Robotics and Autonomous Systems

Lecture 4: Locomotion

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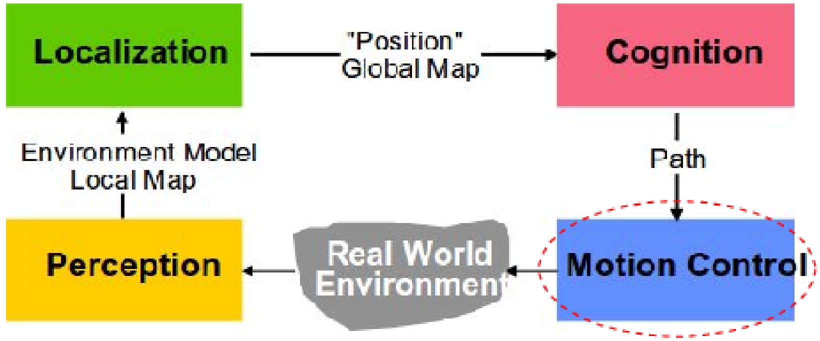
Today



Motion

- Two aspects:
  - Locomotion
  - Kinematics
- Locomotion: What kinds of motion are possible?
- Locomotion: What physical structures are there?
- Kinematics: Mathematical model of motion.
- Kinematics: Models make it possible to predict motion.

Locomotion in nature

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)

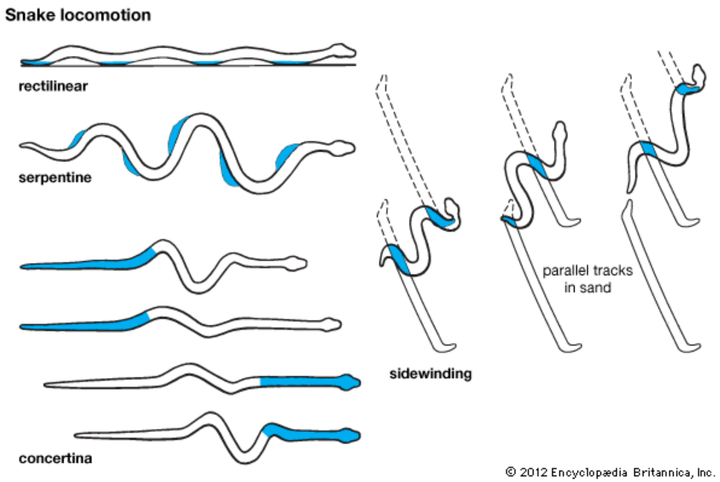
Sliding

- Snakes have four gaits.

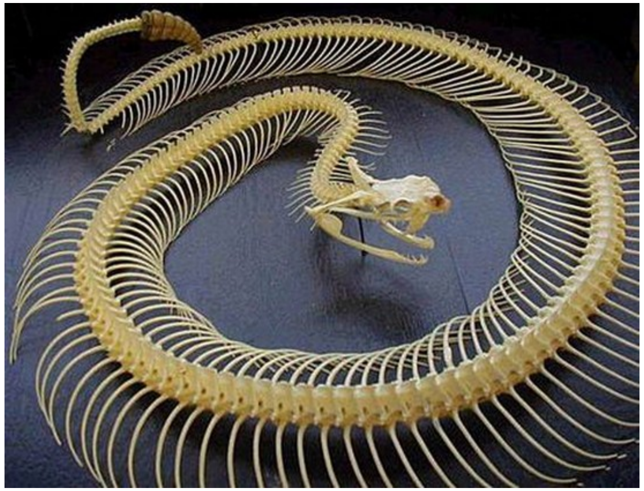
Sliding

- Snakes have four gaits.
- Anyone know what they are?

