On Integrating Omni-Directional Cameras with Pan-Tilt-Zoom Cameras for Visual Surveillance and Monitoring

PTZ

OD

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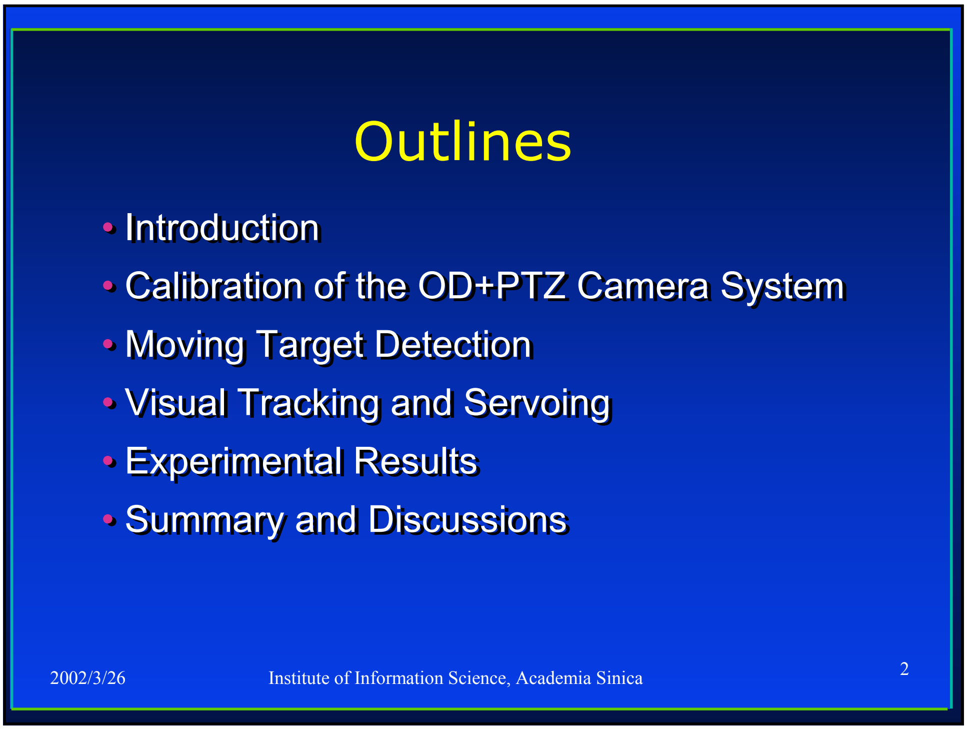
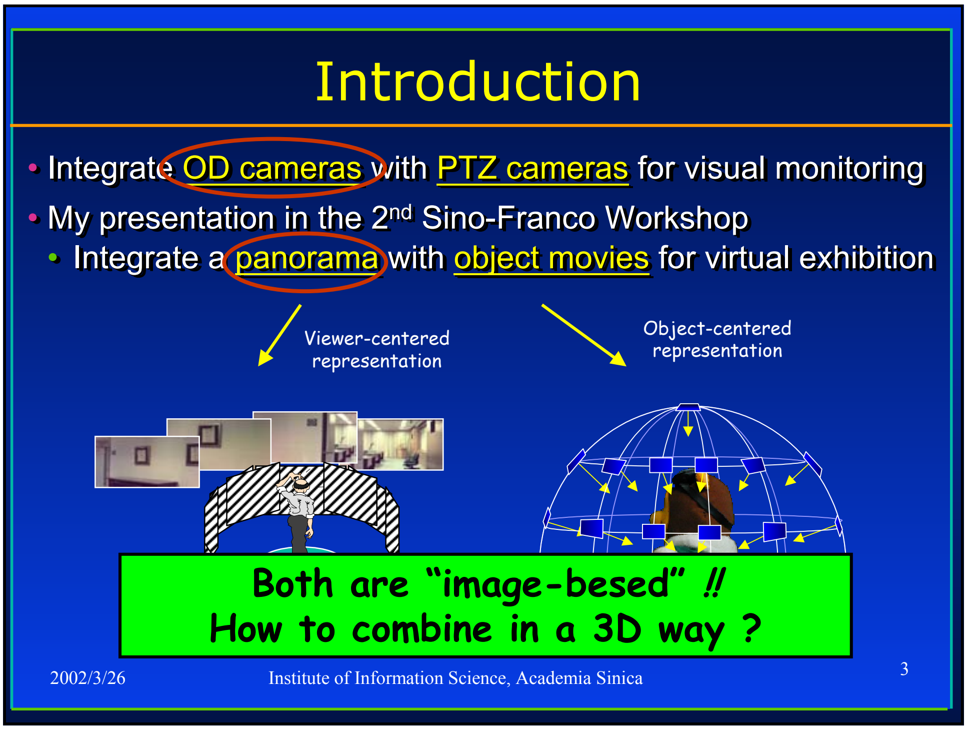


Outlines

- Introduction
- Calibration of the OD+PTZ Camera System
- Moving Target Detection
- Visual Tracking and Servoing
- Experimental Results
- Summary and Discussions



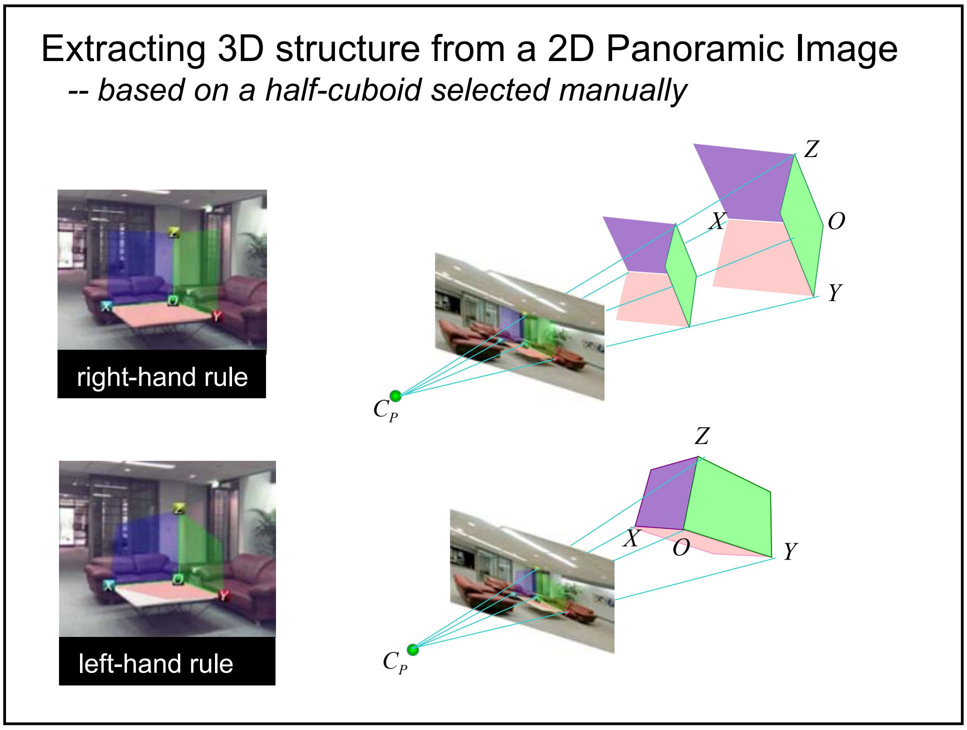
Introduction

- Integrate OD cameras with PTZ cameras for visual monitoring
- My presentation in the 2nd Sino-Franco Workshop
  - Integrate a panorama with object movies for virtual exhibition

Viewer-centered representation

Object-centered representation

Both are "image-besed" !!
How to combine in a 3D way ?



