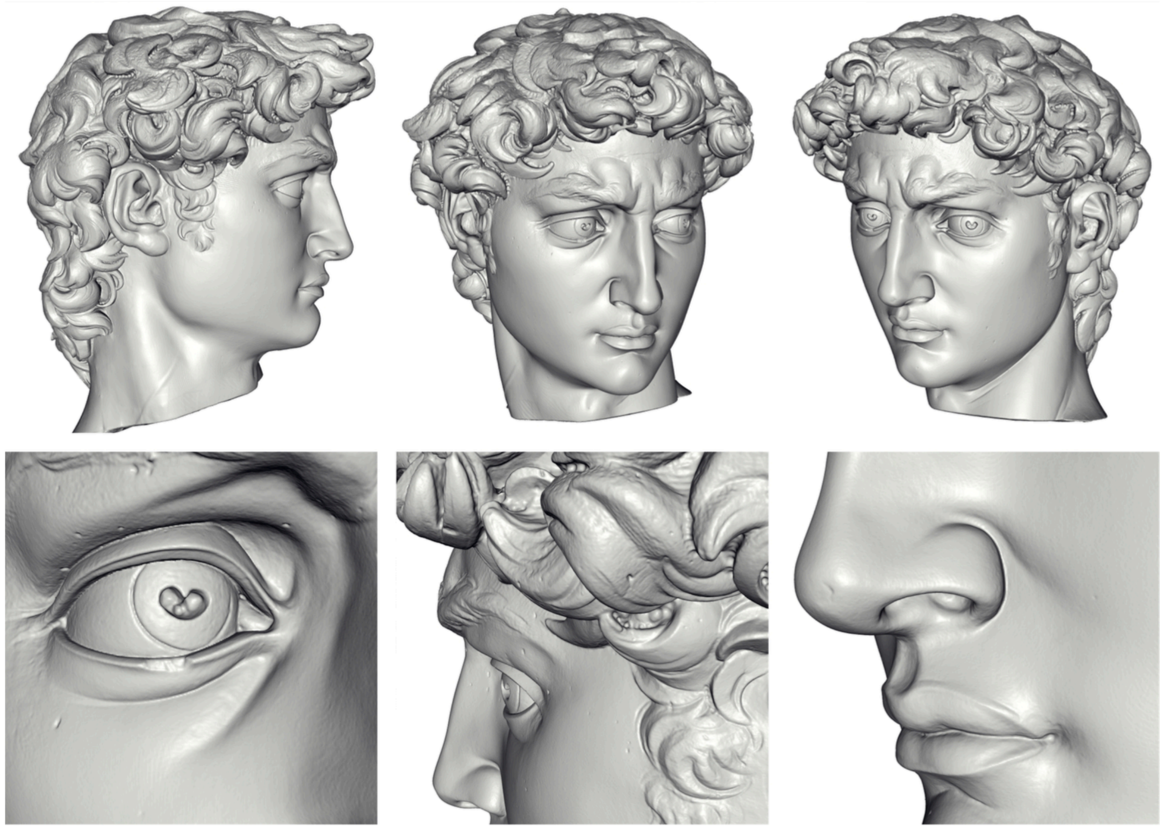


3D Reconstruction

Shanchen Jiang

Kazhdan M, Hoppe H. Screened poisson surface reconstruction[J]. ACM Transactions on Graphics (TOG), 2013, 32(3): 29.

Film Industry

3D Camera + Virtual display

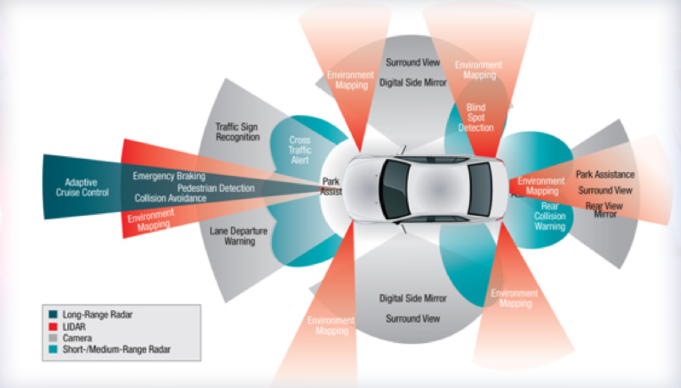
Film Industry

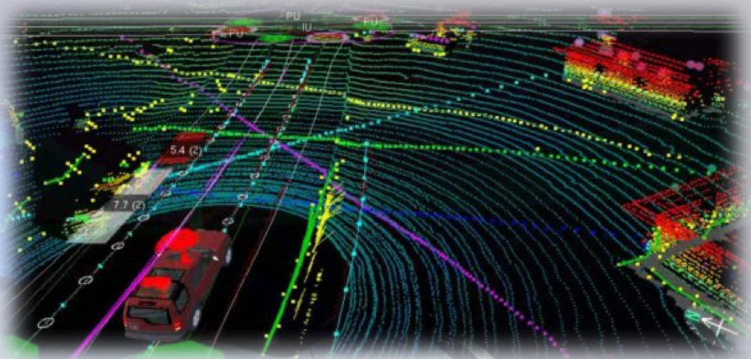
City Planning

Taking Photos + Recovery from images

City Planning

Pilotless Automobile



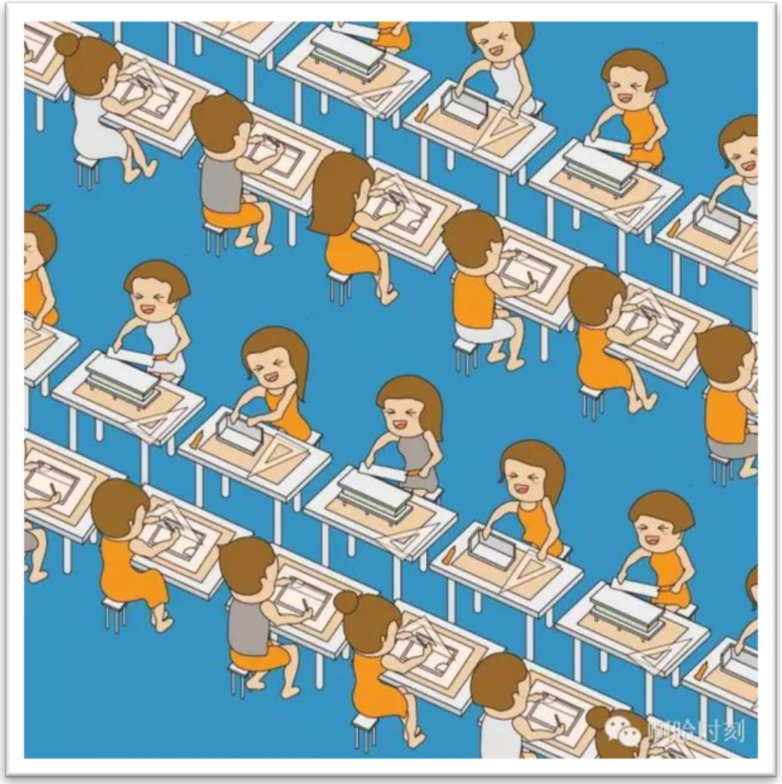


Sensors + Software

Pilotless Automobile

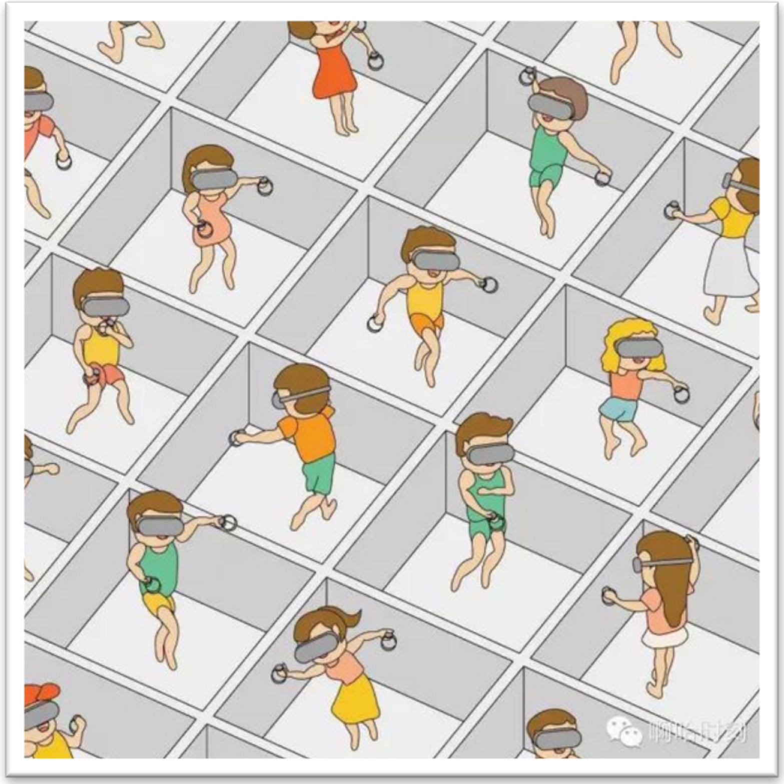
Everything is virtual

Virtual Reality



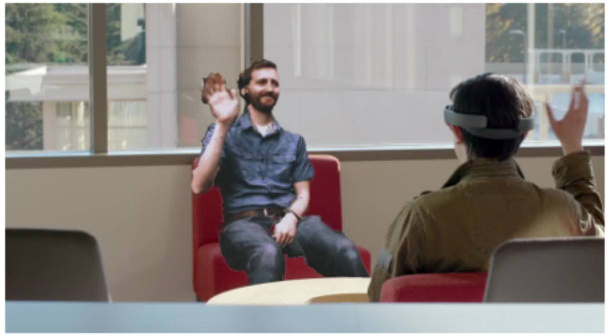
+

=



Virtual Reality






Augmented Reality

Classification

GBM

Geometry Based Modeling

DSM

Depth Scanning Modeling

IBM

Image Based Modeling

In computer vision and computer graphics, 3D reconstruction is the process of capturing the shape and appearance of real objects.

https://en.wikipedia.org/wiki/3D_reconstruction

History

1960s Problem Definition

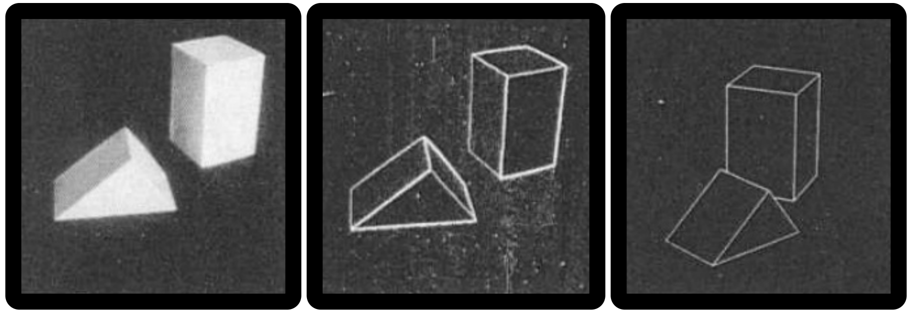
1970s Image Formulation

1980s

1990s Geometry

2000s Reconstruction

2010s Innovation



Input Gradient Output

Roberts L G. Machine perception of three-dimensional soups[D]. Massachusetts Institute of Technology, 1963.

History

1960s Problem Definition

1970s Image Formulation

1980s

1990s Geometry

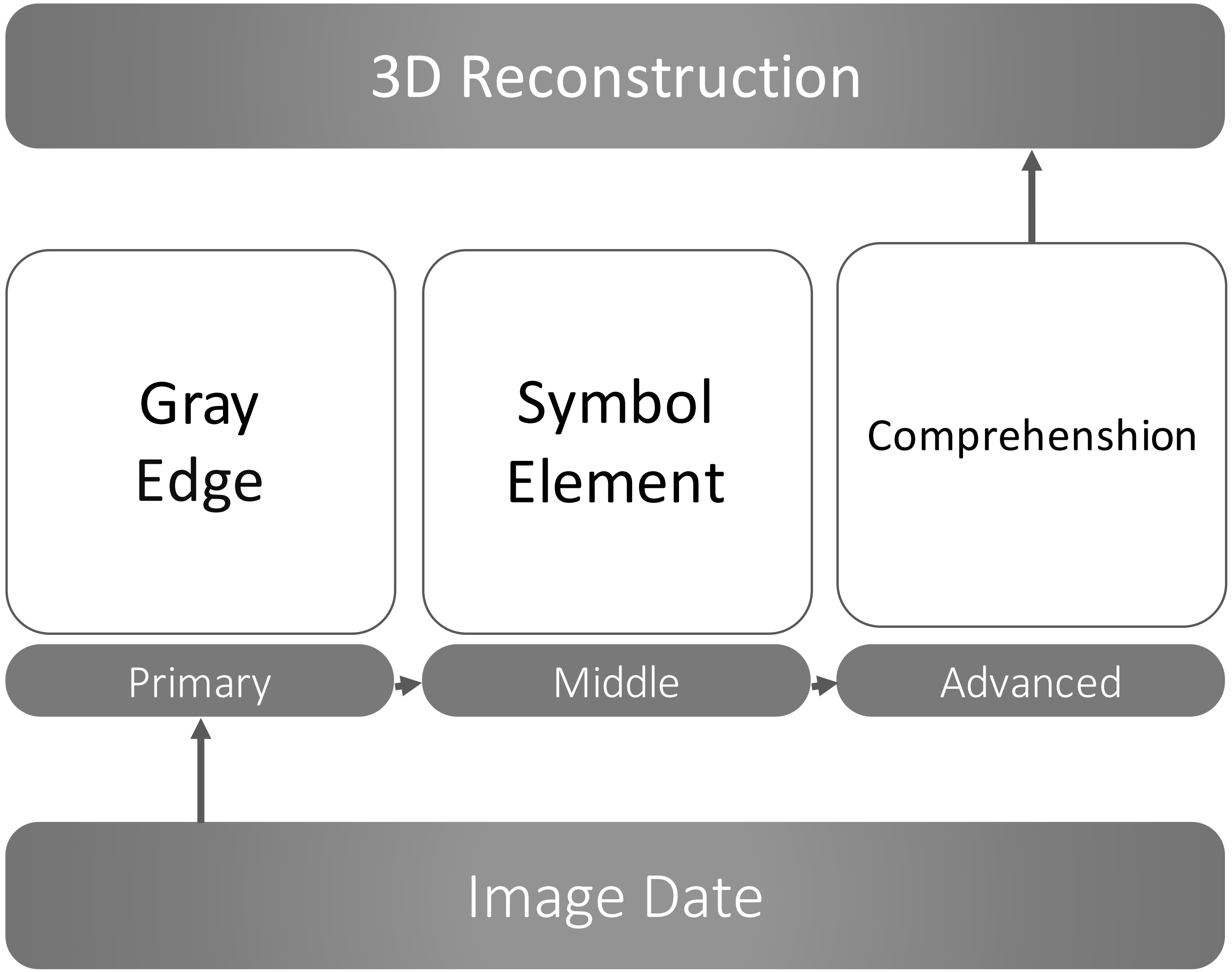
2000s Reconstruction

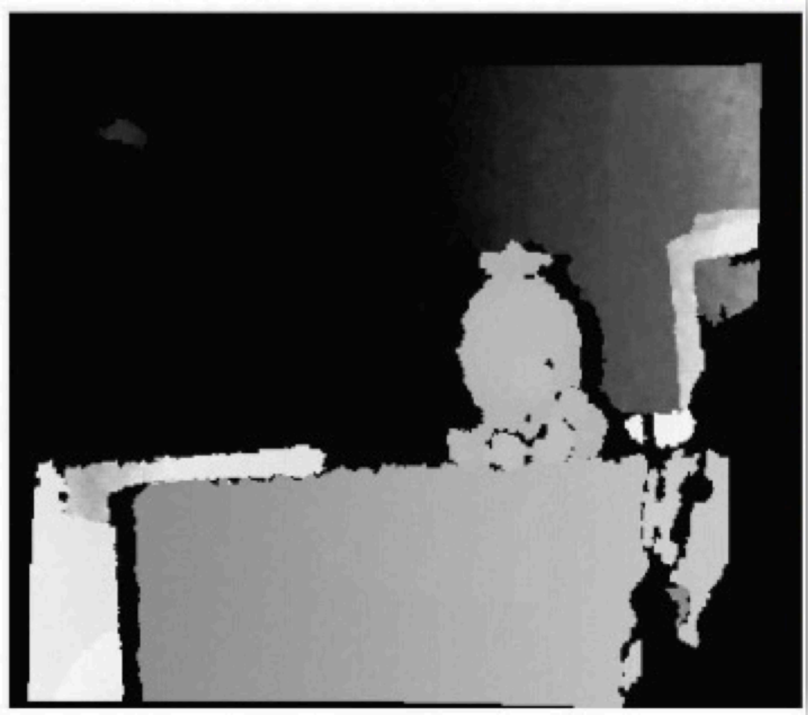
2010s Innovation

D.Marr

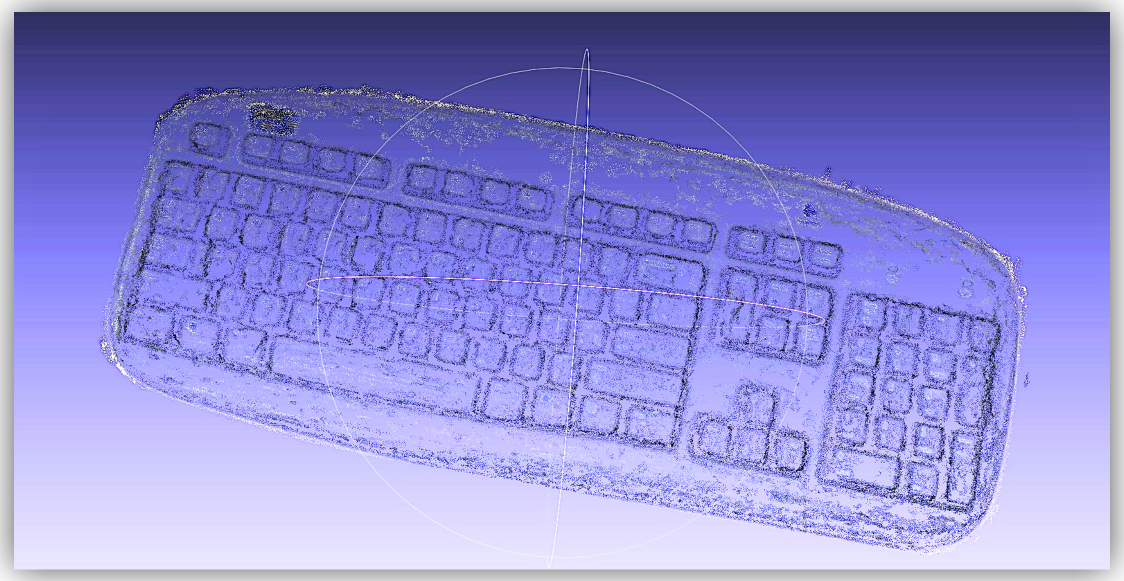
***Vision: A computational investigation into the human representation and processing of visual information* (ISBN 0-7167-1567-8)**

(1969) "A theory of cerebellar cortex." J. Physiol., 202:437-470.
(1970) "A theory for cerebral neocortex." Proceedings of the Royal Society of London B, 176:161-234.
(1971) "Simple memory: a theory for archicortex." Phil. Trans. Royal Soc. London, 262:23-81.
(1974) "The computation of lightness by the primate retina." Vision Research, 14:1377-1388.
(1975) "Approaches to biological information processing." Science, 190:875-876.
(1976) "Early processing of visual information." Phil. Trans. R. Soc. Lond. B, 275:483-524.
(1976) "Cooperative computation of stereo disparity." Science, 194:283-287. (with Tomaso Poggio)
(1976, March) "Artificial intelligence: a personal view." Technical Report AIM 355, MIT AI Laboratory, Cambridge, MA.
(1977) "Artificial intelligence: A personal view." Artificial Intelligence 9(1), 37–48.
(1977) [illegible] Neurosciences Res. Prog. Bull., 15:470-488. (with Tomaso Poggio)
(1978) "Representation and recognition of the spatial organization of three dimensional tructure." Proceedings of the Royal Society of London B, [illegible] (with [illegible] Nishihara)
(1979) "A computational theory of human stereo vision." Proceedings of the Royal Society of London B, 204:301-328. (with Tomaso Poggio)
(1980) "Theory of edge detection." Proc. R. Soc. Lond. B, 207:187-217. (with E. Hildreth)
(1981) "Artificial intelligence: a personal view." In Haugeland, J., ed., Mind Design, chapter 4, pages 129-142. MIT Press, Cambridge, MA.
(1982) "Representation and recognition of the movements of shapes." Proceedings of the Royal Society of London B, 214:501-524. (with L. M. Vaina)
(1982). Vision: A Computational Investigation into the HumanRepresentation and Processing of Visual Information. New York: Freeman.

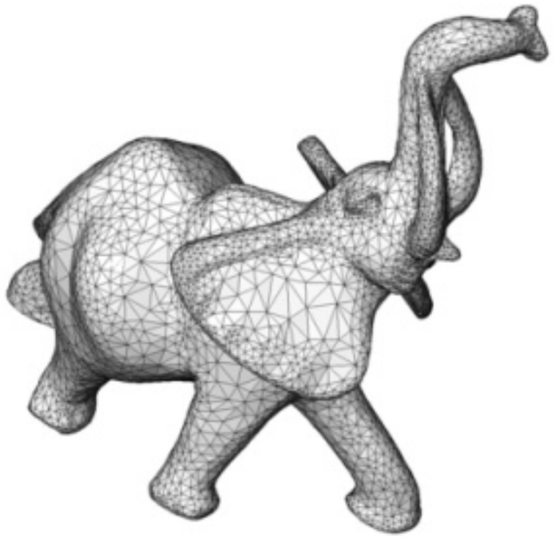

3D Reconstruction
Gray
Edge
Symbol
Element
Comprehenshion
Primary
Middle
Advanced
Image Date



2.5 D information



Point cloud



Grid chart

History

1960s Problem Definition

1970s Image Formulation

1980s

1990s Geometry

2000s Reconstruction

2010s Innovation

Essential Matrix: $X'_\mu Q_{\mu v} X_v = 0$

$$\mathbf{X}'_\mu \mathbf{Q}_{\mu\nu} \mathbf{X}_\nu = 0 \qquad (11)$$

Dividing equation (11) by $\mathbf{X}'_3\mathbf{X}_3$ we arrive at the desired relationship between the image coordinates:

$$\mathbf{x}'_\mu \mathbf{Q}_{\mu\nu} \mathbf{x}_\nu = 0 \qquad (12)$$

Longuet-Higgins H C. A computer algorithm for reconstructing a scene from two projections[J]. Readings in Computer Vision: Issues, Problems, Principles, and Paradigms, MA Fischler and O. Firschein, eds, 1987: 61-62.

History

1960s Problem Definition

1970s Image Formulation

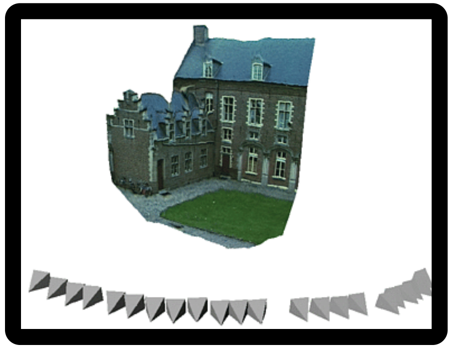
1980s

1990s Geometry

2000s Reconstruction

2010s Innovation

Structure from Motion



Pollefeys et al

Multi-view Stereo

Furukawa & Ponce

History

1960s	Problem Definition
1970s	Image Formulation
1980s	
1990s	Geometry
2000s	Reconstruction
2010s	**Innovation**

Big data
Real time
Deep learning

History

1960s	Problem Definition
1970s	Image Formulation
1980s	
1990s	Geometry
2000s	Reconstruction
2010s	Innovation

Goals of Computer Vision:

- Let machines see
- Let humans see better

basis of 3D reconstruction

DEPTH

Classification

Active methods

Structure light ...

Passive methods

Recover from shadow

Recover from stereoscopic

Structure from motion

Photometric three-dimensional ...

