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# A Two-View based Multilayer Feature Graph for Robot Navigation

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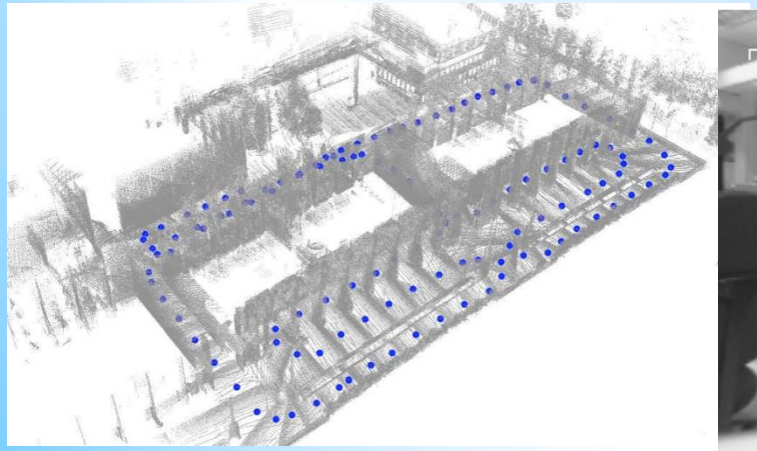
# Motivation & Introduction

- **Landmarks** for Robot Navigation
  - Artificial Landmark

    Bar codes, Colored geometric figures like squares or circles, etc.
  - Natural Landmark

Point Cloud

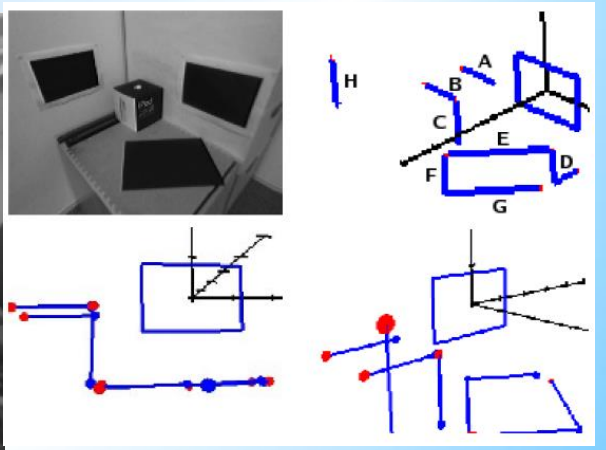


R. Valencia et al, 2009

Salient Points (SIFT)