Extracting 3D structure from a 2D Panoramic Image

-- based on a half-cuboid selected manually

right-hand rule

left-hand rule

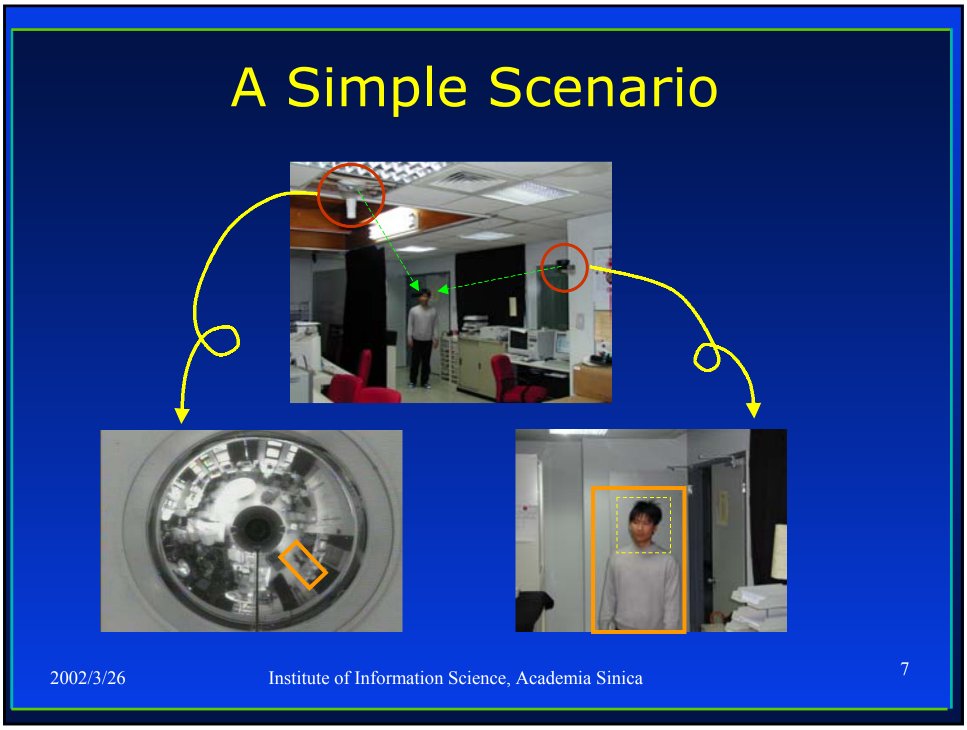
Demo Clips

- Authoring phase
- Browsing phase

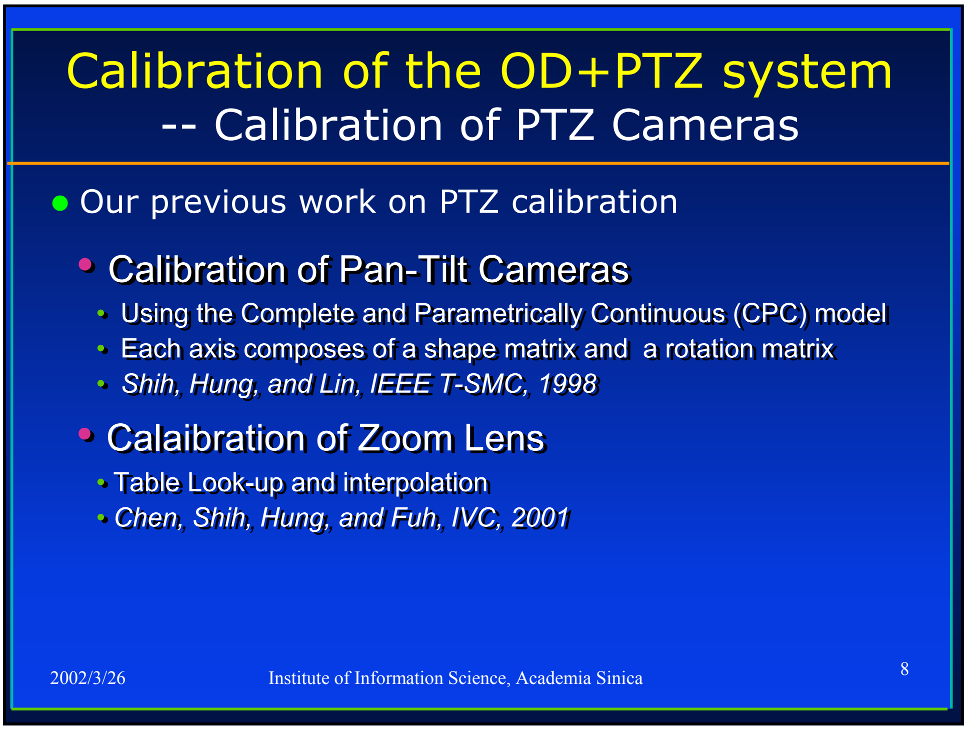
“Multi-Shot” vs “One-Shot” Panoramas

- In this work, use “one-shot” panoramic imaging sensors
  - PanoDome: a Omni-Directional (OD) camera manufactured by EeRise Co., Taiwan

Can be dewarped into one panorama image in real-time !