Active methods

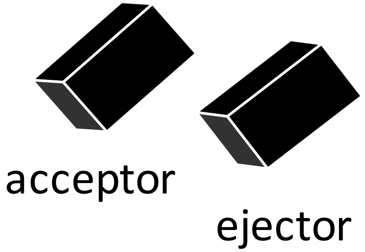
Physical means

light acoustic

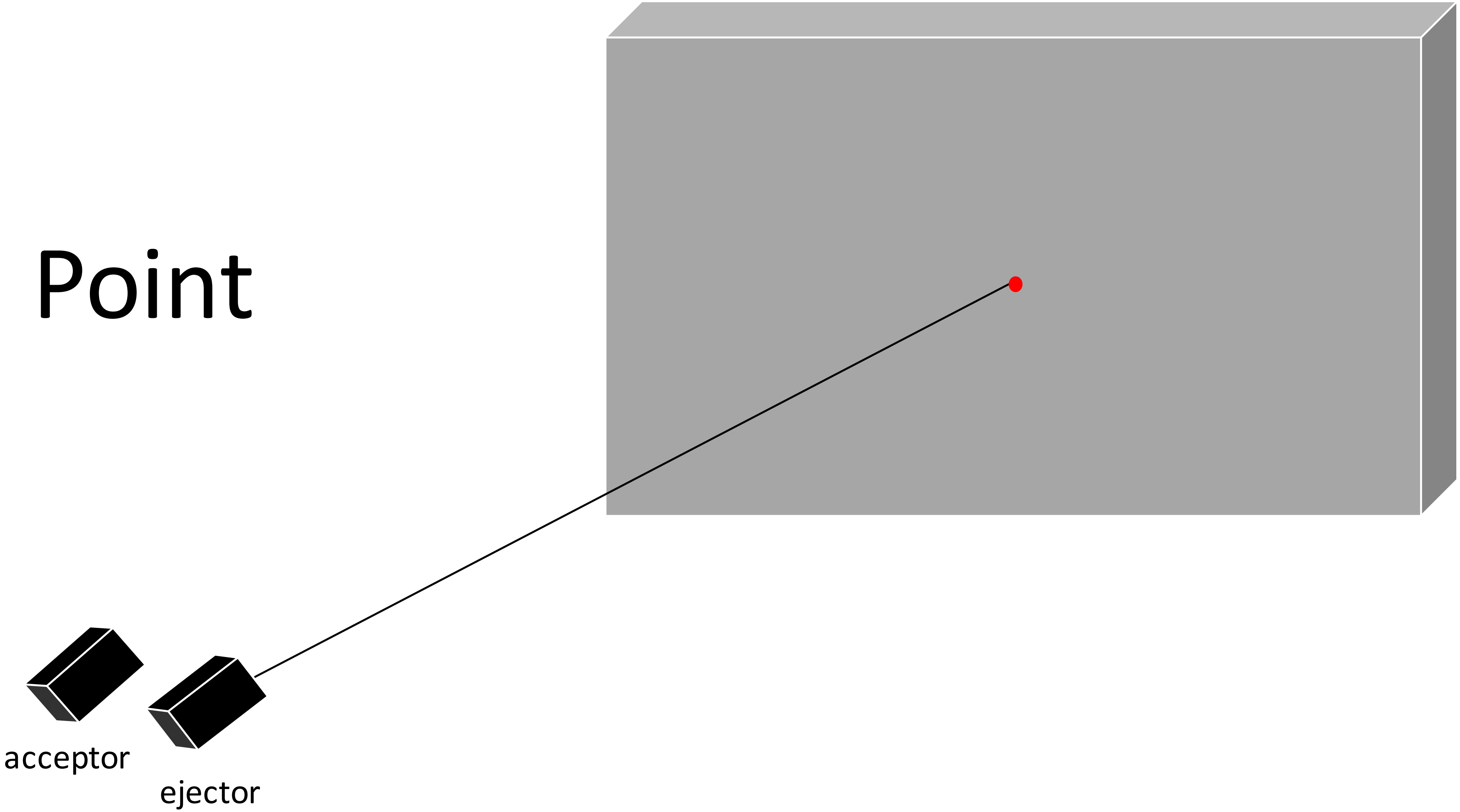
Active methods

Physical means

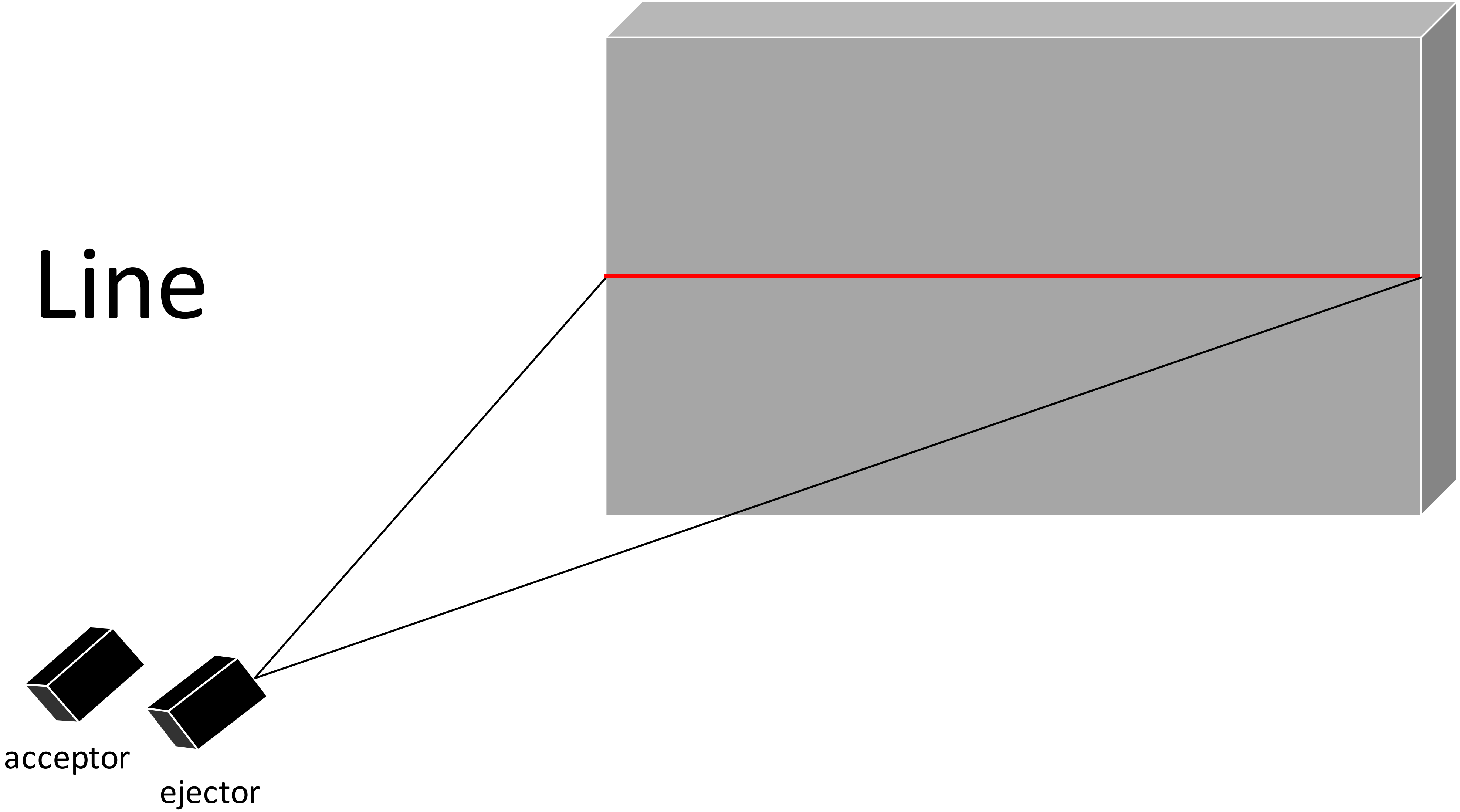
light



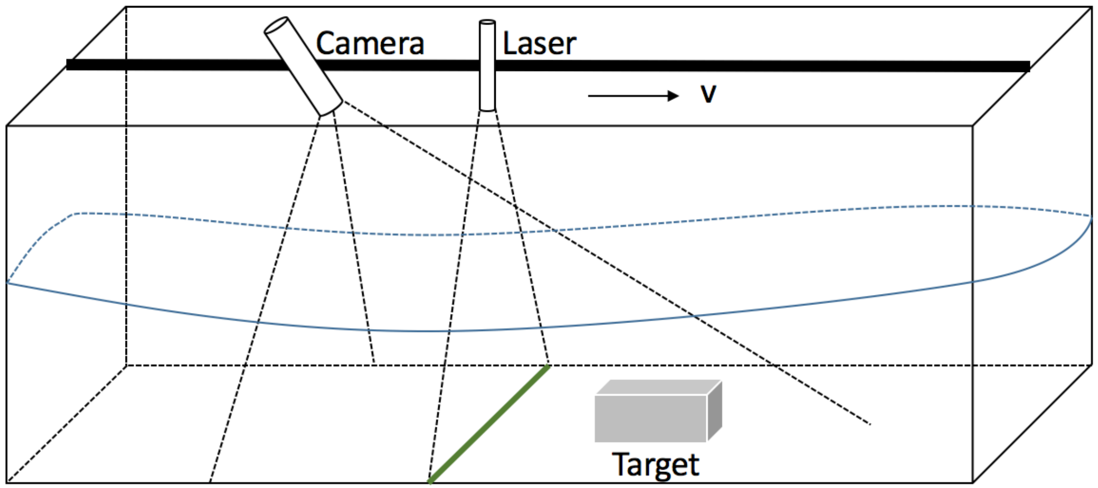
Point



Line



Laser Line Scanning



Calibration

Acquisition

Extraction

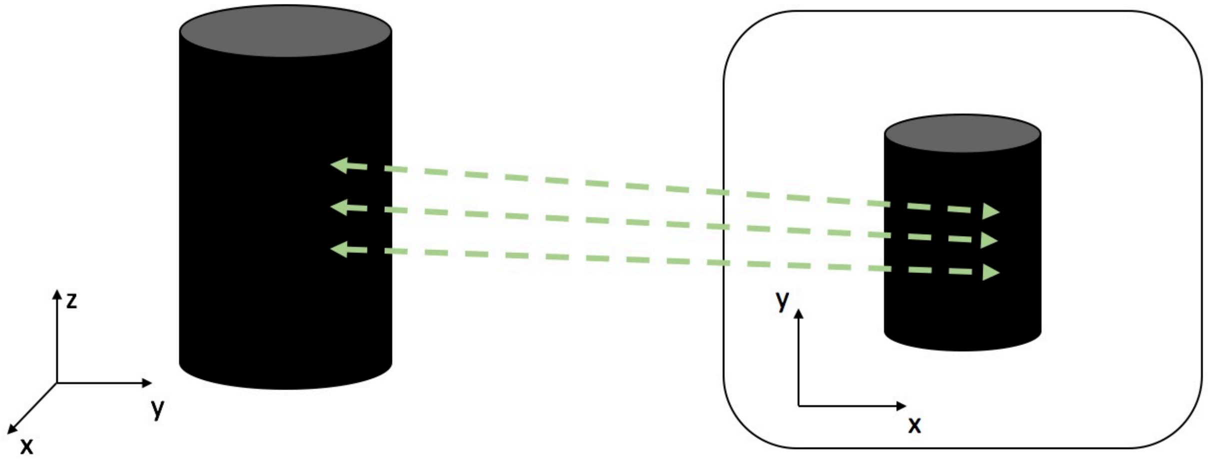
Transformation

Modeling

Calibration

Calibration → Correction → Match → 3D Recover

Internal reference	External reference	Distortion

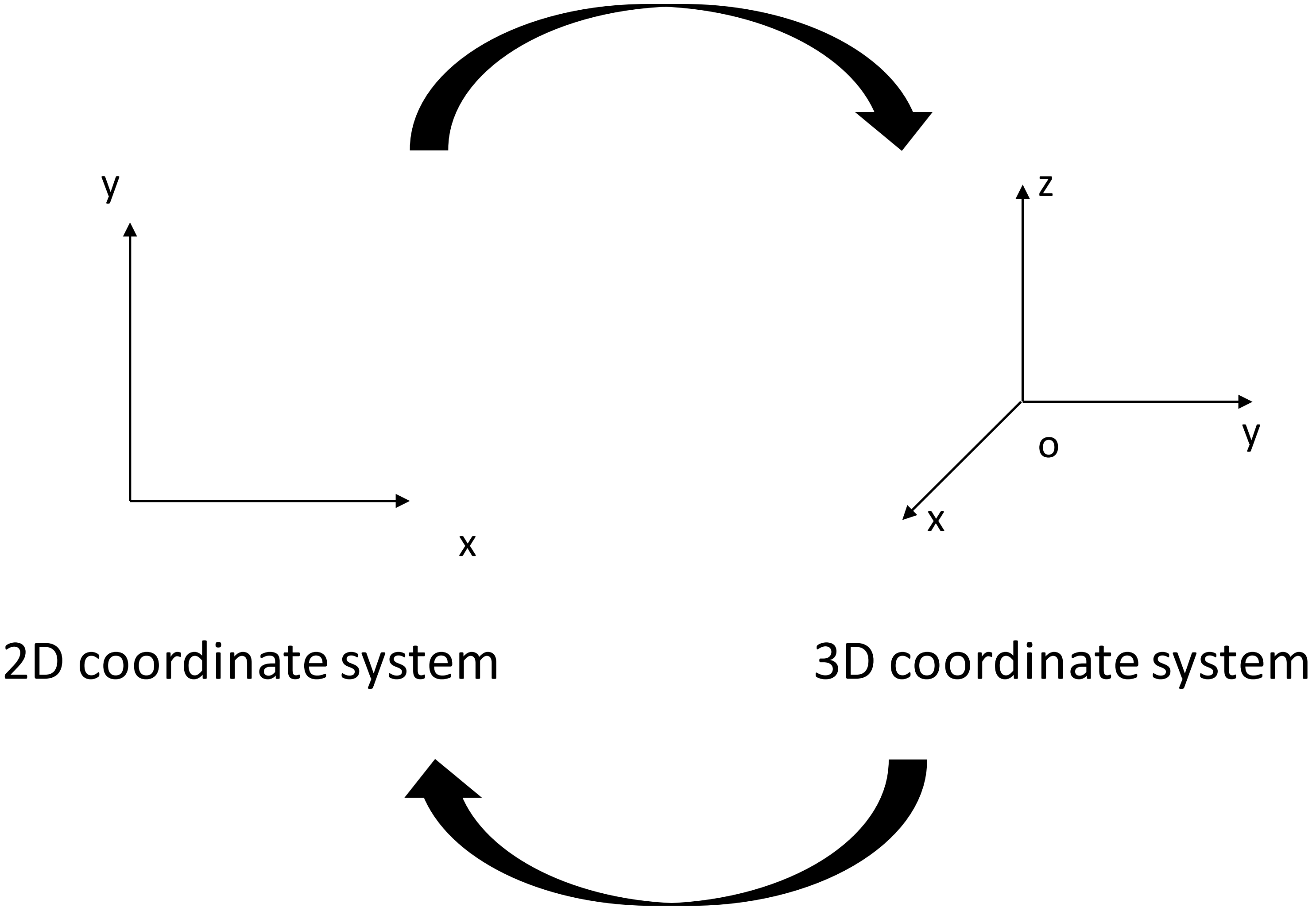


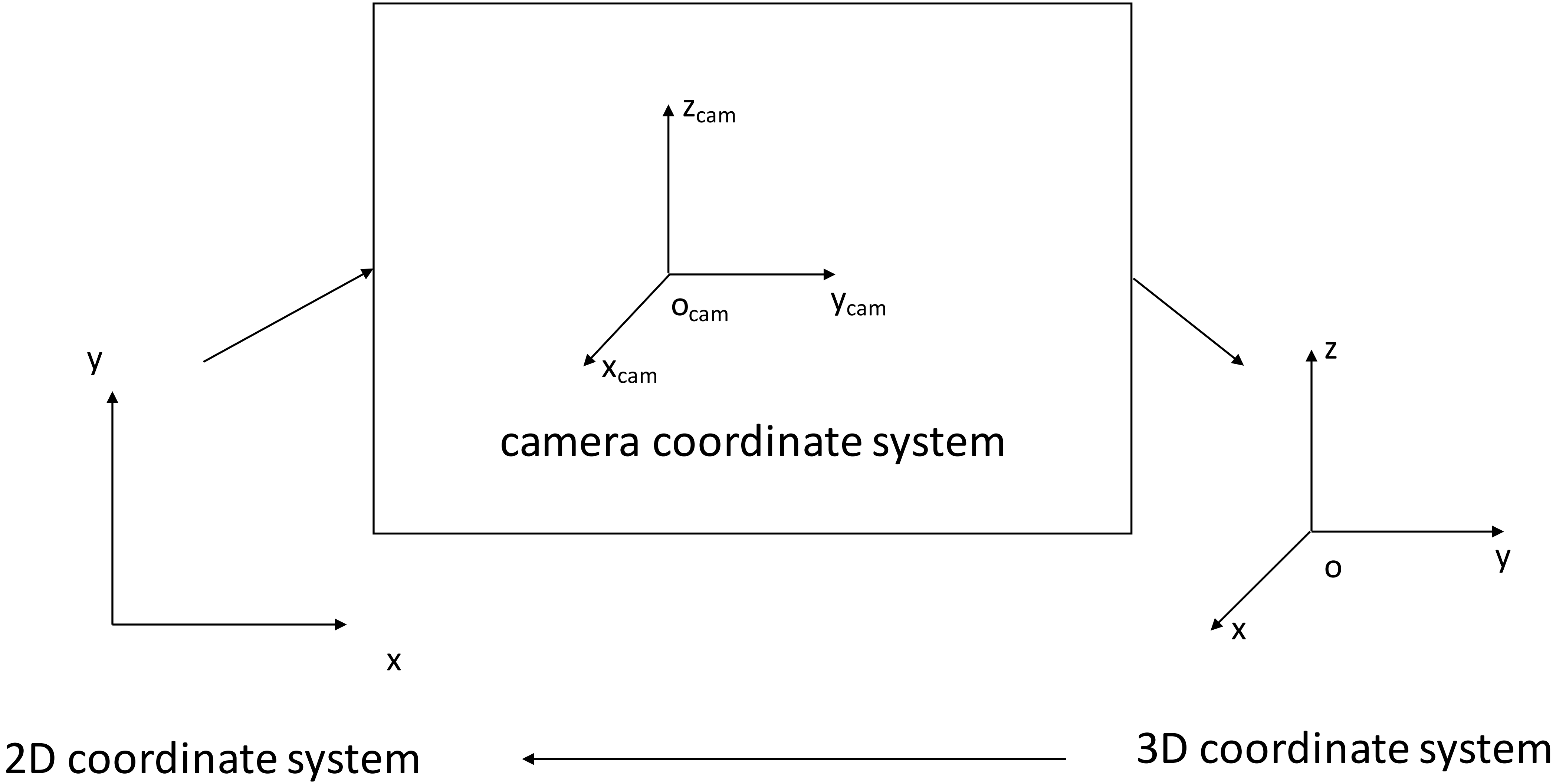
Calibration

$$s\tilde{x} = K[R \quad t]\tilde{X} \tag{1}$$

$$H = [\, h_1 \quad h_2 \quad h_3] = \lambda\, K[\, r_1 \quad r_2 \quad t] \tag{2}$$

[1]O. Faugeras. " Three-Dimensional Computer Vision: A Geometric Viewpoint ". MIT Press, 1993.
[2]Hartley, Richard I. "An algorithm for self calibration from several views." *Cvpr*. Vol. 94. 1994.
[3] Luong, Q-T. "Self-calibration of a moving camera from point correspondences and fundamental matrices." *International Journal of computer vision* 22.3 (1997): 261-289.


y
x
z
o
y
x
2D coordinate system
3D coordinate system



calibration

I am a handsome boy

calibration

I am a 3D Point

I am a 3D Point

•

$$\mathbf{X} = \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

calibration

I am cool

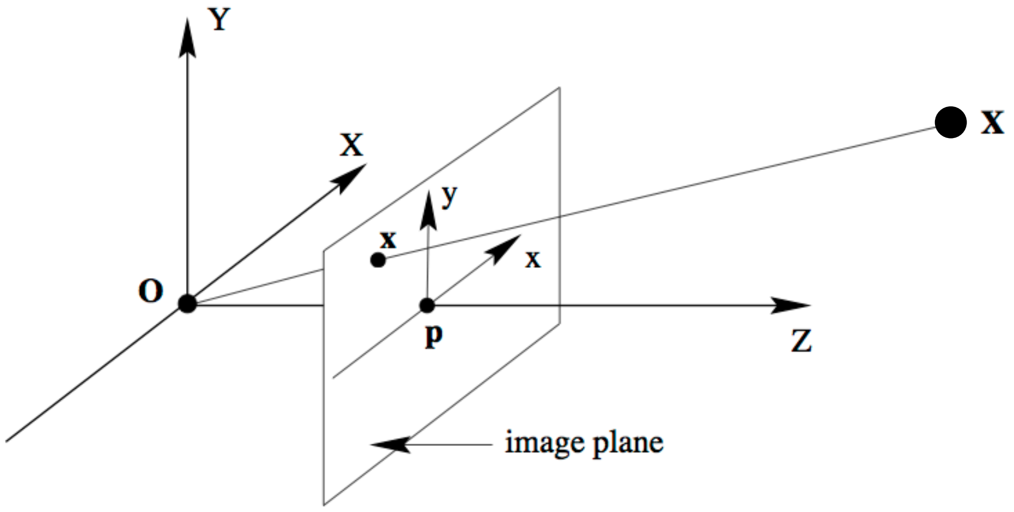
People loves to take picture of me.

$$\mathbf{X} = \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

calibration

I am cool

People loves to take picture of me.

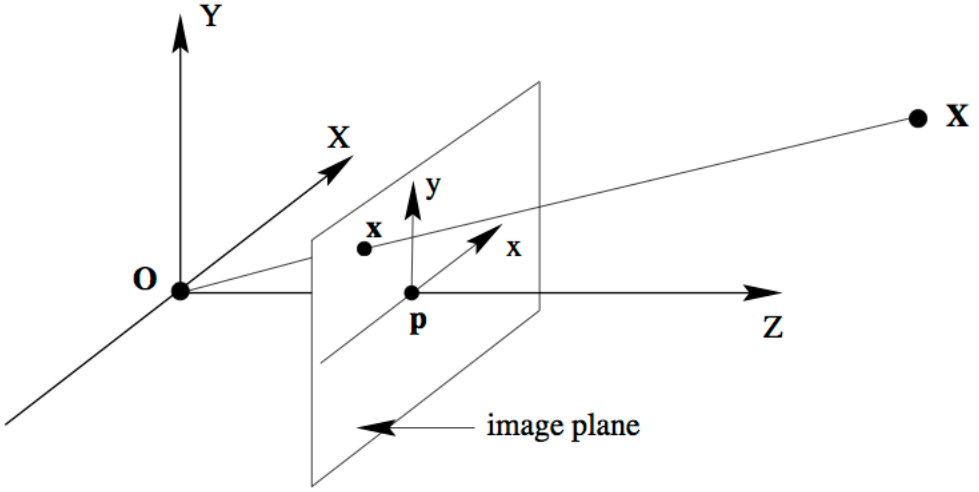


$$\mathbf{x} = \begin{bmatrix} x \\ y \end{bmatrix} \qquad \mathbf{X} = \begin{bmatrix} X \\ Y \\ Z \end{bmatrix}$$

2D   3D

calibration

When they take a picture



$$\begin{bmatrix} x \\ y \\ \boxed{f} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix}$$

2D 3D

$$\mathbf{x} = \mathbf{K}\left[\mathbf{R} \middle| \mathbf{t}\right]\mathbf{X}$$

calibration

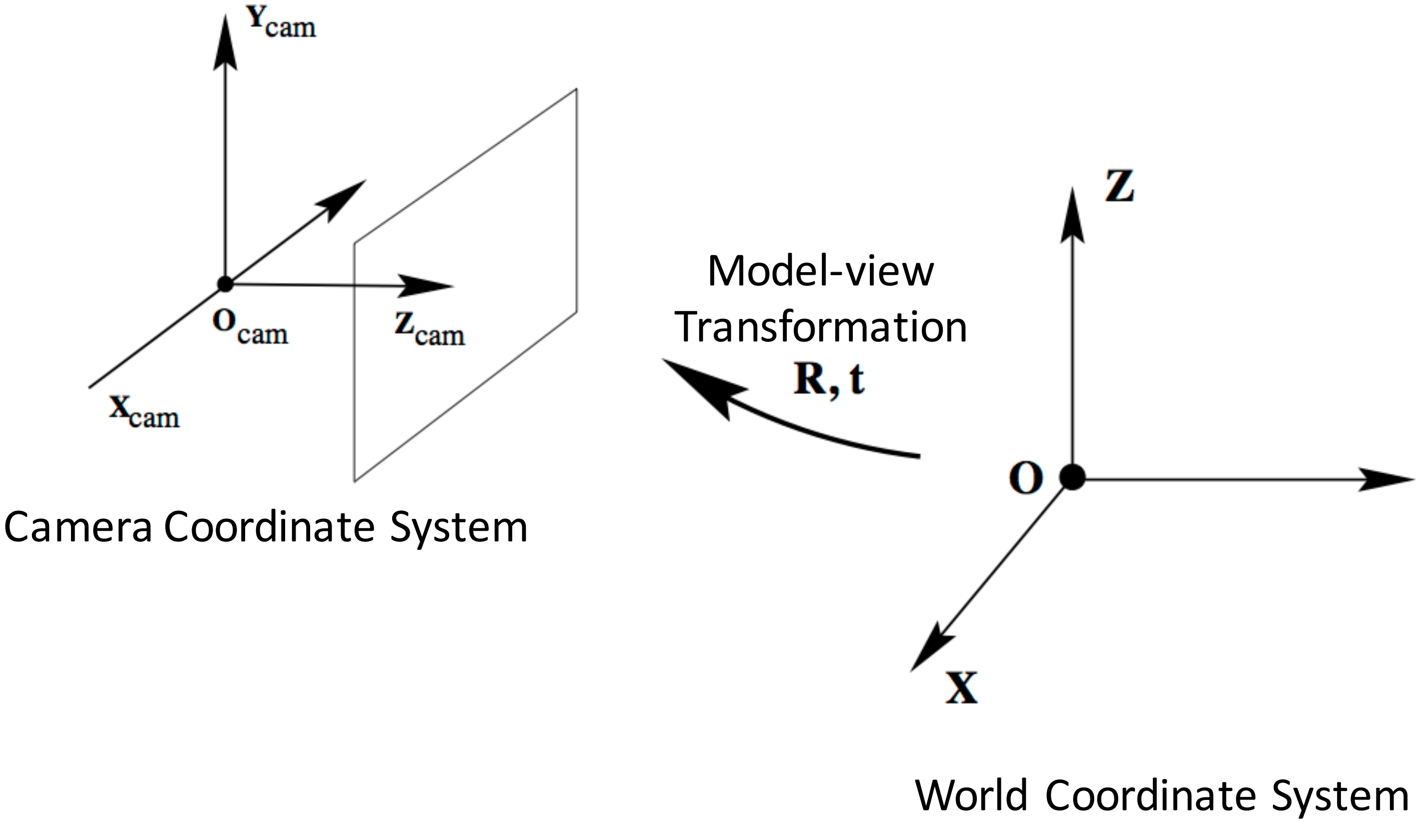
When they take a picture

$$\begin{bmatrix} x \\ y \\ f \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix} \Rightarrow \begin{bmatrix} x \\ y \\ 1 \end{bmatrix} = \begin{bmatrix} f & 0 & 0 \\ 0 & f & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix}$$

$$\mathbf{x} = \mathbf{K}\left[\mathbf{R} \middle| \mathbf{t}\right]\mathbf{X}$$

calibration

I live in a real world



$$\begin{pmatrix} X_{cam} \\ Y_{cam} \\ Z_{cam} \\ 1 \end{pmatrix} = \begin{bmatrix} \mathbf{R} & \mathbf{t} \\ \mathbf{0}^T & 1 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix}$$

3D 3D

$$\mathbf{x} = \mathbf{K}\left[\mathbf{R}\middle|\mathbf{t}\right]\mathbf{X}$$

calibration

World Coor. → Camera Coor.

$$\begin{bmatrix} x \\ y \\ 1 \end{bmatrix} = \begin{bmatrix} f & 0 & 0 \\ 0 & f & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} \mathbf{R} & \mathbf{t} \\ \mathbf{0}^T & 1 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix}$$

$$\mathbf{P} = \mathbf{K}\left[\mathbf{R} \middle| \mathbf{t}\right]$$

Intrinsic Extrinsic

Camera Parameter
Camera Projection Matrix

$$\mathbf{K} = \begin{bmatrix} f & 0 & 0 \\ 0 & f & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad \mathbf{x} = \begin{bmatrix} x \\ y \\ 1 \end{bmatrix} \quad \mathbf{X} = \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix}$$

$$\mathbf{x} = \mathbf{K}\left[\mathbf{R} \middle| \mathbf{t}\right]\mathbf{X}$$

$$\mathbf{x} = \mathbf{P}\mathbf{X}$$

calibration

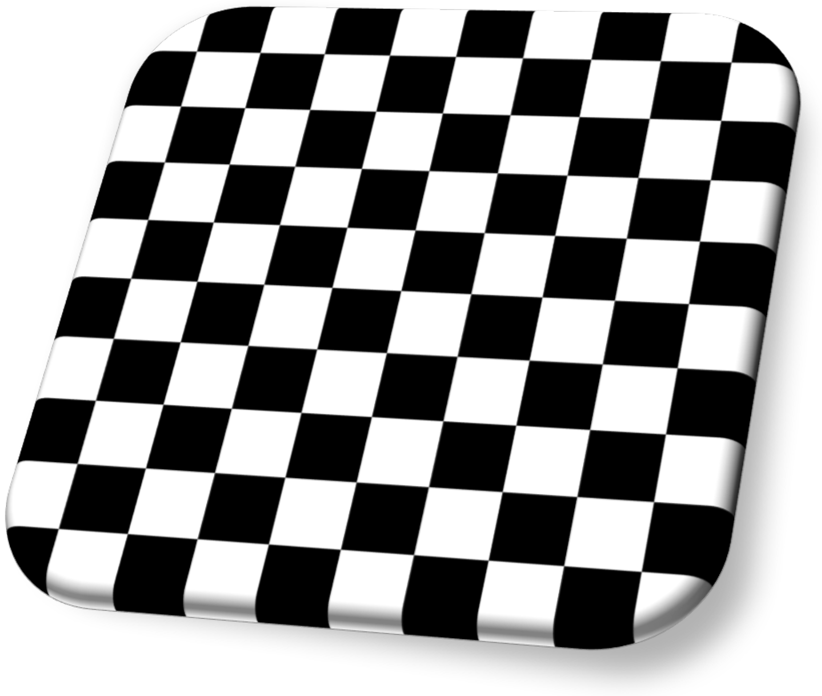
Calibration

Traditional object-based calibration[1]

Self-calibration[2][3]

[1]O. Faugeras. " Three-Dimensional Computer Vision: A Geometric Viewpoint ". MIT Press, 1993.
[2]Hartley, Richard I. "An algorithm for self calibration from several views." *Cvpr*. Vol. 94. 1994.
[3] Luong, Q-T. "Self-calibration of a moving camera from point correspondences and fundamental matrices." *International Journal of computer vision* 22.3 (1997): 261-289.

