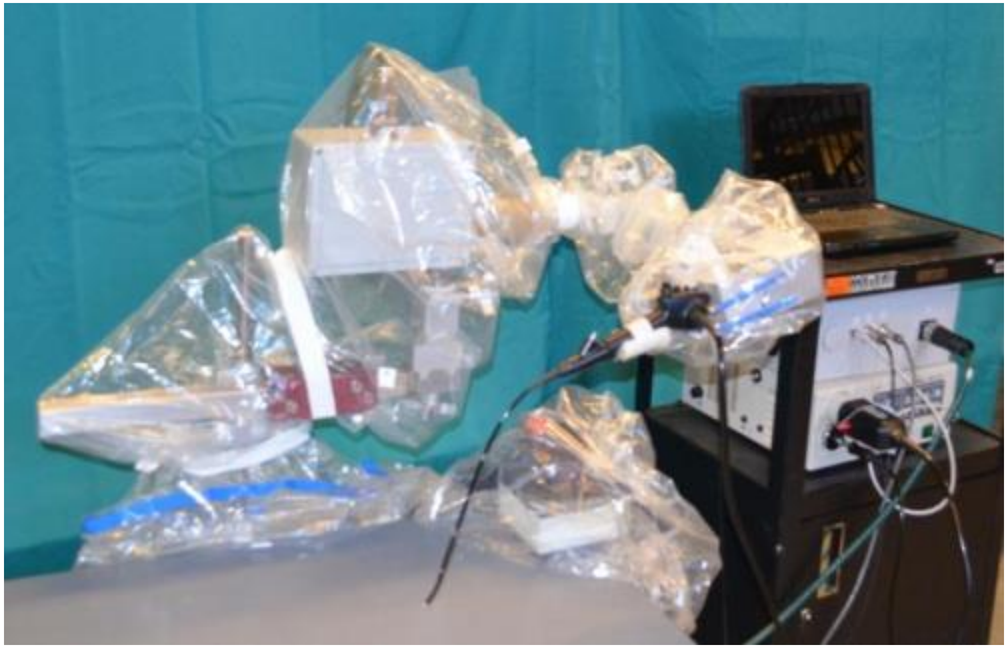
<Robo-ELF>

Human Subject Study, Controller, Computer Vision Tools

Seminar Presentation



Courtesy of Kevin Olds

Mentors

Kevin Olds

Dr. Richmon

Members

Jong Heun Kim (BME)

Tae Soo Kim (CS)

Steve Park (ME)

Project Goal

1. Program capable of providing quantitative endoscopic measurements from several monocular endoscopic images

2. Create ergonomic controller for the robot

3. Acquire clinical experimental data.

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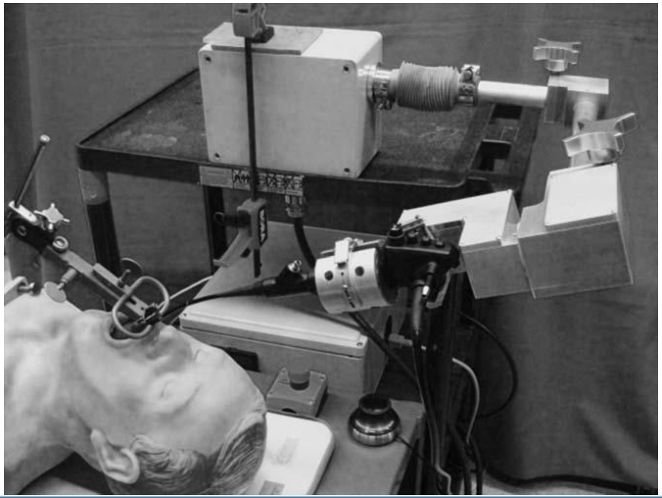
Background/Relevance (Cont.)

- Current Drawbacks
  - Bulky and not-so-ergonomic joystick
    - Digital (only On/Off states)
  - Endotracheal tube insertion for measurements.

Background/Relevance (Cont.)

- Current Drawbacks
  - ~~Bulky and not-so-ergonomic joystick~~
    Design a new intuitive and ergonomic controller.
  - ~~Endotracheal tube insertion for measurements.~~
    Endoscopic measurement software

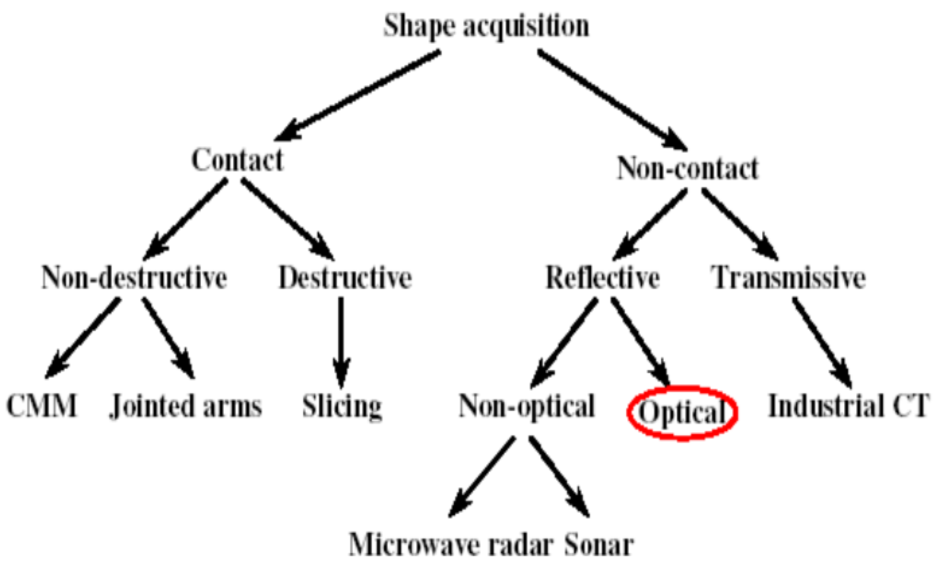


Today's Paper

H. Kawasaki, R. Furukawa, R. Sagawa, Y. Yagi. **Dynamic Scene Shape Reconstruction Using a Single Structured Light Pattern.** *Computer Vision and Pattern Recognition, 2008. CVPR 2008.* IEEE Conference on 1-8.

Motivation

- Wish to obtain physical measurements of a target from an image.
- Dense shape reconstruction using a single frame image.



