

CMPE 185: Autonomous Mobile Robots

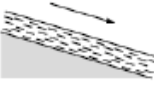


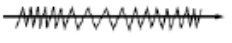

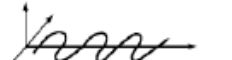






Mobile Robot Locomotion

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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) 

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

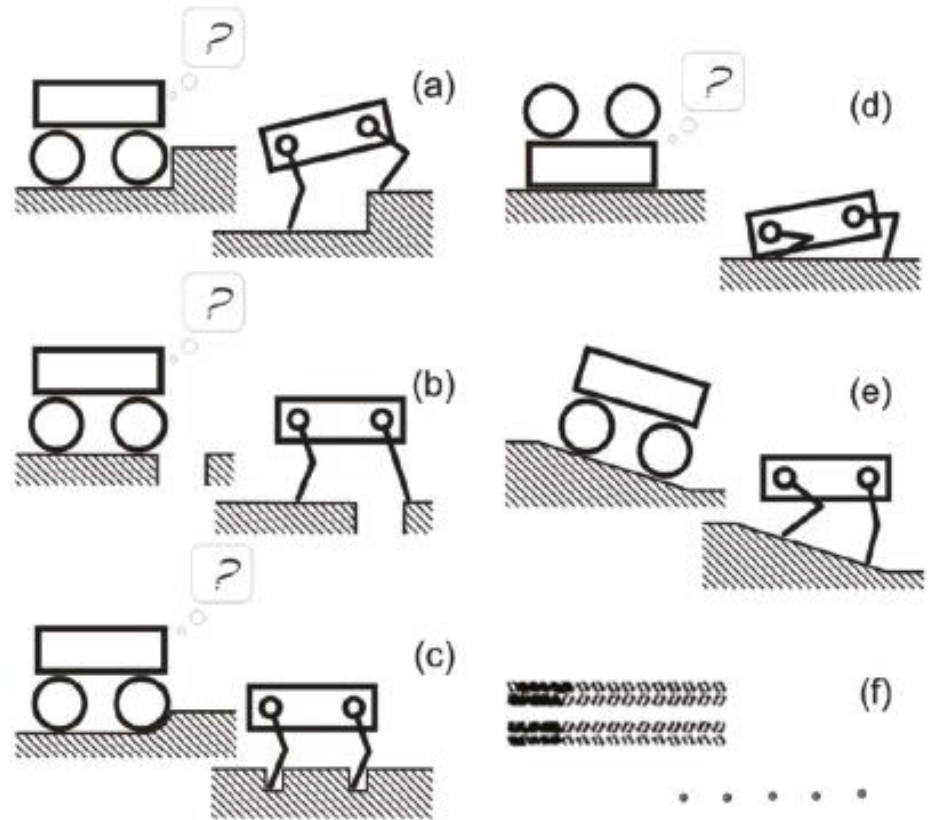
- Legged robot
- Wheeled robot
- Flying robot
- Swimming robot

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?

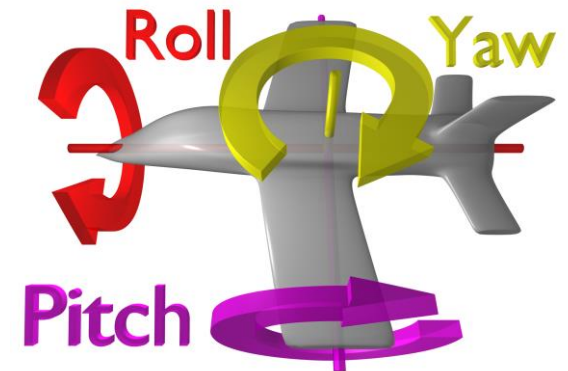
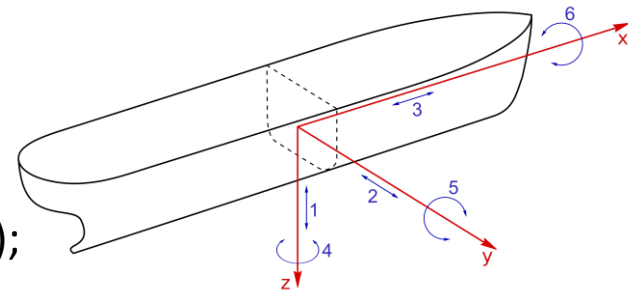


What is DOF?