S. Se et al, 2001

Line Segments

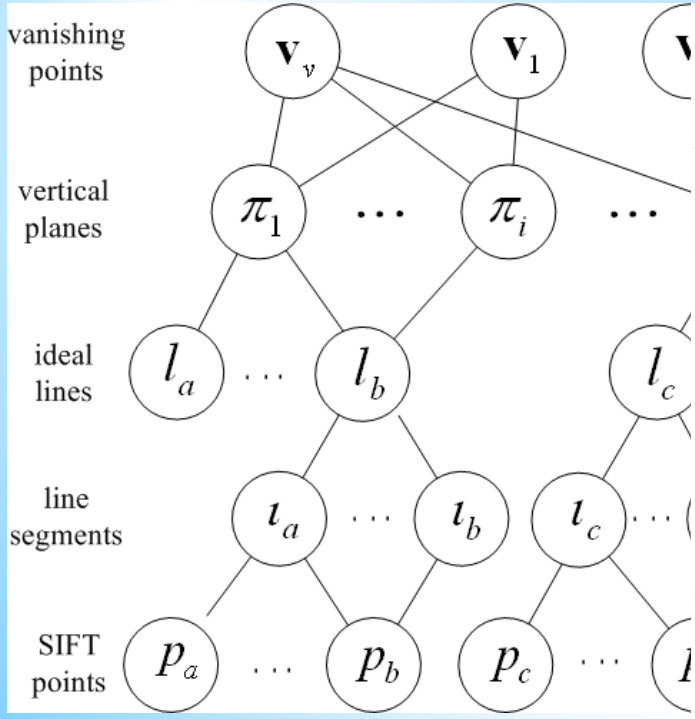



A. Gee and Mayol-Cuevas, 2006

# Motivation & Introduction

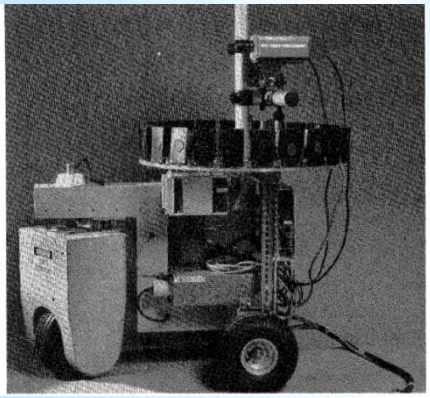
## Our Approach

- Data structure – Multilayer Feature Graph (MFG)
- Method – Feature fusion



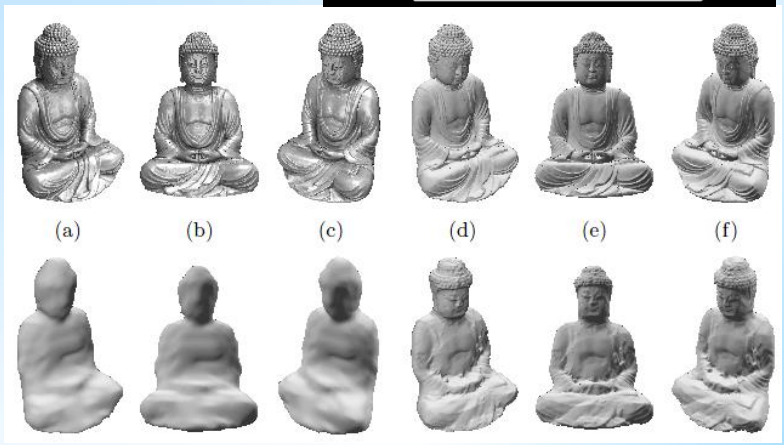

# Related Work

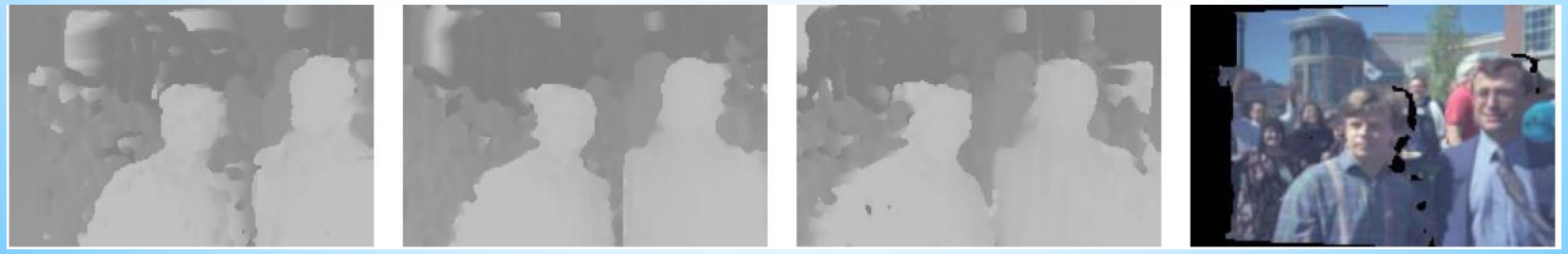
- **Navigation Sensors**
  - Sonar arrays
    - Elfes, 1987
  - Laser range finder
    - Diosi and Kleeman, 2005
    - Nguyen et al, 2006
  - Depth (RGB-D) camera
    - Henry et al, 2010
  - Regular camera
    - Eade et al, 2006
    - Choi et al, 2008
  - Combinations
    - Chen et al, 2004



# Related Work

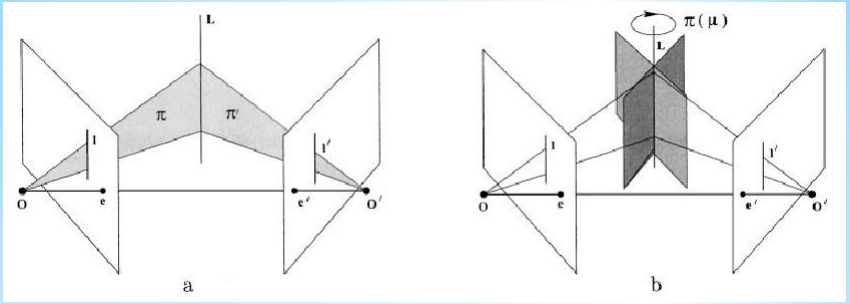
- **3D Reconstruction**
  - Voxels
    - Eisert et al, 1999
  - Level-sets
    - Jin et al, 2005
    - Pons et al, 2005
  - Polygon mesh
    - Yu et al, 2007
  - Multiple depth maps
    - Szeliski, 1999

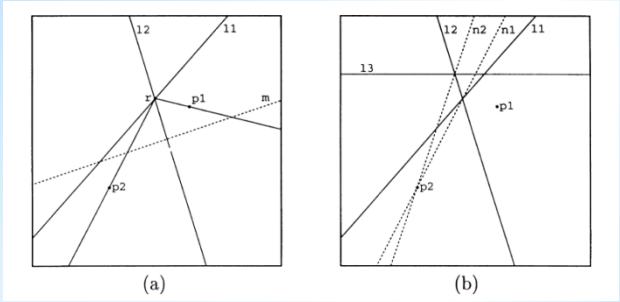


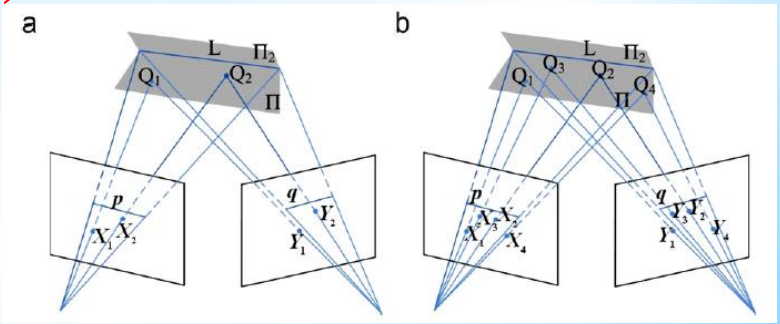



# Related Work

- **Line Segment Matching**
  - Epipolar constraint
    - Schimid and Zisserman, 2000
  - Color based method
    - Guerrero and Sagues, 2003
    - Wang et al, 2009
  - Grouping based methods
    - Lourakis et al, 2000
  - Point based line matching (PBLM)
    - Fan et al, 2010