Sliding

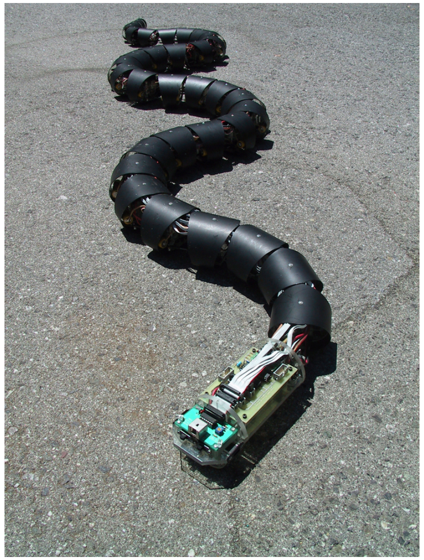


Sliding



Sliding

- Snakes have four gaits.
- Lateral undulation (most common)
- Concertina
- Sidewinding
- Rectilinear

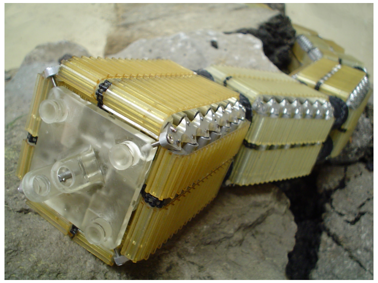


- (S5, S3-slither-to-sidewind)

Sidewinding

Crawling

- Concertina and Rectilinear motion can be considered crawling.



- Not directly implemented.
- The Makro (left) and Omnitread (right) robots crawl, but not exactly like real snakes do.

Characterisation of locomotion

- Locomotion:
  - Physical interaction between the vehicle 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
  - Characteristics of contact
  - Nature of environment

Characterisation of locomotion

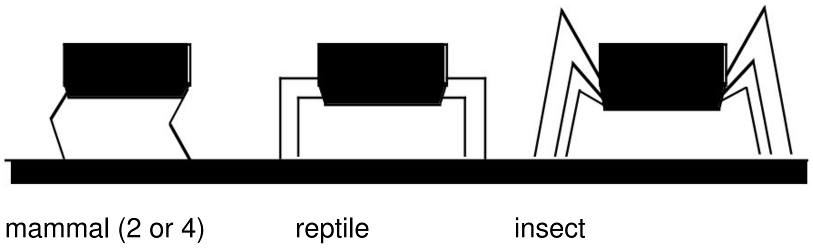
- Stability
  - Number of contact points
  - Center of gravity
  - Static/dynamic stabilization
  - Inclination of terrain
- Characteristics of contact
  - Contact point or contact area
  - Angle of contact
  - Friction
- Nature of environment
  - Structure
  - Medium (water, air, soft or hard ground)

Legged motion

- The fewer legs the more complicated locomotion becomes
  - At least three legs are required for static stability
  - Babies have to learn for quite a while until they are able to stand or walk on their two legs.
- During walking some legs are lifted
- For static walking at least 6 legs are required
  - Alternate between tripod supports.

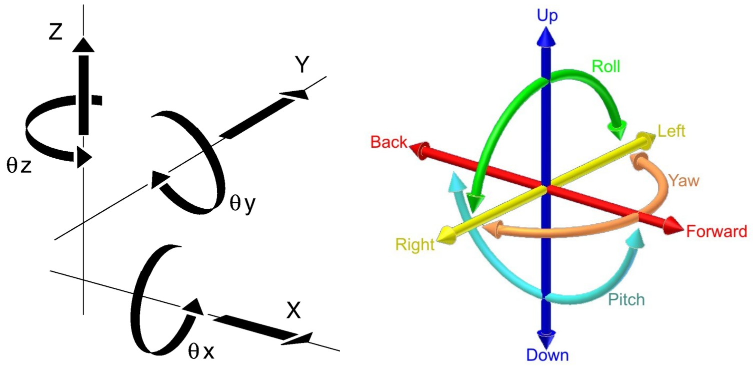
Leg joints

- Variety of leg joints/leg styles in nature.



Degrees of freedom

- Measurement of potential motion.

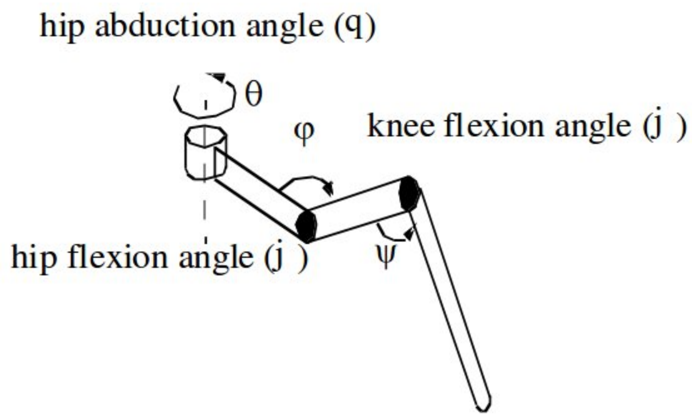


- A three dimensional world allows a particle 6 degrees of freedom.

