Localization

where am I?

Bookkeeping

- Quiz 3 – short review
- Assignment 3: How Thursday will work
- Next Reading: SNS 5.5 – 5.6.4
- Today
  - Scheduling for demos & presentations
  - Localization
Quiz 3: Manipulators

- Which of the following statements is *true* of a manipulator?
  - Synonymous with robot arm.
  - Has *grippers* to grasp or move things.
  - Has six degrees of freedom.
  - Can interact with the world (exteroceptive) or remain passive in the world (proprioceptive).
  - Can mark all false
    - Since many people didn’t, ungraded question

- An open-chain manipulator is modeled as a series of rigid links connected by joints, starting at the base.

Quiz 3: Manipulators

- Where is first joint?
- How many degrees of freedom?
- Is this manipulator's motion
  - Revolute
  - Prismatic
  - Both
- Can paintbrush take any position or orientation in workspace?
- Paintbrush is: end effector
Quiz 3: Manipulators

Which of these is a gripper?

- Bending ‘fingers’ that close around an object.
- Sliding surfaces that pinch an object in between them.
- A contact switch that clicks closed when pressed against an object.
- A vacuum nozzle that seals against the surface of an object.
- A nozzle that dispenses glue between two objects, adhering them together.
- Needles that pierce a piece of cloth on two sides to lift it.
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Quiz 3: Kinematics

- Solving kinematics and IK problems transforms between two frames of reference, or coordinate systems:
  - Global and Initial
  - Robot and Local
  - Cartesian and Joint
  - Plane and World

- How many parameters to describe configuration of a mobile robot, and what are they?
  - If you put \( \{x,y,z\} \), \( r/p/y \), since I didn’t specify wheeled, okay

\[
\xi_I = \begin{bmatrix} x \\ y \\ \theta \end{bmatrix}
\]
Quiz 3: Kinematics

- Forward or Inverse?
  - We know where everything in the room is from a ceiling cam
  - Robot needs charging
  - Trying to decide what commands to send its actuators
  - What kind of kinematics problem do we need to solve?

- Kinematic models of wheels
  - Rolling: all motion accompanied by wheel spin
    - No skidding front to back
  - Sliding: wheel can move only in its plane of rotation
    - No skidding side to side
    - Single point of contact

Quiz 3: Grasping

- Which grasp is best? Why?
  - Note: grasps are independent of pickup action

- Grading
  - Correct cube — or — something about using the back of the hand
  - Otherwise, only -1 if something reasonable
Assignment 3

- Recommendation: read the assignment
- Build LED circuit
  - Breadboard-based circuit building
  - Everyone/each pair should have 2 AA batteries
- Build motor
  - Very simple conceptually
- Writeup
  - Circuit diagram, explanations of current, efficiency of motor
  - 1-1.5 pages
- In-class workshop
  - 12th November: demonstrate stuff working, seek help
- Then: projects time

Why do I have 2 LEDs? (use provided parts ≠ use ALL provided parts)

Resistors

How can I make a switch? (it will have moving parts!)

Localization

- Where am I (in a model of the environment)?

Localization -> Perception

Environment Model (Local Map) -> Real World Environment

“Position”: Global map -> Path

Cognition -> Motion Control
**Sensor Aliasing**

- Robots: non-uniqueness of sensors readings is the norm
- Many-to-one mapping from environmental states to robot's perceptual inputs
- Not NO information

**Odometry & Dead Reckoning**

- Position update is based on proprioceptive sensors
  - Odometry: uses …
  - Dead reckoning: uses …
- How?
  - Sense movement
  - Integrate that into map model to get the position
- Extra sensors **reduce** accumulated errors
  - Same problem
- Effectors introduce uncertainty about future state
Odometry & Diff. Drive

- Given a discrete sampling rate $\Delta t$
- And motion $\Delta s_r, \Delta s_l =$ right wheel, left wheel distance travelled
- Changes in pose are $\Delta x, \Delta y, \Delta \theta$
- Distance between wheels is $b$

\[
\begin{align*}
p &= \begin{bmatrix} x \\ y \\ \theta \end{bmatrix} \\
p' &= p + \begin{bmatrix} \Delta x \\ \Delta y \\ \Delta \theta \end{bmatrix}
\end{align*}
\]