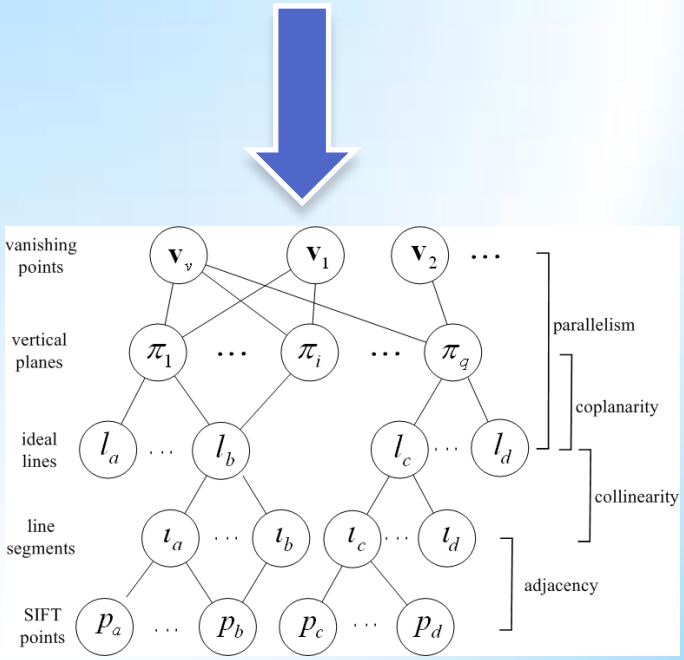


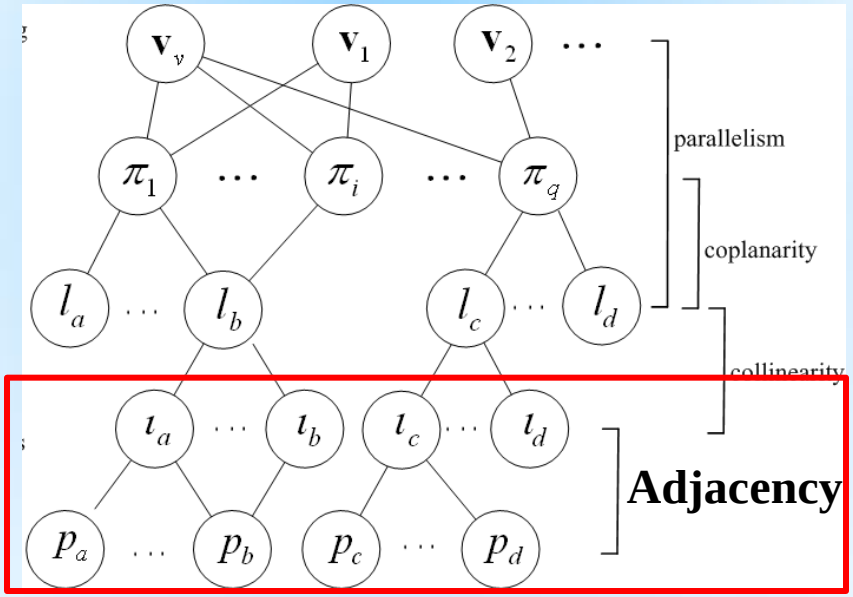



# Problem Description

- **Assumptions**
  - Rectilinear environments
  - Gravity sensor
  - Calibrated camera
- **Input:** Two views
- **Output:** Multilayer Feature Graph



# MFG Layer 1&2: Raw Features



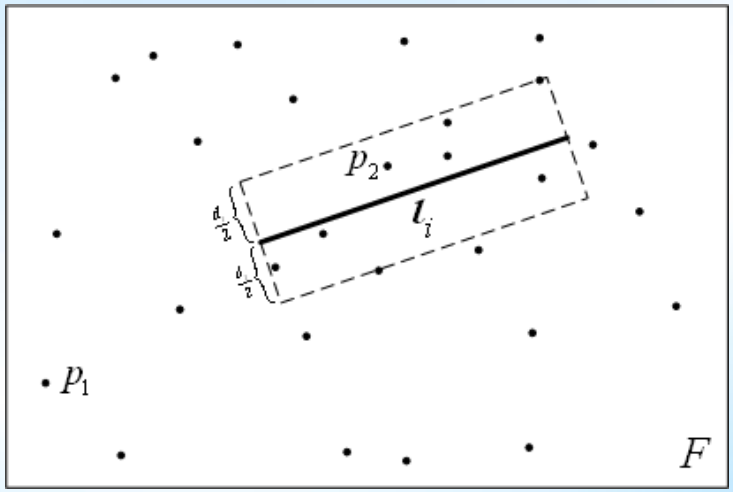

**Layer 2 – Line segments**

**Layer 1 – Key points**

**LSD** (von Gioi et al, 2010)

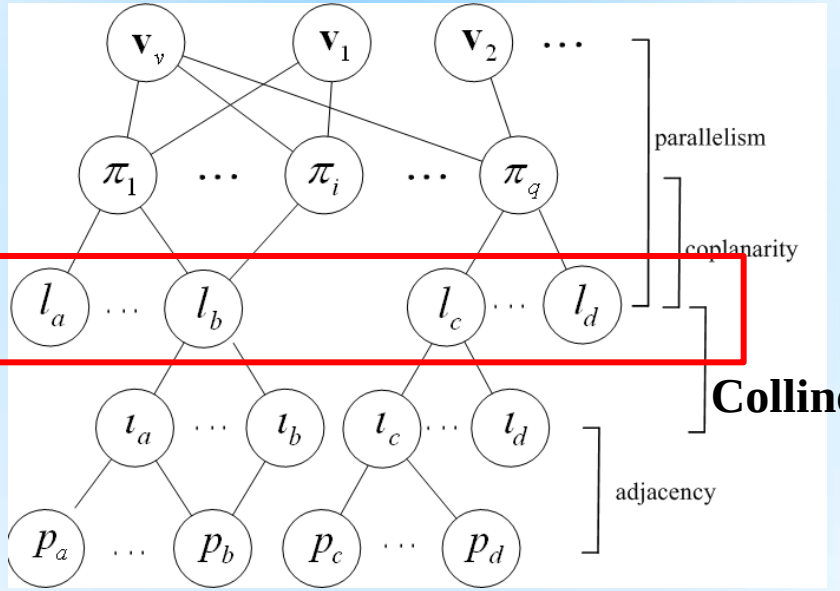
**SIFT** (Lowe, 1999)

