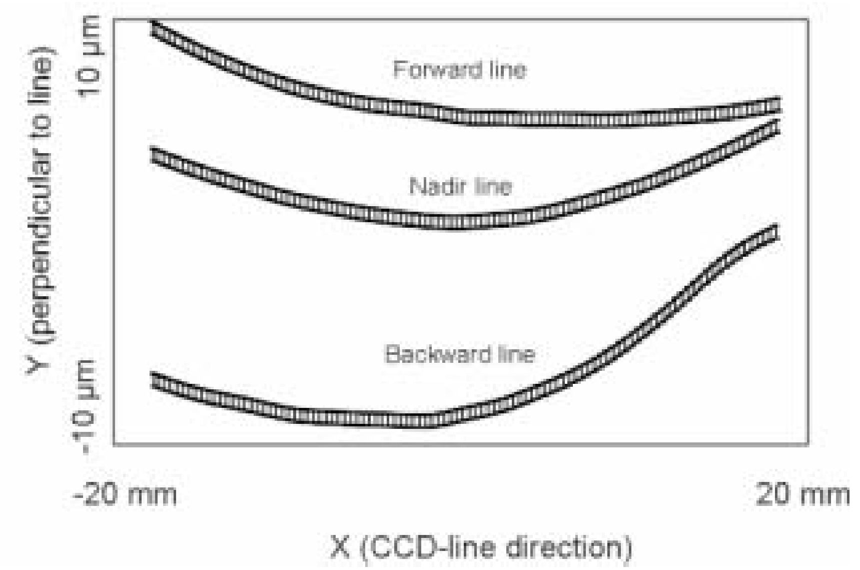


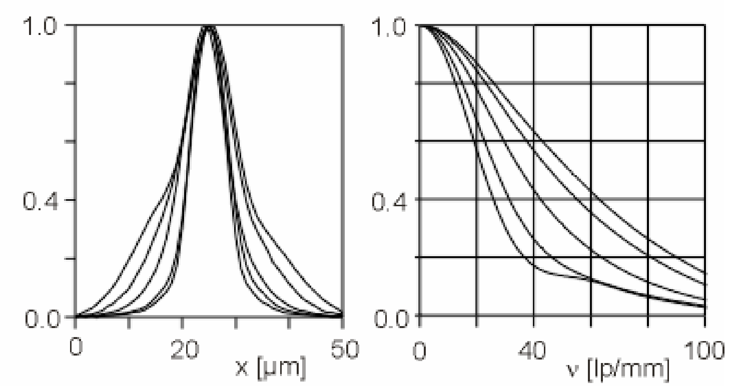
DLR calibration facility

Illumination Source → Movable Slit or Pinhole → Collimator (Parallel Beam) → Camera-Head (Optics & CCD) on Pan- & Tilt-Table → Data-Visualization

