Lecture 2: Robot Basics

CS 344R/393R: Robotics

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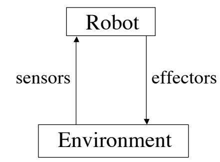
What is a robot?

- A robot is an intelligent system that interacts with the physical environment through sensors and effectors.



- Today we discuss:
  - Abstraction
  - Sensor errors
  - Color perception

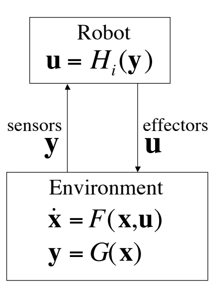
Remember the Amigobot?

- Sonar sensors: front (6), back (2)
- Camera
- Passive gripper
- Differential drive (right/left wheel)
- Odometry
- Wireless communication

Describing the Amigobot

- State vector: $\mathbf{x} = (x, y, \theta)^T$
  - The true state is not known to the robot.
- Sense vector: $\mathbf{y} = (s_1, s_2, s_3, s_4, s_5, s_6, s_7, s_8, o_L, o_R)^T$
  - Sonars and odometry
  - Plus sensory features from camera
- Motor vector: $\mathbf{u} = (v_L, v_R)^T$
  - Left-wheel, right-wheel
- These are functions of time: $\mathbf{x}(t)$, $\mathbf{y}(t)$, $\mathbf{u}(t)$
  - Derivative notation: $\dot{\mathbf{x}} = d\mathbf{x}/dt$

Modeling Robot Interaction



The Unicycle Model

- For the unicycle, $\mathbf{u} = (v, \omega)^T$, where
  - v is linear velocity
  - ω is angular velocity

$$\dot{\mathbf{x}} = \begin{pmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \end{pmatrix} = F(\mathbf{x}, \mathbf{u}) = \begin{pmatrix} v\cos\theta \\ v\sin\theta \\ \omega \end{pmatrix}$$

- A useful abstraction for mobile robots.

The Amigobot is (like) a Unicycle

$$\dot{\mathbf{x}} = \begin{pmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \end{pmatrix} = F(\mathbf{x}, \mathbf{u}) = \begin{pmatrix} v\cos\theta \\ v\sin\theta \\ \omega \end{pmatrix}$$

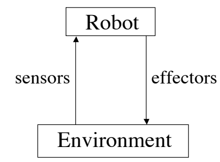
- Amigobot motor vector: $\mathbf{u} = (v_L, v_R)$

$$v = (v_R + v_L)/2 \quad \text{(mm/sec)}$$

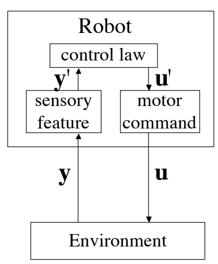
$$\omega = (v_R - v_L)/B \quad \text{(rad/sec)}$$

where B is the robot wheelbase (mm).

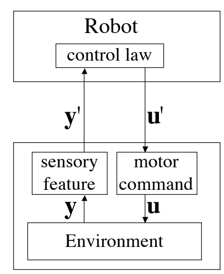
Abstracting the Robot Model



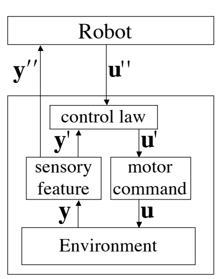
Abstracting the Robot Model



Abstracting the Robot Model



Abstracting the Robot Model



Abstracting the Robot Model

- By implementing sensory features and control laws, we define a new robot model.
  - New sensory features $\mathbf{y}''$
  - New motor signals $\mathbf{u}''$
- The robot's "environment" changes
  - from continuous, local, uncertain …
  - to reliable discrete graph of actions.
  - (For example. Perhaps. If you are lucky.)
- We abstract the Aibo to the Unicycle model
  - Abstracting away joint positions and trajectories

A Topological Abstraction

- For example, the abstracted motor signal $\mathbf{u}''$ could select a control law from:
  - TurnRight, TurnLeft, Rwall, Lwall, Midline
- The abstracted sensor signal $\mathbf{y}''$ could be a Boolean vector describing nearby obstacles:
  - [L, FL, F, FR, R]
- The continuous environment is abstracted to a discrete graph.
  - Discrete actions are implemented as continuous control laws.

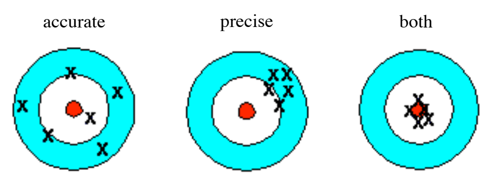
Types of Robots

- Mobile robots
  - Our class focuses on these.
  - Autonomous agent in unfamiliar environment.
- Robot manipulators
  - Often used in factory automation.
  - Programmed for perfectly known workspace.
- Environmental monitoring robots
  - Distributed sensor systems (“motes”)
- And many others …
  - Web ‘bots, etc.

