



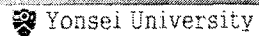
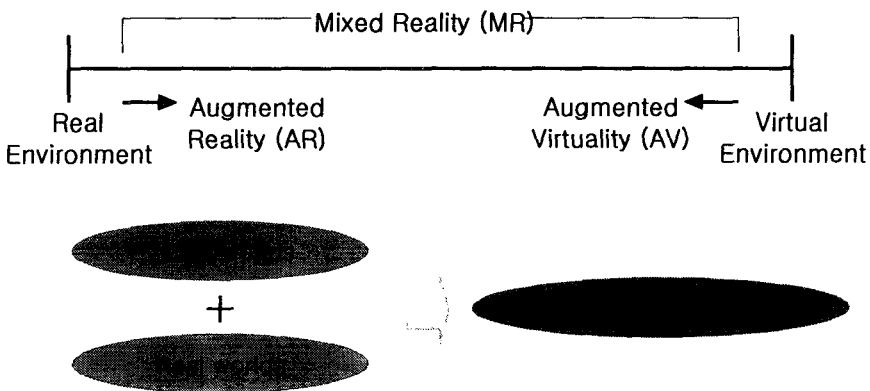
# 3차원 혼합현실 방송 콘텐츠 기술

연세대학교  
전기전자공학과  
손광훈

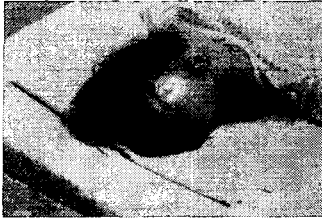


## Mixed Reality

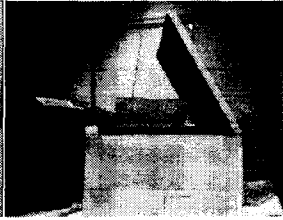
※ Mixed Reality



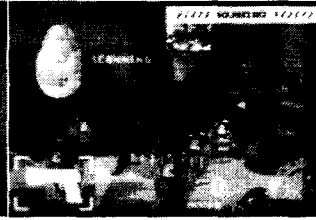
# Applications



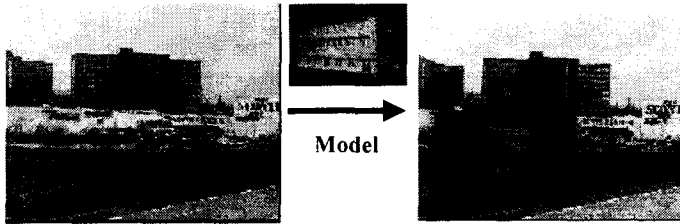
<Medical treatment>



<Hand-free manual>

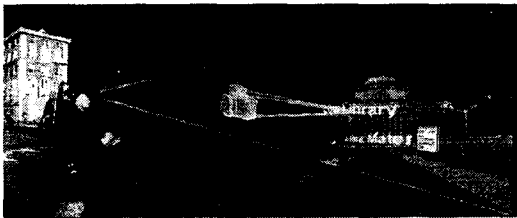


<simulated combat>

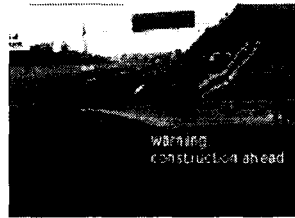


<Construction plan>

# Applications



<Public information>