- 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:**

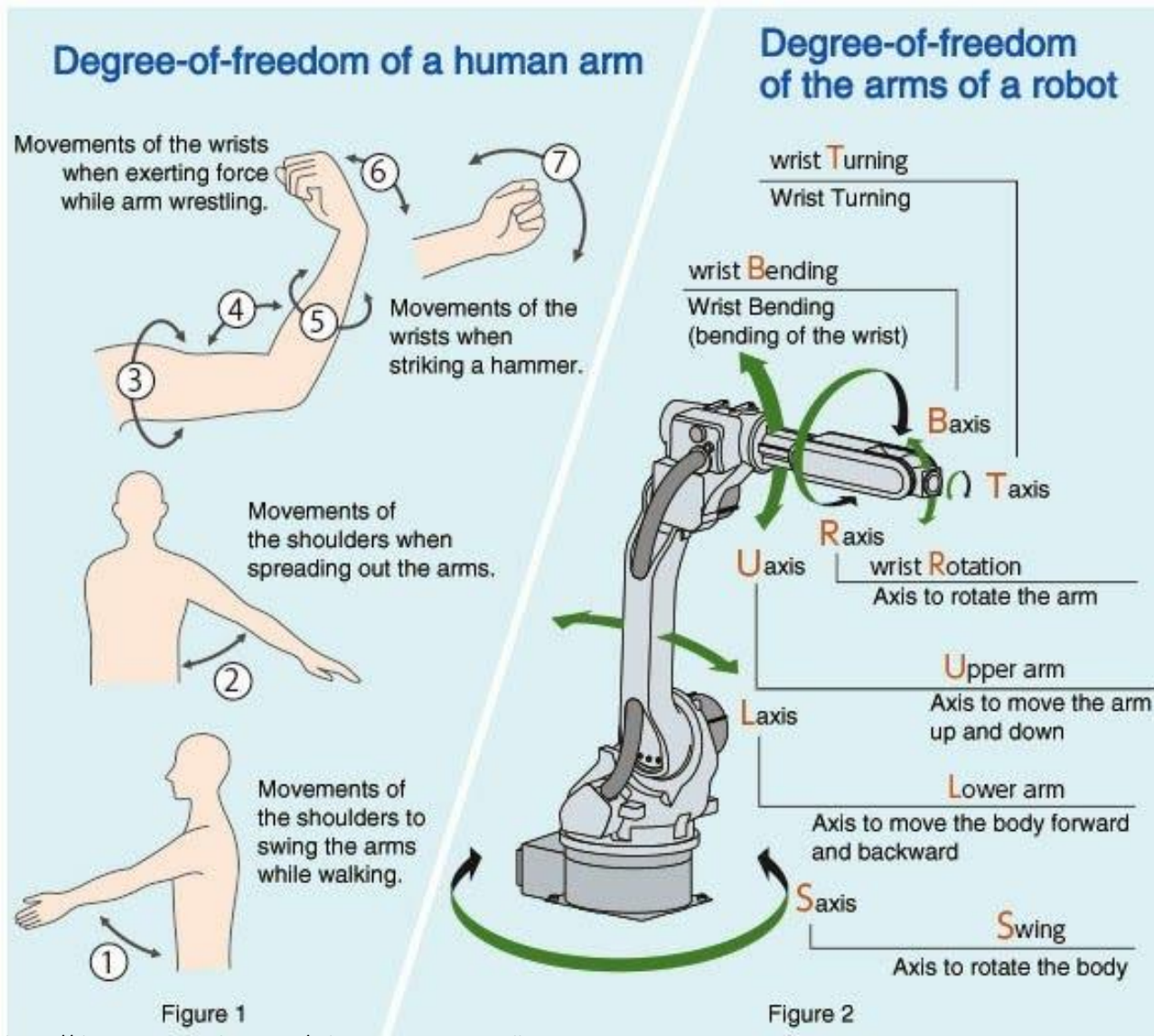
- Moving up and down (elevating/heaving);
- Moving left and right (strafing/swaying);
- Moving forward and backward (walking/surging);
- Swivels left and right ([yawing](#));
- Tilts forward and backward ([pitching](#));
- Pivots side to side ([rolling](#)).