geometric calibration

Example: WAAC with 5184 pixels

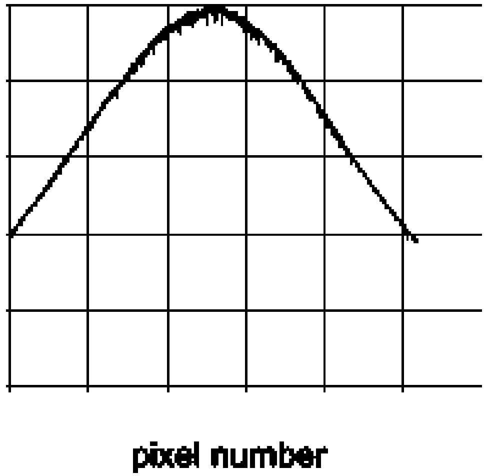


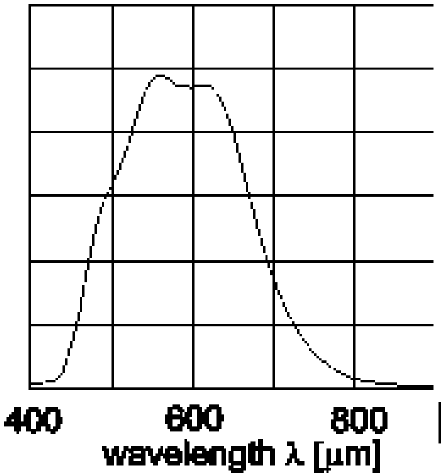


PSF MTF

radiometric calibration

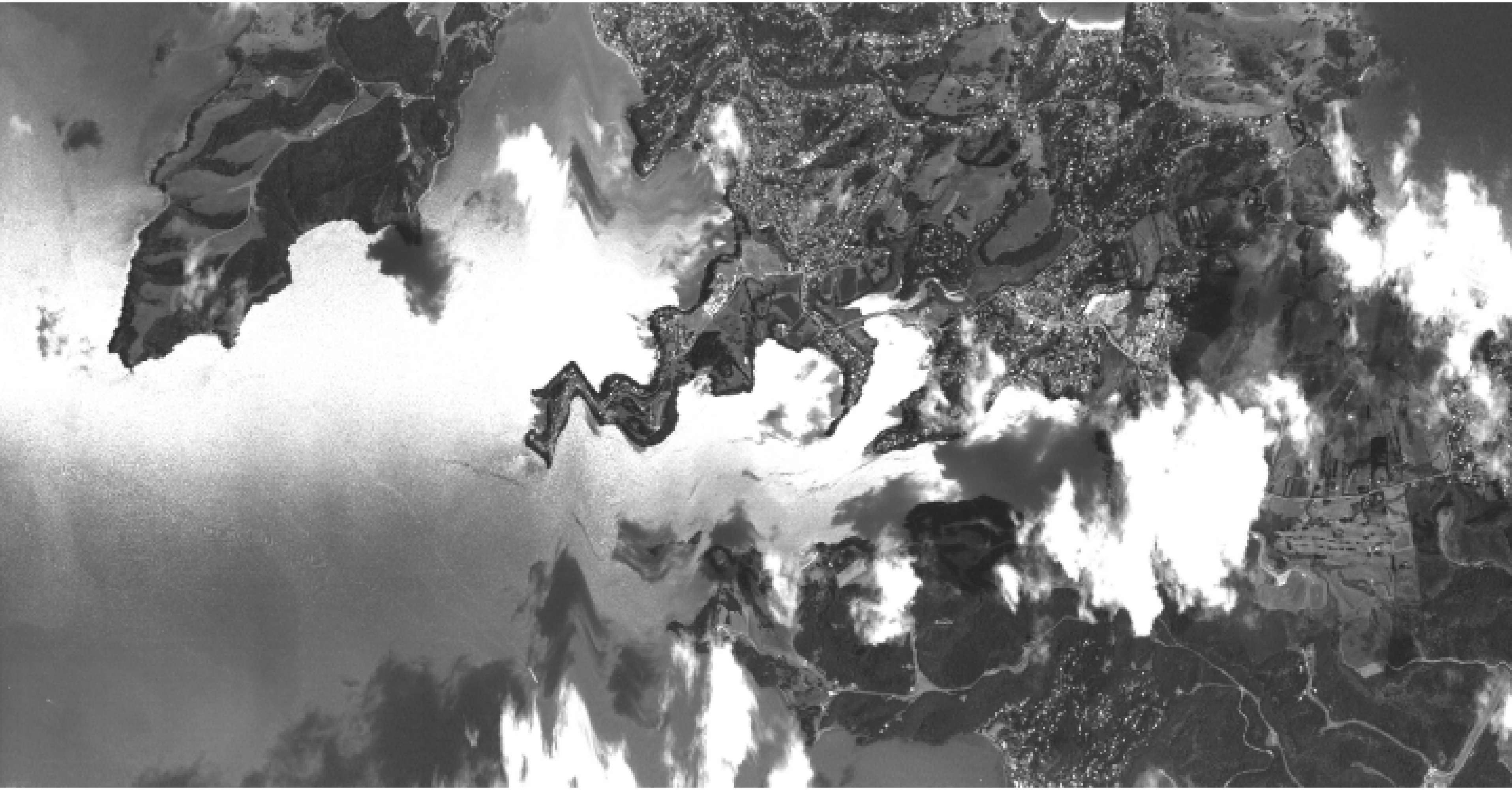
photoresponse non-uniformity





