Lecture 2-2

Move It!:

Locomotion

The Robotics Primer (Ch. 5)

Quote of the Week

"In the fifties, it was predicted that in 5 years robots would be everywhere.
In the sixties, it was predicted that in 10 years robots would be everywhere.
In the seventies, it was predicted that in 20 years robots would be everywhere.
In the eighties, it was predicted that in 40 years robots would be everywhere..."

Marvin Minsky

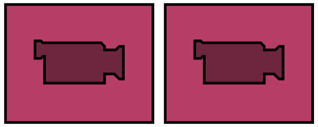
Change of schedule

- Monday’s Quiz on Locomotion (Ch. 5)
- We will skip Ch. 6
- Monday’s Lecture will be Kinematics (not in book)
- Tuesday 3/23/09 Quiz will be on kinematics
- Tuesday’s Lecture will be sensors (Ch. 7, 8)
- Monday 3/30/09 quiz on Ch. 7, 8

- Lab 2 now includes wall following also. Updated on Angel

Locomotion

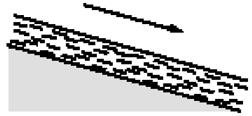
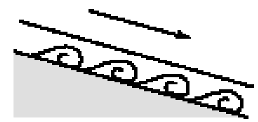
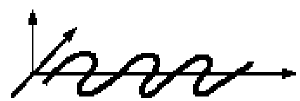
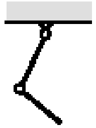
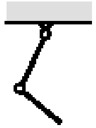
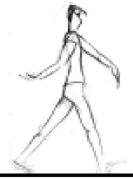
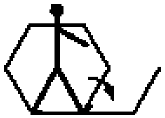
- **Locomotion** refers to the way that a robot moves from place to place
- Legged Locomotion in robotics is most difficult because of the increased DOF to control and stability issues



Locomotion is the complement of manipulation

- In **locomotion**, the environment is fixed and the robot moves by imparting force to the environment
- In **manipulation**, the robot arm is fixed but moves objects by imparting force to the environment

Biological Inspirations for Locomotion

Type of motion	Resistance to motion	Basic kinematics of motion
Flow in a Channel 	Hydrodynamic forces	Eddies 
Crawl 	Friction forces	 Longitudinal vibration
Sliding 	Friction forces	 Transverse vibration
Running 	Loss of kinetic energy	Oscillatory movement of a multi-link pendulum 
Jumping 	Loss of kinetic energy	Oscillatory movement of a multi-link pendulum 
Walking 	Gravitational forces	Rolling of a polygon (see figure 2.2) 

Stability

Stability means that the robot does not lean or fall over easily

- **Static stability** means the robot can stand still without falling over
- This requires enough legs or wheels to provide sufficient static points
- The center of gravity **(COG)** needs to be above the area covered by the ground points (polygon of support)

Dynamic Stability

- **Dynamic stability** means the robot must actively balance or move to remain stable
- Two-legged walking and one-legged hopping are dynamically stable
- **Static stability** is achieved through the mechanical design of the robot
- **Dynamic stability** is achieved through control

Moving and Gaits

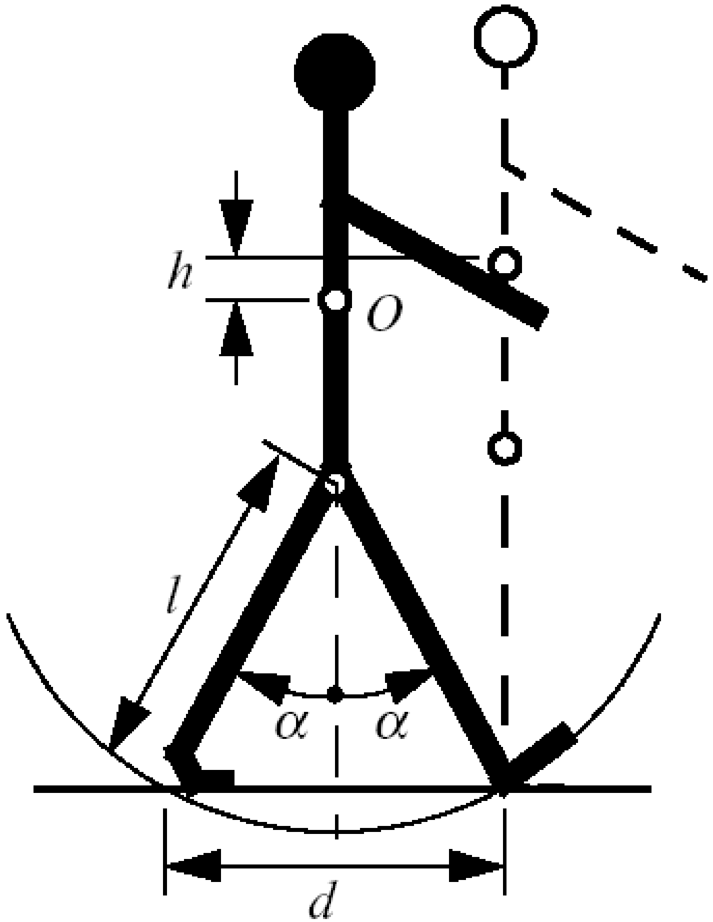
- A **gait** is the particular way a robot moves including the order in which it lifts and lowers its legs
- Robot gaits have the following properties:
  - Stability
  - Speed
  - Energy efficiency
  - Robustness
  - simplicity