Zhang Zhengyou calibration method



Closed-Form solution

$\downarrow$ *maximum-likelihood criterion*

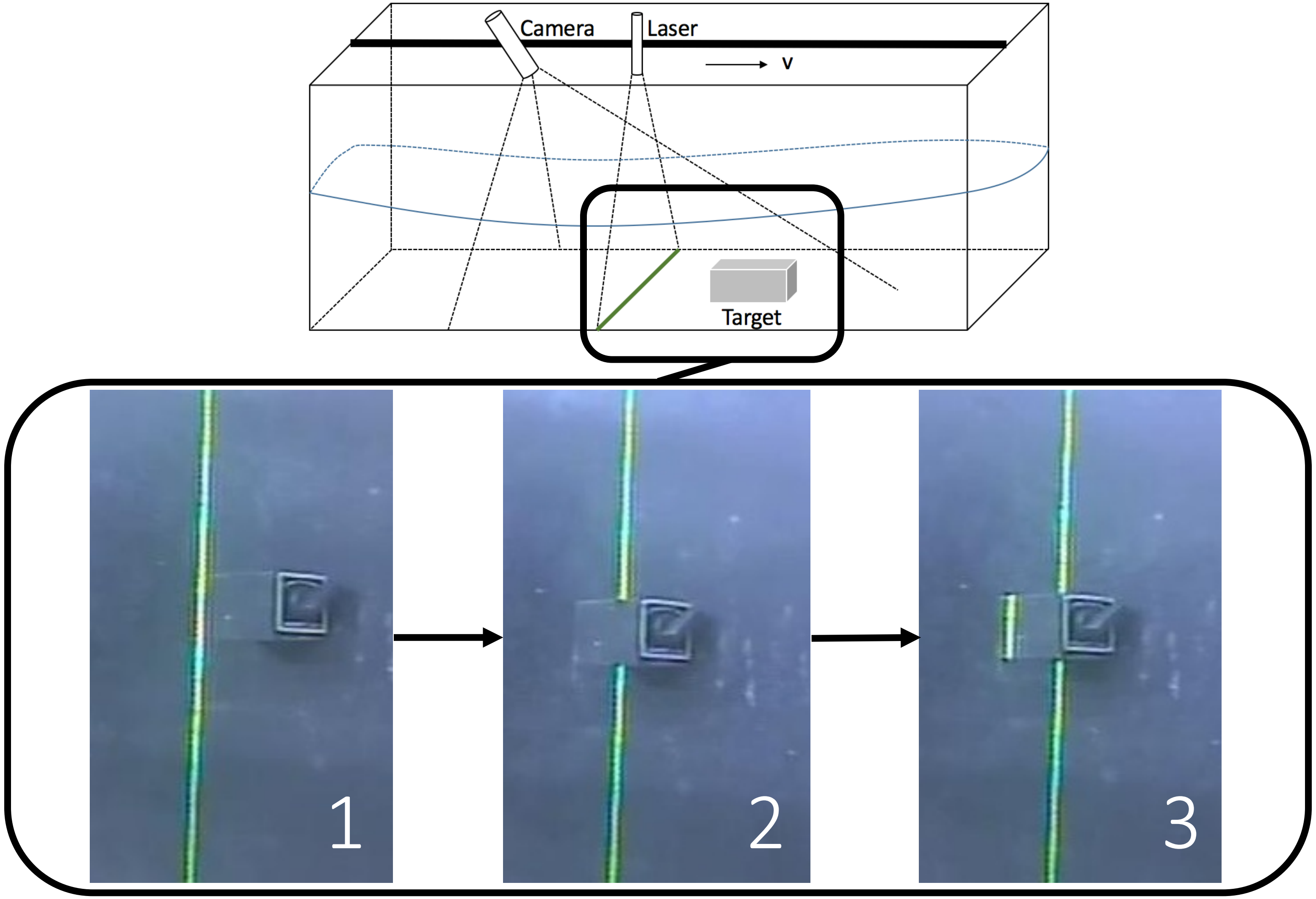
Nonlinear optimization solution

$\downarrow$ *radial distortion*

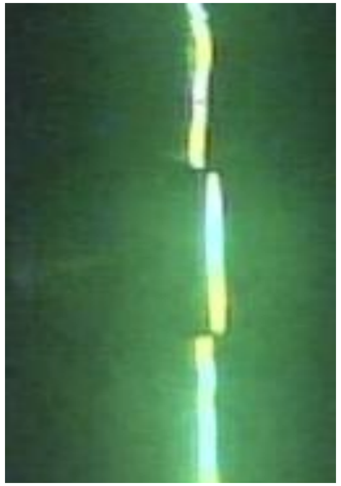
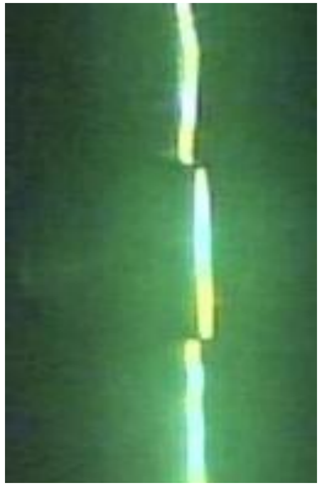
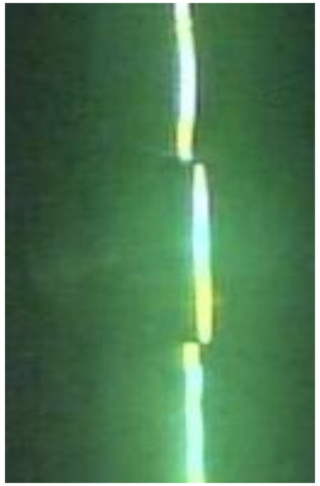
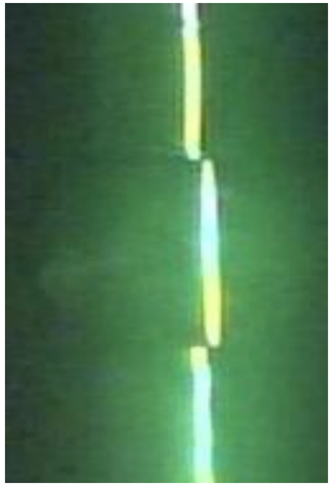
Analytical solution + Nonlinear solution

Zhang, Zhengyou. "A flexible new technique for camera calibration."
IEEE Transactions on pattern analysis and machine intelligence 22.11 (2000): 1330-1334.

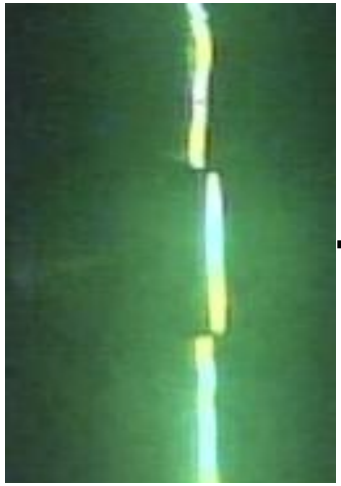
Acquisition

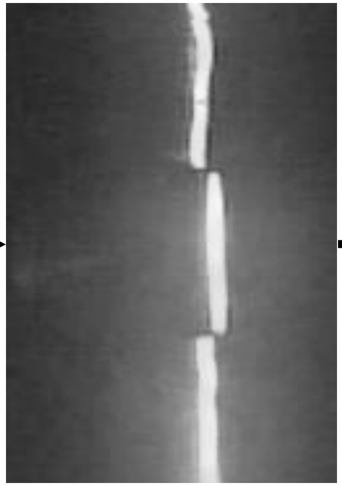


Acquisition

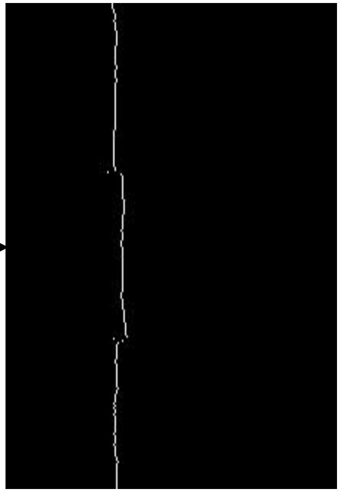

Extraction

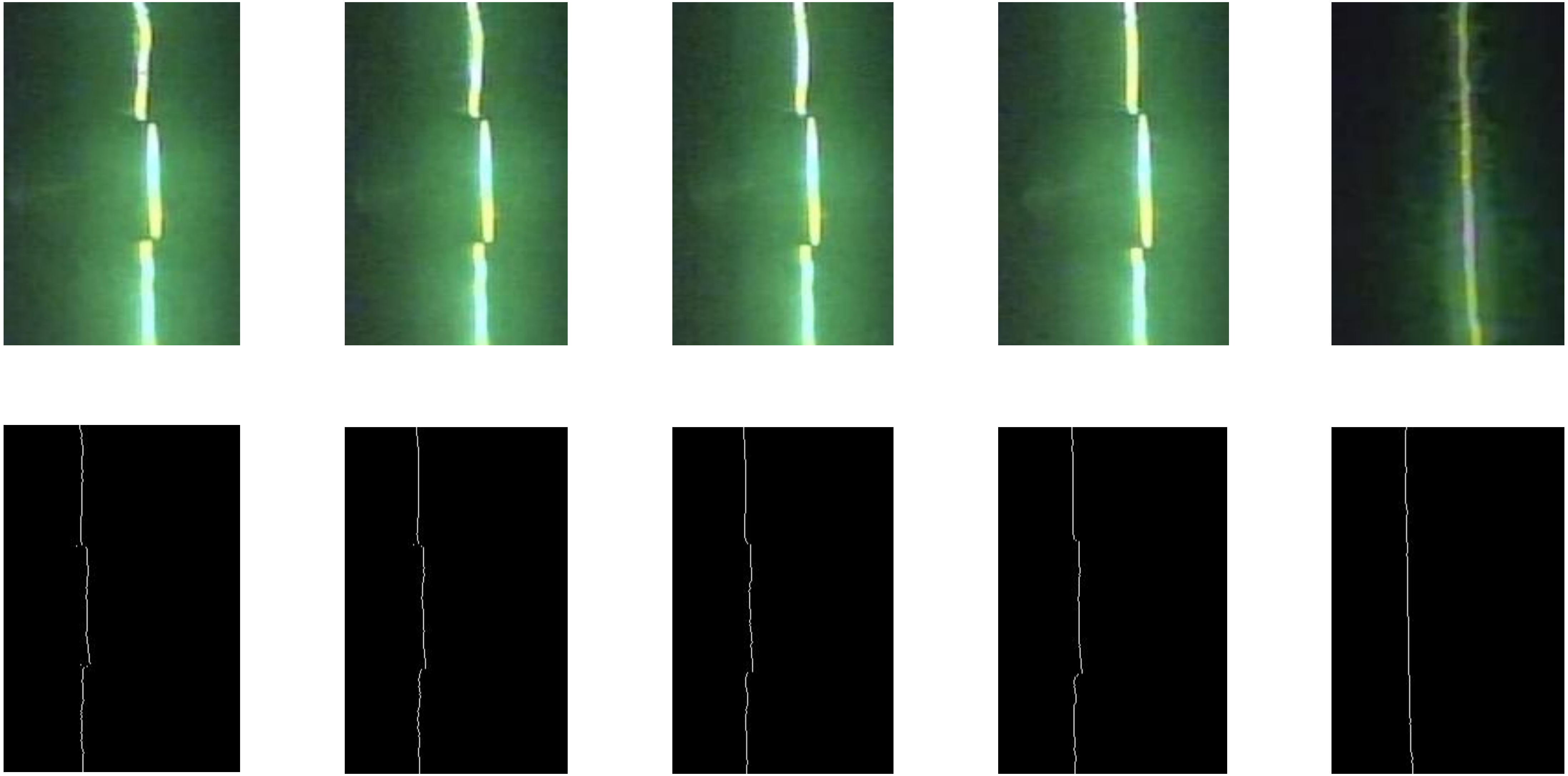




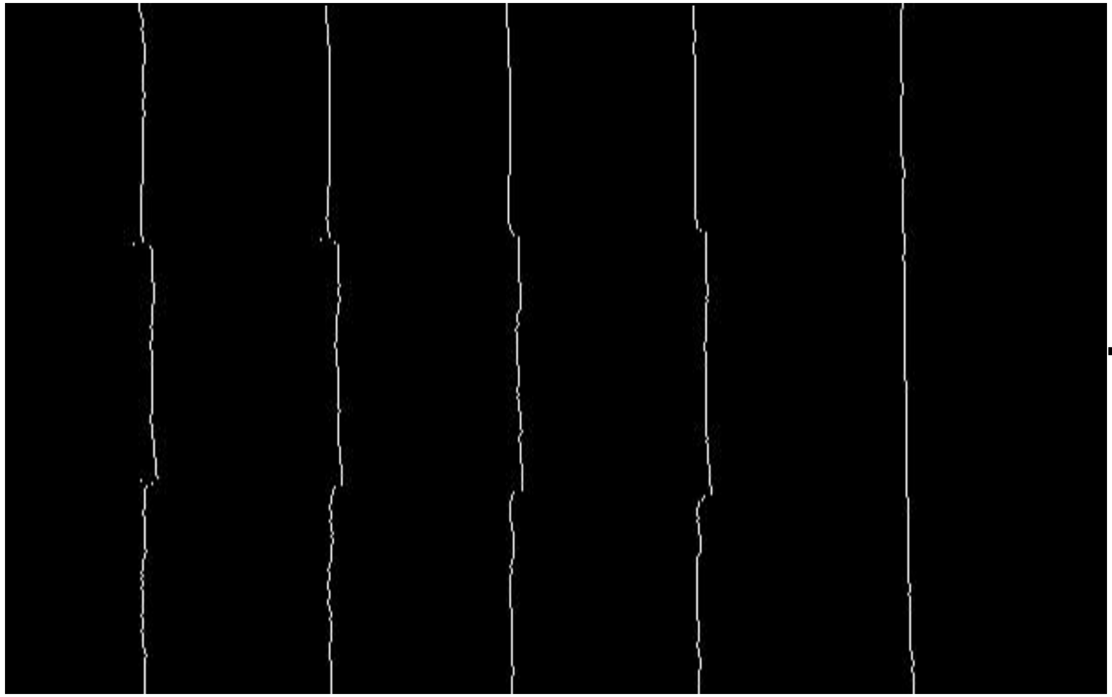
$$x_0 = \frac{\sum_x x \cdot I_x}{\sum_x I_x}$$

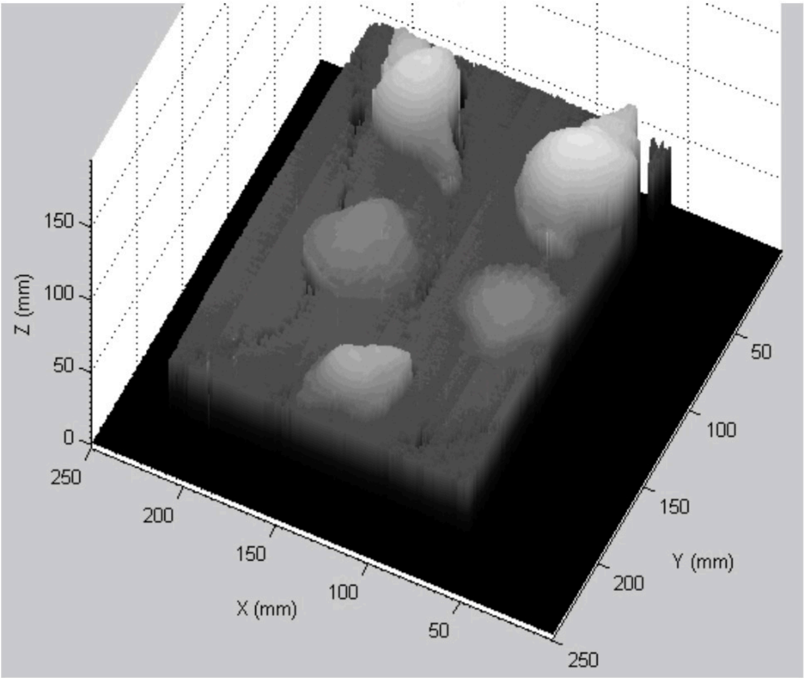
Center of gravity



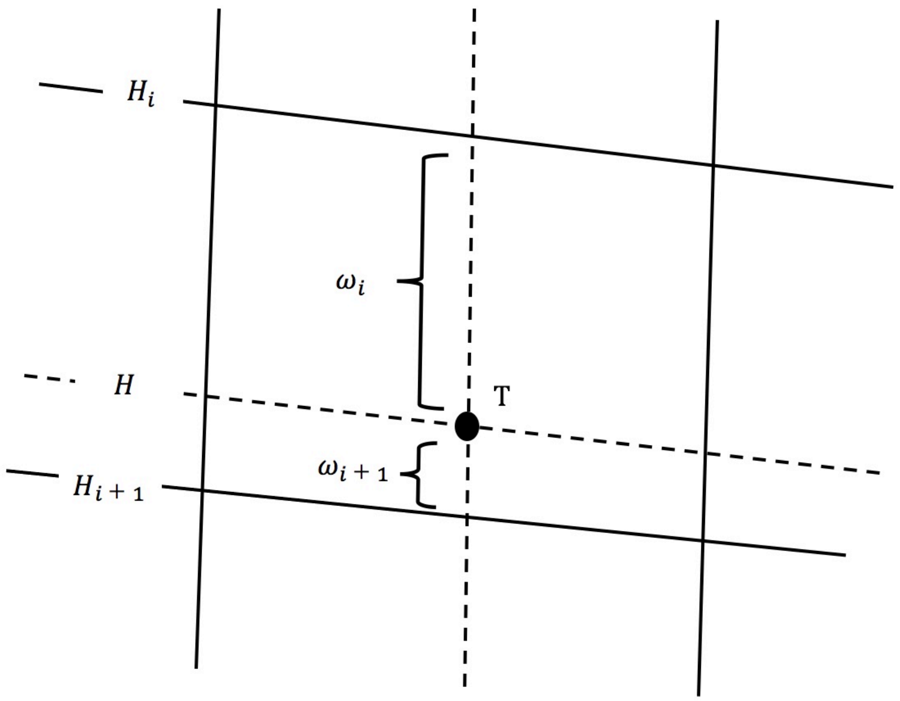


Transformation





Transformation

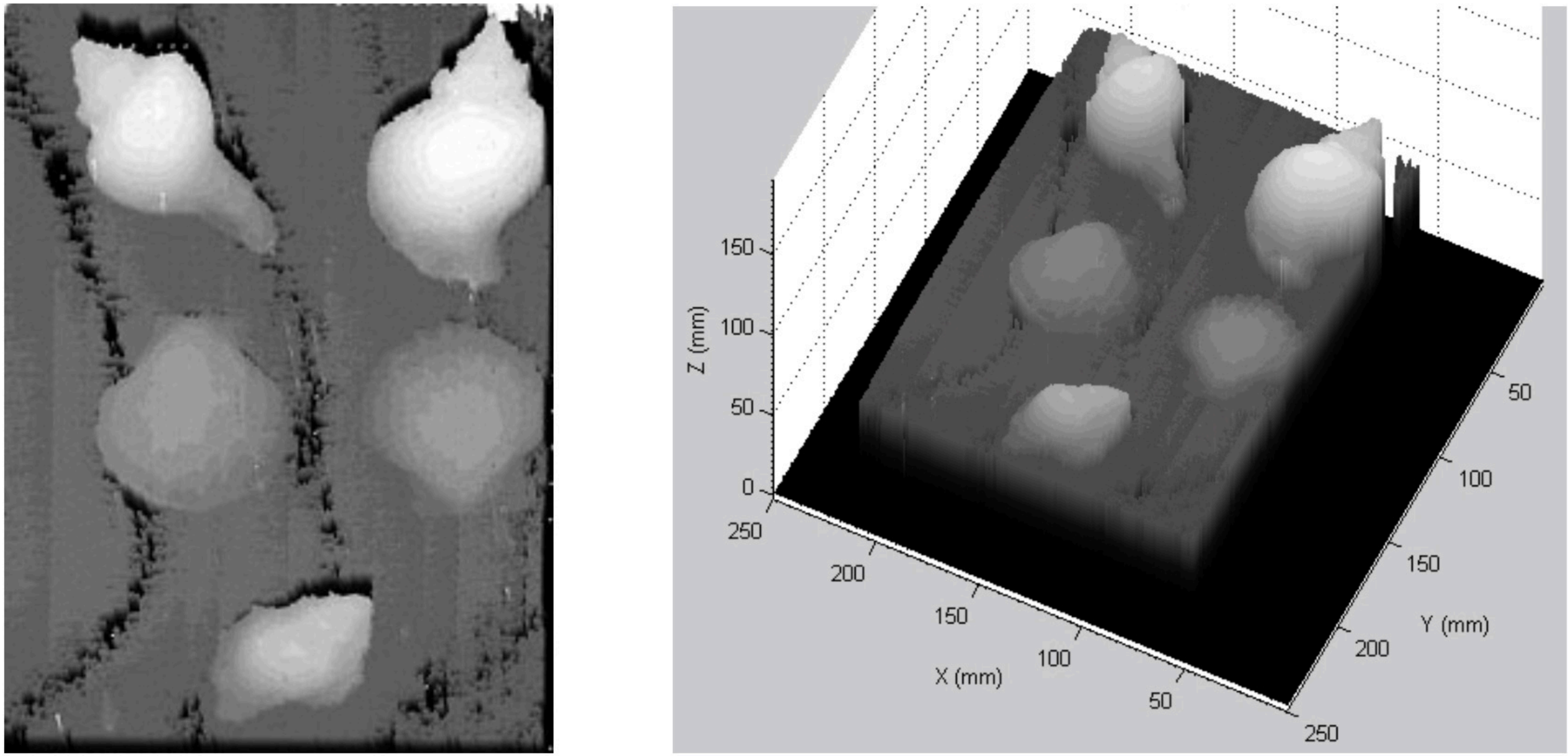


$$\omega_i = \frac{H - H_i}{H_{i+1} - H_i}$$

$$\omega_i + \omega_{i+1} = 1$$

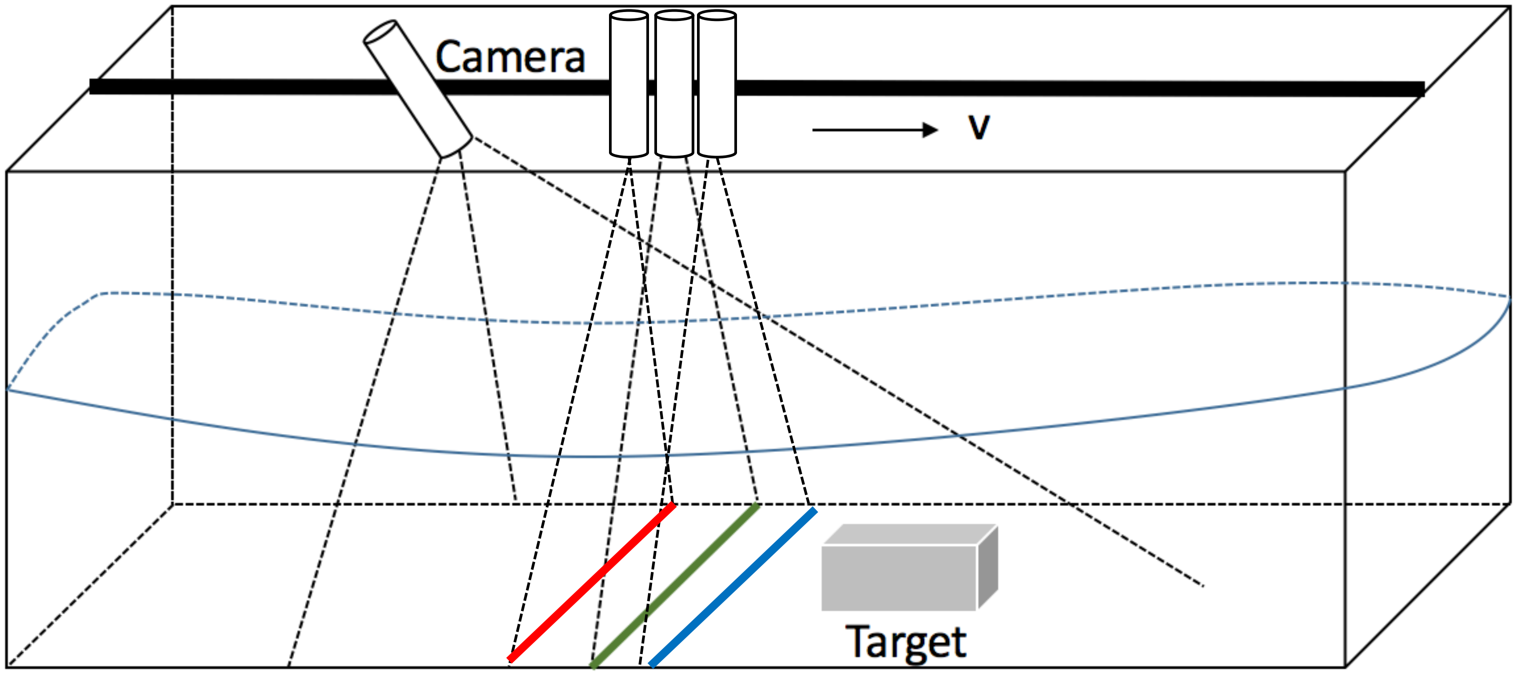
$$h = \omega_i H_i + \omega_{i+1} H_{i+1}$$

Wang, Chau-Chang, and Min-Shine Cheng. "Nonmetric camera calibration for underwater laser scanning system." *IEEE Journal of Oceanic Engineering* 32.2 (2007): 383-399.



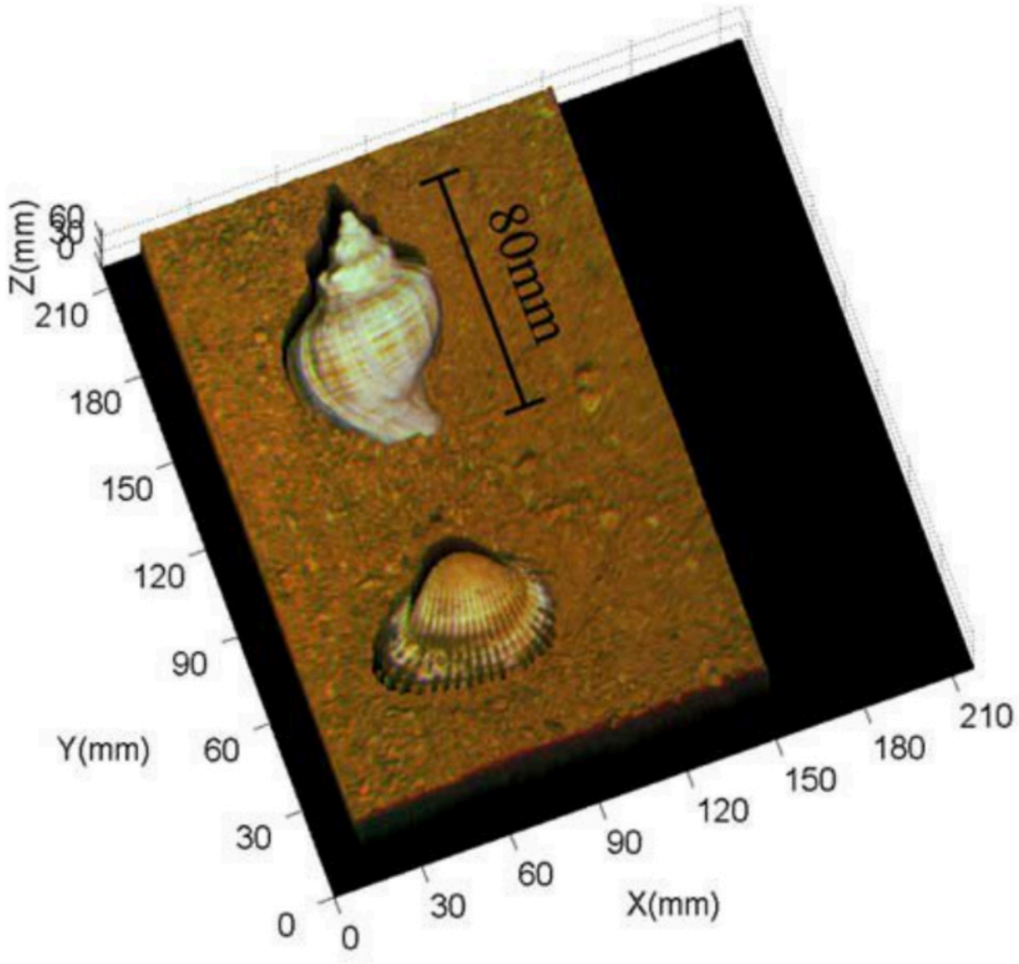
(a) (b)

Yang, Yu, et al. "3D reconstruction for underwater laser line scanning." *OCEANS-Bergen, 2013 MTS/IEEE*. IEEE, 2013.