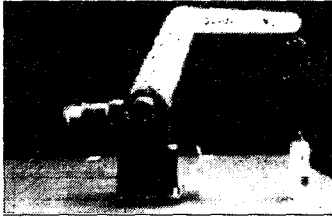
<Broadcasting>



# Applications



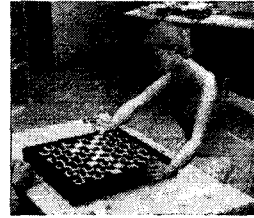
<Wearable computer>



<Robot path planning>



<Entertainment>

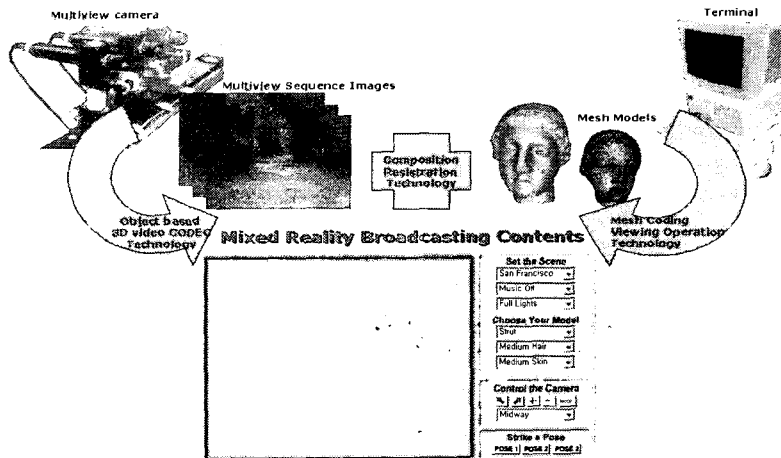


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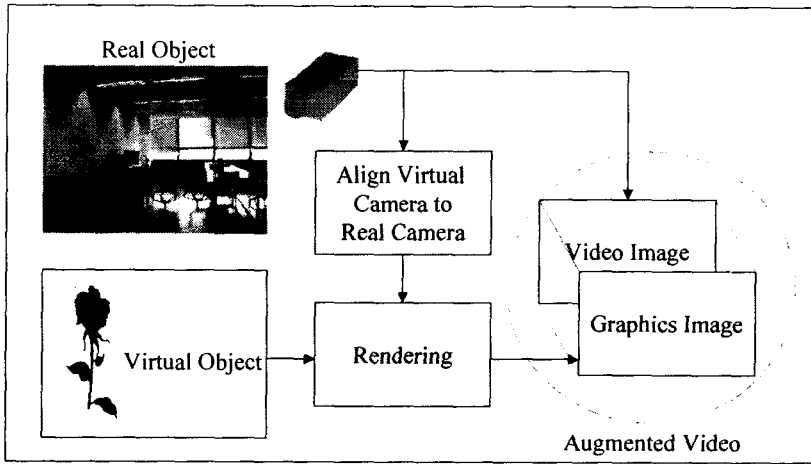
# Applications

## \*Interactive MR broadcasting system



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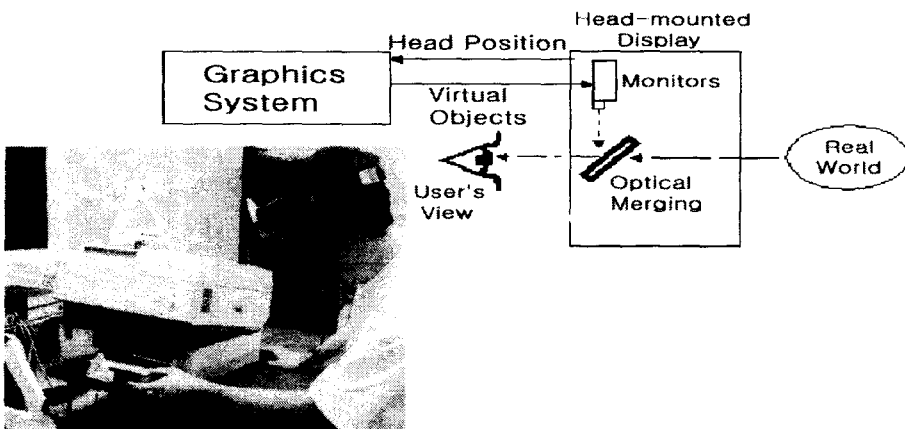
# Mixed Reality System



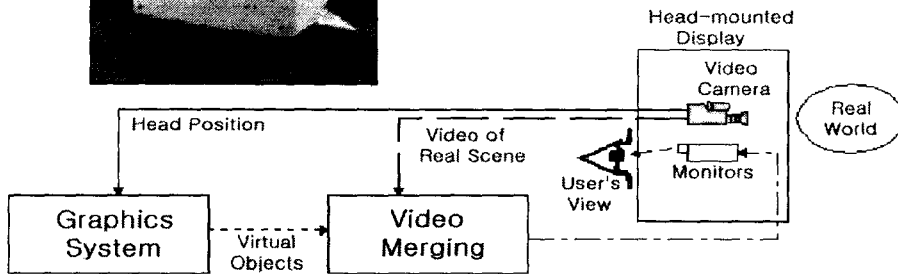
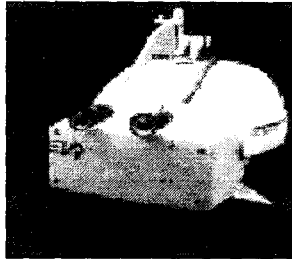
# MR System

