Shape acquisition and registration for 3D endoscope based on grid pattern projection

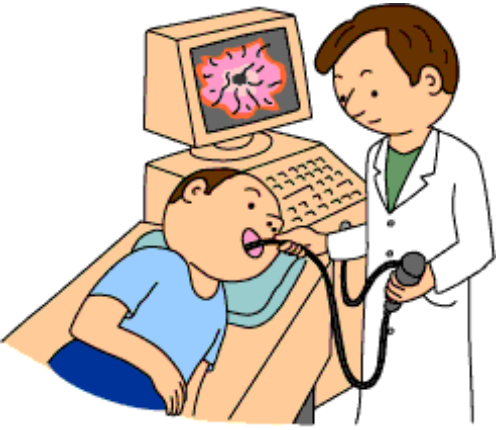
14th Oct. 2016

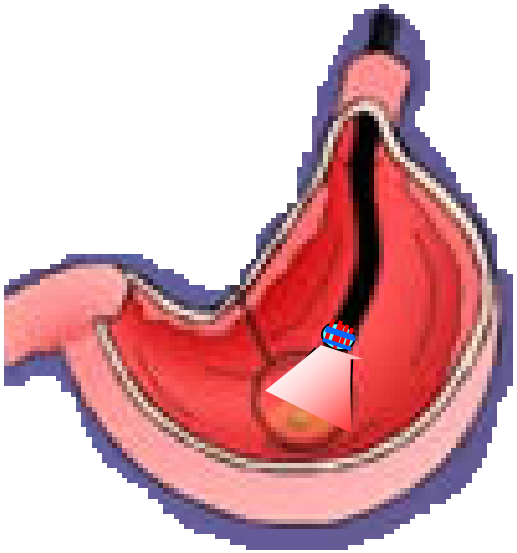
ECCV Amsterdam

Ryo Furukawa, Hiroki Morinaga,
Yoji Sanomura, Shinji Tanaka,
Shigeto Yoshida, and Hiroshi Kawasaki
Hiroshima city University Japan, Kagoshima university Japan

Background

- Strong demand on 3D endoscope
  - Early diagnosis
  - Support remote surgery





Challenges on endoscopic system

- Internal organ
  - Less texture
  - Severe light absorption and specularity
- System requirement
  - Ultra small size
  - Strong intensity (light power)
- Dynamic environment
  - Organs
  - Sensors

- Active stereo
  - Static pattern (one-shot)
- SLAM approach

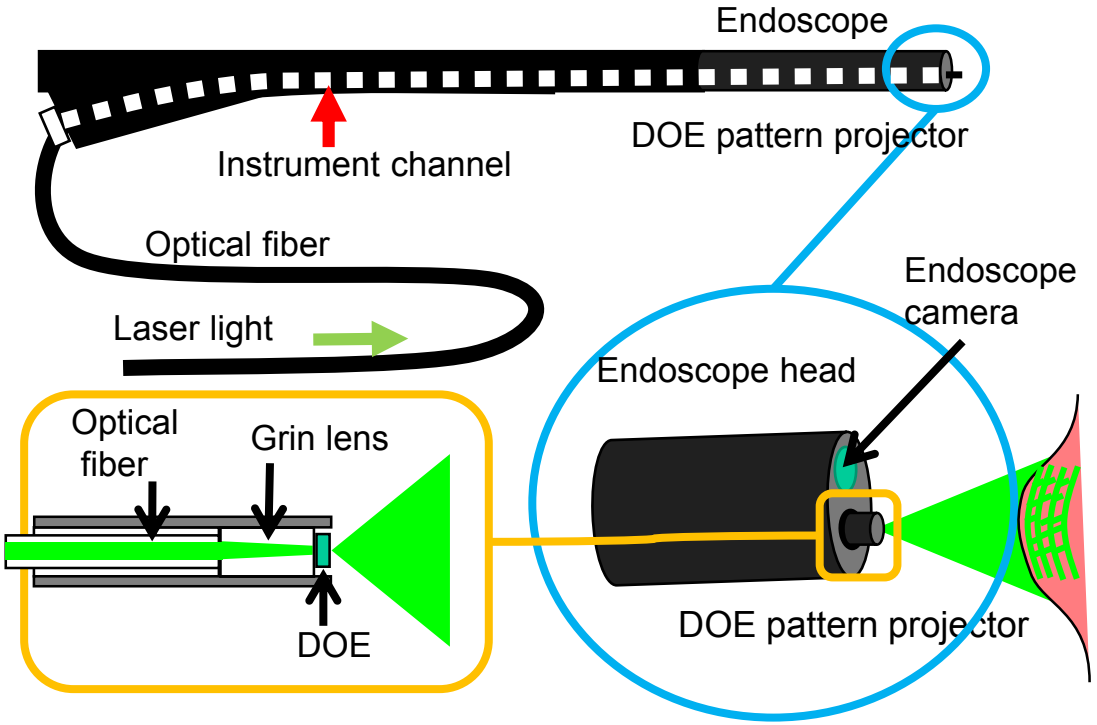
Summary of our approach

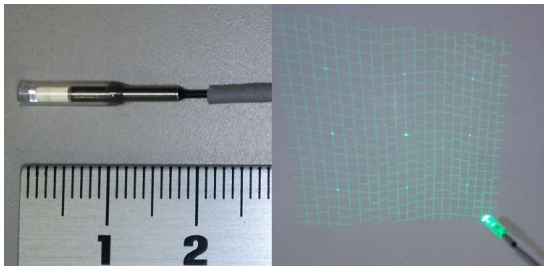
- Active stereo
  - Static pattern (oneshot scan)
  - Robust to subsurface scattering
- SLAM approach
  - Sparse shape registration
  - Non-rigid registration

Summary of our approach

- Active stereo
  - Static pattern (oneshot scan)
  - Robust to subsurface scattering
- SLAM approach
  - Sparse shape registration
  - Non-rigid registration

System Configuration

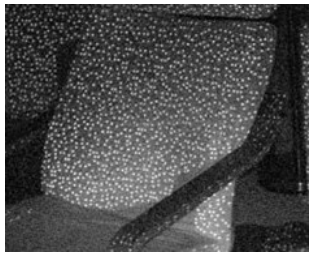




Lenth ~ 19mm
Diamiter ~1.8mm
Light efficiency ~ 95%

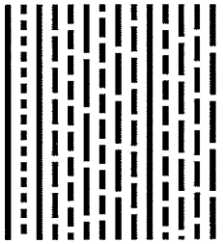
Single color oneshot scan

- Random dot pattern
  - Kinect v1
  - Stable and standard technique



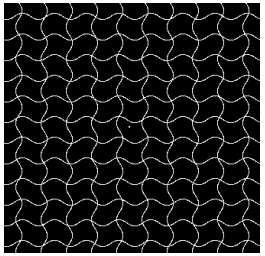
[Kinect v1, 2010]

- Line based pattern
  - Stable and robust to wide baseline



[Artec, US patent, 2007]

- Grid based pattern
  - Robust to wide baseline

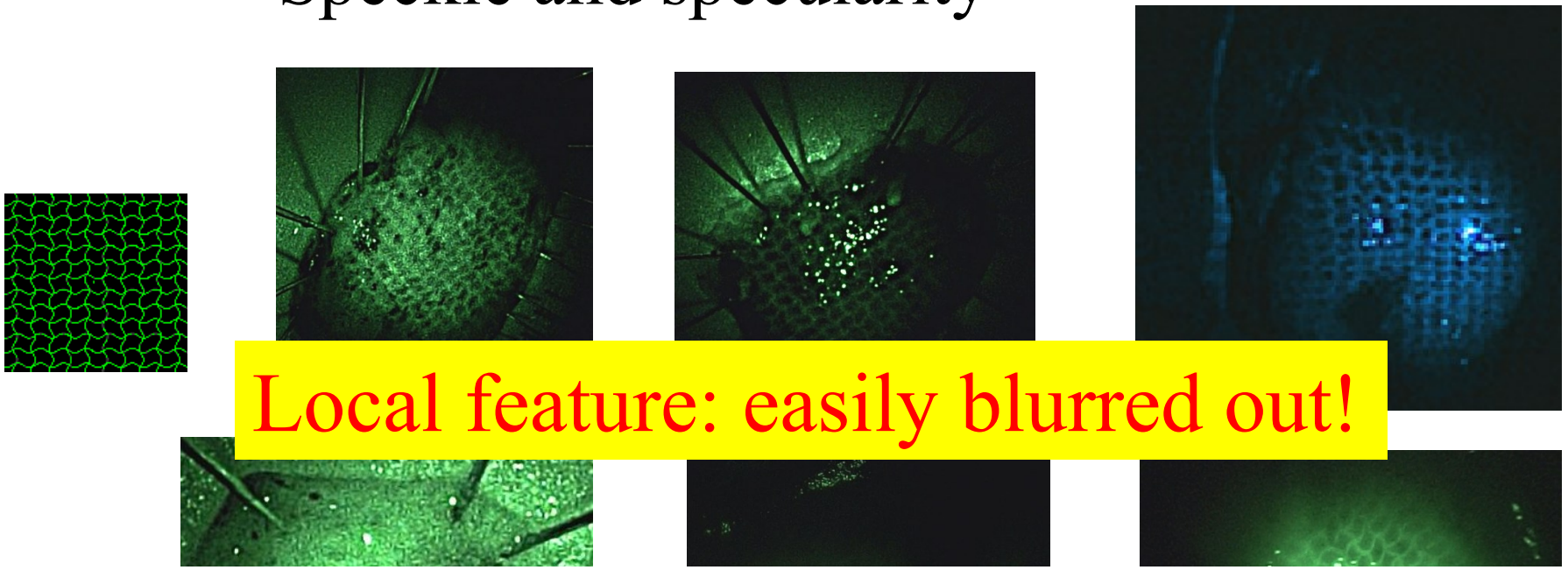


[Sagawa et.al, ICCV13]

Local feature encoded in the pattern

Real endoscopic environment

- Subsurface scattering
- Speckle and specularity



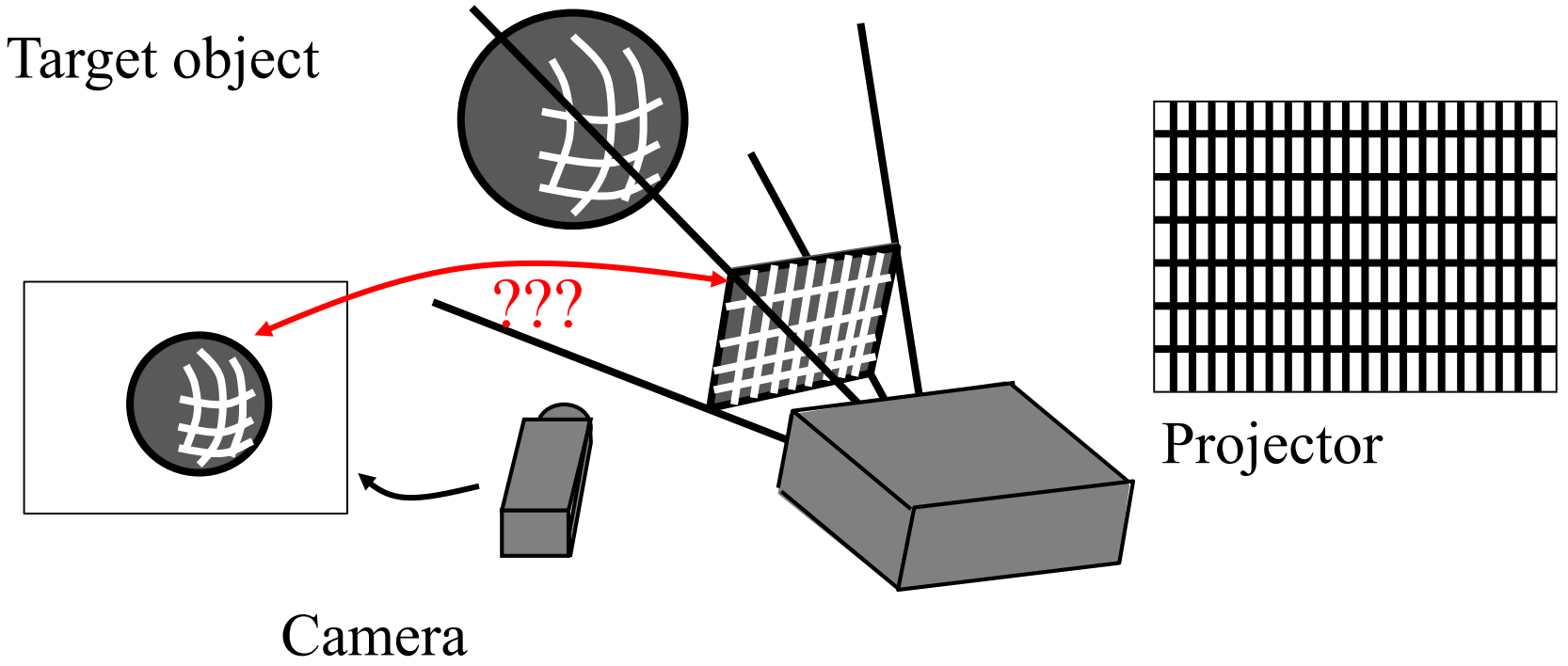
Local feature: easily blurred out!