Passive
vs.
Active
Stereo vision

Image courtesy of S. Narasimhan of CMU

Introduction

- Single scanning technique.
- Use a grid pattern formed by a number of straight horizontal and vertical lines.
- **No global smoothness constraint required**

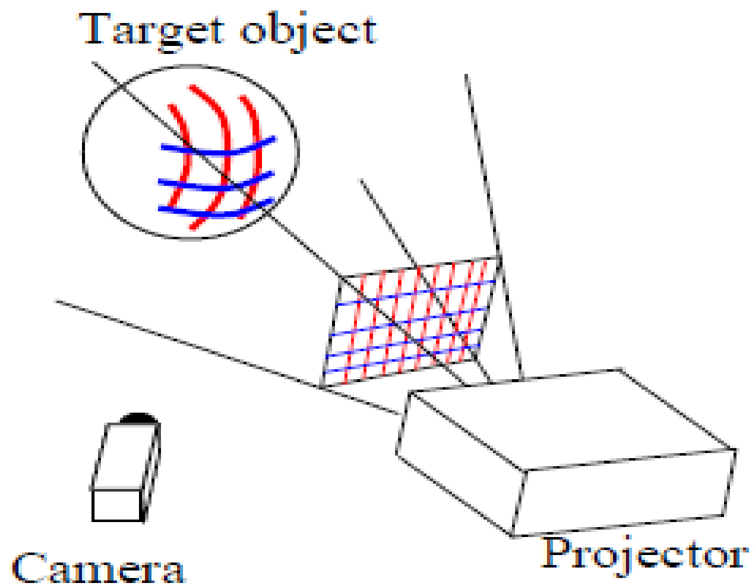
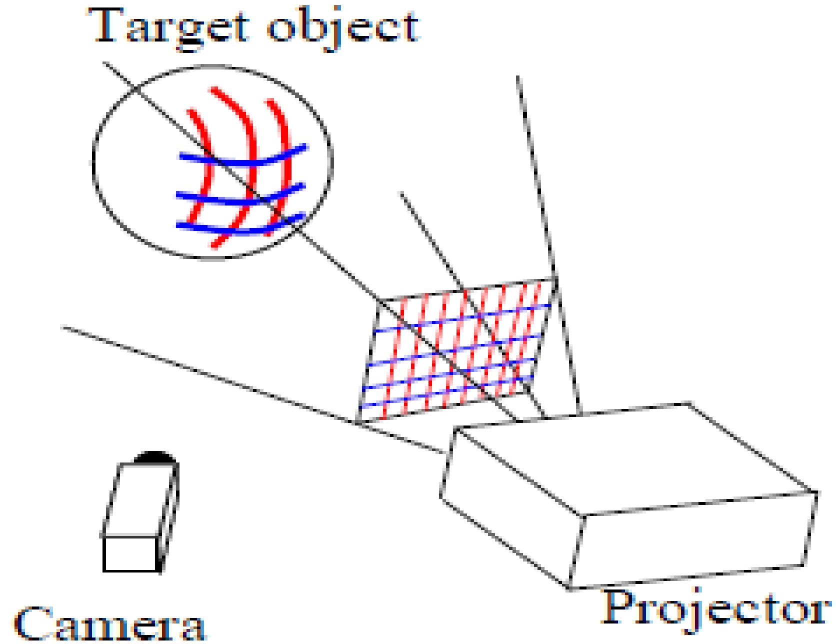


Image courtesy of H. Kawasaki, R. Furukawa, R. Sagawa and Y. Yagi

System Configuration

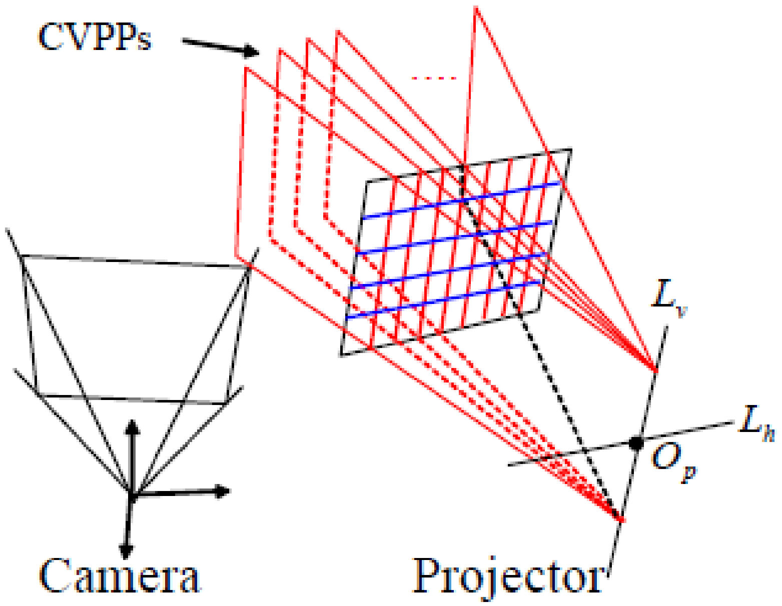
- A camera and a projector (calibrated)
  -> Intrinsic parameters, relative positions and orientations
- A grid pattern projected and captured by camera



Problem Definition

- CVPP = **C**alibrated **V**ertical **P**attern **P**lane
- CHPP = **C**alibrated **H**orizontal **P**attern **P**lane
- L*v* = Line contained by all CVPP
- L*h* = Line contained by all CVPP

A calibrated projector means that..
-> All parameters for the VPPs and HPPs in 3D space are known.



Problem Definition Cont.

- VPC = **V**ertical **P**attern **C**urve
- HPC = **H**orizontal **P**attern **C**urve
- Captured intersections = Intersections between VPCs and HPCs
- UVPP = **U**nknown **V**ertical **P**attern **P**lane

  The VPP that contains a given VPC. (No knowledge of correspondence)
- UHPP = similarly..