Tripod Gait

- Six-legged walking is highly robust and common in nature
- The **tripod gait** is statically stable walking where three legs stay on the ground to form a tripod
- The **ripple gait** can be used for robots with more than six legs similar to a centipede
- A robot that can fly, swim or one with one or two leg has more balance and stability issues and is more complex to control
- Thus, most mobile robots have six legs or wheels

Wheeled motion versus Walking

- Rolling is
  - most efficient on hard surfaces
  - simple to implement and well suited to flat ground
- Wheeled motion versus legged motion has
  - A smaller number of actuators
  - Less structural complexity
  - Less control expense
  - More energy efficient on hard surfaces
- The movement of a walking biped is close to rolling
  - Wheeled locomotion is a human invention but bipedal walking can be approximated by a rolling polygon with sides equal in length d to the span of the step
  - The smaller the step gets, the more the polygon tends to a circle (wheel)



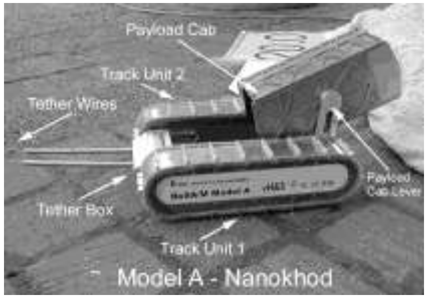
Wheels

- Wheels are more energy efficient and simpler to control and the locomotion effector of choice in robotics
- Wheels are designed to be statically stable
- Wheels may not be necessarily holonomic unless they are **omnidirectional**
- **Holonomic** means that the robot can control all of its available degrees of freedom

Steering

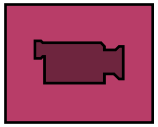
- The ability to drive wheels separately and independently through separate motors is **differential drive**
- The ability to steer wheels independently is **differential steering**
- If both wheels are driven at the same speed the robot moves forward or backward
- If the wheels have the same speed but opposite direction, the robot spins
- If one wheel is driven faster than the other, the robot moves in a circle or turns

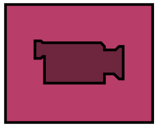
Tracked Mobile Robots



- Robots that make use of tread have larger ground contact and significantly improved maneuverability and traction
- However, changing the orientation requires a **slip/skid turn**.
- A slip/skid turn is where the robot spins wheels facing the same direction at different speeds or in opposite directions.
- A slip/skid turn on a high friction surface will overcome the torque of the motors
- The **disadvantage** is that the slip/skid steering makes it hard to determine the exact center of rotation of the robot. This makes it difficult to predict the exact change in position and orientation depending on ground friction
- **Dead reckoning** is also highly inaccurate on these robots