Types of Sensors

- Range-finders: sonar, laser, IR
- Odometry: shaft encoders, ded reckoning
- Bump: contact, threshold
- Orientation: compass, accelerometers
- GPS
- Vision: high-res image, blobs to track, motion
- …

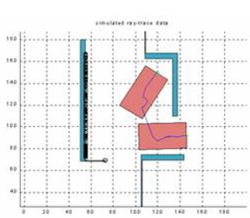
Sensor Errors: Accuracy and Precision



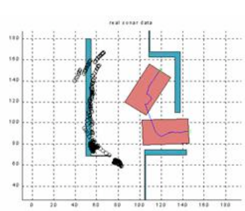
- Related to random vs systematic errors

Sonar vs Ray-Tracing

- Sonar doesn't perceive distance directly.
- It measures "time to echo" and estimates distance.

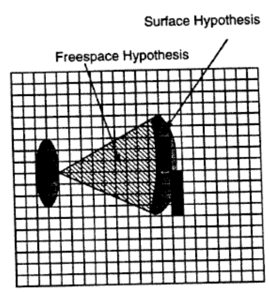


Simulated Ray-Trace Data



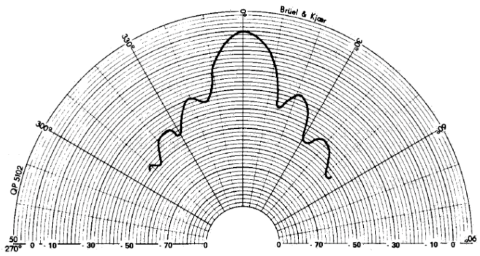
Real Sonar Data

Sonar Sweeps a Wide Cone. One return tells us about many cells.



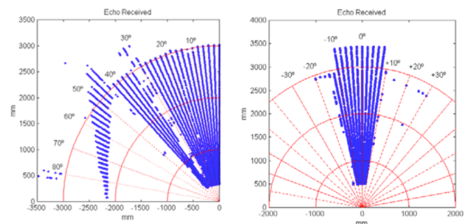
- Obstacle could be anywhere on the arc at distance D.
- The space closer than D is likely to be free.
- Two Gaussians in polar coordinates.

Sonar chirp fills a wide cone



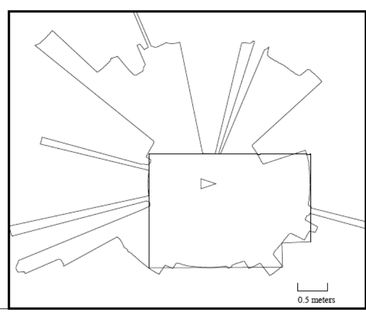
Data on sonar responses

- Sensing a flat board (Left) or pole (Right) at different distances and angles.
- For the board (2'x8'), secondary and tertiary lobes of the sonar signal are important.

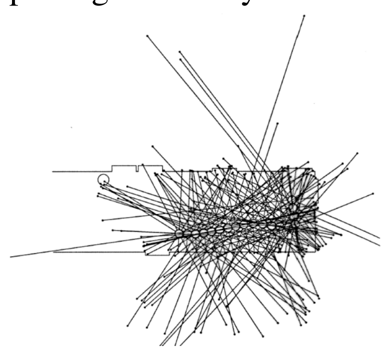


Specular Reflections in Sonar

- Multi-path (specular) reflections give spuriously long range measurements.

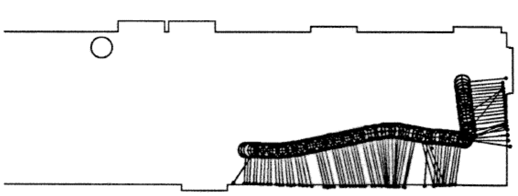


Exploring a Hallway with Sonar



A Useful Heuristic for Sonar

- Short sonar returns are reliable.
  - They are likely to be perpendicular reflections.

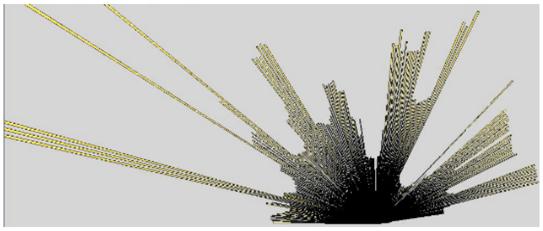


Lassie "sees" the world with a Laser Rangefinder

- 180 ranges over 180° planar field of view
- About 13" above the ground plane
- 10-12 scans per second

Laser Rangefinder Image

- 180 narrow beams at 1° intervals.