- Solution
  - Pattern with macro-structure

Pattern with macro-structure

- Grid pattern based active stereo

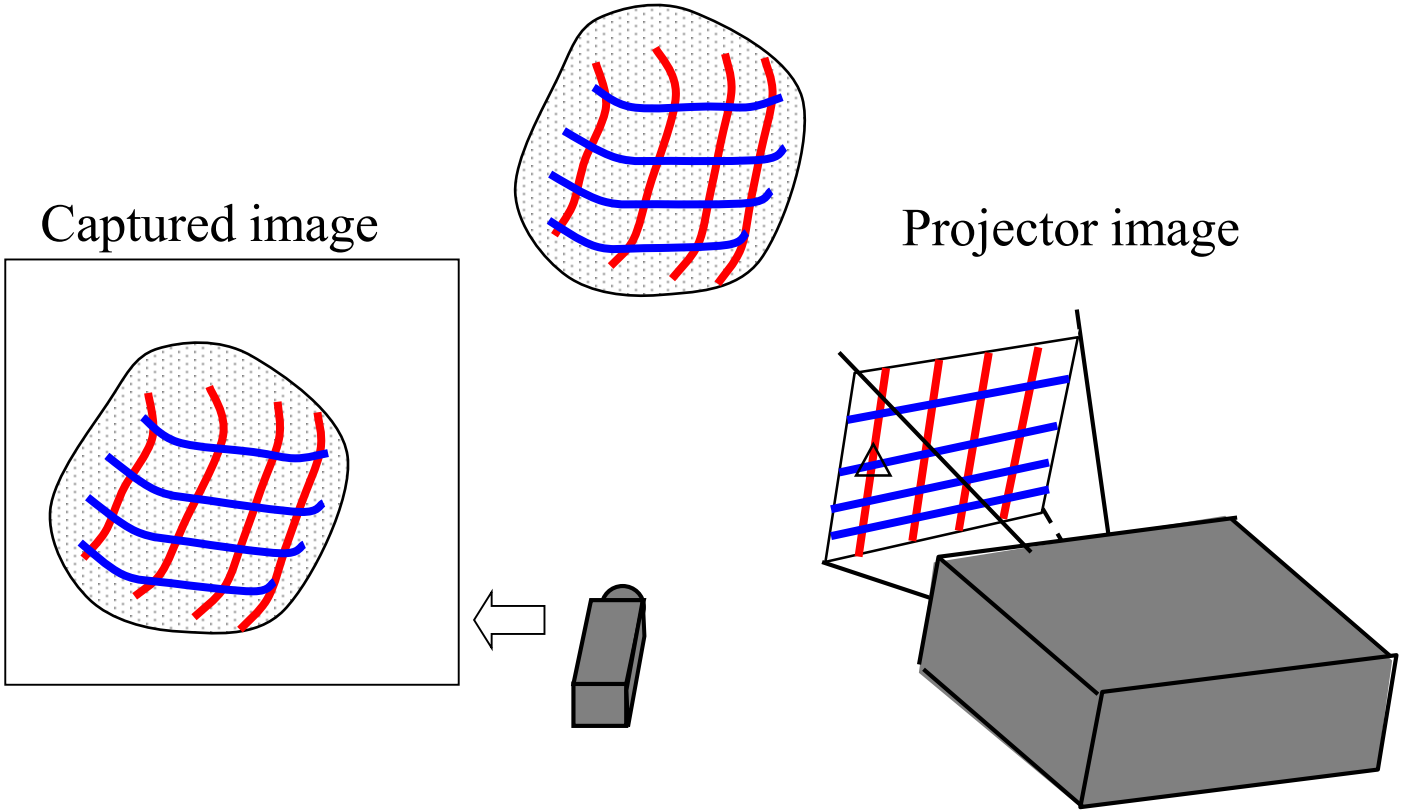
[Kawasaki et.al, CVPR08, Sagawa et.al, ICCV13]



Correspondence problem

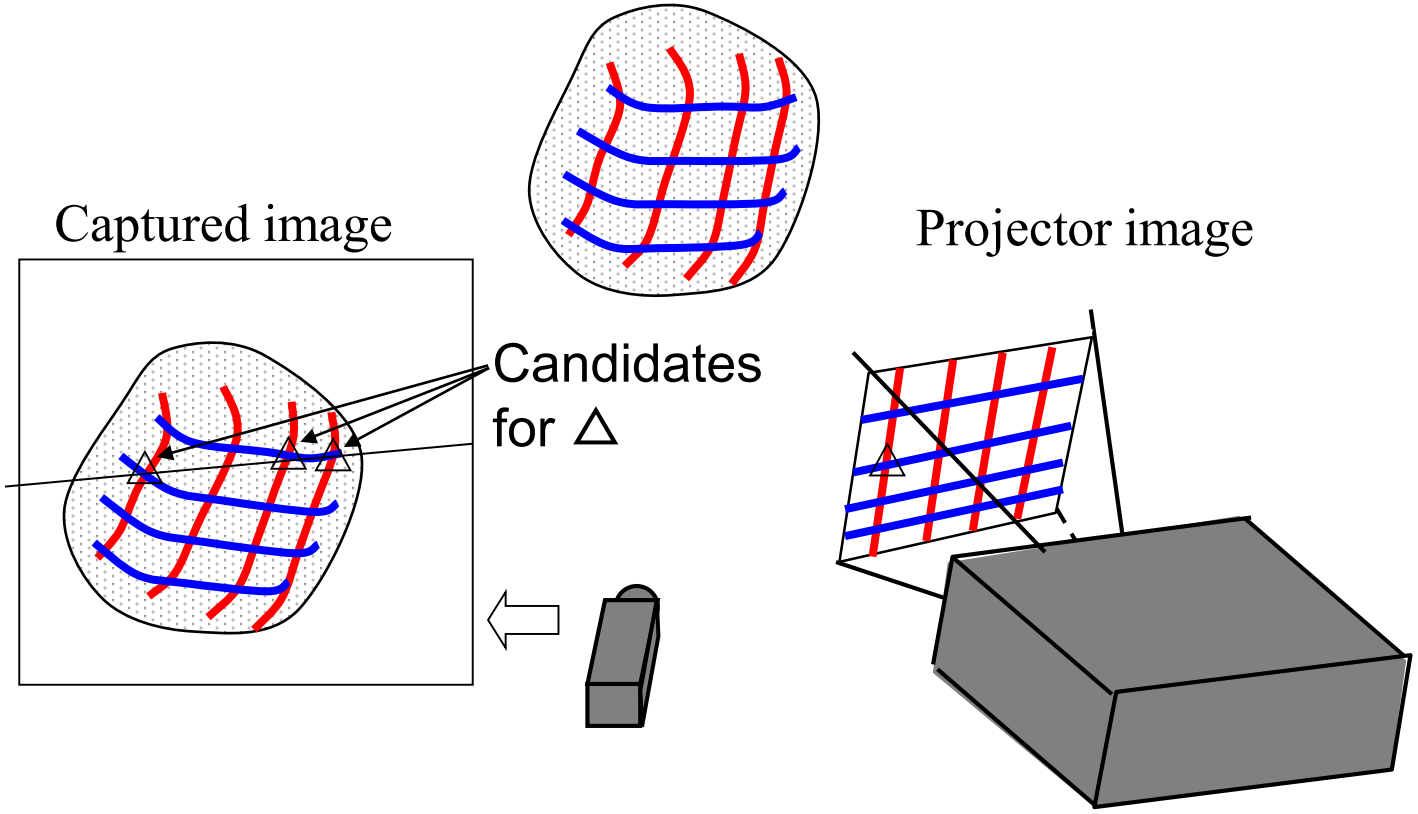
Correspondence problem on Grid based active stereo

- Encoded in graph connectivity



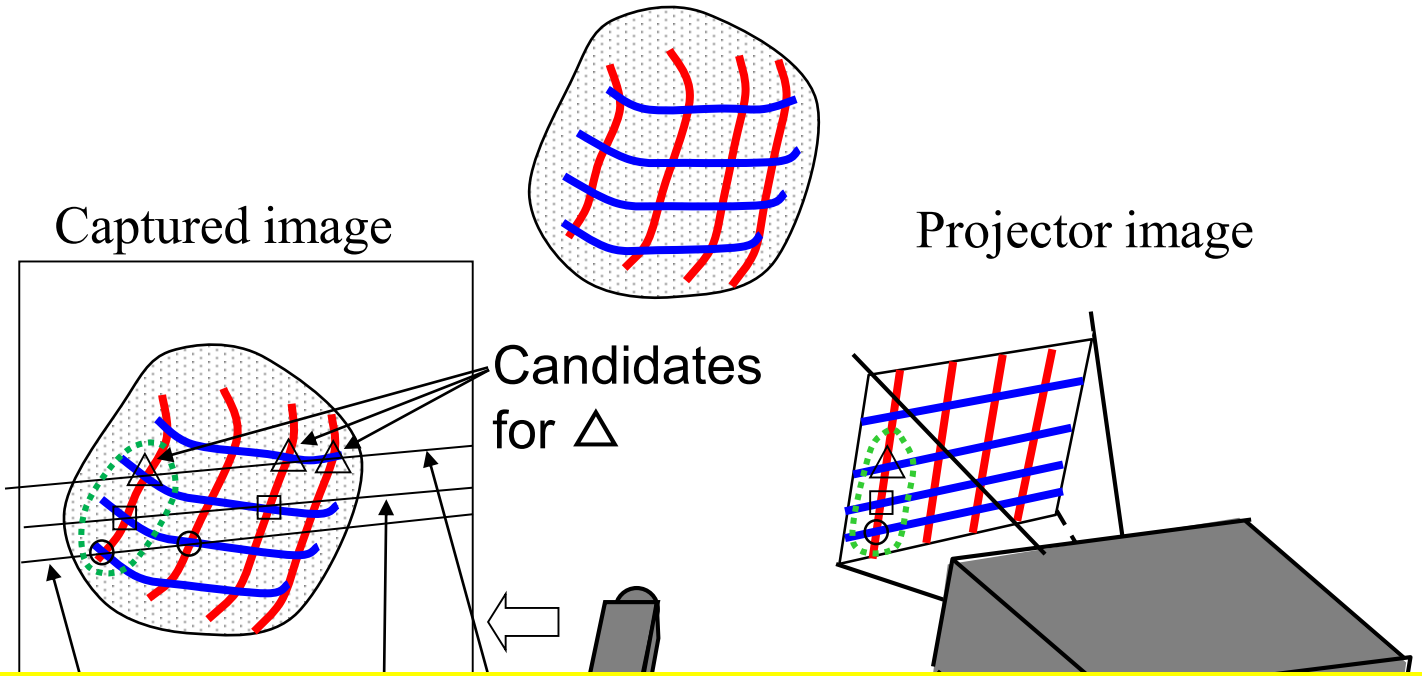
Correspondence problem on Grid based active stereo

- Encoded in graph connectivity



Correspondence problem on Grid based active stereo

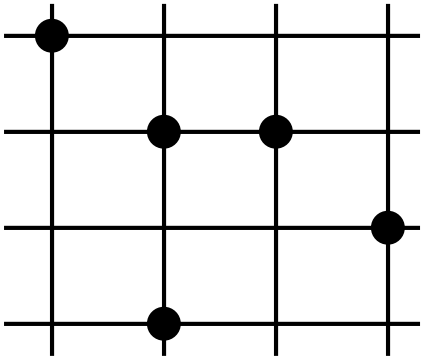
- Encoded in graph connectivity

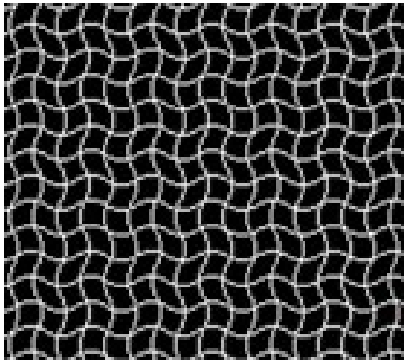


Small region = small graph → not enough constraint
→ Need additional information

Additional information for grid based active stereo

- Micro feature:

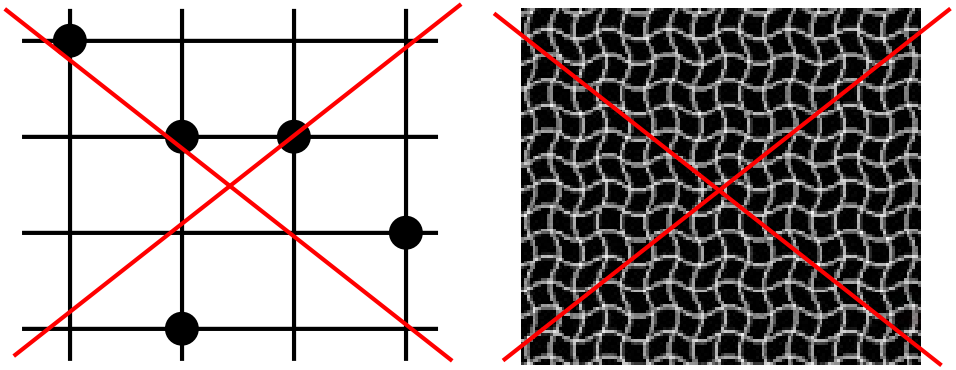




[Sagawa et.al, ICCV13]

Additional information for grid based active stereo

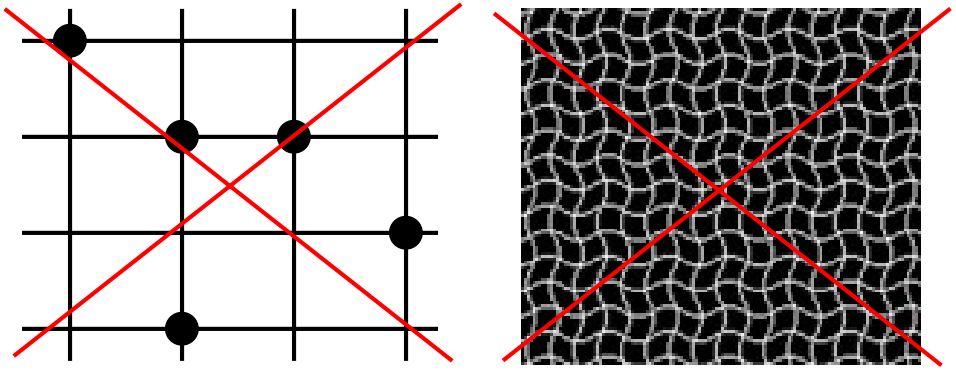
- Micro feature: easily blurred out



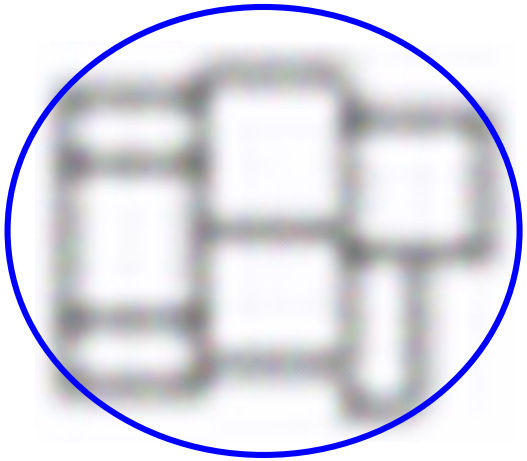
[Sagawa et.al, ICCV13]