Tracked Mobile Robots



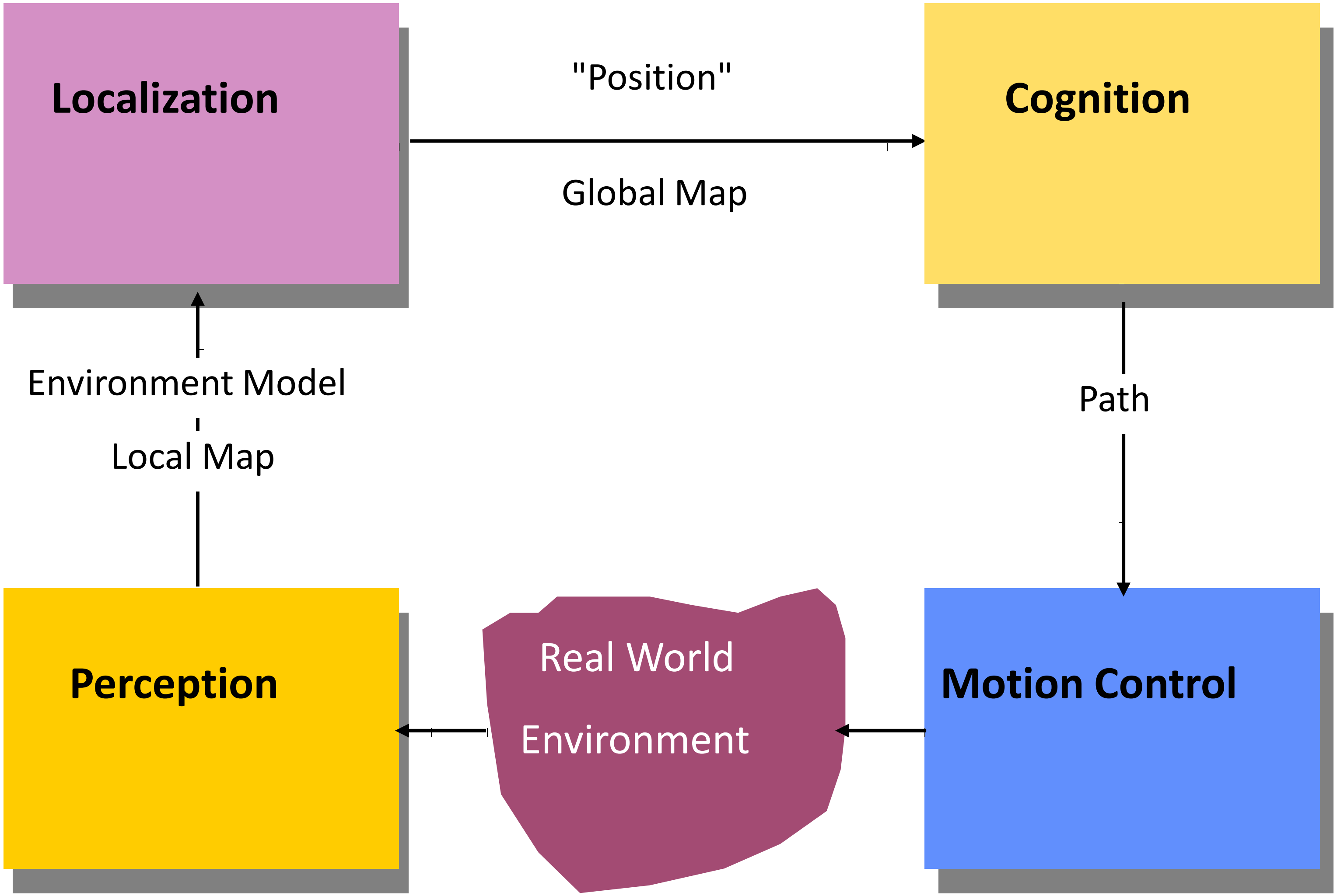


- Differentially Driven Vehicle
- Tracks are controlled by a servo motor using a closed-loop control system (typically a PID controller)
- Important because it has the ability to climb over obstacles not passable with wheels
- Generally, slower than wheeled vehicles
- Typically used military operations

Trajectory and Motion Planning

- Two concerns in locomotion
  - Getting the robot to a particular location (goal)
  - Having the robot follow a trajectory
- **Navigation** is concerned with getting to a goal
- **Trajectory planning (motion/path planning)** is more difficult than moving the robot to a particular location. This is related to forward and inverse kinematics.
- **Optimal trajectory** deals with finding the safest, shorts, or most efficient path

Locomotion Concepts: Path Planning



Mobile Robot Kinematics

- **Mobile robot kinematics** is the dynamic model of how a mobile robot behaves
- Kinematics is a description of mechanical behavior of the robot for design and control
- Mobile Robot Kinematics is used for:
  - Position estimation
  - Motion estimation
- Mobile robots move unbounded with respect to their environment
  - There is no direct way to measure robot position
  - Position must be integrated over time
  - The integration leads to inaccuracies in position and motion estimation

Odometry

- Odometry is a means of implementing **Dead Reckoning**
- A way of determining a robot’s position based upon previous known position information given a specific course heading and velocity
- Periodically requires error measurement to be ‘fixed’ or reset
- Meant for short distance measurements

Relative Positioning: Odometry and Kinematics

- Given wheel velocities at any given time, compute position/orientation for any future time
- Advantages
  - Self-contained
  - Can get positions anywhere along curved paths
  - Always provides an “estimate” of position
- Disadvantages
  - Requires accurate measurement of wheel velocities over time, including measuring acceleration and deceleration
  - Position error grows over time