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Odometry & Diff. Drive

- Kinematics

\[
\begin{align*}
\Delta x &= \Delta s \cos(\theta + \Delta \theta / 2) \\
\Delta y &= \Delta s \sin(\theta + \Delta \theta / 2) \\
\Delta \theta &= \frac{\Delta s_r - \Delta s_l}{b} \\
\Delta s &= \frac{\Delta s_r + \Delta s_l}{2} \\
p' &= f(x, y, \theta, \Delta s_r, \Delta s_l) = \begin{bmatrix} x' \\ y' \\ \theta' \end{bmatrix} + \begin{bmatrix} \Delta s + \Delta s_l \cos\left(\theta + \frac{\Delta s_r - \Delta s_l}{2b}\right) \\
\Delta s + \Delta s_l \sin\left(\theta + \frac{\Delta s_r - \Delta s_l}{2b}\right) \\
\frac{\Delta s_r - \Delta s_l}{b} \end{bmatrix}
\end{align*}
\]
Odometry & Diff. Drive

- Error model – represent uncertainty of location over time in covariance matrix
- \( \Sigma_p \) is initial matrix
- Errors of 2 wheels independent
- Variance of error \( \propto \Delta s_r, \Delta s_l \)

\[
\Sigma_A = \text{covar}(\Delta s_r, \Delta s_l) = \begin{bmatrix} k & 0 \\ 0 & k \end{bmatrix}
\]

\[
\Sigma_p = \nabla_p f \cdot \Sigma_p \cdot \nabla_p f^T + \nabla \Delta_p f \cdot \Sigma_A \cdot \nabla \Delta_p f^T
\]

\[
F_p = \nabla \phi f = \begin{bmatrix} \frac{\partial \phi}{\partial x} \frac{\partial \phi}{\partial y} \end{bmatrix} = \begin{bmatrix} 1 & 0 \Delta \sin(\theta + \Delta \theta/2) \\ 0 & 1 \Delta \cos(\theta + \Delta \theta/2) \end{bmatrix}
\]

\[
F_{\Delta} = \begin{bmatrix} \frac{1}{2} \cos \left( \theta + \frac{\Delta \theta}{2} \right) \Delta s \sin \left( \theta + \frac{\Delta \theta}{2} \right) \frac{1}{2} \cos \left( \theta + \frac{\Delta \theta}{2} \right) \\ \frac{1}{2} \sin \left( \theta + \frac{\Delta \theta}{2} \right) \frac{1}{2} \cos \left( \theta + \frac{\Delta \theta}{2} \right) \end{bmatrix}
\]

Odometry: Growth of Pose Uncertainty for Straight Line Movement

- Note: Errors perpendicular to the direction of movement are growing much faster!
Odometry:
Growth of Pose uncertainty for Movement on a Circle

- Note: Errors ellipse in does not remain perpendicular to the direction of movement!

Calibration of Errors

- The unidirectional square path experiment
Calibration of Errors

- The bi-directional square path experiment
  
  Start → End
  Forward
  Curved instead of straight path (due to unequal wheel diameters). In the example here, this causes a 3° orientation error.
  93° turn instead of 90° turn (due to uncertainty about the effective wheelbase).
  Preprogrammed square path, 4x4 m.

- The deterministic and non-deterministic errors

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Calibration of Errors

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- The deterministic and non-deterministic errors
Localize, Or Not?

- How to navigate between A and B
- Navigation without hitting obstacles
- Detection of goal location
- Do you need to know where you are in the map?

Behavior Based Navigation

- Fast to implement
- Effective in unchanging environment
- Does not scale to new environments
- Behaviors must be designed and debugged
- Sensor changes change behavior
- Harder to represent to users
Behavior Based Navigation

- Communicate data
- Discover new area
- Detect goal position
- Avoid obstacles
- Follow right / left wall

Actuators: Coordination / fusion (e.g., fusion via vector summation)

Model Based Navigation

- Perception

Output: Localization / map-building

Output: Cognition / planning

Output: Motion control

Actuators:
Belief Representation

- a) Continuous map with single hypothesis
- b) Continuous map with multiple hypothesis
- d) Discretized map with probability distribution
- d) Discretized topological map with probability distribution
Characteristics

Belief Representation can be…

- Continuous
  - Precision bound by sensor data
  - Typically single hypothesis pose estimate
  - Lost when diverging (for single hypothesis)
  - Compact representation and typically reasonable in processing power.

- Discrete
  - Precision bound by resolution of discretisation
  - Typically multiple hypothesis pose estimate
  - Never lost (when diverges converges to another cell)
  - Important memory and processing power needed. (not the case for topological maps)