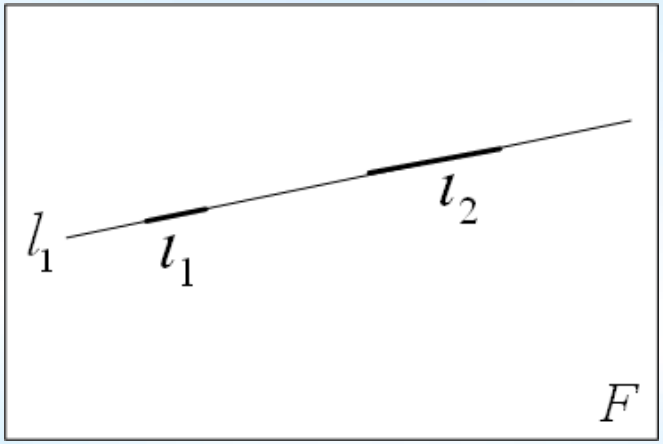
$$p_2 \in Ne(\iota_i),\ p_1 \notin Ne(\iota_i)$$



# MFG Layer 3: Ideal Lines

**Layer 3 – Ideal lines**

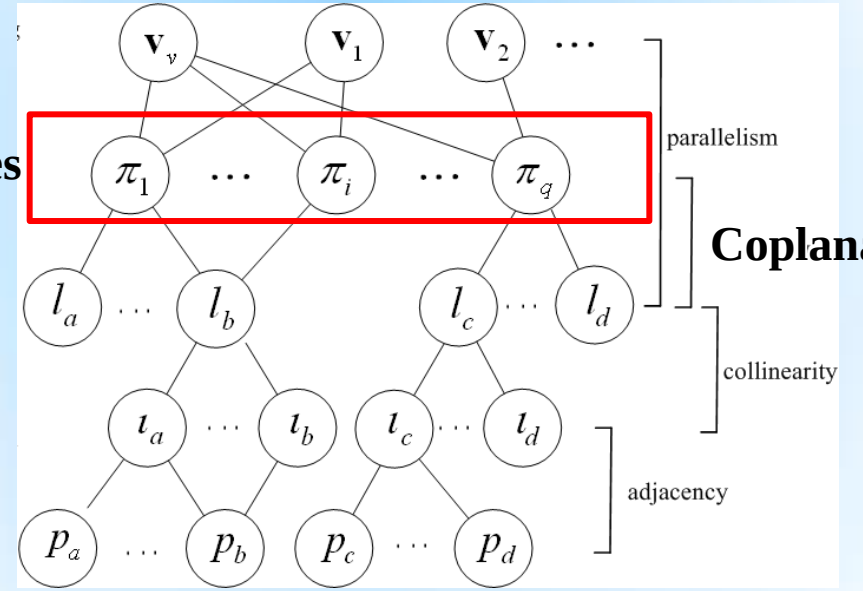


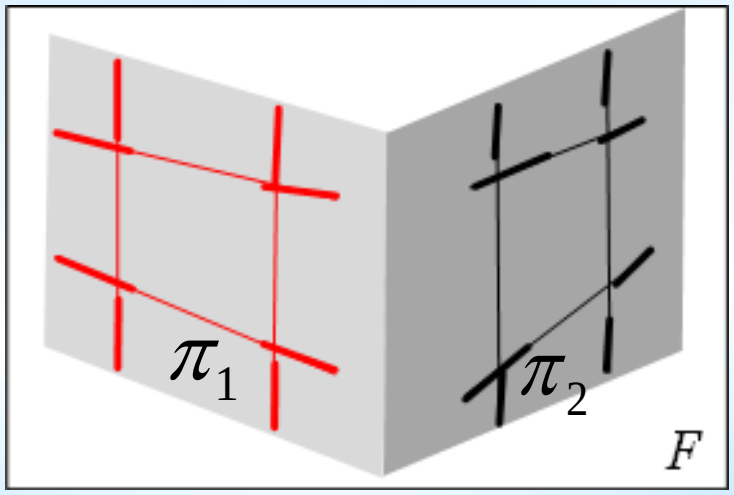

$\iota_1 \in l_1, \iota_2 \in l_1$

# MFG Layer 4: Vertical Planes

**Layer 4 – Vertical Planes**

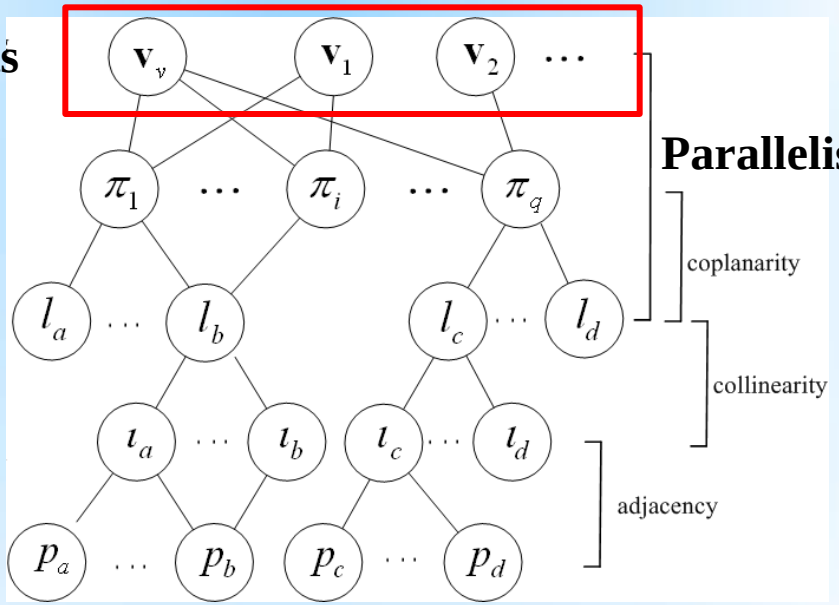


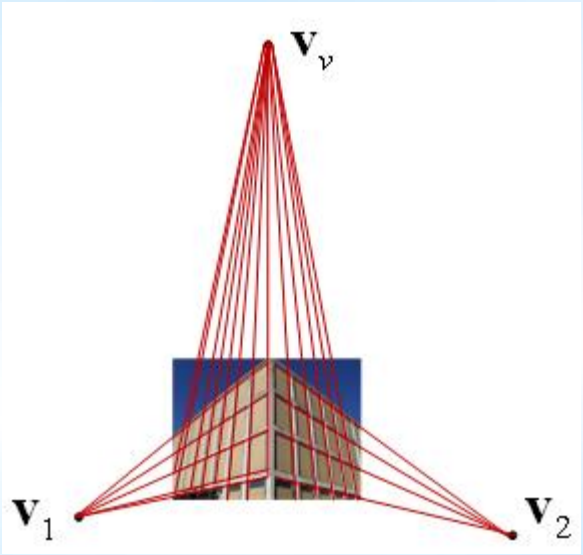