※ Display Device

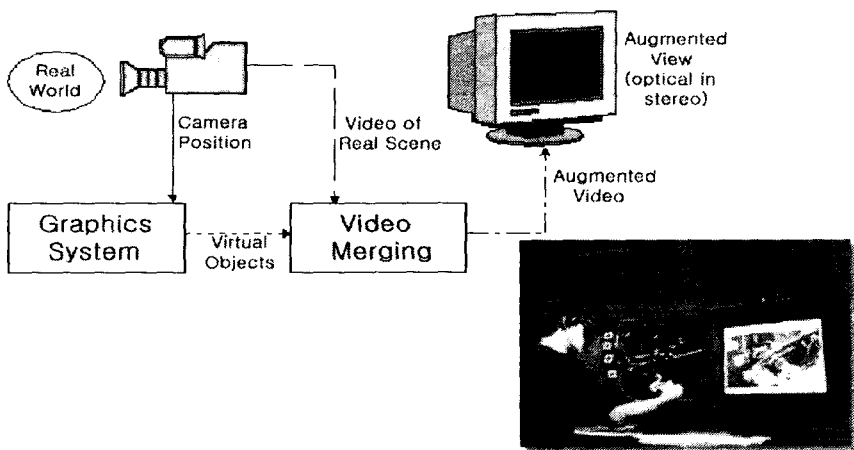
▪ Optical see-through HMD



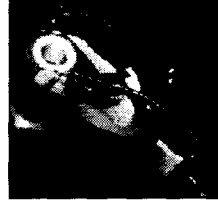
## ▪ Video see-through HMD



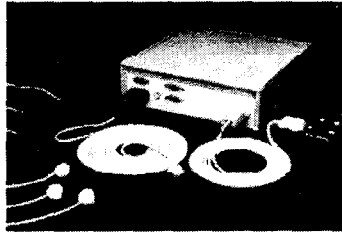
## ▪ Stereo glasses-Monitor Based System



✧ Haptic device



✧ Tracking Device



✧ 3D?

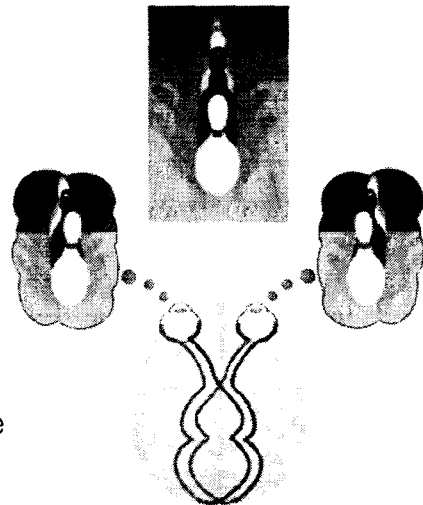
- 2D = width + height
- 3D = 2D + depth  
Increase reality

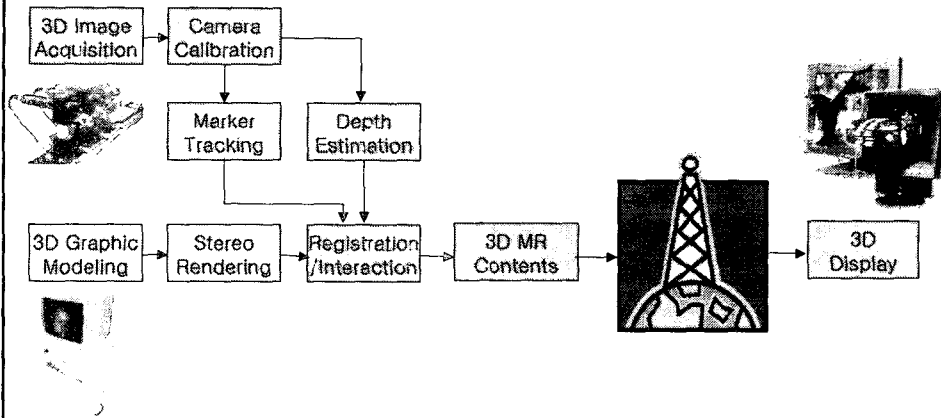
✧ Human perception

- Two eyes + Brain  
two 2D images      a 3D view

✧ 3D video sequence

- Left eye view sequence  
+ Right eye view sequence

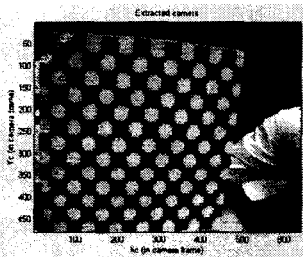




- \* Virtual Object Generation
  - 3D Modeling & Photorealistic Rendering
- \* Camera Calibration & Image analysis
  - Camera calibration
  - Feature extraction
  - Depth estimation
- \* Marker tracking & Registration
  - Realtime marker tracking
  - Object registration
- \* Synthesis & Interaction
  - Media Synchronization
  - HCI
  - Mutual interaction between real and virtual world

