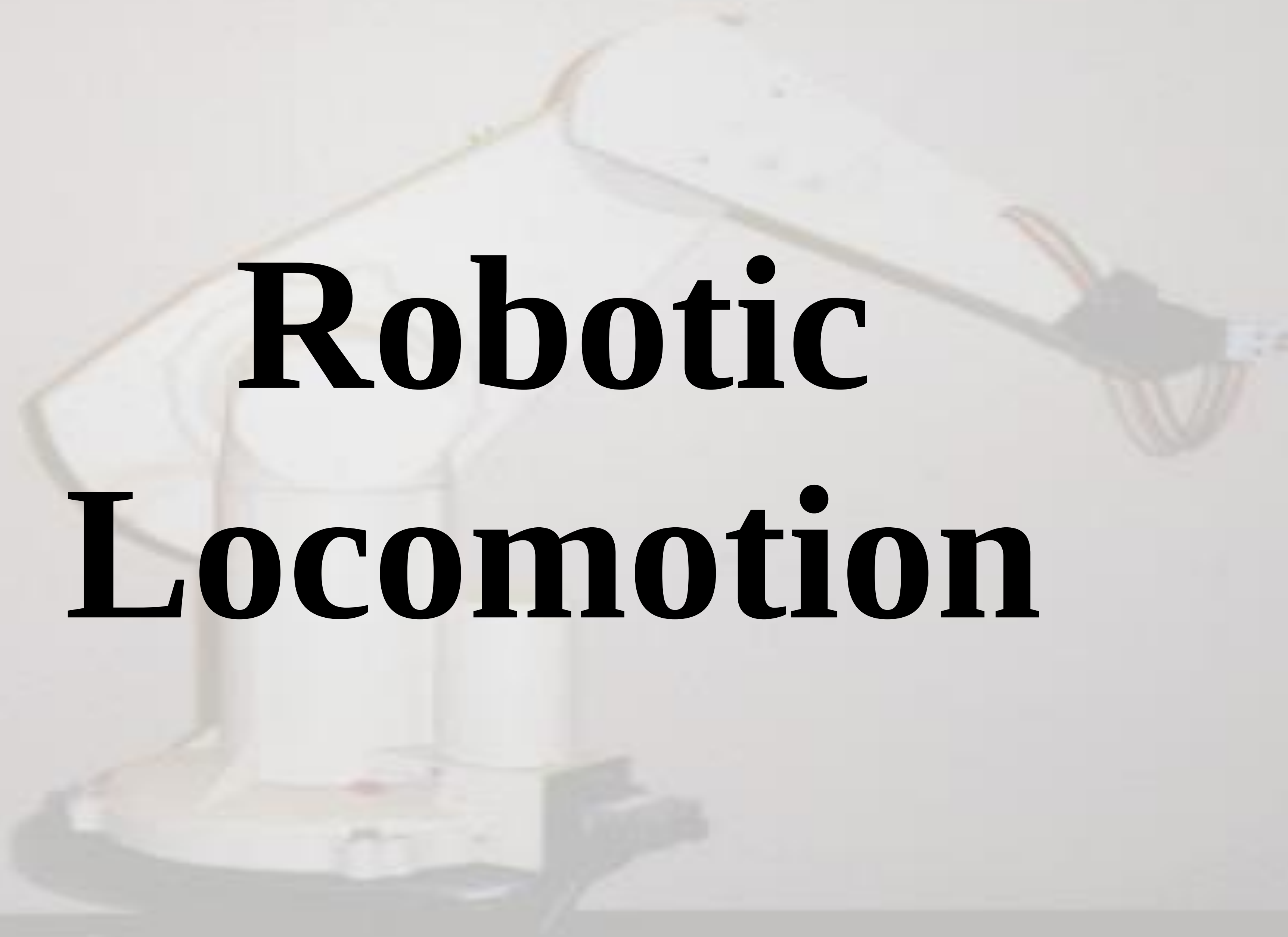
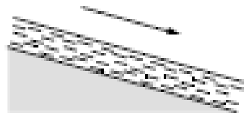
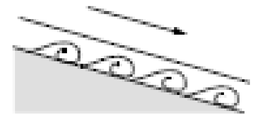
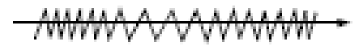
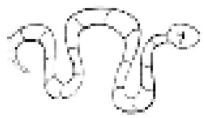
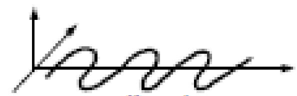
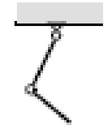
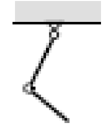
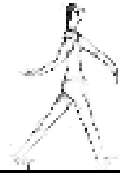
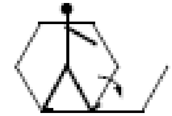