normalized spectral sensitivity

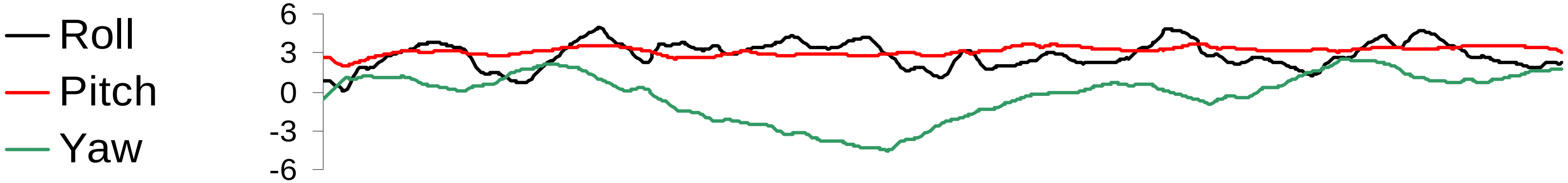
Registration for Airborne Cameras



Rectification of aerial images

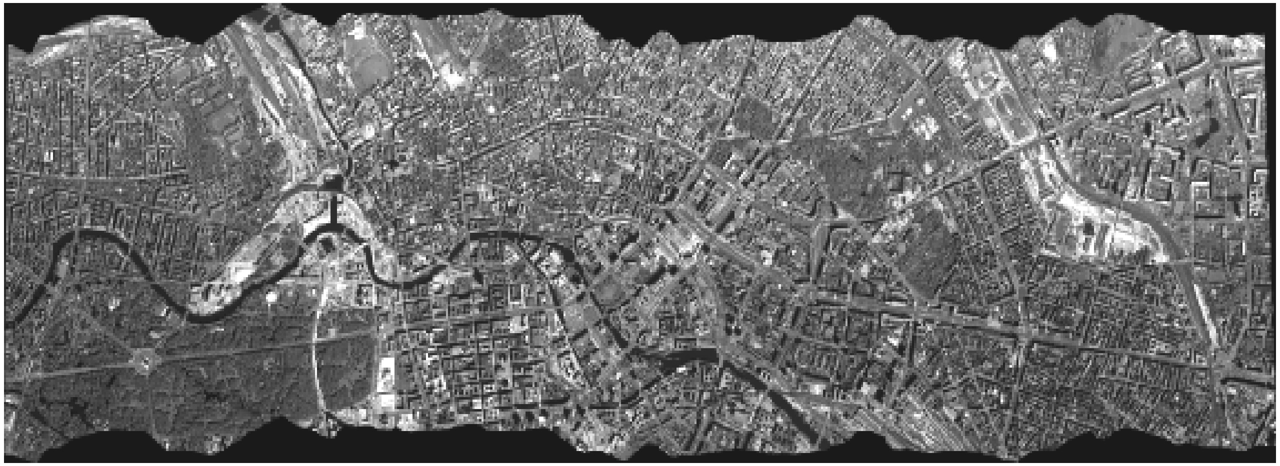
Original Scene

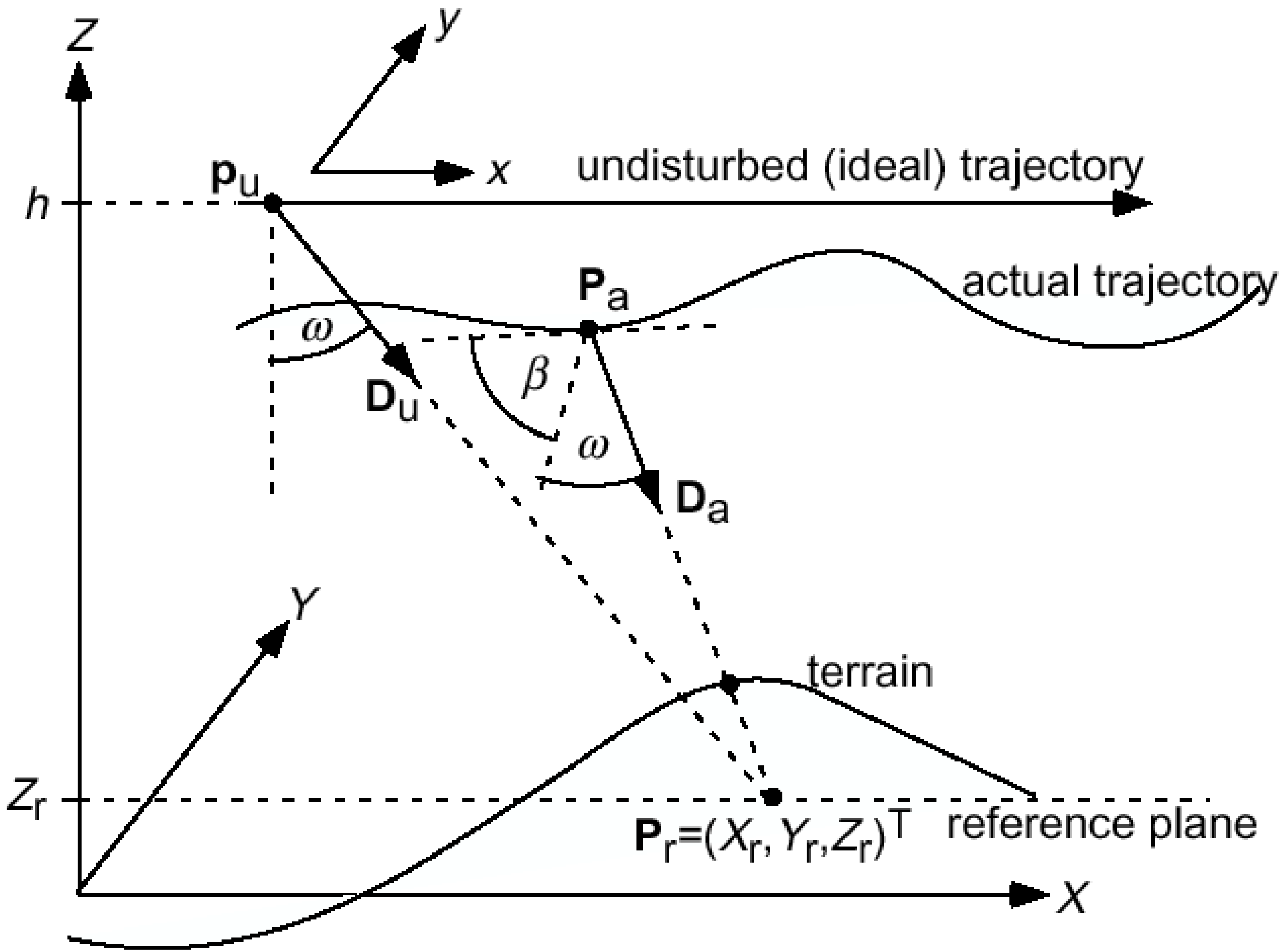
(without gyro stabilization)