Leg joints

- Robot structure restricts the DOF of a point on the leg.
  - Typically interested in the foot.
- 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
- Fourth DOF for the ankle joint
  - Might improve walking
  - However, additional joint (DOF) increases the complexity of the design and especially of the locomotion control.

Leg structure



- How many degrees of freedom does this leg have?

Number of gaits

- Gait is characterized as the sequence of lift and release events of the individual legs.
- Depends on the number of legs
- The number of possible events N for a walking machine with k legs is:

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

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

$$N = (4 - 1)! = 3! = 3 \times 2 \times 1 = 6$$

Number of gaits

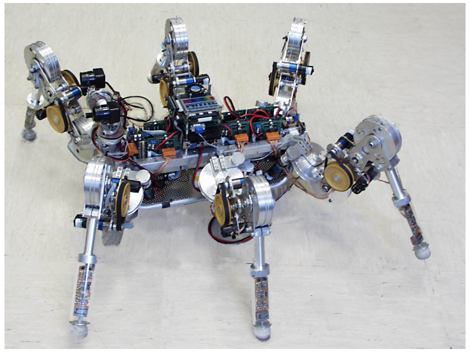
- What are these events?

Number of gaits

- The 6 different events are:
  1. lift right leg
  2. lift left leg
  3. release right leg
  4. release left leg
  5. lift both legs together
  6. release both legs together

Number of gaits

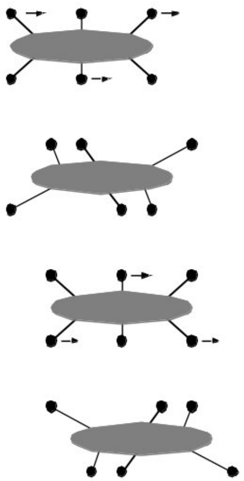
- For a robot with 6 legs (hexapod), such as:



- N is already

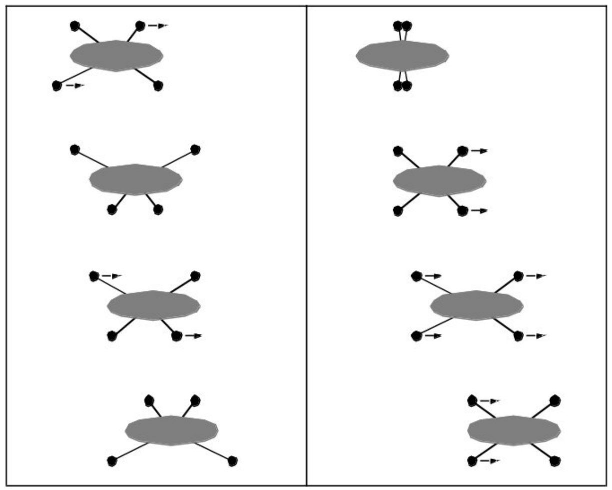
$$N = 11! = 39,916,800$$

Obvious 6-legged gait



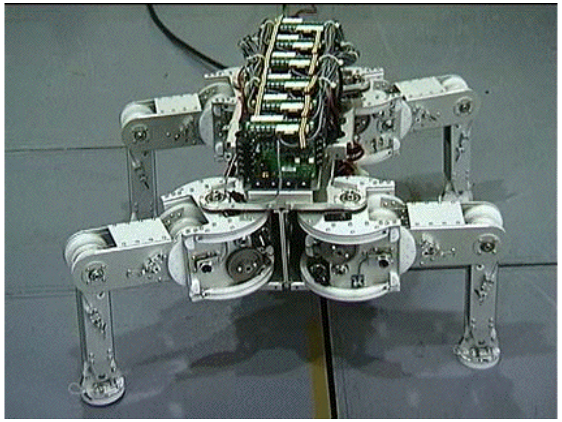
- Static stability— the robot is always stable. (six-legged-crawl)

