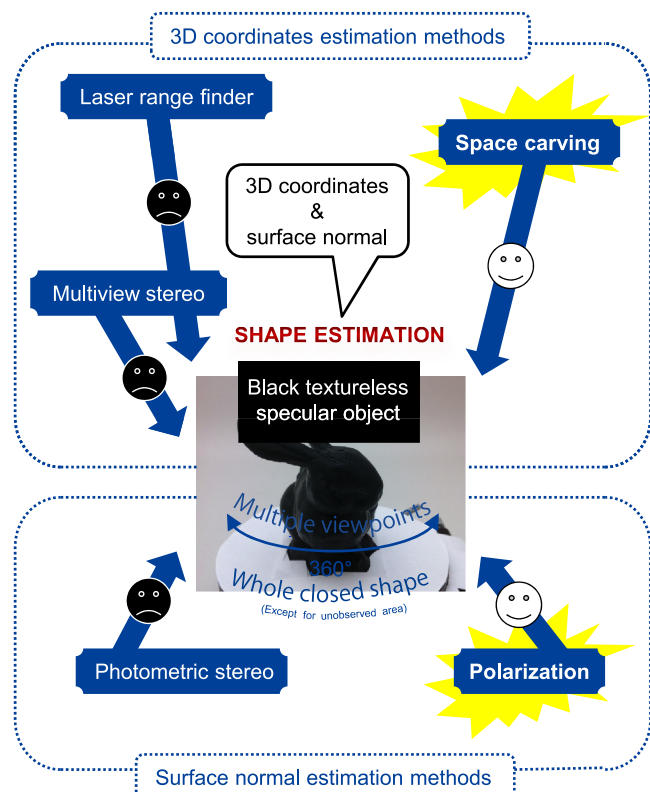# Polarization-based surface normal estimation of black specular objects from multiple viewpoints
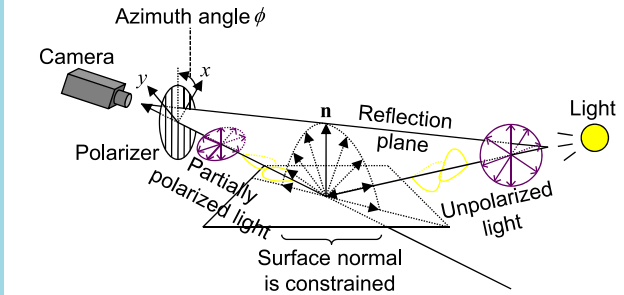
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▶▶ Concept

3D coordinates estimation methods

Laser range finder

Space carving

3D coordinates & surface normal

Multiview stereo

SHAPE ESTIMATION

Black textureless specular object

Multiple viewpoints 360° Whole closed shape (Except for unobserved area)

Photometric stereo
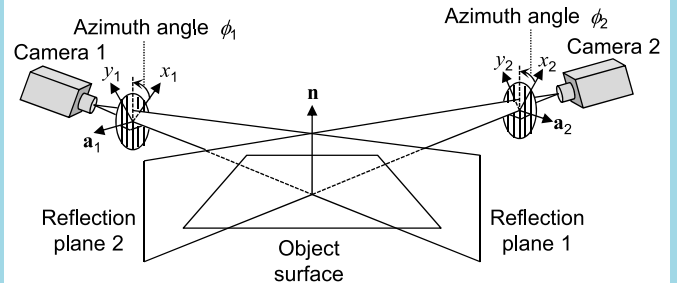
Polarization

Surface normal estimation methods

[Theorem]   Only quadric surfaces can be estimated when corresponding points are automatically searched

[Proof]   S. Rahmann, "Reconstruction of quadrics from two polarization views," Iberian Conference on Pattern Recognition and Image Analysis, 2003