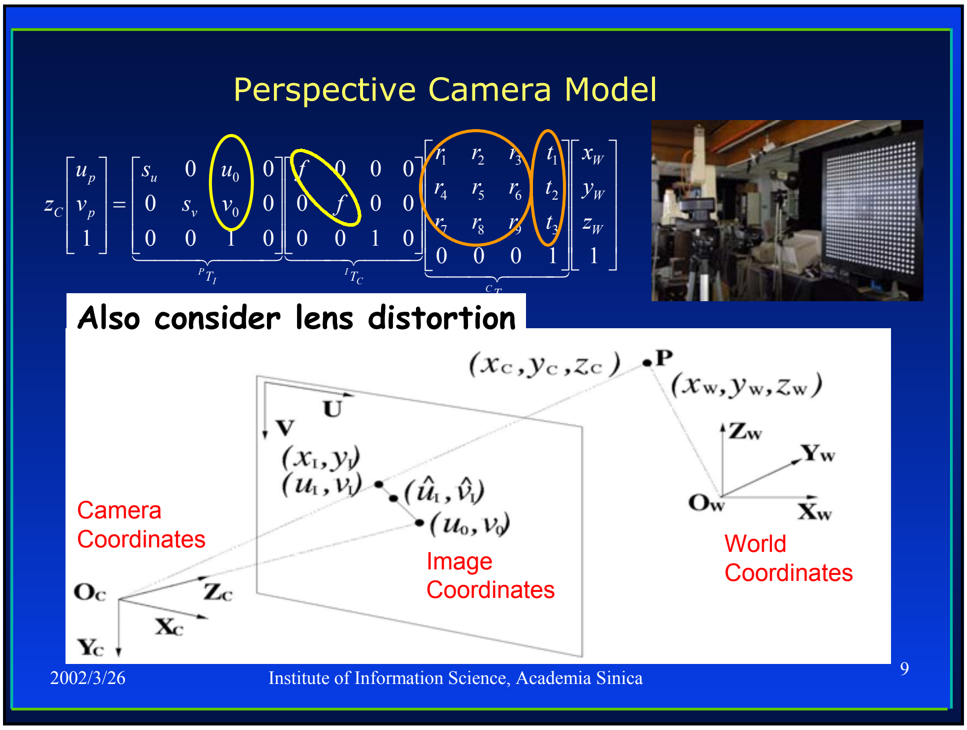


A Simple Scenario



Calibration of the OD+PTZ system
-- Calibration of PTZ Cameras

- Our previous work on PTZ calibration
  - Calibration of Pan-Tilt Cameras
    - Using the Complete and Parametrically Continuous (CPC) model
    - Each axis composes of a shape matrix and a rotation matrix
    - *Shih, Hung, and Lin, IEEE T-SMC, 1998*
  - Calaibration of Zoom Lens
    - Table Look-up and interpolation
    - *Chen, Shih, Hung, and Fuh, IVC, 2001*



Perspective Camera Model

$$z_C \begin{bmatrix} u_p \\ v_p \\ 1 \end{bmatrix} = \underbrace{\begin{bmatrix} s_u & 0 & u_0 & 0 \\ 0 & s_v & v_0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix}}_{{}^{P}T_{I}} \underbrace{\begin{bmatrix} f & 0 & 0 & 0 \\ 0 & f & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix}}_{{}^{I}T_{C}} \underbrace{\begin{bmatrix} r_1 & r_2 & r_3 & t_1 \\ r_4 & r_5 & r_6 & t_2 \\ r_7 & r_8 & r_9 & t_3 \\ 0 & 0 & 0 & 1 \end{bmatrix}}_{{}^{C}T} \begin{bmatrix} x_W \\ y_W \\ z_W \\ 1 \end{bmatrix}$$

Also consider lens distortion

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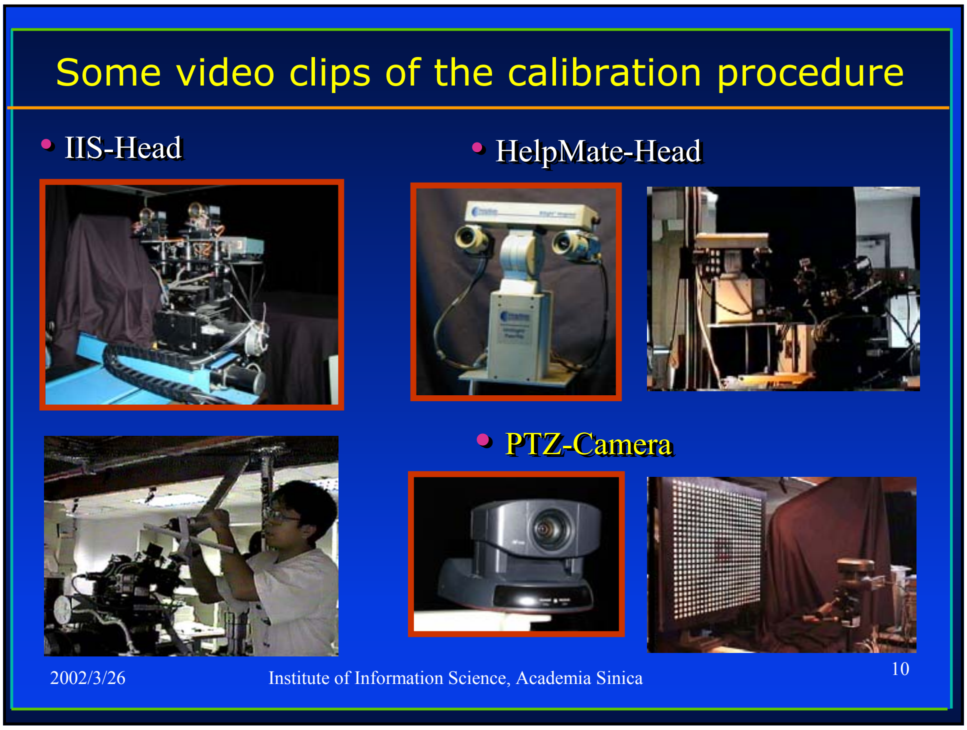

