CMPE 185: Autonomous Mobile Robots

Mobile Robot Locomotion

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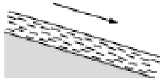
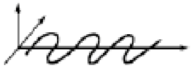
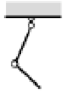
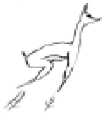
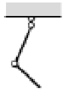
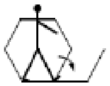
Locomotion Concepts: Principles Found in Nature

- **Robot locomotion** is the collective name for the various methods that robots use to transport themselves from place to place.

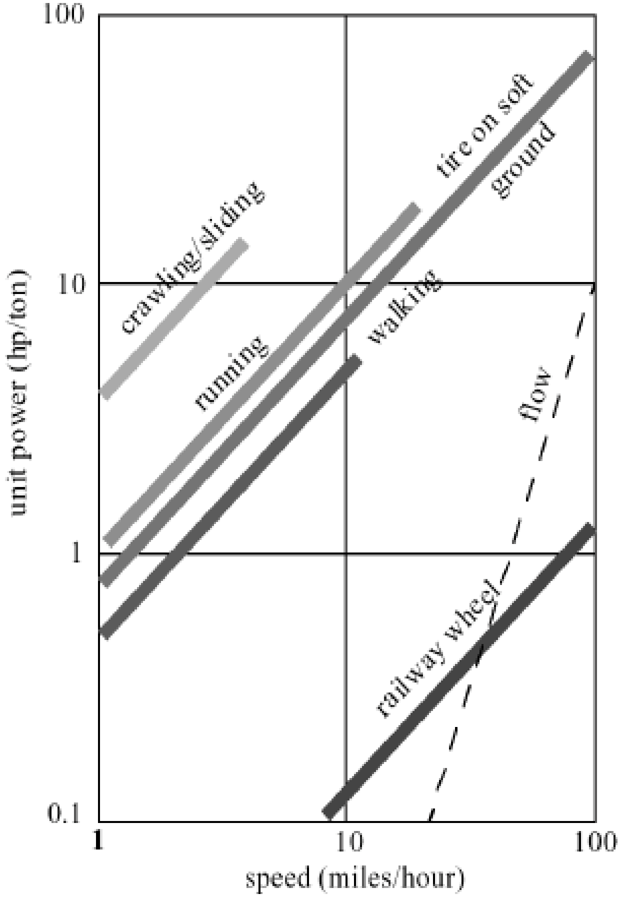
- Nature came up with a multitude of locomotion concepts
  - Adaptation to environmental characteristics
  - Adaptation to the perceived environment (e.g. size)

- Concepts found in nature
  - Difficulty to imitate technically
  - Do not employ wheels
  - Sometimes imitate wheels (bipedal walking)

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) 

Walking or Rolling?

- Number of actuators
  - An actuator: a component of a machine that is responsible for moving and controlling a mechanism or system
  - Requires a control signal and a source of energy
- Structural complexity
- Control expense
- Energy efficient
  - Terrain (flat ground, soft ground, climbing…)
- Movement of the involved masses
  - Walking / running includes up and down movement of COG
  - Some extra losses
- Most technical systems today use wheels
  - Legged locomotion is still mostly a research topic



Characterization of Locomotion Concept

- Locomotion
  - Physical interaction between the robot and its environment
- Locomotion is concerned with interaction forces, and the mechanisms and actuators that generate them
- The most important issues in locomotion are
  - Stability
    - Number of contact points
    - Center of gravity
    - Static/dynamic stabilization
    - Inclination of terrain
  - Characteristics of contact
    - Contact point or contact area, angle of contact, friction…
  - Type of environment
    - Structure, medium (water, air, soft or hard ground)