# Camera Calibration

- \* The extrinsic parameters
  - Translation matrix, T
  - Rotation matrix, R
- \* The intrinsic parameters
  - Focal length, f
  - The location,  $(u_x, v_y)$
  - Effective pixel size  $(s_x, s_y)$
  - The radial distortion coefficient, k(or  $\theta$ )



```

Repeat until satisfied (exit aspect ratio = 1) -> both components of f are estimated (OFFLINE)
Principal point optimized (under optimization) (ONLINE) -> to reject principal point, set corner options
then set optimized exit aspect ratio = 1 (OFFLINE)
Distortion not fully estimated (checked by the variable exit_ratio)
Check corner detection and estimated first distortion (ONLINE)
then estimation of the principal point of the center of the image
Initialization of the image distortion to zero
Initialization of the intrinsic parameters using the matching points of planar pattern.
Initialization of the reference parameters. Number of images: 20

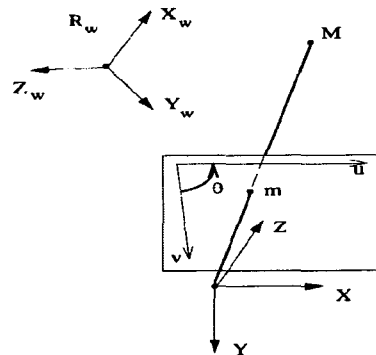
Calibration parameters after initialization
Focal length:   fx = 0.0010000  0.0010000
Principal point:  cx = 0.0000000  0.0000000
Skew:          alpha = 0.0000000  0.0000000
Distortion:     k1 = 0.0000000  0.0000000  0.0000000  0.0000000
Main calibration optimization program:  Number of images: 20
Number of used iterations: 1000  0.0000000  0.0000000  0.0000000  0.0000000
Termination of optimization:  done

Calibration results after optimization (with uncertainties):
Focal length:   fx = 0.0010000  0.0010000  0.0010000  0.0010000
Principal point:  cx = 0.0000000  0.0000000  0.0000000  0.0000000
Skew:          alpha = 0.0000000  0.0000000  0.0000000  0.0000000
Distortion:     k1 = 0.0000000  0.0000000  0.0000000  0.0000000
Principal error:  err = 0.0000000  0.0000000
Note: the numerical errors are approximately three times the standard deviation (for reference).
Recommendation: some distortion coefficients are found equal to zero (within their uncertainties).
To reject them from the optimization set exit ratio (EXIT_RATIO) and run calibration
    
```

# Camera Calibration

- \* Camera model and stereo geometry
  - maps a 3D point to 2D image point

$$\begin{bmatrix} x \\ y \\ s \end{bmatrix} = \mathbf{A} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \mathbf{D} \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix} = \mathbf{P} \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix}$$



- P : perspective projection matrix
- S : scale parameter
- A : intrinsic parameters matrix
- D : extrinsic parameters matrix



# Camera Calibration

$$A = \begin{bmatrix} f \cdot k_u & f \cdot k_u \cdot \cot \theta & u_0 \\ 0 & f \frac{v}{\sin \theta} & v_0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$D = \begin{bmatrix} \mathbf{R} & \mathbf{t} \\ \mathbf{0}_3^T & 1 \end{bmatrix}$$

where:

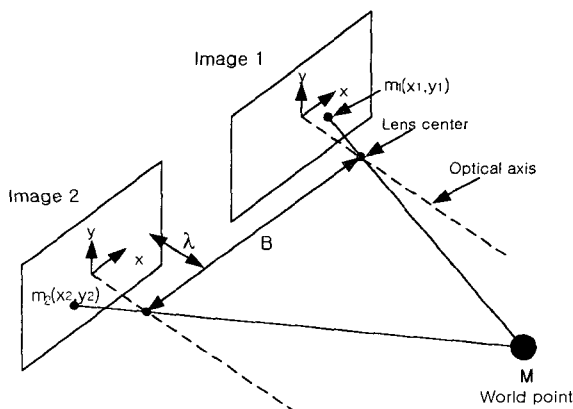
- $f$ : focal length
- $k_u, k_v$ : scale factors
- $u_0, v_0$ : principal points
- $\theta$ : angle between retina axes

where:  $\mathbf{R}$ :  $3 \times 3$  rotation matrix  
 $\mathbf{t}$ :  $3 \times 1$  translation vector

=>If we know both the intrinsic and extrinsic parameters of the stereo system, we can reconstruct the 3D location of the point  $M$  from  $m_1$  and  $m_2$