Additional information for grid based active stereo

- Micro feature: easily blurred out

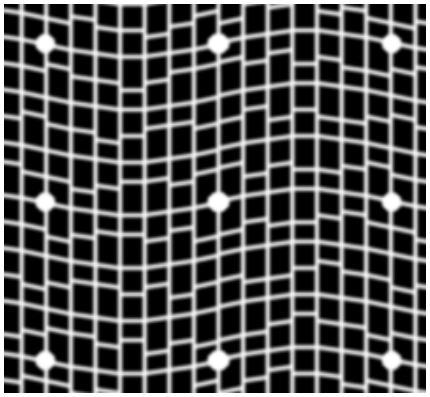


- Positional information: remains against blur
  - Relative position

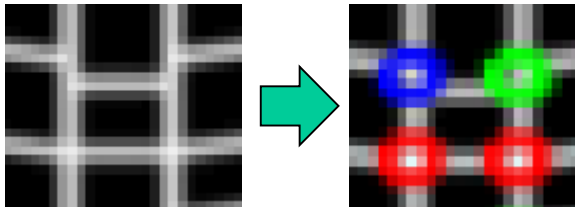


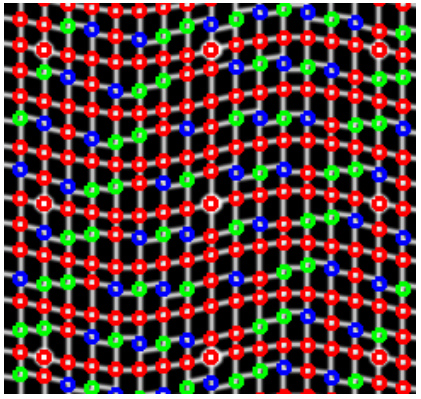
Blur robust grid pattern
-- gap coding --

- Relative positional information: Gap
  - (+) Plus, (-) minus, (0) same



Gap coded pattern



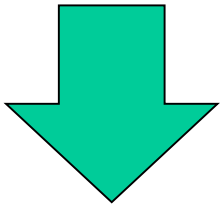


Codes of intersection points

Low frequency modulation to avoid singular rotation angle

Ambiguity elimination by gap coding

- Detected graph has connection errors or decoding errors

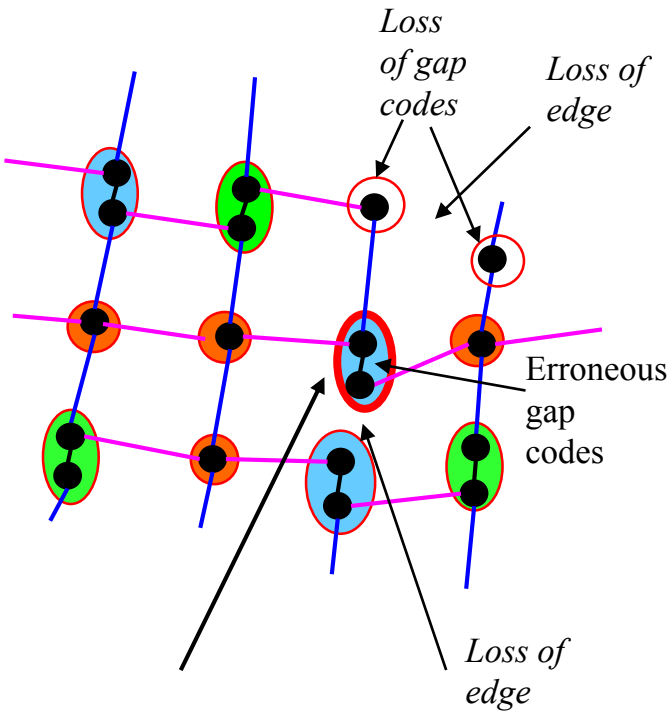


1. Prepare sub-graph dictionary
2. Matching between detected grid graph and sub-graph
3. Vote if it is matched

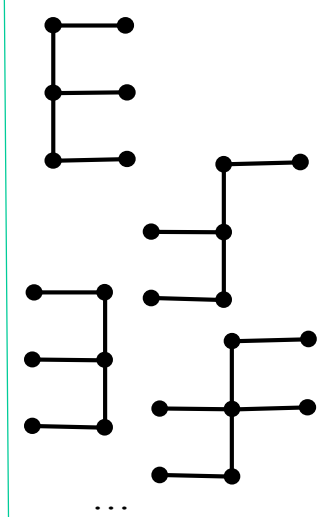
Ambiguity elimination by gap coding

Matching grid graphs using sub-graph patterns

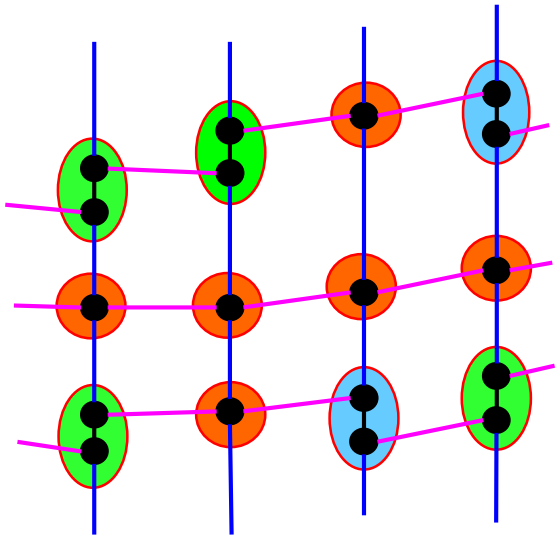
Grid graph *G* from captured image



Local sub-graph patterns (LSGP)

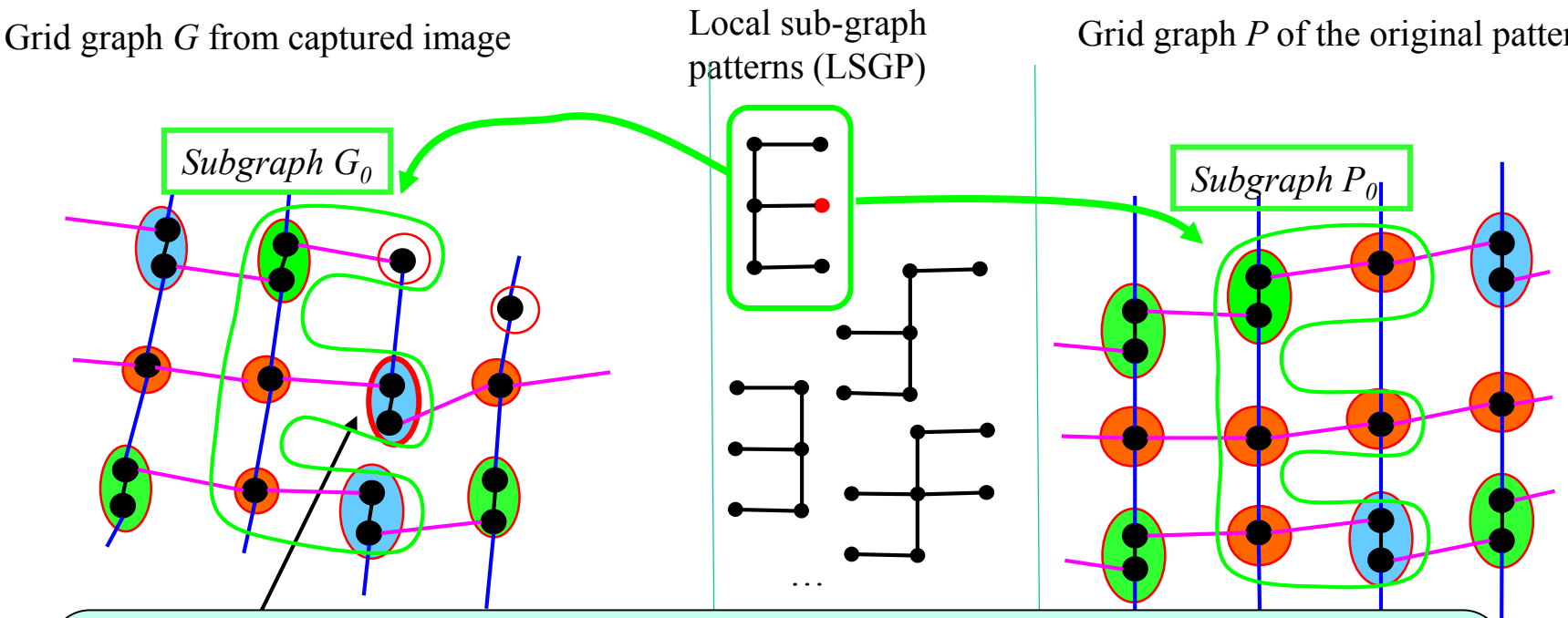


Grid graph *P* of the original pattern



Ambiguity elimination by gap coding

Matching grid graphs using sub-graph patterns

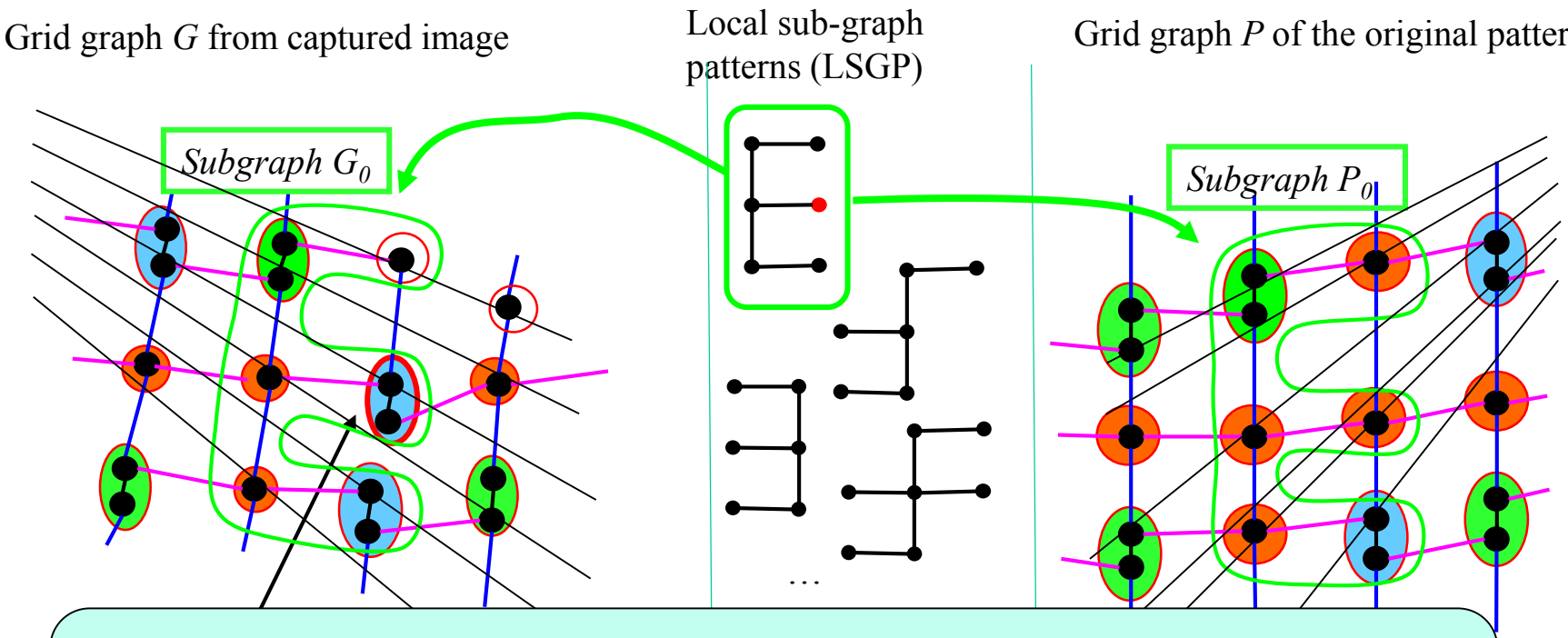


Matching criteria between G_0 and P_0

- **All nodes satisfy epipolar constraints**
- **Number of nodes with same gap-code** is above threshold

Ambiguity elimination by gap coding

Matching grid graphs using sub-graph patterns

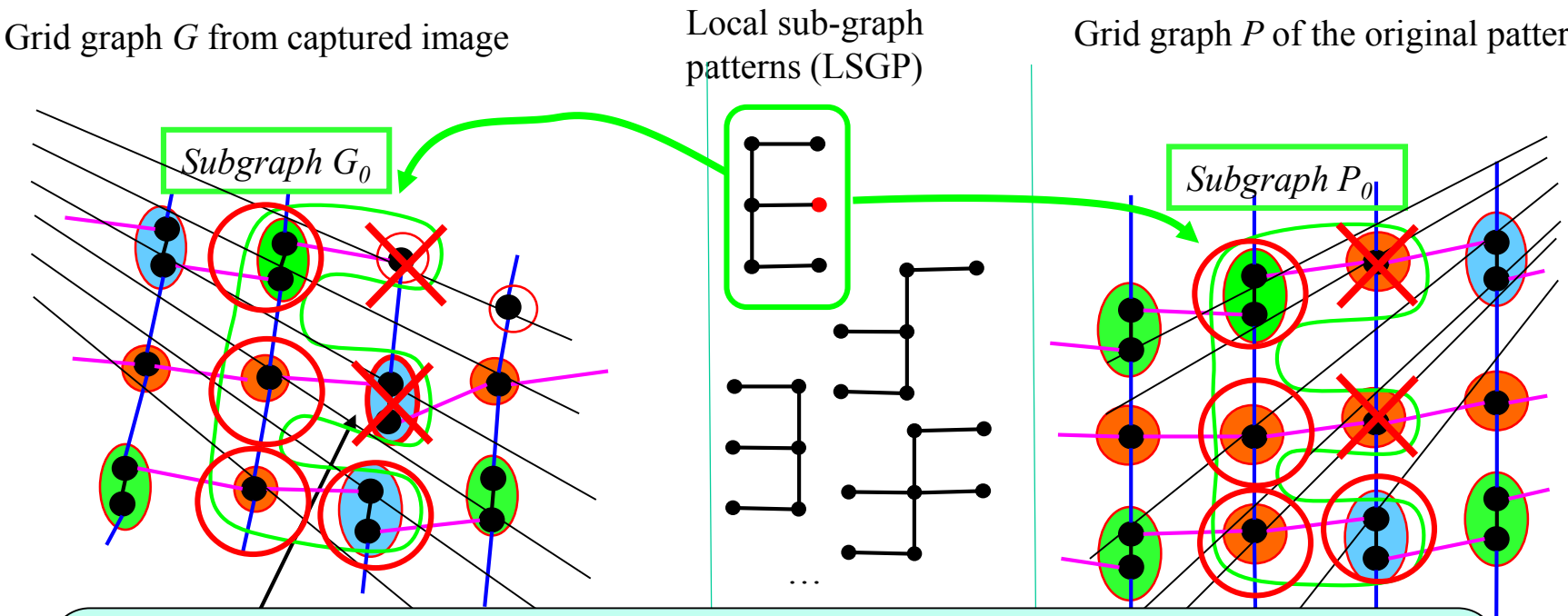


Matching criteria between G_0 and P_0

- **All nodes satisfy epipolar constraints**
- **Number of nodes with same gap-code** is above threshold

