6.141: Robotics systems and science Lecture 4: Locomotion

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http://courses.csail.mit.edu/6.141/
Challenge: Build a Shelter on Mars
Thanks to Keith Kotay for Figures

Last week we saw

- Bang-bang control
- Open loop control
- Closed loop control: P, I, D
- Motors

Today:

- Locomotion for robots
- Wheeled locomotion
- Legged locomotion
- Non-terrestrial locomotion

The Role of Locomotion

- The power to move the the robot from one place to another
  - Terrestrial: wheels (efficient), legs (versatile)
  - Aquatic
  - Airborne
  - Space
- Locomotion types
  - Statically stable
  - Dynamically stable

Odometry

- Robots need to know where they are but this is challenging
- Humans have evolved good system; robots rely on imperfect sensors
- Odometry: the use of motion sensors to compute relative position to known place

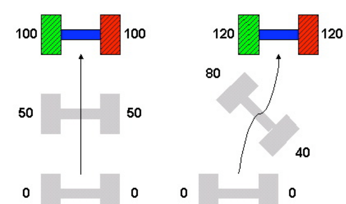
Odometry computation

- Estimate distance traveled using wheel turns; each turn $2 \Pi R$
- Use encoders: fixed number of pulses per wheel revolution
- Issues:

Odometry computation

- Estimate distance traveled using wheel turns; each turn $2 \Pi R$
- Use encoders: fixed number of pulses per wheel revolution
- Issues: inaccurate wheel diameter, lateral slip, spinning in place, pulse counting errors, slow processing, different wheel diameter

Slow Odometry



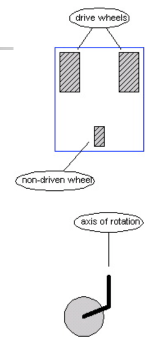
Each wheel actuated by separate motor
Numbers represent encoder values
A slow encoder that looks at final values concludes "straight line"

Wheeled Locomotion

- Differential drive
- Synchronous drive
- Car-type drive
- Skid-steer drive
- Articulated drive
- Pivot drive
- Dual differential drive

Differential Drive

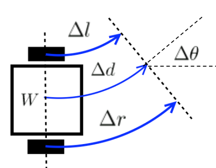
- 2 wheels on common axis
- Caster for balance
- Kinematics
- Translation: turn wheels at same speed, same dir.
- In-place rotation: turn wheels at same speed, opposite dir.
- Rotation while translating



Differential Drive

- Pro: simplicity
- Con: independent wheels => straight line control difficult
- Strategy: adjust motor RPM very often

Odometry Example



$$\Delta d = \frac{\Delta r + \Delta l}{2}$$

$$\Delta \theta = \frac{\Delta r - \Delta l}{W}$$

$$x \longleftarrow x + \Delta d \cos(\theta)$$

$$y \longleftarrow y + \Delta d \sin(\theta)$$

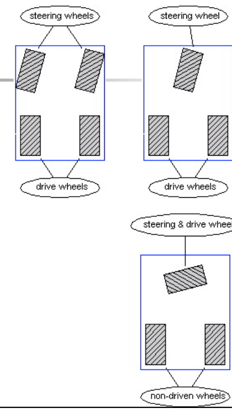
$$\theta \longleftarrow \theta + \Delta \theta$$

Synchronous Drive

- Pros: control
- Cons: complexity of mechanism, alignment

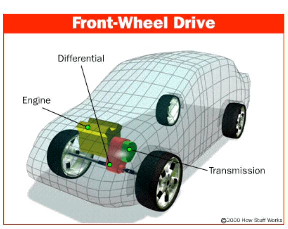
Car-drive

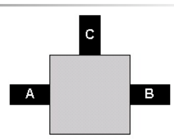
- 1 or 2 steering wheels
- 2 driving wheels
- Only 2 of the 3 DOFs directly controllable so non-holonomic system
- Turning wheels travel differently and slip
- To reduce odometry error place encoder on non-slipping wheels



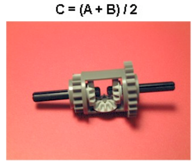
Differential

allows force to be combined

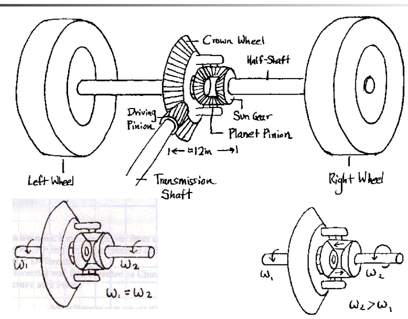




C = (A + B) / 2



How the differential works

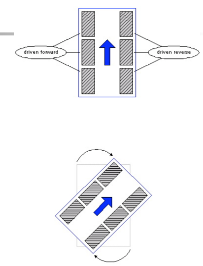


Car drive

- Pro: simple but turning mechanism must be precise
- Con: planning hard due to non-holonomic nature of the system
- Why is highway driving easy?

