Review from last lecture

- What are five solutions to increase frame rate?
- What is tearing? And how to solve it?
- Which one has less inertia? Head or finger?
- What are flaws of post-rendering image warp?
Challenges for Rendering in VR: Latency

Motion-to-photon latency: the amount of time that it takes to update the display in response to head motion (change in current position and orientation)

Latency: key obstacle of past generations of VR

Current methods for latency reduction:
- Lower complexity of virtual world
- Improve rendering pipeline performance
- Remove delays along the path from rendered image to switching pixels

Problem: all of these need to work for higher resolution & faster fps screens!

Reducing “effective” latency:
- Use prediction to estimate future viewpoints and world states
- Shift or distort image to compensate for last-minute viewpoint errors
Mathematical modeling of motion

- The physics of both real and virtual worlds impact VR experiences.
- Physics engines may model the motions of dynamic bodies in the virtual world, but not the motion of the virtual world itself.
- Tracking methods rely on accelerations and velocities.
- Human vestibular organs rely on accelerations and velocities.
How to display the world right?

- Only have one display
- But you have *more* than two senses that detect motion (eye, ear, proprioception)
## Vestibular and visual perception of motion mismatch

<table>
<thead>
<tr>
<th>Vestibular system</th>
<th>Vision</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>Delayed</td>
<td>Mismatched</td>
</tr>
</tbody>
</table>
Motion Detection Circuitry
Motion Detection Circuitry

HitchcockZoom_Micael_Reynaud.gif

“Hitchcock effect”

Example of vection

Is it comfortable?
**1D Motion**

- How do I find out \( y(t) \)?

GPS-like sensor for \( y(t) \) would be great but may be expensive / inaccurate / impractical.

We have velocity sensor for \( v(t) \)

\[
v(t) = \frac{dy(t)}{dt} \quad y(t) = y(0) + \int_0^t v(t)\,dt
\]

For constant \( v(t) \), \( y(t) = ? \)

For varying \( v(t) \), \( y(t) = ? \)
1D Motion using odometer (e.g. 200Hz to 1KHz)

Example:
1 KHz Measurement frequency so Δt = 0.001 s
Numerical measurement error is Δv_i = 0.0001 m s^{-1}
Tracking error > 1 m, when N > ?

(Linear)Drift !!
1D Motion

Sensor for $a(t) \rightarrow$ accelerometer

\[ v(t) = \frac{dy(t)}{dt} \]

\[ a(t) = \frac{dv(t)}{dt} \]

Numerical solution

\[ y(t) \approx y(0) + \sum_{i=0}^{N} v_i \cdot dt \]

\[ v(t) = v(0) + \sum_{i=0}^{N} a_i \cdot dt \]

Example:

\[ \text{(0.5s)} \cdot (v_0 + v_1 + v_2 + \ldots + v_{N-1} + v_N) \cdot \Delta t \]

Quadratic drift !!!
Tracking System in VR: Estimating 2D Orientation

How do I find out $\theta(t)$?

Sensor for $\theta(t)$ (GPS) would be nice

Otherwise: sensor for $\omega(t)$: gyroscope

$$\omega(t) = \frac{d\theta(t)}{dt} \quad \theta(T) = \theta_0 + \int_0^T \omega(t) \cdot dt$$

Numerical Solution:

$$\theta(T) = \theta_0 + \sum_{i=0}^{T} \omega_i \cdot \Delta t$$
3D Motion?

Sensor for \([x(t); y(t); z(t)]\)

\[
\begin{pmatrix}
x_T \\
y_T \\
z_T
\end{pmatrix} = \begin{pmatrix}
x_0 \\
y_0 \\
z_0
\end{pmatrix} + \int_0^T \begin{pmatrix}
v_x \\
v_y \\
v_z
\end{pmatrix} \cdot dt
\]

Numerical solution

\[
\begin{pmatrix}
x_T \\
y_T \\
z_T
\end{pmatrix} = \begin{pmatrix}
x_0 \\
y_0 \\
z_0
\end{pmatrix} + \sum_{i=0}^{N} \begin{pmatrix}
v_{xi} \\
v_{yi} \\
v_{zi}
\end{pmatrix} \cdot \Delta t
\]
Tracking System in VR: Estimating 3D Orientation

How do I find out $Q(t)$?

Sensor for $Q(t)$ (GPS) would be nice

Otherwise: sensor for $[\omega_x(t); \omega_y(t); \omega_z(t)]$ : gyroscope

$$\omega(t) = \left(\frac{d\alpha}{dt}, \frac{d\beta}{dt}, \frac{d\gamma}{dt}\right) \quad Q_t = Q_0 \circ \int_0^T \omega(t) \cdot dt$$

Numerical Solution:

$$Q_t = Q_0 \circ \bigcap_{i=0}^{N} \Delta Q_i, \Delta Q_i = (axis, angle)$$
Human Vestibular System
Review from today

- What happens if there’s vestibular system and vision mismatch?
- What’s the reason for drift?
- What’s difference between estimating 2D orientation and 3D orientation?
Announcements

- See you next week and keep your final project on track!
- Read Chapter 12