Ambiguity elimination by gap coding

Matching grid graphs using sub-graph patterns

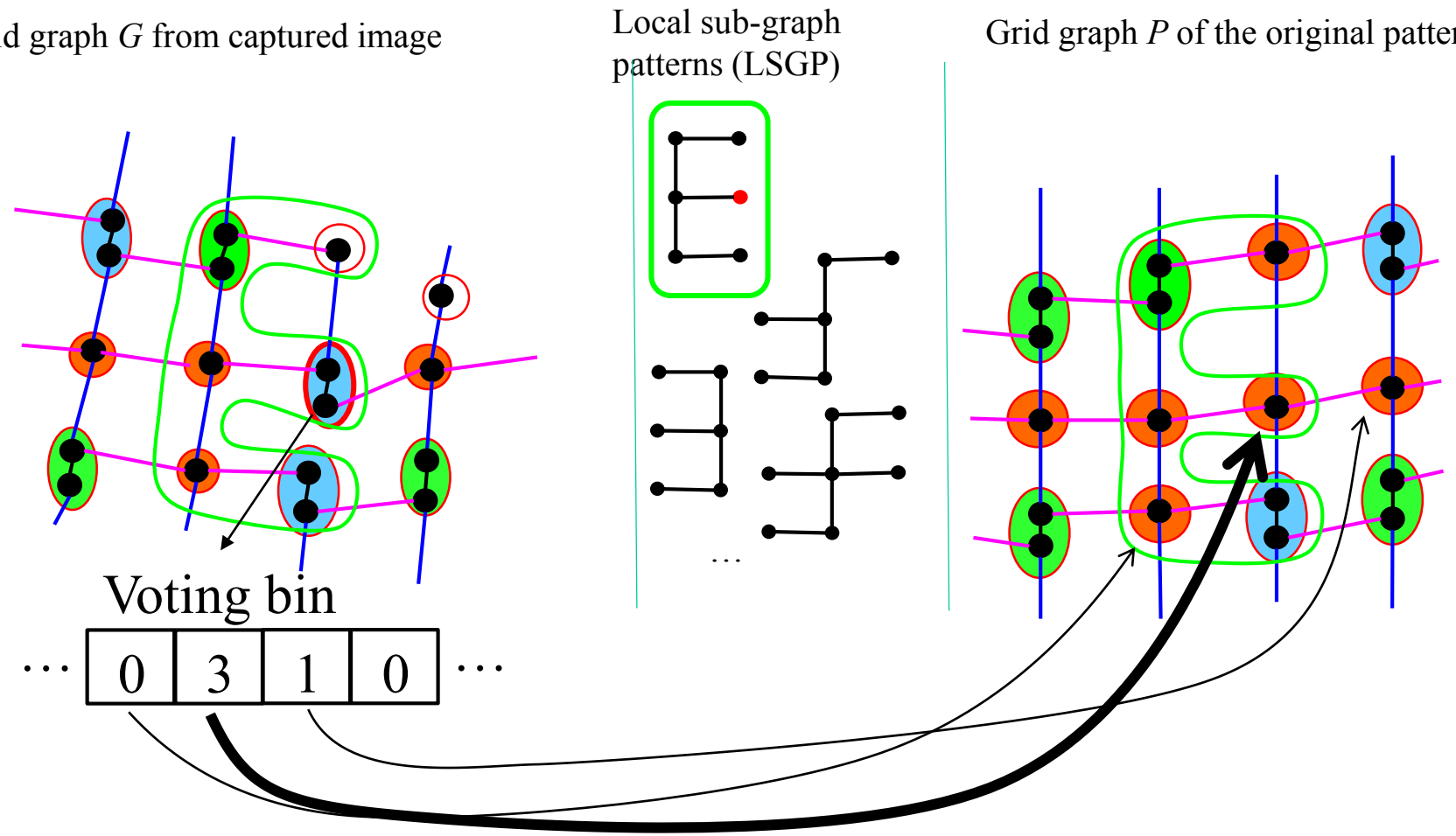


Matching criteria between G_0 and P_0

- **All nodes satisfy epipolar constraints**
- **Number of nodes with same gap-code** is above threshold

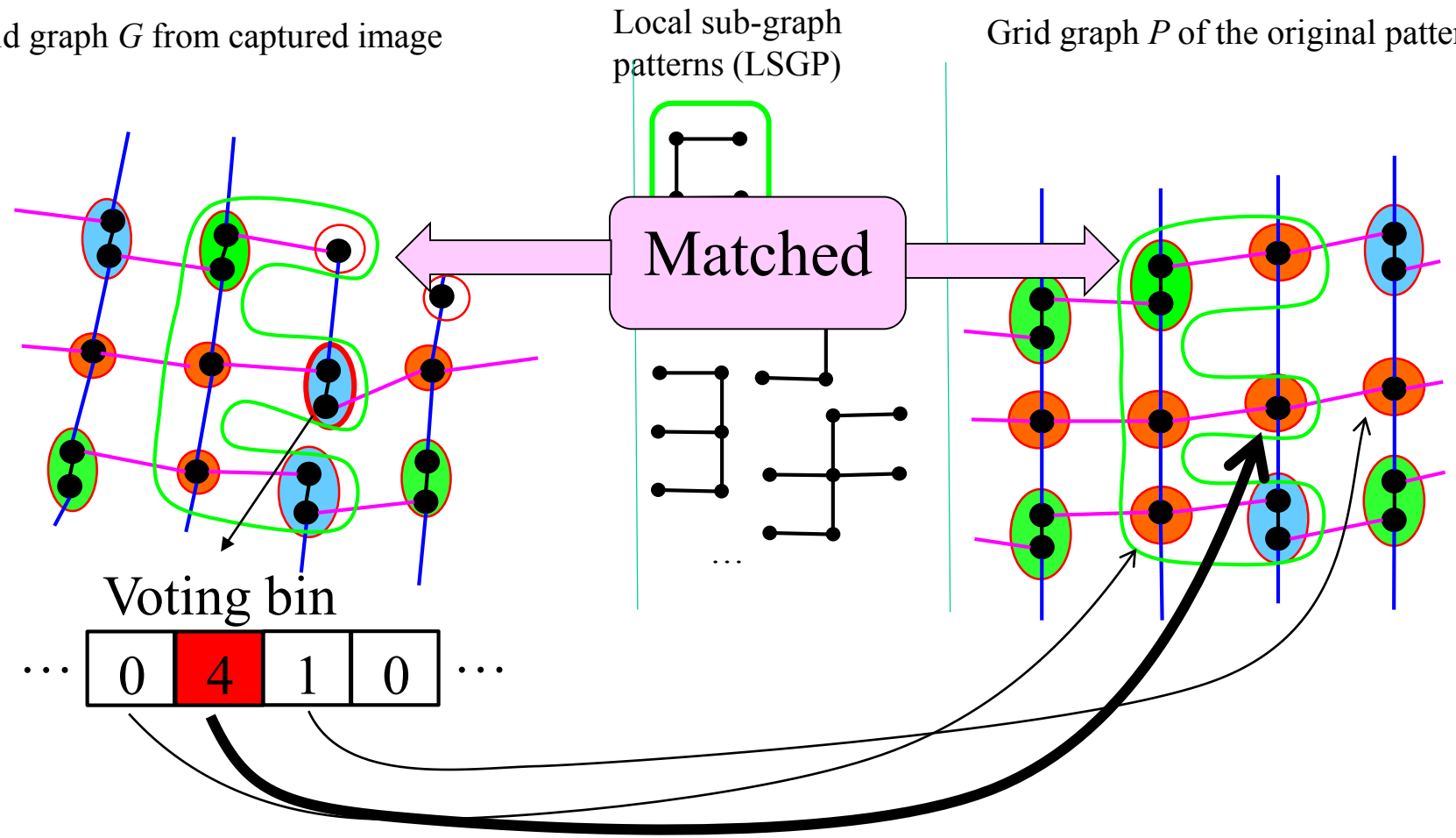
Ambiguity elimination by gap coding

Voting for correspondences for all LSGPs



Ambiguity elimination by gap coding

Voting for correspondences for all LSGPs



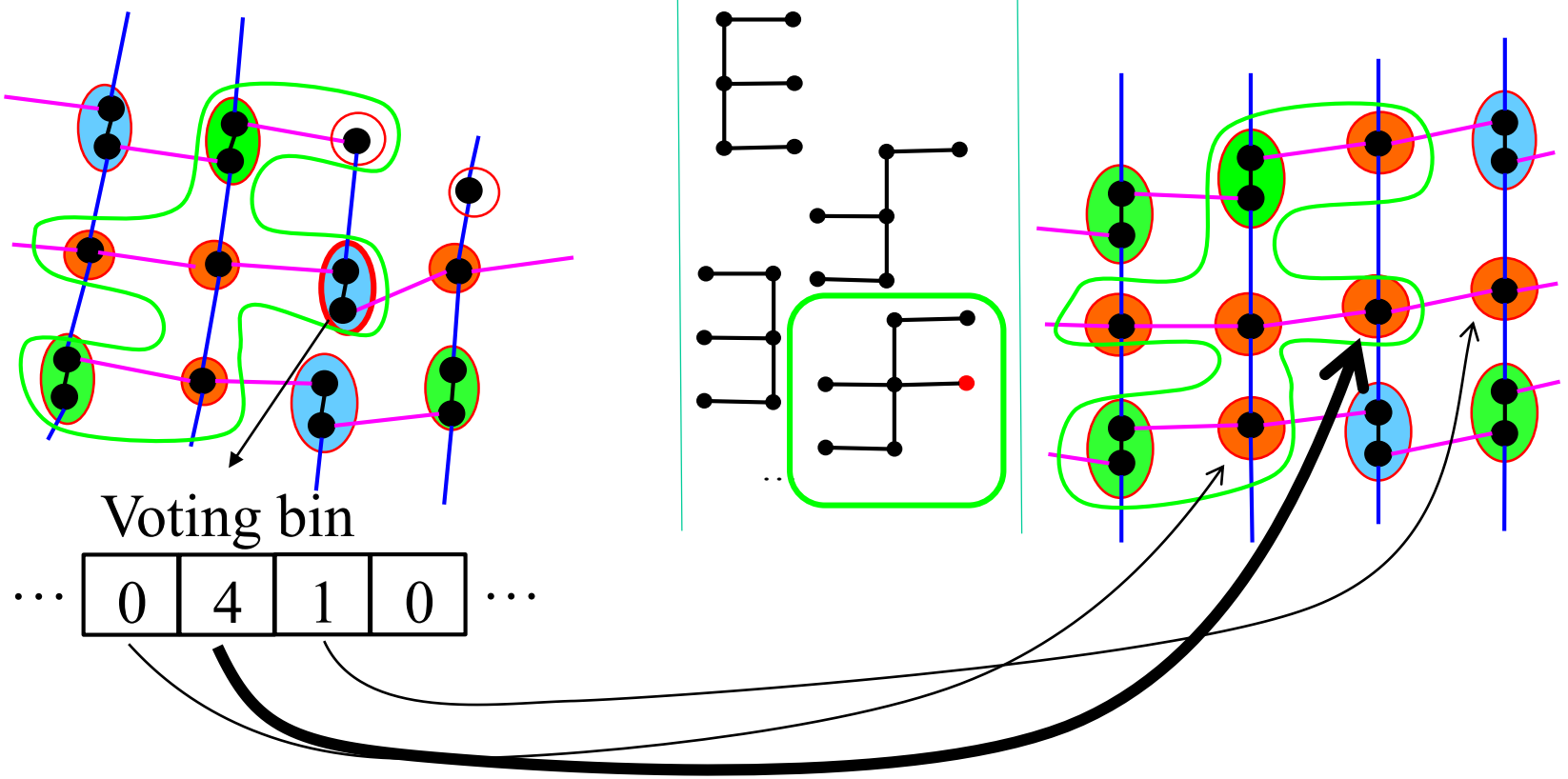
Ambiguity elimination by gap coding

Voting for correspondences for all LSGPs

Grid graph *G* from captured image

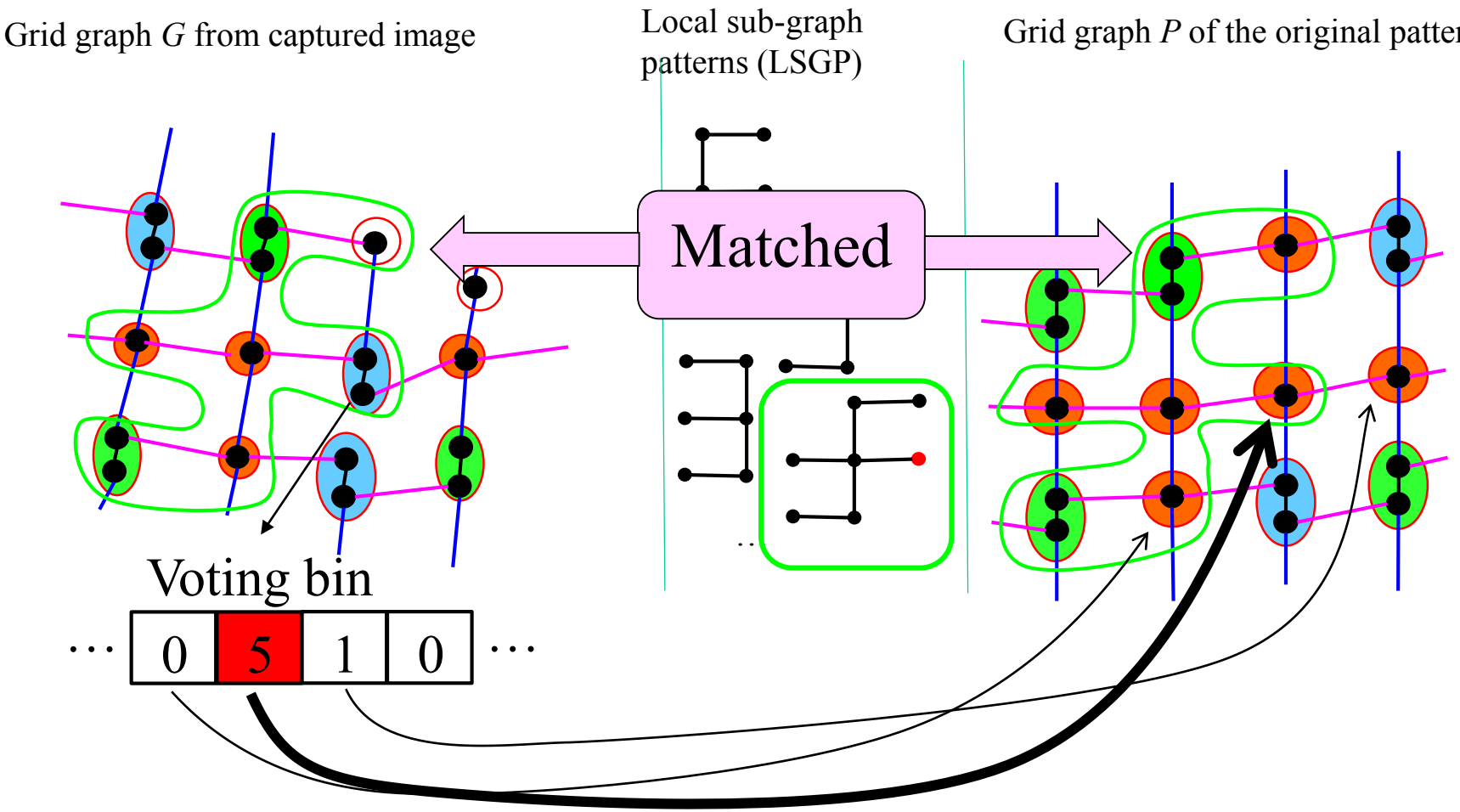
Local sub-graph patterns (LSGP)