Photos from wikipedia

- Question: the DOF of your arm?

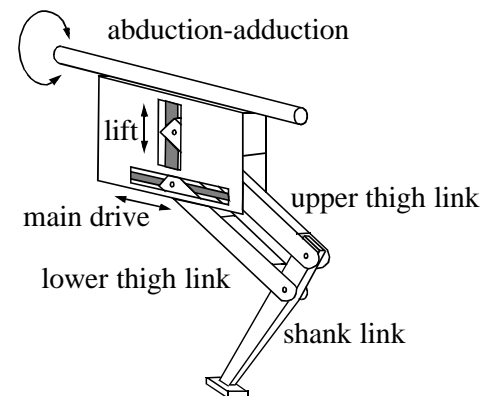
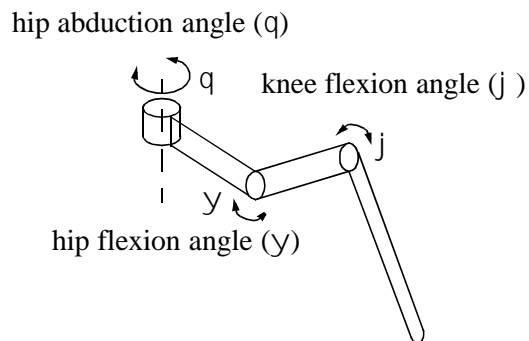
What is DOF - The DOF of your arm?



<https://shaype0725.medium.com/robotic-arms-78998e3dbe0>

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



- 4th 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 legs is

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

$$N = (2 \times 6 - 1)!$$

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

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

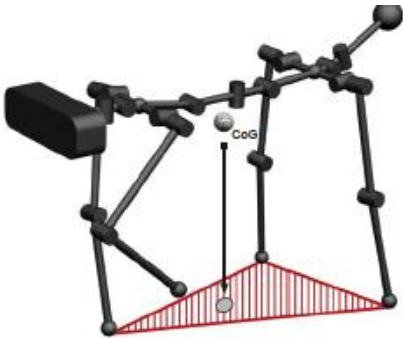
1. Lift left leg
2. Release left leg
3. Lift right leg
4. Release right leg
5. Lift both legs together
6. Release both legs together

