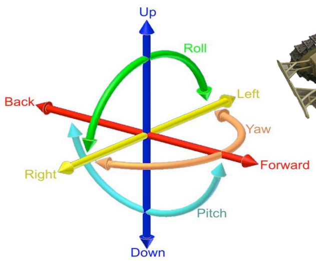
Mobility 2
DoFs, Wheels, and Wings



Many slides adapted from slides © R. Siegwart, ETH Zürich – Autonomous Systems Laboratory

1

Today

- Last time: walking and wheels (mostly)

Today:

- More DoFs, roll/pitch/yaw
- More mobility terminology
  - A bit more about wheels and treads
- Wings/propellers
- Other mobile actuators
- Walking wheels, passive flight, swimming, …

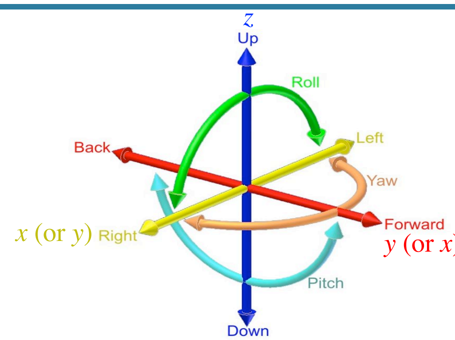
2

Degrees of Freedom (formally)

- DoFs: the number of independent parameters that define the state of a physical system.
  - Fine, but it underdefines "state"
- In robotics: any of…
  - The number of independently controlled actuators.
  - Possible changes of orientation of some set of parts:
- Now includes "the whole robot"
- Orientation, in 3-space: Pitch, yaw and roll
- Translation (position change): x, y, z

3

Pose DoFs: Pitch, Roll, Yaw



https://en.wikipedia.org/wiki/Six_degrees_of_freedom

4

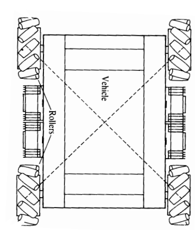
More About Omni Wheels

- Swedish (Mecanum, Ilon, Omni) wheel
  - Three degrees of freedom
  - Rotation around the (motorized) wheel axle, (sometimes motorized) rollers, contact point

5

Omni Movement

- Alternating left and right-handed rollers
  - Wheel applies force at right angles to the wheelbase diagonal
  - Can move in any direction by varying speed, direction of rotation of each wheel
- Types of motion
  - All four wheels in same direction: forward or backward
  - Wheels on one side opposite to other side: rotation
  - Wheels on one diagonal direction to wheels on other diagonal: sideways movement



https://en.wikipedia.org/wiki/Mecanum_wheel

6

More Characterization

- Maneuverability
  - How many different maneuvers a robot can do
    - "An act or instance of changing direction"
    - "To change the position of by a maneuver"
    - "To steer in various directions as required"
- Controllability
  - How easy it is to get the robot to do what you intend
    - Mechanically: e.g., slippage
    - Programmatically: e.g., 4 independently controlled wheels moving in unison
- Maneuverability / controllability are ≈ inversely correlated

7

7

Treads, Slip and Skid

- Great at moving heavy things
  - Lots of support
  - Even over bad terrain
- Treads are "wheels" with large surface contact
  - Violate the "point contact" assumption
- Q: How do you turn a tank?
  - What's the difficulty?
- A: Rotate treads opposite directions
  - How can this work?

8

8

Treads, Slip and Skid

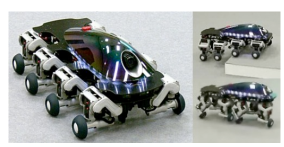
- Tradeoffs?
  - Friction on flat surfaces (= inefficiency)
  - High torque requirements
  - Tread wear
  - Terrain damage
  - Odometry

9

9

Walking Wheels

- Active or passive
- Roll and lift/release
- Roll and rollover



Halluc II, Chiba Inst. Of Tech.