Grid graph *P* of the original pattern



Ambiguity elimination by gap coding

Voting for correspondences for all LSGPs



Summary of our approach

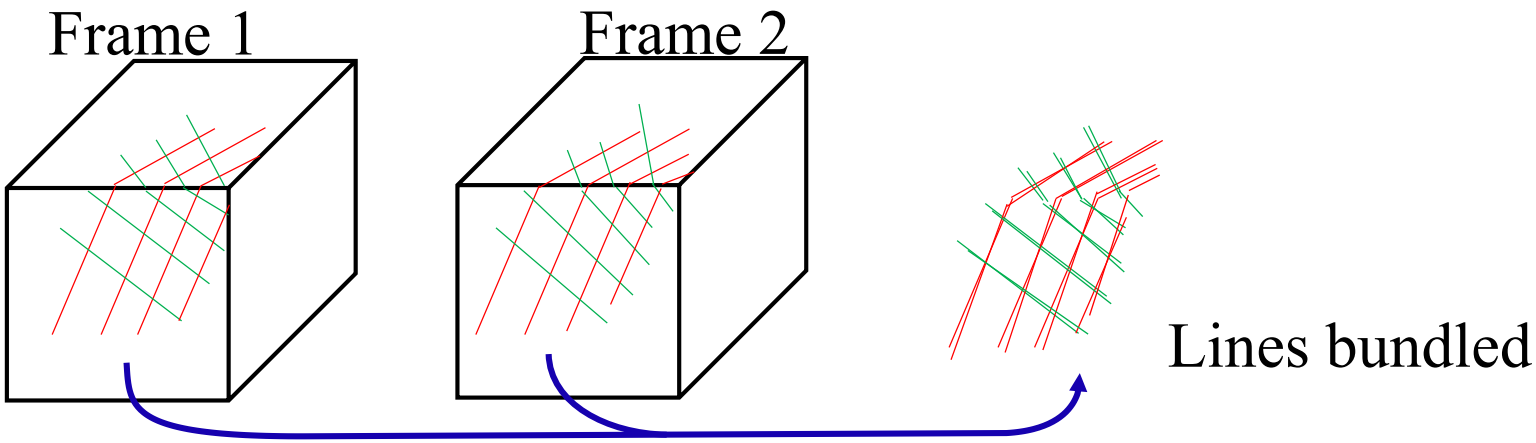
- Active stereo
  - Static pattern (oneshot scan)
  - Robust to subsurface scattering
- SLAM approach
  - Sparse shape registration
  - Non-rigid registration

SLAM with endoscopic system

- Rigid registration
  - For short period of time
  - Small region
- Non-rigid registration
  - Body part moves dynamically

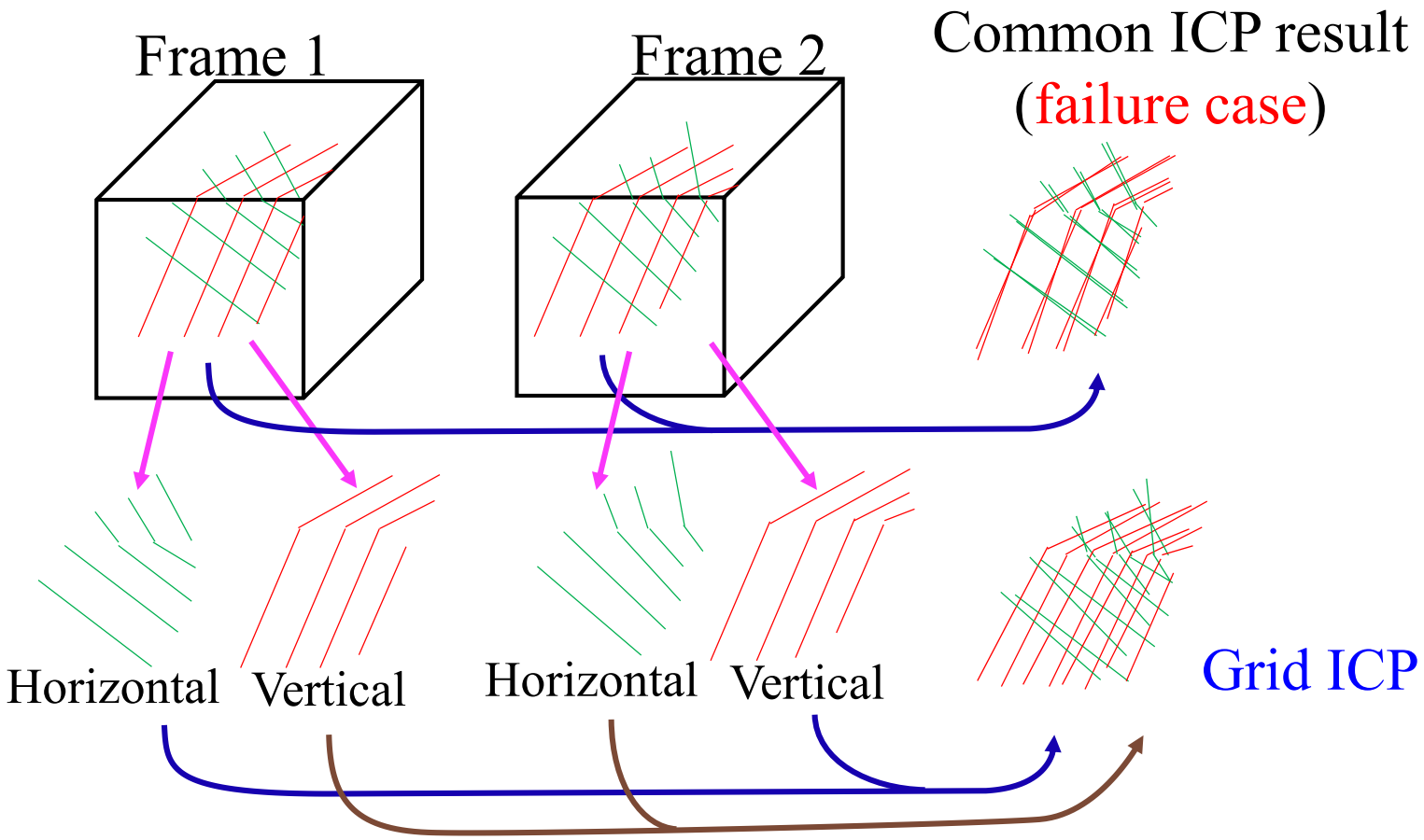
Rigid registration algorithm

- ICP is a most common algorithm, but does not work well for grid-based shapes.
- Reason:
  - Parallel curves between different frames tend to pull together

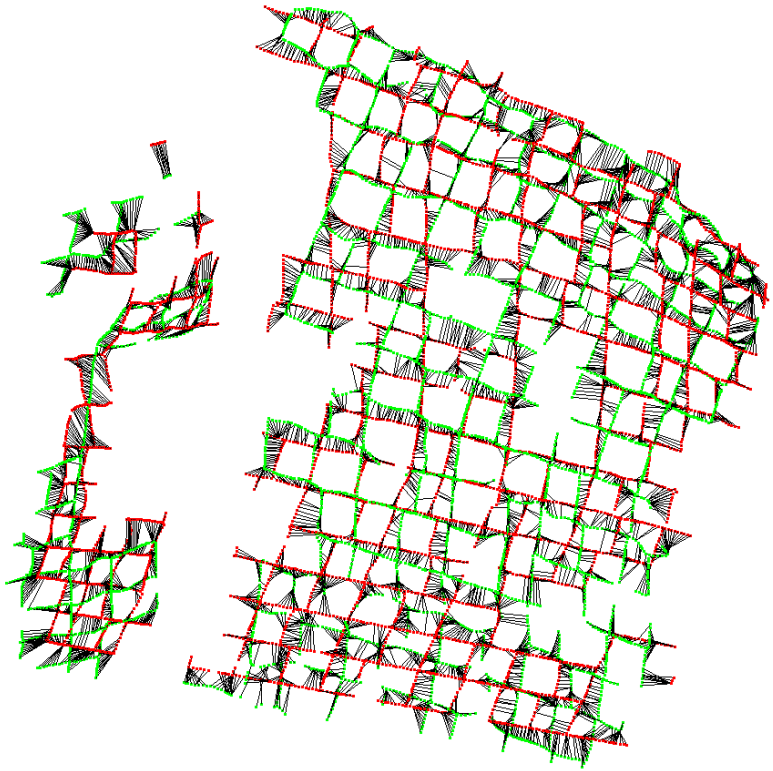


Solution for sparse grid shapes

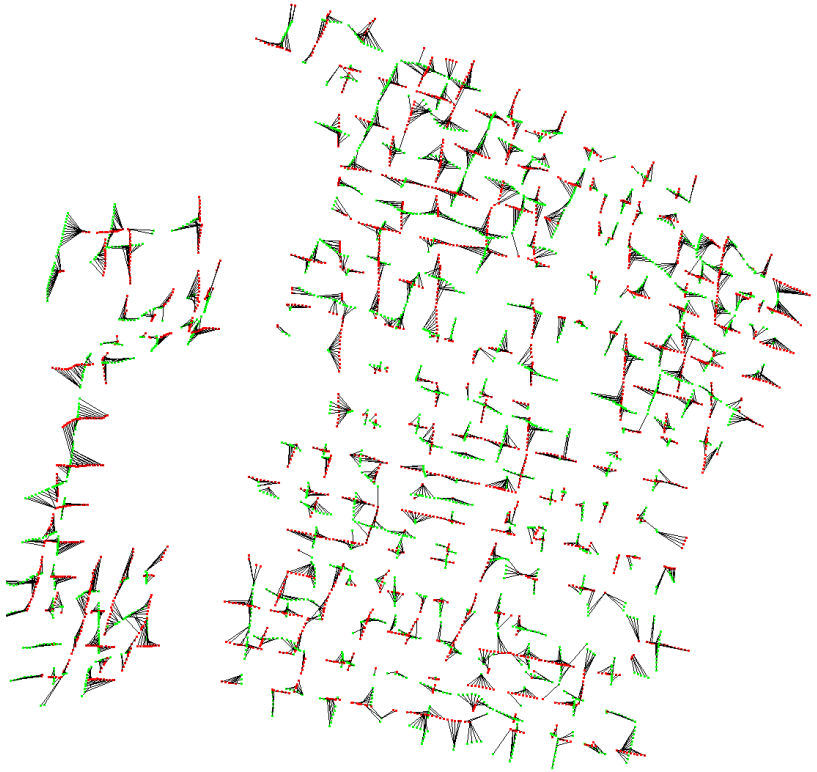
- Correspondences between horizontal and vertical lines



Inter-frame correspondences of both strategy



Correspondences between all points in the frames

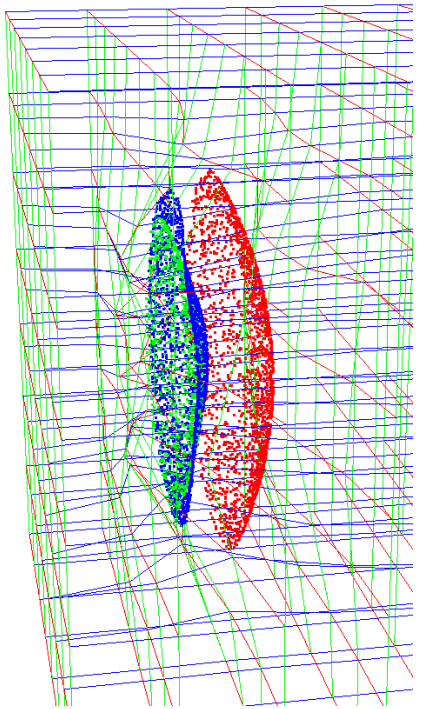


Correspondences only between vertical and horizontal point sets

Non-rigid registration

- Bio-tissues measured in endoscopic analysis are non-rigid

- Non-rigid registration algorithm based on free-form deformation (FFD) is implemented
  - 3D space is deformed by 3rd order spline function
  - Correspondences → Grid ICP based

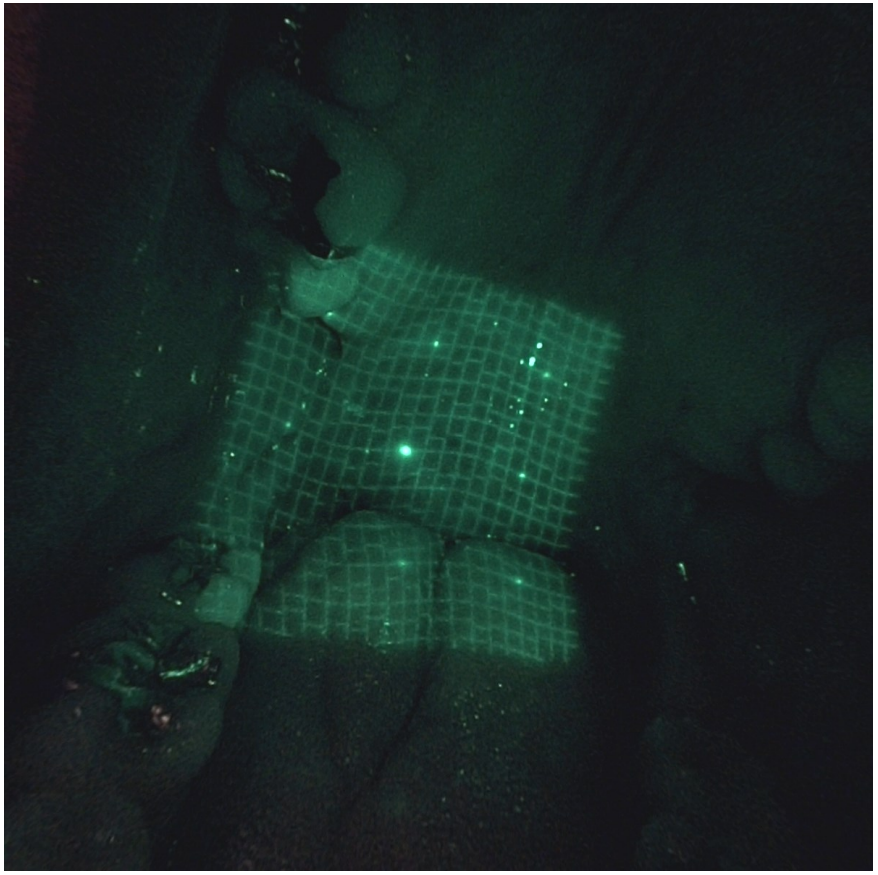


Experiment

- Calibration
- Decoding pattern
- 3D reconstruction
- Grid based non-rigid registration