applanix system:
one decimeter accuracy

Rectified Scene





Z
y
x
undisturbed (ideal) trajectory
$\mathbf{p}_u$
h
$\mathbf{P}_a$
actual trajectory
ω
β
$\mathbf{D}_u$
ω
$\mathbf{D}_a$
Y
terrain
Z_r
$\mathbf{P}_r=(X_r,Y_r,Z_r)^T$
reference plane
X

TASK: calculate pixel position $\mathbf{p}_u = (x, y, h)$

which "sees" $\mathbf{P}_r = \mathbf{p}_u + t \cdot \mathbf{D}_u$

$\mathbf{D}_a = \mathbf{R} \cdot \mathbf{D}_u$

rotation matrix, flight disturbance (roll, pitch, yaw)

$\mathbf{P}_r = \mathbf{P}_a + s \cdot \mathbf{D}_a = (X_r, Y_r, Z_r)$

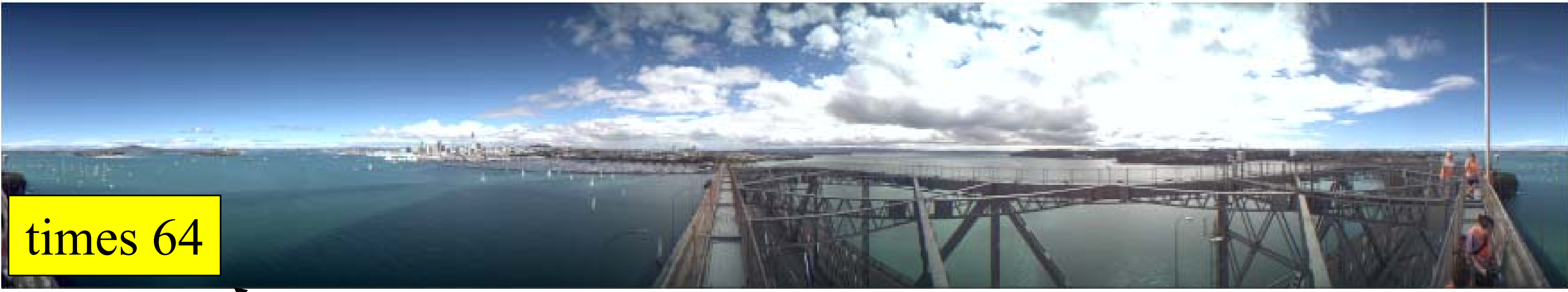
τ = scan time for a single line

ν = scaling factor for CCD line

$$x = \frac{1}{\nu\tau} \cdot \begin{cases} X_r & \text{if nadir line} \\ X_r \pm (h - Z_r) tan\,\omega & \text{if back- or forward line} \end{cases}$$

$$y = \frac{n+1}{2} + \frac{Y_r \cdot f}{(h - Z_r) \cdot \Delta_{IFOV}} \quad \text{(independent of viewing angle)}$$