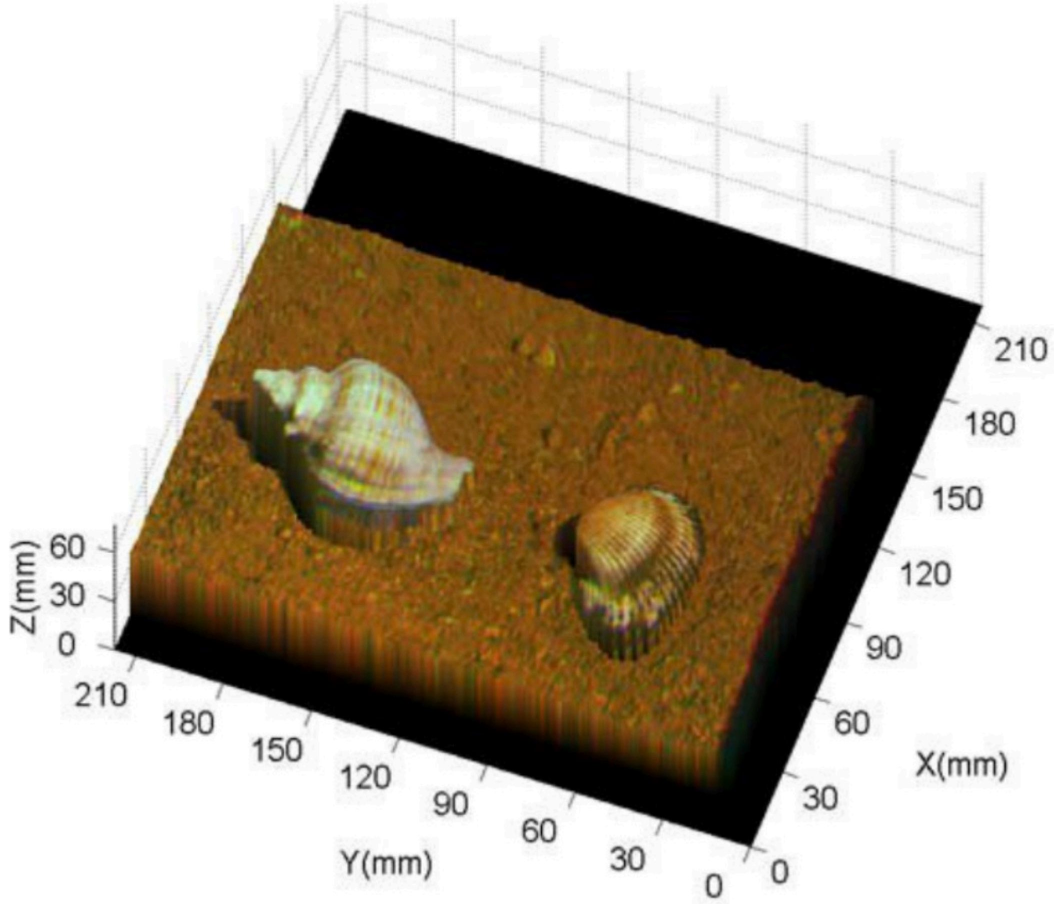
Calibration + Color calibration

Transformation + Color compound



Z(mm)
60
30
0
210
180
150
120
90
60
30
0
Y(mm)
0
30
60
90
120
150
180
210
X(mm)
80mm

(a)



Z(mm)
60
30
0
210
180
150
120
90
60
30
0
Y(mm)
210
180
150
120
90
60
30
0
X(mm)

(b)

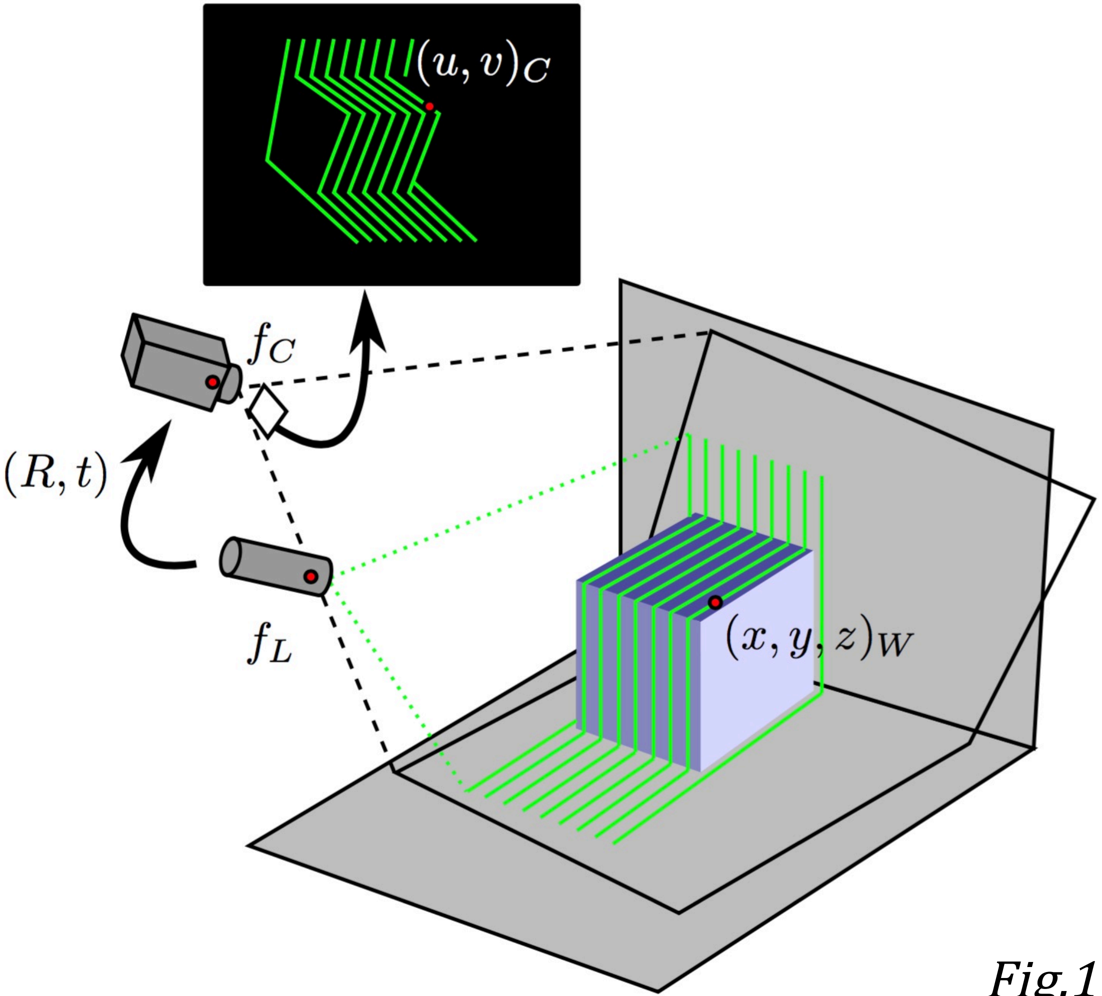


Fig.1

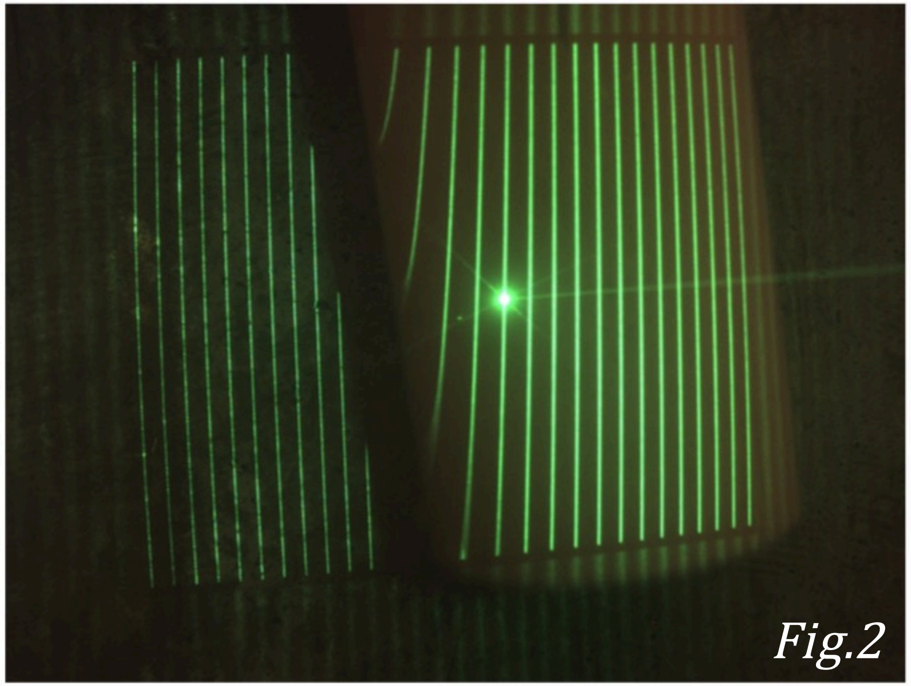


Fig.2

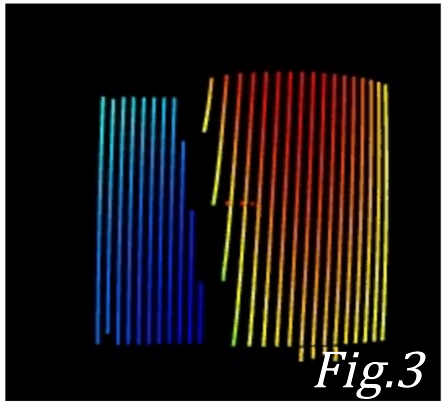


Fig.3

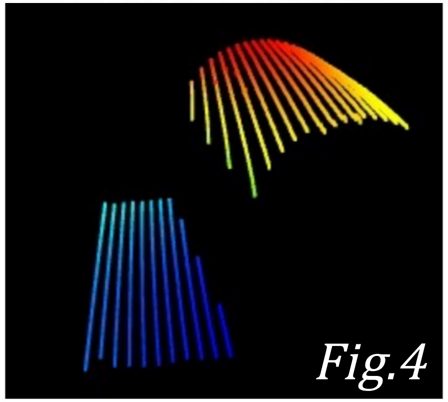
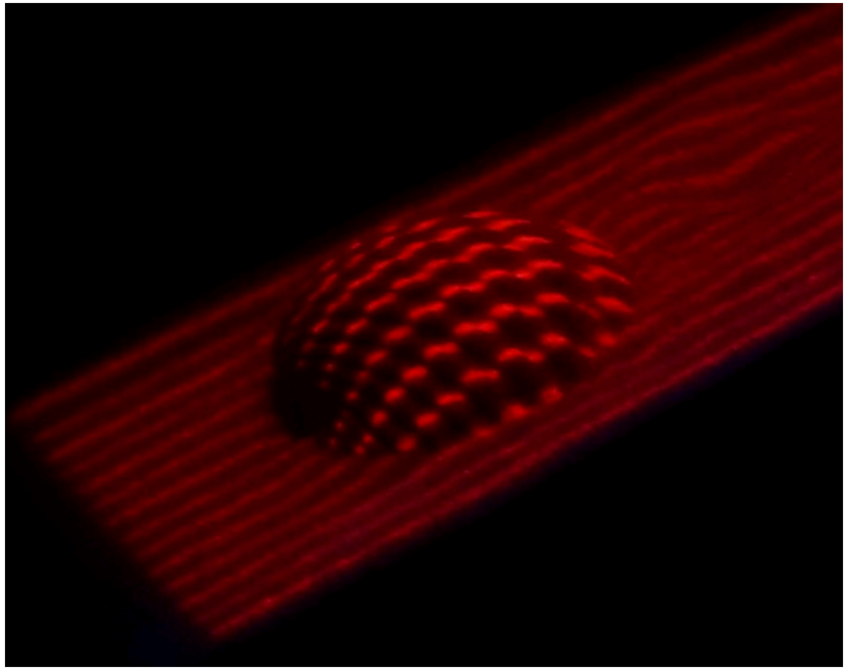
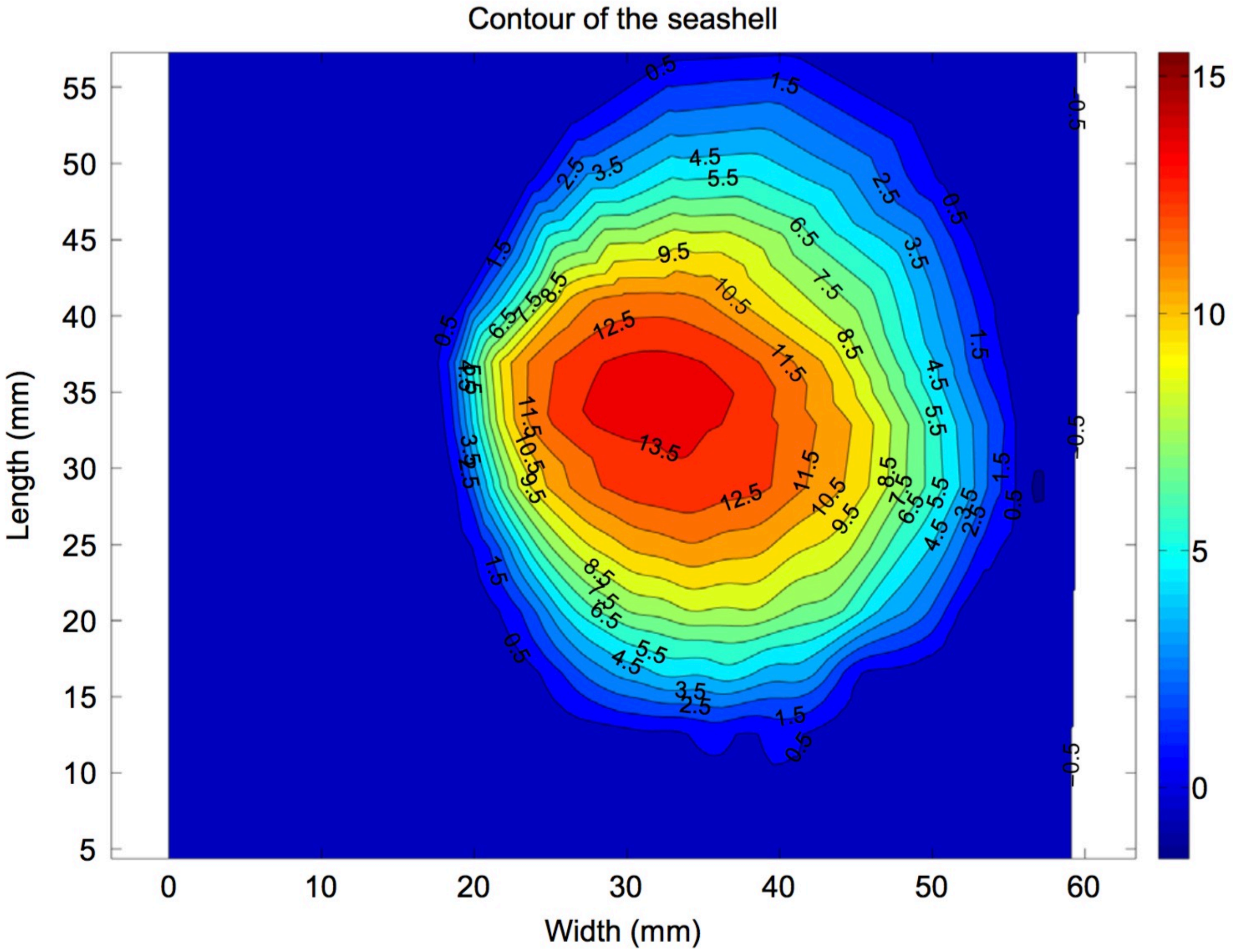


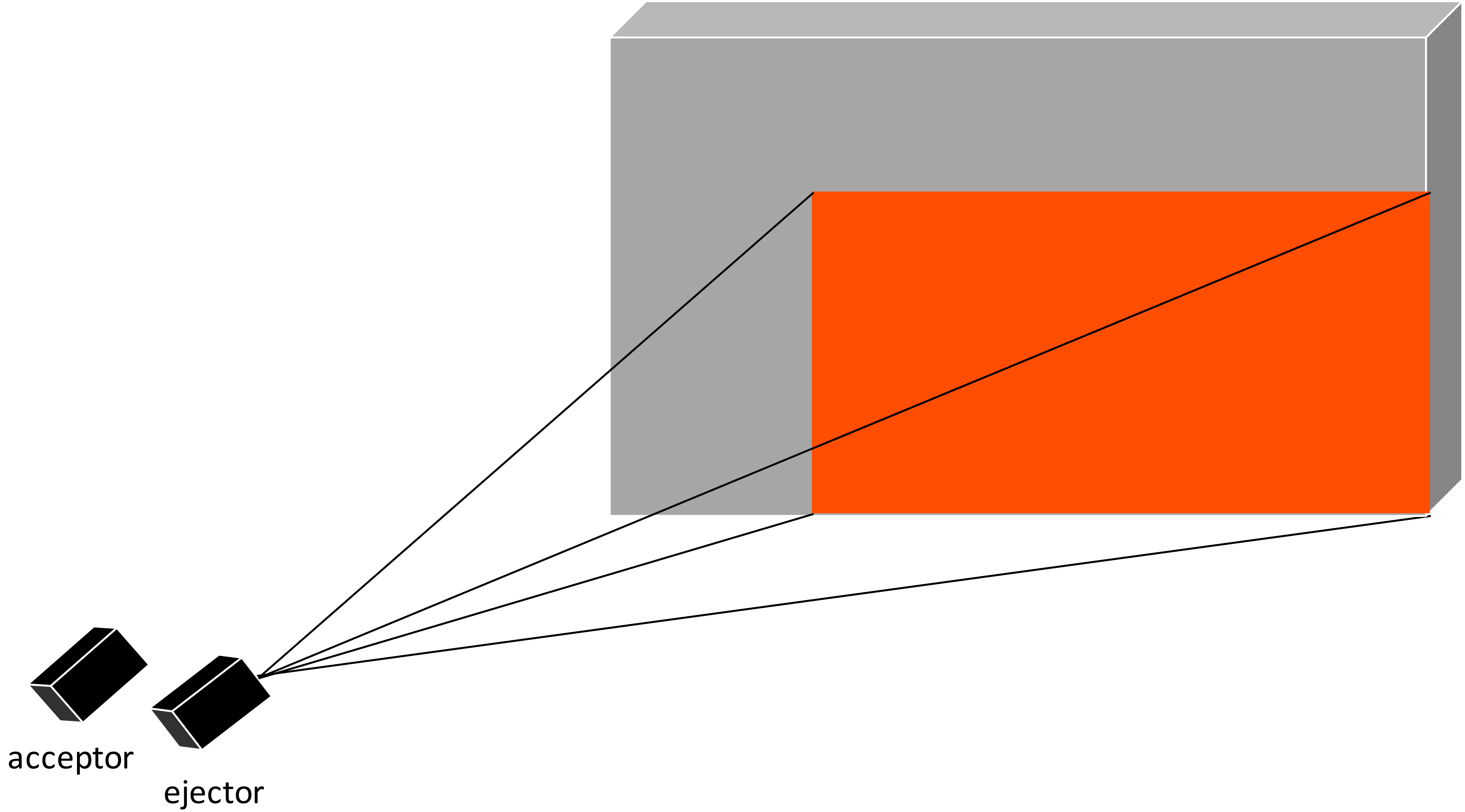
Fig.4

Massot-Campos, Miquel, and Gabriel Oliver-Codina. "One-shot underwater 3D reconstruction." *Emerging Technology and Factory Automation (ETFA), 2014 IEEE*. IEEE, 2014.





Cebrián-Robles, D., and J. Ortega-Casanova. "Low cost 3D underwater surface reconstruction technique by image processing." *Ocean Engineering* 113 (2016): 24-33.


