Master in Computer Vision *Barcelona*

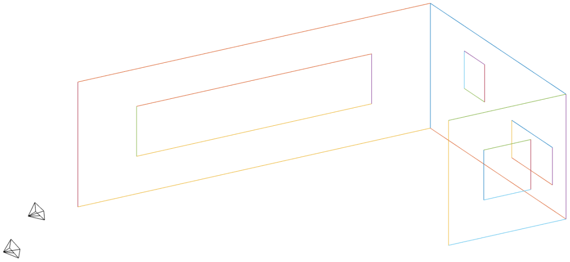
Module: 3D Vision
Project: 3D recovery of urban scenes
Session 5

Gloria Haro

Session 5

Goal: Reconstruction from uncalibrated images with a stratified method (recovery of camera matrices and a sparse set of 3D points)

Synthetic data



Projection of corner points in both images → 2D-2D correspondences

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Goal: Reconstruction from uncalibrated images with a stratified method (recovery of camera matrices and a sparse set of 3D points)

Real data

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Mandatory tasks:

- **Projective reconstruction** (synthetic and real data)
  Factorization method for projective reconstruction
  Compare two different initializations for λ_j^i:
  - $\lambda_j^i = 1$ for all i, j
  - Initialization proposed by [Sturm and Triggs 1996]:
    $\lambda_j^i = \frac{(x_j^1)^T F_{i1}(e \times x_j^i)}{||e \times x_j^i||^2} \lambda_j^1$ with $\lambda_j^1 = 1$
    (the epipolar line of x_j^1 in image i is the line through the corresponding point x_j^i and the epipole e)

  Compare the reprojection error in both cases
- **Affine and metric reconstruction** (synthetic data)
- Projective reconstruction (real data)
- Affine and metric reconstruction (real data)

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Optional tasks:

- Projective recons. from two views (P, P' from F)
- Projective recons. from more than two views (add a 3rd view)
- Any other improvement you may icorporate (add a 4th view, incorporate new 3D points by triangulation, incorporate new views by resectioning, any processing of the point cloud, ...)

Auto-calibration

$$H_{e\leftarrow p} = \underbrace{\begin{pmatrix} K & \mathbf{0} \\ \mathbf{0}^T & 1 \end{pmatrix}}_{H_{e\leftarrow a}} \underbrace{\begin{pmatrix} I & \mathbf{0} \\ \mathbf{p}^T & 1 \end{pmatrix}}_{H_{a\leftarrow p}}$$

- $H_{a\leftarrow p}$ permits to upgrade the projective recons. into an affine one **Affine reconstruction**
  By applying $H_{a\leftarrow p}$ we will map $\mathbf{p}$ to $\Pi_\infty = (0,0,0,1)^T$ and we will recover te paralellism.
- $H_{e\leftarrow a}$ permits to upgrade the affine recons. into a metric one **Metric reconstruction**

Metric reconstruction

The key to metric reconstruction is to find the image of the absolute conic in one of the images $\omega = K^{-T}K^{-1}$

Metric reconstruction

The key to metric reconstruction is to find the image of the absolute conic in one of the images $\omega = K^{-T}K^{-1}$

Suppose that the image of the absolute conic is known in some image to be ω, and one has an affine recons. in which the corresponding camera matrix is given by $P = [M|m]$. Then, the affine recons. may be transformed to a metric recons. by applying a 3D transformation of the form:

$$H_{e \leftarrow a} = \begin{pmatrix} A^{-1} & \mathbf{0} \\ \mathbf{0}^T & 1 \end{pmatrix}$$

where A is obtained by Cholesky factorization: $AA^T = (M^T \omega M)^{-1}$

Metric reconstruction

The approach relies on identiying ω. There are various ways of doing this.

There are different kinds of constraints on ω:

- Constraints coming from scene orthogonality.
- Constraints coming from known internal parameters.
- Constraints arising from the same cameras (same matrix K) in all images.

Typically, a combination of these constraints is used.

Metric reconstruction

Constraints coming from scene orthogonality

If $\mathbf{v}_1$ and $\mathbf{v}_2$ is a pair of vanishing points arising from orthogonal scene lines, then we have a linear constraint on ω:

$$\mathbf{v}_1^T \omega \mathbf{v}_2 = 0$$

Metric reconstruction

Constraints coming from known internal parameters

Since

$$\omega = K^{-T}K^{-1} = \begin{pmatrix} \omega_{11} & \omega_{12} & \omega_{13} \\ \omega_{12} & \omega_{22} & \omega_{23} \\ \omega_{13} & \omega_{23} & \omega_{33} \end{pmatrix}$$

knowledge about some restrictions on the internal parameters contained in K may be used to constraint or determine the elements of ω.

Metric reconstruction

Constraints coming from known internal parameters

Since

$$\omega = K^{-T}K^{-1} = \begin{pmatrix} \omega_{11} & \omega_{12} & \omega_{13} \\ \omega_{12} & \omega_{22} & \omega_{23} \\ \omega_{13} & \omega_{23} & \omega_{33} \end{pmatrix}$$

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If we assume the camera has zero skew, then $\omega_{12} = 0$.