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

$$N = 11! = 39916800$$

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

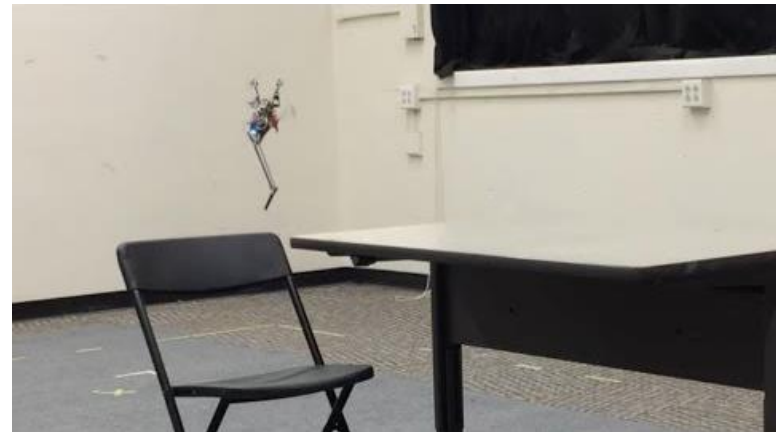


Legged Robots

- **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

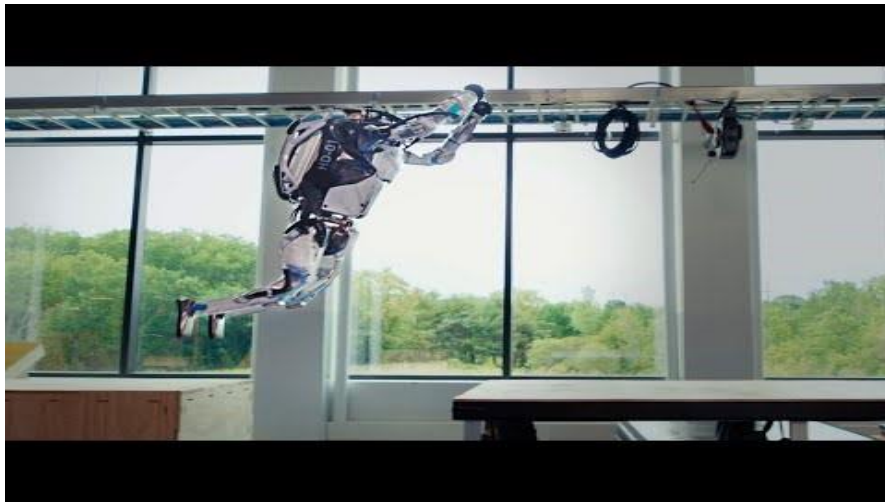


Raibert hopper



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 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

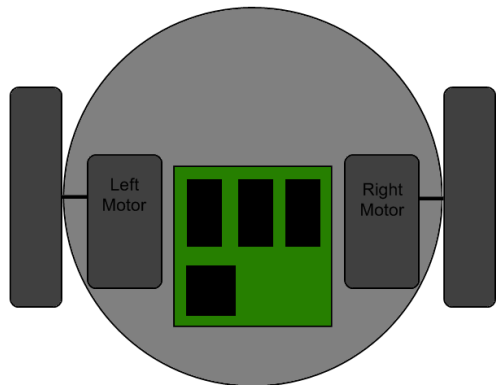


Wheeled Robots

- **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

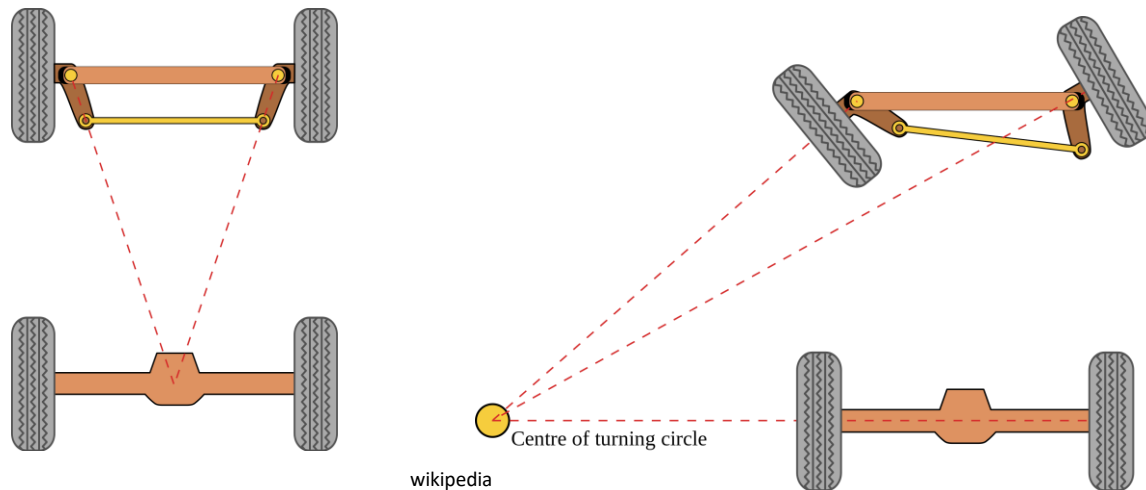


- Main disadvantage: difficult straight line control

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

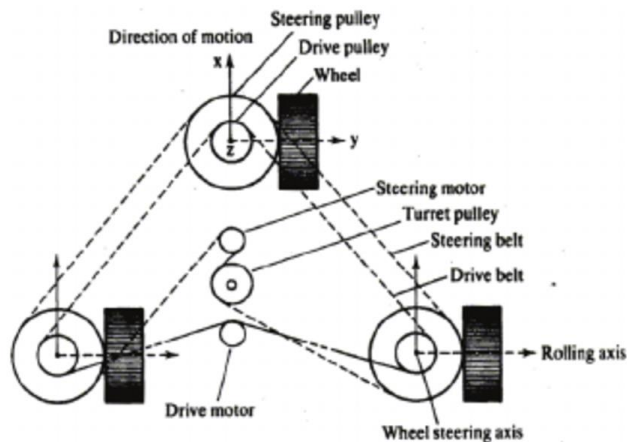
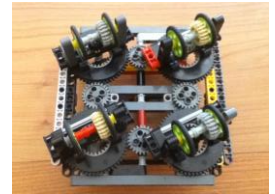