Mobile Robot Locomotion

- Legged robot
- Wheeled robot
- Flying robot
- Swimming robot

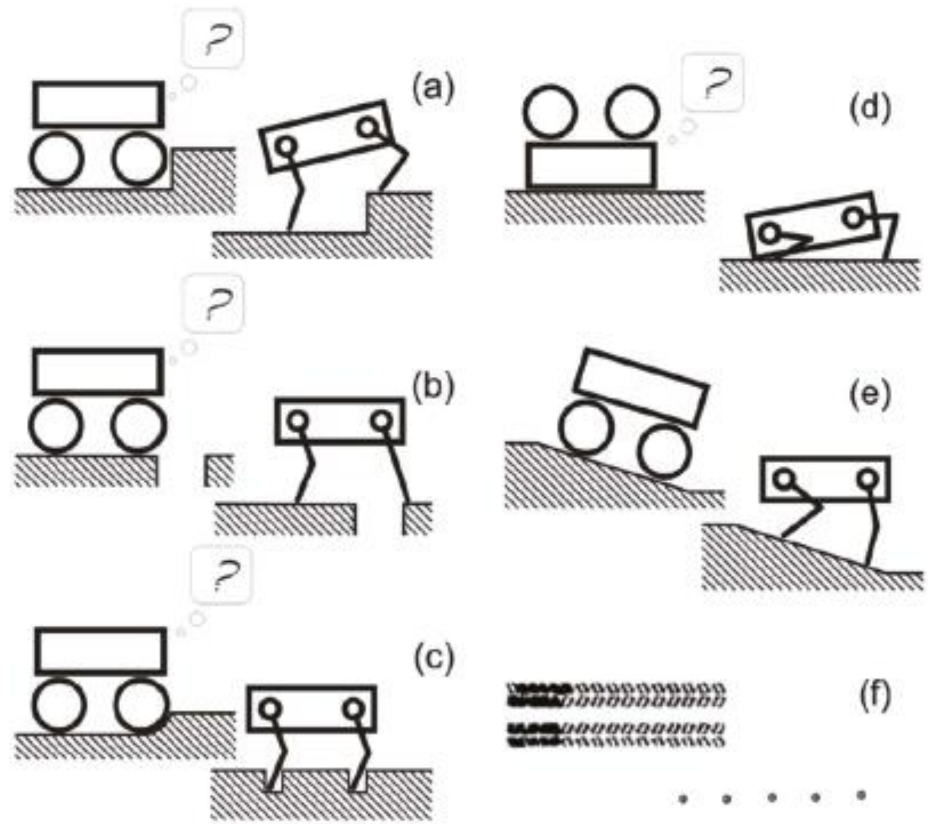
Legged Robots

Why Legged Robots

- Legged systems can overcome many obstacles, that are not reachable by wheeled systems

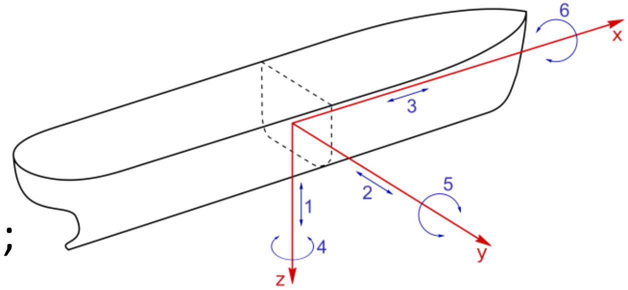
- But it is quite hard to achieve this since
  - Many DOFs must be controlled in a coordinated way
  - The robot must see detailed elements of the terrain

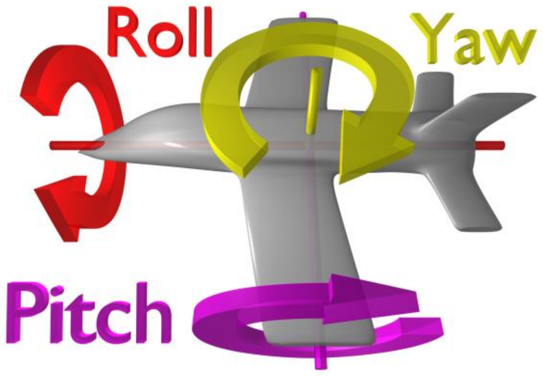
  - DOF?



What is DOF?

- The **degree of freedom (DOF)** of a mechanical system is the number of independent parameters that define its configuration.
- The motion of a ship at sea has the six degrees of freedom of a rigid body, and is described as:
  - **Translation and rotation:**
    - Moving up and down (elevating/heaving);
    - Moving left and right (strafing/swaying);
    - Moving forward and backward (walking/surging);
    - Swivels left and right (yawing);
    - Tilts forward and backward (pitching);
    - Pivots side to side (rolling).