[Our approach]   Corresponding points obtained from space carving
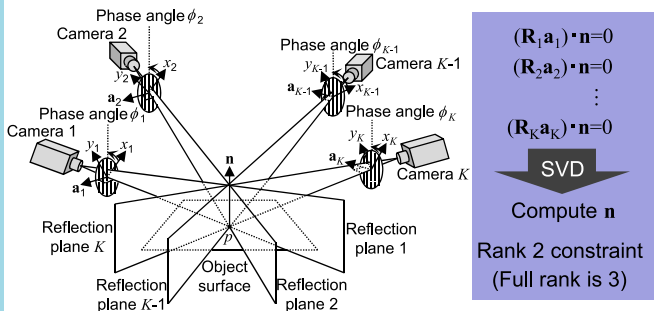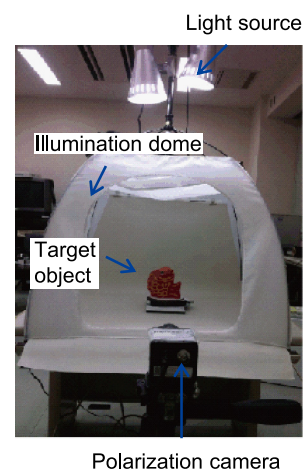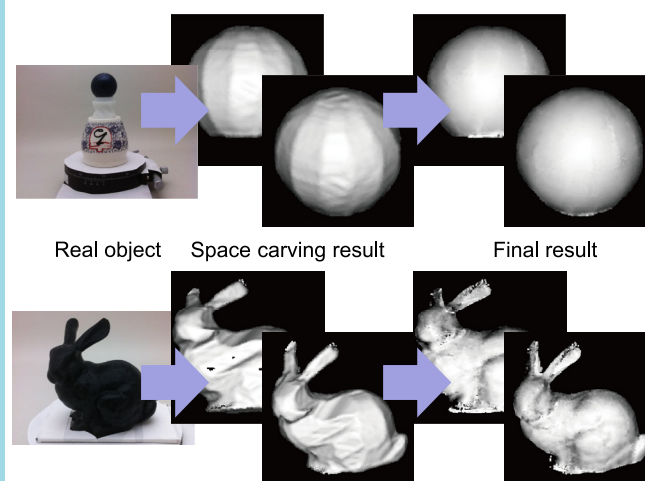
▶▶ One Viewpoint

Azimuth angle ϕ

Camera

Polarizer

Partially polarized light

$\mathbf{n}$

Reflection plane

Light

Unpolarized light

Surface normal is constrained

▶▶ Two Viewpoints

Azimuth angle ϕ_1

Camera 1

y_1 x_1

$\mathbf{a}_1$

Azimuth angle ϕ_2

Camera 2

y_2 x_2

$\mathbf{a}_2$

$\mathbf{n}$

Reflection plane 2

Reflection plane 1

Object surface

▶▶ Multiple Viewpoints

Phase angle ϕ_2
Camera 2

y_2 x_2

$\mathbf{a}_2$

Phase angle ϕ_1
Camera 1

y_1 x_1

$\mathbf{a}_1$

Phase angle ϕ_{K-1}
Camera K-1

y_{K-1} x_{K-1}

$\mathbf{a}_{K-1}$

Phase angle ϕ_K
Camera K

y_K x_K

$\mathbf{a}_K$

$\mathbf{n}$

Reflection plane K

Reflection plane K-1

Reflection plane 1

Reflection plane 2

Object surface

$$(\mathbf{R}_1\mathbf{a}_1)\cdot\mathbf{n}=0$$
$$(\mathbf{R}_2\mathbf{a}_2)\cdot\mathbf{n}=0$$
$$\vdots$$
$$(\mathbf{R}_K\mathbf{a}_K)\cdot\mathbf{n}=0$$

SVD

Compute $\mathbf{n}$

Rank 2 constraint
(Full rank is 3)

▶▶ Apparatus

Light source

Illumination dome

Target object

Polarization camera

▶▶ Result

Real object   Space carving result   Final result

▶▶ Contribution

Shape estimation of black textureless specular object
- Impossible for common laser range finder
- Impossible for conventional multiview stereo
- Impossible for conventional photometric stereo

Both 3D coordinates and surface normal
- Reasonable combination of space carving and polarization
- Various application field

Polarization analysis of multiple viewpoints
- Solve ambiguity problem using space carving
- Surface normal of whole part is obtained
- SVD-based estimation robust to Gaussian noise