- Easy to implement
- Main disadvantage: can't change robot position and orientation easily (think of parallel parking a car)

Wheeled Robots

- **Synchro drive**

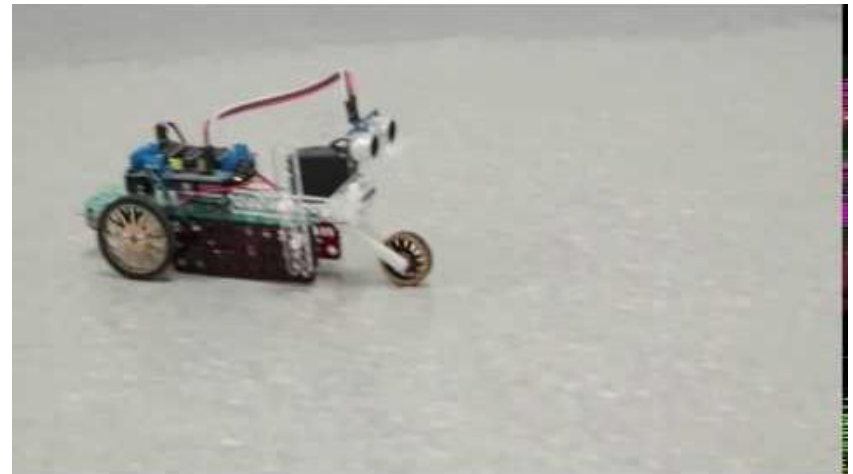
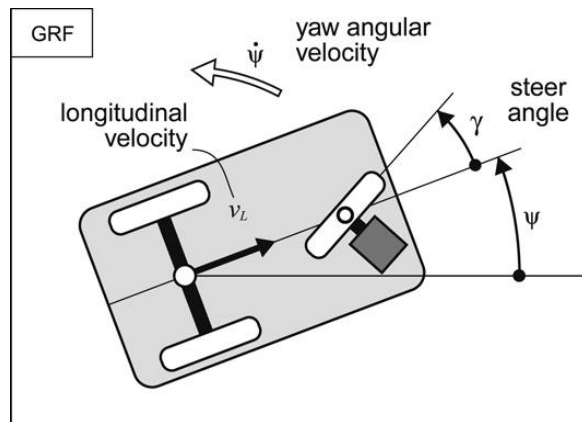
- The synchro drive system is a two motor, three/four wheeled drive configuration
- One motor rotates all wheels to produce motion and the other motor turns all wheels to change direction,
- Mechanically or electrically synchronized motors
- Each wheel is capable of being driven and steered



- Main disadvantage: complex design and implementation

Wheeled Robots

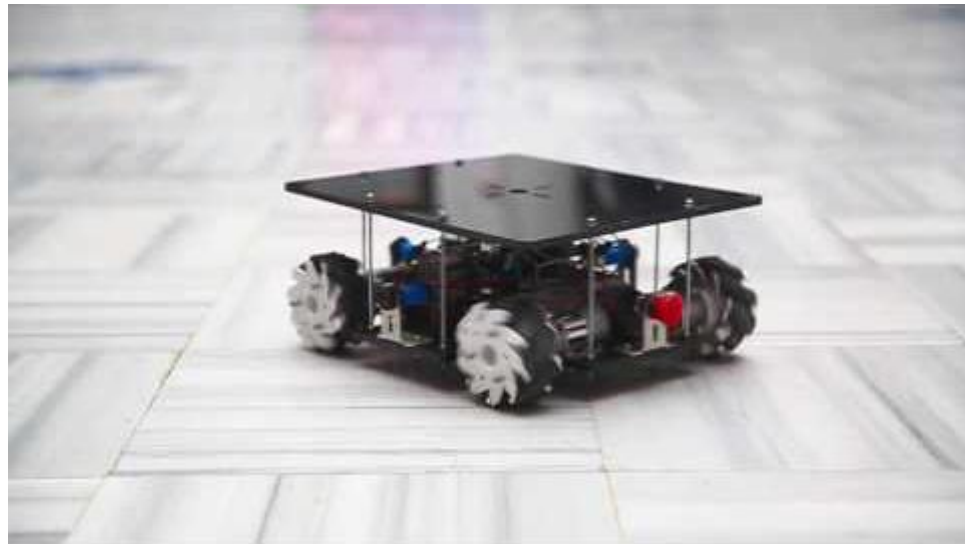
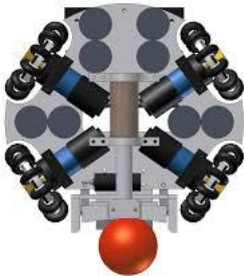
- **Tricycle/bicycle drive**
 - Sometimes called bogey or wagon drive
 - Two/one rear wheel(s) are passive ones
 - The front wheel provides steering and power for the robot
- Easy to control since only one wheel drives and steer