Robotic Locomotion

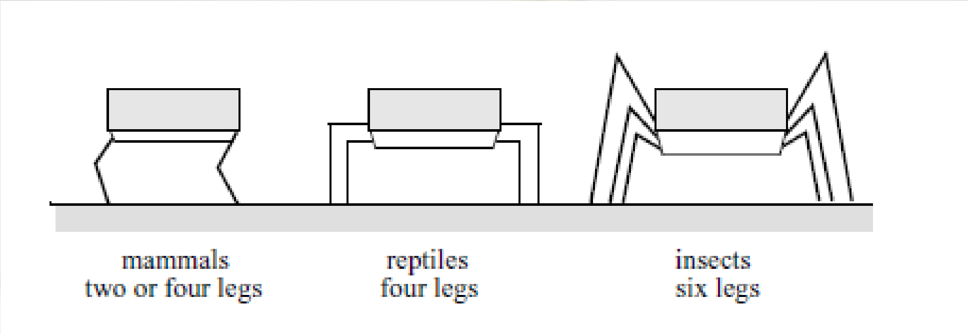
Locomotion

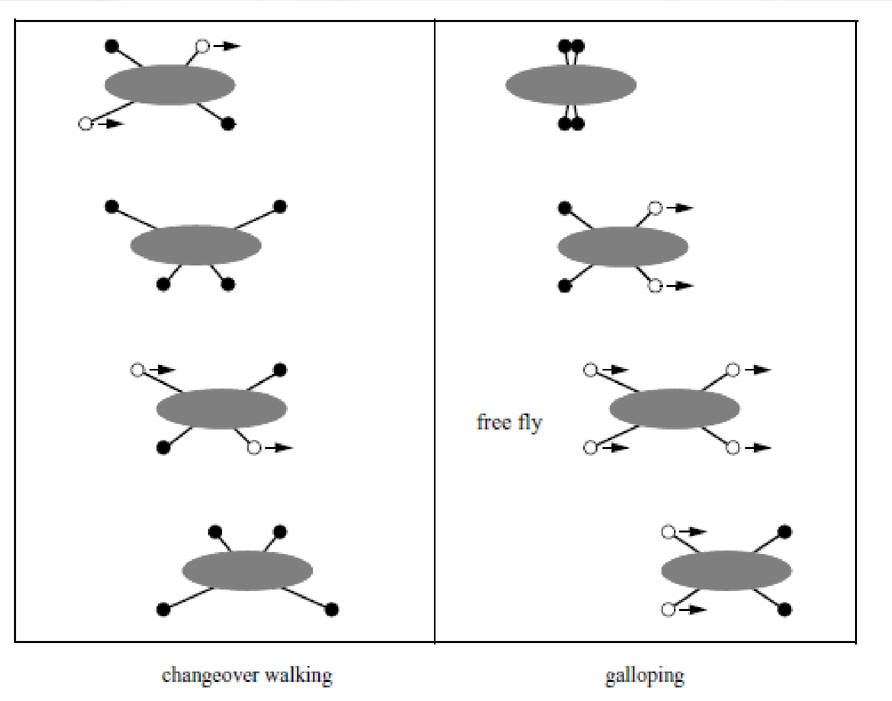
- Motion technique for one place to another
- includes the motion and driving strategies