Registration for Panorama Cameras



registration problem due to bridge vibration

no registration problem


times 32


times 16


times 8


times 4

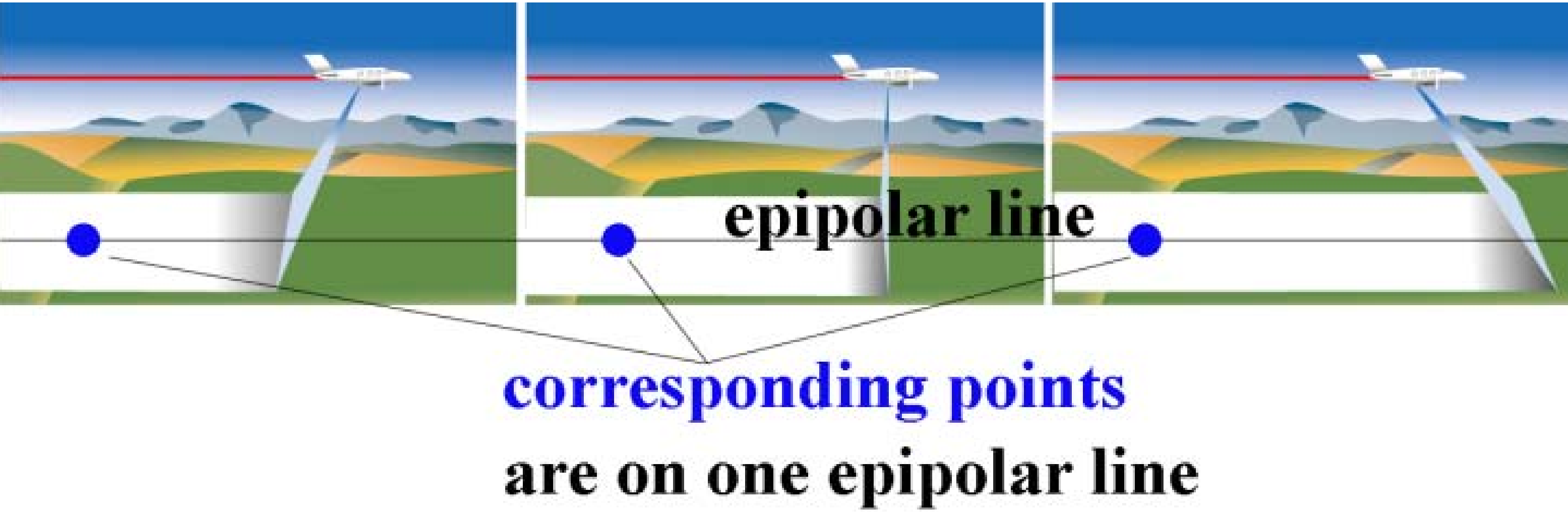

times 2


times 1


AA
times .5

Epipolar Geometry

along-track after registration : *simple epipolar geometry*



polycentric panoramic images :

different rotation axes, R 's, f 's, ω 's

Fay Huang, **Shou-kang Wei** and **Reinhard Klette**

2001, ICCV Vancouver

epipolar curve equations

for

any type of polycentric panoramas

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 **R**, **T** and
parameters of first image

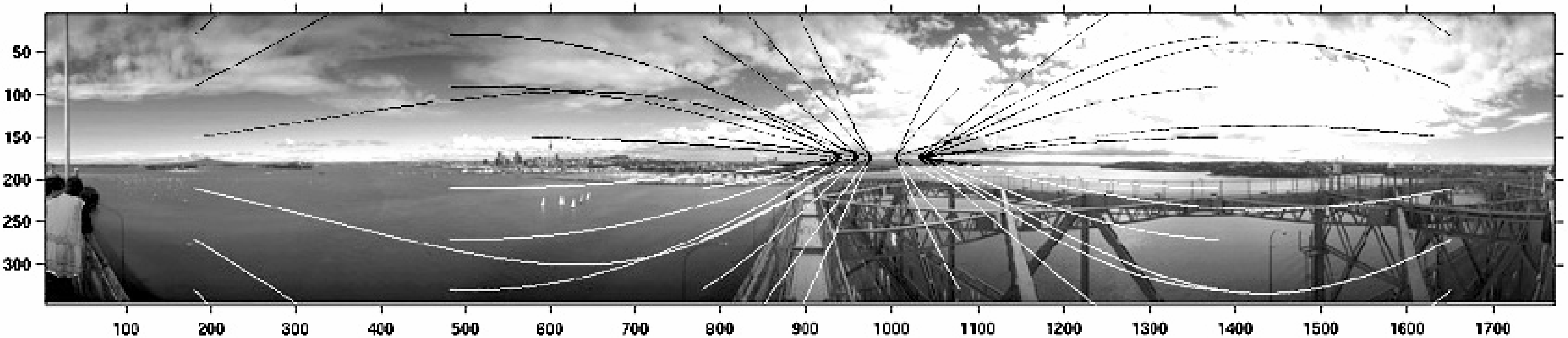
$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = \mathbf{R}(\mathbf{V} + k\mathbf{W})$$