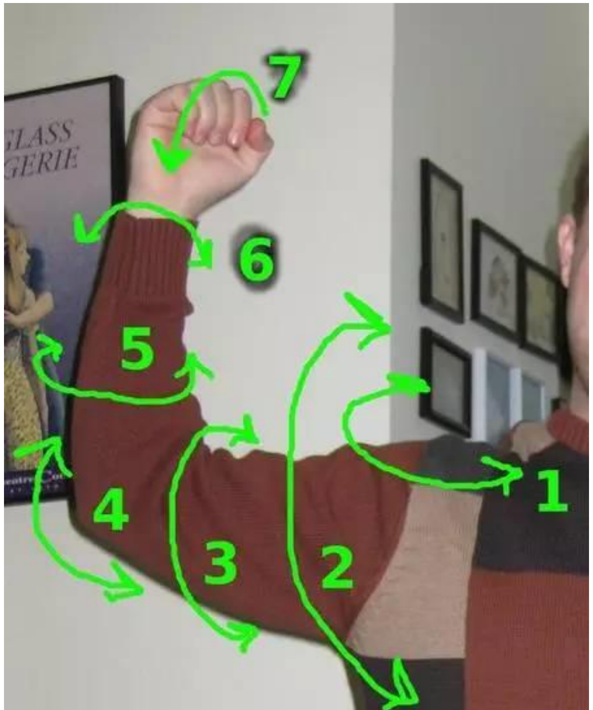


- Question: the DOF of your arm?

Photos from wikipedia

What is DOF?

- The DOF of your arm?



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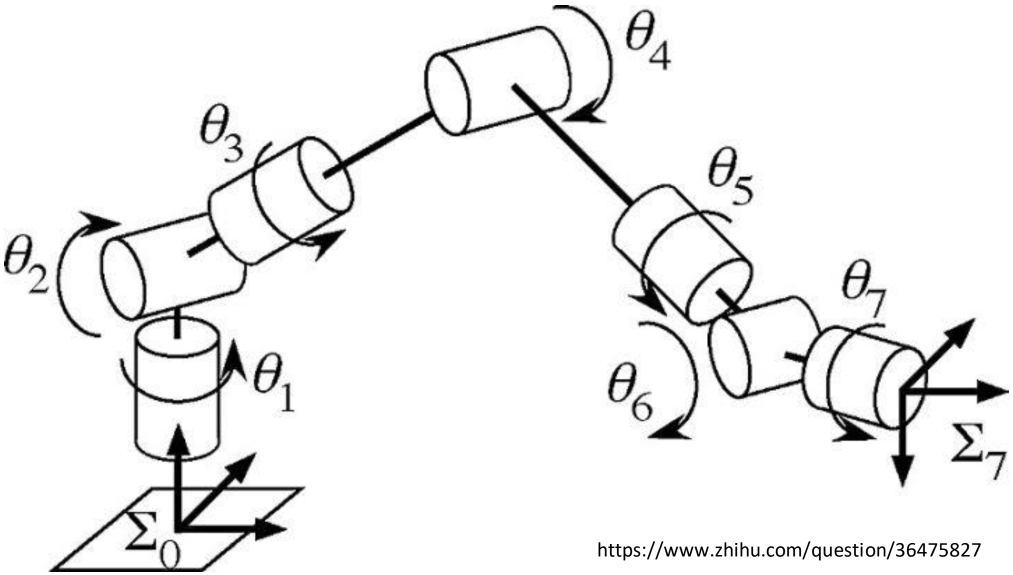

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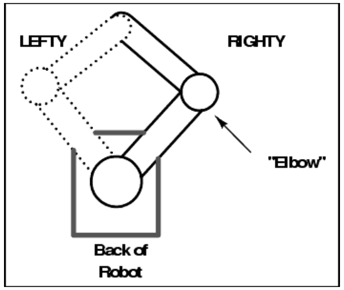
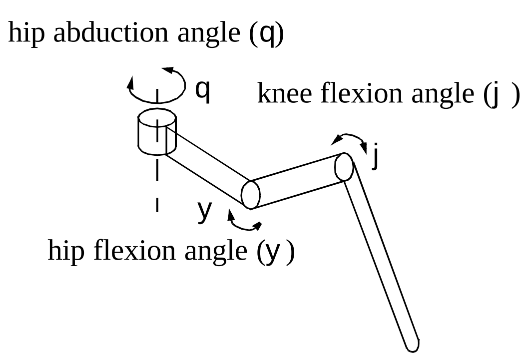
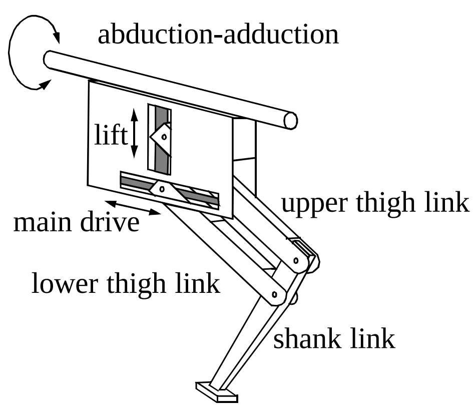