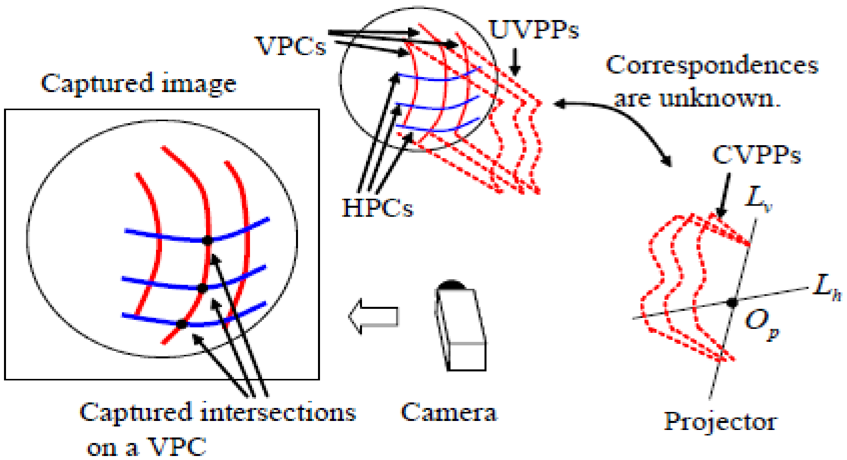
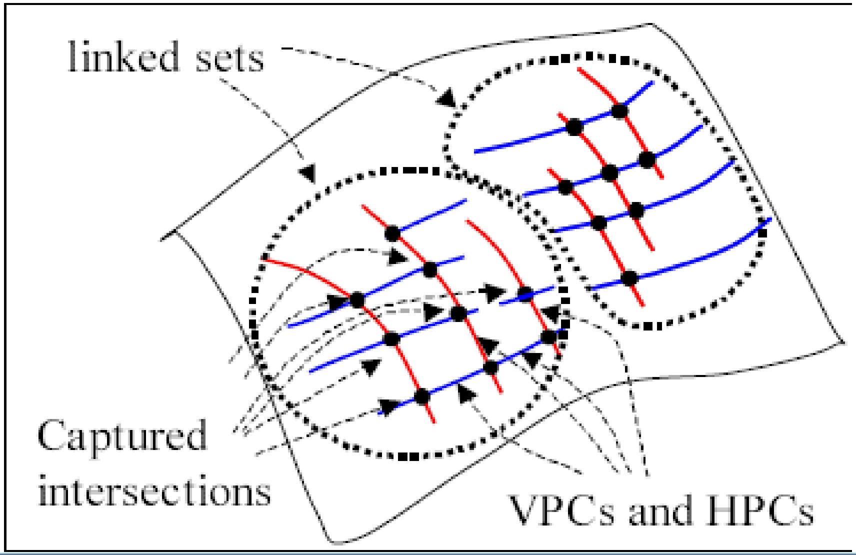


Figure 2. CVPPs and UVPPs.

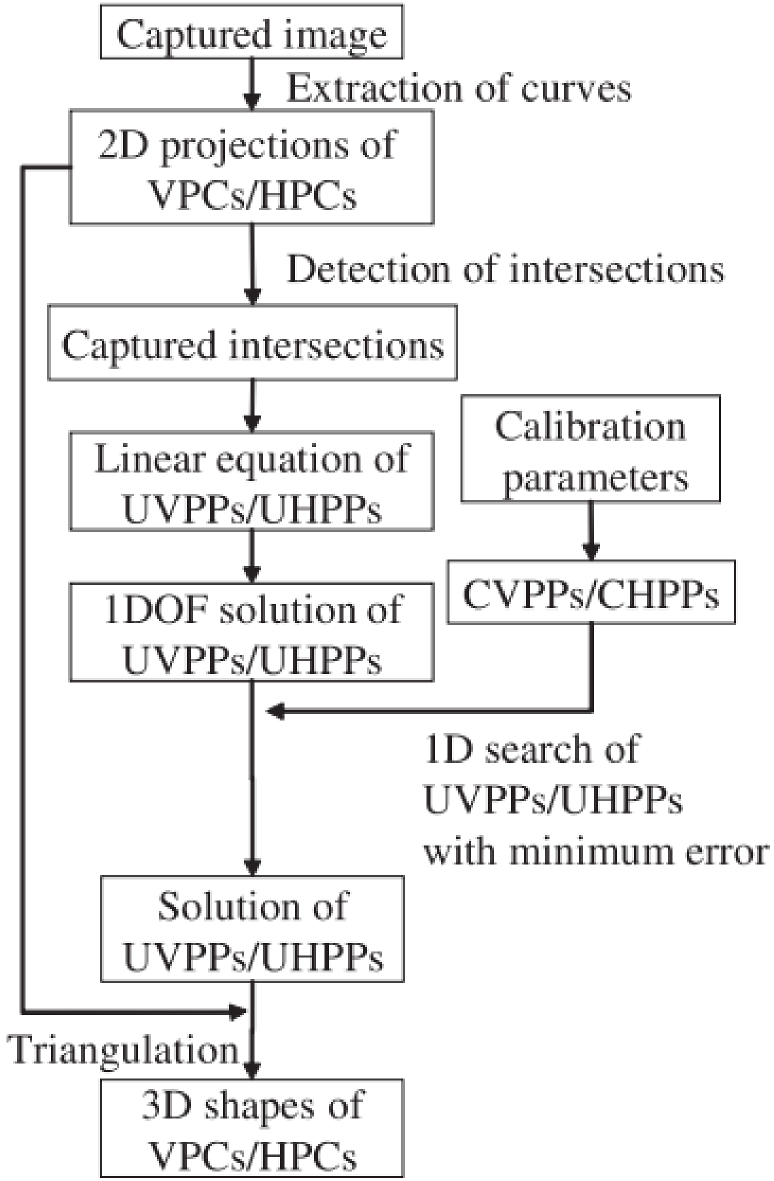


Problem Definition Cont.

- Given all that, the **goal** is to:

Determine correspondences between the UVPPs (UHPPs) and CVPPs (CHPPs)

3D positions of all the captured intersections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2D projections of VPCs/HPCs
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Captured intersections
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Calibration parameters
1DOF solution of UVPPs/UHPPs
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1D search of UVPPs/UHPPs with minimum error
Solution of UVPPs/UHPPs
Triangulation
3D shapes of VPCs/HPCs

Outline of the Solution

Intuition: Derive linear equations based on conditions of co-planarity with regard to UVPPs and UHPPs.

1. Captured intersection provides a linear constraint equation with regard to the UVPP or UHPP that contains it.

2. All UVPPs must include L_v , similarly with UHPPs

These constraints form a
system of linear equations

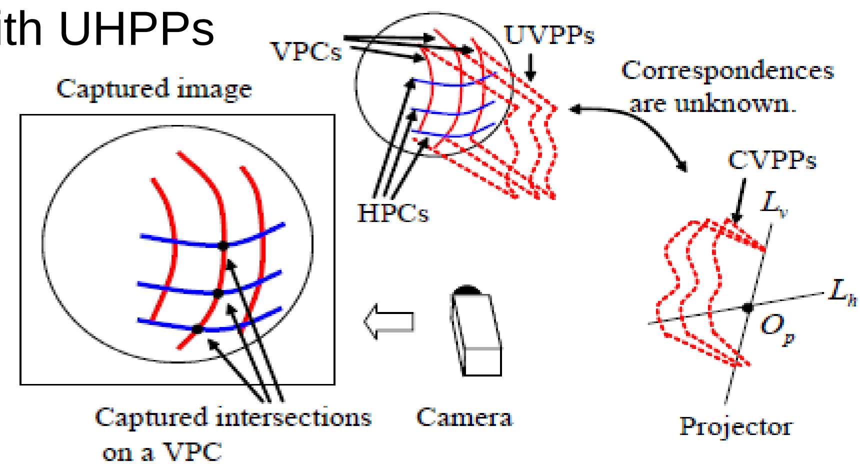

Figure 2. CVPPs and UVPPs.

