Announcements

Final project upcoming deadlines:

- **Nov 13**, a short video of your progress. Submit via Compass, 10% of the final project total.

- **Dec 16**, 7-11pm in Siebel 4240. Final project presentations and Open House for press!

Grades are out for:

- Midterm 1
- Project abstract and picture-title
Tracking Systems in VR: Estimating 3D Orientation

Integrate sensor readings to estimate orientation:

\[ \hat{\Theta} = \Theta_0 + \sum_{i=1}^{k} \Delta \hat{\Theta}_i = \Delta \hat{\Theta}_k + \Delta \hat{\Theta}_{k-1} + \ldots + \Delta \hat{\Theta}_1 + \Theta_0 \]
\[ \Delta \hat{\Theta}_i = \hat{\omega}_i \Delta t \]

Now 3D:
\[ \hat{Q} = \Delta \hat{Q}_k \circ \Delta \hat{Q}_{k-1} \circ \ldots \circ \Delta \hat{Q}_2 \circ \Delta \hat{Q}_1 \circ \hat{Q}_0 \]
Each \( \Delta \hat{Q}_i = \text{Quat}(\hat{\nu}_i, \Delta \hat{\Theta}_i) \)

Problem: Drift or dead reckoning
Estimating 3D Orientation: Drift Correction

Separate the rotational drift error into two components:

1) **Tilt error**: Pitch + roll

   To correct: need a gravity or “up” vector

2) **Yaw error**

   To correct: need a “compass”

- Complementary Filters on SO(3), Mahoney, 2008
- Head Tracking for the Oculus Rift, ICRA 2014
  S. LaValle, A. Yershova, M. Katsev, and M. Antonov
Use Accelerometer to Correct "Tilt Error"

"up vector" is always

What is $\mathbf{Q}\mathbf{u}$? Assume $\mathbf{Q}$ is accurate.

What if $\mathbf{Q}\mathbf{u}$ is not aligned with y-axis?
Use Accelerometer to Correct "Tilt Error"

Apply $\hat{Q}_k$ to accelerometer reading

$\hat{\mathbf{a}} = (\hat{a}_x, \hat{a}_y, \hat{a}_z)$

Tilt axis in $XZ$ plane:

$\mathbf{V}_{\text{tilt}} = (\quad)$

Now rotate by $\varphi$ about $\mathbf{V}_{\text{tilt}}$ to fix $\hat{Q}_k$

$\hat{Q}_{\text{corrected}} = \circ \hat{Q}_k$
Use Accelerometer to Correct "Tilt Error"

Complementary filter:

In each $dt$,
rotate by
about $\vec{V}_{tilt}$
to fix $\hat{Q}_k$

$\hat{Q}_{corrected} = \text{Quat}(\vec{V}_{tilt}, \psi) \circ \hat{Q}_k$

Gain coefficient $d > 0$, $d \approx 0$ (ex. $d = 0.0001$)

$d$ needs to be large enough to
but small enough to
What Does Accelerometer Measure?

Rift is free falling:

\[ \vec{\bar{a}} = -\vec{g} \]

Rift lying on a side:

\[ \vec{\bar{a}} = (\quad ) \quad \vec{\bar{a}} = (\quad ) \quad \vec{\bar{a}} = (\quad ) \]
Use Accelerometer to Correct "Tilt Error"

Problem:

Accelerometer measures vector sum of gravity and linear acceleration of sensor.

Solution:

Use heuristic to detect when "not moving" and apply correction only then.

Example: $\|\vec{a}\| \approx 9.81$
Use Magnetometer to Correct Yaw Error

Similar to tilt correction:

- Calculate reference error
- Gradually apply using complementary filter

Problems:

- Vector sum of
  - Calibration is
  - Field might vary over

accuracy ≈ 5 degrees
Estimating Position and Orientation

Problem setup:

• Allow and track parallax motions
• IMU (gyro + accelerometer + magnetometer) not enough
  • Drift too fast from double integration
  • No way to detect drift errors
• Need sub-millimeter accuracy, stable estimates

Solutions:

1. Generate non-constant magnetic or EM field
   • RazerHydra, STEM Sixense
   • UWBradio
2. Visibility or line of sight methods
Position Tracking: Visibility Methods

Camera arrangements:

On headset

inside-out

In world

outside-in
Position Tracking: Visibility Methods

Pinhole camera:

Features in an image:
Position Tracking: Visibility Methods

FEATURES:

1) Natural
   • Hard computer vision
   • Extract and maintain from natural scenes
   • Remove moving objects
   • Reliability low

2) Artificial
   • Trivial computer vision (blob detection)
   • QR tags, retro reflective markers, LEDs, laser projections
   • Can stay in IR spectrum (invisible to humans)
Position Tracking: Blob Detection

PnP Problem:

Determine rigid body transformation from identified, observed features on a rigid body.

P1P Problem:

DOF analysis:
- Start with 6 DOFs (rigid body)
- Each feature subtracts 2 DOFs
Position Tracking: Blob Detection

P2P Problem:

Determine position and orientation of triangle from features in image.

DOFs left:
Position Tracking: Blob Detection

P3P Problem:

Determine position and orientation of triangle from features in image.

DOFs left:

Solution: A system of polynomial equations leads to 8 solutions (but only 4 in front of the camera). The beginnings of computational real algebraic geometry.
Position Tracking: Incremental Blob Detection

Incremental PnP Problem:

Determine position and orientation of triangle from features in image, given current estimate.