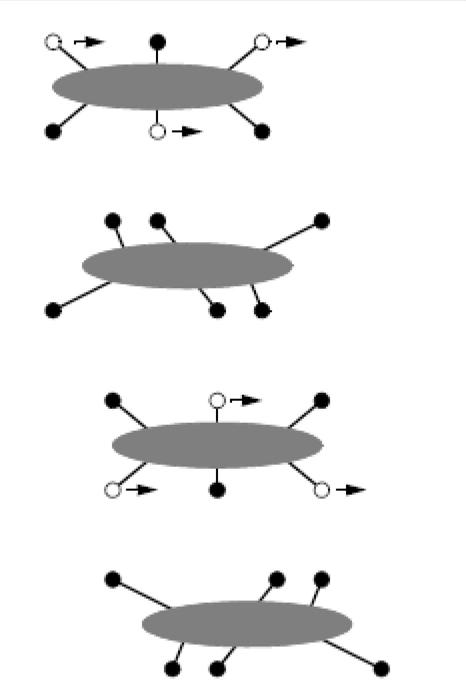
Biological Locomotion Techniques

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) 

Leg Variations of Animals



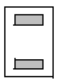
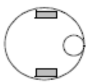
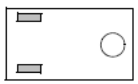
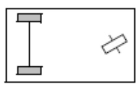
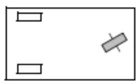
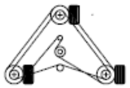


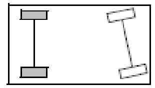
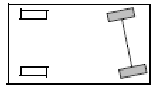
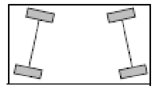
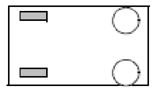
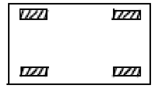
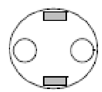
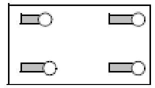


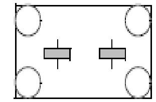
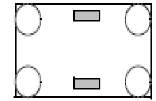
Design Tradeoffs with Mobility Configurations

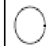
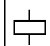
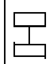
- Maneuverability
- Controllability
- Traction
- Climbing ability
- Stability
- Efficiency
- Maintenance
- Environmental impact
- Navigational considerations

Wheel Configurations

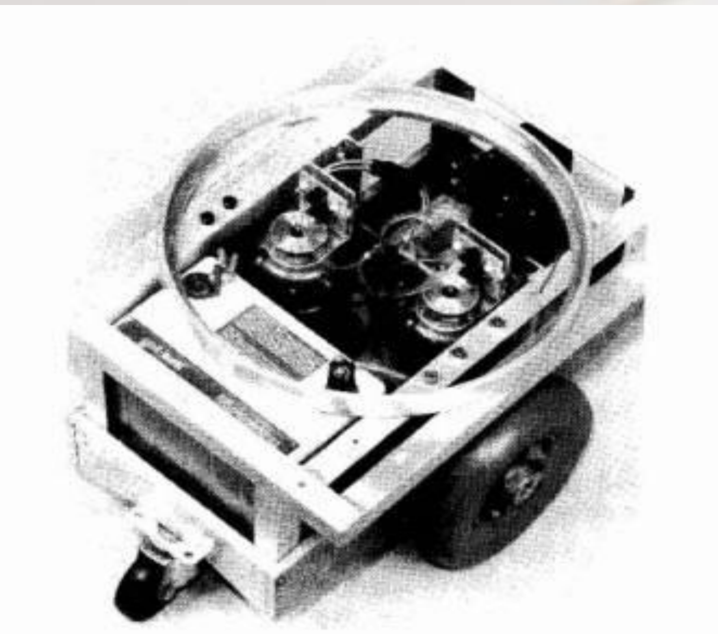
# of wheels	Arrangement	Description	Typical examples
2		One steering wheel in the front, one traction wheel in the rear	Bicycle, motorcycle
		Two-wheel differential drive with the center of mass (COM) below the axle	Cye personal robot
3		Two-wheel centered differential drive with a third point of contact	Nomad Scout, smartRob EPFL
		Two independently driven wheels in the rear/front, 1 unpowered omnidirectional wheel in the front/rear	Many indoor robots, including the EPFL robots Pygmalion and Alice
		Two connected traction wheels (differential) in rear, 1 steered free wheel in front	Piaggio minitrucks
		Two free wheels in rear, 1 steered traction wheel in front	Neptune (Carnegie Mellon University), Hero-1
		Three motorized Swedish or spherical wheels arranged in a triangle; omnidirectional movement is possible	Stanford wheel Tribolo EPFL, Palm Pilot Robot Kit (CMU)
		Three synchronously motorized and steered wheels; the orientation is not controllable	"Synchro drive" Denning MRV-2, Georgia Institute of Technology, I-Robot B24, Nomad 200