acceptor
ejector

Modified method

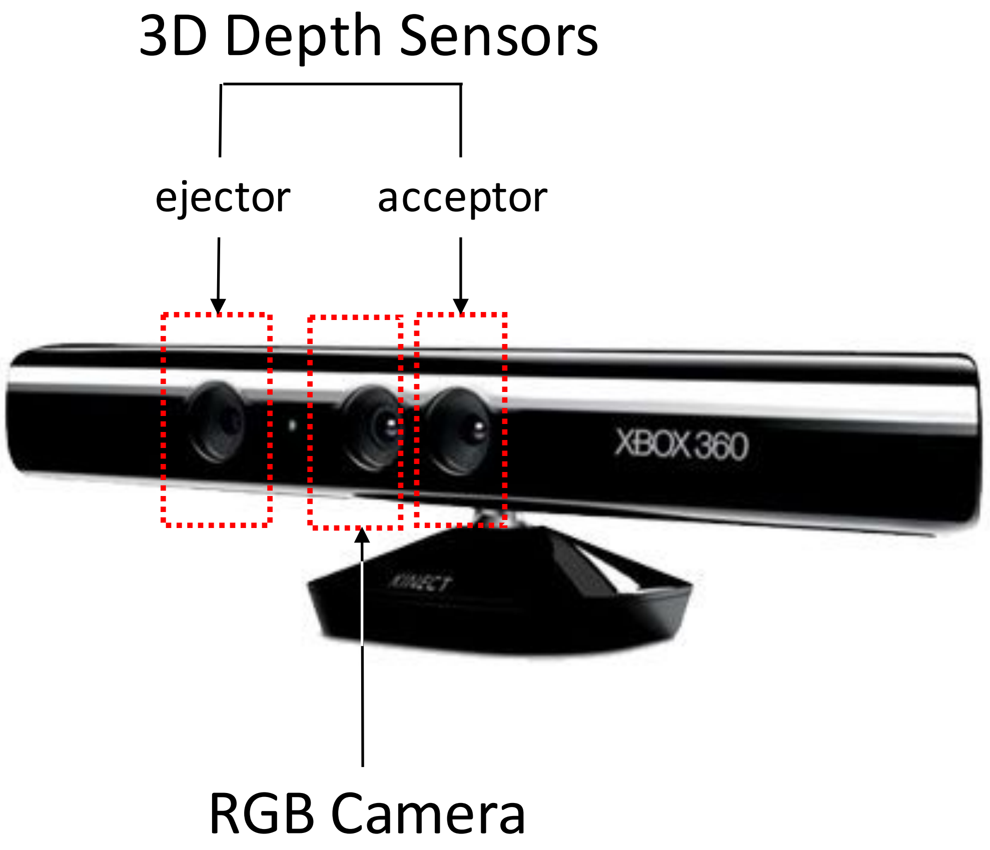
Kinect

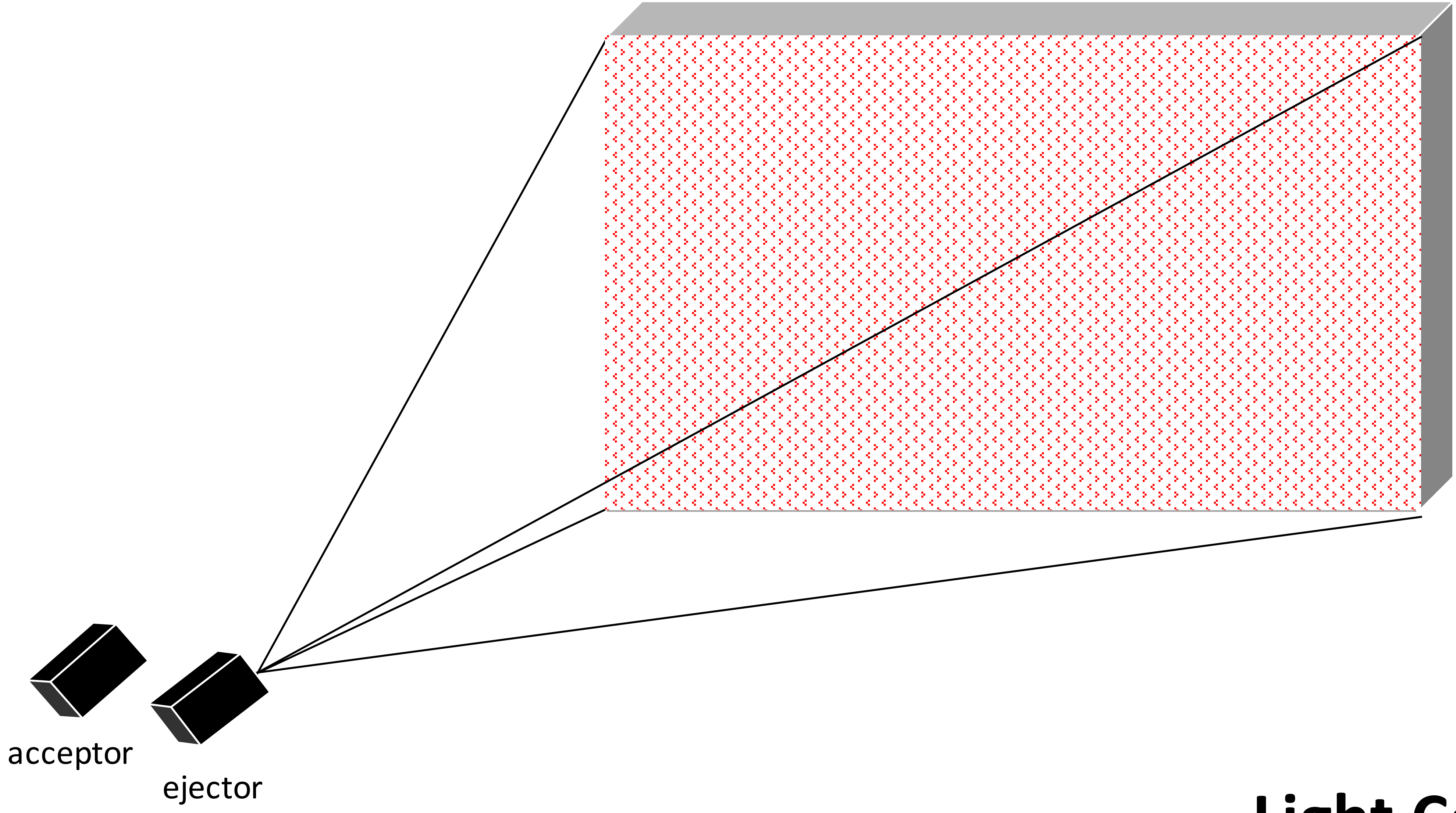
First generation

Light Coding

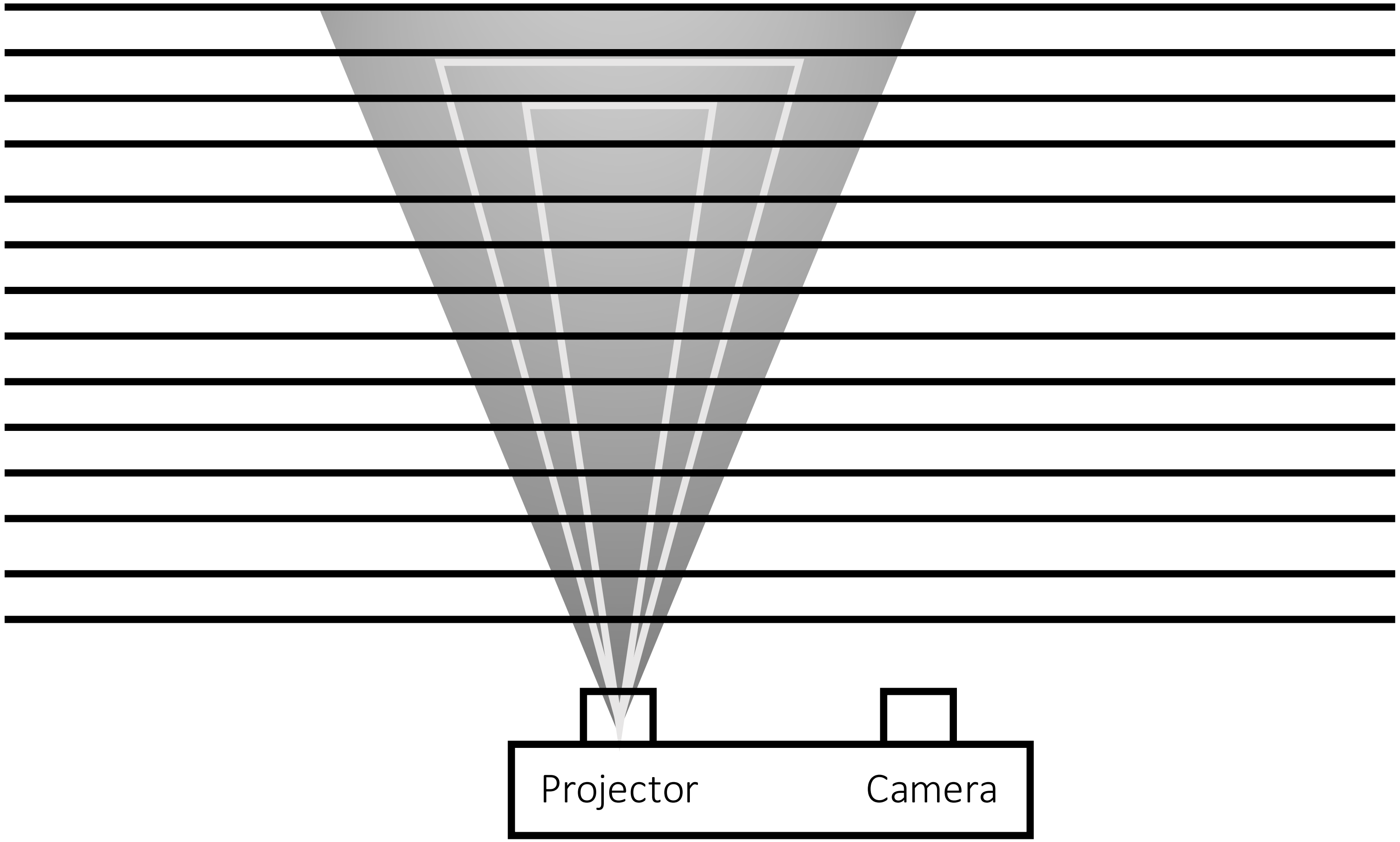
Second generation

Time of Flight


3D Depth Sensors
ejector
acceptor
XBOX 360
RGB Camera



Light Coding

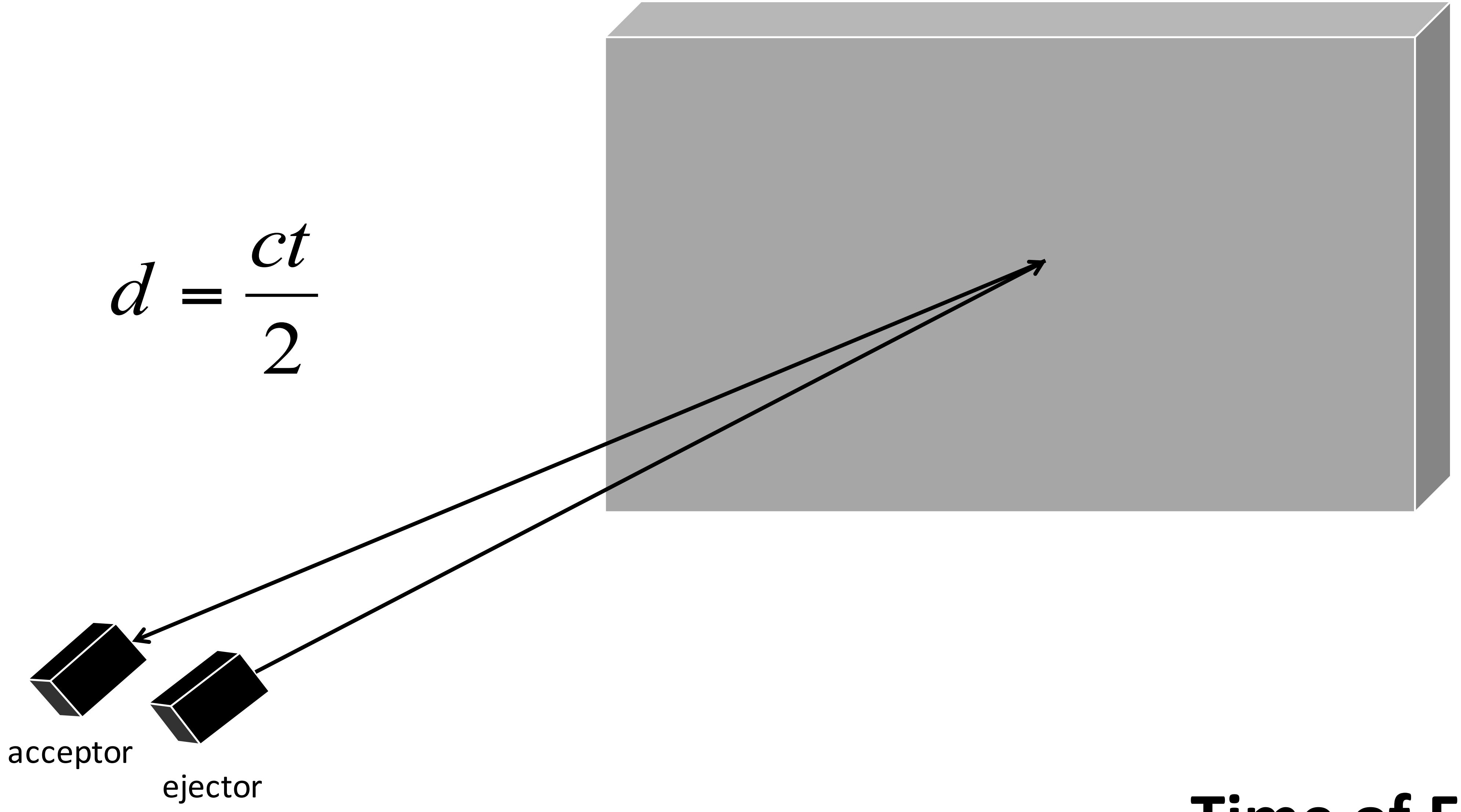


Light Coding

3D Depth Sensors

RGB Camera

$$d = \frac{ct}{2}$$



Time of Flight

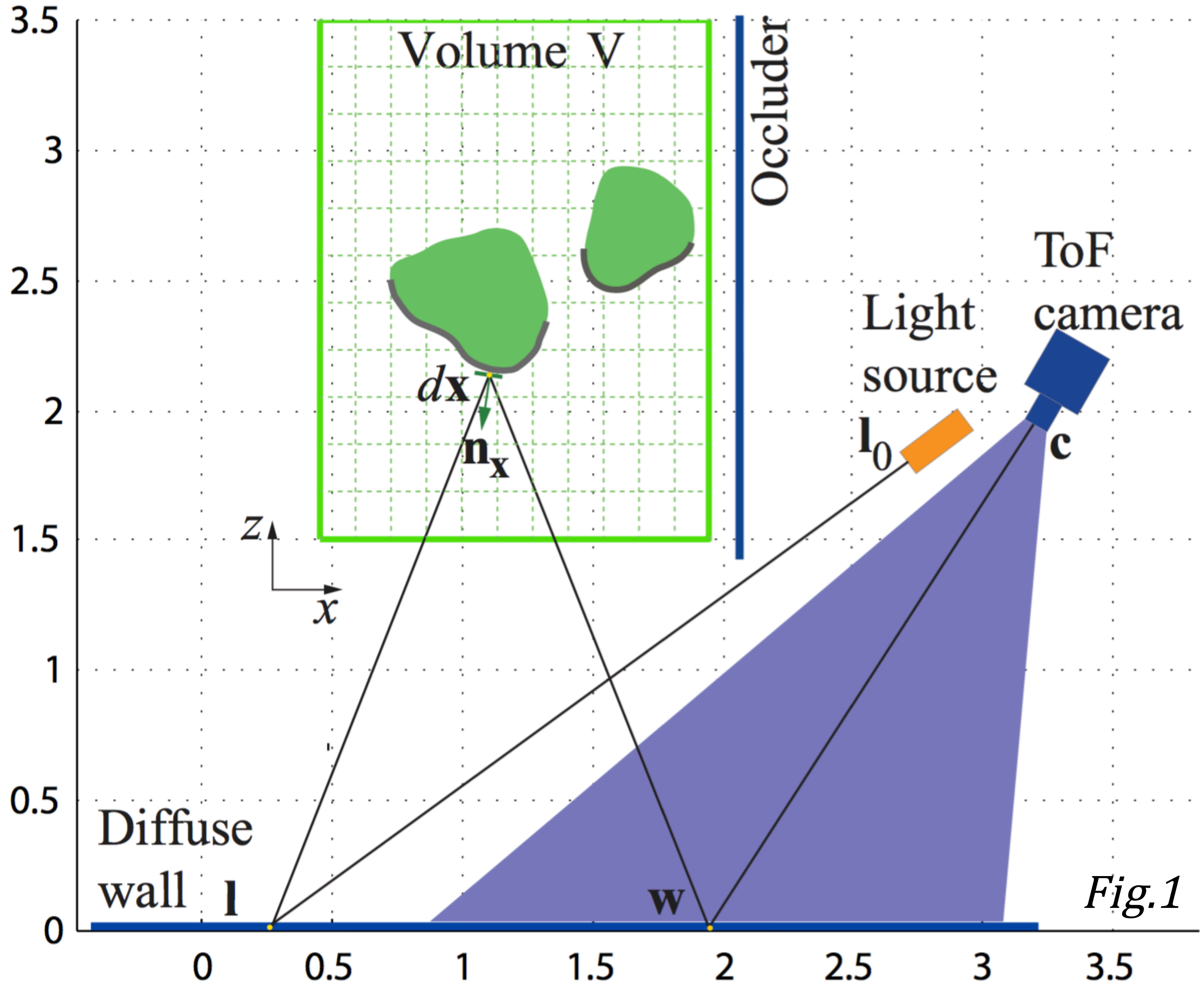


Fig.1

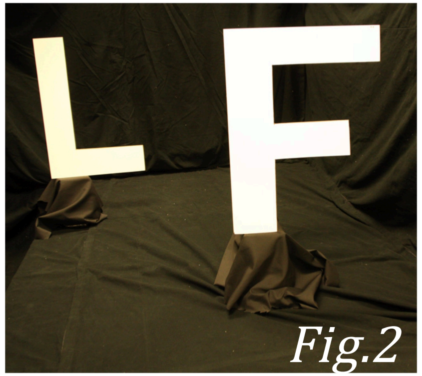


Fig.2

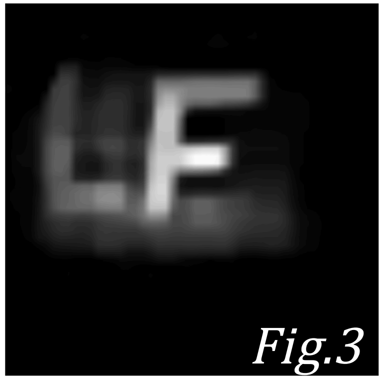


Fig.3

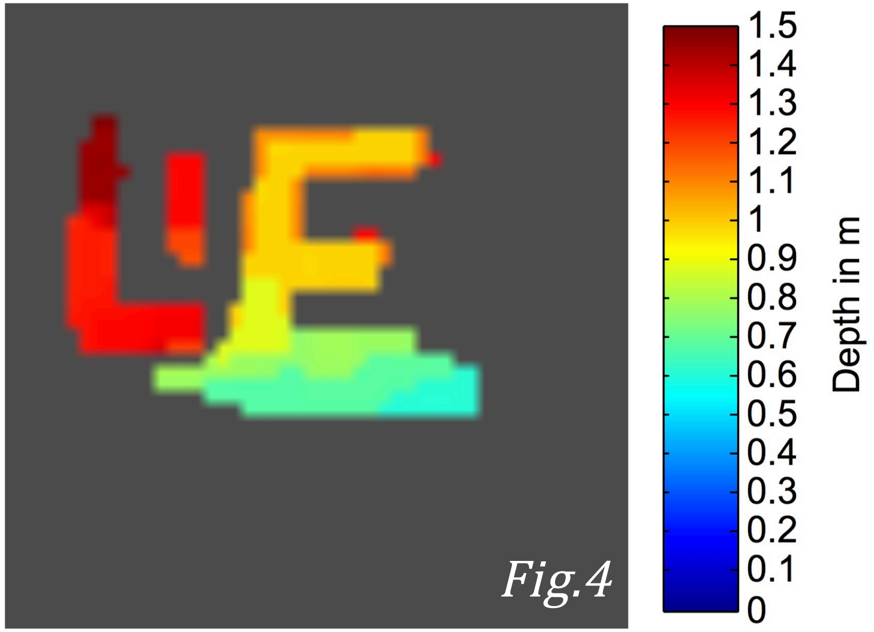


Fig.4

Heide, Felix, et al. "Diffuse Mirrors: 3D Reconstruction from Diffuse Indirect Illumination Using Inexpensive Time-of-Flight Sensors." *IEEE Conference on Computer Vision and Pattern Recognition* IEEE Computer Society, 2014:3222-3229.

Passive methods

Photos

Monocular vision

One camera

Binocular vision

Two parallel camera

Structure from Motion

two-dimensional image sequences

three-dimensional structures

Structure from Motion

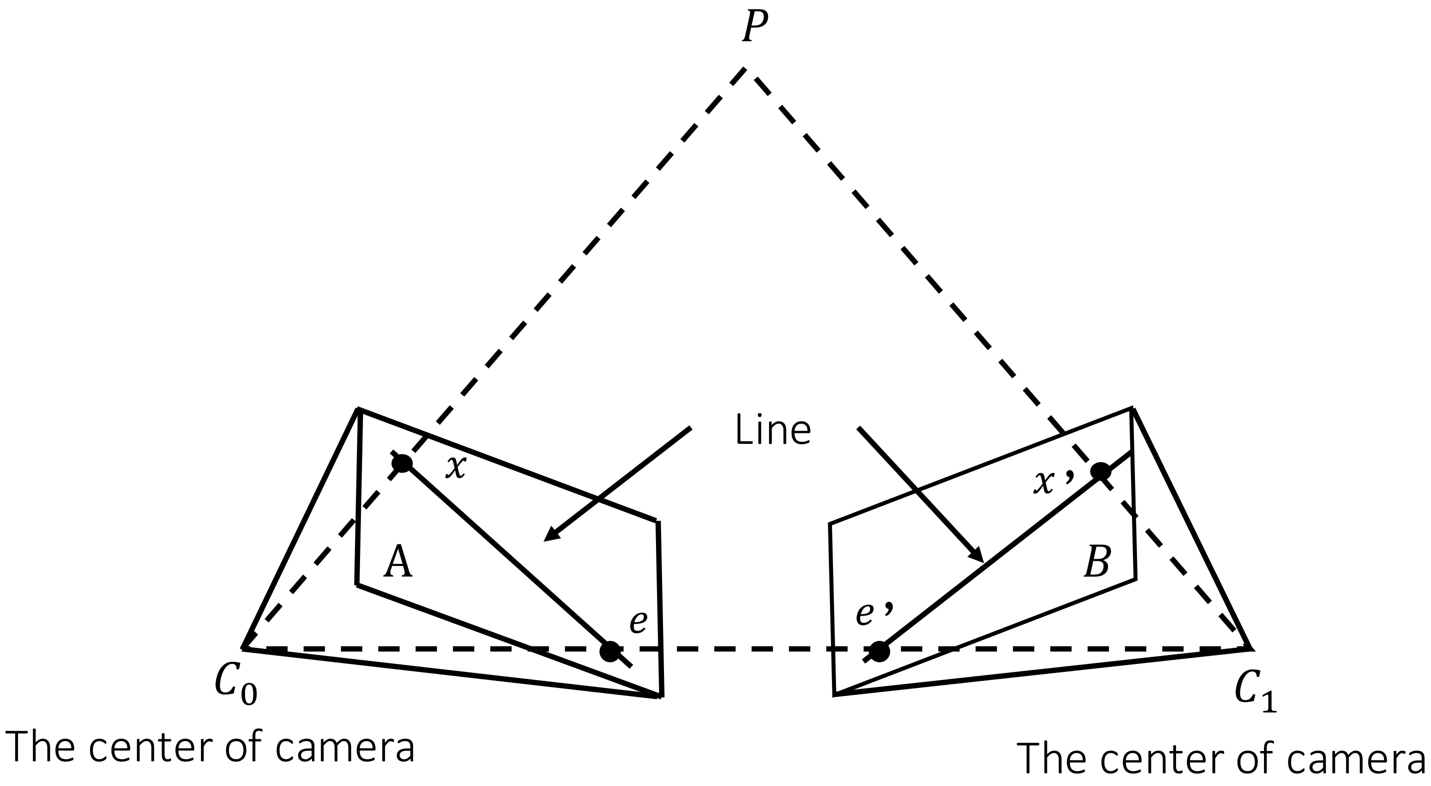
advantage

1. Calibration
2. Acquisition
3. Scene

disadvantage

1. Arithmetic
2. Accuracy
3. Time

Introduction



Introduction

Image acquisition → Sparse reconstruction

Dense reconstruction

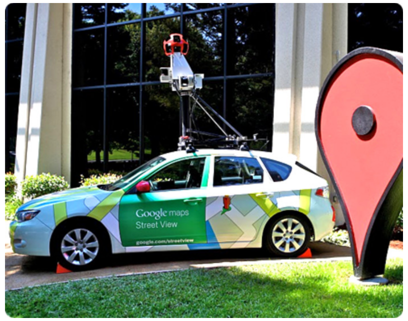
Surface reconstruction

Acquisition

UAV

Digital camera

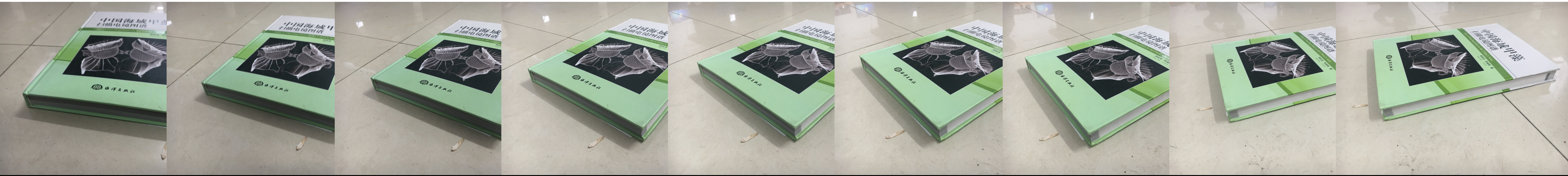
Camera



Street car

Mobile phone


中国海域甲藻
扫描电镜图谱
Atlas of Dinoflagellates in the China's Seas
杨世民 李瑞香 著

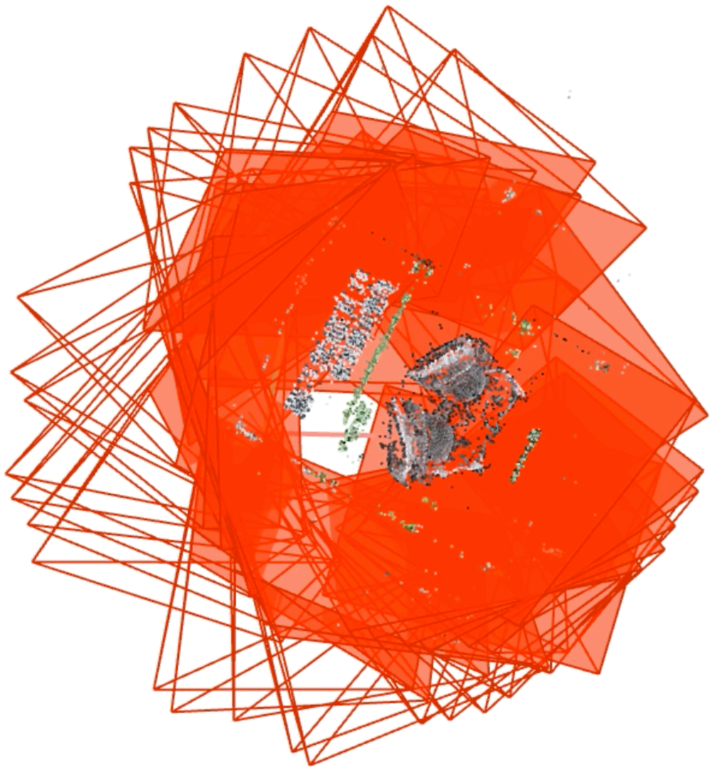


Sparse reconstruction

Feature point matching

Calculation of camera parameters

Bundle adjustment



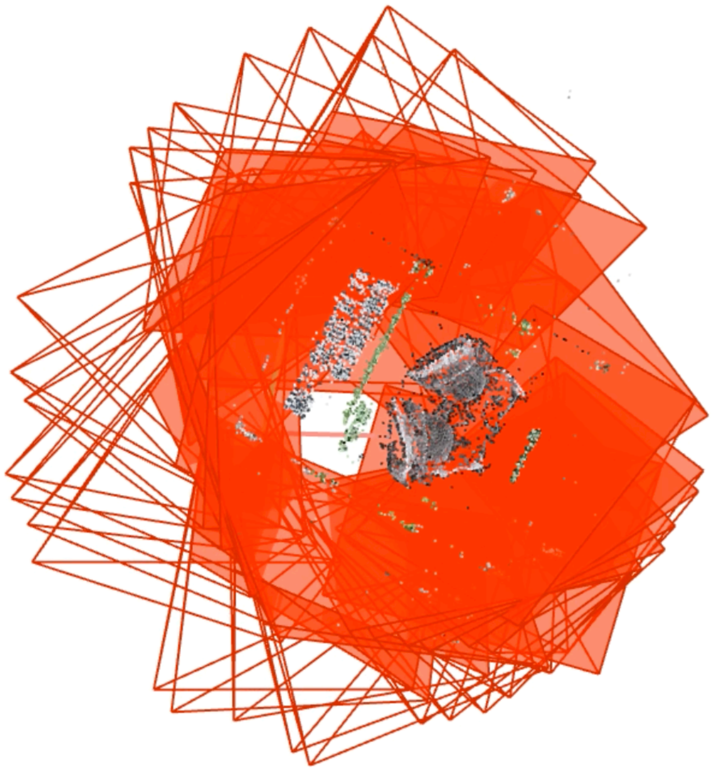
The generated process of Sparse reconstruction

Sparse reconstruction

Feature point matching

Calculation of camera parameters

Bundle adjustment



The generated process of Sparse reconstruction

Feature point matching

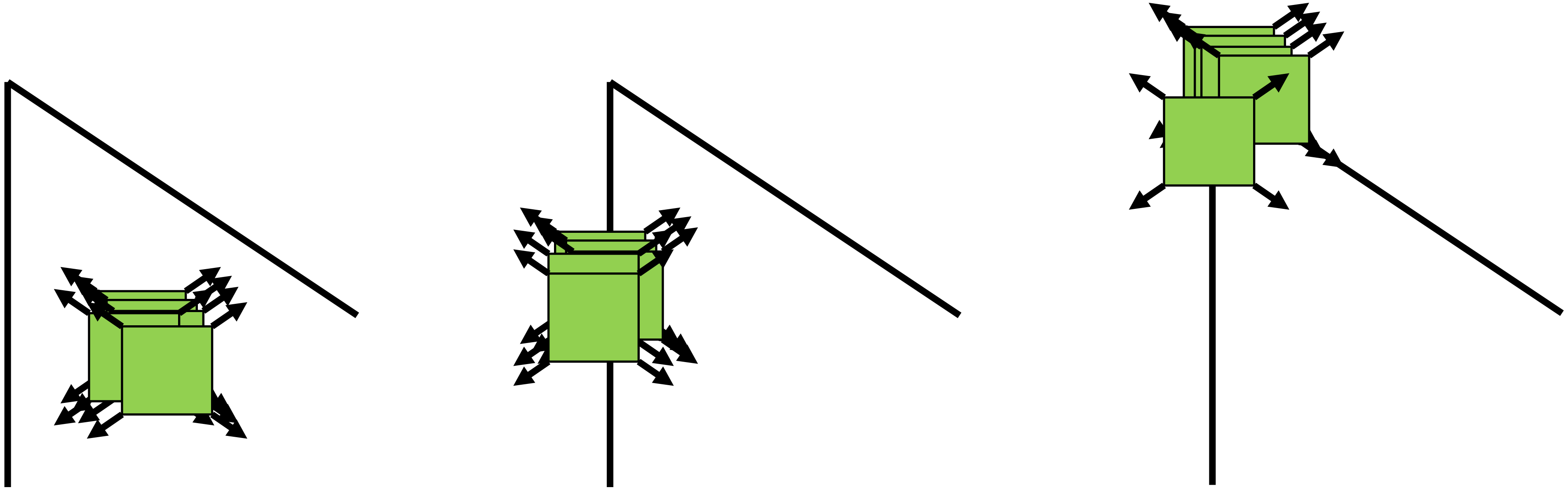
Harris corner detection[1]

SIFT（Scale-invariant feature transform）[2]

SURF（Speeded Up Robust Features）[3]

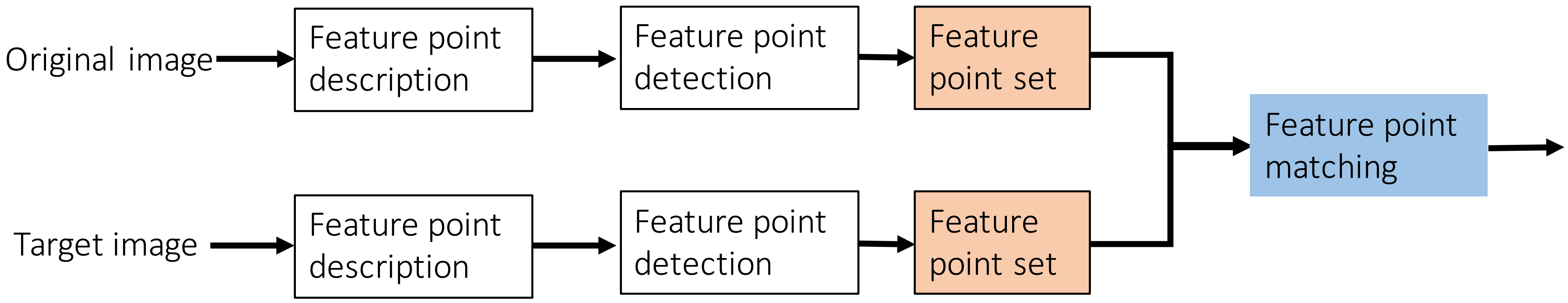
[1]Harris, Chris, and Mike Stephens. "A combined corner and edge detector." *Alvey vision conference*. Vol. 15. No. 50. 1988.
[2]Lowe, David G. "Object recognition from local scale-invariant features." *Computer vision, 1999. The proceedings of the seventh IEEE international conference on*. Vol. 2. Ieee, 1999.
[3] Bay, Herbert, Tinne Tuytelaars, and Luc Van Gool. "Surf: Speeded up robust features." *Computer vision–ECCV 2006* (2006): 404-417.

Harris corner detection



Harris, Chris, and Mike Stephens. "A combined corner and edge detector." *Alvey vision conference*. Vol. 15. No. 50. 1988.

SIFT



Lowe, David G. "Object recognition from local scale-invariant features." *Computer vision, 1999. The proceedings of the seventh IEEE international conference on*. Vol. 2. Ieee, 1999.

SIFT vs SURF

The establishment of scale space

The extraction of feature points

The generation of feature descriptors

The matching of feature points

similarity

The way of convolution

The detection of feature points

The way of finding direction

The descriptor of feature point

difference

Comparison

Method	Time	Scale	Rotation	Blur	Illumination	Affine
SIFT	common	$\boxed{\text{best}}$	$\boxed{\text{best}}$	$\boxed{\text{best}}$	common	good
PCA-SIFT	good	common	good	common	good	good
SURF	$\boxed{\text{best}}$	good	common	good	$\boxed{\text{best}}$	good

Graffiti dataset

Juan, Luo, and Oubong Gwun. "A comparison of sift, pca-sift and surf." *International Journal of Image Processing (IJIP)* 3.4 (2009): 143-152.