Some video clips of the calibration procedure

- IIS-Head
- HelpMate-Head
- PTZ-Camera

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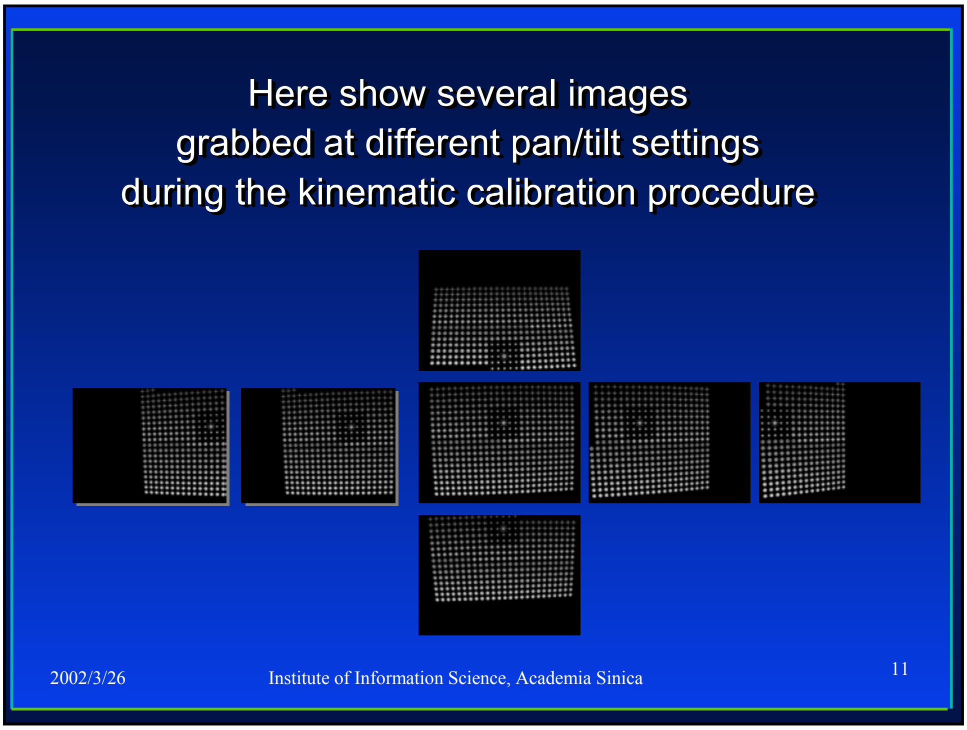
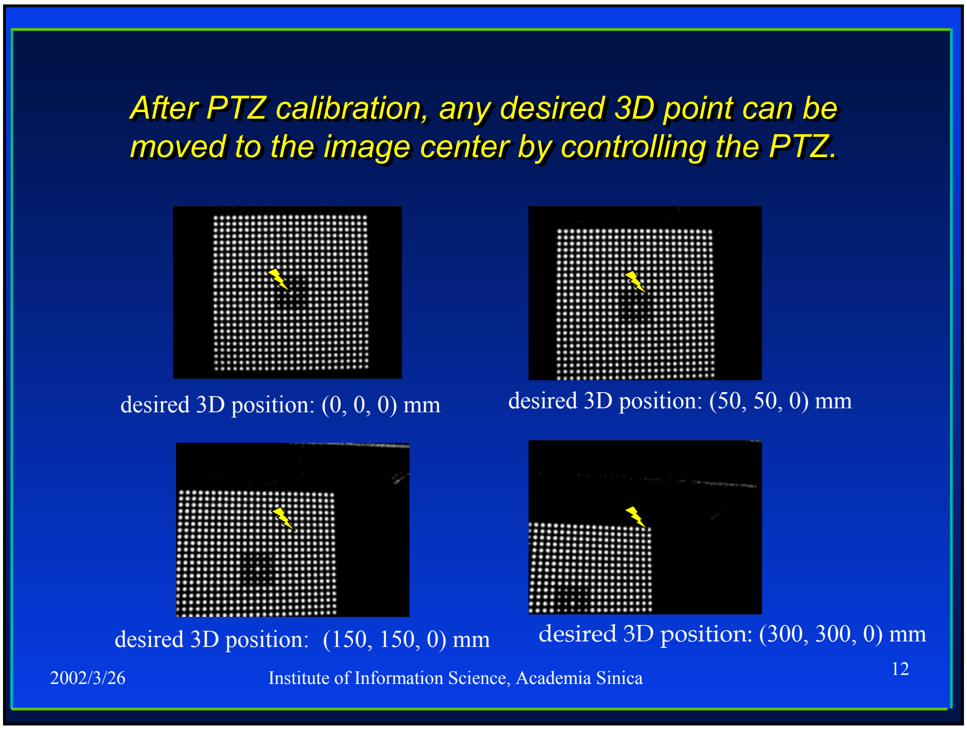


Here show several images grabbed at different pan/tilt settings during the kinematic calibration procedure



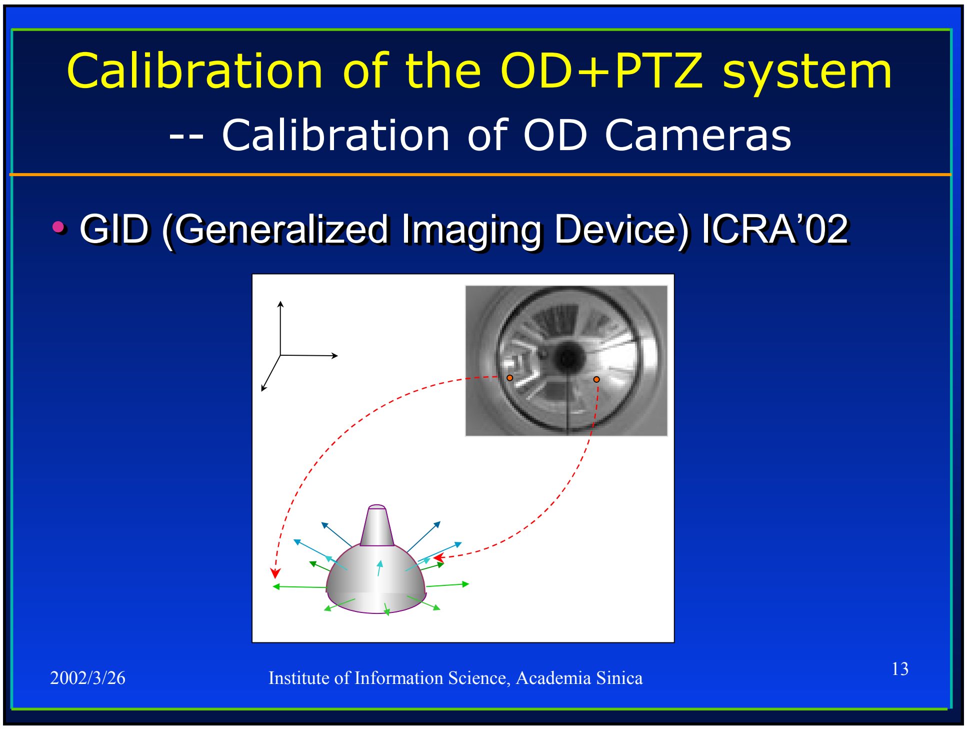
After PTZ calibration, any desired 3D point can be moved to the image center by controlling the PTZ.