Number of Joints of Each Leg

- A minimum of two DOF is required to move a leg forward
  - A lift and a swing motion
  - Sliding-free motion in more than one direction not possible
- Three DOF for each leg in most cases





- 4^{th} DOF for the ankle joint
  - Might improve walking and stability
  - Additional joint (DOF) increases the complexity of the design and especially of the locomotion control

The Number of Distinct Event Sequences (Gaits)

- The gait is characterized as the distinct sequence of lift and release events of the individual legs
  - It depends on the number of legs
  - The number of possible events N for a walking machine with k kegs is

$$N = (2k-1)!$$

- For a biped walker (k = 2), the number of possible events N is

$$N = (2k-1)! = 3! = 3 \cdot 2 \cdot 1 = 6$$

1. *Lift left leg*
2. *Release left leg*
3. *Lift right leg*
4. *Release right leg*
5. *Lift both legs together*
6. *Release both legs together*

- For a robot with 6 legs (hexapod), N is

$$N = 11! = 39'916'800$$

Dynamic Walking v.s. Static Walking

- Statically stable

- Body weight supported by at least three legs
- Even if all joints ‘freeze’ instantaneously, the robot will not fall
- Safe, slow and inefficient

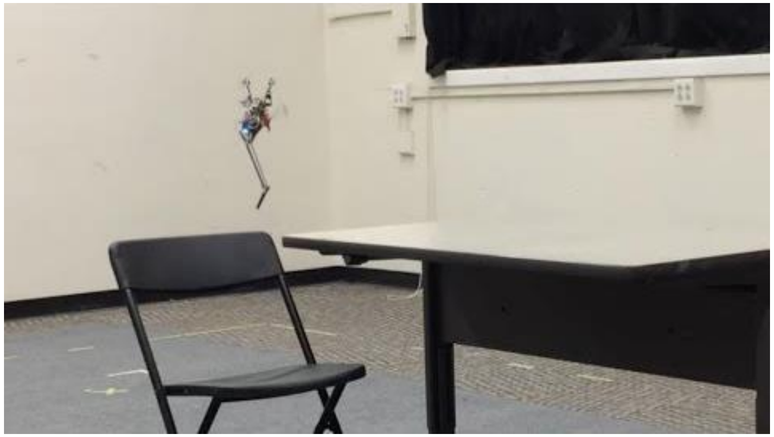
- Dynamic stable

- The robot will fall if not continuously moving
- Less than three legs can be in ground contact
- Fast, efficient and demanding for actuation and control

Legged Robots

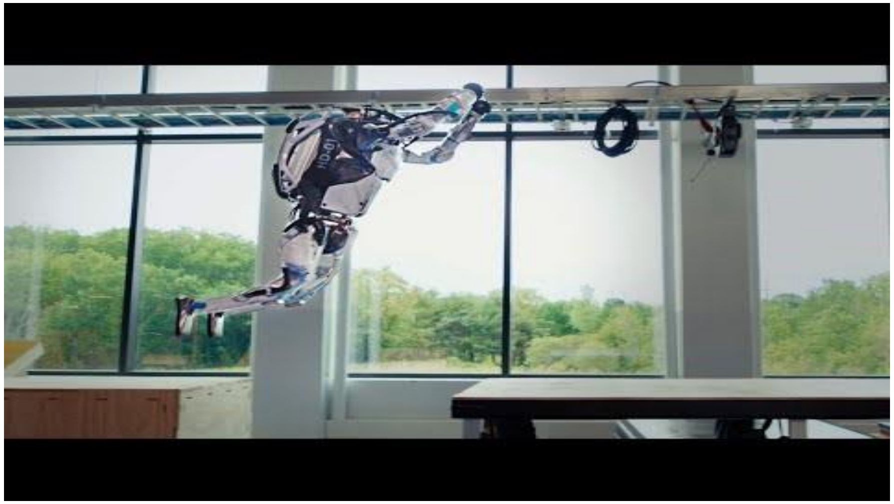
- **One leg**
  - No leg coordination needed
  - Single point of contact with the ground in lieu of an entire track
  - May dynamically cross a gap that is larger than its stride
- Challenge: balance, static walking / static stability is impossible

Raibert hopper



Legged Robots

- Two Legs (Biped)
  - can be built to have the same approximate dimensions as human -- good for human-robot interaction
  - can only be statically stable within some limits



Boston Dynamics Atlas

Honda Asimo

Legged Robots

- Four Legs (Quadruped)
  - Standing still is passive stable
  - Walking is still challenging because to remain stable the robot's center of gravity must be actively shifted during the gait

Legged Robotics – Impressive Mobility

- Boston Dynamics Spot
  - Uses LIDAR and stereo and other sensors to sense the environment
  - Carries a 23 kg payload and operates for 45 minutes on a battery charge

Legged Robotics – Impressive Mobility

- Boston Dynamics Spot Mini
  - small four-legged robot that comfortably fits in an office or home
  - inherits all of the mobility of its bigger brother, [Spot](), while adding the ability to pick up and handle objects using its 5 degree-of-freedom arm and beefed up perception sensors.