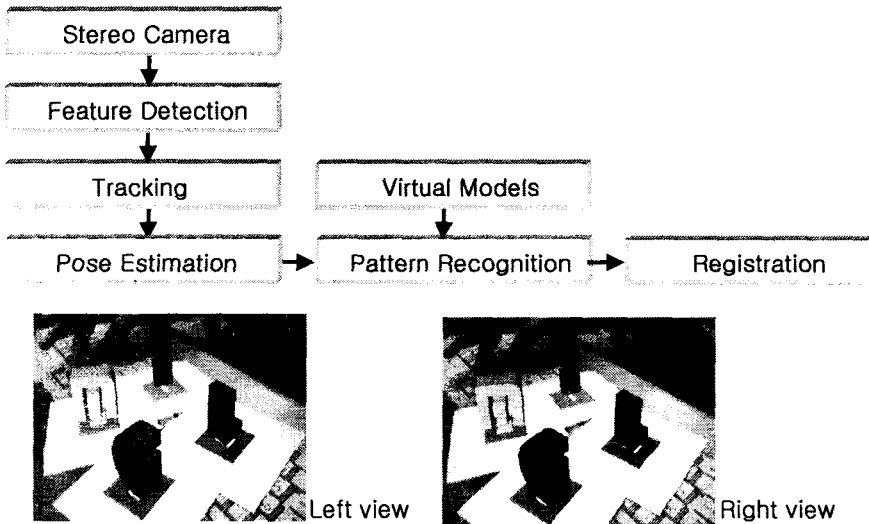
# Camera Calibration

\* Simple case of a parallel camera system

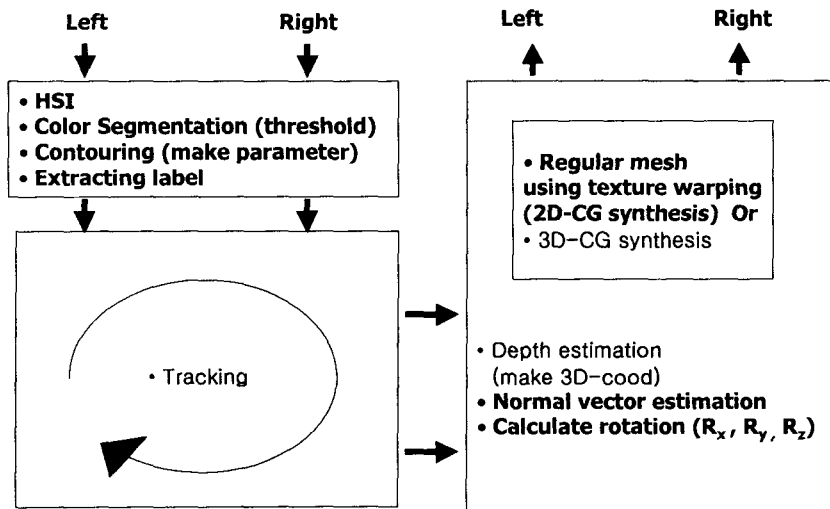


$$Z = \lambda \frac{\lambda B}{x_2 - x_1}$$

# Marker tracking & Registration

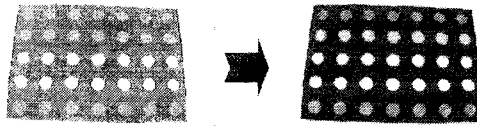


# Multimarker-based MR system

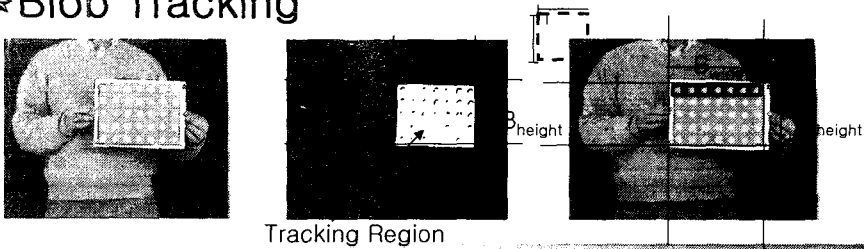


# DTM- Multimarker-based MR system

\*HIS color enhancement



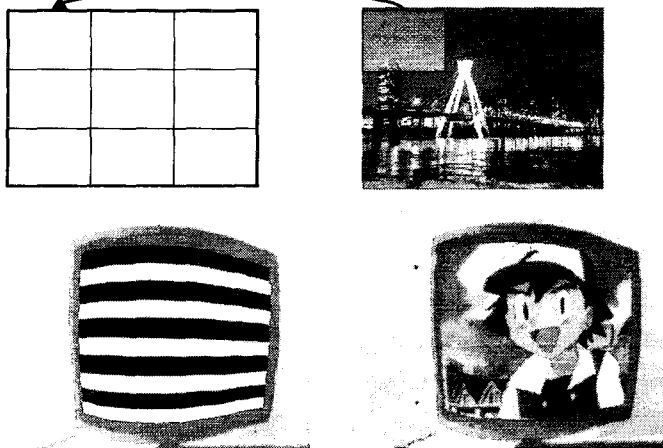
\*Blob Tracking



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# DTM- Multimarker-based MR system

\*Texture warping using regular mesh

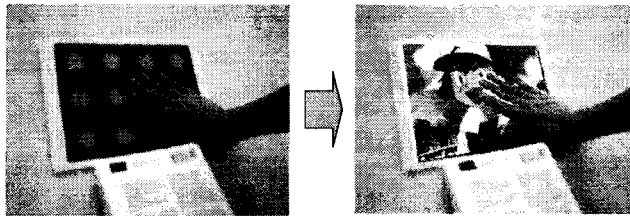


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## DIML Multimarker-based MR system

### \*Lost Marker Estimation and Occlusion

- Lost blob position estimation from the rest of the blobs
- Synthesis using Depth data

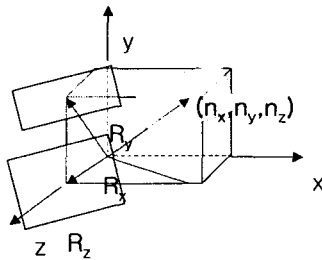


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## DIML Multimarker-based MR system