desired 3D position: (0, 0, 0) mm

desired 3D position: (50, 50, 0) mm

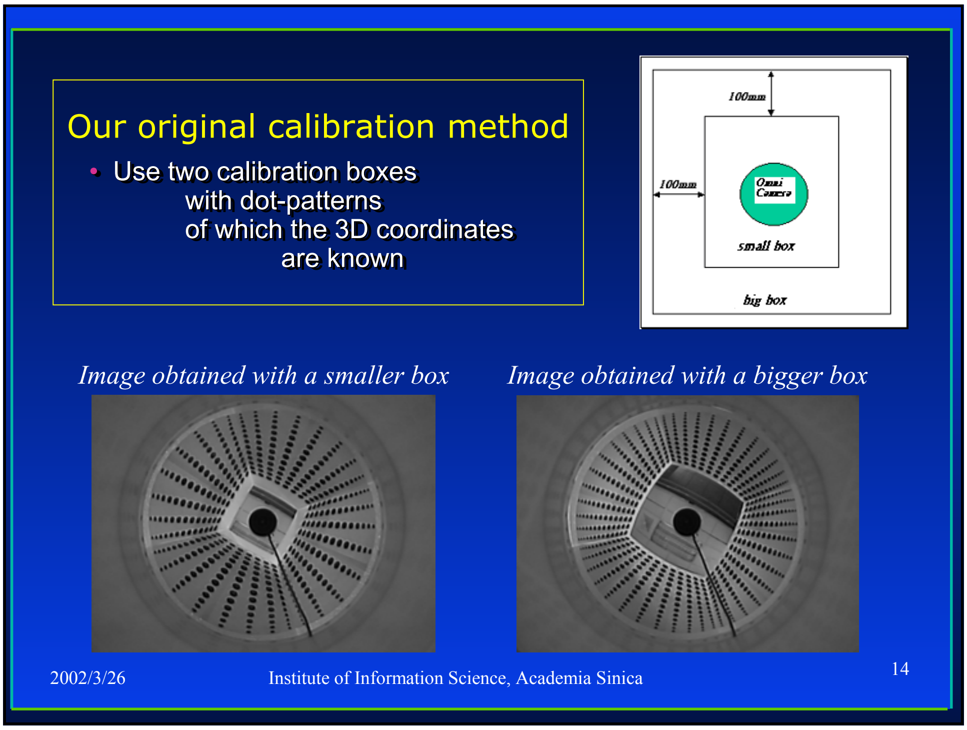
desired 3D position: (150, 150, 0) mm

desired 3D position: (300, 300, 0) mm



Calibration of the OD+PTZ system
-- Calibration of OD Cameras

- GID (Generalized Imaging Device) ICRA’02

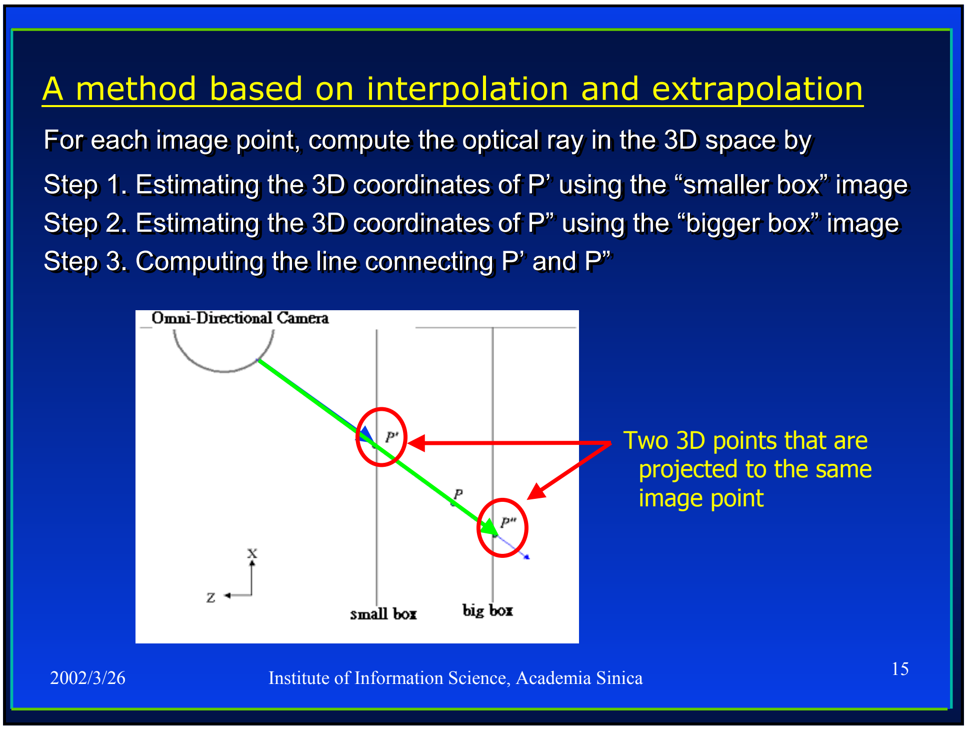


Our original calibration method

- Use two calibration boxes
  with dot-patterns
  of which the 3D coordinates
  are known

Image obtained with a smaller box

Image obtained with a bigger box



A method based on interpolation and extrapolation

For each image point, compute the optical ray in the 3D space by

Step 1. Estimating the 3D coordinates of P' using the "smaller box" image

Step 2. Estimating the 3D coordinates of P" using the "bigger box" image

Step 3. Computing the line connecting P' and P"

Two 3D points that are projected to the same image point

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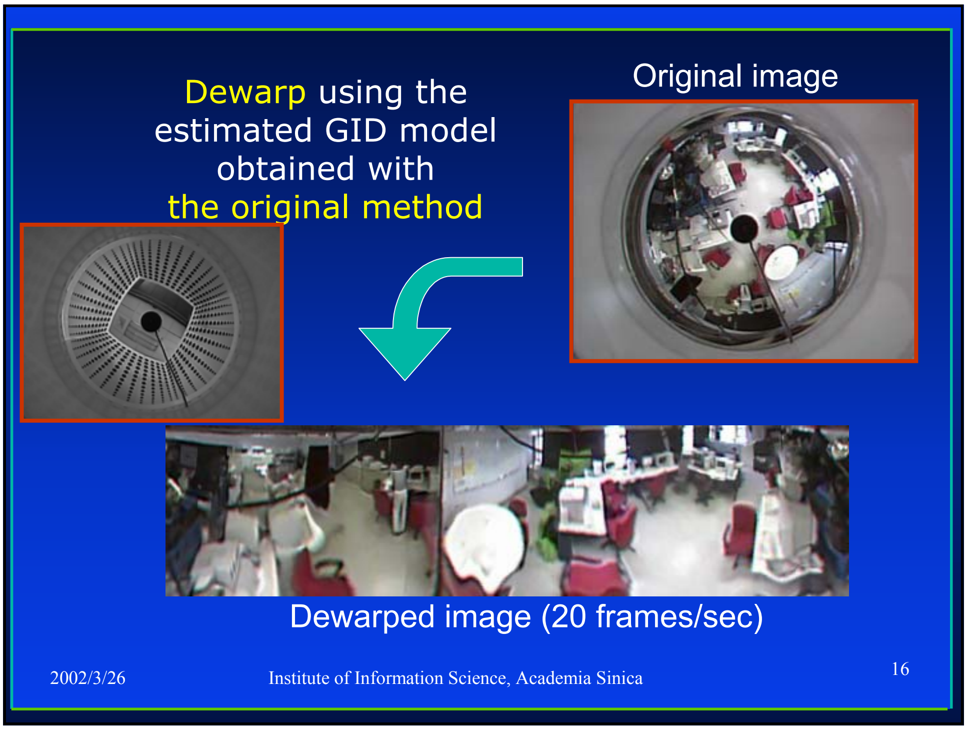