Calculation of camera parameters

3D reconstruction

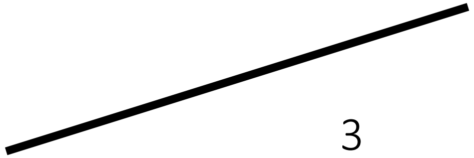
motion estimation

fundamental matrix

self-calibration

Mapping & tracking

The redundancy of feature point



3

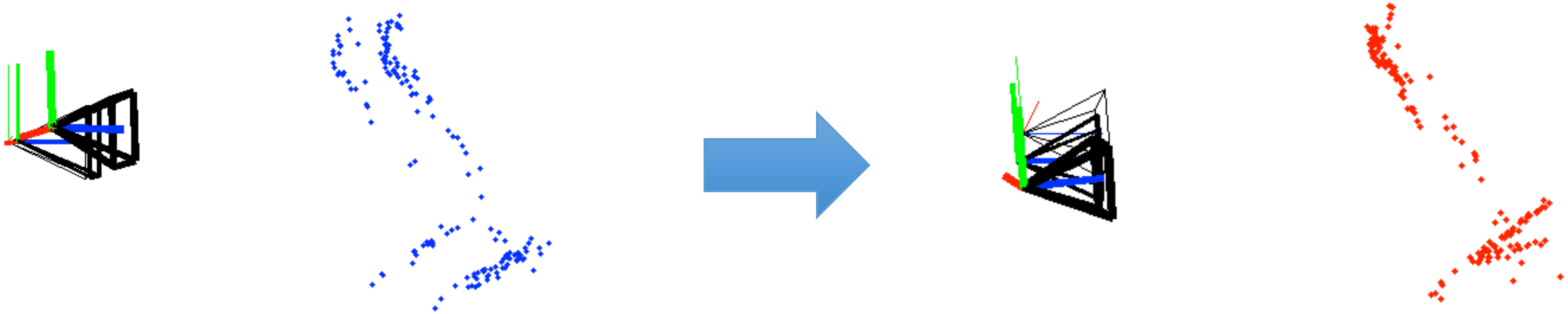
5

[1]Hartley, Richard I. "In defense of the eight-point algorithm." *IEEE Transactions on pattern analysis and machine intelligence* 19.6 (1997): 580-593.
[2] Torr, Philip HS, and David W. Murray. "The development and comparison of robust methods for estimating the fundamental matrix." *International journal of computer vision* 24.3 (1997): 271-300.

Bundle adjustment

iterative
optimization

parameter optimization → nonlinear optimization



Triggs, Bill, et al. "Bundle adjustment—a modern synthesis." *International workshop on vision algorithms*. Springer Berlin Heidelberg, 1999.

Bundler `Noah Snavely`

C
C++

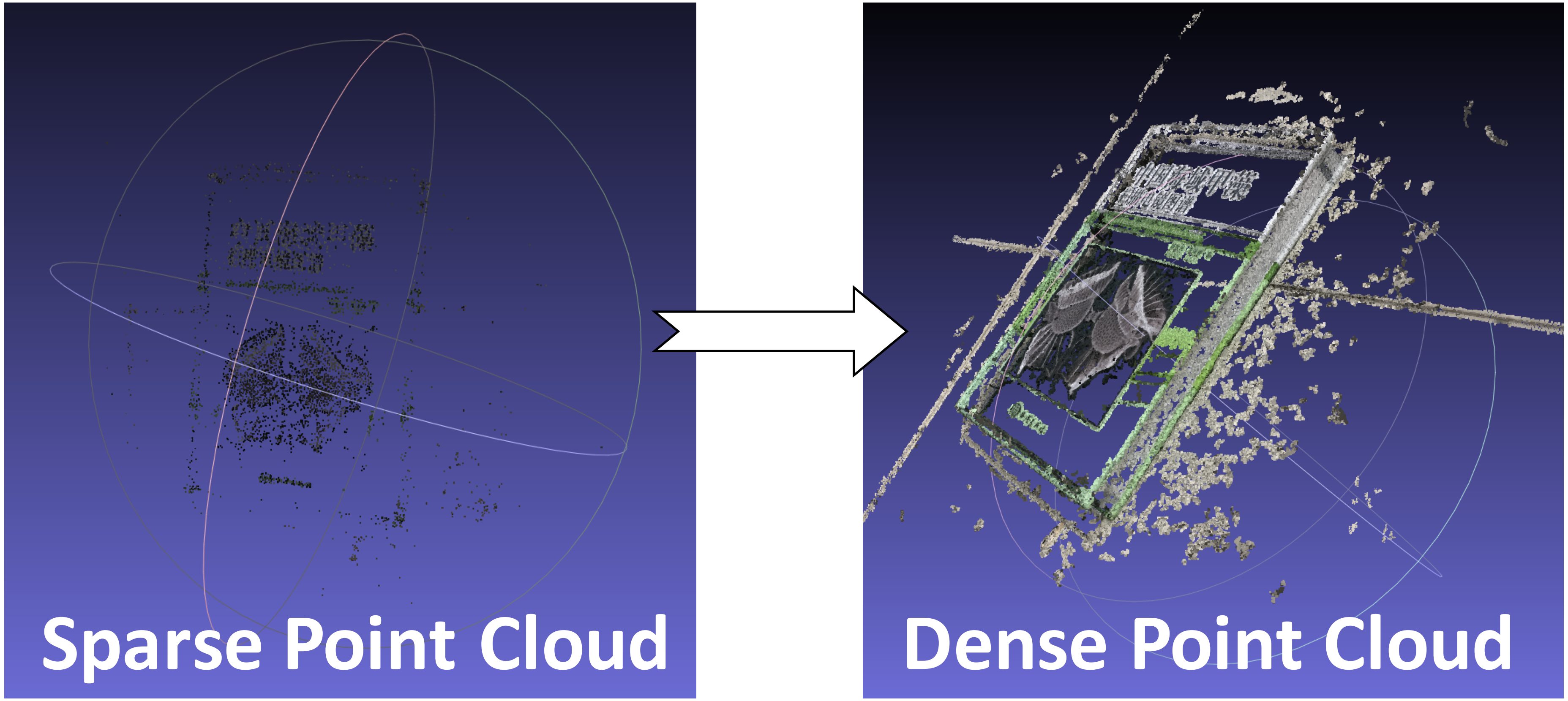
→

Sparse point clouds
Camera parameters

Introduction: http://www.cs.cornell.edu/%7Esnavely/bundler
Code: https://github.com/snavely/bundler_sfm

Video

Dense reconstruction



Dense reconstruction

light and shade[1]

geometry

surface profile[2]

[1]Durou, Jean-Denis, Maurizio Falcone, and Manuela Sagona. "Numerical methods for shape-from-shading: A new survey with benchmarks." *Computer Vision and Image Understanding* 109.1 (2008): 22-43.
[2]Boyer, Edmond, and Jean-Sébastien Franco. "A hybrid approach for computing visual hulls of complex objects." *Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition*. IEEE Computer Society Press, 2003.