$$k = \frac{R_d \sin\omega_d + \cos\left(\frac{2\pi x_d}{W_d} + \omega_d\right)\mathbf{r}_1^T \cdot \mathbf{V} - \sin\left(\frac{2\pi x_d}{W_d} + \omega_d\right)\mathbf{r}_3^T \cdot \mathbf{V}}{\sin\left(\frac{2\pi x_d}{W_d} + \omega_d\right)\mathbf{r}_3^T \cdot \mathbf{W} - \cos\left(\frac{2\pi x_d}{W_d} + \omega_d\right)\mathbf{r}_1^T \cdot \mathbf{W}}$$

$$\mathbf{V} = \begin{pmatrix} R\sin\left(\frac{2\pi x}{W}\right) \\ 0 \\ R\cos\left(\frac{2\pi x}{W}\right) \end{pmatrix} - \mathbf{T}$$

$$\mathbf{W} = \begin{pmatrix} \sin\left(\frac{2\pi x}{W} + \omega\right)\cos\left(\tan^{-1}\left(\frac{y}{f}\right)\right) \\ \sin\left(\tan^{-1}\left(\frac{y}{f}\right)\right) \\ \cos\left(\frac{2\pi x}{W} + \omega\right)\cos\left(\tan^{-1}\left(\frac{y}{f}\right)\right) \end{pmatrix}$$

Height-aligned polycentric panoramas



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

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

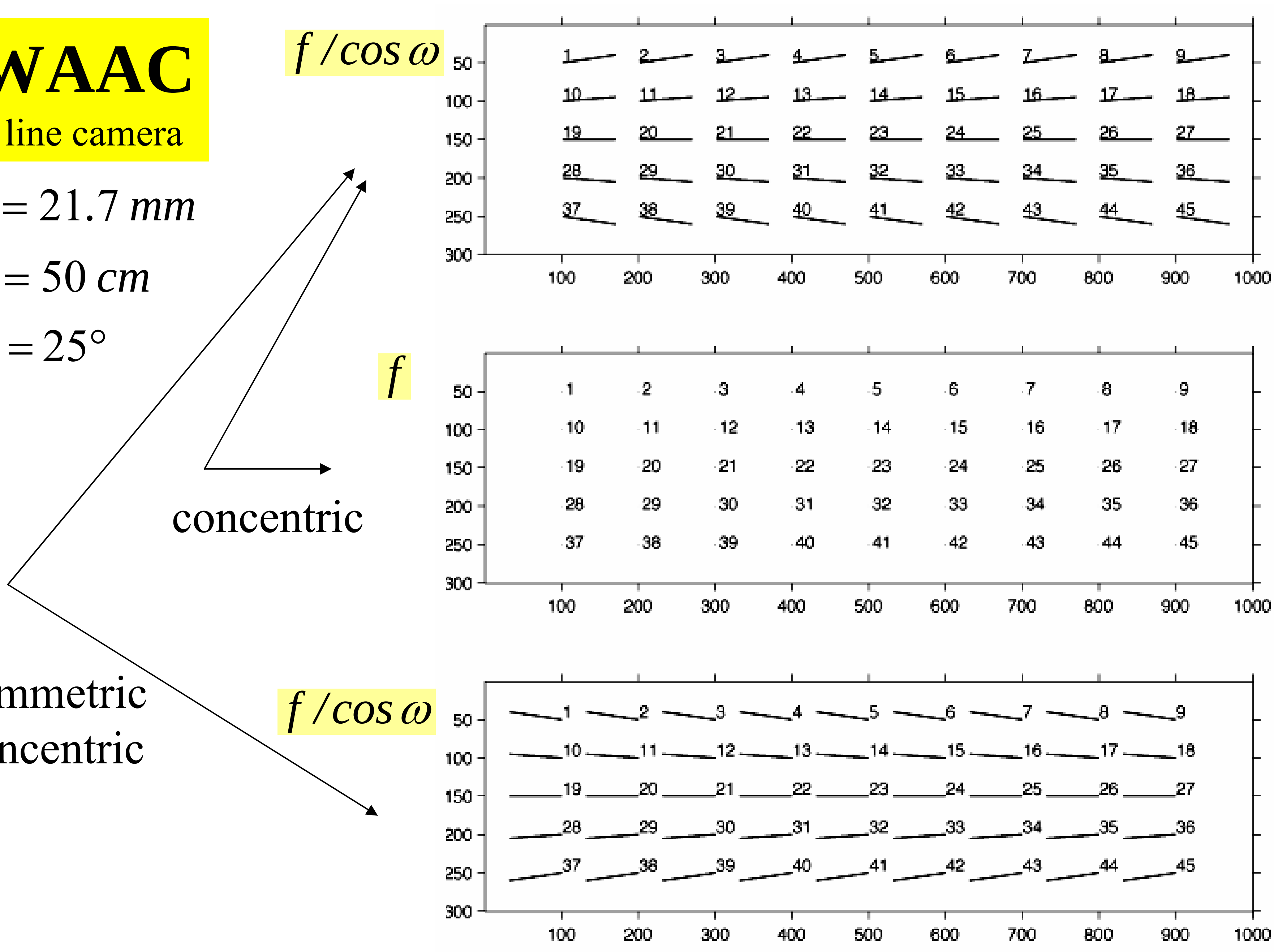
WAAC

3 line camera

$f = 21.7\ mm$

$R = 50\ cm$

$\omega = 25°$



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Stereo Matching

find corresponding points (along epipolar lines)