Solving Coplanarity Constraints (Math)

- Let v_k and h_l be some UVPP and UHPP obtained from the captured image.
- $(s_{k,l}, t_{k,l})$ be image coordinates of the intersection between v_k and h_l .
- The planes v_k and h_l are represented by

(1) $$a_k x + b_k y + c_k z + 1 = 0, \; d_l x + e_l y + f_l z + 1 = 0.$$

- The location of the intersection (x,y,z) can be represented in image coordinates

(2) $$x = \gamma \, s_{k,l}, \; y = \gamma \, t_{k,l}, \; z = -\gamma.$$

- Combining these equations

(3) $$s_{k,l}(a_k - d_l) + t_{k,l}(b_k - e_l) - (c_k - f_l) = 0$$

Known (computed from the captured image)

Solving Coplanarity Constraints (Math)

- v_k must contain the line L_v which contains the optical center O_p at (P_x, P_y, P_z) and with the direction vector for L_v being (Q_x, Q_y, Q_z)

(4) $$a_k P_x + b_k P_y + c_k P_z + 1 = 0,$$

(5) $$a_k Q_x + b_k Q_y + c_k Q_z = 0.$$

- Similar holds for the h_l with the direction vector for L_h being (R_x, R_y, R_z)

(6) $$d_l P_x + e_l P_y + f_l P_z + 1 = 0,$$

(7) $$d_l R_x + e_l R_y + f_l R_z = 0.$$

Note: (P_x, P_y, P_z) and (Q_x, Q_y, Q_z) are known

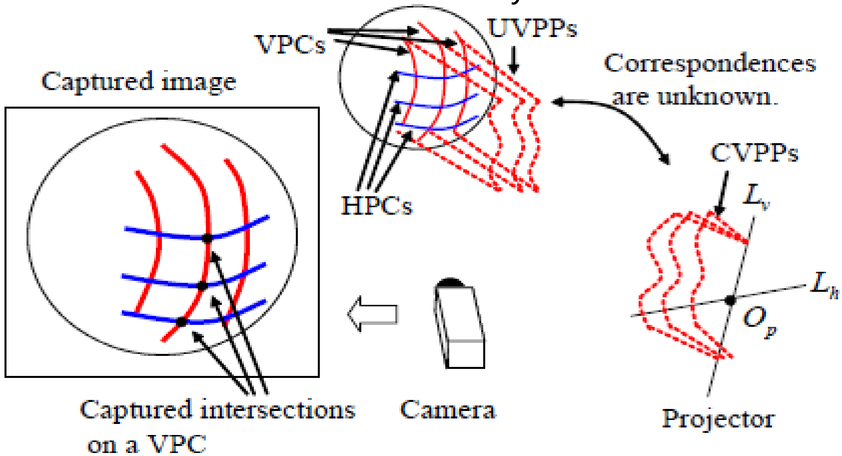

Figure 2. CVPPs and UVPPs.

Solving Coplanarity Constraints (Math)

- Put together all constraints to form a system of linear equations

(3) $$s_{k,l}(a_k - d_l) + t_{k,l}(b_k - e_l) - (c_k - f_l) = 0$$

(4) $$a_k P_x + b_k P_y + c_k P_z + 1 = 0,$$

(5) $$a_k Q_x + b_k Q_y + c_k Q_z = 0.$$

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Highlighted in green: **Unknown coefficients** that we wish to find.

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- Put together all constraints to form a system of linear equations

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(5) $$a_k Q_x + b_k Q_y + c_k Q_z = 0.$$

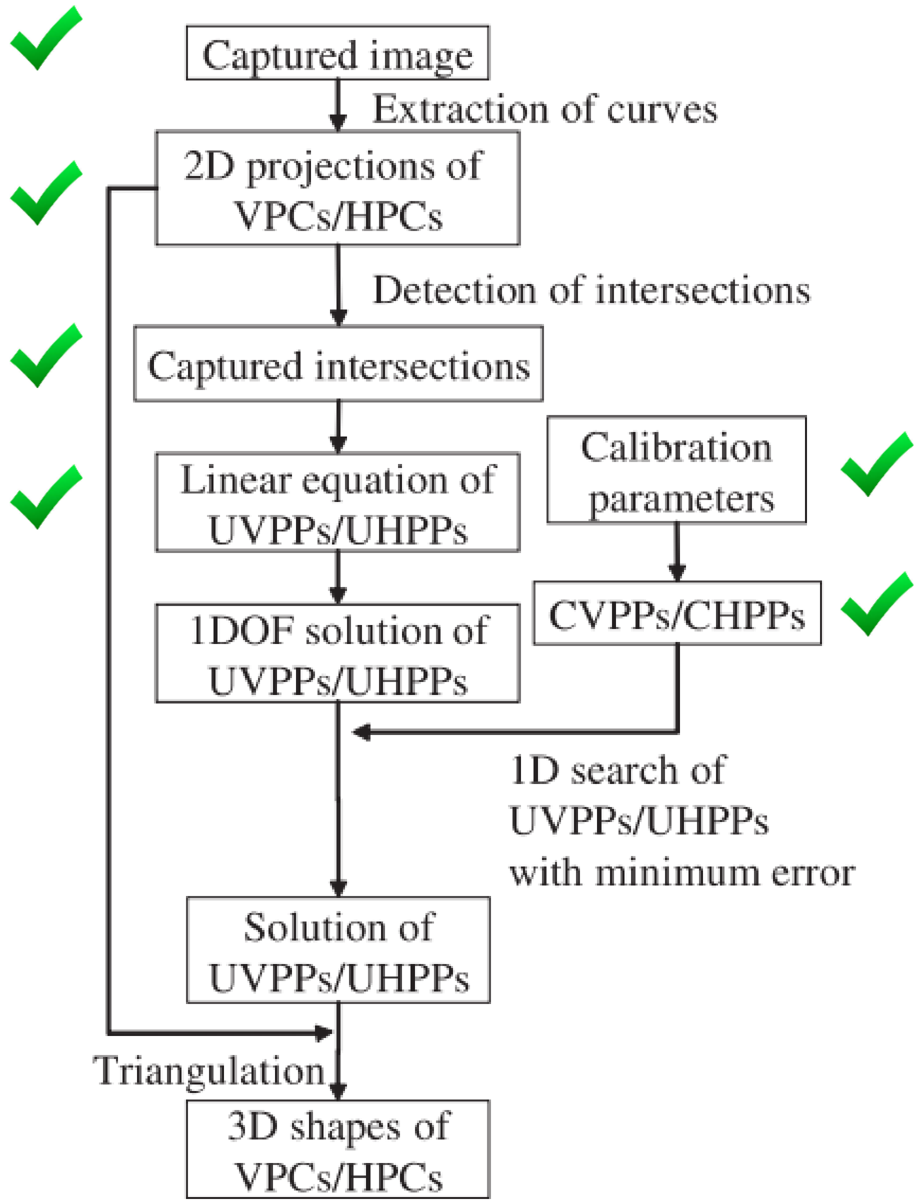
(6) $$d_l P_x + e_l P_y + f_l P_z + 1 = 0,$$