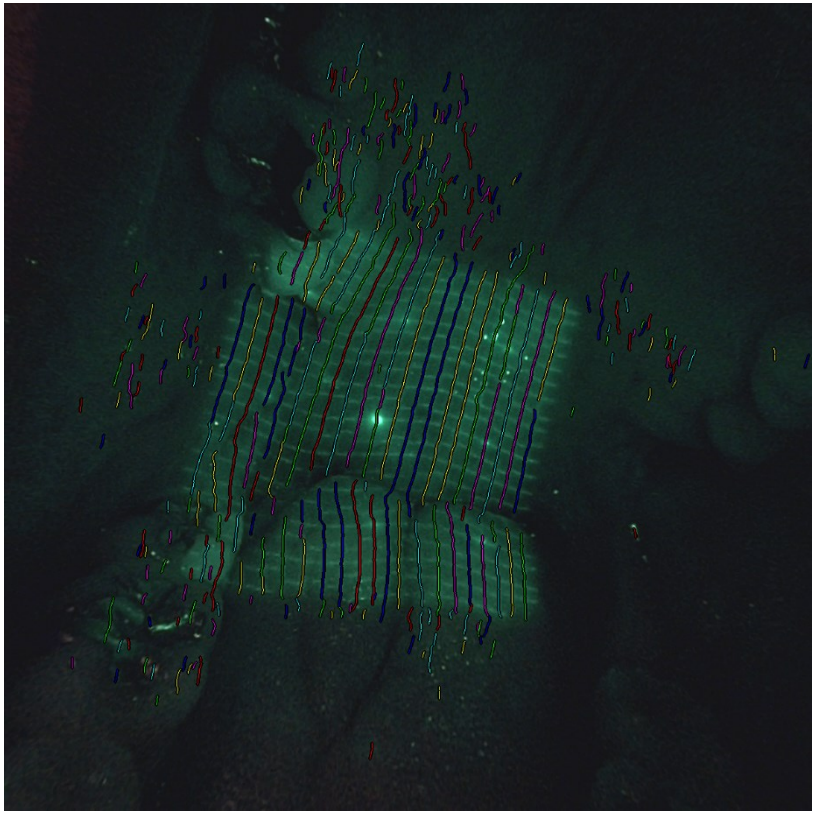
3D Shape reconstruction

- Captured image (after undistortion)