Dewarp using the estimated GID model obtained with the original method

Original image

Dewarped image (20 frames/sec)

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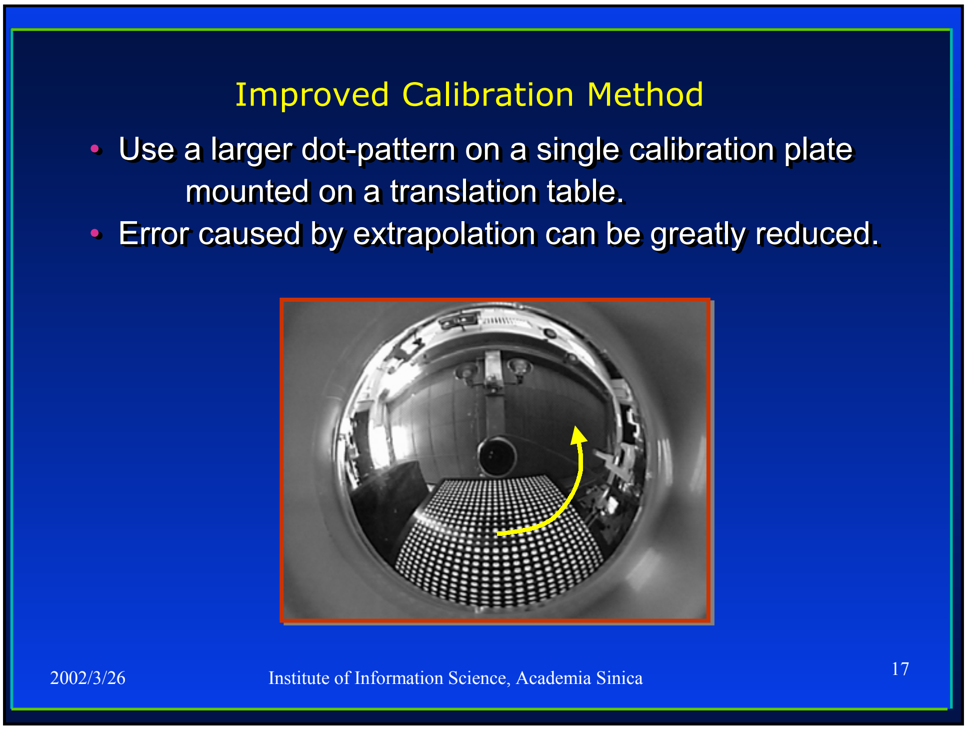
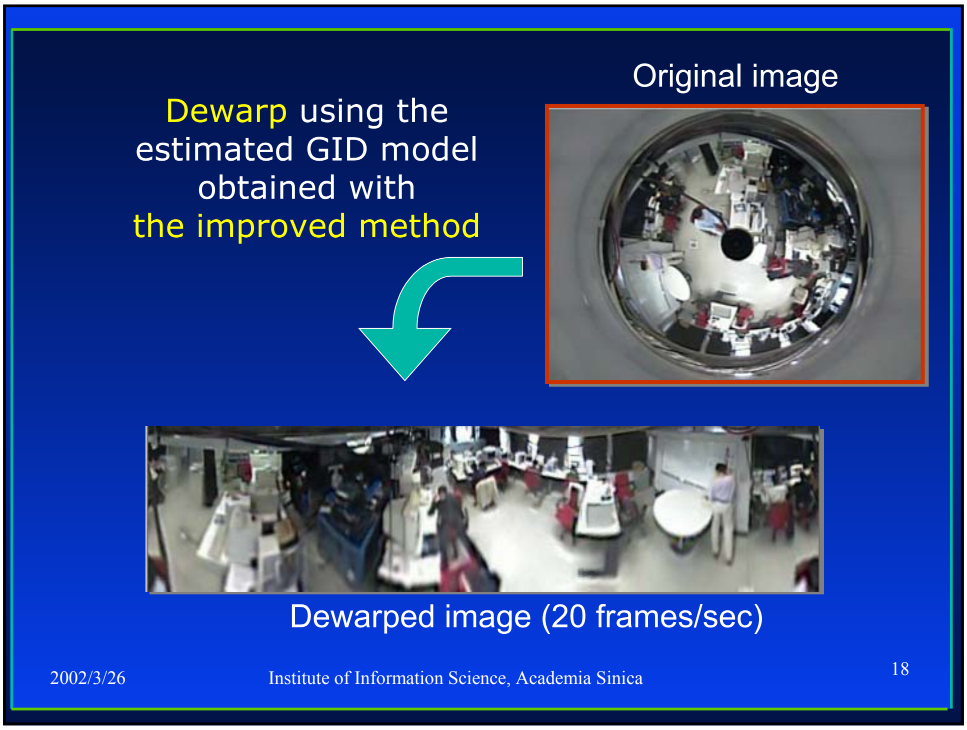


Improved Calibration Method

- Use a larger dot-pattern on a single calibration plate mounted on a translation table.
- Error caused by extrapolation can be greatly reduced.



Dewarp using the estimated GID model obtained with the improved method

Original image

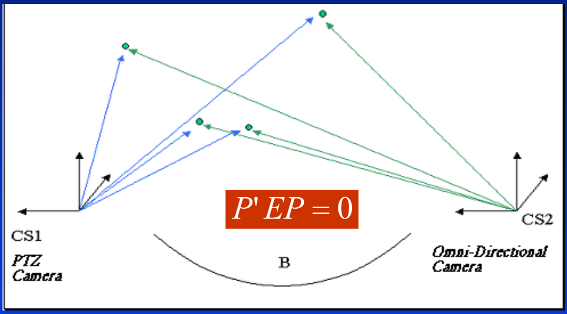
Dewarped image (20 frames/sec)

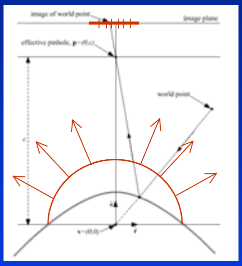
Calibration of the OD+PTZ system

-- Calibration of Relationship between OD Cameras and PTZ Cameras

1. Calibration with static PTZ

-- First, assume
OD camera is
perspective





Step1: Assume perspective OD
Fix the PTZ Camera
Grab image-pairs of 3D calibrating points
Estimate the essential matrix ***E***
Estimate the initial translation and rotation matrix by SVD