(7) $$d_l R_x + e_l R_y + f_l R_z = 0.$$

Mx = b

$$\mathbf{x} = (a_1, b_1, c_1, \cdots, a_m, b_m, c_m, \cdots, d_1, e_1, f_1, \cdots, d_n, e_n, f_n)^t$$

m = # of UVPPs , n = # of UHPPs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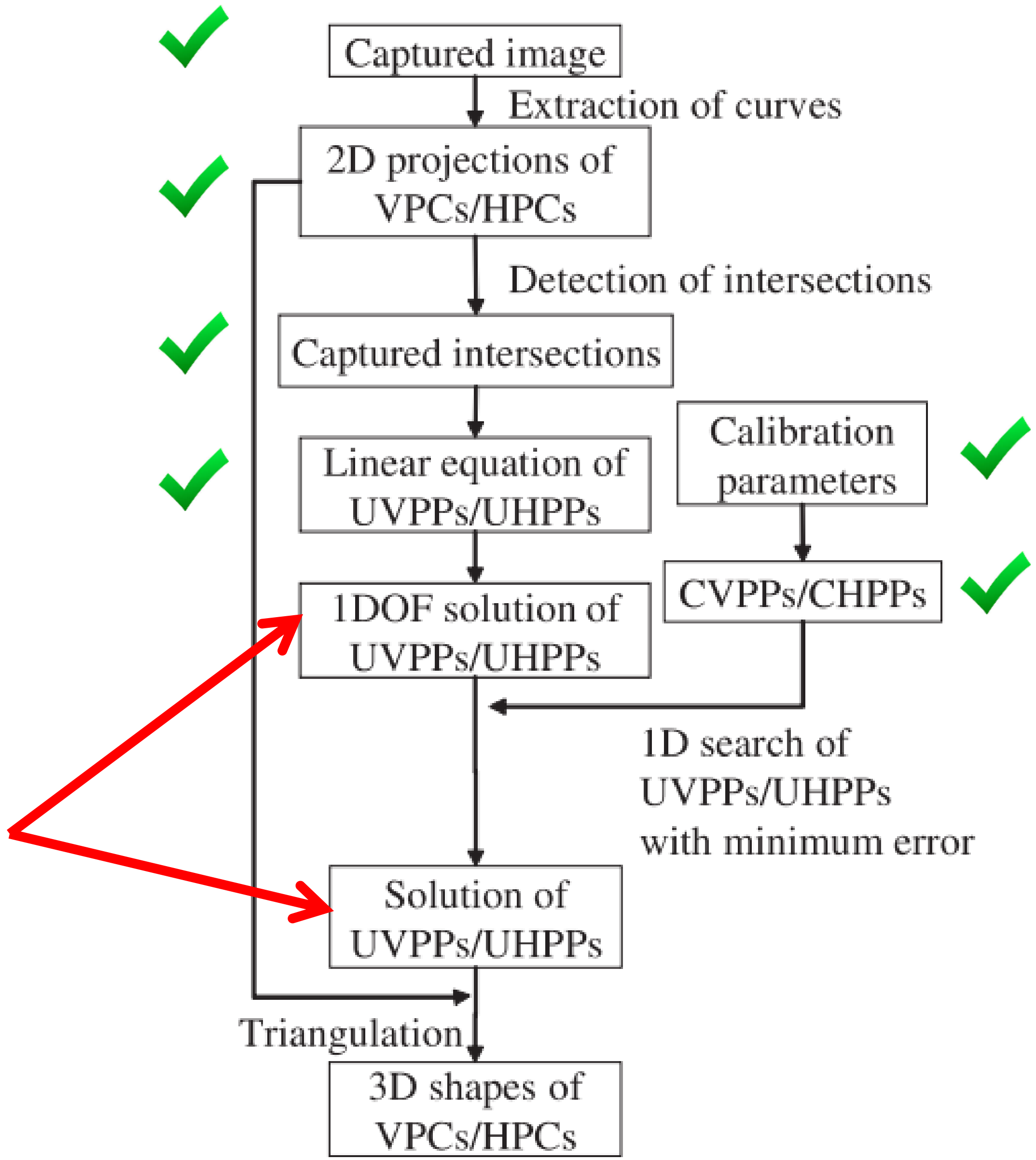
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Determining Ambiguity (More Math)