Legged Robots

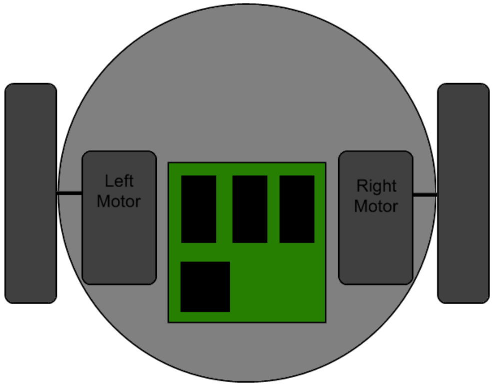
- Six legs (hexapod)
  - Insects, which are arguably the most successful locomoting creatures on earth, excel at traversing all forms of terrain with six legs, even upside down.

Wheeled Robots

- Differential drive
- Car drive (Ackerman)
- Synchro drive
- Tricycle/bicycle drive
- Omnidirectional drive

Wheeled Robots

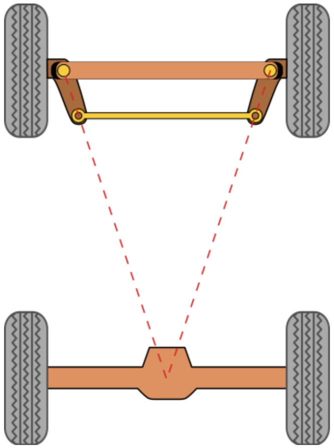
- **Differential drive**
  - Simplest drive mechanism: most popular wheeled mobile robotic locomotion
  - Consists of two wheels mounted on a common axis
  - Each wheel is controlled by a separate motor
- How to change its direction?
- Easy to control robot motion

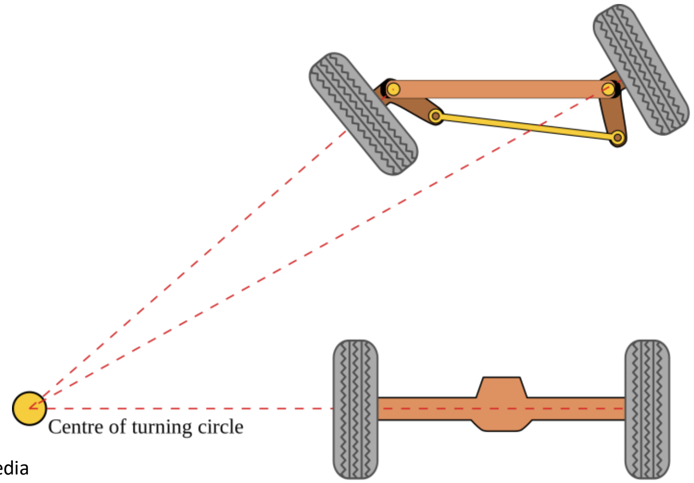


- Main disadvantage: difficult straight line control

Wheeled Robots

- **Car drive (Ackerman-like)**
  - Found of most cars, great for larger outdoor vehicles
  - The front steering wheels rotate to provide steering
  - The back drive wheels power the motion of the vehicle
  - can carry very heavy payloads



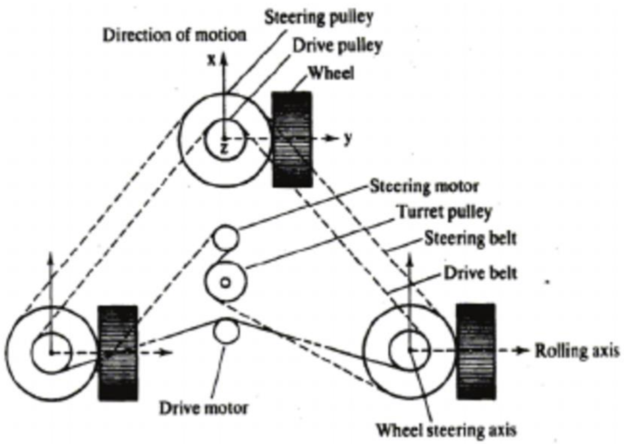


wikipedia

- Easy to implement
- Main disadvantage: can't change robot position and orientation easily (think of parallel parking a car)