Obvious 4-legged gaits



Changeover walk Gallop

Titan VIII



- A family of 9 robots, developed from 1976, to explore gaits.
  (Titan_walk)

Aibo

(Aibo)

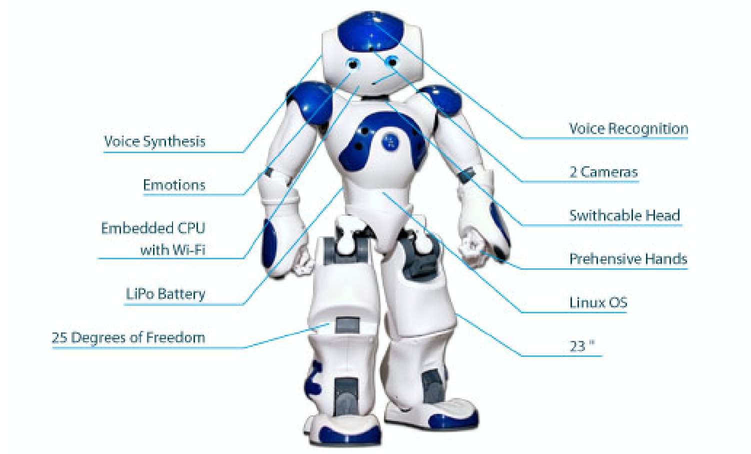
Big Dog, Little Dog


- Work grew out of the MIT Leg Lab.
  (leg-lab-spring-flamingo)

Humanoid Robots


- Two-legged gaits are difficult to achieve — human gait, for example is very unstable.

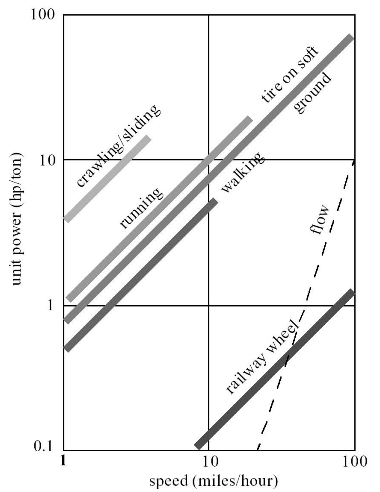
Nao



- Aldebaran.
  (NAO-playtime)

Walking or rolling?

- Number of actuators
- Structural complexity
- Control expense
- Energy efficient
- Terrain (flat ground, soft ground, climbing..)



RHex

- Somewhere in between walking and rolling.

(rhex)

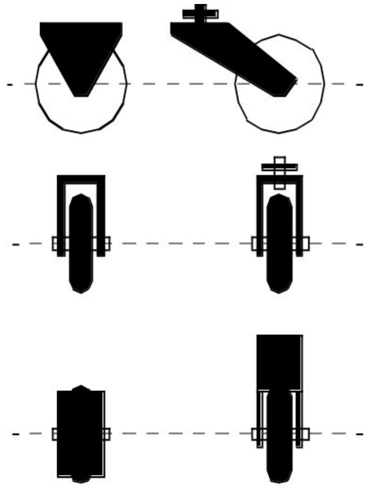
RHex

Wheeled robots

- Wheels are the most appropriate solution for many applications
  - Avoid the complexity of controlling legs
- Basic wheel layouts limited to easy terrain
  - Motivation for work on legged robots
  - Much work on adapting wheeled robots to hard terrain.
- Three wheels are sufficient to guarantee stability
  - With more than three wheels a flexible suspension is required
- Selection of wheels depends on the application

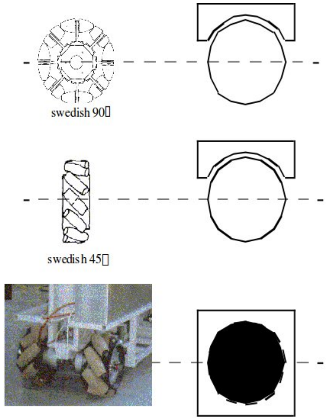
Four basic wheels

- Standard wheel: Two degrees of freedom; rotation around the (motorized) wheel axle and the contact point
- Castor wheel: Three degrees of freedom; rotation around the wheel axle, the contact point and the castor axle



Four basic wheels (II)

- Swedish wheel: Three degrees of freedom; rotation around the (motorized) wheel axle, around the rollers and around the contact point.
- Ball (also called spherical) wheel: Omnidirectional. Suspension is technically not solved.



