3D Photography Using Shadows

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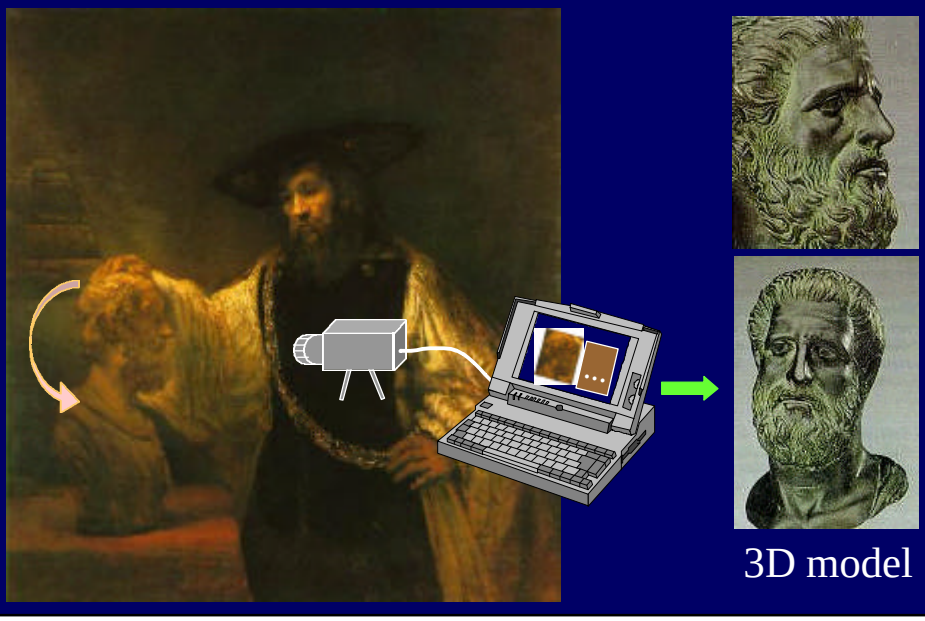
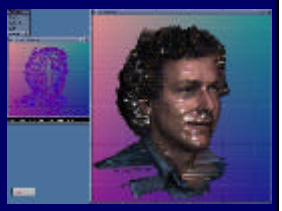
Goal: 3D reconstruction

