The IBM Pieta Project: A Historical Perspective

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IBM Pietà 3D Scanning Project: 1998-2000

http://www.research.ibm.com/pieta
Data Capture: Range + multi-texture

5 point light sources

“Virtuoso” Multi-baseline Stereo camera
Photometric capture  Our Addition

- Same viewpoint, different lighting
- Resolution of .5mm with Virtuoso built-in camera
- Compute reflectance and normals per pixel
Capturing ~800 scans (1998)
Design Considerations: Length Scales

Examine on the scale of Meters to study proportion, design

Examine on the scale of millimeters to study Tool marks
Controlled Views

How was sculpture supposed to be viewed?
Orthographic and Impossible Views

How was sculpture constructed?
Representation for Interactive Viewing

- **Simplified, textured model**

- **Polygon Mesh**

- **Full-res model, albedo, normals**

- **Camera parameters**

- **Light editor**

- **Bump map**

- **Color map**
Reconstruction Pipeline
Pieta ` Project

Ball Pivoting

- To create a mesh from a point cloud
  A ball "walks" over the point cloud, creating a triangle for every three points it touches
Pieta ` Project

Improving Registration: Using Textures to Refine Alignment
Pieta Project

Photometric Processing

- Computing colors and normals consistent with underlying geometry and each other

color images for five light positions

details

color
SHAPE FROM SHADING

We can infer shape from a monocular image if the illumination and surface properties are known. If multiple images are available under different illumination directions, we can compute the surface orientation at each point in the image.

Reflectance Functions: First, we need to know how a surface reflects incident light energy. A common model is a diffuse or Lambertian surface. This is a surface that reflects incident light energy equally in all viewing directions. The amount of this light energy is proportional to the cosine of the angle between the surface normal and the light source direction.

\[ \Phi(n, s, v) = \rho \cos(i) \]

where \( i \) is angle between surface normal \( n \) and light source direction \( s \), and \( v \) is viewing (camera direction). \( \rho \) is the albedo of the surface; it is a gain that determines what percentage of the light is transmitted by the surface versus absorbed. \( \rho \) will be high for smooth, glossy objects and lower for rough objects. We will assume it to be a constant over the surface; i.e. a homogeneous surface material.

If we examine the equation below, we see that if the lighting direction \( s \) and viewing direction \( v \) are known, then the brightness at a point in the image is simply a function of the surface normal and the albedo (which we assume is constant over the surface).

\[ \Phi(n, s, v) = \rho \cos(i) \]

PHOTOMETRIC STEREO

If we have a Lambertian surface, and we shine a known light source on it, we generate a reflectance map that can be characterized for each pixel in the image as:

\[ I_k(u, v) = \rho \cos(i_k) = \rho (s_k \cdot n) \]

The intensity at a pixel is proportional to the incident angle. Given three light source directions, \( s_1, s_2, s_3 \), we can create a matrix equation \( \mathbf{I} = \rho \mathbf{S} \mathbf{n} \):

\[
\begin{bmatrix}
I_1(u, v) \\
I_2(u, v) \\
I_3(u, v)
\end{bmatrix} = \rho \begin{bmatrix}
s_{11} & s_{12} & s_{13} \\
s_{21} & s_{22} & s_{23} \\
s_{31} & s_{32} & s_{33}
\end{bmatrix} \begin{bmatrix}
n_1 \\
n_2 \\
n_3
\end{bmatrix}
\]

Since \( \mathbf{n} \) is a unit vector, we can solve for \( \rho \) and \( \mathbf{n} \):

\[ \rho = \| \mathbf{S}^{-1} \mathbf{I} \| ; \quad \mathbf{n} = \frac{1}{\rho} \mathbf{S}^{-1} \mathbf{I} \]
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“Virtuoso” Multi-baseline Stereo camera
$L_r = \rho L \cos \theta \Delta \omega / \pi$
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Remapping Unique Texture
for each patch
for each camera pos
compute tex coords
init z-buffer with depth map
render weights
for tex in {alb, np, nm}
  render textured patch
  acctex += rendered*weight
  accwgt += weight
end
end
normalize
save the three images
end

Blend textures with weights based on data reliability

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Captured

Geometric registration

Single photometric

Texture registration
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