### \*3D Object Registration

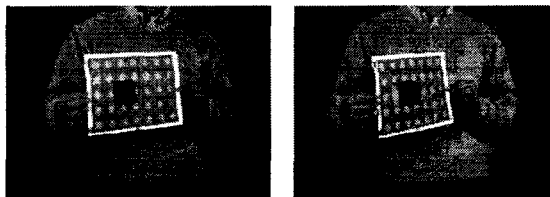
- Calculate the surface normal vector



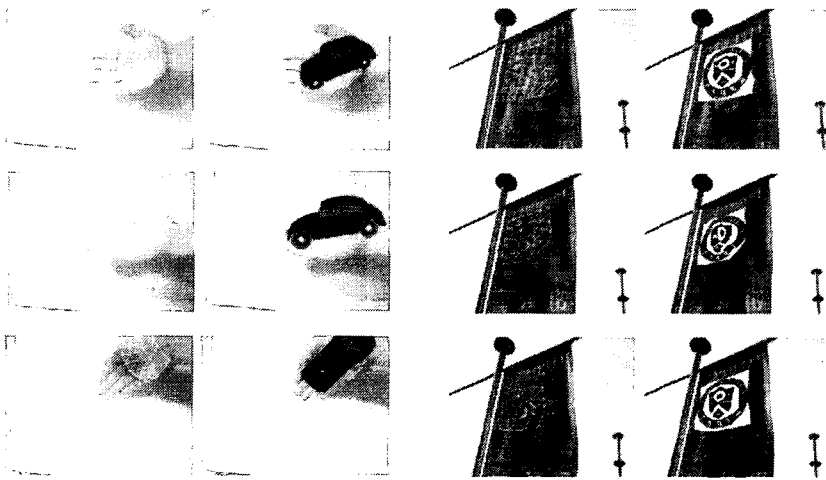
$$R_x = a \cos(n_z / \sqrt{(n_y^2 + n_z^2)})$$

$$R_y = a \cos(n_z / \sqrt{(n_x^2 + n_z^2)})$$

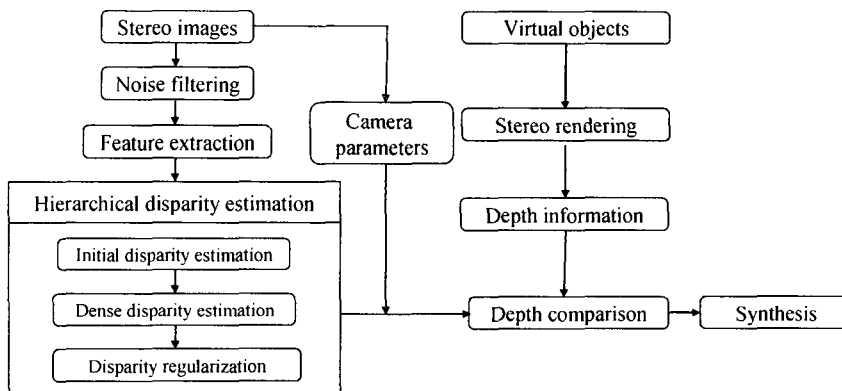
$$R_z = a \cos(\sqrt{(y_2^2 - y_1^2)} / \sqrt{(x_2^2 - x_1^2)})$$



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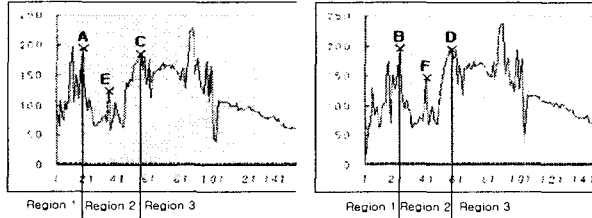


## \* Block diagram

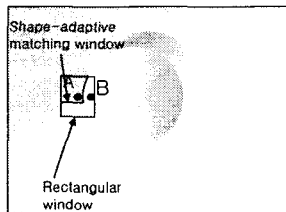


## \* Disparity estimation

- Region-dividing technique



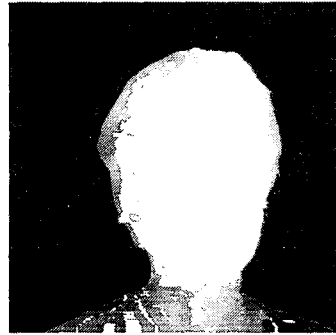
- Shape-adaptive matching windows



## \* Hierarchical disparity estimation

- Initial Disparity Estimation
  - Block-based disparity estimation in the subsampled images
  - The region-dividing technique
- Dense Disparity Estimation
  - Pixel-based estimation in full resolution images
  - The region-dividing technique and the shape-adaptive window technique

## \* Dense disparity with occlusion



## \* Disparity regularization

- ★ The resultant disparity vector map should be smooth and detailed
  - continuous surfaces should produce smooth disparity map
  - preserves its discontinuities at the object boundaries
- Regularization of the vector fields
  - By minimizing the proposed energy functional

$$E(d(r)) = \int_{\Omega} (I_1(r) - I_2(r + d(r)))^2 dr + \lambda \int_{\Omega} \psi(\nabla d(r), \nabla I_1(r)) dr$$