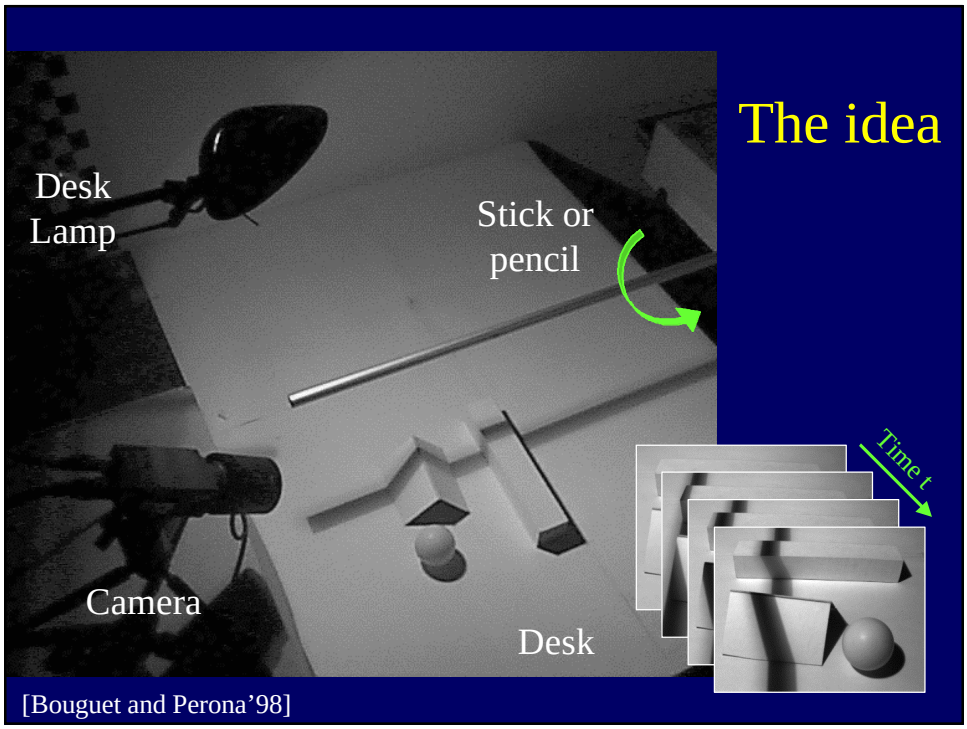


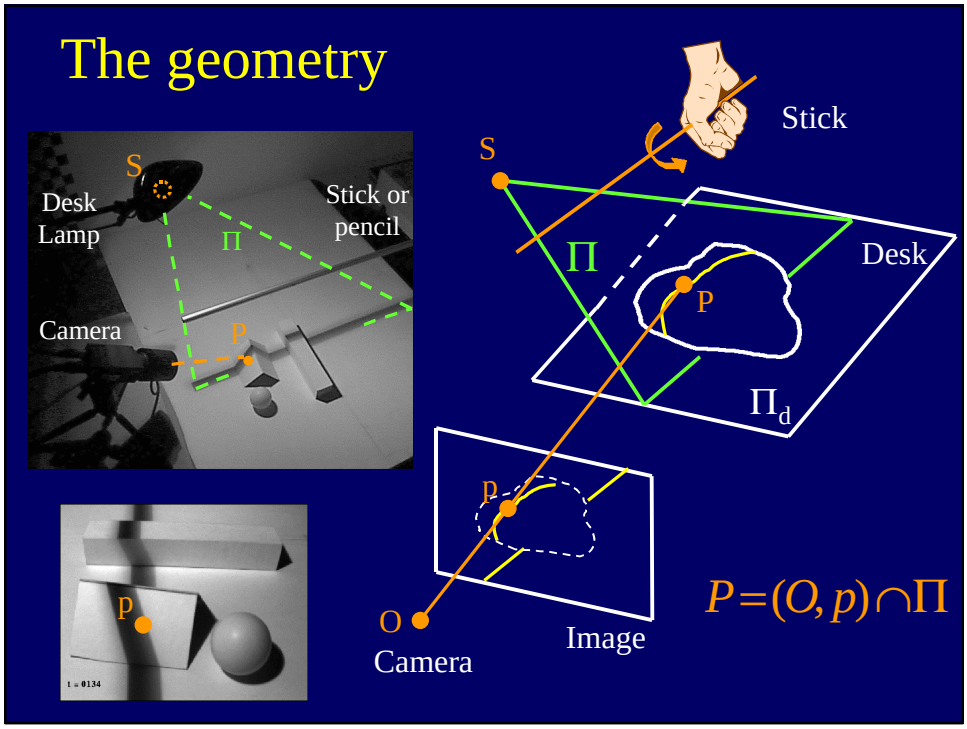
State of the art



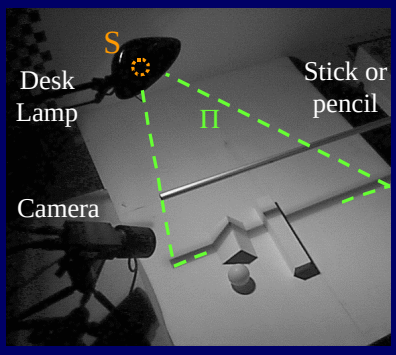
- Accurate
- Bulky
- Complicated
- Cost: >10k$