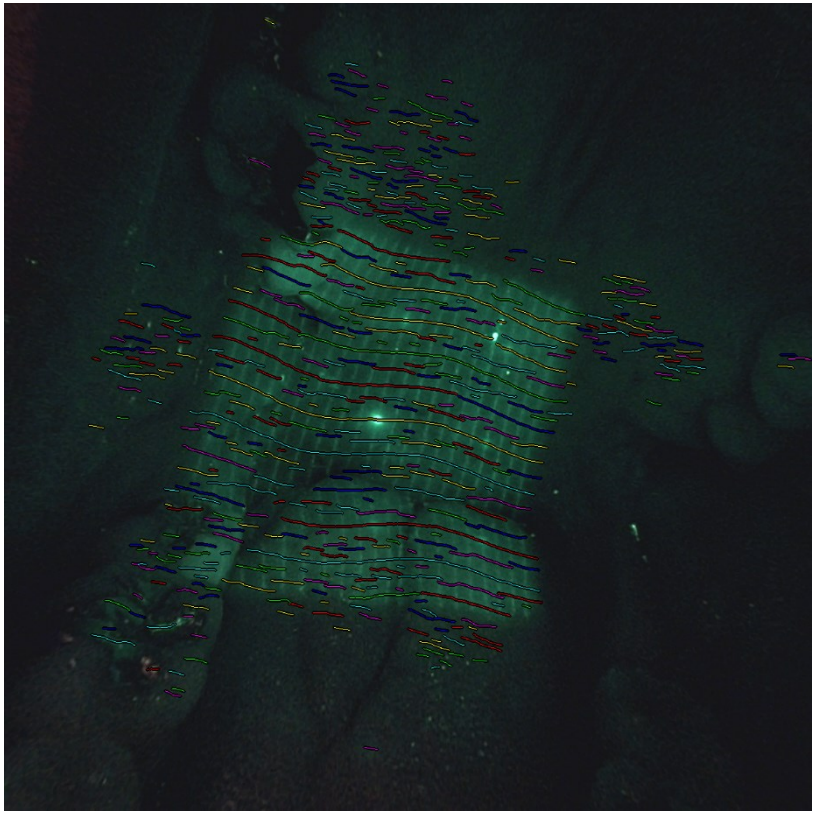


Curve detection

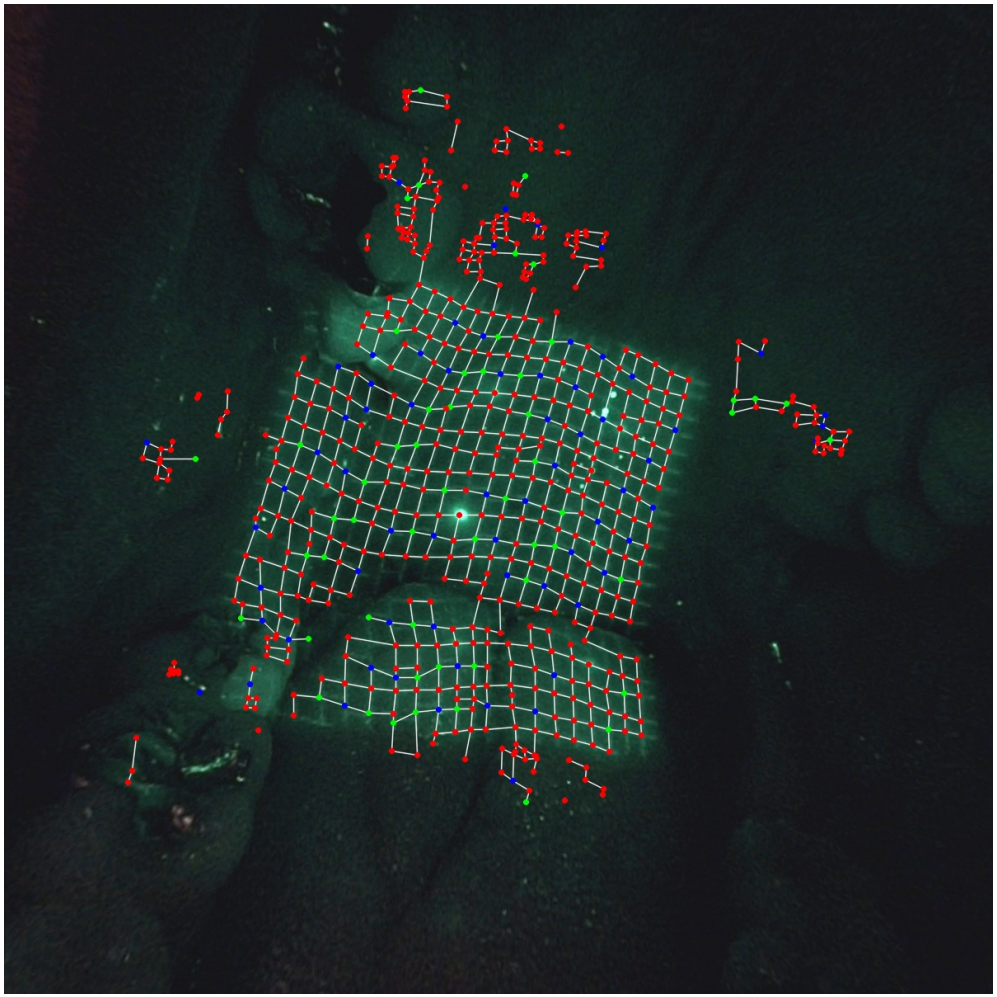
Horizontal direction



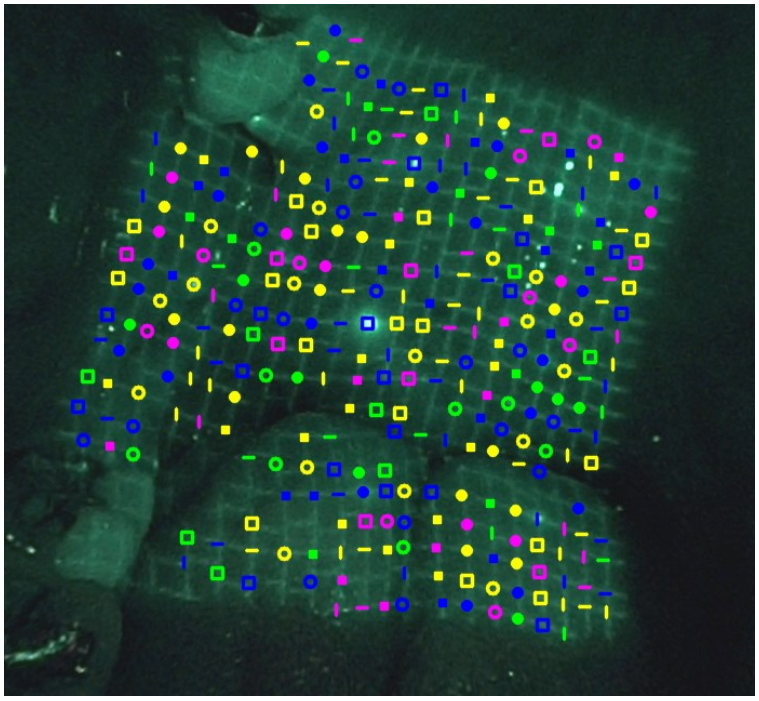
Vertical direction

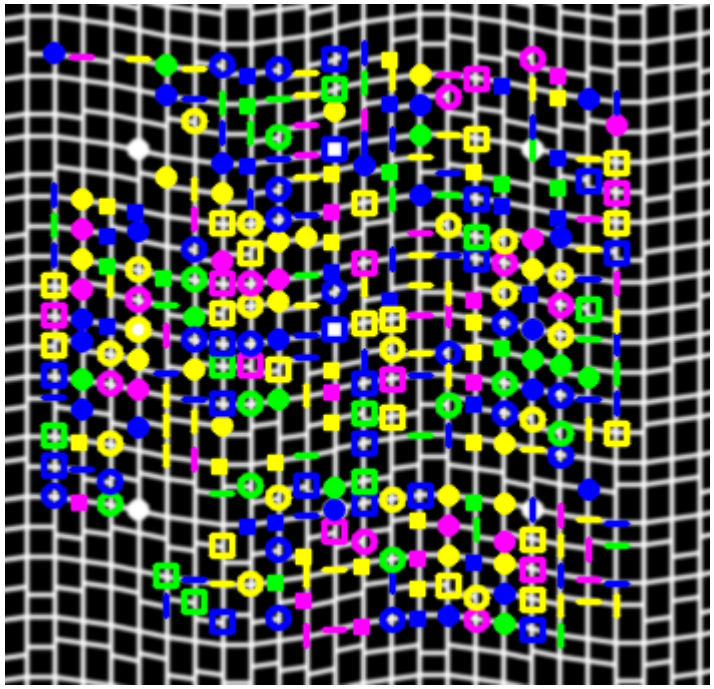


Gap decoding

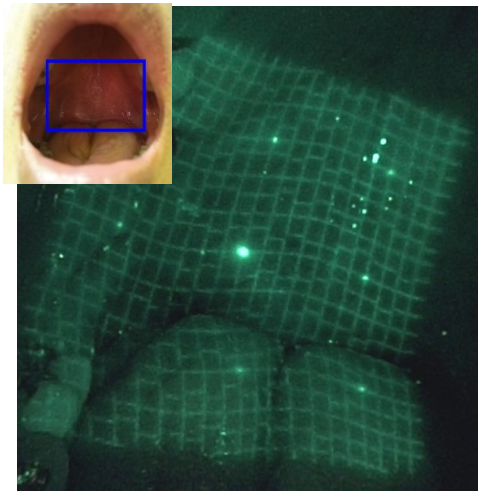


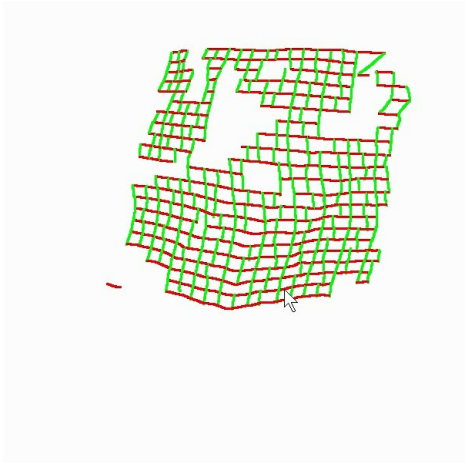
Correspondences

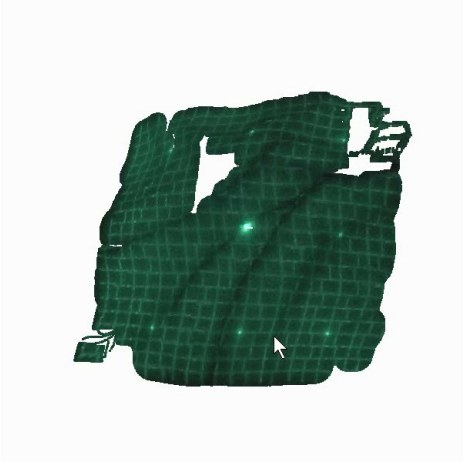


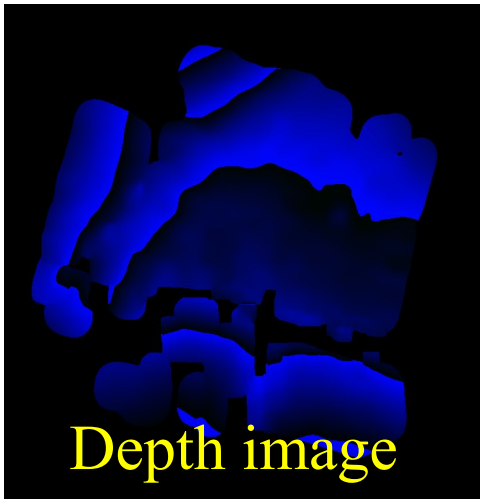


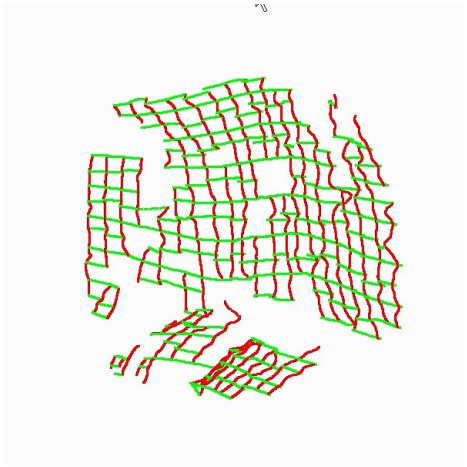
3D reconstruction result



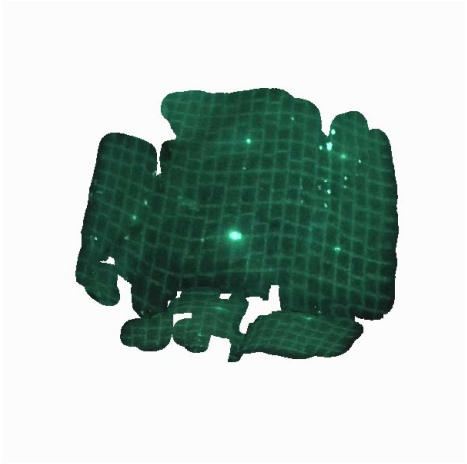






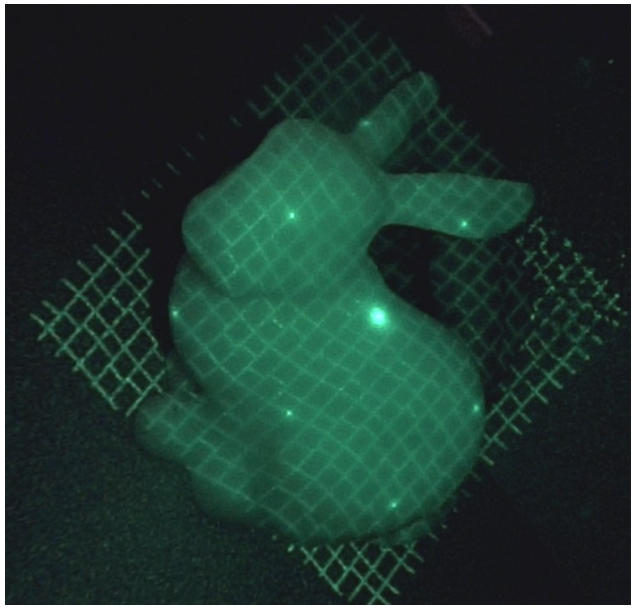


Grid lines

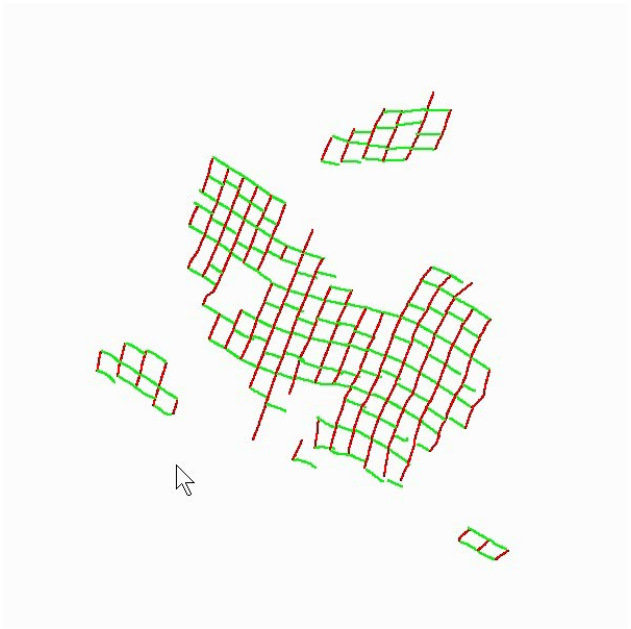


Interpolated textured points

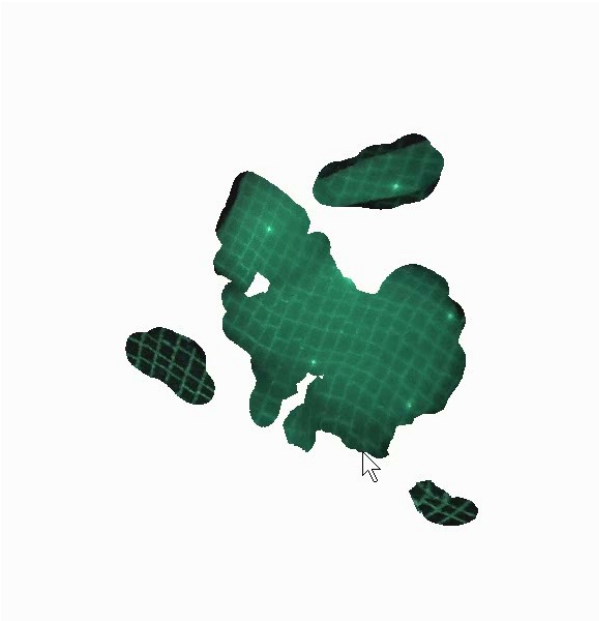
3D reconstruction results



Captured image

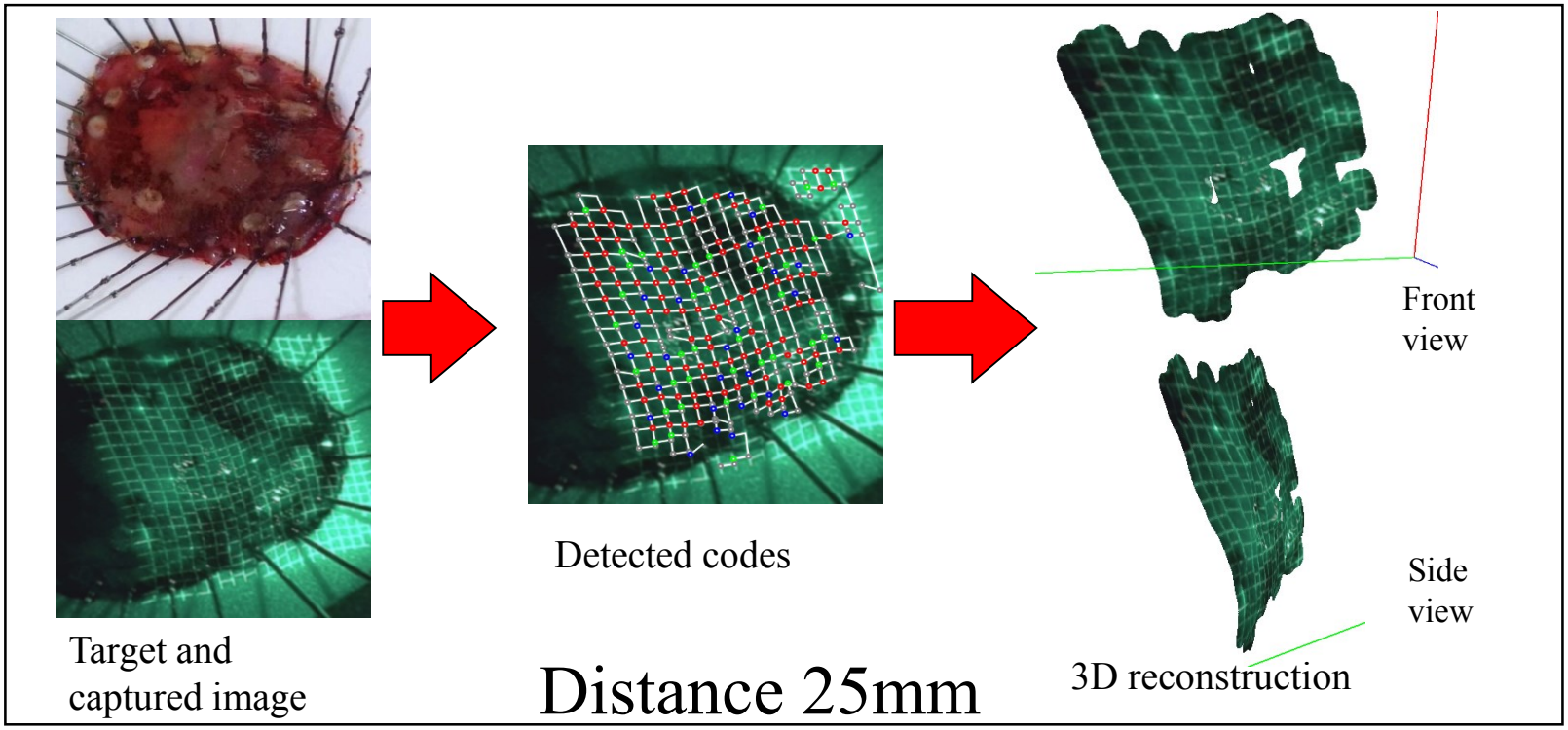


Grid lines



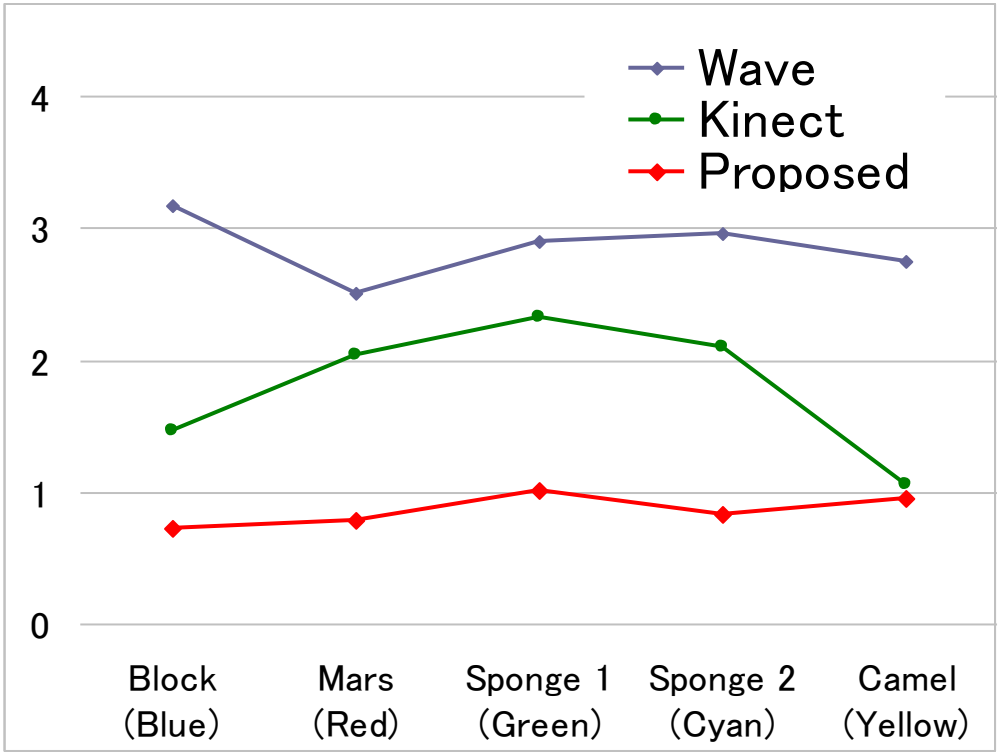
Interpolated textured points

Real endescopic experiment



Evaluation of gap coded pattern

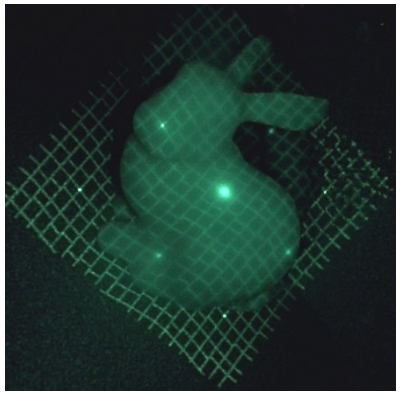
- Comparison with existing methods
  - Distance 1m from projector camera system

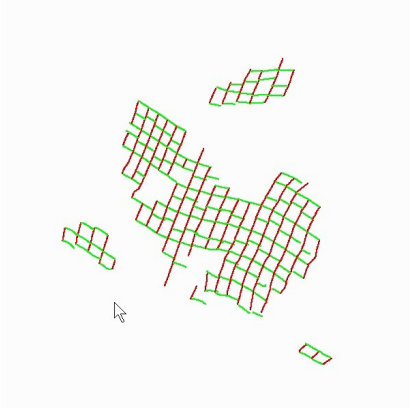


Experiment

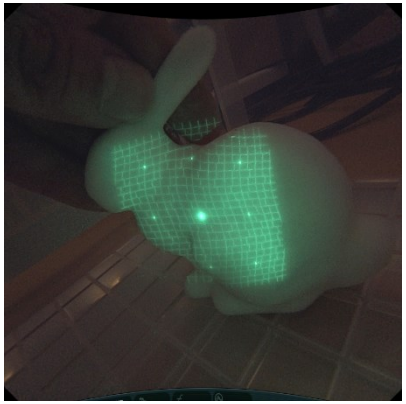
- Calibration
- Decoding pattern
- 3D reconstruction
- Grid based registration
  - Rigid & non-rigid