10

10

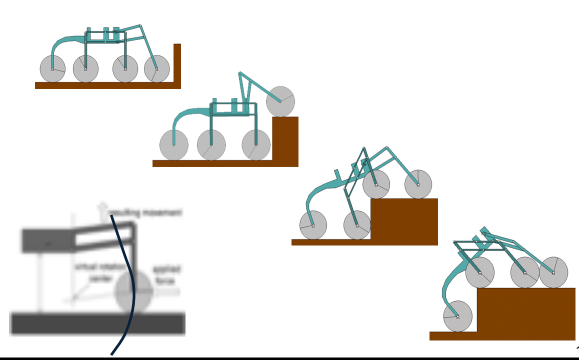
Passive: the Shrimp

- Passive locomotion on rough terrain
- 6 wheels
  - One fixed wheel in back
  - Two bogies on each side
  - Front wheel, spring suspension
- ≈ 60 cm long, 20 cm tall
- Highly stable in rough terrain
- Climbs obstacles up to 2x wheel diameter

11

11

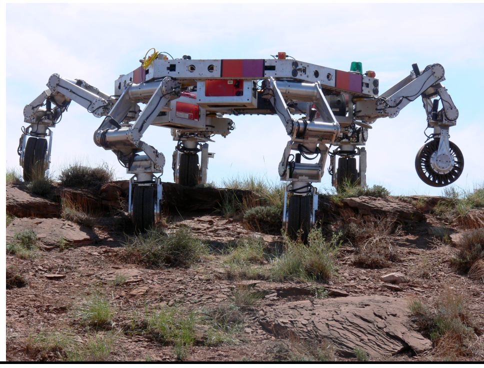
Shrimp "Walking"



12

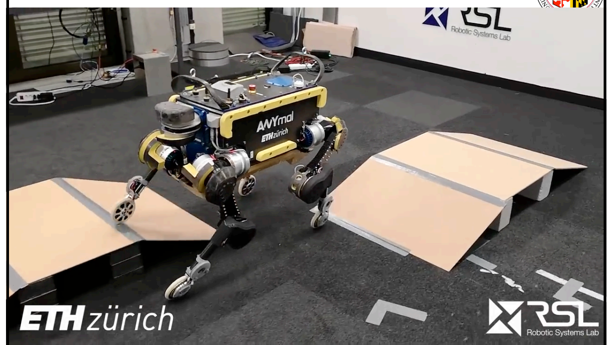
12

Active



13

13



https://www.youtube.com/watch?v=nGLUsyx9Vvc

14

14

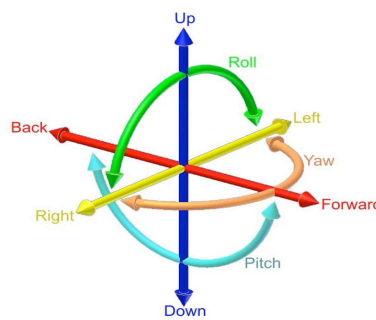
Flying

- Advantages
  - Rough terrain
  - Ground-inaccessible areas
  - Z-axis maneuverability
  - High-up perspective for mapping & sensing
  - Flying is cool
- Disadvantages
  - Control problems
  - Z-axis controllability
  - Weight & scaling laws
  - Flying is dangerous

16

16

3D Position DoFs



https://en.wikipedia.org/wiki/Six_degrees_of_freedom

17

17

Pitch, Yaw, Roll

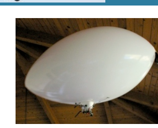
https://www.youtube.com/watch?v=rlVw-SNU8cM