- **Correlation methods**

  still the most popular method in digital photogrammetry

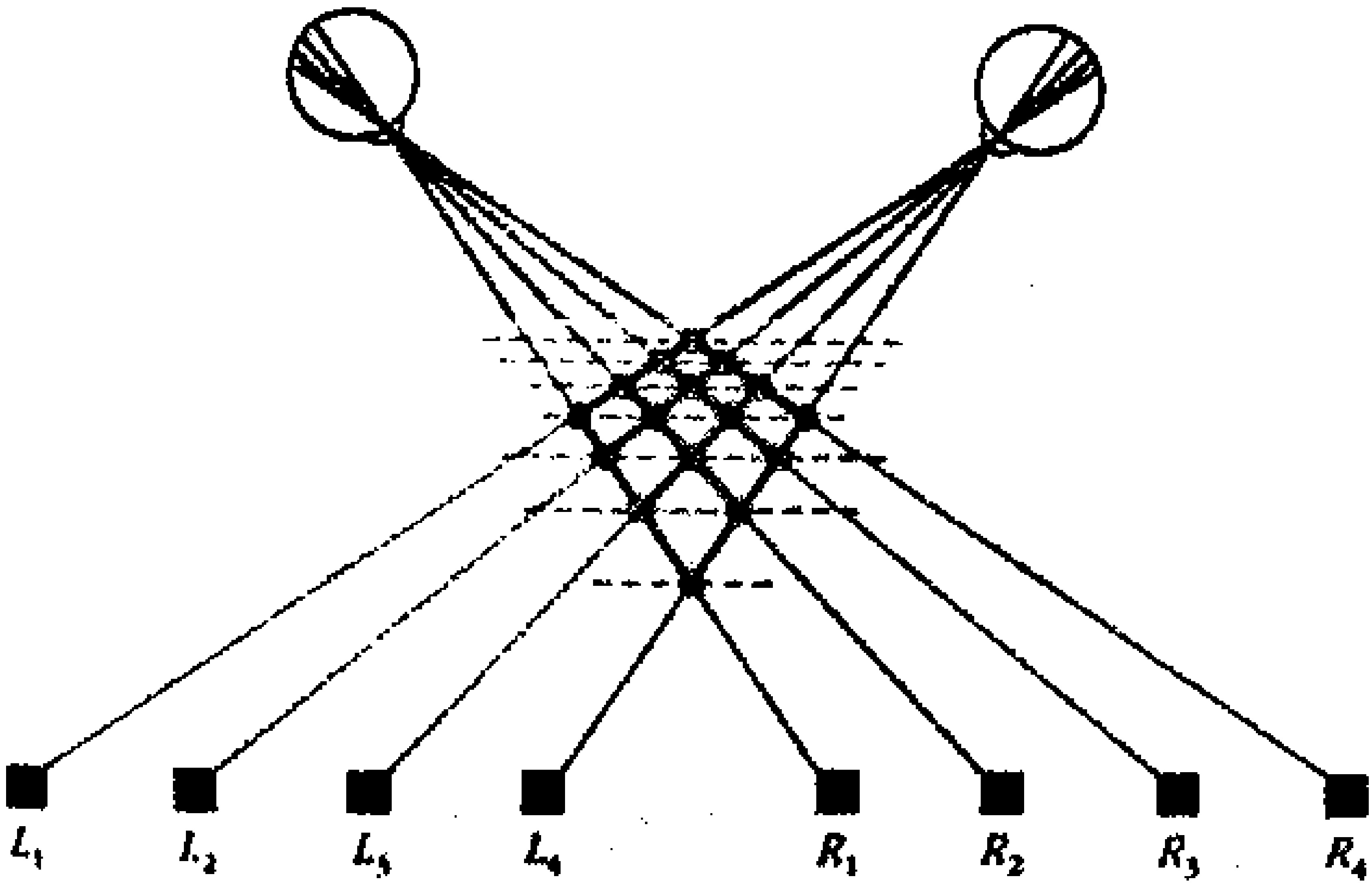
- **Global approaches**

  epipolar profiles are modelled by a Markov chain of transitions between neighboring nodes