**Coplanarity**



# MFG Layer 5: Vanishing Points

**Layer 5 – Vanishing Points**

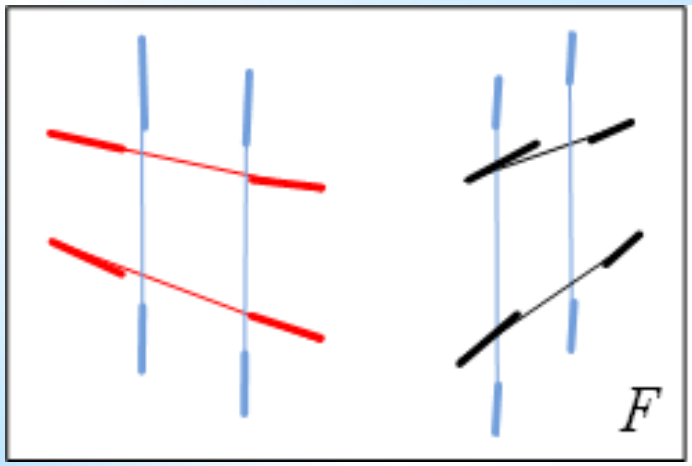


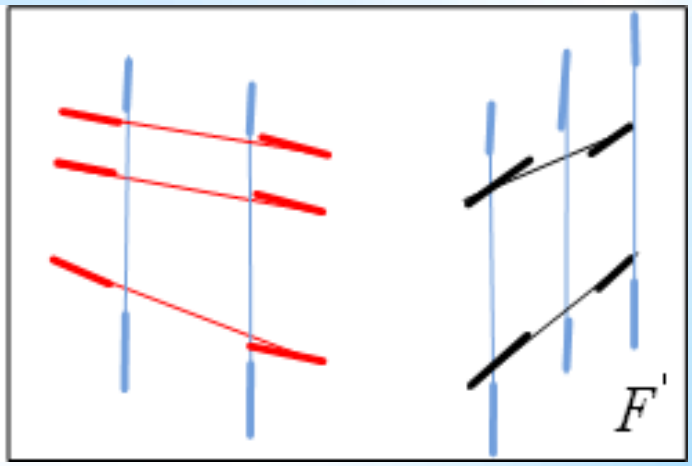



# MFG Construction

## ◆ Parallelism Verification

- ➢ Vanishing point estimation
- ➢ Ideal line estimation
- ➢ Vanishing point matching

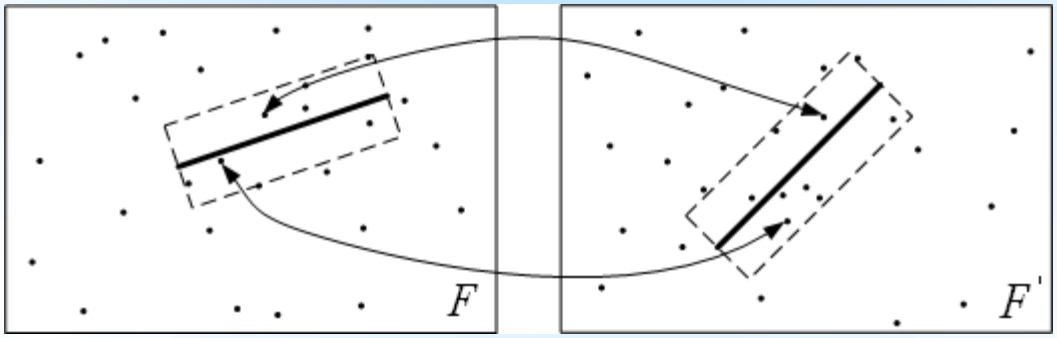


# MFG Construction (cont'd)

## ◆ Collinearity Verification

- ➢ Key point correspondences
- ➢ Point-based line matching (PBLM)