## Depth estimation

- $\psi(\nabla d, \nabla I_1)$  is a potential function whose gradient is given by :

$$\nabla(\psi(\nabla d, \nabla I_1)) = g(|\nabla I_1|^2) \nabla d$$

- Associated PDE (with the Neumann boundary conditions)

$$\frac{\partial d}{\partial t} = \lambda \operatorname{div}(g(|\nabla I_1|^2) \nabla d) + (I_1(r) - I_2(r+d)) \nabla I_2(r+d)$$

- Diffusion tensor

$$g(s^2) = \frac{1}{(1+s^2)^2}$$

## Depth estimation

### \* Numerical approximation

$$\begin{aligned} \frac{d^{k+1}(x,y) - d^k(x,y)}{\tau} = & \lambda \left\{ \frac{\partial}{\partial x} \left( g \left( \left| \frac{\partial I_1(x,y)}{\partial x} \right| \right) \times \frac{\partial d^k(x,y)}{\partial x} \right) + \frac{\partial}{\partial y} \left( g \left( \left| \frac{\partial I_1(x,y)}{\partial y} \right| \right) \times \frac{\partial d^k(x,y)}{\partial y} \right) \right\} \\ & + (I_2(x+d^k(x,y), y) - I_1(x,y)) \times \frac{\partial I_2(x+d^k(x,y), y)}{\partial x} \\ & + (d^k(x,y) - d^{k+1}(x,y)) \times \left( \frac{\partial I_2(x+d^k(x,y), y)}{\partial x} \right)^2 \end{aligned}$$

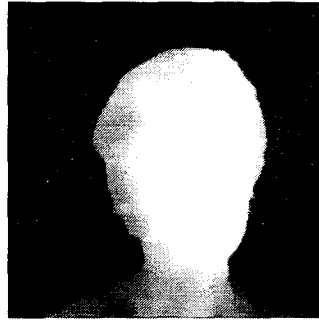
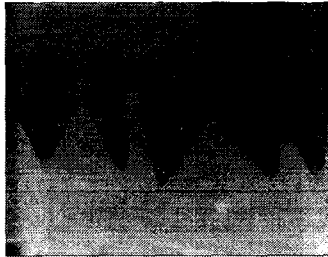
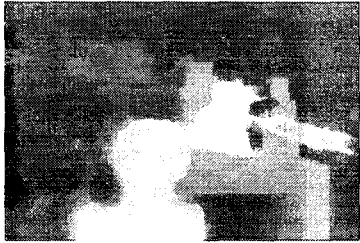
- Iterative solver

$$\begin{aligned} d^{k+1}(x,y) = & d^k(x,y) + \frac{\tau}{1 + \tau \left( \frac{\partial I_2(x+d^k(x,y), y)}{\partial x} \right)^2} \\ & \times \left[ \lambda \left\{ \frac{\partial}{\partial x} \left( g \left( \left| \frac{\partial I_1(x,y)}{\partial x} \right| \right) \times \frac{\partial d^k(x,y)}{\partial x} \right) + \frac{\partial}{\partial y} \left( g \left( \left| \frac{\partial I_1(x,y)}{\partial y} \right| \right) \times \frac{\partial d^k(x,y)}{\partial y} \right) \right\} \right. \\ & \left. + (I_2(x+d^k(x,y), y) - I_1(x,y)) \times \frac{\partial I_2(x+d^k(x,y), y)}{\partial x} \right] \end{aligned}$$