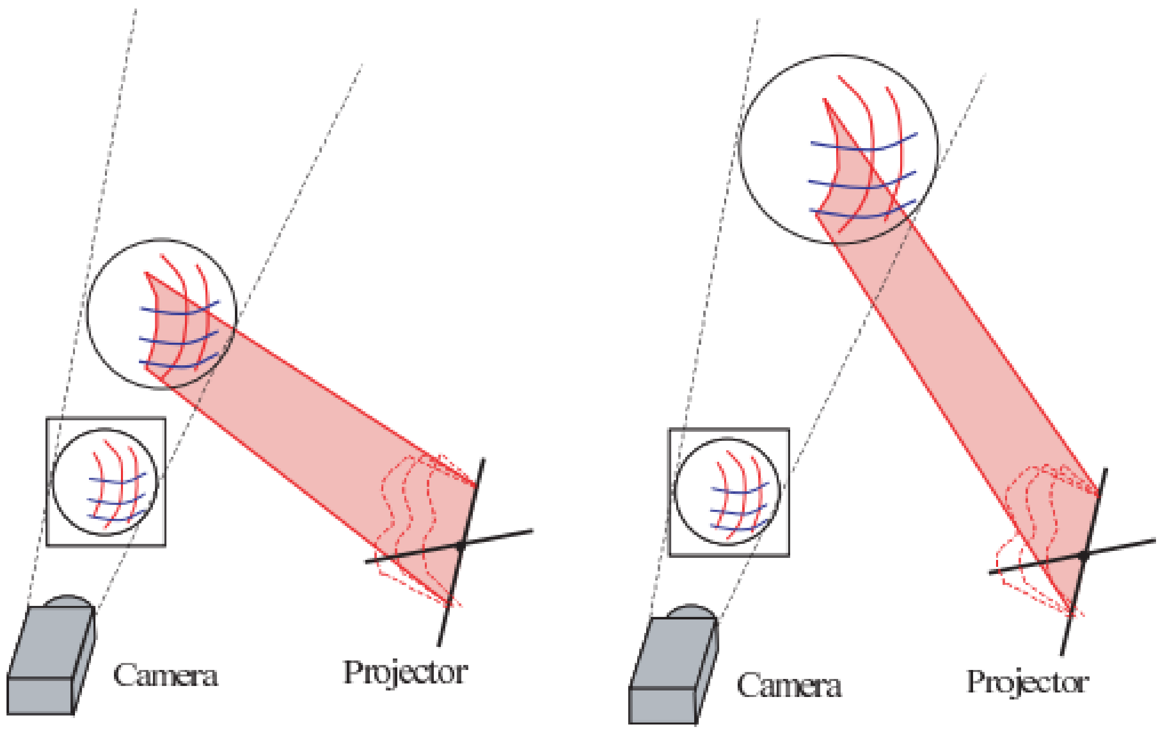
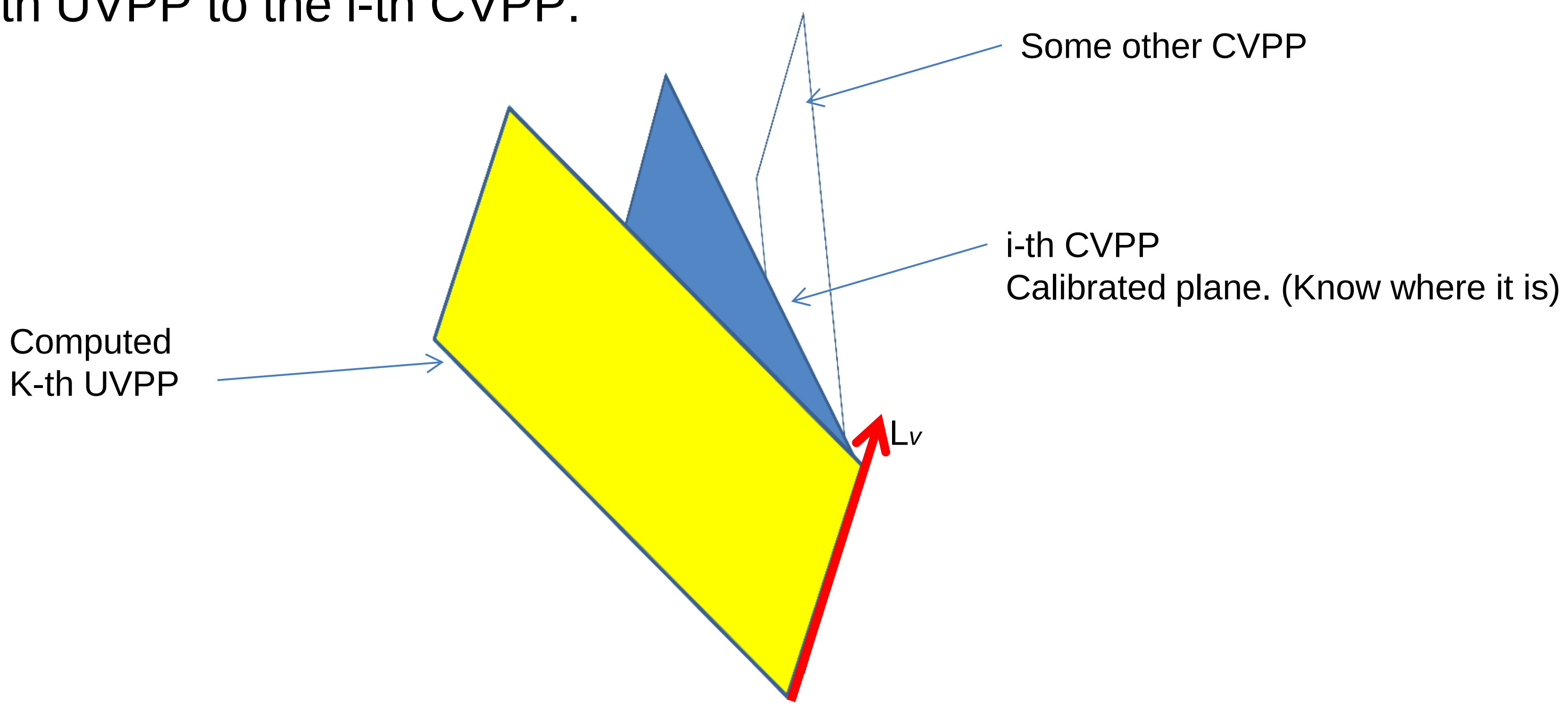


Fig. 5 1-DOF indeterminacy similar to scaling ambiguity.

Determining Ambiguity (More Math)

- Calculate the ambiguity by finding a specific correspondence from k-th UVPP to the i-th CVPP.



Determining Ambiguity (More Math)

- Minimize the error function E(i) where

  $E_k(i)$ = Error between v_k (UVPP) and V_i (CVPP)

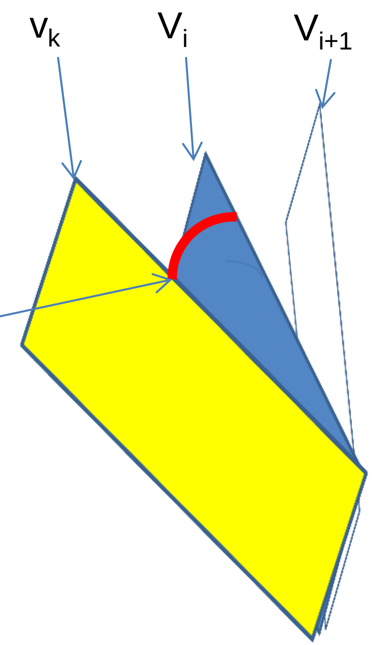
$$E_{k'}(i') \equiv \sum_{k=1}^{m} \min_{i=1,\ldots,M} \{D(\mathbf{v}_k(k',i'),\mathbf{V}_i)\}^2 + \sum_{l=1}^{n} \min_{j=1,\ldots,N} \{D(\mathbf{h}_l(k',i'),\mathbf{H}_j)\}^2,$$

and

$$D(\mathbf{v}_k,\mathbf{V}_i) \equiv \arccos\left(\frac{\mathbf{v}_k \cdot \mathbf{V}_i}{||\mathbf{v}_k||\ ||\mathbf{V}_i||}\right).$$

$$i'_{min} \equiv \arg\min_{i'} E_{k'}(i')$$

Angle between two planes v_k and V_i



Determining Ambiguity (More Math)

- Knowing the optimum correspondence, ambiguity is solved.

