# Chapter 2 - Locomotion

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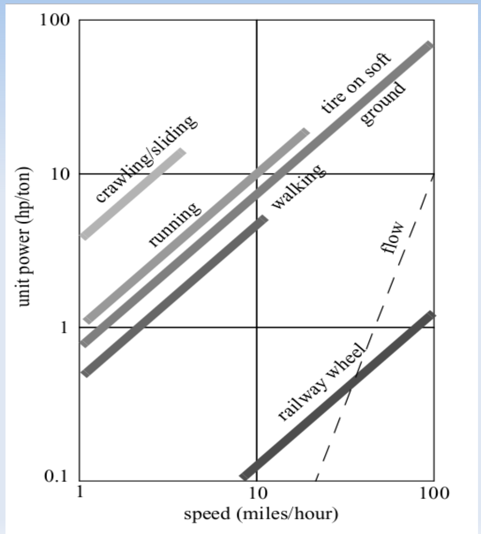
# Locomotion

- Why locomotion?
  - To move unboundedly throughout environment
- Modes of locomotion?
  - Walk, jump, run, slide, skate, swim, fly, roll
- Locomotion modes inspired by biology
  - Exception is the wheel
- Nature has not developed a rotating actively powered joint

# Price of Motion




# Biological Motion

- Biological motion systems succeed in a wide variety of harsh environments
- Hence, it is good to copy them
- However, this poses problems
  - Structural complexity
  - Miniaturization
  - Energy density
- Legs work better in unstructured terrain

## Legged Motion – Key Issues

- Stability
  - Number and geometry of contact points
  - Center of gravity
  - Static/dynamic stability
  - Inclination
- Contact characteristics
  - Geometry of contact
  - Friction
- Type of environment

## Legged Motion – Pros & Cons

- Pros
  - Adaptability to rough terrain
  - Increased maneuverability
  - Possibility to manipulate objects while in motion
- Cons
  - Mechanical complexity
  - High power requirements
  - High DoF in legs – Complex control needed

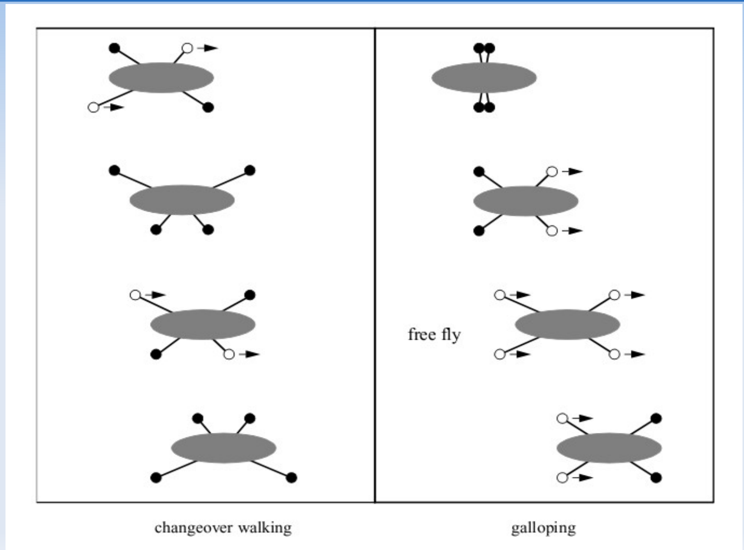
## Legged Motion - Stability

- Depends on number of legs, DoF of a leg
- A tripod configuration is stable, when CG is within 'contact triangle'
- Hexapods – always stable
- Quadropods – statically stable, dynamically unstable
- Bipeds/Unipeds – Not stable even when standing still
- As number of legs reduce, increasingly active control needed

## Legged Motion - Gaits

- A Gait is a sequence of 'lift and release' events for each leg
- Can be though of as 'style of walking'
- Number of possible gaits increase with number of legs and DoF of each leg

# Example of a Gait




# Legged motion - Performance

- Insects outperform robots with same number of legs
  - This is due to use of passive structures e.g: barbs
- Actuators do not approach efficiency of muscles
- Energy storage methods do not achieve the storage density of organic cells
- A hybrid approach, combining legs with wheels outperforms purely legged locomotion

# Quadruped Motion - Example

# Biped Motion - Example

## Wheel Geometry

- The choice of wheel types for a mobile robot is strongly linked to the choice of wheel arrangement
- Three factors: Maneuverability, controllability, and stability
- There is no “ideal” drive configuration that simultaneously maximizes the three