Wheeled Robots

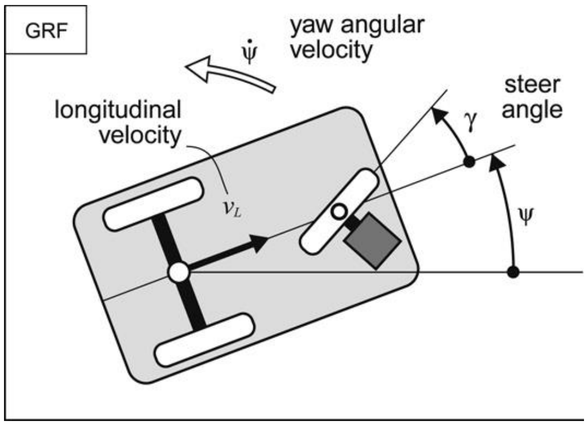
- **Synchro drive**
  - The synchro drive system is a two motor, three/four wheeled drive configuration
  - One motor rotates all wheels to produce motion and the other motor turns all wheels to change direction,
  - Mechanically or electrically synchronized motors
  - Each wheel is capable of being driven and steered

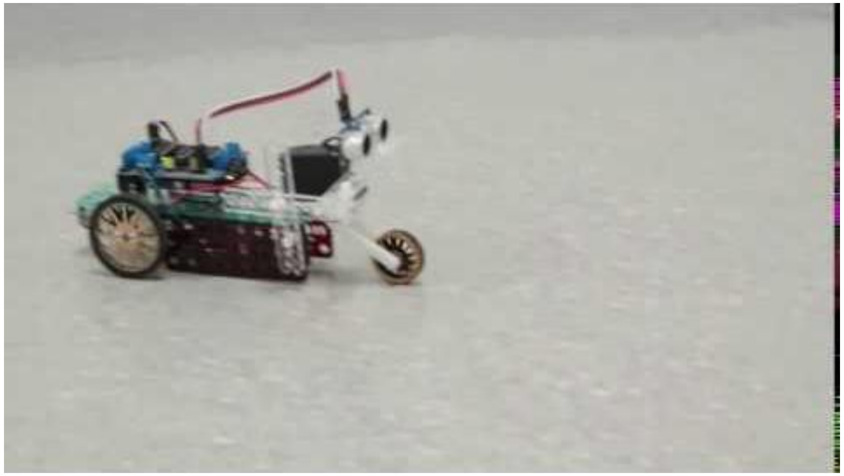


- Main disadvantage: complex design and implementation

Wheeled Robots

- **Tricycle/bicycle drive**
  - Sometimes called bogey or wagon drive
  - Two/one rear wheel(s) are passive ones
  - The front wheel provides steering and power for the robot
- Easy to control since only one wheel drives and steer