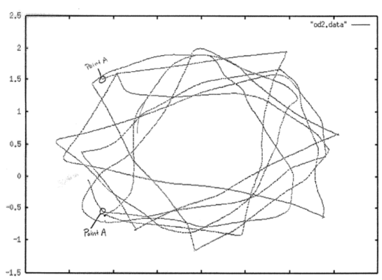
Ded ("Dead") Reckoning

- From shaft encoders, **ded**uce (Δx_i, Δy_i, $\Delta\theta_i$)
- **Ded**uce total displacement from start:

$$(x, y, \theta) = (0,0,0) + \sum_i (\Delta x_i, \Delta y_i, \Delta\theta_i)$$

- How reliable is this? It's pretty bad.
  - Each (Δx_i, Δy_i, $\Delta\theta_i$) is OK.
  - Cumulative errors in θ make x and y unreliable, too.

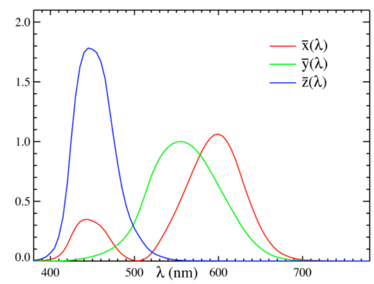
Odometry-Only Tracking: 6 times around a 2m x 3m area



- This will be worse for the Aibo walking.

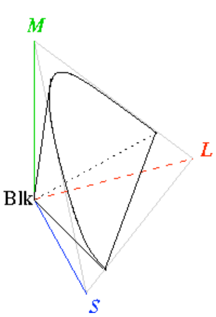
Human Color Perception

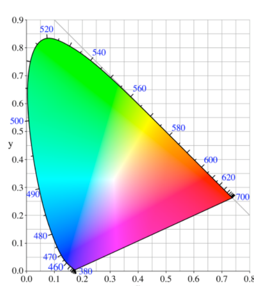
- Perceived color is a function of the relative activation of three types of cones in the retina



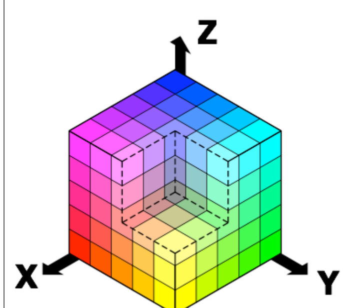
The Gamut of the Human Eye

- Gamut: the set of expressible colors





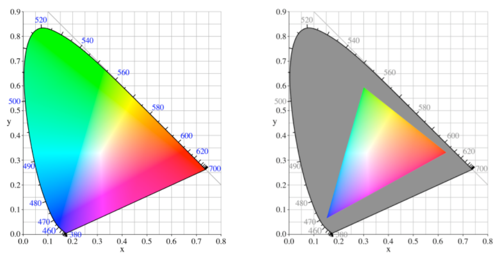
RGB: An Additive Color Model



Three primary colors stimulate the three types of cones, to achieve the desired color perception.

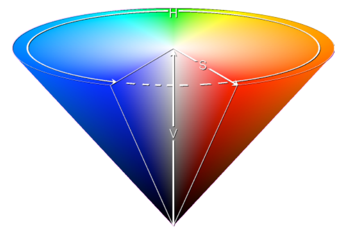
Color Perception and Display

- Only some human-perceptible colors can be displayed using three primaries.



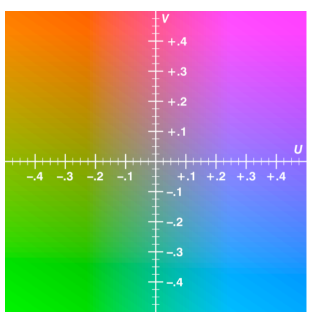
HSV: Hue-Saturation-Value

- HSV attempts to model human perception
  - $L^*a^*b^*$ (CIELAB) is more perceptually accurate
  - Lightness; a^*: red-green axis; b^*: yellow-blue



Aibo Uses the YUV Color Model

- RGB rotated
  - Y: Luminance
  - U-V: hue
- Used in PAL video format
- To track, define a region in color space.
  - See Tekkotsu tutorial



Our Goals for Robotics

- From noisy low-level sensors and effectors, we want to define
  - reliable higher-level sensory features,
  - reliable control laws for meaningful actions,
  - reliable higher-level motor commands.
- Understand the sensors and effectors
  - Especially including their errors
- Use abstraction