COMP 546

Lecture 9

eye movements

Tues. Feb. 7, 2017
What is the image motion seen by a (moving) observer?
What computational vision problems is he solving?
Motion field

For each image location \((x, y)\), there is a velocity \((v_x, v_y)\).

In lecture 7, I discussed how to estimate image velocities.

The Yosemite sequence
What is the motion field for a translating observer?
The path of the scene point in the eye’s coordinate system is:

\[
( X(t), Y(t), Z(t) ) = ( X_0 - T_x t, Y_0 - T_y t, Z_0 - T_z t )
\]

The relative 3D velocity of the scene point \((- T_x, - T_y, - T_z)\)
What is the **image path** of the scene point?

\[
x(t) = f \frac{X(t)}{Z(t)}
\]

\[
x(t) = f \frac{X_0 - T_X t}{Z_0 - T_Z t}
\]
What is the **image velocity** of the scene point?

\[ v_x = \frac{d}{dt} x(t) \bigg|_{t=0} \]

\[ = f \left( -\frac{T_x Z_0 + T_z X_0}{Z_0^2} \right) \]

\[ Z = f \]
\[(v_x, v_y) = \left( f \left( -\frac{T_X Z_0 + T_Z X_0}{Z_0^2} \right), f \left( -\frac{T_Y Z_0 + T_Z Y_0}{Z_0^2} \right) \right) \]

\[= \frac{f}{Z_0} \left( -T_X, -T_Y \right) + \frac{f T_Z}{Z_0} \left( \frac{X_0}{Z_0}, \frac{Y_0}{Z_0} \right) \]

Lateral component  |  Forward component
Lateral Component \((T_Z = 0)\)

\[
(\nu_x, \nu_y) = \frac{f}{Z_o} (-T_x, -T_y)
\]
Lateral Motion and Balance

Pose is difficult

Pose is easy

Why?
Dizziness (‘height vertigo’)

Not to be confused with a more general ‘acrophobia’ (fear of heights)
Forward Component \((T_X = T_Y = 0)\)

What does a pilot see when approaching the runway? (from JJ Gibson 1950)
Forward Component \((T_X = T_Y = 0)\)

\[
(v_x, v_y) = \frac{T_Z}{Z_o} (x, y)
\]

In case of a wall.
General Translation \((Tx, Ty, Tz)\), where \(Tz \neq 0\)

\[
(V_x, V_y) = \frac{T_z}{z_o} \left( x, y \right) + \frac{f}{z_o} \left( -T_x, -T_y \right)
\]

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careful
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\[
= \frac{T_z}{z_o} \left( x - f \frac{T_x}{T_z}, y - f \frac{T_y}{T_z} \right)
\]

where \((f \frac{T_x}{T_z}, f \frac{T_y}{T_z})\) is the "direction of heading" or "focus of expansion"
\[(V_x, V_y) = \frac{T_z}{Z} (x - f \frac{T_x}{T_z}, y - f \frac{T_y}{T_z})\]

\[T_z \neq 0\]
Computational Problem: How does a translating observer estimate heading and depth?

1) Estimate motion field \((v_x, v_y)\).

2) Estimate the heading \((T_X, T_Y, T_Z)\) up to unknown scale factor.

3) Estimate the depth map \(Z(x, y)\).
How/where does the brain solve this problem?

V1 : normal velocities

→ MT (middle temporal lobe) : velocities \((v_x, v_y)\)

→ MST (medial superior temporal lobe) : global motion field
e.g. sensitive to expansion
What is the motion field for a rotating observer?

- head
- eye
- pan
- tilt
- roll
pan
Eye Rotations (called "eye movements")
All eye movement *motor* (output) signals come from mid-brain e.g. oculomotor nerve, and other ‘cranial’ nerves.

These nerves also control accommodation, blinks, pupil contraction.
Types of eye movements

- VOR (vestibulo-ocular reflex)
- smooth pursuit
- saccades
- vergence (last lecture)
- OKN (optokinetic nystagmus) OMIT
VOR
(eye rotations due to head movement)
Vestibular System
(in the inner ear)
Vestibular system: the brain’s IMU

(inertial measurement unit – a term used in robotics)

It measures:

- angular acceleration of head

\[ \frac{d}{dt} (\text{pan, tilt, roll}) \]

- linear acceleration of head

\[ \frac{d}{dt} (T_X, T_Y, T_Z) \]
Rotation
(angular acceleration)

Translation
(linear acceleration)

otoliths
Vestibular System (in the inner ear)

Rotation

Translation

Hearing
Smooth Pursuit Eye Movements

Smoothly tracking a moving object.

Goal: Keep the fovea ‘on the object’ to get high resolution detail i.e. cancel the object motion.

Max speed of tracking is much slower than VOR. Why?
Saccades
"The Unexpected Visitor"
classic experiment by Yarbus 1960s
1. Free examination.
2. Estimate material circumstances of the family.
3. Give the ages of the people.
4. Surmise what the family had been doing before the arrival of the unexpected visitor.
5. Remember the clothes worn by the people.
6. Remember positions of people and objects in the room.
7. Estimate how long the visitor had been away from the family.

3 min. recordings of the same subject.
Eye Tracking

Making a cup of tea

Driving a car
How to integrate the images?
So... What computational vision problems are they solving?
3D Perception

1) Estimate image velocity at each \((x,y)\).

2) Estimate self translation and rotation
   - using vision
   - using vestibular system

3) Estimate the 3D spatial layout and positions of objects

Action

- Recognize objects
- Visually Guided Control (Reaching, Locomotion)
Announcements

• Midterm exam
  • You are allowed one double sided 8x11 crib sheet
  • Short answer questions
  • Lectures 1-7
  • Do the Exercises.
  • Let me know if there are mistakes in the notes.