Swedish wheel

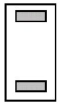
- Invented in 1973 by Bengt Ilon, who was working for the Swedish company Mecanum AB.
- Also called a Mecanum or Ilon wheel.

Characteristics of wheeled vehicles

- Stability of a vehicle is be guaranteed with 3 wheels.
  - Center of gravity is within the triangle with is formed by the ground contact point of the wheels.
- Stability is improved by 4 and more wheels.
  - However, such arrangements are hyperstatic and require a flexible suspension system.
- Bigger wheels allow robot to overcome higher obstacles.
  - But they require higher torque or reductions in the gear box.
- Most wheel arrangements are non-holonomic (see later)
  - Require high control effort
- Combining actuation and steering on one wheel makes the design complex and adds additional errors for odometry.

Two wheels

- Steering wheel at front, drive wheel at back.



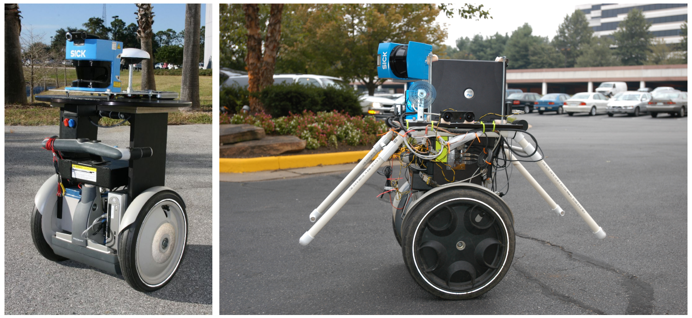
- Differential drive. Center of mass above or below axle.

Two wheels

- The two wheel differential drive pattern was used in Cye.

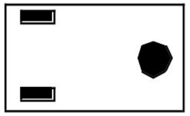
- Cye was an early attempt at a robot for home use.

Segway RMP

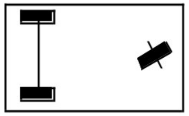


- The Segway RMP has its center of mass above the wheels

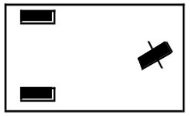
Three wheels



- Differential drive plus caster or omnidirectional wheel.



- Connected drive wheels at rear, steered wheel at front.



- Two free wheels in rear, steered drive wheel in front.

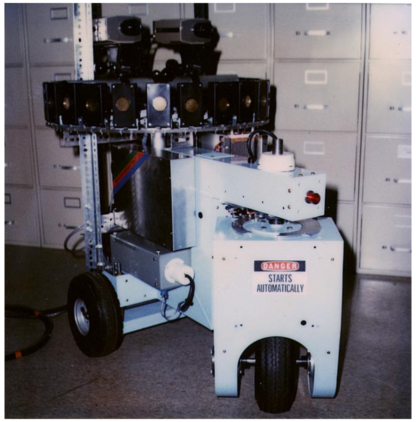
Differential drive plus caster

- Highly maneuverable, but limited to moving forwards/backwards and rotating.

Turtlebot

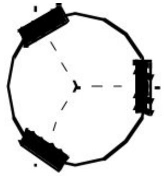
- Another standard research platform with the same drive.

Neptune

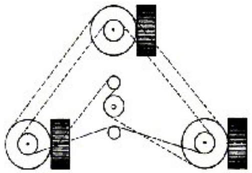


- Neptune: an early experimental robot from CMU.

Other three wheel drives

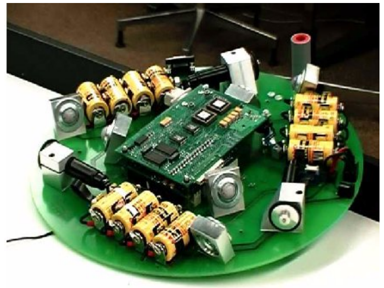


- Omnidirectional
- Three drive wheels.
- Swedish or spherical.



- Synchro drive
- Three drive wheels.
- Can't control orientation.