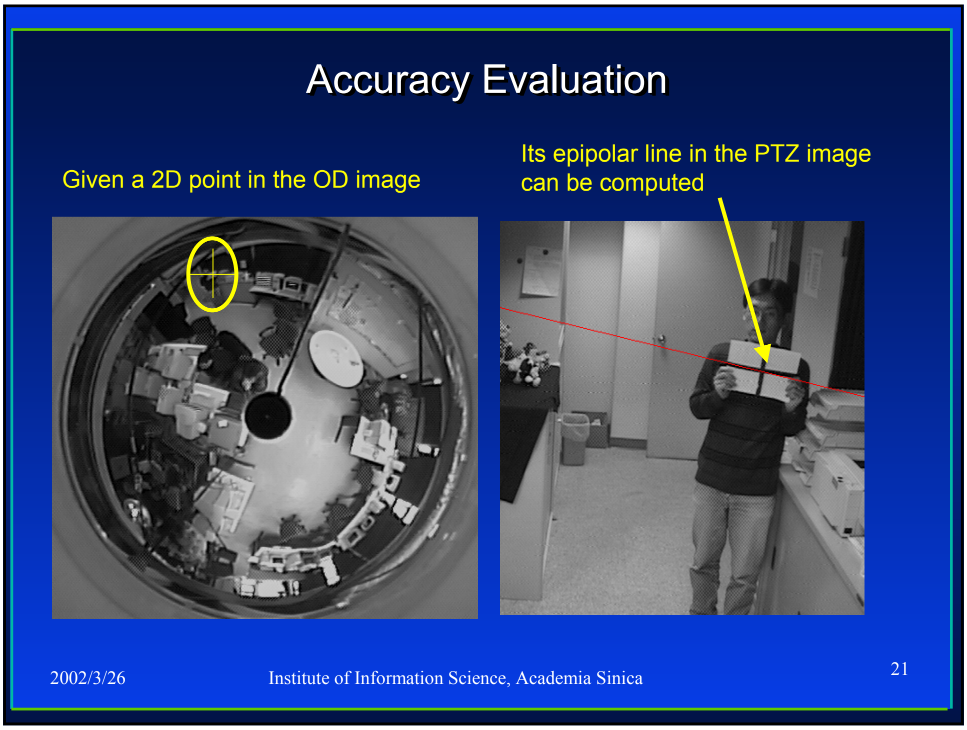
Step 2: Refine the rotation and translation by minimizing 3D distance between corresponding 3D rays without perspective assumption

Images acquired by the OD Camera

Set f to be a large number

Images acquired by the PTZ camera (*P*)

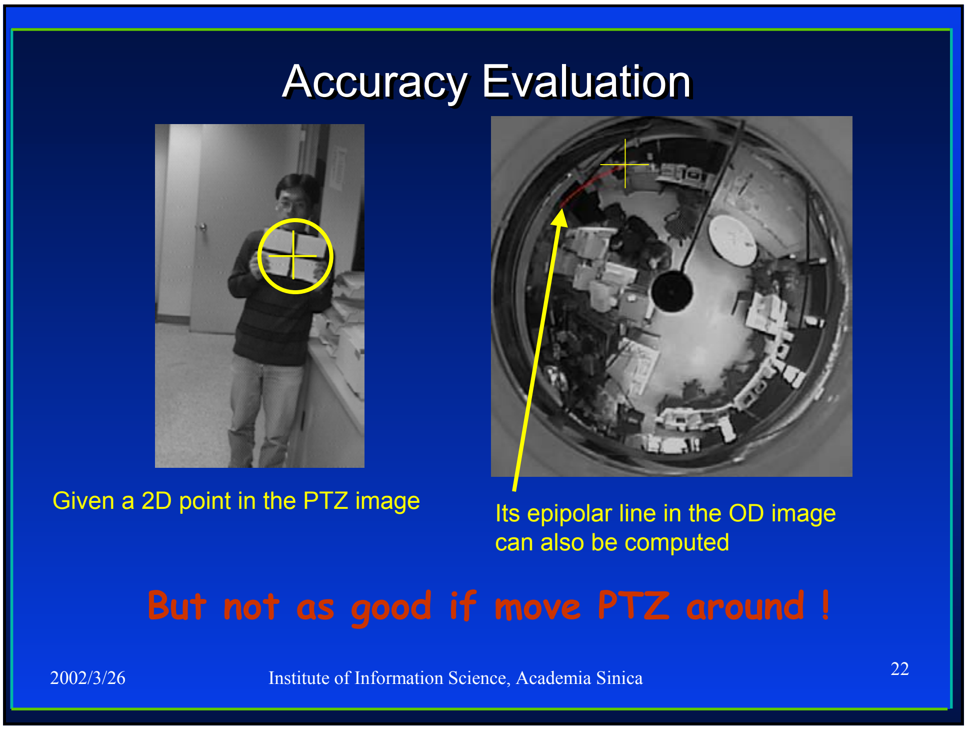
Projected image (*P'*)



Accuracy Evaluation

Given a 2D point in the OD image

Its epipolar line in the PTZ image can be computed



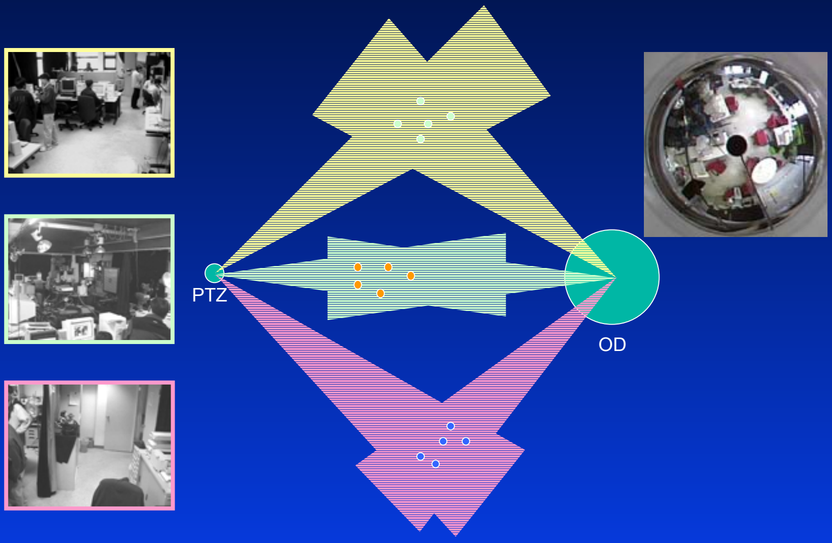
Accuracy Evaluation

Given a 2D point in the PTZ image

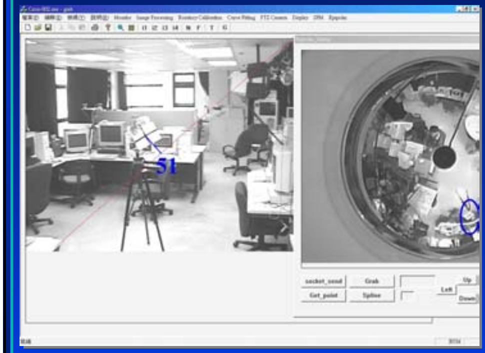
Its epipolar line in the OD image can also be computed

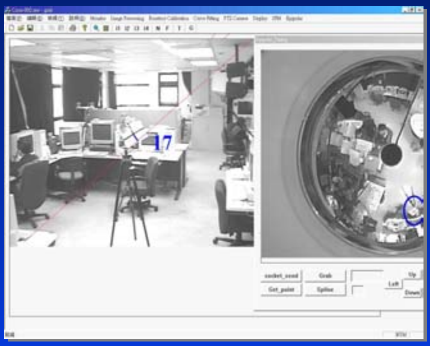
But not as good if move PTZ around !