18

18

Types of Flyers

- Fixed wing (sometimes flaps)
- Flapping wing
- Rotors/props
  - Axial (single)
  - Coaxial (reversed)
  - Tandem (two non-coaxial)
  - Quadcopters (+)
- Lighter-than-air



https://robotics.eecs.berkeley.edu/~ronf/Ornithopter/index.html

19

19

Disadvantages

- Fixed wing (sometimes with flaps)
  - Aerodynamics change drastically when miniaturized
  - Forward-only flight
- Flapping wing
  - Complex movements not perfectly understood
  - Scaling laws, wingspan, flapping speed
  - Hovering possible but not guaranteed
- Lighter-than-air
  - Slow, subject to wind and air conditions, temperature sensitive
- Rotors/props
  - Dangerous and/or fragile if contacted

20

20

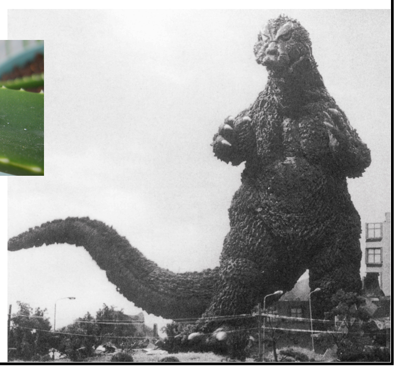
Quadcopters

- Most popular for small robots
- Advantages
  - Hovering
  - VTOL
  - Maneuverability
  - Simple construction
    - No tilt-rotors
- Disadvantages
  - Stabilization & control
    - But, largely automated now
  - Fragility (rotors)

21

21

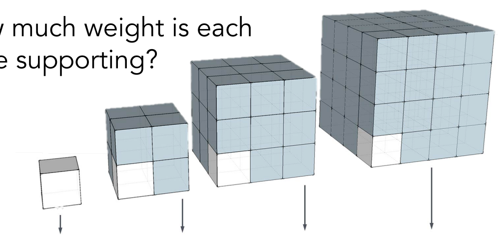
Scaling



22

The Square-Cube Law

- Volume increases as a cube function, but support area increases as a square function
- How much weight is each cube supporting?

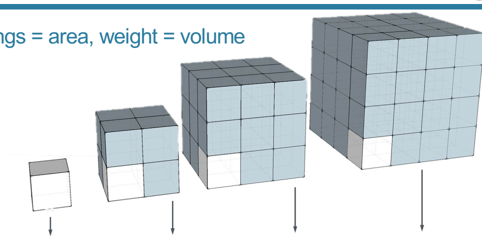


23

23

The Square-Cube Law

- Wings = area, weight = volume



Volume:

Area/face:

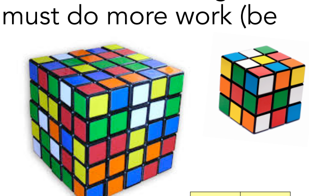
Force/cube:

24

24

Scaling

- The upshot: if you just make something bigger, the material must do more work (be stronger)
- Implications
  - For miniaturization
  - For power
  - For heat dissipation
  - For structural strength



	Small	Large
Area	54	150
Volume	27	125
A:V Ratio	***2***	***1.2***

25

25

Wings and Scaling

- What we care about: **lift**
  - Upward-acting force on a wing
  - Opposes gravity's pull on mass (holds robot up)
    - As well as various friction forces
- Factors producing lift
  - Wing area: directly related
  - Flap speed: indirectly correlated
- Scaling
  - Wingspan/speed scale logarithmically with mass

https://www.thespruce.com/bird-wing-parts-387365

28

28

Mobile Efficiency

- **Cost of transportation** – how much energy to move the robot itself?
- "Best" depends heavily on terrain and task
  - On flat terrain: tires
  - On uneven or soft terrain: legs
  - Hovering in still air: blimps
  - For fast flight: wings
  - For material efficiency: fixed wings
  - In water: swimming or propulsion
  - And so on…

30

30

Transportation Costs

- Leg lift and carry
- Deceleration
- Contact friction
- Internal friction
- Damping
- …

Next time: Sensors!

31

31