Metric reconstruction

Constraints coming from known internal parameters

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$$\omega = K^{-T}K^{-1} = \begin{pmatrix} \omega_{11} & \omega_{12} & \omega_{13} \\ \omega_{12} & \omega_{22} & \omega_{23} \\ \omega_{13} & \omega_{23} & \omega_{33} \end{pmatrix}$$

knowledge about some restrictions on the internal parameters contained in K may be used to constraint or determine the elements of ω.

If we assume the camera has zero skew, then $\omega_{12} = 0$.

If the pixels are square, that is, zero skew and $\alpha_x = \alpha_y$, then: $\omega_{11} = \omega_{22}$.

Metric reconstruction

Combination of the previous constraints

Five constraints on ω:

$$\mathbf{u}^T \omega \mathbf{v} = 0$$

$$\mathbf{u}^T \omega \mathbf{z} = 0$$

$$\mathbf{v}^T \omega \mathbf{z} = 0$$

$$\omega_{11} = \omega_{22}$$

$$\omega_{12} = 0$$

In matrix form: $A\omega_V = \mathbf{0}$,
where $\omega_V = (\omega_{11}, \omega_{12}, \omega_{13}, \omega_{22}, \omega_{23}, \omega_{33})^T$

$$A = \begin{pmatrix} u_1 v_1 & u_1 v_2 + u_2 v_1 & u_1 v_3 + u_3 v_1 & u_2 v_2 & u_2 v_3 + u_3 v_2 & u_3 v_3 \\ u_1 z_1 & u_1 z_2 + u_2 z_1 & u_1 z_3 + u_3 z_1 & u_2 z_2 & u_2 z_3 + u_3 z_2 & u_3 z_3 \\ v_1 z_1 & v_1 z_2 + v_2 z_1 & v_1 z_3 + v_3 z_1 & v_2 z_2 & v_2 z_3 + v_3 z_2 & v_3 z_3 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & -1 & 0 & 0 \end{pmatrix}$$

The solution ω_V is the null vector of A.

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Projective reconstruction: Particular case of 2 views

If we estimate F we can extract two possible camera matrices:

$$P = [I \mid 0]$$
$$P' = [SF \mid e']$$

where S is any skew-symmetric matrix (such that P' has rank 3).
A good choice is: $S = [e']_x$.
The epipole may be computed from $e'^T F = 0$

Session 5

Language: MATLAB

Provided functions: lab5.m, euclid.m, homog.m, fundamental_matrix.m, ransac_fundamental_matrix.m, triangulate.m, normalise2dpts.m

lab5.m is the guided file with the different steps of the lab session.

triangulate.m is part of the solution of lab 4.

To Do:

- Complete the code in lab5.m as indicated in the same file (create the functions you may need)
- In the report, comment the results of the different initializations in the projective reconstruction

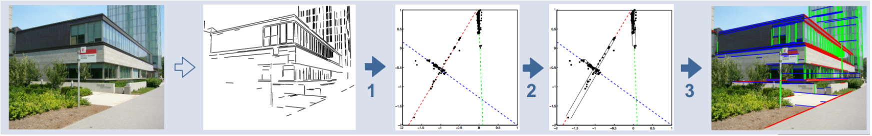
Session 5

Vanishing point computation:

2014 IEEE Conference on Computer Vision and Pattern Recognition

Finding Vanishing Points via Point Alignments in Image Primal and Dual Domains

José Lezama[*†], Rafael Grompone von Gioi[*], Gregory Randall[†], Jean-Michel Morel[*]
[*]CMLA, ENS Cachan, France, [†]IIE, Universidad de la República, Uruguay
{lezama, grompone, morel}@cmla.ens-cachan.fr, randall@fing.edu.uy



http://dev.ipol.im/~jlezama/vanishing_points/

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Vanishing point computation:

Evaluation

Grading:

- Report **1.5 points**
- Projective recons. (synthetic data): **3.5 points**
- Affine recons. (synthetic data): **1.25 points**
- Metric recons. (synthetic data): **1.25 point**
- Projective recons. (real data): **1 point**
- Affine recons (real data): **1 point**
- Metric recons (real data): **0.5 points**
- Optional P, P' from F: **+0.25 points**
- Optional add a 3rd view: **+1 point**
- Free optionals: **up to 2 extra points**

Evaluation

To deliver **January 31, before 9am**:

- **Code deliverable:**
  - READY TO BE LAUNCHED on the provided images
- **Short document (around 10 pages):**
  - Results
  - Problems, comments and conclusions

To deliver **February 1, before 1pm**:

- **Final presentation (10 min):**
  - Present an overview/synthesis of all the lab sessions, link the different labs, and comment the results and methods you find more interesting.

Reminder:

- February 1 (project presentation) at 52.329, from 16h to 19h
- February 15 (exam) at 52.119, from 16h to 18h