Camera Drones
Lecture 3 – 3D data generation

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Outline

- SfM introduction
- SfM concept
- Feature matching
- Camera pose estimation
- Bundle adjustment
- Dense matching
- Data products (Orthophoto, DSM)
Orthophoto
Structure-from-Motion (SfM) concept
Structure-from-Motion (SfM) concept

- Initialize Motion
  ($P_1$, $P_2$ compatible with $F$)

- Initialize Structure
  (minimize reprojection error)

- Extend motion
  (compute pose through matches seen in 2 or more previous views)

- Extend structure
  (Initialize new structure, refine existing structure)
Structure-from-Motion (SfM) core pipeline

- **Images**
  - Pose Prior
    - Feature Extraction
      - Local Descriptors
    - Coarse Matching
      - Image Overlap
    - Detailed Matching
    - Geometric Verification
      - Epipolar Graph
    - Geometric Estimation
      - Camera Poses 3D Points
Structure-from-Motion (SfM) overall pipeline
Feature extraction

- SIFT features (best working features for matching right now)
- Each descriptor is a vector of length 128 (gradient histogram)
Coarse matching

- Cluster similar images by similarity using visual words
- Will be used for speeding up exhaustive (nxn) matching

Image similarity
Detailed matching

- Typically using NN-search with a Kd-tree
Epipolar graph

- Defines the sequential order for geometry processing
- Is a plot of the number of geometrically verified feature matches

Image similarity

Epipolar graph
Geometry estimation

- Following the sequence ordering from the epipolar graph geometry is estimated for all images
- Geometry estimation is an alternating scheme:
  - Estimate camera pose of new images (position, rotation)
  - Triangulate new 3D data points seen in new image
  - Refinement by non-linear optimization (Bundle adjustment)
Geometry estimation steps

- Compute camera poses of the first two images from feature matches

$$P = K[I|0]$$

$$P' = K'[R'|t']$$
Geometry estimation steps

- Computation of first 3D points by triangulation

\[ P = K[I|0] \]

\[ P' = K'[R'|t'] \]
Geometry estimation steps

- Triangulate all feature matches of the first images

\[ P = K[I|0] \]

\[ P' = K'[R'|t'] \]
Geometry estimation steps

- First refinement of camera poses and 3D points by non-linear estimation of the re-projection error through bundle adjustment

\[ P = K[I|0] \]

\[ P' = K'[R'|t'] \]
Geometry estimation steps

- Start processing the next image

\[ P = K[I|0] \]

\[ P'' = ? \]

\[ P' = K'[R'|t'] \]
Geometry estimation steps

- First, create feature matches to all the previous, neighboring images

\[
P = K[I|0] \quad P'' = ? \quad P' = K'[R'|t']
\]
Geometry estimation steps

- Feature matches give correspondences to already computed 3D points
- From corresponding 2D and 3D points the pose of the new camera can be computed using the PnP-Algorithm

\[ P = K[I|0] \]

\[ P' = K'[R'|t'] \]

\[ P'' = ? \]
Geometry estimation steps

- Repeat the process starting again from triangulation of new features

\[ P = K[I|0] \]

\[ P'' = K''[R''|t''] \]

\[ P' = K'[R'|t'] \]
Bundle adjustment

- Levenberg-Marquard optimization of re-projection error
- Parameters are camera poses and all 3D points (millions of parameters to optimize!)

\[
\min_{P_j,X_i} \left( \sum_i \sum_j \| x_{i,j} - P_j X_i \| \right)
\]
3 paradigms

- Sequential
- Hierarchical
- Global
Dense matching

- SfM only gives sparse 3D data
- Only SURF feature points are triangulated – for most pixel no 3D data is computed
- Dense image matching computes a 3D point for every pixel in the image (1MP image leads to 1 million 3D points)
- Dense matching algorithms need camera poses as prerequisite
Geometric relation

- Stereo normal case
- Depth $Z$ [m] can be computed from disparity $d$ [pixel]

$$d = f \frac{B}{Z}$$
Rectification

- Image transformation to simplify the correspondence search
  - Makes all epipolar lines parallel
  - Image x-axis parallel to epipolar line
  - Corresponds to parallel camera configuration

Before rectification

„Stereo normal case“
Dense matching process

- Estimate disparity (height) for all pixels in image left.
  - Evaluate correspondence measure for every possible pixel location on the line (e.g. NCC, SAD)

- Disparity \( d \): Offset between pixel \( p \) in the left image and its correspondent pixel \( q \) in the right image.
Dense matching process

reference image

matching image

epipolar line

matching cost

depth
Dense matching process

Matching image

Matching cost

Depth

Cost column
Dense matching process

matching image

cost volume

cost column
Semiglobal matching

Dense Cost Computation → Cost Aggregation

LR Check, Filtering ← Disparity images D(p), D(q) ← Disparity Selection
Plane sweep method

- Costs are created by “sweeping” a plane across the scene
- Method suitable for more than 2 images
Digital Surface Model (DSM)

- 1 height value per ground location

original image
digital surface model
(color represents height)
Orthophoto generation

- Orthophoto is a nadir looking image
- True orthophoto does not contain facades and needs a DSM for computation