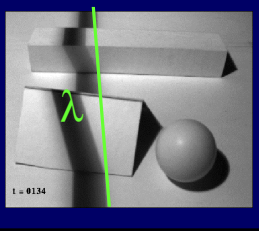
Weak structured lighting system

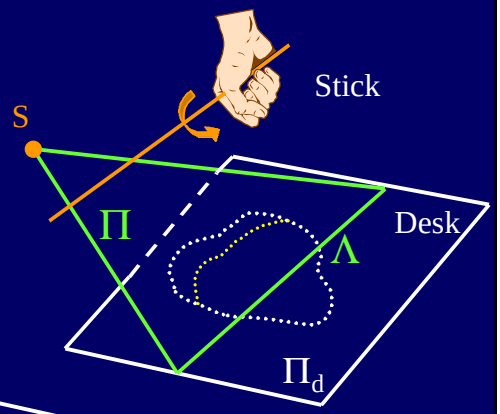

The idea
Desk
Lamp
Stick or
pencil
Camera
Desk
Time t
[Bouguet and Perona'98]

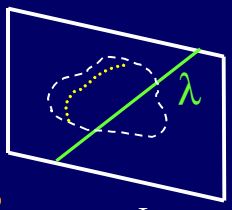

The geometry
S
Desk
Lamp
Stick or
pencil
Π
Camera
P
p
Stick
S
Π
Desk
P
Π_d
p
O
Camera
Image
$P=(O,p)\cap\Pi$