PMVS2 Yasutaka Furukawa& Jean Ponce

Sparse point clouds
Camera parameters

⇒

Dense point clouds

Introduction & code: http://www.di.ens.fr/pmvs

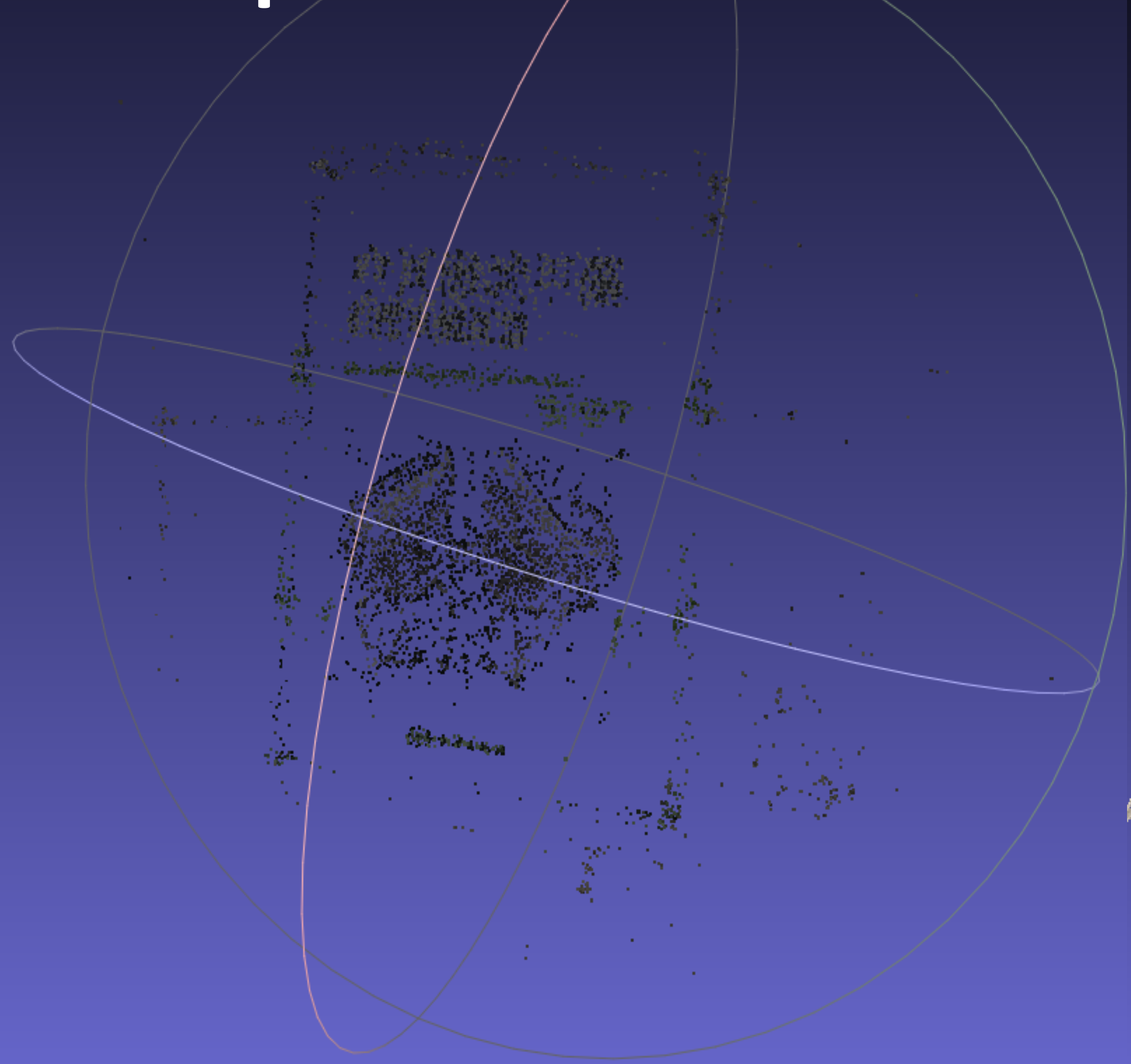
Meshlab

Open source software

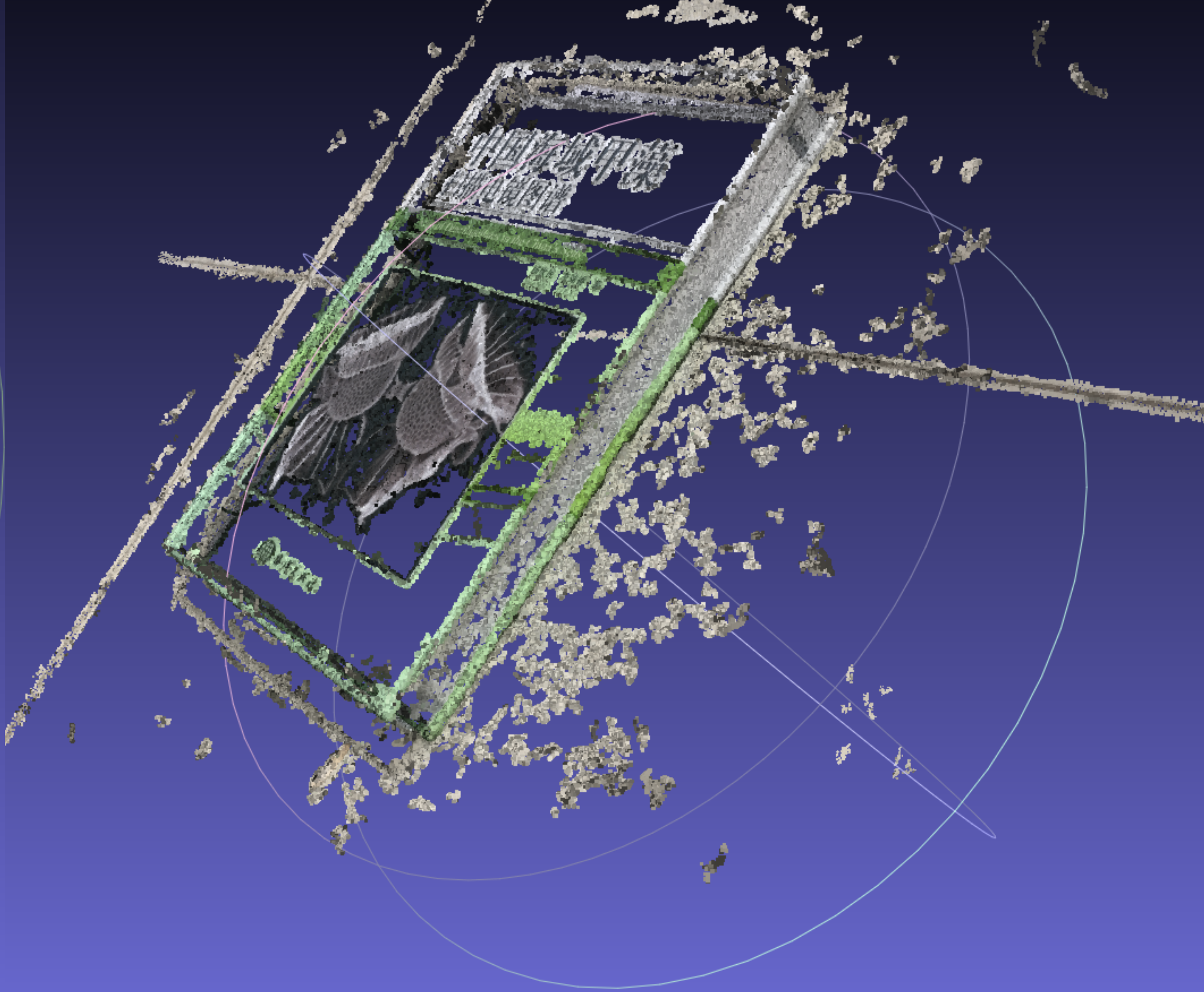
3D reconstruction processing tool

http://www.meshlab.net

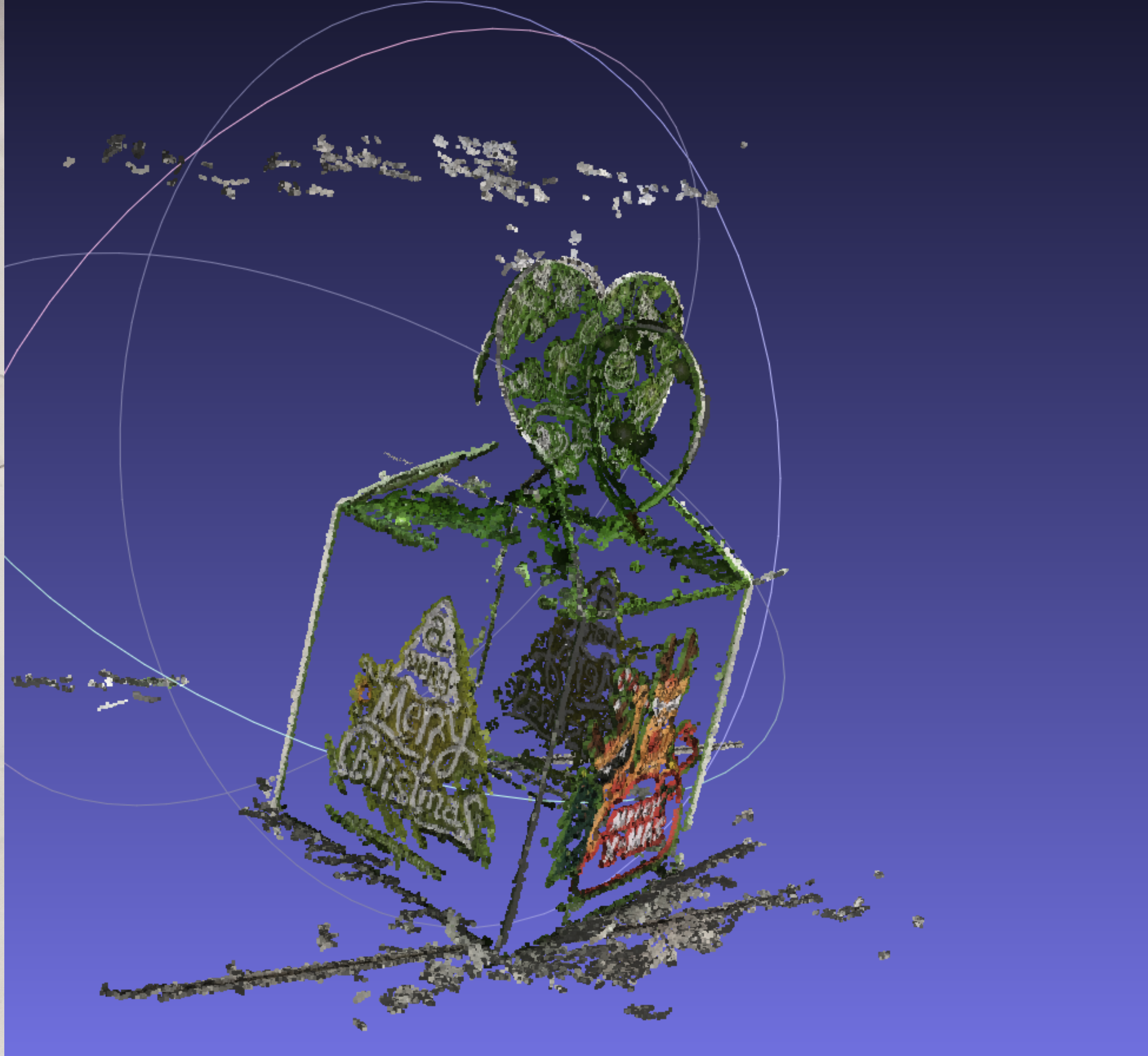
Sparse Point Cloud



Dense Point Cloud

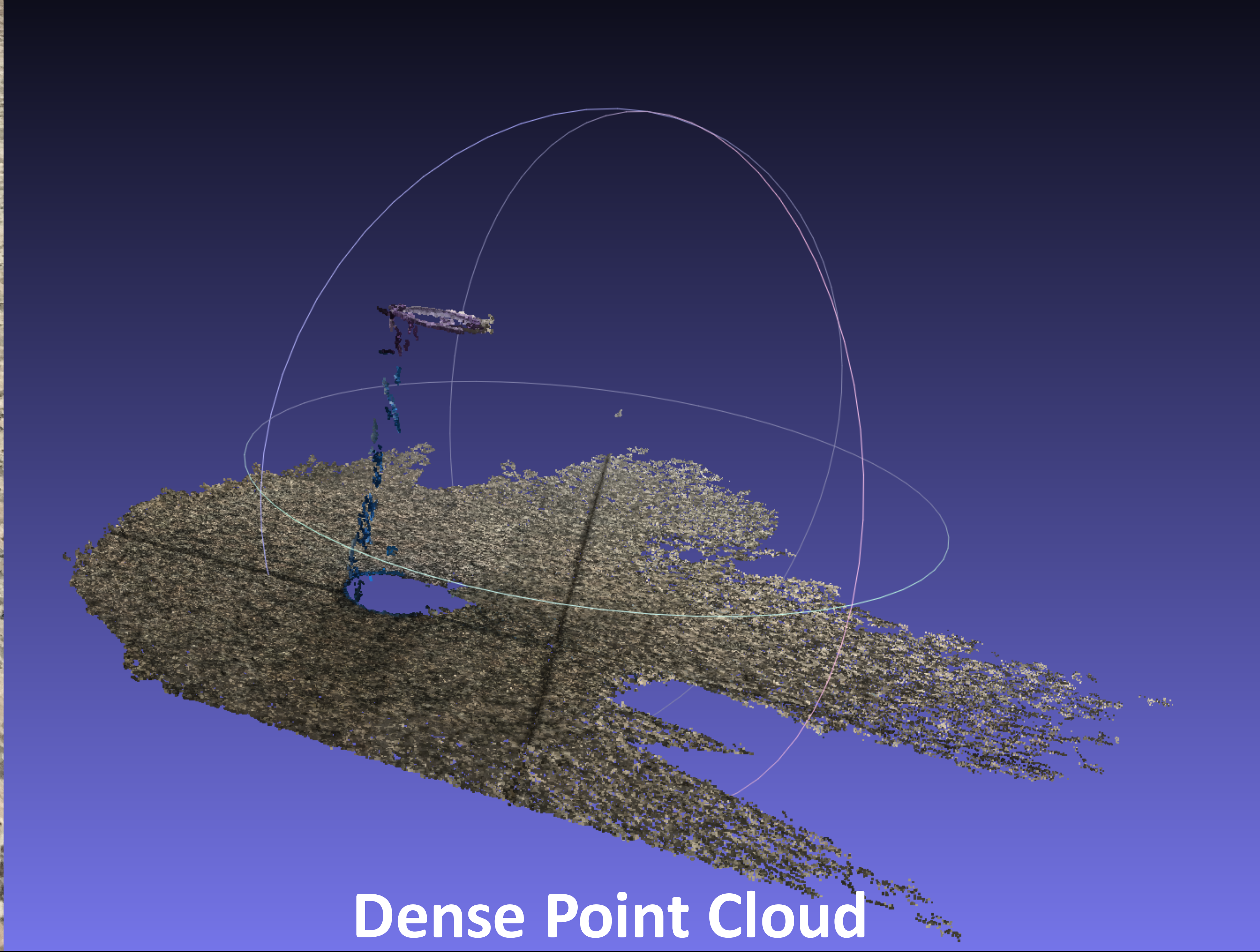


RGB

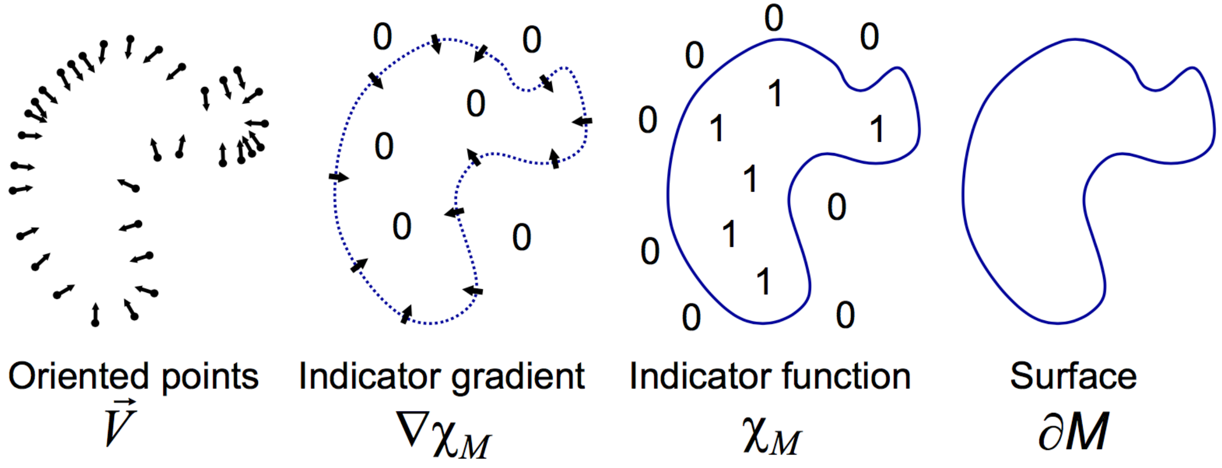


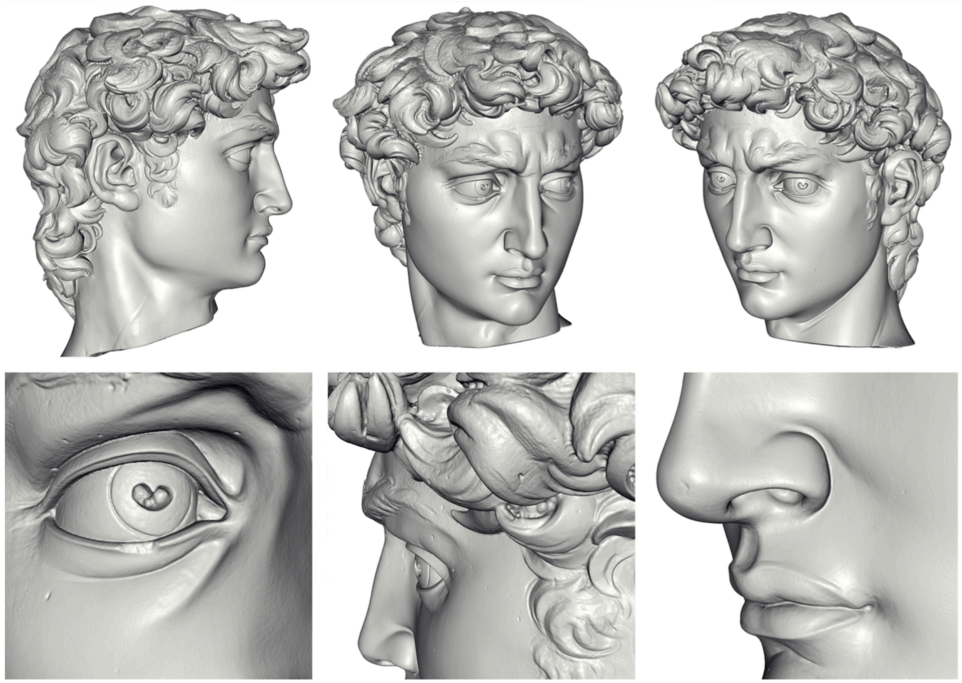
Dense Point Cloud


RGB


Dense Point Cloud

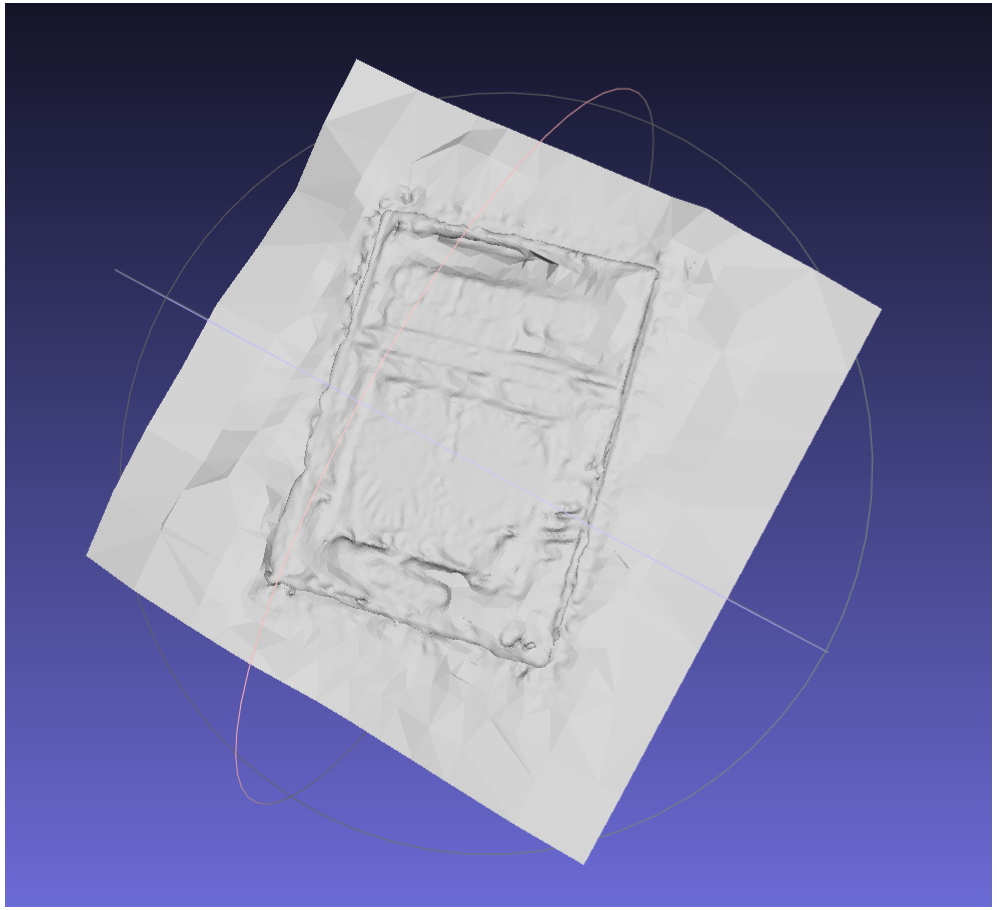
Poisson Surface Reconstruction

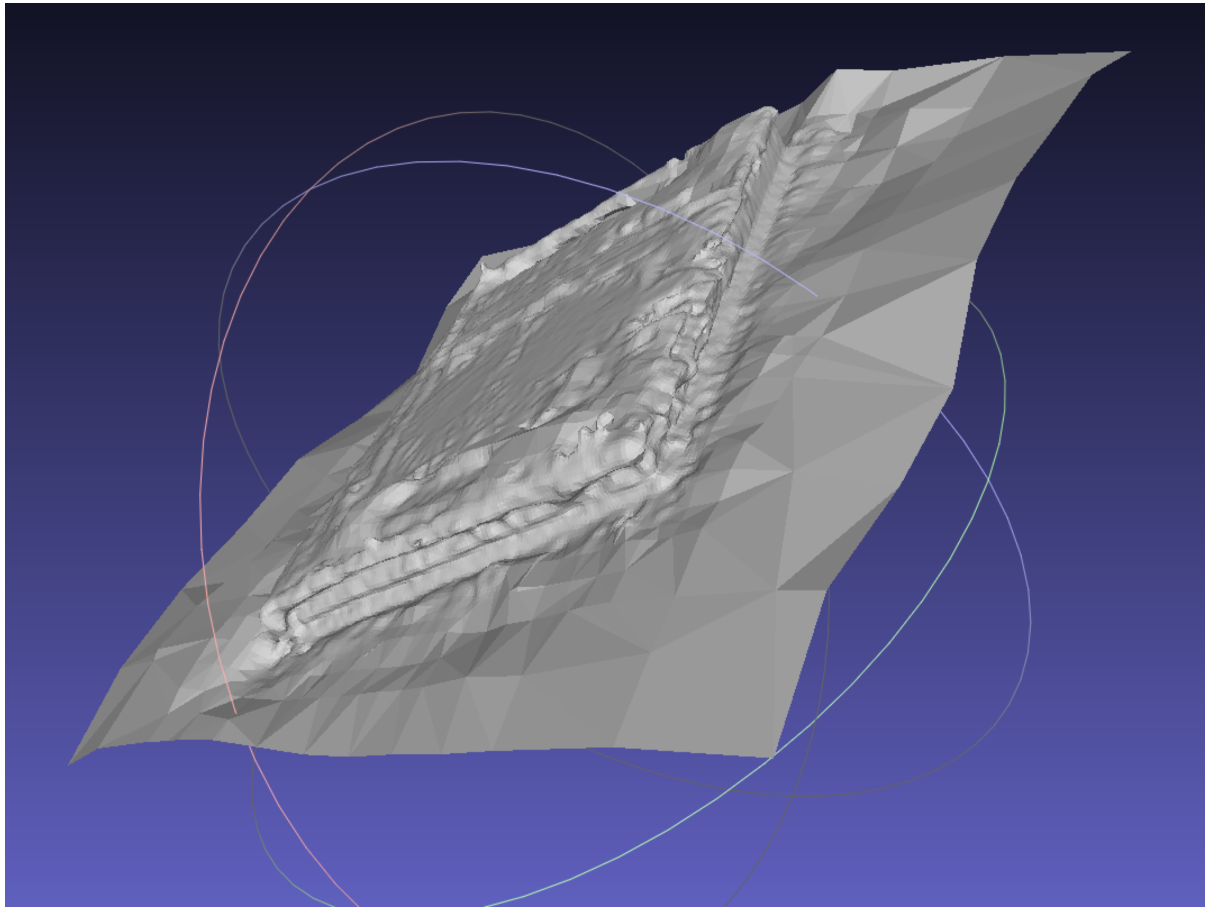




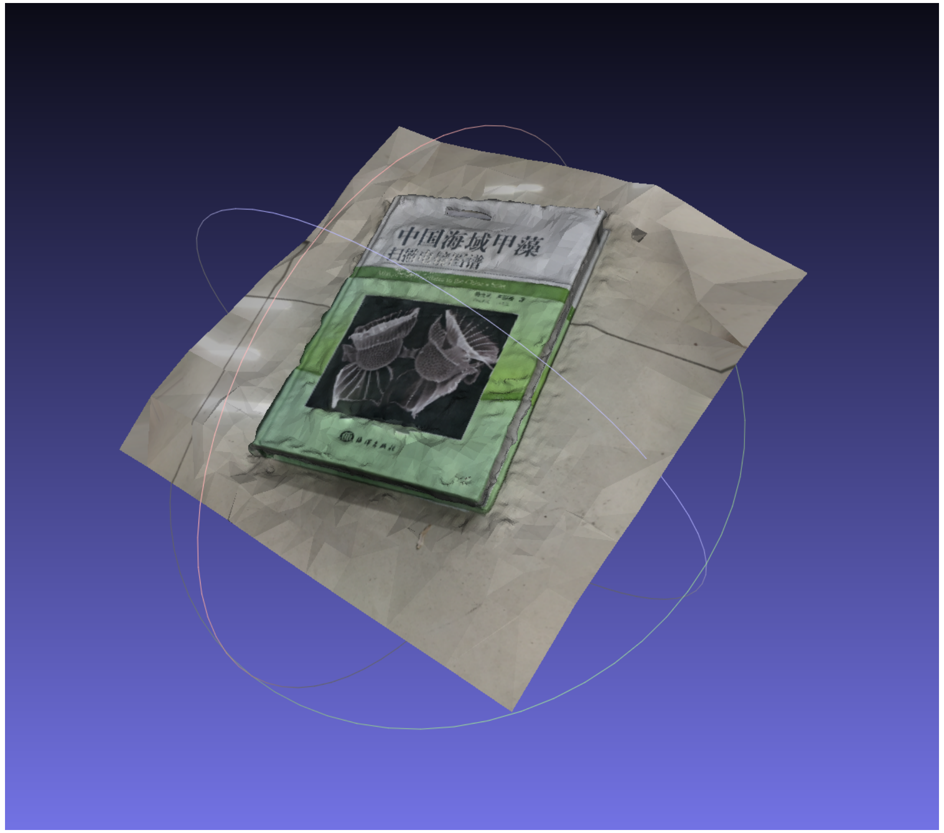
Kazhdan M, Hoppe H. Screened poisson surface reconstruction[J]. ACM Transactions on Graphics (TOG), 2013, 32(3): 29.

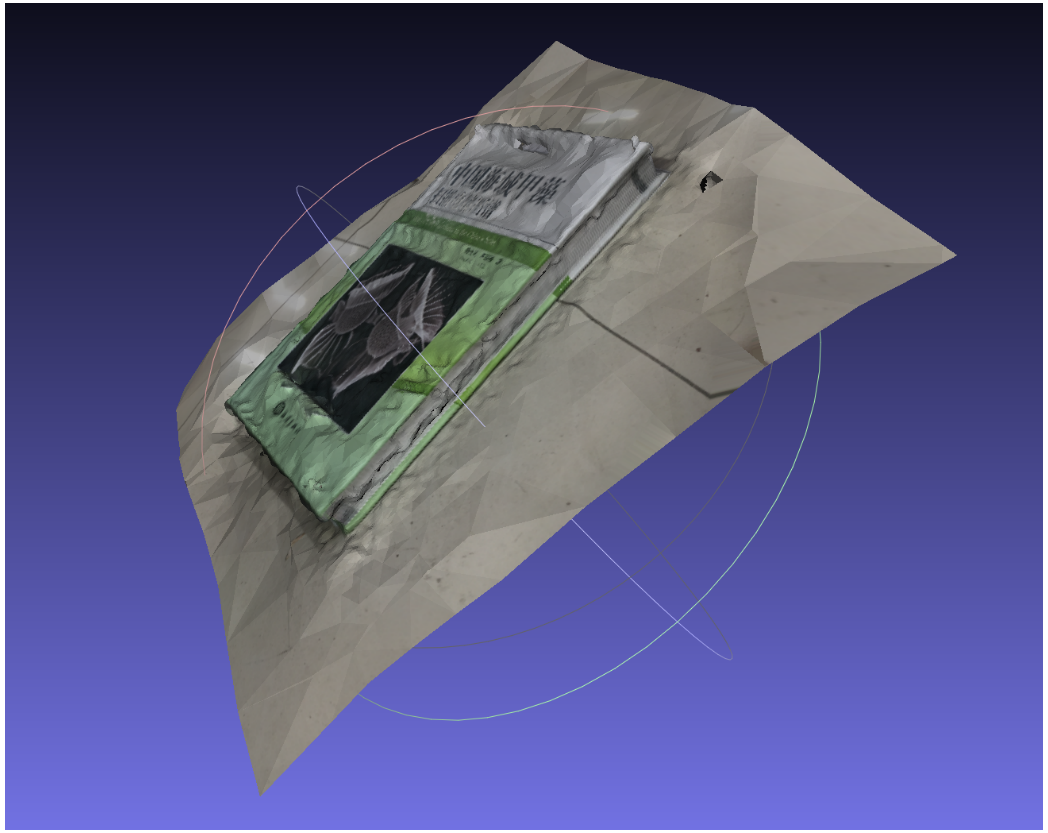
Result



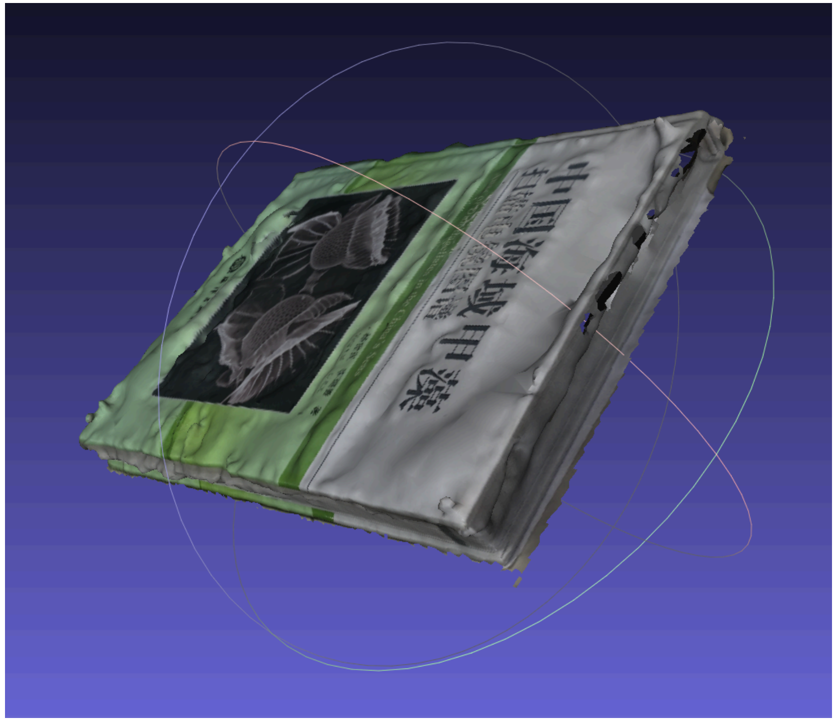


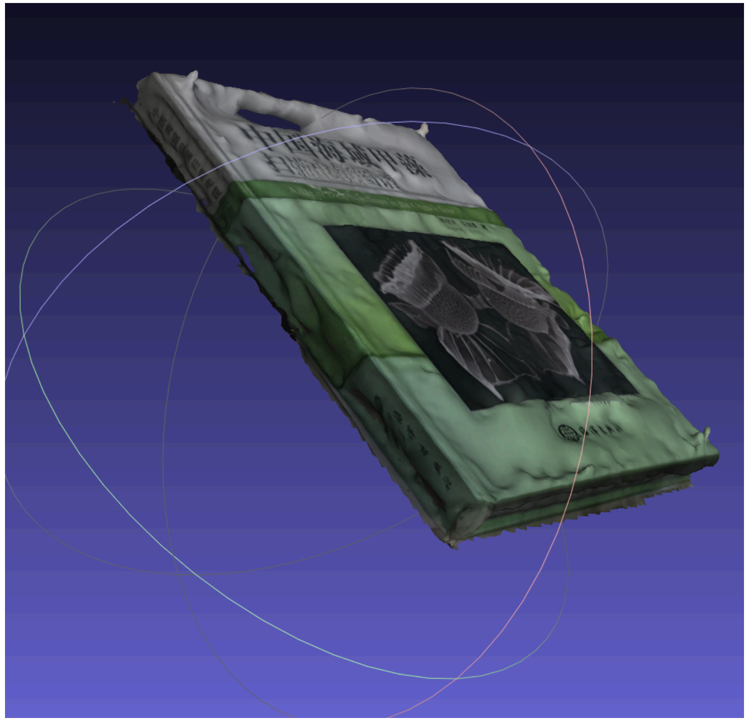
Texture mapping

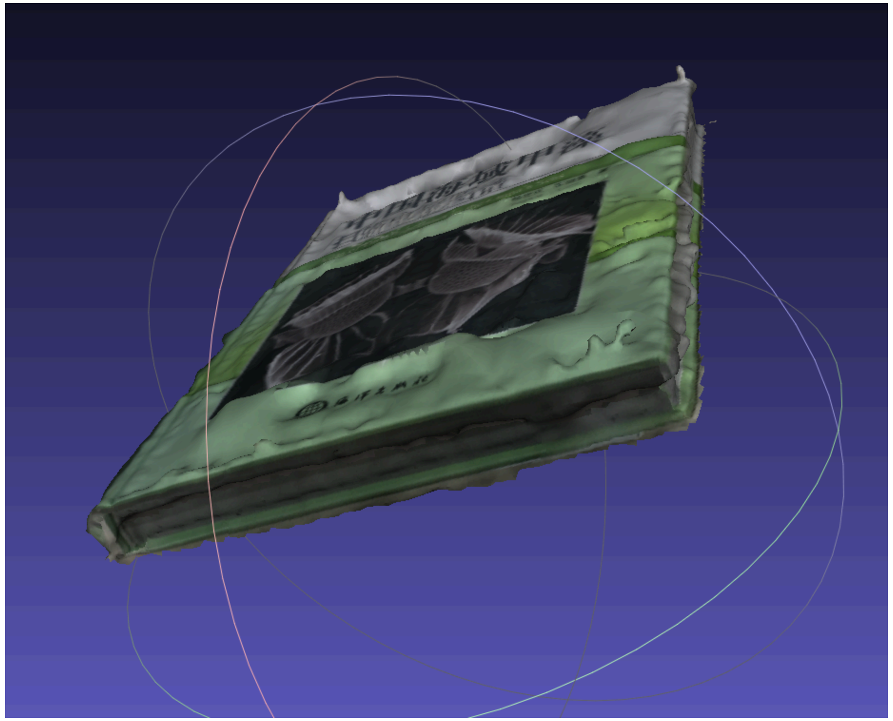


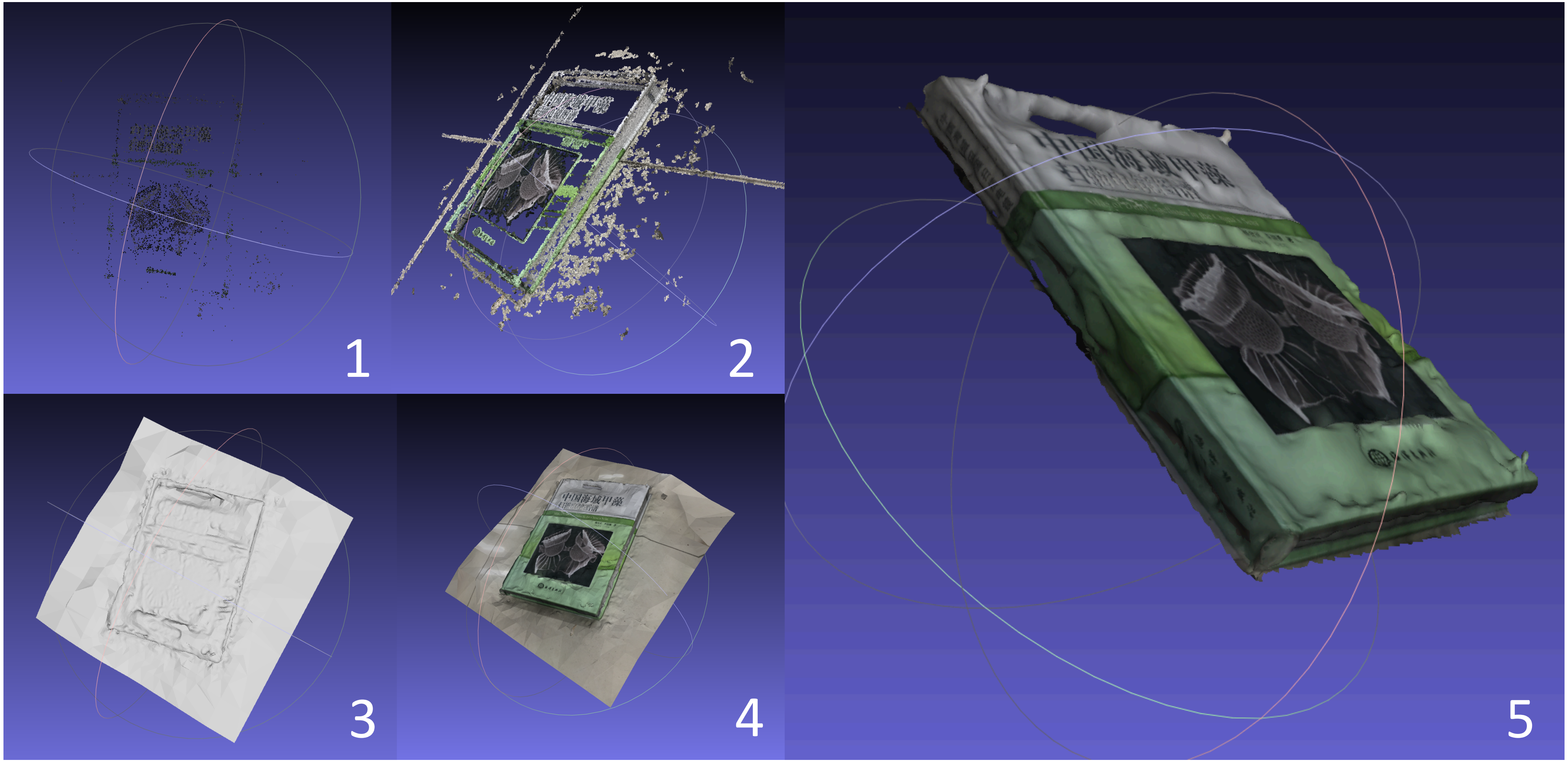


Final result



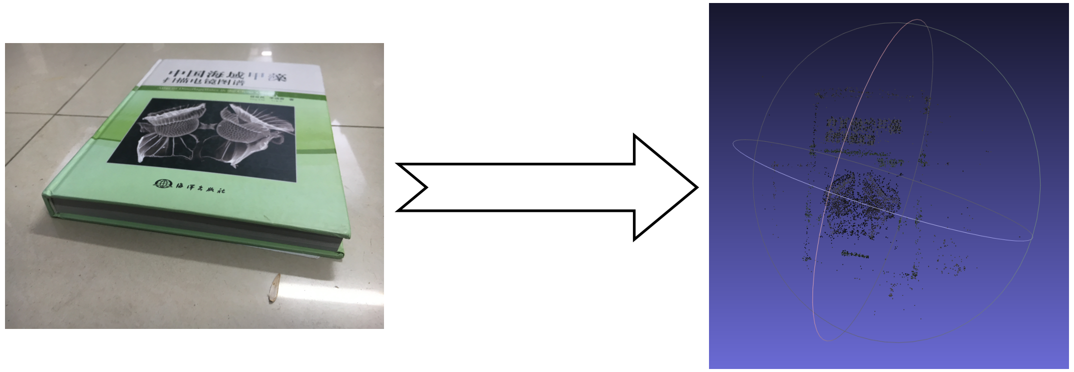





1
2
3
4
5

Steps

	Images → Points:	Structure from Motion
	Points → More points:	Multiple View Stereo
	Points → Meshes:	Model Fitting
+	Meshes → Models:	Texture Mapping
=	Images → Models:	Image-based Modeling



Steps

	Images → Points:	Structure from Motion
	Points → More points:	Multiple View Stereo
	Points → Meshes:	Model Fitting
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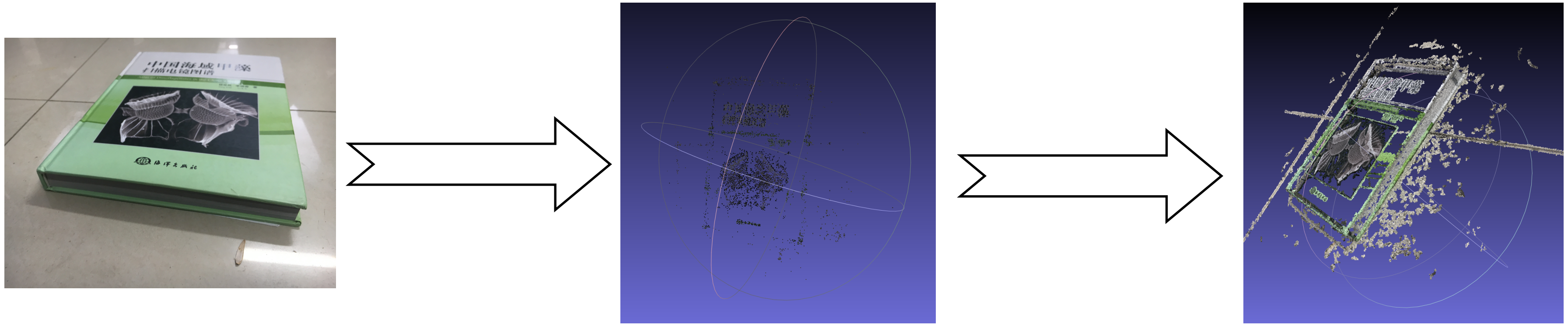


Steps

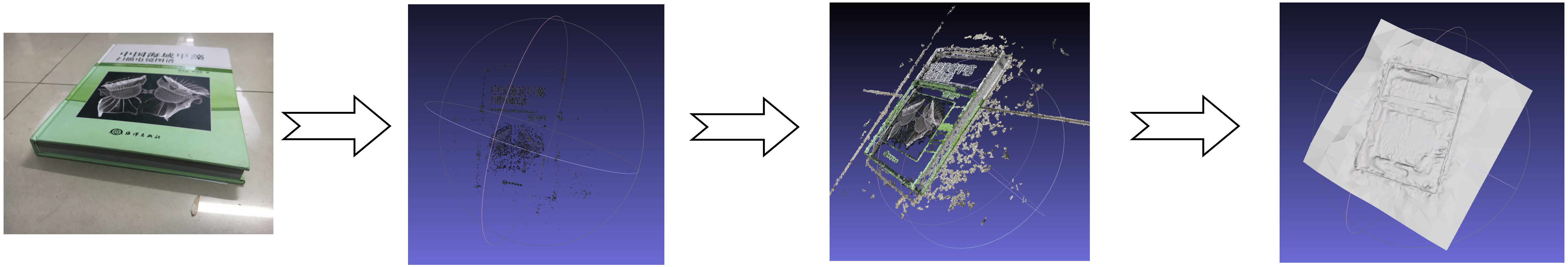
Images → Points: Structure from Motion

Points → More points: Multiple View Stereo

Points → Meshes: Model Fitting

\+ Meshes → Models: Texture Mapping

= Images → Models: Image-based Modeling



Steps

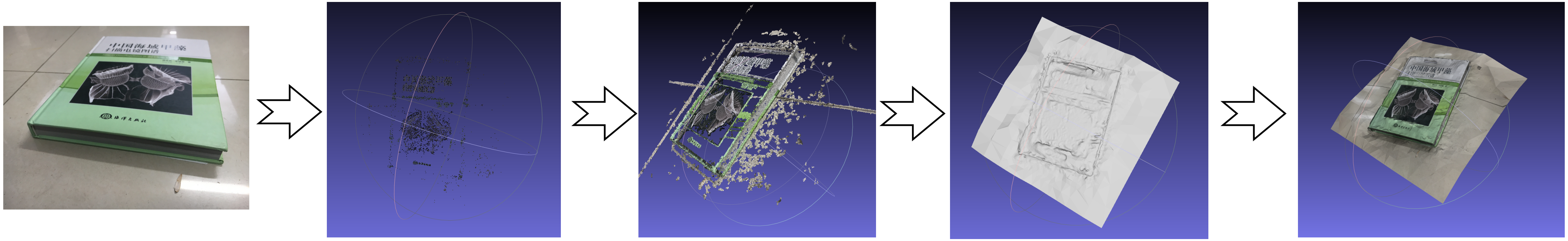
Images → Points: Structure from Motion

Points → More points: Multiple View Stereo

Points → Meshes: Model Fitting

\+ Meshes → Models: Texture Mapping

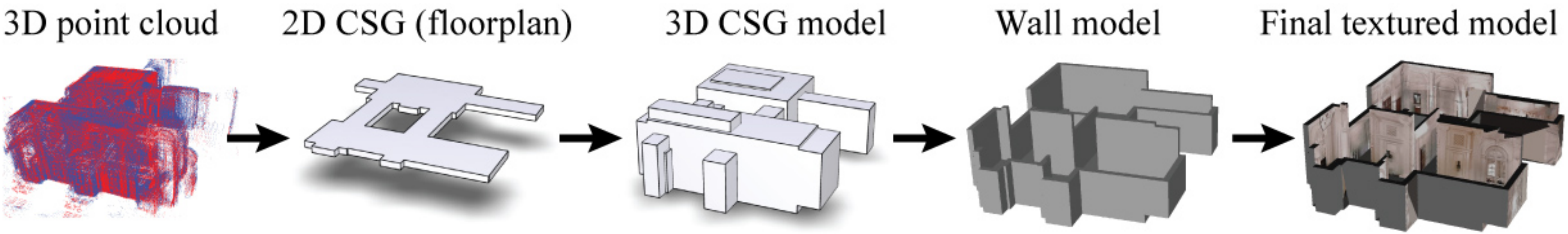
= Images → Models: Image-based Modeling



Other tools

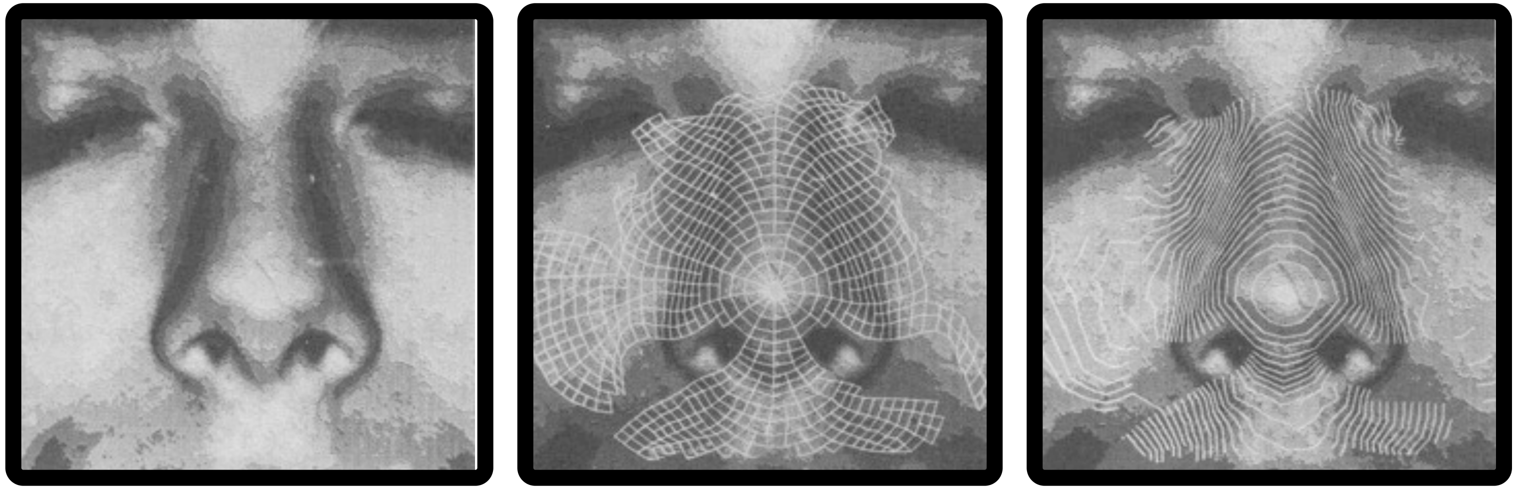
- Surface Reconstruction
  - Marching Cubes: http://en.wikipedia.org/wiki/Marching_cubes
  - Poisson Surface Reconstructionhttp://research.microsoft.com/en-us/um/people/hoppe/proj/poissonrecon/
- Model Fitting
  - RANSAC & J-linkage http://www.diegm.uniud.it/fusiello/demo/jlk/
  - InverseCSG
  - GlobFit http://code.google.com/p/globfit/
  - Face Model Fitting http://research.microsoft.com/apps/pubs/default.aspx?id=73211

Application



Other methods

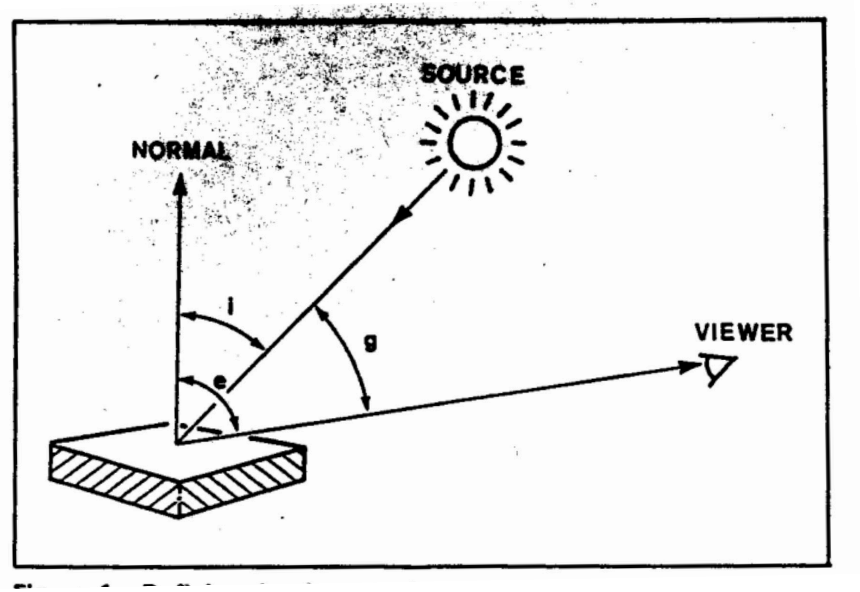
Shape from Shading



1.Bronte model
2. Infinite point
3. Rectangular projection

Horn, Berthold KP. "Shape from shading: A method for obtaining the shape of a smooth opaque object from one view." (1970).