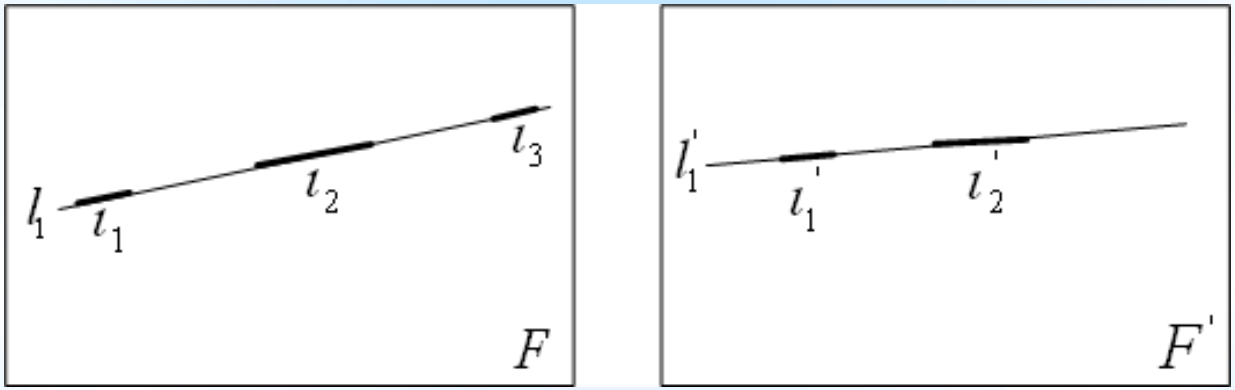



Similarity measurement: For SIFT pair $(p_i, p_i^{'})$, if $p_i \in Ne(\iota_a), p_i^{'} \in Ne(\iota_b^{'})$

then the similarity between $\iota_a$ and $\iota_b^{'}$ increases by 1.

# MFG Construction (cont'd)

- **Collinearity Verification (cont'd)**
  - Ideal line matching by voting
  - Line-guided line segment matching



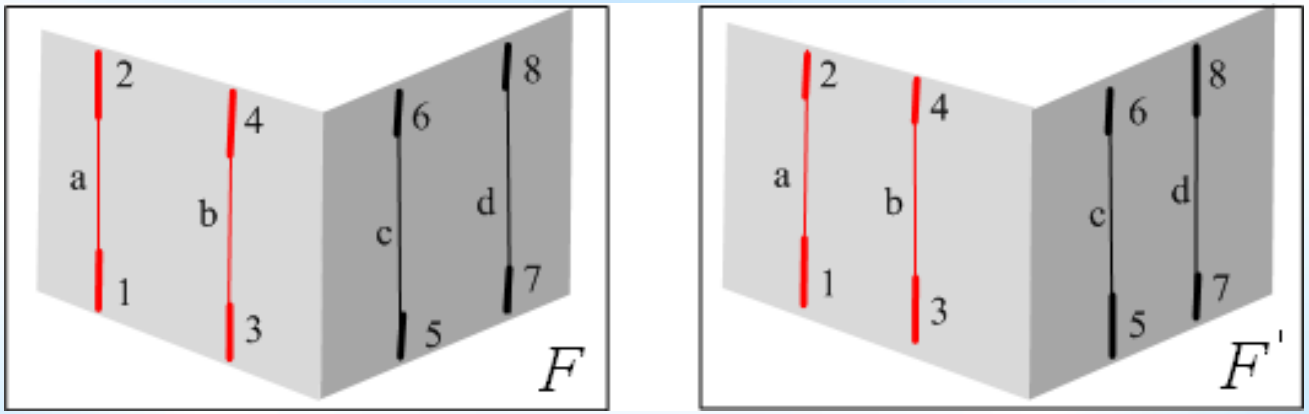

$$(l_1, l_1') \Rightarrow (l_1, l_1') \Rightarrow (l_2, l_2')$$

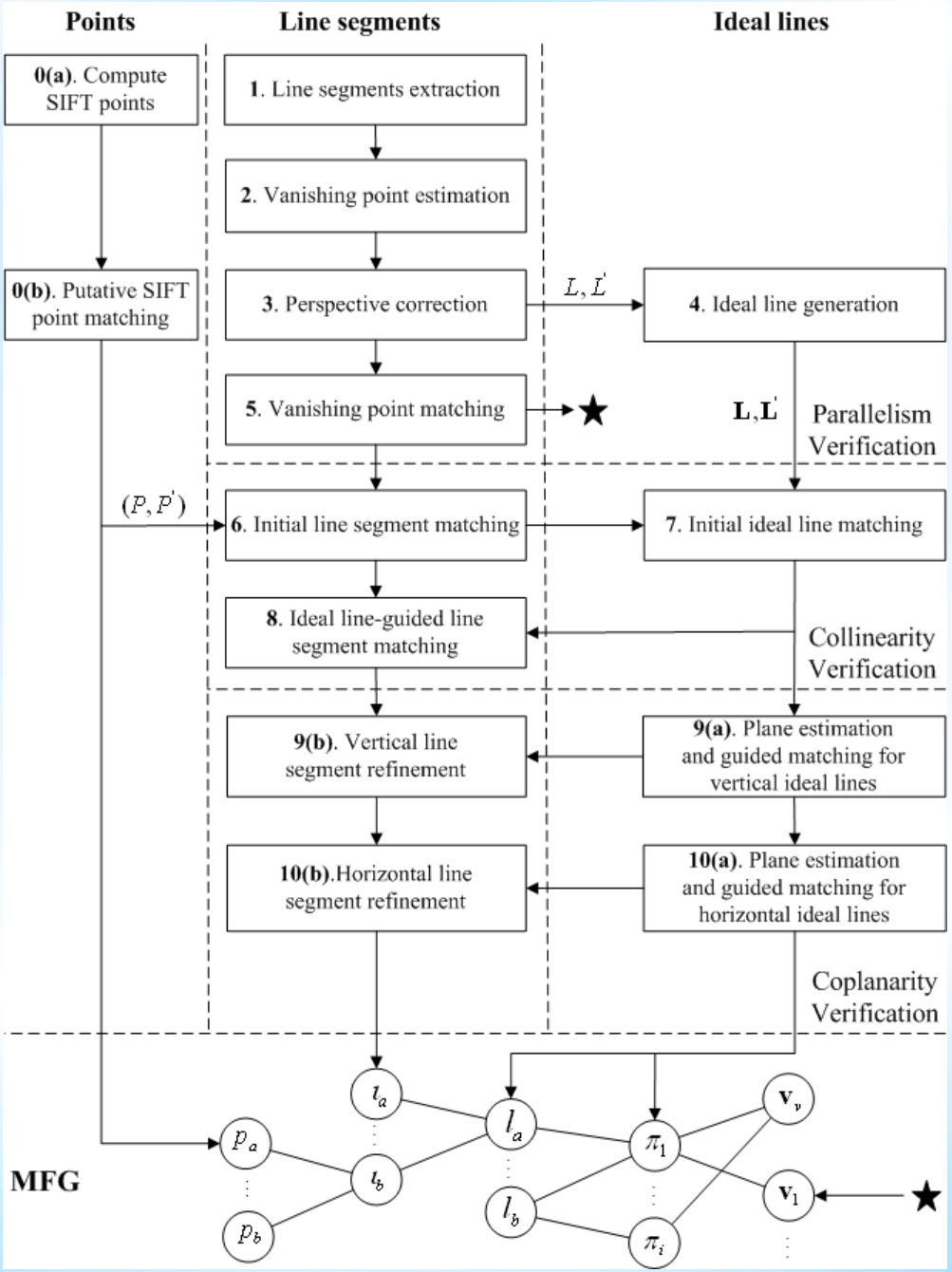
# MFG Construction (cont'd)