The geometry







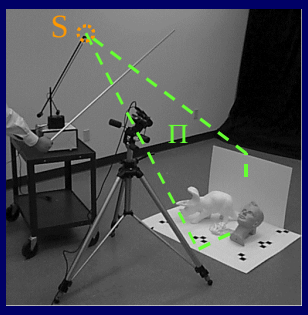


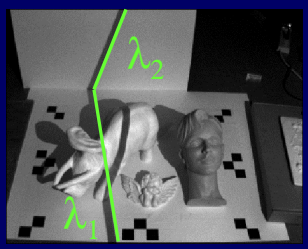
O
Camera
Image

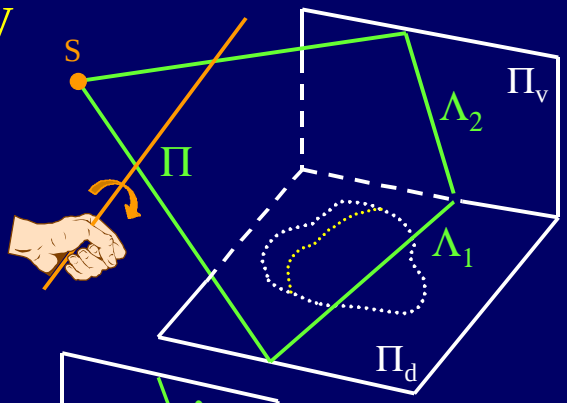
$\Lambda = (O, l) \cap \Pi_d$

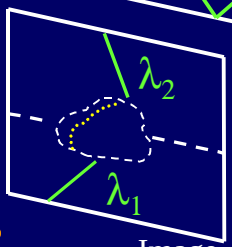
$\Pi = (S, \Lambda)$

The geometry









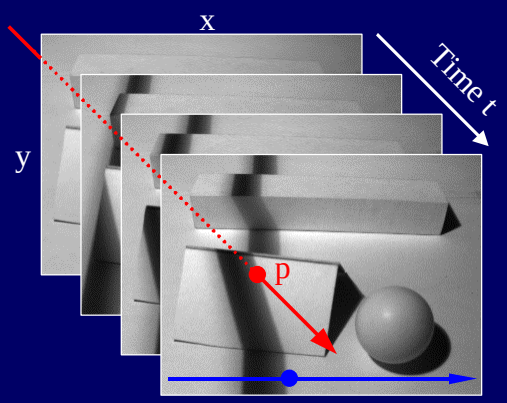
O
Camera
Image

$\Lambda_1 = (O, l_1) \cap \Pi_d$

$\Lambda_2 = (O, l_2) \cap \Pi_v$

$\Pi = (\Lambda_1, \Lambda_2)$

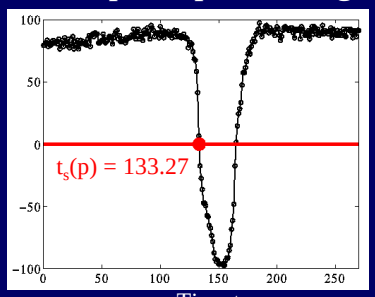
Spatio-temporal processing



$t_s(p) = 133.27$