Given v_k (UVPP) and V_i (CVPP) correspondences and h_l (UHPP) and H_i (CHPP) correspondences

↓

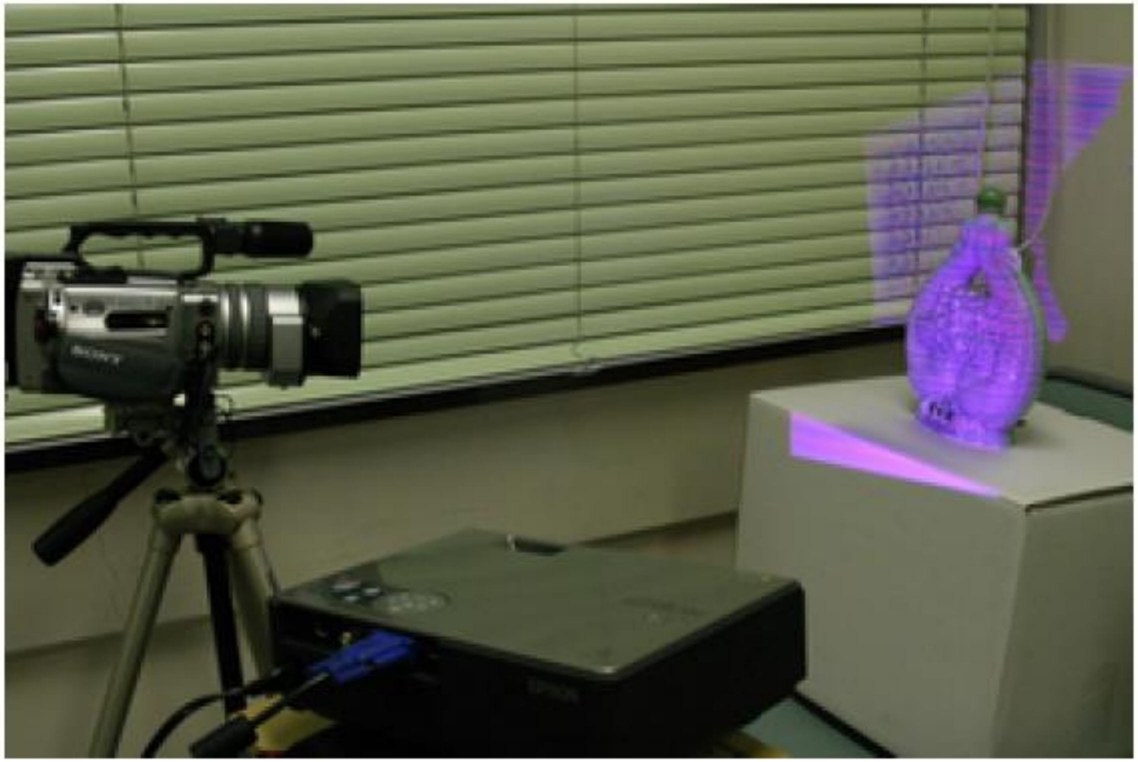
3D position of intersection of v_k and h_l

↓

Repeat for all intersections

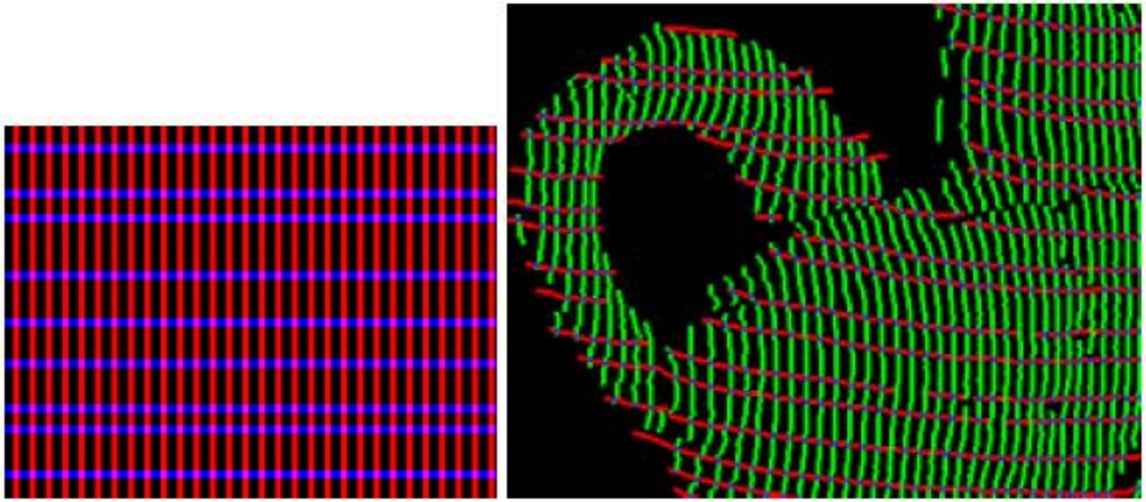
Results

- Setup



Results

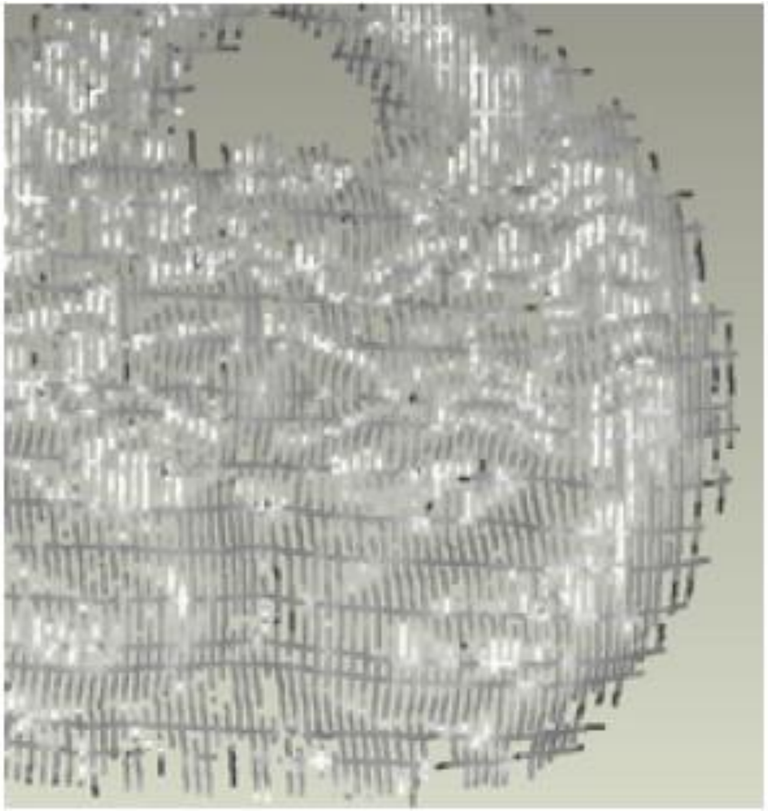
- Projected grid pattern and detected VPC and HPC