- **Coplanarity Verification**

3D Plane $\pi = (\mathbf{n}^T, d)^T$

Line Homography: $l_i = \mathrm{H}^T l_i'$ where $\mathrm{H} = \mathrm{K}(\mathrm{R} - \mathbf{t}\mathbf{n}^T/d)\mathrm{K}^{-1}$




Points
Line segments
Ideal lines
0(a). Compute SIFT points
1. Line segments extraction
2. Vanishing point estimation
0(b). Putative SIFT point matching
3. Perspective correction
L, L'
4. Ideal line generation
5. Vanishing point matching
L,L'
Parallelism Verification
(P, P')
6. Initial line segment matching
7. Initial ideal line matching
8. Ideal line-guided line segment matching
Collinearity Verification
9(b). Vertical line segment refinement
9(a). Plane estimation and guided matching for vertical ideal lines
10(b).Horizontal line segment refinement
10(a). Plane estimation and guided matching for horizontal ideal lines
Coplanarity Verification
MFG

# Experiments

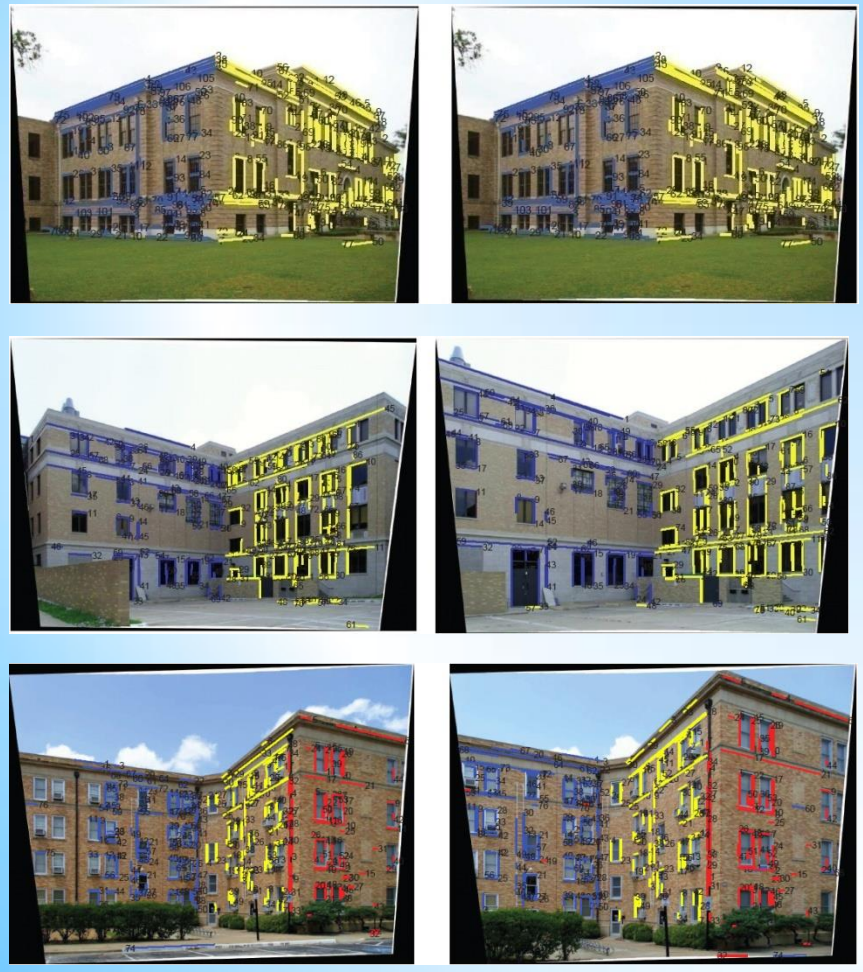
## Experiment setup

Laptop PC, Windows XP, Matlab

## Image data (first view, 640x480)

# Experiments

## Experiment 1: Line Segment Matching



# Experiments

## Experiment 1: Line Segment Matching

| No. | PBLM | | MFG | | TM difference | CR difference |
|---|---|---|---|---|---|---|
| | TM | CR | TM | CR | | |
| 1 | 224 | 93.3% | 297 | 95.6% | 73 | 2.3% |
| 2 | 157 | 94.9% | 289 | 92.0% | 132 | -2.9% |
| 3 | 124 | 92.7% | 178 | 96.2% | 54 | 3.5% |
| 4 | 186 | 93.5% | 282 | 96.1% | 96 | 2.6% |
| 5 | 157 | 93.0% | 274 | 95.3% | 117 | 2.3% |
| 6 | 219 | 93.6% | 302 | 94.0% | 83 | 0.4% |
| 7 | 126 | 94.4% | 189 | 94.7% | 73 | 0.3% |
| 8 | 194 | 92.3% | 314 | 95.5% | 120 | 3.2% |