- 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



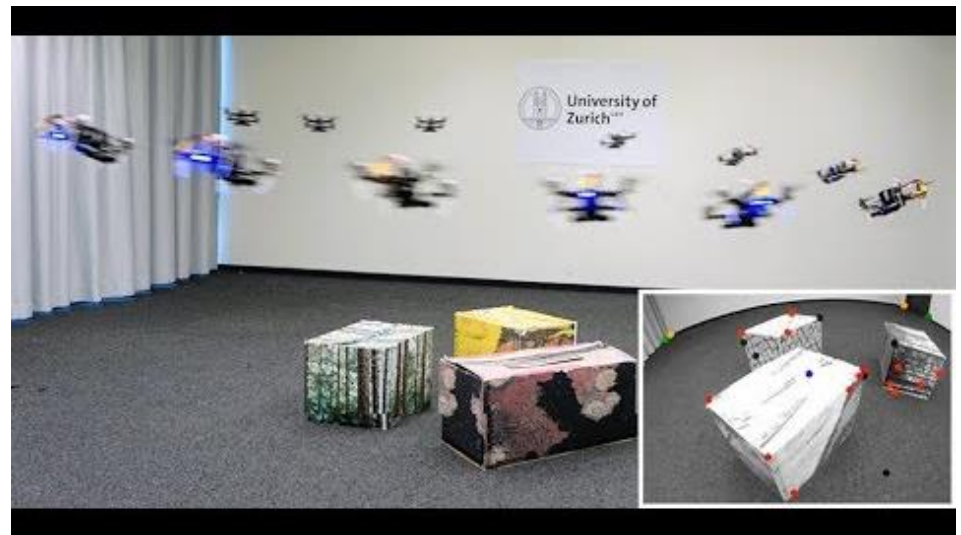
How to Fly (Unmanned Aerial Vehicles)

- **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.



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)