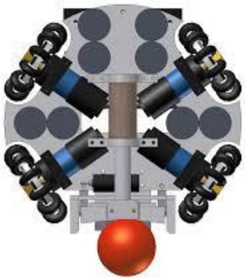


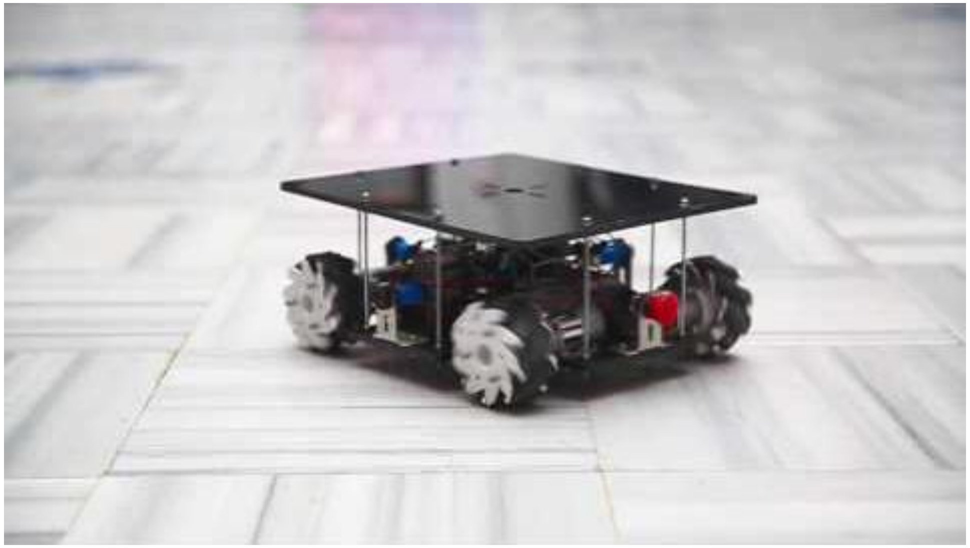


- Main disadvantage: difficult to control in tight spots

Wheeled Robots

- **Omnidirectional drive**
  - Most complex drive mechanism
  - Each wheel can go forward and sideways simultaneously
  - Robot can go in any direction smoothly
- Capable of very precise movements in all directions





- Main disadvantage: complex implementation and control

Combining Legged and Wheeled Robots?

- Boston Dynamics Handle

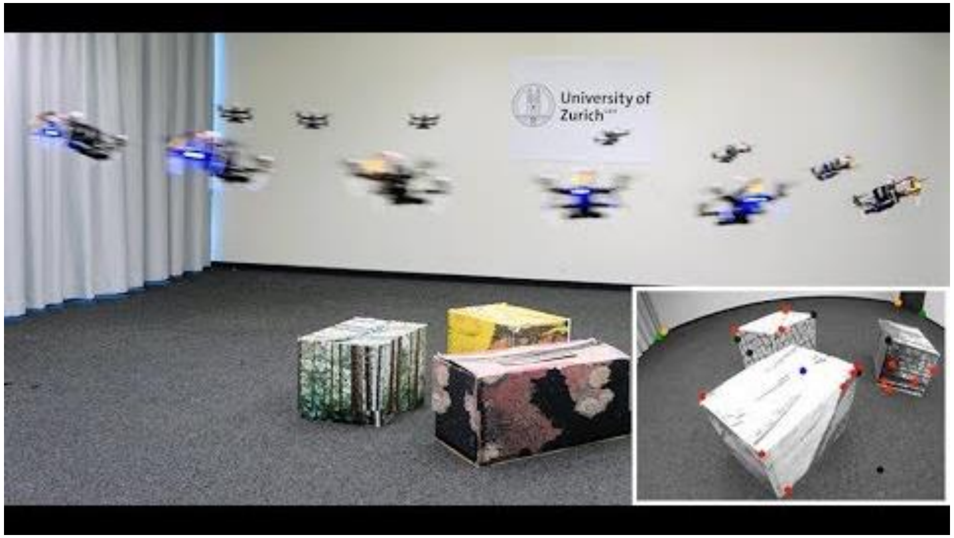
Flying Robots

- Helicopters
- Fixed wing airplanes
- Blimp: lighter-than-air
- Flapping wings

How to Fly (Unmanned Aerial Vehicles)

- **Helicopters**
  - < 20 minutes
  - Highly dynamic and agility
- Quadrotors
  - A **quadcopter,** also called a **quadrotor helicopter** or **quadrotor** is a multirotor helicopter that is lifted and propelled by four rotors.

By Doodybutch - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=47682806



How to Fly (Unmanned Aerial Vehicles)

- **Fixed wing airplanes**
  - > some hours; continuous flights possible
  - Non-holonomic constraints

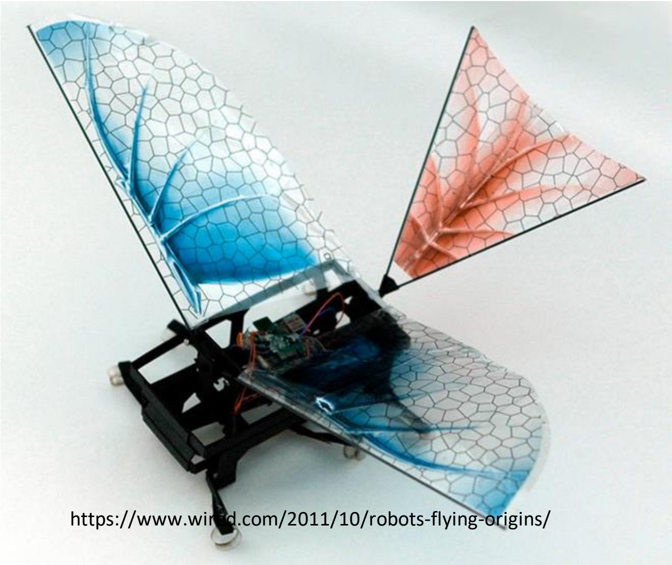
How to Fly (Unmanned Aerial Vehicles)