PBLM : Point based line matching (Fan et al, 2010)

TM : Total matches

CR : Correct ratio

# Experiments

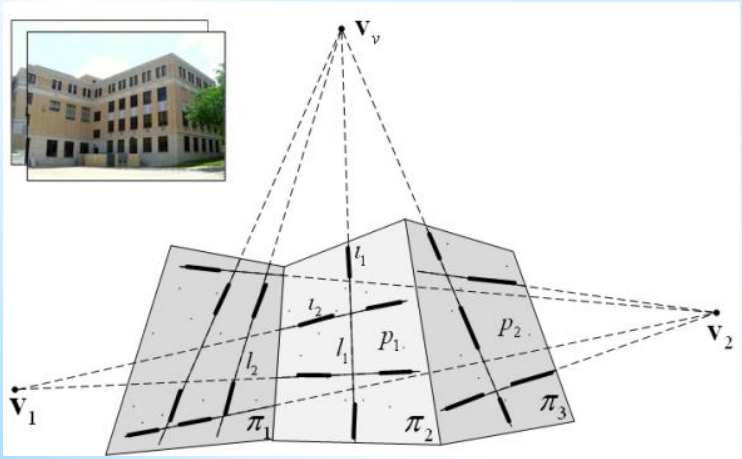
## Experiment 2: Vertical Plane Estimation

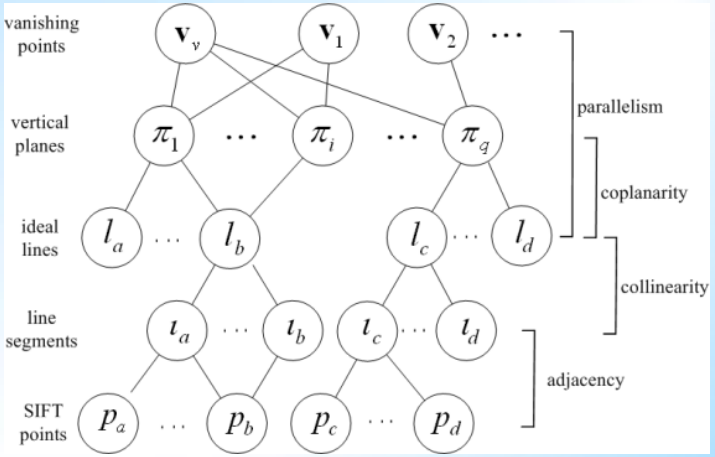
| No. | $\pi_1$ | | $\pi_2$ | | $\pi_3$ | | $\pi_4$ | |
|---|---|---|---|---|---|---|---|---|
| | mean | std. dev. | mean | std. dev. | mean | std. dev. | mean | std. dev. |
| 1 | 2.58 | 0.82 | 4.11 | 1.18 | | | | |
| 2 | 3.33 | 0.48 | 3.16 | 0.88 | | | | |
| 3 | 4.02 | 1.28 | 4.49 | 0.92 | | | | |
| 4 | 4.10 | 1.03 | 4.67 | 0.41 | | | | |
| 5 | 3.43 | 0.14 | 4.43 | 0.28 | 4.37 | 0.28 | | |
| 6 | 5.18 | 0.74 | 4.02 | 0.64 | 2.64 | 0.44 | | |
| 7 | 4.08 | 0.16 | 4.18 | 0.43 | 5.20 | 0.47 | | |
| 8 | 4.88 | 0.29 | 3.00 | 0.48 | 4.41 | 0.15 | 6.01 | 0.26 |

$$\frac{\|\bar{X}_j - \hat{X}_j\|}{\|\bar{X}_j\|}$$

# Conclusions

- A novel multilayer feature graph for robot scene understanding and navigation
- A feature fusion approach for MFG construction
- Robustness and accuracy verified by experiments

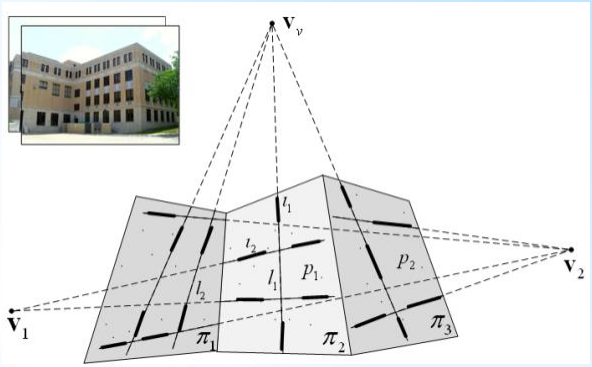


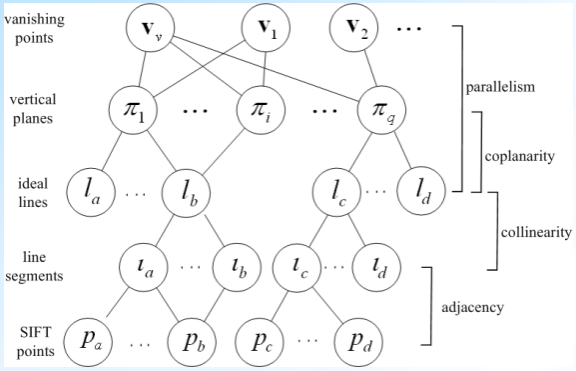



# Future Works

- MFG-based localization
- N-view(N>2) MFG construction
- Computation complexity analysis and efficient data structure development
- Distributed and parallel implementation
- Consider horizontal plane (ground plane)

# Thank You ! Q&A

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**IRAIS, Nankai University** http://robot.nankai.edu.cn