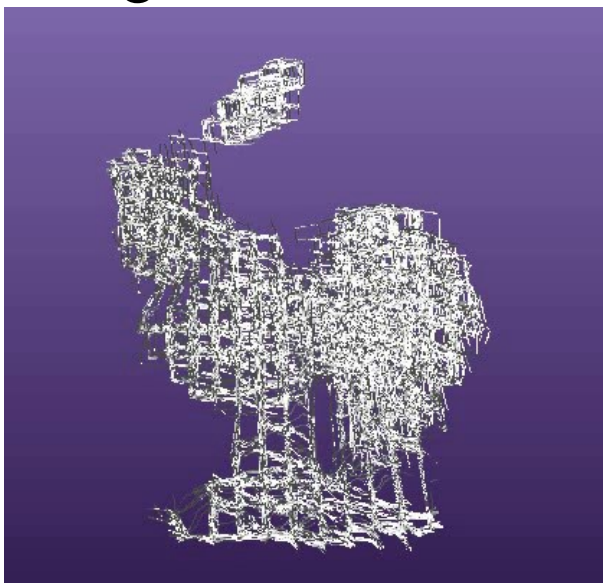
SLAM on bunny data



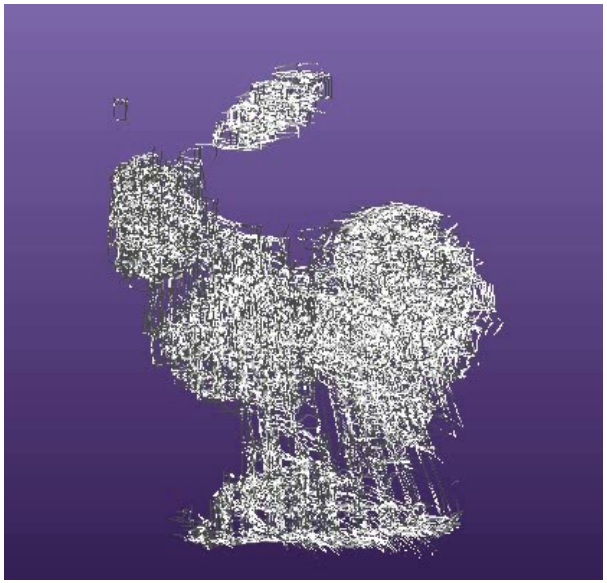


Original reconst of 1 frame



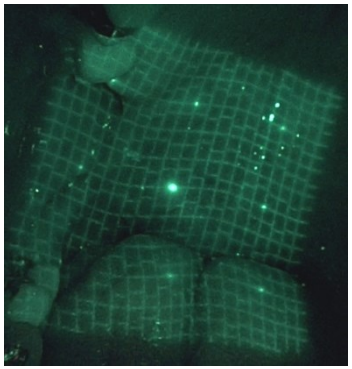


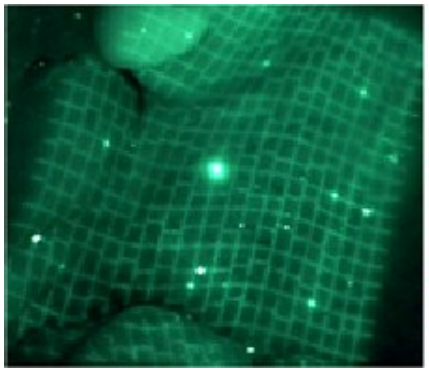
Common ICP result

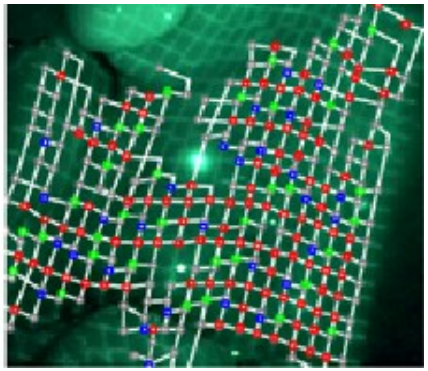


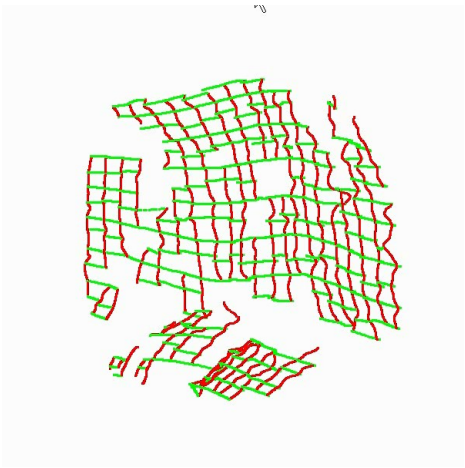
Grid ICP result

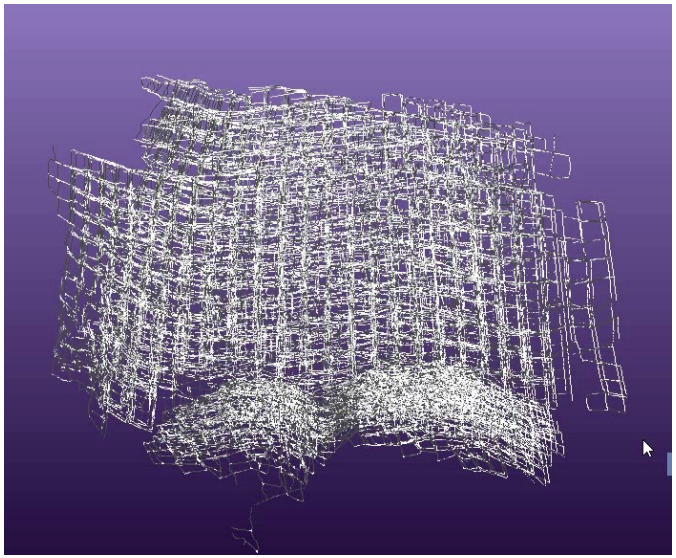
SLAM on mouth data

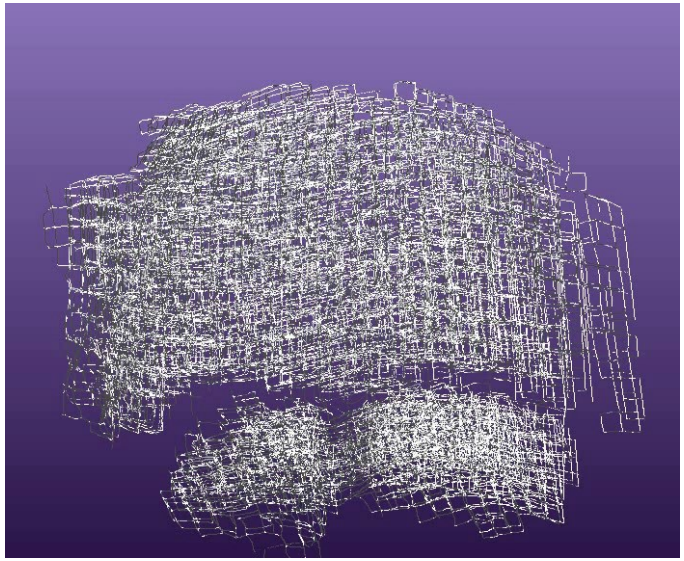










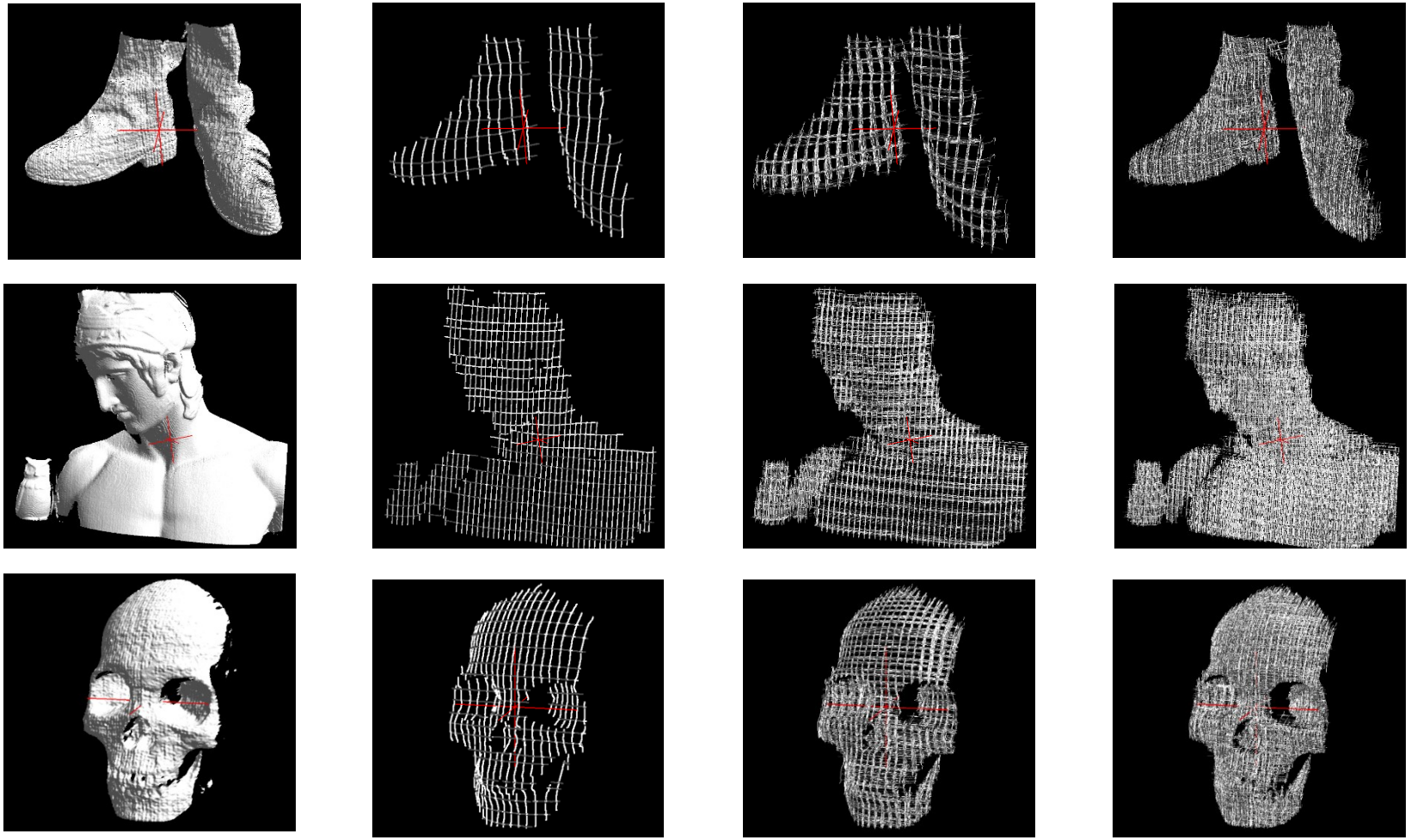


1 frame reconst.

Common ICP result

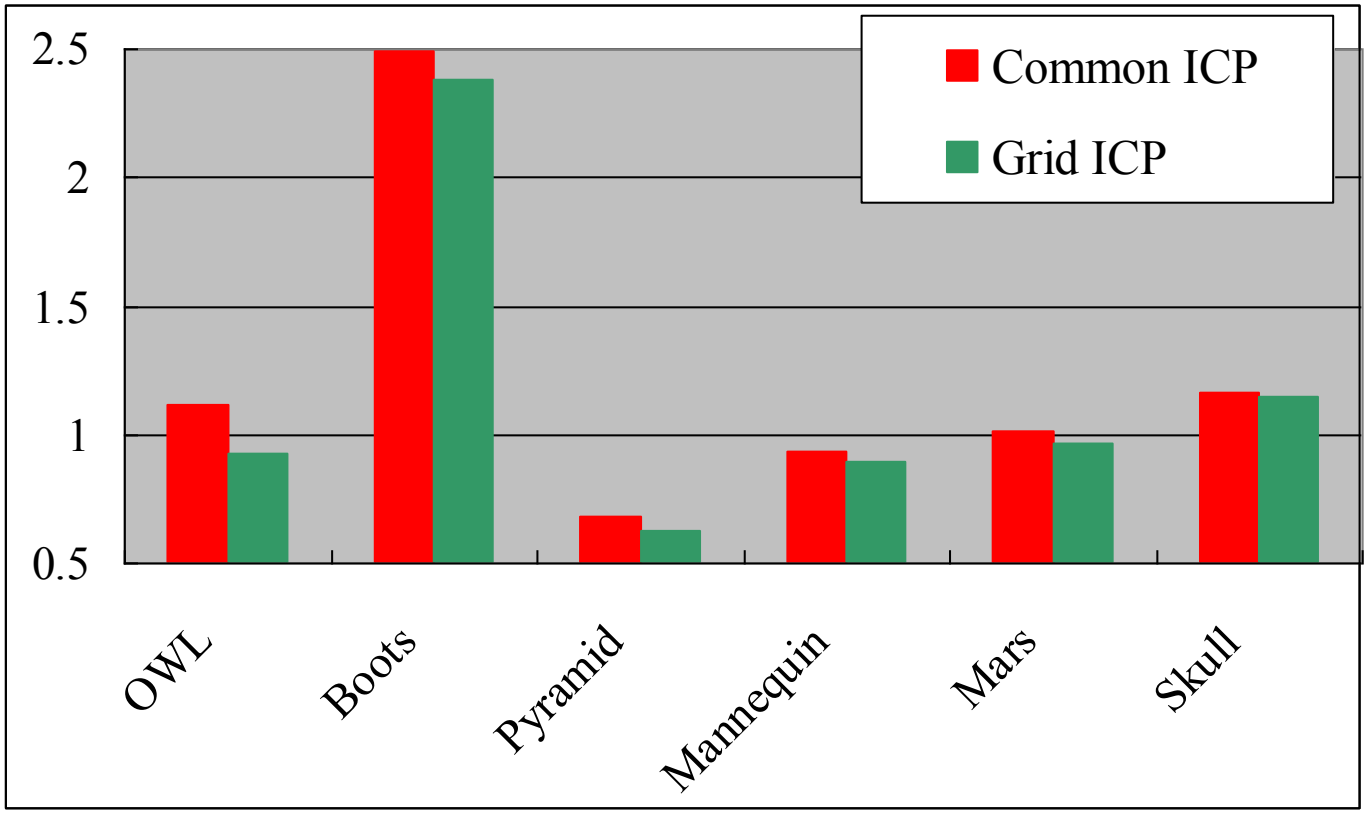
Grid ICP result

Evaluation on rigid registration



Ground truth | 1 Frame | Multi-frames (ICP registered) | Multi-frames (proposed)

Evaluation on rigid registration



Conclusion

- Issues for endoscopic 3D scanning system
  - Subsurface scattering
  - Sparse and small areal reconstruction
- New pattern designed for strong blur and specularity
  - Gap coding (relative positional information)
- SLAM for grid shapes
  - Selective correspondence finding scheme
  - Rigid and non-rigid registration implemented

Thanks

Please come to my poster!