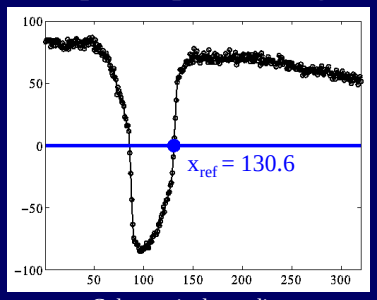
[Kanade'91,Curless'95]

Temporal processing



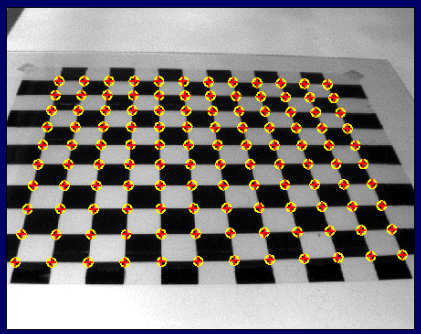
Time t

Spatial processing



Column pixel coordinate x

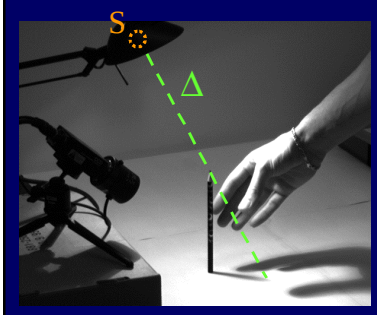
Camera calibration

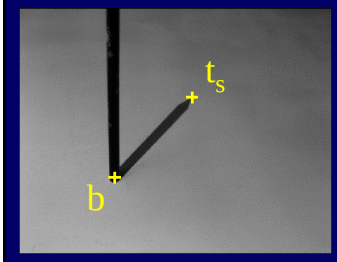


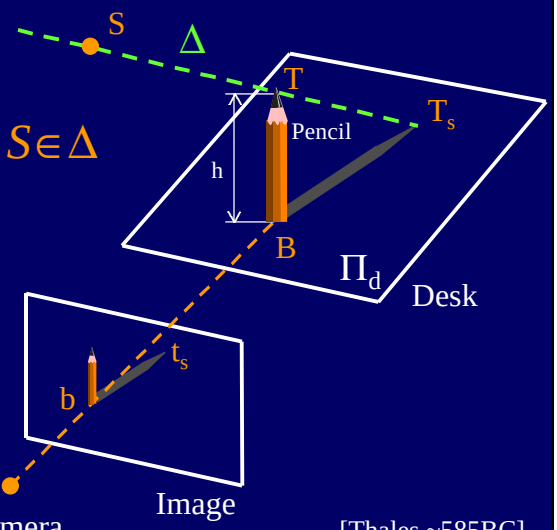
[Tsai'87, Abdel-Aziz and Karara'71]

- Position of the desk plane
- Internal parameters of the camera

Lamp calibration



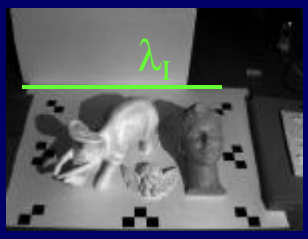


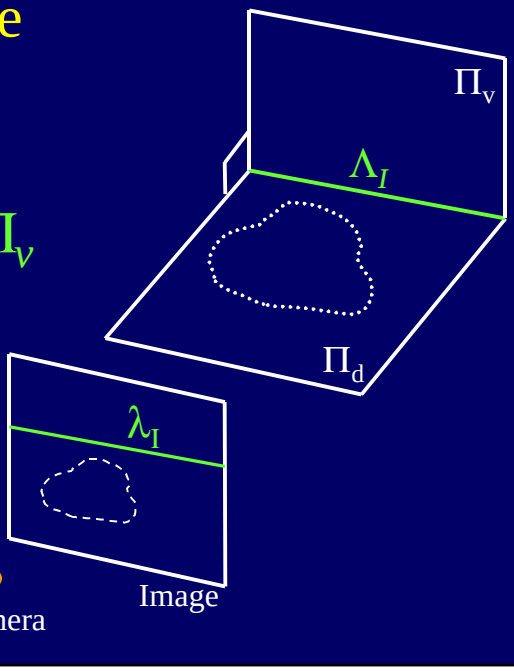


[Thales ~585BC]