Skid-steer Drive

- For tracked vehicles and also >4 wheels
- Wheels on one side driven at same rate
- Steering by actuating each side at diff rate or different direction
- 1 motor per side

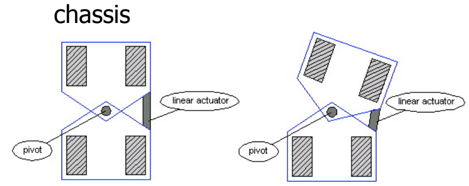


Skid-steer drive

- Pro: simplicity (no explicit steering mechanism) and great traction due to multiple wheels per side
- Con: control (straight-line motion hard as with differential drive) and skidding increases odometry error

Articulated Drive

- Car drive type with turning as deformation of the chassis
- 2 motors: one to drive, one to pivot chassis

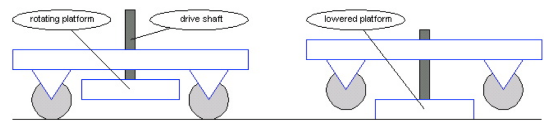


Articulated Drive

- Pro: simple but turning mechanism must be controlled precisely
- Con: planning---non-holonomic system

Pivot Drive

- 4 wheel chassis with non-pivoting wheels + rotating platform that can be raised and lowered
- 3 motors: drive straight, move platform, rotate

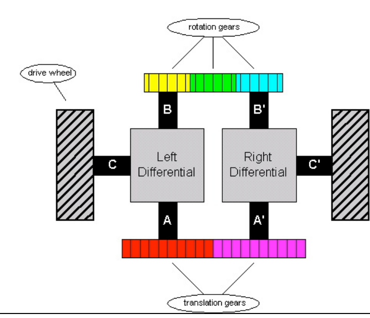


Pivot drive

- Pro: control: straight-line motion mechanically guaranteed, non need for interrupt-driven control
- Con: mechanism complexity, versatility (translation and rotation mutually exclusive)

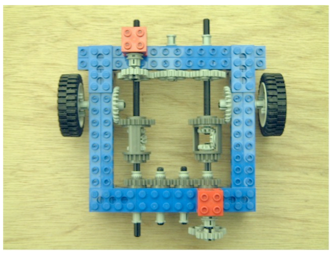
Dual Differential Drive

- Each wheel has a differential
- Differentials combine the forces from input shafts and resulting sum drives the wheel

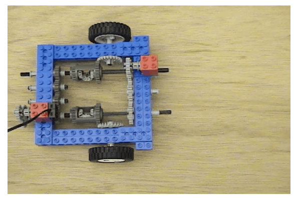


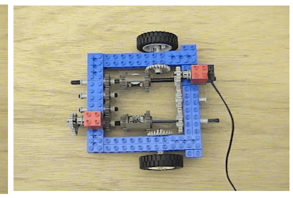
Dual Differential Drive

- 2 motors: one to drive wheels in same direction and one to drive in opposite direction



Dual Differential Drive





Dual Differential Drive

- Pros: control---straight-line motion guaranteed mechanically
- Cons: efficiency--too many gears

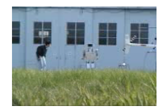
Omniirirectional Motion

Legged Locomotion

- Biped
- Quadruped
- Hexapod

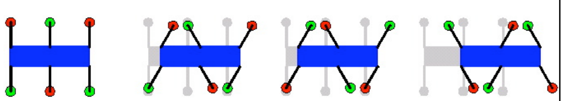
Biped Locomotion

- Statically vs dynamically stable
- Motors: depends on architecture >5 per leg
- Pro: versatility
- Con: complexity



Hexapod Locomotion

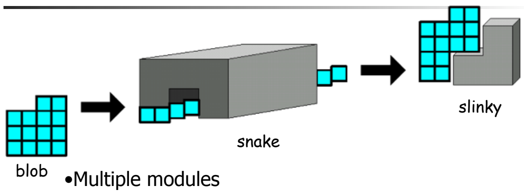
- Tripod gait
- Easy straight-line motion
- Hard turning



Hexapod Locomotion

- Pro: versatility and stability
- Con: complexity, large no motors

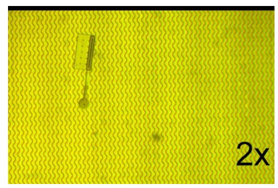
Other Robot Locomotion

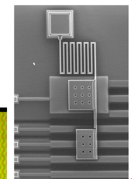


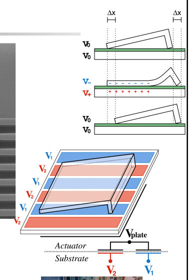
- Multiple modules
- Physically connected
- Capable of autonomous structural change
- Multiple functionalities---form follows function

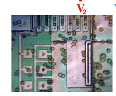
Microrobots

- Untethered actuators
- Self-release
- Power-delivery









With B. Donald, C. Levey, C. McGray, I Paprotny

AMOUR Movie

Future Robot Locomotion