lecture 14

Cues 4: Observer motion

Wed Feb 27, 2013

What causes image motion?

- moving objects in the scene (last lecture)
- observer motion: body, head, eyes (today’s lecture)

Translating Observer

\[
(T_x, T_y, T_z) \rightarrow (X_0, Y_0, Z_0)
\]

3D velocity relative to the observer \((-T_x, -T_y, -T_z)\)

\[
(x(t), y(t), z(t)) = (x_0 - T_x t, y_0 - T_y t, z_0 - T_z t)
\]

View from above

\[
x(t) = \frac{X(t)}{Z(t)} = \frac{x_0 - T_x t}{Z_0 - T_z t}
\]

\[
v_x = \lim_{t \to 0} \frac{dx(t)}{dt} = \frac{x_0 - T_x Z_0 + T_z x_0}{Z_0^2}
\]

"Lateral motion" \((T_z = 0)\)

\[
(V_x, V_y) = \frac{1}{Z_0} \left(-T_x Z_0 - T_y x_0\right)
\]

\[
= \frac{1}{Z_0} \left(-T_x, -T_y\right) + \frac{T_z}{Z_0} \left(\frac{x_0}{Z_0}, \frac{y_0}{Z_0}\right)
\]

"lateral" "forward"

\[
(T_x, T_y, 0) \rightarrow (x(t), y(t))
\]
"Lateral motion" ($T_z = 0$)

$$ (V_x, V_y) = \frac{1}{z_0} (-T_x, -T_y) $$

Lateral motion and balance

difficult
(no retinal motion since points are at infinity)

easier (lots of motion for points on ground)

Fear of heights - perceptual factors

Motion Parallax

$\Delta (V_x, V_y) = \left(\frac{1}{z_0} - \frac{1}{z_1}\right) (-T_x, -T_y)$

Forward Motion ($T_x = T_y = 0$)

in case of wall $z_0 = c$

$$ (V_x, V_y) = \frac{T_z}{z_0} \left( \frac{x}{z}, \frac{y}{z} \right) $$

$$ = \frac{T_z}{z_0} \left( x, y \right) $$

[NOTE: illegal use of symbol $T_x$ to mean two things.]
"Optical Flow"

What does a pilot see when approaching the runway? (from J.J. Gibson, 1950)

General Translation \((T_x, T_y, T_z)\)

where \(T_z \neq 0\)

\[
\begin{align*}
(V_x, V_y) &= \frac{T_z}{T_0} \left(-T_x, -T_y\right) + \frac{T_z}{T_0} \left(\frac{x}{T_z}, \frac{y}{T_z}\right) \\
&= \frac{T_z}{T_0} \left(x - \frac{T_x}{T_z}, y - \frac{T_y}{T_z}\right)
\end{align*}
\]

where \((\frac{T_x}{T_z}, \frac{T_y}{T_z})\) is the "direction of heading".

Motion blur seen by translating observer is very similar to image of parallel straight lines. Why?

\[
(X(t), Y(t), Z(t)) = (X_0, Y_0, Z_0) + t \left(\frac{T_x}{T_z}, \frac{T_y}{T_z}\right)
\]

Computational Problem (translating observer)

1) Estimate \((V_x, V_y)\) at each \((x, y)\)

2) Estimate direction of heading \((\frac{T_x}{T_z}, \frac{T_y}{T_z})\)

3) Estimate distance \(\frac{T_z}{2}\) is unknown

Observer Rotation

head       eye

pan

tilt

roll
Velocity field is approximately constant within ± 20 degrees from forea. (Equations omitted)

Eye Rotations
(called "Eye Movements")

1. Superior rectus muscle
2. Superior oblique muscle
3. Medial rectus muscle
4. Lateral rectus muscle
5. Inferior rectus muscle
6. Inferior oblique muscle

Types of Eye Movements

1. Saccades
2. Smooth pursuit
3. VOR (vestibulo ocular reflex)
4. OKN (optokinetic nystagmus)

1.) Saccades

- Very fast rotation speed
  (vision system ignores motion during this rotation)
- Fixations last ~ 1/3 second
  (i.e., 3 per second on average)
- Saccade targets and sequence depend on many factors

Bring the forea to interesting points.
2. Smooth Pursuit
- follow a moving object
  (ball, person, car, ...)
- keep the fovea on the object
to get high resolution detail
- cancel the motion (if possible)
  \((V_x V_y) + (V_x V_y)_{\text{due to object}} = 0\)
due to object
due to observer

3. Eye Rotations due to Head Movement (VDH)
(head rotation and/or translation)

- not driven by visual input
  (amazingly fast)
- happens with eye closed too
- too fast and too accurate to depend
  on cortical processing of image motion
  (compare visual experience of rapid
  head rotation vs. shaking an object at
  same frequency)

What is the mechanism?

IMU - inertial measurement unit
(term used in robotics)

Measures
- linear accelerations
  \(\frac{d}{dt} (T_x T_y T_z)\)
- rotations (pan, tilt, roll)

The brain has two IMUs,
Vestibular System (in the inner ear)

Rotations (pan, tilt, roll)

Semicircular canals

Tubular ducts containing endolymph

Utricle

Saccule

Cochlea

Linear Acceleration

\[ \frac{d}{dt} \left( T_x, T_y, T_z \right) \]

Figure 2: The Vestibular System - semicircular canals and otolith organs

Semicircular tubes (canals) that contain fluid which creates a drag

Otoliths are little stones

These motions are sensed by small hairs that are attached to mechanical sensitive cells, which send signals to brain.

Computation Problem for General Moving Observer (Translation + Rotation)

1.) Estimate \((x, y)\)

2.) Estimate observer translation, rotation

   \((x_T, y_T)\) - pursuit

   \(T_z\) - saccade

   \(VOR\) - own

3.) Estimate depth \(\frac{1}{z}\)