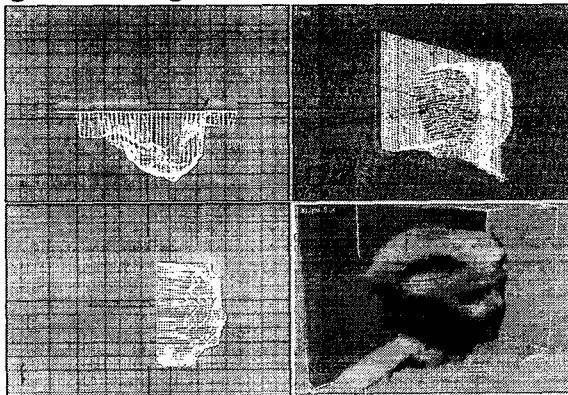
## Depth estimation

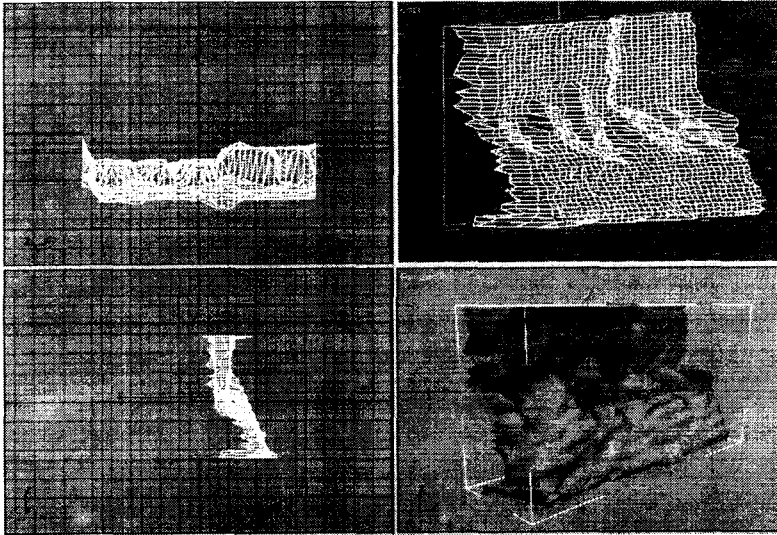
- \* Final disparity map



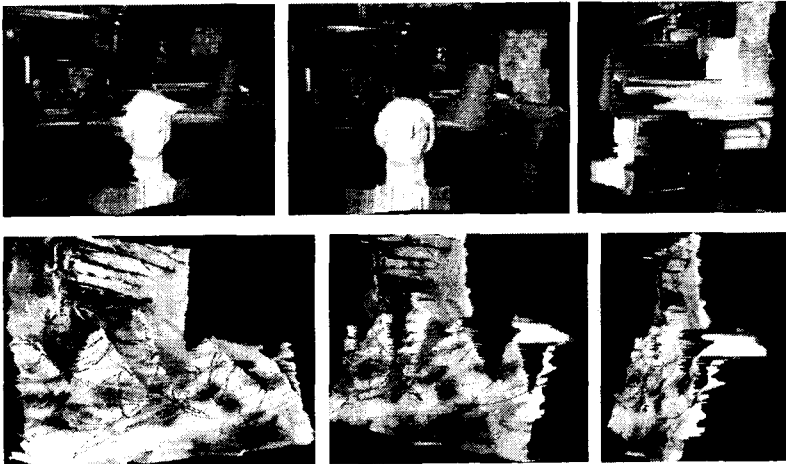
## 3D Reconstruction

- \* Reconstruct 3D model with 3D MAX
  - Estimated depth map=>displace map
  - Original image=>diffuse map





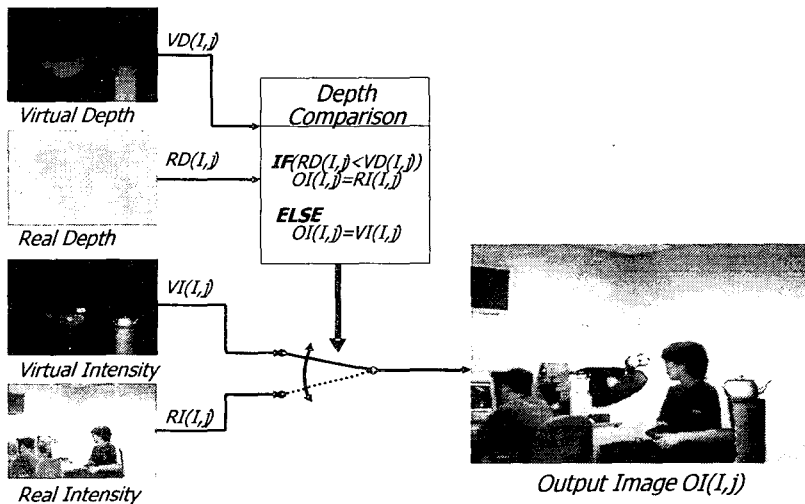
## \* Rendered images



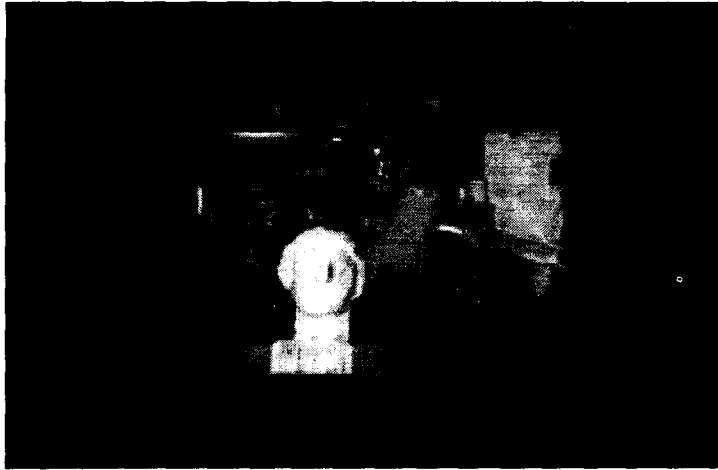
## 3D Reconstruction




## Synthesis and Interaction



# **DIML** Synthesis and Interaction



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