- **Blimp: lighter-than-air**
  - > some hours (dependent on wind conditions)
  - Sensitive to wind
  - Mostly large size (dependent on payload)

https://www.youtube.com/watch?v=7NfUU1V6jxs

How to Fly (Unmanned Aerial Vehicles)

- **Flapping wings**
  - < 20 minutes; gliding mode possible
  - Non-holonomic constraints
  - Very complex mechanics



Swimming Robots

- ROVs
- AUVs
- Hybrid Vehicles

Remotely Operated Underwater Vehicle (**ROV**)

- A remotely operated underwater vehicle (**ROV**) is a tethered underwater mobile device.
- All tethered -- Tether provides power and transmits data
- Usually equipped with video/TV Cameras
- Highly maneuverable

Heavy duty ROVs

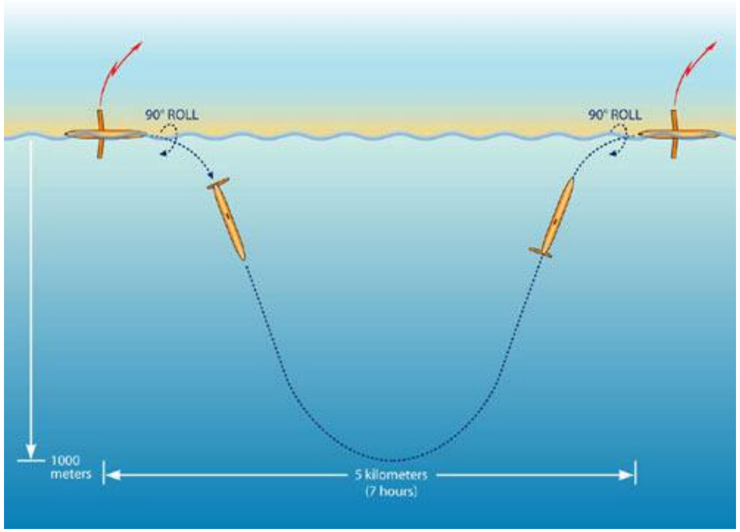
Small ROVs

Autonomous Underwater Vehicle

- An **autonomous underwater vehicle** (**AUV**) is a robot that travels underwater without requiring input from an operator.
- Tether less
- Carries its own power
- No pilot and pre-Programmed

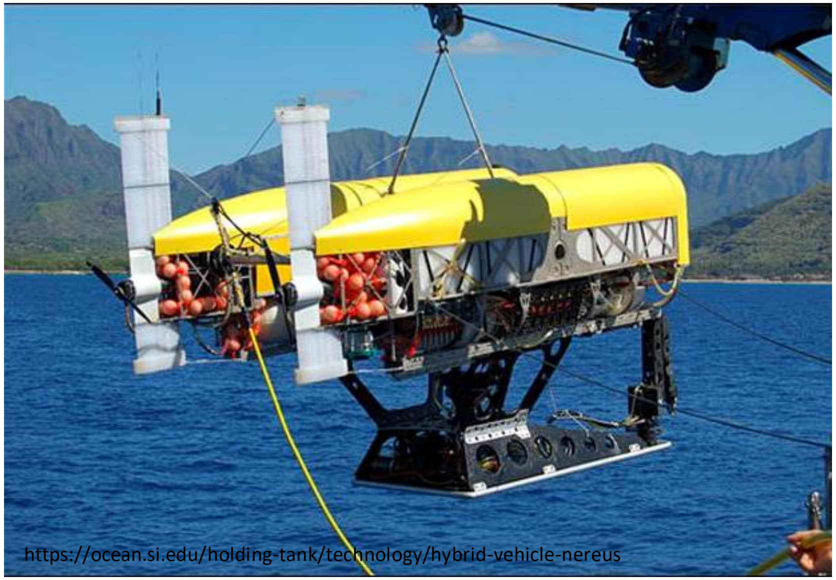
Underwater Gliders

- An **underwater glider** is a type of AUV that uses small changes in its buoyancy in order to move up and down in the ocean like a profiling float
- Requires less stored energy



Hybrid Underwater Vehicles

- A **hybrid underwater vehicle** combines the best features of an ROV, which is connected to a ship in order to transmit data and video feeds, and an AUV, which can swim freely and cover a larger area.
- Nereus
- On May 31, 2009, Nereus reached the deepest part of the ocean—the Marianas Trench, located in the western Pacific Ocean, 10,902 meters (6.8 miles) below the surface. That makes the [remotely operated Nereus] the deepest-diving vehicle currently in service.



- Thank you!