Corners + Stereo

Computer Vision I
CSE252A
Lecture 14

Announcement
• HW3 assigned
• CSE MS Town Hall

Canny Edge Detector
• Smooth with Gaussian
• Compute Gradient: $df/dx$, $df/dy$
• Compute magnitude and direction
• Non-maximal suppression – local maximum of the magnitude of the gradient, in the direction of the gradient.
• Linking with hysteresis thresholding

Corner Detection

Feature extraction: Corners and blobs

Why extract features?
• Motivation: panorama stitching
  – We have two images – how do we combine them?
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• Motivation: panorama stitching
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Step 1: extract features
Step 2: match features

The Basic Idea

• We should easily recognize the point by looking through a small window
• Shifting a window in any direction should give a large change in intensity

"flat" region: no change in all directions
"edge": no change along the edge direction
"corner": significant change in all directions

Edge Detectors Tend to Fail at Corners

Intuition:
• Right at corner, gradient is ill-defined.
• Near corner, gradient has two different values.

Distribution of gradients for different image patches

Formula for Finding Corners

Shi-Tomasi Detector

We look at matrix:

\[ C(x, y) = \left[ \frac{\sum I_x^2}{\sum I_x I_y} \right] \left[ \frac{\sum I_y^2}{\sum I_x I_y} \right] \]

Matrix is symmetric

WHY THIS?
General Case:

Because $C$ is a symmetric positive definite matrix, it can be factored as follows:

$$C = R^{-1} \begin{bmatrix} \lambda_1 & 0 \\ 0 & \lambda_2 \end{bmatrix} R$$

Where $R$ is a 2x2 rotation matrix and $\lambda$ is non-negative.

What is region like if:
1. $\lambda_1 = 0$?
2. $\lambda_2 = 0$?
3. $\lambda_1 = 0$ and $\lambda_2 = 0$?
4. $\lambda_1 > 0$ and $\lambda_2 > 0$?

Shi-Tomasi Corner Detector

- Filter image with a Gaussian.
- Compute the gradient everywhere.
- Move window over image and construct $C$ over the window.

$$C(x,y) = \left[ \frac{\sum I_x^2}{\sum I_x I_y} \right]$$

- Use linear algebra to find $\lambda_1$ and $\lambda_2$.
- If they are both large, we have a corner.
  1. Let $e(x,y) = \min(\lambda_1(x,y), \lambda_2(x,y))$
  2. $(x,y)$ is a corner if it’s local maximum of $e(x,y)$ and $e(x,y) > \tau$

Parameters: Gaussian std. dev, window size, threshold

Corner Detection Sample Results

Threshold=25,000
Threshold=10,000
Threshold=5,000

Binocular Stereopsis: Mars

Given two images of a scene where relative locations of cameras are known, estimate depth of all common scene points.

Two images of Mars (Viking Lander)

An Application: Mobile Robot Navigation


The INRIA Mobile Robot, 1990.
Stereo Vision Outline

- Offline: Calibrate cameras & determine “epipolar geometry”
- Online
  1. Acquire stereo images
  2. Rectify images to convenient epipolar geometry
  3. Establish correspondence
  4. Estimate depth

Triangulation

\[ X = \frac{d X_L}{X_L - X_R} \]
\[ Z = \frac{f}{d} \frac{d X_L}{X_L - X_R} \]

Binocular Stereo System

Estimating Depth:
2D world with 1-D image plane

- Two measurements: \( X_L, X_R \)
- Two unknowns: \( X, Z \)
- Baseline: \( d \)
- Focal length: \( f \)
- \( X = \frac{d X_L}{X_L - X_R} \)
- \( Z = \frac{f}{d} \frac{d X_L}{X_L - X_R} \)
- Disparity: \( (X_L - X_R) \)

(Adapted from Hager)
Reconstruction: General 3-D case

Given two image measurements \( p \) and \( p' \), estimate \( P \).

- **Linear Method:** find \( P \) such that
  \[
  \begin{align*}
  p \times M P &= 0 \\
  p' \times M' P &= 0
  \end{align*}
  \]
  Where \( M \) is camera matrix

- **Non-Linear Method:** find \( Q \) minimizing
  \[
  \min Q \text{ where } q = M Q \text{ and } q' = M' Q
  \]

Two Approaches

1. **Feature-Based**
   - From each image, process “monocular” image to obtain cues (e.g., corners, lines).
   - Establish correspondence between

2. **Area-Based**
   - Directly compare image regions between the two images.

Human Stereopsis: Binocular Fusion

How are the correspondences established?

Julesz (1971): Is the mechanism for binocular fusion a monocular process or a binocular one?
- There is anecdotal evidence for the latter (camouflage).

Random Dot Stereograms

- Random dot stereograms provide an objective answer

Was Rembrandt Stereo Blind?
- Detail of a 1639 etching.
• In Rembrandt's painted self-portraits (left panel) in which the eyes are clearly visible, his left eye frequently looks straight out and the right off to the side. It is the opposite in his etchings (right panel).