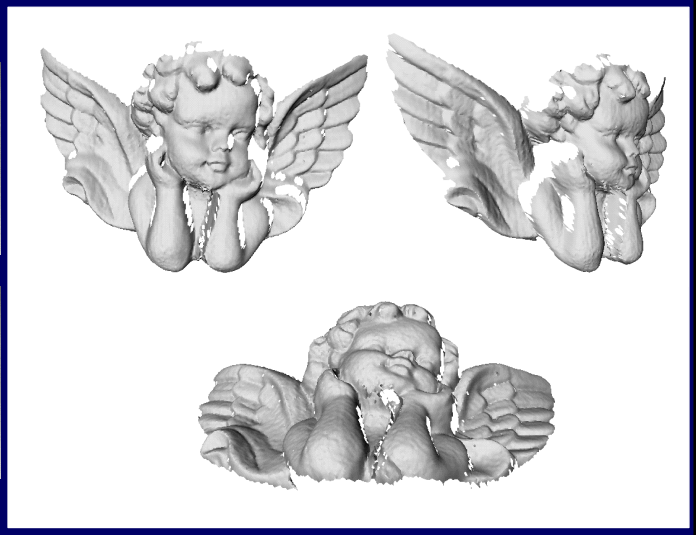
Vertical plane calibration

$\{\Pi_d, l_I\} \rightarrow \Pi_v$





Angel experiment

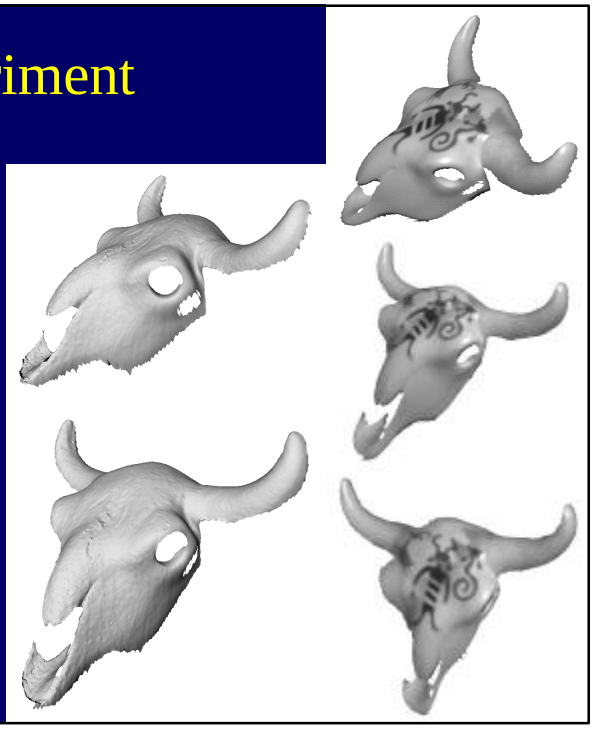


Accuracy: 0.1mm over 10cm → ~ 0.1% error

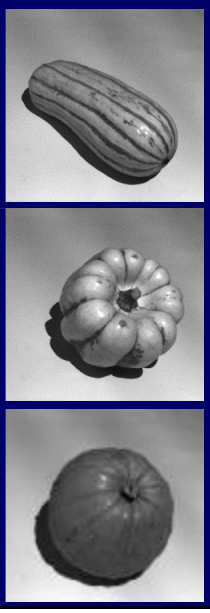
Skull experiment

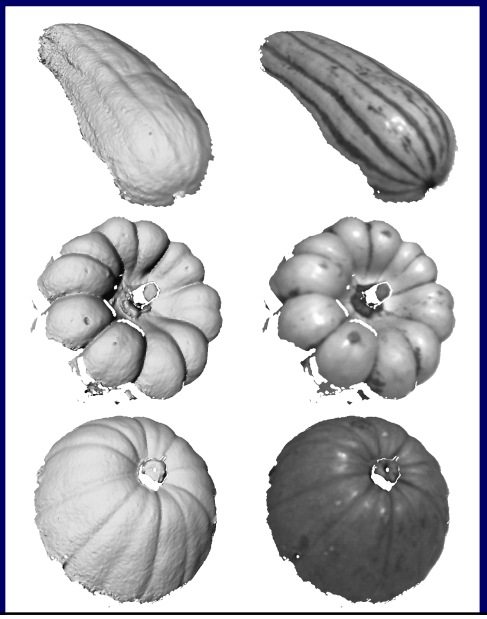
Accuracy: 0.1mm over 10cm

→ ~ 0.1% error



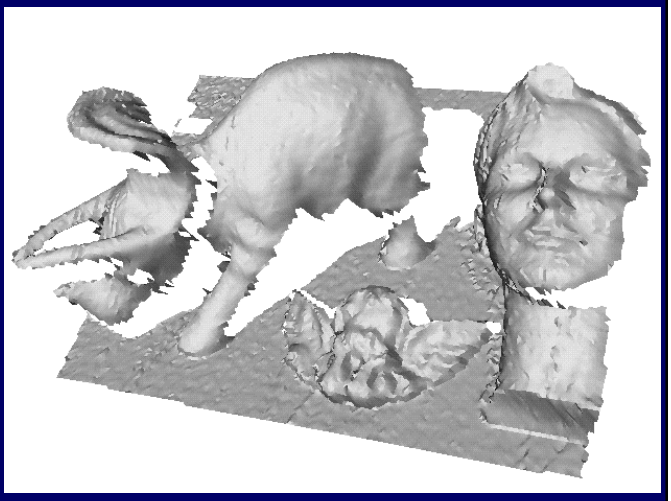
Textured objects





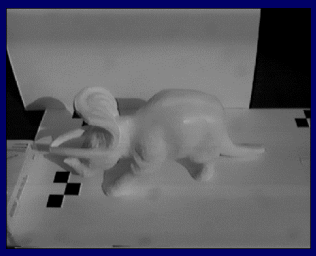
Other objects

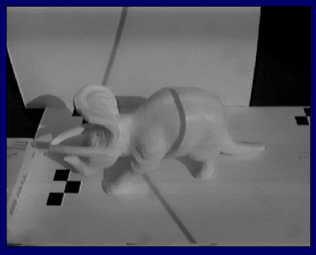
Pot-pourri scan



Accuracy: 0.5mm over 50cm → ~ 0.1% error

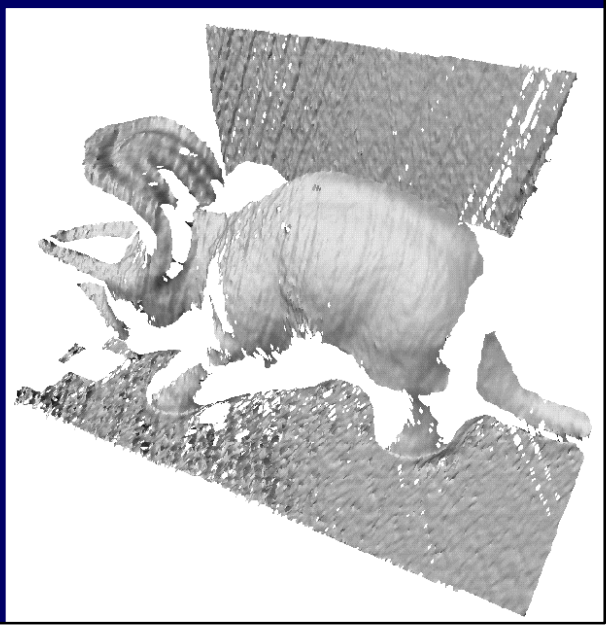
Scanning with the sun





Accuracy: 1mm over 50cm

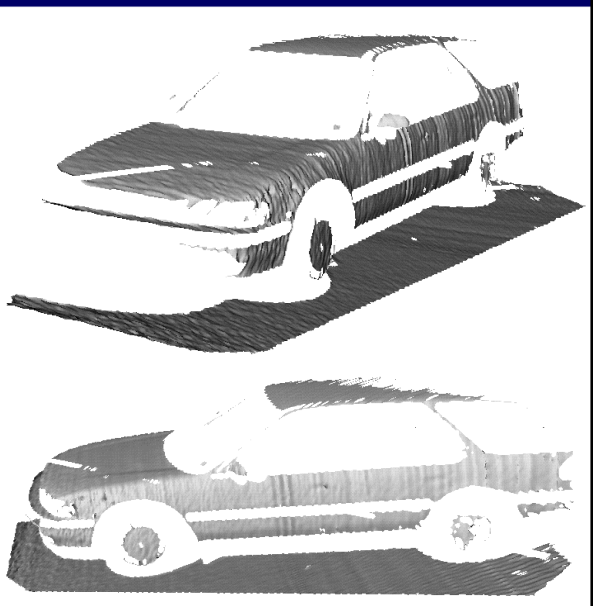
→ ~ 0.5% error



Scanning with the sun

Accuracy: 1cm over 2m

~ 0.5% error



Error analysis

$$s_Z^2 \propto \frac{1}{d^2} \cdot \frac{1}{\nabla I^2} \cdot s_I^2$$

Variance of the error in depth estimate

d : distance of the shadow plane Π to the camera optical center

∇I : shadow edge sharpness (image gradient)

Image brightness noise

[Bouguet'99]

Real-time implementation

- Performance: 30Hz, 320x240, Pentium II 300MHz
- Single shadow pass: 20 - 30 seconds (600-900 frames)
- Refined scanning: 1 - 2 minutes

Conclusions

✓ Low cost and simple technique for dense 3D shape acquisition

✗ Does not work with specular or dark objects

What's next?

- Registration of multiple scans
  ➡ complete models [Turk'94, Curless'96]

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Space-time analysis:

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- T. Kanade, A. Gruss and L. Carley, "A very fast VLSI rangefinder", IEEE International Conference on Robotics and Automation, volume 39, pages 1322-1329, April 1991

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- Y. I. Abdel-Aziz and H. M. Karara, "Direct linear transformation into object space coordinates in close-range photogrammetry", Proc. ASP Symposium on Close-Range Photogrammetry, Urbana, Illinois, pages 1-18, 1971

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Multiple view registration:

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- B. Curless and M. Levoy, “A volumetric method for building complex models from range images”, SIGGRAPH’96, 1996

Shadow scanning:

- J.-Y. Bouguet and P. Perona, “3D Photography on your desk”, ICCV’98, pages 43-50, January 1998
  available at: http://www.vision.caltech.edu/bouguetj/ICCV98/
- J.-Y. Bouguet, “Passive and Active visual techniques for 3D modeling”, Ph.D. thesis, California Institute of Technology, June 1999
  available at: http://www.vision.caltech.edu/bouguetj/

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Related work on shape from shadows:

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- J. J. Clark, and L. Wang ,” Trajectories for Optimal Temporal Integration in Active Vision Systems”, Proceedings of the International Conference on Robotics and Automation, Albuquerque, April, 1997, pages 431-436
- M. Daum and G. Dudek, “On 3-D Surface Reconstruction Using Shape from Shadows”, CVPR’98, pages 461-468, June 1998
- J.-Y. Bouguet, M. Weber and P. Perona, “What do planar shadows tell us about scene geometry?”, CVPR’99, June 1999