Omnidirectional

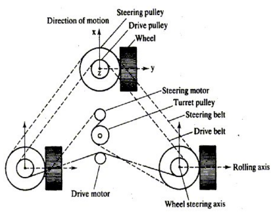


- The Palm Pilot Robot Kit (left) and the Tribolo (right) (Tribolo)

Synchro

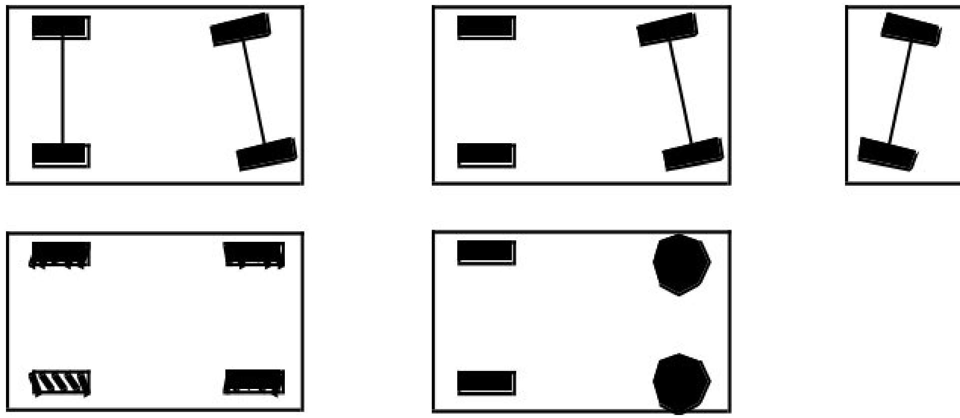
- All wheels are actuated synchronously by one motor
  - Defines the speed of the vehicle
- All wheels steered synchronously by a second motor
  - Sets the heading of the vehicle

(Borenstein)



- The orientation in space of the robot frame will always remain the same

Four wheels



- Various combinations of steered, driven wheels and omnidirectional wheels.

Four steering wheels


- Highly maneuverable, hard to control.

Nomad

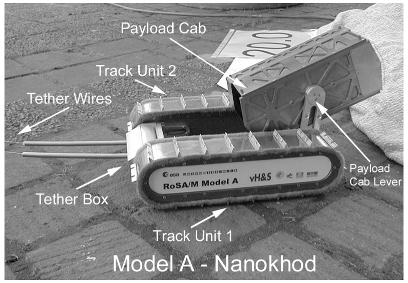
- The Nomad series of robots from Nomadic Teachnologies had four casters, driven and steered.

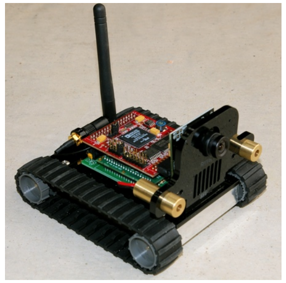
Uranus

- Four omnidirectional driven wheels.

- Not a minimal arrangement, since only three degrees of freedom.
- Four wheels for stability.

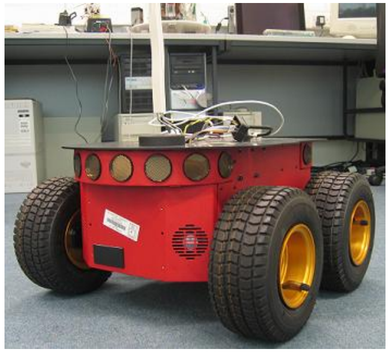
Tracked robots





- Large contact area means good traction.
- Use slip/skid steering.

Slip/skid steering



- Also used on ATV versions of differential drive platforms.
- Causes problems with odometry.

Aerial robots

- Lots of interest in the last few years
- Aim is to use them for search and surveillance tasks.


- Starmac (left) and YARB (right)

Fish robots


- Incorporating various kinds of motion.

Onwards

- When building a robot, it is useful to know how it will move.
  - This helps in developing the control program.
  - Less trial and error.
- Studying kinematics is one way of achieving this.

Summary

- This lecture looked at locomotion.
- It discussed many of the kinds of motion that robots use, giving examples.
- Next time we will move on to look at the other part of motion, kinematics.
- In this we move from purely qualitative descriptions of motion to more mathematical descriptions.
- These have the great advantage of allowing us to compute useful things about motion.