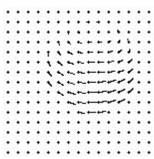
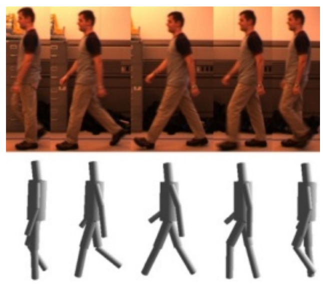
Motion Analysis: Optical Flow

Finally: Motion and tracking

Tracking objects, video analysis, low level motion





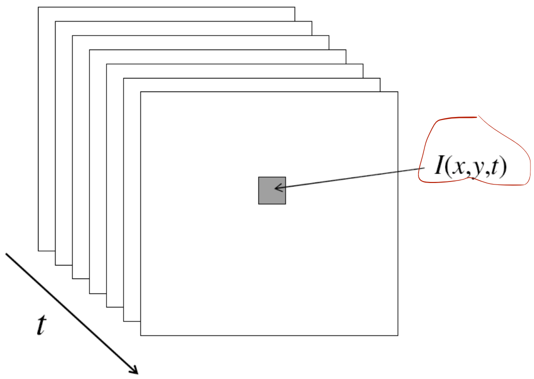
Tomas Izo

Uses of motion

- Estimating 3D structure
- Segmenting objects based on motion cues
- Learning dynamical models
- Recognizing events and activities
- Improving video quality (motion stabilization)

Video

- A video is a sequence of frames captured over time
- Now our image data is a function of space (x, y) and time (t)

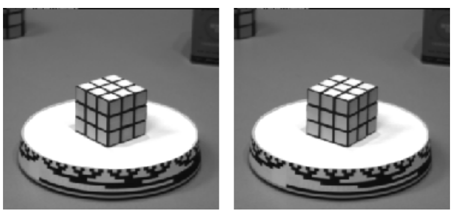


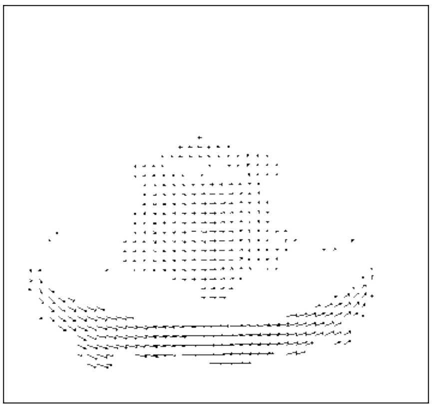
Lecture’s goals

- Motion Analysis
  - Optical flow

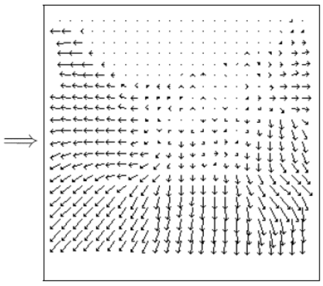
Motion field

- The motion field is the projection of the 3D scene motion into the image





Motion field + camera motion



Length of flow vectors inversely proportional to depth Z of 3d point

Figure 1.2: Two images taken from a helicopter flying through a canyon and the computed optical flow field.

points closer to the camera move more quickly across the image plane

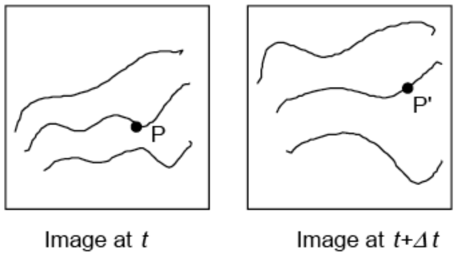
Figure from Michael Black, Ph.D. Thesis

Optical Flow (Image Flow)

- Estimate velocity based on brightness pattern
- Originates from early psychological work on human vision
  - Cues used by pilots in landing aircraft.
- Local estimates of the velocity of the brightness field
  - Do not require image structure
  - Dense velocity maps

Motion of the Brightness Pattern

- Motion field
  - Velocity vector at each point in the scene
- Optical Flow
  - Apparent motion of the brightness pattern
  - Components u, v at each point on the image
- Mostly they correspond



Correspondence Problem

The Optical Flow Equation

$$I(x, y, t) = I(x+dx, y+dy, t+dt)$$

Image structure doesn't change, just moves

$$I(x+dx, y+dy, t+dt) = I(x, y, t) + \frac{\partial I}{\partial x}dx + \frac{\partial I}{\partial y}dy + \frac{\partial I}{\partial t}dt + (h.o.t)$$

Taylor expansion

$$\frac{\partial I}{\partial x}dx + \frac{\partial I}{\partial y}dy + \frac{\partial I}{\partial t}dt = 0 \qquad \frac{\partial I}{\partial x}\frac{dx}{dt} + \frac{\partial I}{\partial y}\frac{dy}{dt} + \frac{\partial I}{\partial t} = 0$$

$$\frac{\partial I}{\partial x}u + \frac{\partial I}{\partial y}v + \frac{\partial I}{\partial t} = 0$$