Stage 2. Calibration with dynamic PTZ



An example of accuracy improvement





Before global optimization
→ error: 51 pixels

After global optimization
→ error: 17 pixels

Moving Object Detection
-- via Modeling the Background Statistically

- Adopt *non-parametric model* to learn the background
  - proposed by Larry Davis [*ECCV 2000*]
  - pixel-by-pixel operation
  - applied to images acquired by OD cameras
- Three issues are considered:
  1. Background modeling
  2. Suppression of false detection
     - *by considering the neighborhood*
  3. Background update
     - *long-term model: selective update*
     - *short term model: blind update*

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1. Background Modeling

- Pixel-by-pixel non-parametric modeling
  with Gaussian kernel:

$$P_r(x_t) = \frac{1}{\ }\sum^{N}\frac{1}{\sqrt{\ }\ {}_2}\, e^{-\frac{1}{2}\frac{(x_t-x_i)^2}{\sigma^2}}$$

A pixel is considered foreground if

2. Suppression of false detection

3. Background Update

- Short-term model
  - selective-update
    - *add the new sample to the model only if it is classified as a background sample.*
  - Update model with the most recent N background sample values.
- Long-term model
  - blind-update
    - *just add the new sample to the model*
  - This model captures a more stable representation of the scene background, and can used to adapt the lighting change.
- Final result: intersection of long-term and short-term results.

An Example on *Moving Object Detection*

Visual Tracking and Servoing

- Visual Tracking
  - Use color histogram to represent a target
  - Bhattacharyya coefficient & mean-shift
    - *Comaniciu, Ramesh, and Meer, CVPR'00*
  - Kullback-Leibler distance & trust-region
    - *Chen and Liu, ICCV'01*
- Visual Servoing
  - Image Jocobian
  - Fuzzy control

Representation of Target

- RGB color distribution
  - *based on weighted color histogram*

Target model

$$\hat{q}_u = C\sum_{i=1}^{n} k\left(\|\mathbf{x}_i\|^2\right)\delta[b(\mathbf{x}_i)-u],\ \mathbf{x}_i \in window$$

$$\text{where } C = \frac{1}{\sum_{i=1}^{n} k\left(\|\mathbf{x}_i\|^2\right)},\quad k(x) = \frac{1}{2\pi}e^{-\left(\frac{1}{2}x\right)}$$

$$\delta[b(\mathrm{x}_i)-u] = \begin{cases} 1, & when\ b(\mathrm{x}_i)=u \\ 0, & o.w. \end{cases},\ b(\mathrm{x}_i) \in \mathbf{z}\ (eg.\,(R,G,B))$$

Target candidate

$$\hat{p}_u(\mathbf{y}) = C_h\sum_{i=1}^{n} k\left(\left\|\frac{\mathbf{y}-\mathbf{x}_i}{h}\right\|^2\right)\delta[b(\mathbf{x}_i)-u]$$

$$\text{where } C_h = \frac{1}{\sum_{i=1}^{n} k\left(\left\|\frac{\mathbf{y}-\mathbf{x}_i}{h}\right\|^2\right)}$$

Bhattacharyya Coefficient

- Distance between these two distributions can be defined as

$$d(\mathbf{y}) = \sqrt{1 - \rho\left[\hat{p}(\mathbf{y}), \hat{q}\right]}$$

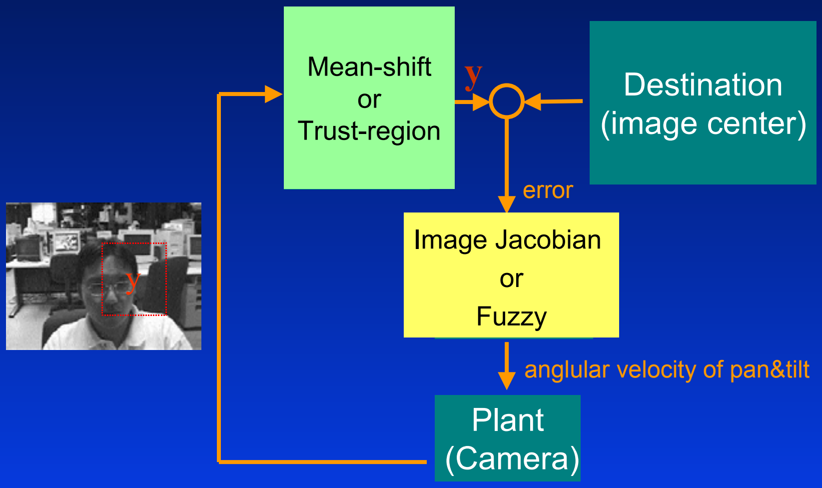
Bhattacharyya Coefficient

$$\rho(\mathbf{y}) \equiv \rho\left[\hat{p}(\mathbf{y}), \hat{q}\right] = \sum_{u=1}^{m} \sqrt{\hat{p}_u(\mathbf{y})\hat{q}_u}$$

- Finding the best match of $\mathbf{y}$ is formulated as minimizing the above distance or maximizing the Bhattacharyya coefficient

➔ Use either *mean-shift* or *trust-region*

Visual Servoing



Mean-shift or Trust-region

y

Destination (image center)

error

Image Jacobian or Fuzzy

anglular velocity of pan&tilt

Plant (Camera)

Some Experimental Results

* Target tracking using a fixed camera

* Target tracking using a PTZ camera

* Target tracking after integrating OD with PTZ

Summary and Discussions

- Calibration of OD+PTZ camera system:
  - OD calibration – used GID model
  - PTZ calibration – first PT calibration by CPC model,
    then Z calibration by table look-up
  - Calib of relationship – first with static PTZ, then with dynamic PTZ
- Moving object detection:
  - Adopted non-parametric background modeling
- Visual tracking:
  - Used either "Bhattacharyya coefficient & mean-shift"
    or "Kullback-Leibler distance & trust region"
- Visual servoing:
  - Used either image Jocobian or fuzzy control rule