Master in Computer Vision | Barcelona

Module: 3D Vision
Project: Structure from Motion

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Goal

Reconstruction from uncalibrated images with a stratified method, by designing and applying a Structure from Motion (SfM) pipeline in order to achieve a 3D reconstruction.

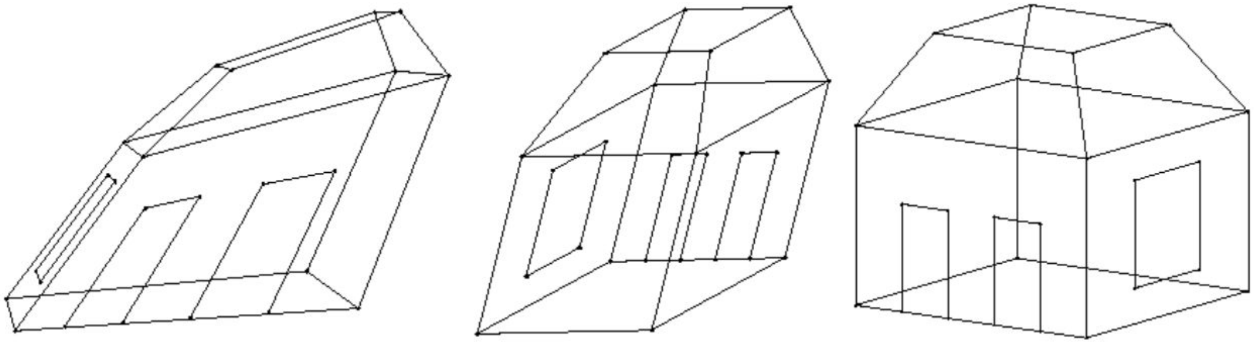
Mandatory Tasks:

- Computation of Projective cameras (for the case n=2) 1.0
- Affine and Metric rectification.. 4.0
  - Homography estimation
- Estimation of reprojection error 1.0
- Bundle Adjustment.. 1.0
  - Intrinsic parameter factorization
  - Construction and understanding of optimization formulation....... 1.0
    - Sparse Jacobian
    - Non-Linear problem
- Report 3.0

Optional Tasks

- Estimate affine homography from the 3 vanishing points and F (Alg.13.1 p332, result 10.3 p271) **(0.5)**
- Perform Bundle Adjustment over the estimation of the vanishing points and all available images, with PySBA. **(1.0)**
- Implement the resection method, as explained in MVG, Alg 7.1. **(2.0)**
- Implement track management for more than 2 images, with tracks structure **(1.0)**
- Investigate strategies to improve the pipeline: **(1.0)**
    - on results: number of points, reprojection error, camera poses.
    - on implementation: time of computation, resources, etc.

Affine And Metric Rectification



Affine Rectification

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

Projective to Affine Space.

$\mathbf{p}$ is the plane to infinity. Which you find estimating the image vanishing points in the image.

How?

- Geometric and algebraic intuition
- Try to plot the vanishing point

2-Line Exhaustive Searching for Real-Time Vanishing Point Estimation in Manhattan World
Xiaohu Lu, Jian Yao † , Haoang Li, Yahui Liu

Metric Rectification

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

Projective to Euclidean Space.

Find the Absolute Conic Image

- **What is the Absolute Conic Image.**
- **Why is it relevant in our application?**
- **What assumptions you should make to estimate it?**
- Geometric and algebraic intuition

Metric Rectification

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 Rectification

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 Rectification

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 Rectification

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.

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 Rectification

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.

Deliverables

- Jupyter Notebook with **all** auxiliary modules and files.
- Short report with
  - Analysis of process and results.
  - Problems, comments and conclusions.