Photometric Stereo

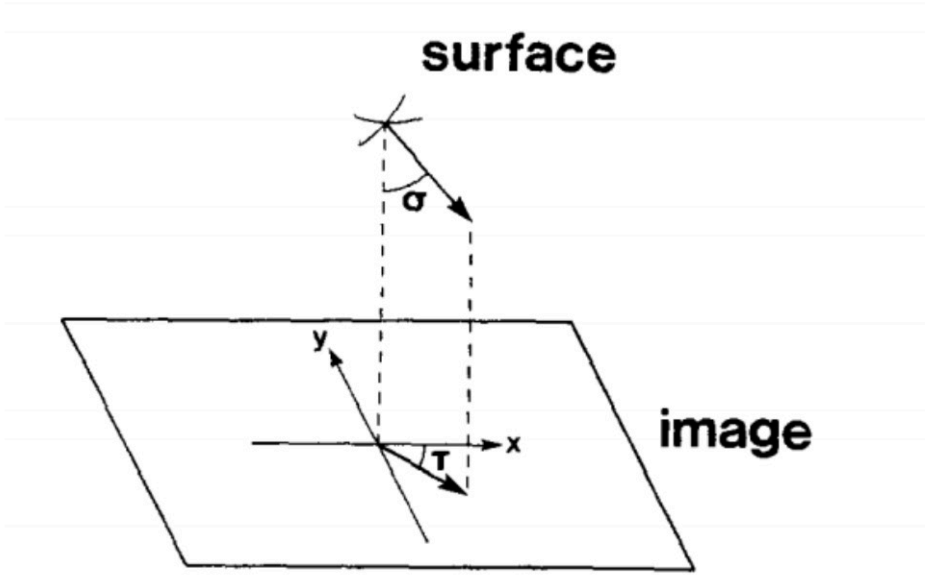


Nonlinearity and Noise Reduction 2003;
Gradient Control Point 2004;
Credibility Passed with Markov Random Field 2005;
Three - dimensional reconstruction of light conditions under unknown conditions in 2007;
Non - Lambert 2007;
Reconstruction of colored light in 2007;

Woodham, Robert J. "Photometric method for determining surface orientation from multiple images." *Optical engineering* 19.1 (1980): 191139-191139.

Other methods

Shape from Texture

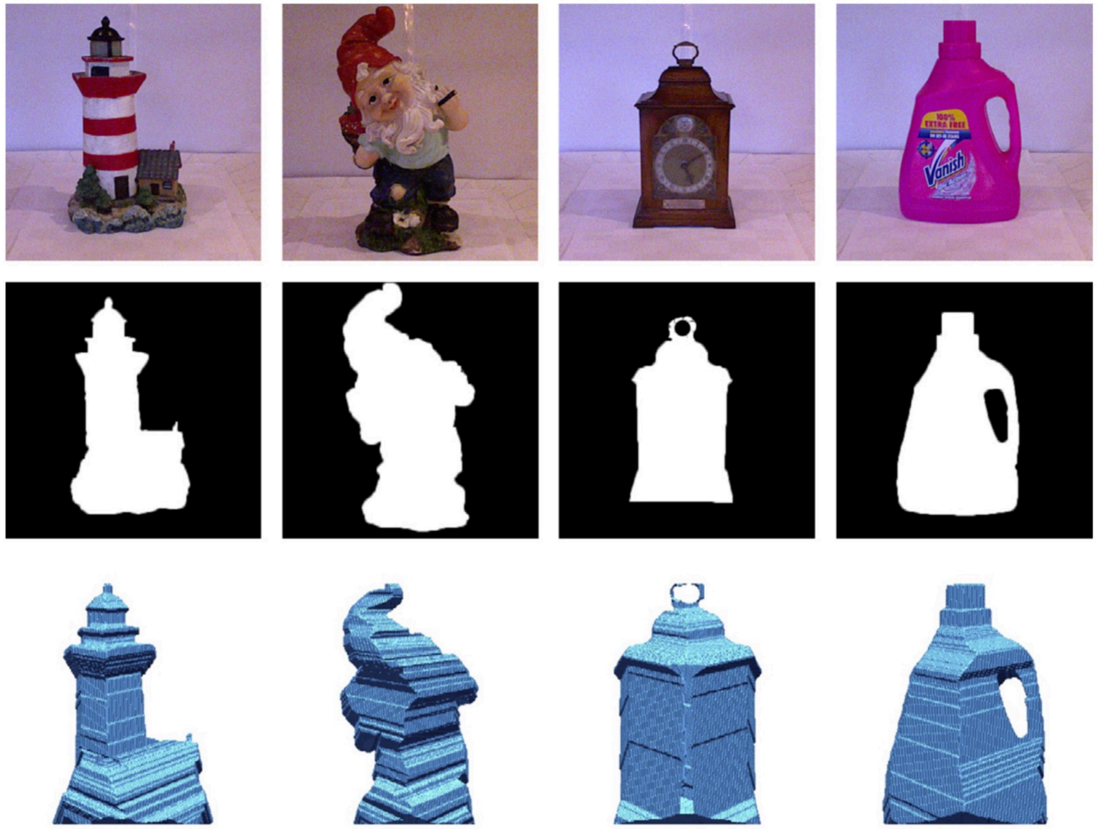


Witkin, Andrew P. "Recovering surface shape and orientation from texture." *Artificial intelligence* 17.1-3 (1981): 17-45.

Other methods

Shape from Silhouettes

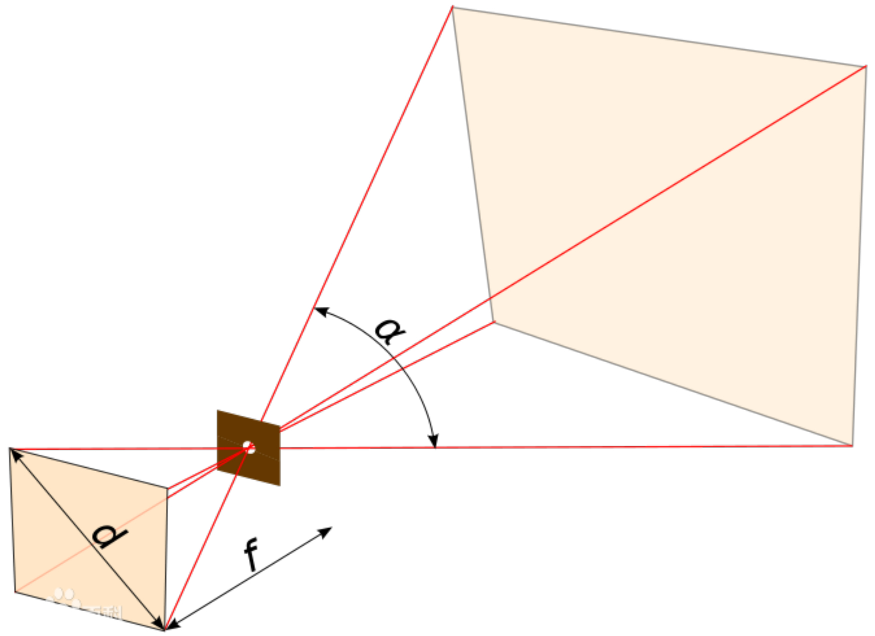
Divide the three-dimensional space into voxels



Martin, Worthy N., and Jagdishkumar Keshoram Aggarwal. "Volumetric descriptions of objects from multiple views." *IEEE transactions on pattern analysis and machine intelligence* 2 (1983): 150-158.

Other methods

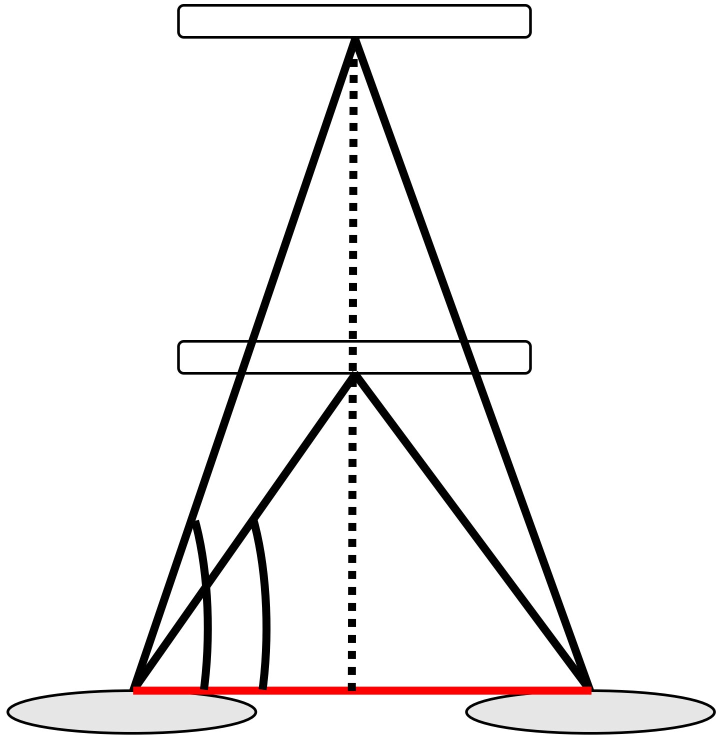
Shape from Focus



Rajagopalan, A. N., and Subhasis Chaudhuri. "Optimal selection of camera parameters for recovery of depth from defocused images." *Computer Vision and Pattern Recognition, 1997. Proceedings., 1997 IEEE Computer Society Conference on*. IEEE, 1997.

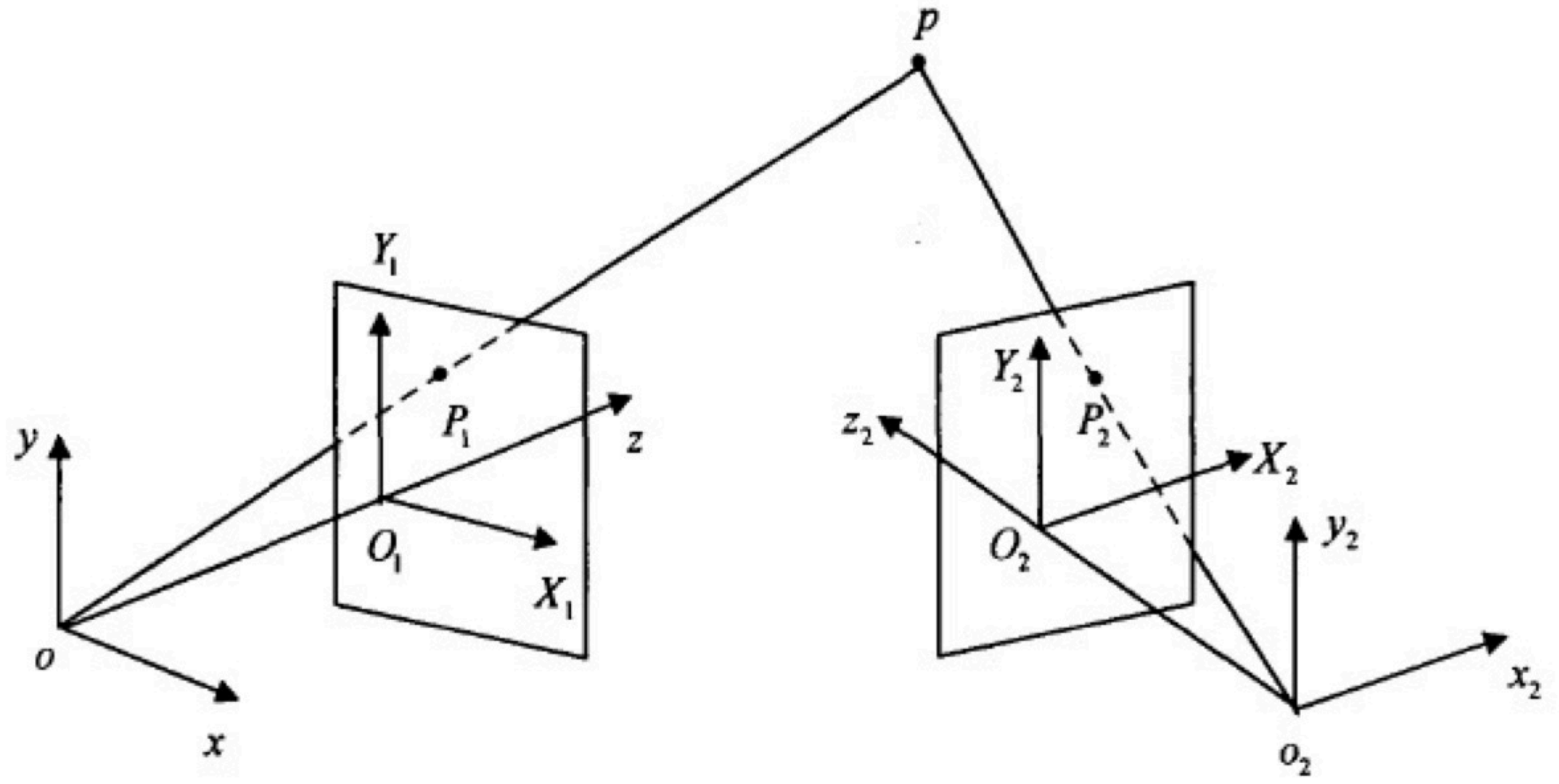
Binocular vision

How to work？

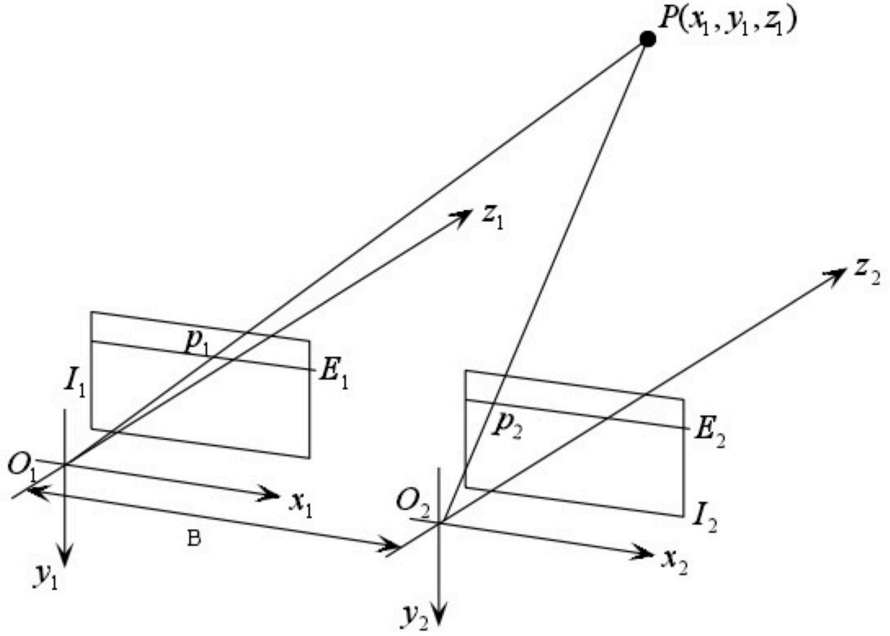


GAME

Binocular vision



Parallel binocular stereo vision model



$$Z = \frac{Bf}{x_1 - x_2}$$

Steps

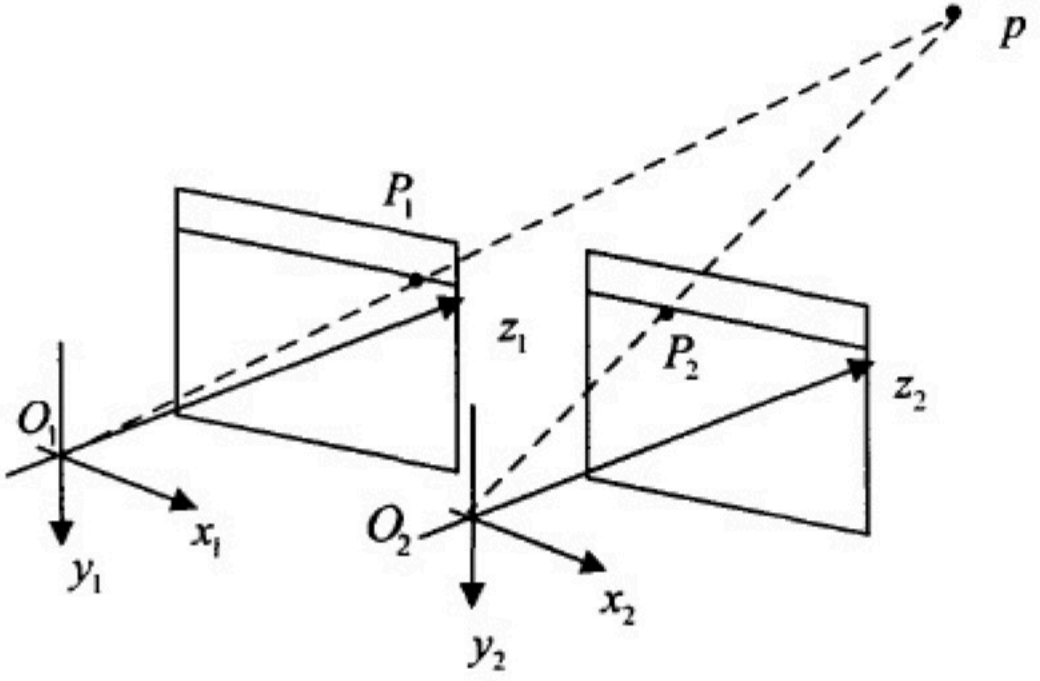
Calibration

Acquisition

Pretreatment

Stereo matching

Recovering



Acquisition & Calibration

Traditional object-based calibration[1]

Self-calibration[2][3]

[1]O. Faugeras. " Three-Dimensional Computer Vision: A Geometric Viewpoint ". MIT Press, 1993.
[2]Hartley, Richard I. "An algorithm for self calibration from several views." *Cvpr*. Vol. 94. 1994.
[3] Luong, Q-T. "Self-calibration of a moving camera from point correspondences and fundamental matrices." *International Journal of computer vision* 22.3 (1997): 261-289.

Pretreatment

Image enhancement

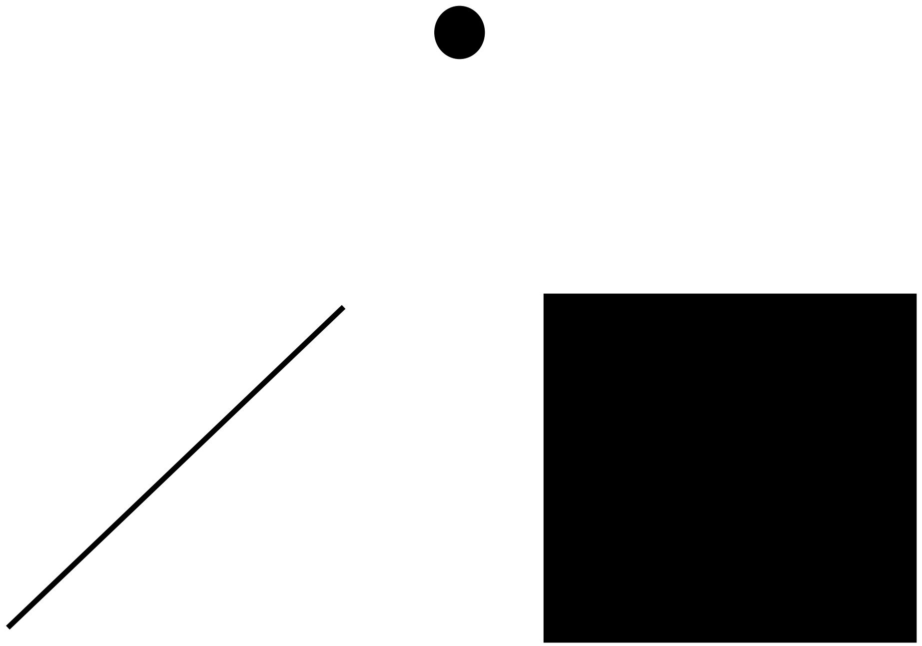
Geometric correction

Smoothing filtering

Image restoration

Stereo matching

element



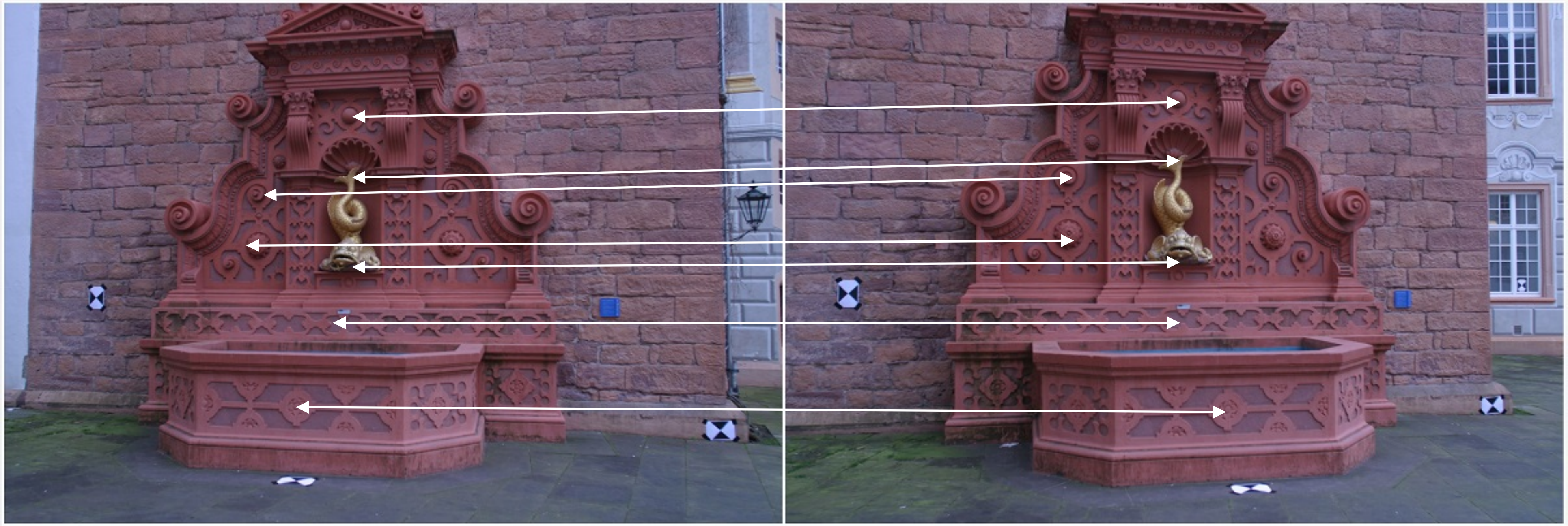
Gray matching

Feature matching

Phase matching

Constraint condition

uniqueness

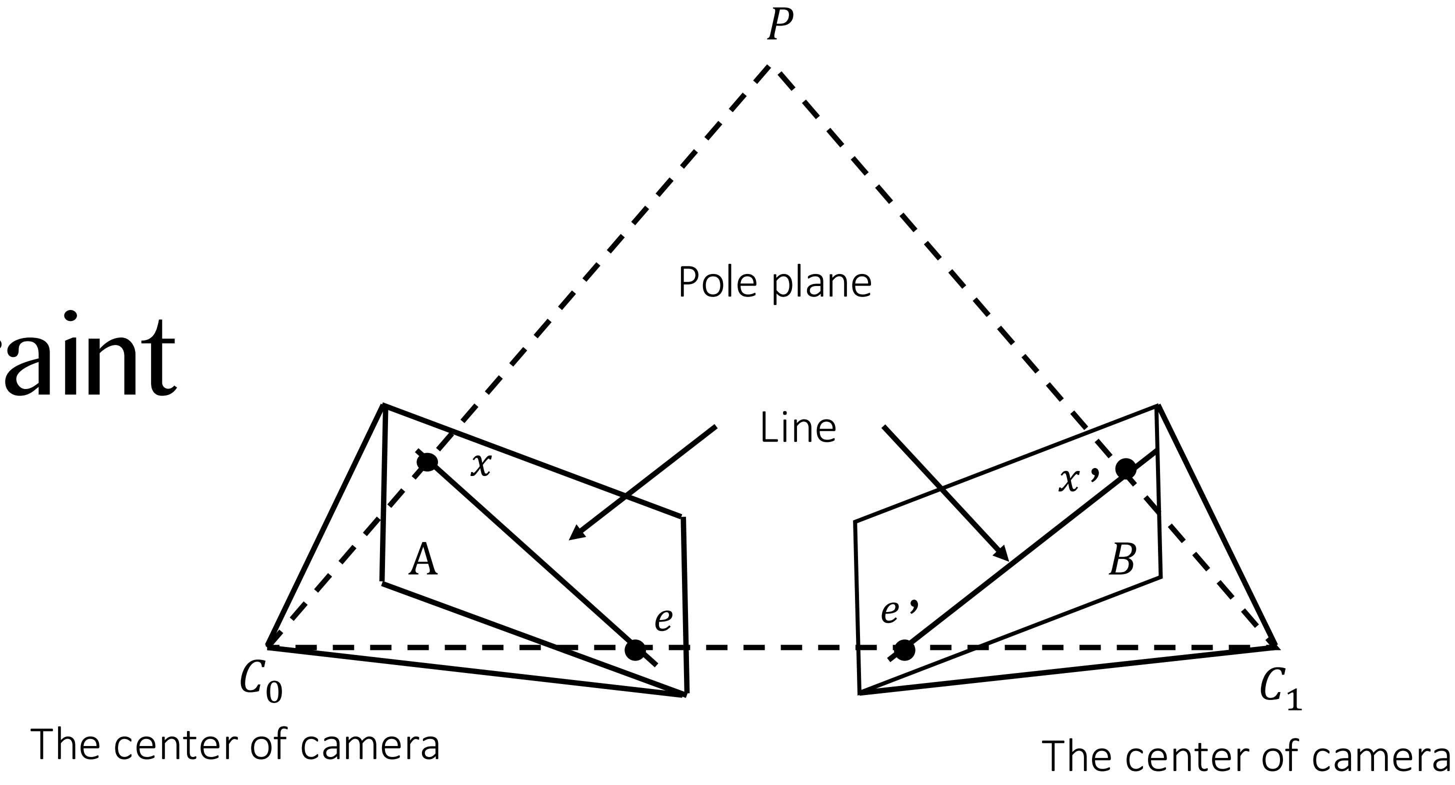


Constraint condition

Continuity

Constraint condition

epipolar constraint



Constraint condition