## Stability

- The minimum number of wheels required for static stability is:
  - 2 wheels – only if the center of mass is below the wheel axle
  - 3 wheels - center of gravity is within the triangle
- Stability is improved by 4 and more wheels
  - Will require some form of flexible suspension on uneven terrain
- Bigger wheels?
  - Overcome higher obstacles, but require higher torque

## Maneuverability

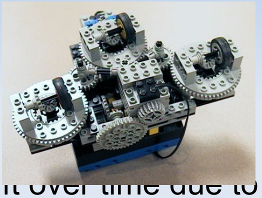
- Omnidirectional: can move at any time in any direction along the ground plane (x,y)
  - Swedish or spherical wheels
  - Ground clearance problem
    - 4 castor wheel configuration: each castor wheel is actively steered and actively translated
- Almost-omnidirectional design
  - May initially require a rotational motion
  - Circular chassis and an axis of rotation at the center of the robot
- Ackerman steering comparison

## Controllability

- General inverse correlation between controllability and maneuverability
  - Ackerman steering vehicle: can go straight simply by locking the steerable wheels and driving the drive wheels
  - Differential-drive vehicle: the two motors attached to the two wheels must be driven along exactly the same velocity
  - Swedish wheel: accumulation of slippage, reduce accuracy

## Case studies: Synchro drive

- Three driven and steered wheels, only two motors used
- "Omnidirectional"
- Problem with direction
  - The chassis orientation does drift over time due to uneven tire slippage
  - Causes rotational dead-reckoning error
  - Posible solution: independently rotating turret that attaches to the wheel chassis

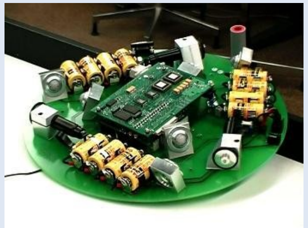


## Case studies: Synchro drive

- Other dead reckoning considerations
  - Whenever the drive motor engages, the closest wheel begins spinning before the furthest wheel
    - small change in the orientation of the chassis
    - accumulative error
  - No control on the chasis: the wheel thrust can be highly asymmetric

## Case studies: Omnidirectional drive

- Valuable characteristic: if ominidirectional, robots are also holonomic
- Spherical wheels:
  - *The Tribolo designed at EPFL*
    - One motor for each wheel
    - Excellent maneuverability
    - Simple in design
    - Limited to flat surfaces



## Case studies: Omnidirectional drive

- Swedish wheels:
  - *The Carnegie Mellon Uranus robot*
    - *45-degree wheels, one motor for each*
    - *Can move and spin at the same time*
    - *The base can move without rotating the structure*

## Case studies: Omnidirectional drive

- Castor wheels:
  - *Nomad XR4000 from Nomadic Technologies*
    - 4 wheels with 8 motors
    - Excellent maneuverability

## Case studies: Tracked slip/skid locomotion

- Spinning wheels that are facing the same direction at different speeds
- Larger ground contact patches. The track must slide against the terrain
  - Extremely good maneuverability and traction over rough and loose terrain
  - Dead reckoning is highly inaccurate
  - Power efficiency: good in rough terrain, bad otherwise

## Case studies: Tracked slip/skid locomotion

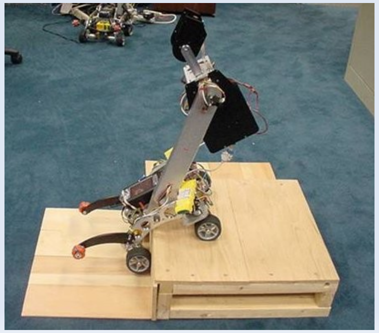
## Case studies: Walking wheels

- Combining the adaptability of legs with the efficiency of wheels
- Space Robotics: *The Sojourner robot of NASA/ JPL*
- *Shrimp of EPFL*
  - Six motorized wheels
  - Climb objects up to 2 times its whe

  - Rhombus configuration: good climbing ability due to the position of the COM over the time

# Case studies: Walking wheels

- *Personal Rover*
  - Active COM shifting to climb edges
  - A majority of the weight is borne at the top



# Hybrids: Whegs

- Advantages of wheels and legs
  - Fast on glat ground
  - Can climb obstacles

# Hybrids: Galileo

- Advantages of wheels and tracked locomotion