Odometry errors

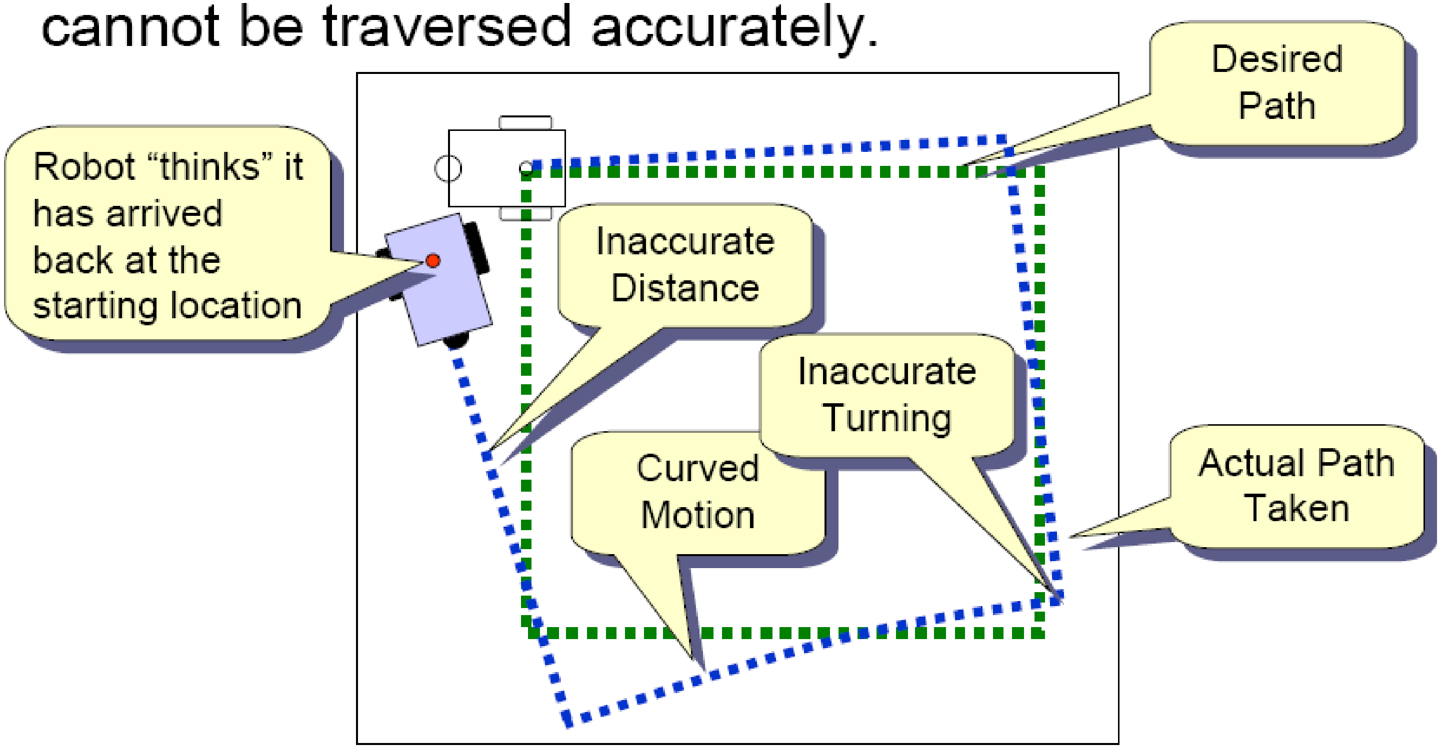
- Systematic
  - Unequal wheel diameters
  - Misalignment of wheels
  - Finite encoder resolution
  - Finite encoder sampling rate
- Non-systematic
  - Travel over uneven floors
  - Unexpected objects in the floor
  - Wheel slippage due to
    - Over acceleration
    - Slippery floor
    - skidding

Odometry errors

- Imprecise measurements
  - Discrepancy with actual speed and turn angles
- Inaccurate control model
  - Tracks/Wheels/Motors are not perfectly aligned or do not make contact at a single point
- Immeasurable physical characteristics
  - Friction
  - Wobbling wheels
  - Surface is not perfectly smooth and hard
  - Sliding

Dead Reckoning

- As a result of these error factors, a simple path cannot be traversed accurately.



Open Loop Control

- **Open Loop Control** does not use sensory feedback, and the robot state is not fed back into the system
- **Feed-forward control**
  - The command signal is a function of some parameters measured in advance
- Feed-forward systems **are effective** only if
  - They are well calibrated
  - The environment is predictable and does not change