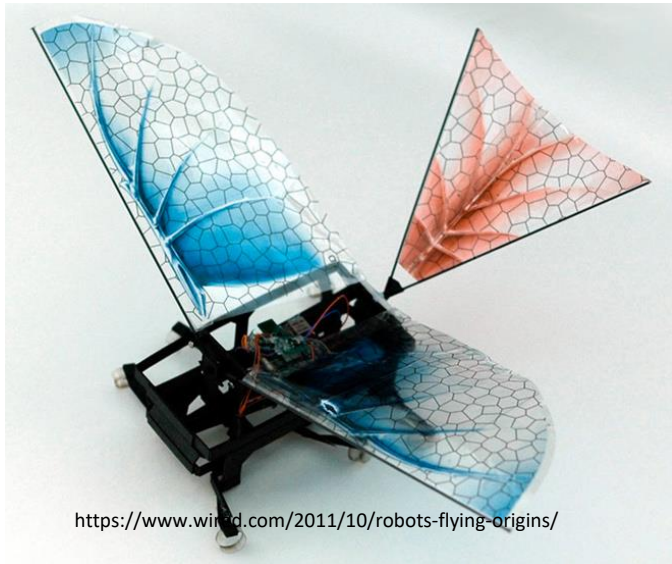


<https://www.youtube.com/watch?v=7NfUU1V6jxs>

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



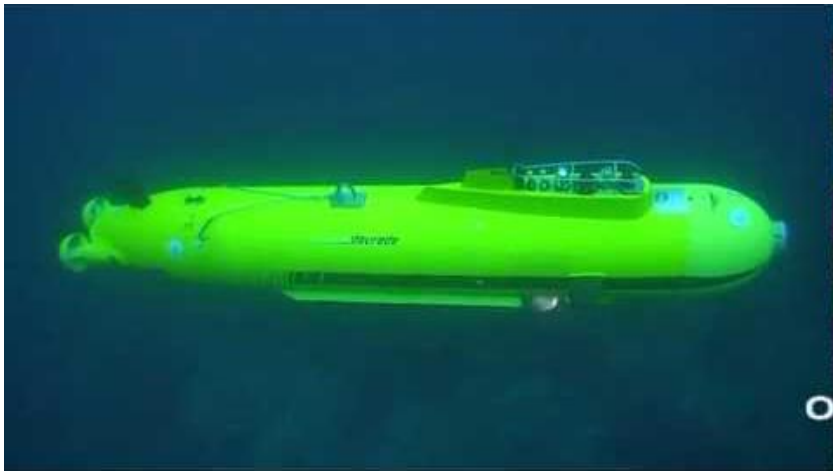
Heavy duty ROVs



Small ROVs

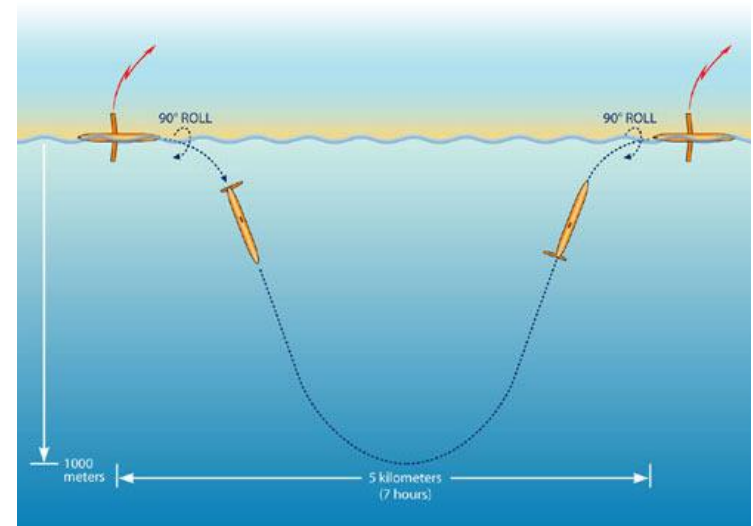
Autonomous Underwater Vehicle

- 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



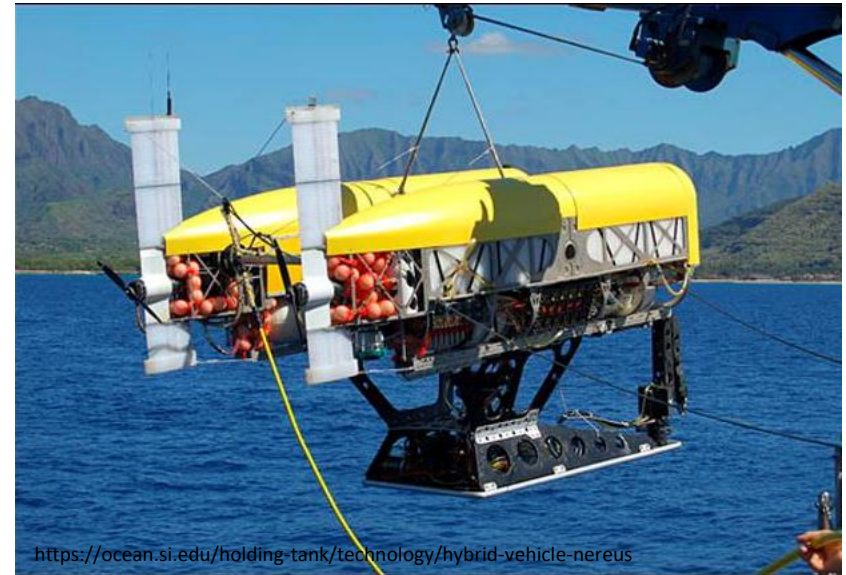
Underwater Gliders

- 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.



<https://ocean.si.edu/holding-tank/technology/hybrid-vehicle-nereus>

- Thank you!