Simultaneous Local and Global State Estimation for Robotic Navigation

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ICRA 2009
Talk Outline

- Define problem of state estimation
- Discuss two traditional coordinate frames:
  - Globally-referenced coordinate system
  - Body-centered coordinate system
- Propose new representation: “Local Frame”
- Show simulations and collected data
State Estimation in Mobile Robotics

- Two general classes of measured state information:
  - **Globally referenced**
    - GPS Position
    - Map constructed using SLAM
  - **Body-referenced**
    - Sensor data (LIDAR, cameras, radar, etc.)
    - Inertial measurement (gyro, accelerometer)
    - Kinematics (odometry, joint position, etc.)

How do we reconcile this state data?
Reconciling Global and Body State

One solution:

Transform all state into the global frame before storing it or reasoning with it
What happened?

- Alice lost GPS under some power lines.
- Signal returned, but new state estimate had a bias.
- Obstacle map was still registered against previous localization.
- Alice obeyed previous obstacle map and drove into barriers.
- Conclusion: Don't store persistent data in the global frame.
GPS Discontinuities

- Gradual bias
- 3.8m jump

**Graphs:**
- IMU + odometry
- GPS + IMU + odometry
Body Frame

- Vehicle position defined as (0,0,0)
- Sensor data:
  - Project into body frame per sensor
  - Corrupted by intrinsic sensor and projection error
- Globally-registered data:
  - Project into body frame using localization fix
  - Corrupted by noise from localization system
- Primary disadvantage:
  
  Must propagate stored map data at every time step
Three Possible Frames

Representing Uncertainty

Global Frame

Local Frame

Body Frame

△ robot
× globally referenced
+ locally sensed
The Local Frame Defined

- Traditional position update in same frame $L_t$:
  \[
  x_{t+1}^{L_t} = F(x_t^{L_t}, u_t) + w_t^{L_t}
  \]

- Local frame update:
  - Position update into new frame $L_{t+1}$ without noise:
    \[
    x_{t+1}^{L_{t+1}} = F(x_t^{L_t}, u_t)
    \]
  - Must also migrate map data into $L_{t+1}$ with noise

- Key feature: Maximum Likelihood Estimate of map data is the same in $L_t$ and $L_{t+1}$
Local Frame Simulation

Uncertainty of a map feature in the local frame

- 2 circles ($r=64m$)
- 1 circle ($r=127m$)
- Wide turn ($r=509m$)
- Straight line

$|\Sigma_{mm}|$ vs. time (s)
Global vs. Local in the Real World

Global Frame

Local Frame
Conclusions

- Global frame is not recommended for storing measured sensor data.
- Body frame is suitable, but can be expensive to do time updates.
- The local frame is a good alternative.
- Request for manufacturers of high-end Inertial Navigation Systems (INS):
  Please provide a purely inertial position/attitude estimate *in addition* to traditional GPS-fused position estimate.
Questions?