Results

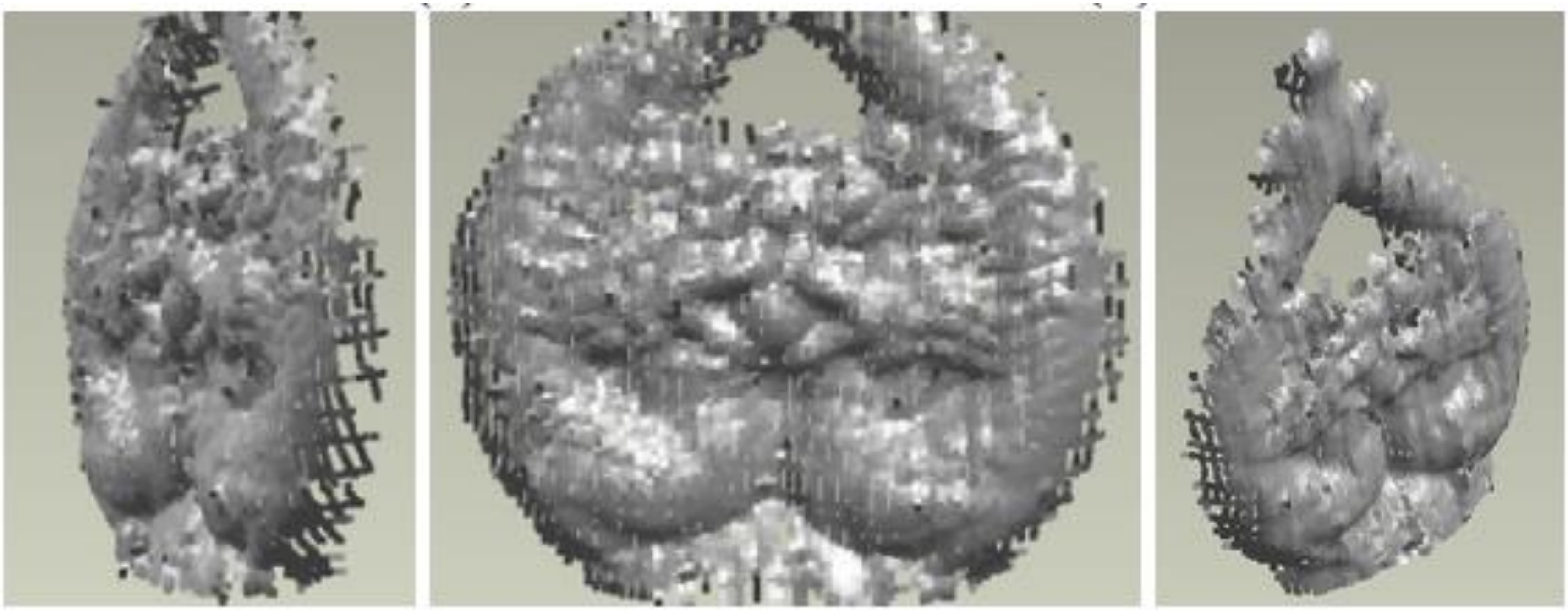
Target object

Close-up of reconstructed shape



Results

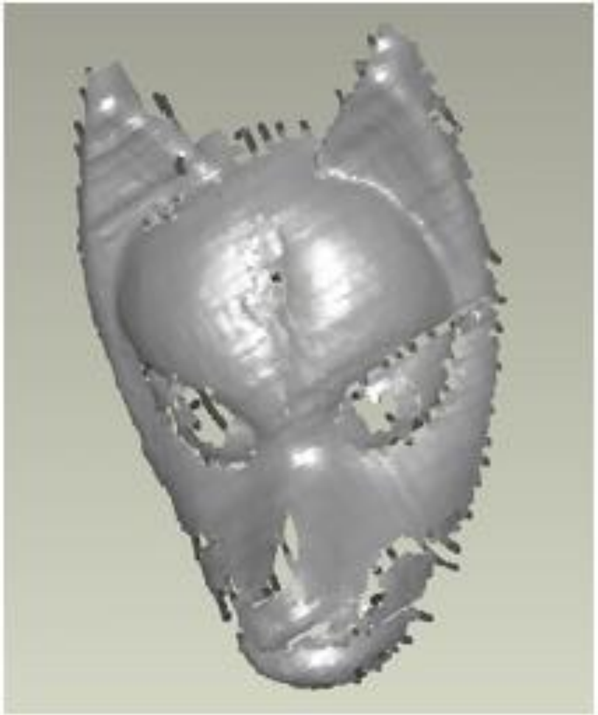
- Reconstructed shape
- Error – RMS error from ground truth = 0.52 mm



Results

target

reconstruction



textured with hole-filling

Discussion

- Positives
  - Very relevant to Robo-ELF project (might be an alternative to current passive stereo approach)
  - Robustness and efficiency of the algorithm (~1.6 seconds)
  - Single frame
  - Thorough mathematical derivations
  - Helpful figures
- Negatives
  - No description of the calibration procedure
  - Algorithm is heavily dependent on calibration

Reference

H. Kawasaki, R. Furukawa, R. Sagawa, Y. Yagi. **Dynamic Scene Shape Reconstruction Using a Single Structured Light Pattern.** *Computer Vision and Pattern Recognition, 2008. CVPR 2008.* IEEE Conference on 1-8.

H. Kawasaki, R. Furukawa, R. Sagawa, Y. Yagi. **Shape from Grid Pattern Based on Coplanarity Constraints for One-shot canning.** *IPSJ Transactions on Computer Vision and Applications 2009.* Vol. 1, 139-157

Questions?