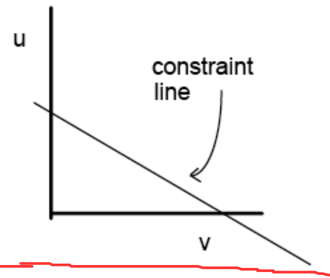
Optical Flow Equation

Solving Optical Flow

$$\frac{\partial I}{\partial x}u + \frac{\partial I}{\partial y}v + \frac{\partial I}{\partial t} = 0$$

Image gradient

Rate of change of brightness with time



Equation of straight line

No unique solution for u and v

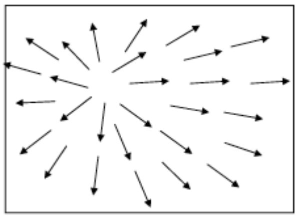
Constrained solution

- Smoothness
  - Should be small $\rightarrow$ $\begin{cases} u_x = \frac{\partial u}{\partial x}; & u_y = \frac{\partial u}{\partial y} \\ v_x = \frac{\partial v}{\partial x}; & v_y = \frac{\partial v}{\partial y} \end{cases}$ x and y derivatives of u and v
- Optical Flow constraint $\frac{\partial I}{\partial x}u + \frac{\partial I}{\partial y}v + \frac{\partial I}{\partial t} = 0$
- Minimise $\rightarrow$ $\begin{cases} \sum\sum\left(u_x^2 + u_y^2\right) + \left(v_x^2 + v_y^2\right) \\ \sum\sum\left(\frac{\partial I}{\partial x}u + \frac{\partial I}{\partial y}v + \frac{\partial I}{\partial t}\right) \end{cases}$

Optical Flow Due to Camera Translation

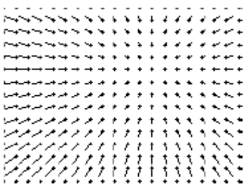
Intervening frames

Focus of Expansion

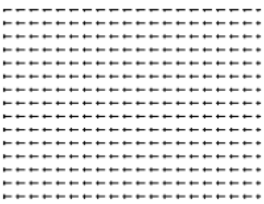


Defines instantaneous direction of camera motion

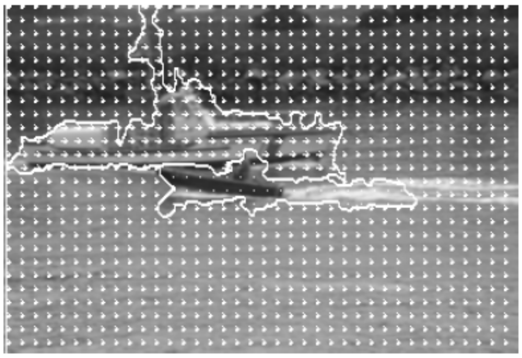
Optical Flow



Focus of contraction



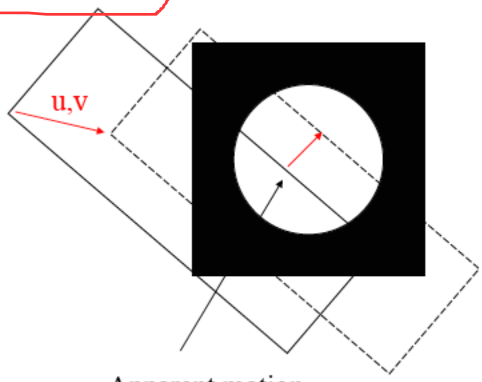
Panning



Motion-based segmentation.
Camera panning left (following smaller boat)
Larger boat moving right.

The Aperture Problem

- Using local information (e.g. derivatives) we can only measure velocity vector *normal to local image gradient*.
- Ned to apply further constraints
  - e.g. smoothness
  - Nearby points should have similar velocities



Optical Flow

When/where does this break down?

In what situations does the displacement of pixel patches not represent physical movement of points in space?

A uniform rotating sphere

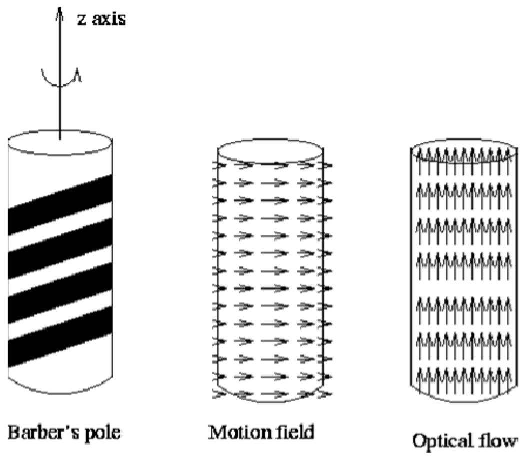
Nothing seems to move, yet it is rotating

Changing directions or intensities of lighting can make things seem to move

For example, if the specular highlight on a rotating sphere moves.

Aperture Problem

Barber pole illusion



Tracking

- Identify significant points
- Track from frame to frame
- Aperture problem avoided if we use identifiable structure.
- Simplest to match structure using cross-correlation
- No epipolar constraint
- May be able to predict motion.