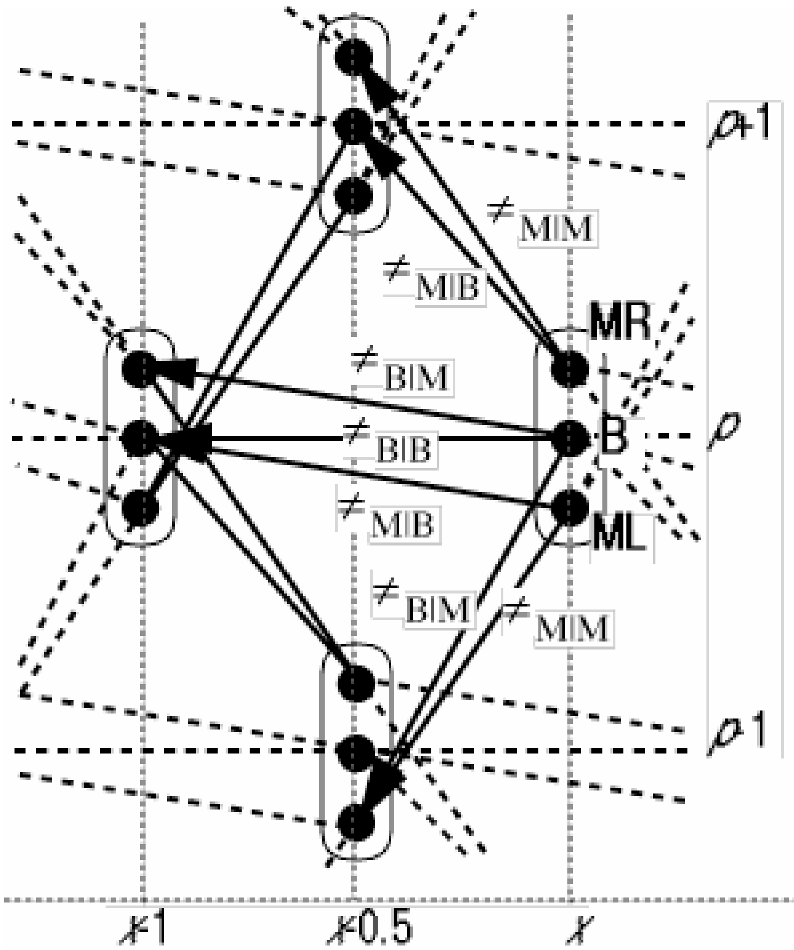
- **Probabilistic regularisation**

  search for epipolar lines having a maximum likelihood ratio

illposed problem : different profiles cause identical images



Graph of variants of the height profile



1979 **Georgy Gimel'farb** - *dynamic programming approach*

QuickTime?and a
Video decompressor
are needed to see this picture.

1999

WAAC **backward** and **nadir** image

(2400 x 2400 subwindows of larger images)

Symmetric dynamic programming stereo (SDPS) **reconstruction**

grey-coded range image
(DEM - *digital elevation map*)

cyclopean image
fusion of both images based on DEM

Visualisation

- DEM's
- Texture-mapped 2.5 D surfaces
- Animations (fly-through)
- High-resolution visualisation

2001 Example of a 3.5 Giga Byte panoramic image

7.5cm

times 64

7.5cm x 64 = 480 cm


times 32
PHILIPS


times 16


times 8


times 4


times 2
half of available resolution


times 64

EyeScan stereo pair of panoramas

(R = 0 and ω = 0)

very small window in **upper** and **lower** image

(40cm height difference on same tripod position)

SDPS reconstruction: grey-coded **DE M** and **cyclopean image**

QuickTime?and a
Microsoft Video 1 decompressor
are needed to see this picture.

Next step: improve panoramic 3D reconstruction by multi-view data surface simplification ->

<- **incremental surface visualisation**

Assume a given surface with n vertices and their neighborhoods, find a series of approximation surfaces with m vertices, $m = i, i{+}1, \ldots, n$, with $i > 0$), or find a series of approximation surfaces with approximation errors $\varepsilon_1 \geq \varepsilon_2 \geq \ldots \geq \varepsilon_m \geq 0$, for $m \leq n$.

P = projection of set of surface points into plane
N = two triangles in 3D enclosing P in the plane
V = set of vertices of N
until (approximation threshold satisfied)
  let $p \in P$ which introduces maximum error
  insert p into V and delete p in P
  N = Delaunay retriangulation of N

QuickTime?and a
Video decompressor
are needed to see this picture.

QuickTime?and a
decompressor
are needed to see this picture.

Shao-zheng Zhou

2000

Conclusions

exciting new technology

allowing to have

fully **digital photogrammetry**

and *new camera designs* ,

e.g. for **panoramic images** ,

for a *broad diversity of applications*,

with many new

theoretical challenges

(calibration, ….., stereo analysis)

THE END