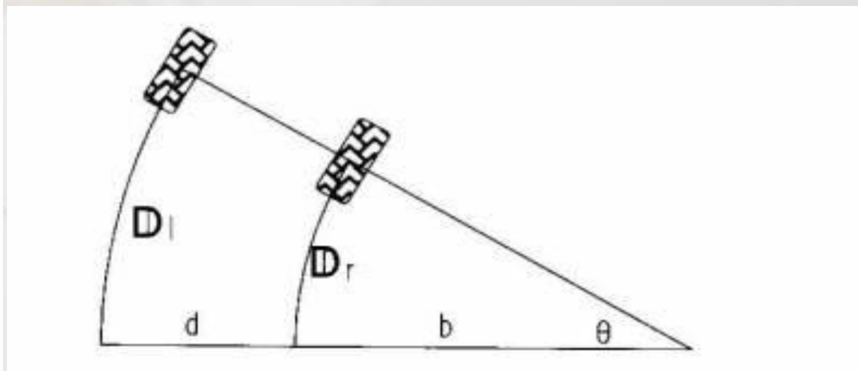
# of wheels	Arrangement	Description	Typical examples
4		Two motorized wheels in the rear, 2 steered wheels in the front; steering has to be different for the 2 wheels to avoid slipping/skidding.	Car with rear-wheel drive
		Two motorized and steered wheels in the front, 2 free wheels in the rear; steering has to be different for the 2 wheels to avoid slipping/skidding.	Car with front-wheel drive
		Four steered and motorized wheels	Four-wheel drive, four-wheel steering Hyperion (CMU)
		Two traction wheels (differential) in rear/front, 2 omnidirectional wheels in the front/rear	Charlie (DMT-EPFL)
		Four omnidirectional wheels	Carnegie Mellon Uranus
		Two-wheel differential drive with 2 additional points of contact	EPFL Khepera, Hyperbot Chip
		Four motorized and steered castor wheels	Nomad XR4000

# of wheels	Arrangement	Description	Typical examples
6		Two motorized and steered wheels aligned in center, 1 omnidirectional wheel at each corner	First
		Two traction wheels (differential) in center, 1 omnidirectional wheel at each corner	Terregator (Carnegie Mellon University)

Icons for the each wheel type are as follows:	
	unpowered omnidirectional wheel (spherical, castor, Swedish);
	motorized Swedish wheel (Stanford wheel);
	unpowered standard wheel;
	motorized standard wheel;
	motorized and steered castor wheel;
	steered standard wheel;
	connected wheels.

Differential Drive





$$D = \frac{D_l + D_r}{2}$$

$$\theta = \frac{D_l - D_r}{d}$$

Pictures from "Navigating Mobile Robots: Systems and Techniques" Borenstein, J.

Where D represents the arc length of the center of the robot from start to finish of the movement.

Differential Drive (continued)

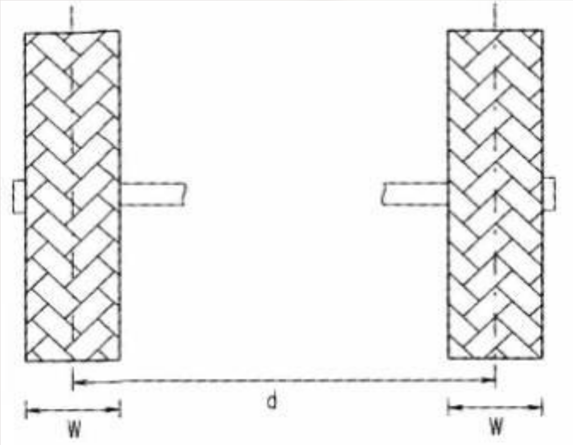
Advantages:

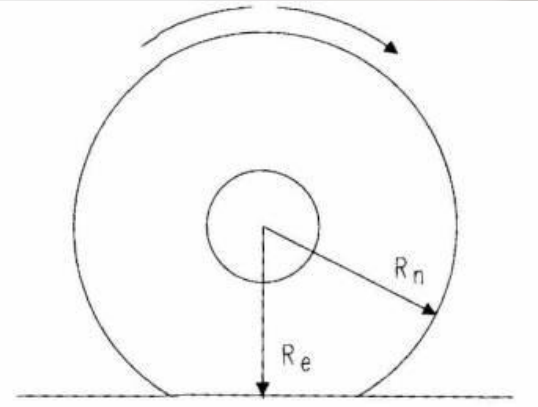
- Cheap to build
- Easy to implement
- Simple design

Disadvantages:

- Difficult straight line motion

Problem with Differential Drive: Knobbie Tires

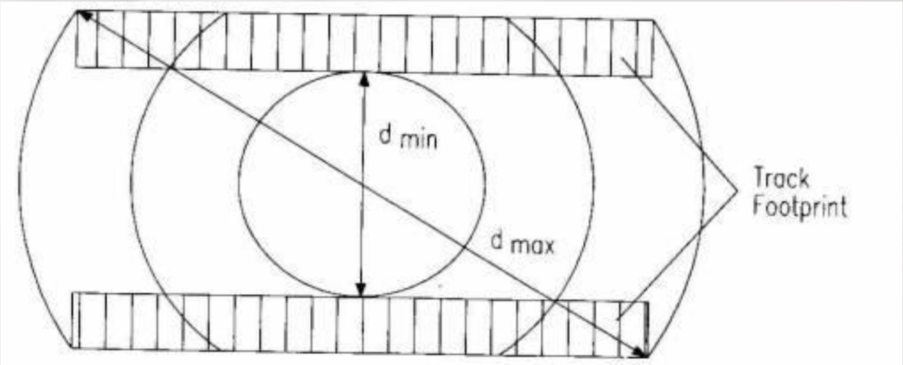




Pictures from “Navigating Mobile Robots: Systems and Techniques” Borenstein, J.

Changing diameter makes for uncertainty in dead-reckoning error

Skid Steering



Advantages:

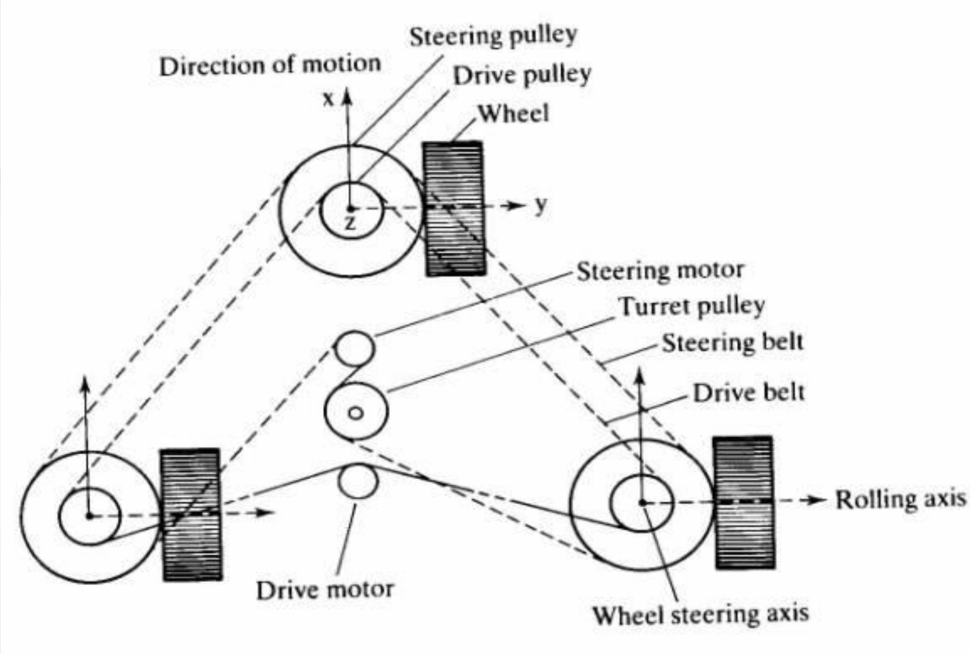
•Simple drive system

Disadvantages:

•Slippage and poor odometry results

•Requires a large amount of power to turn

Synchro Drive



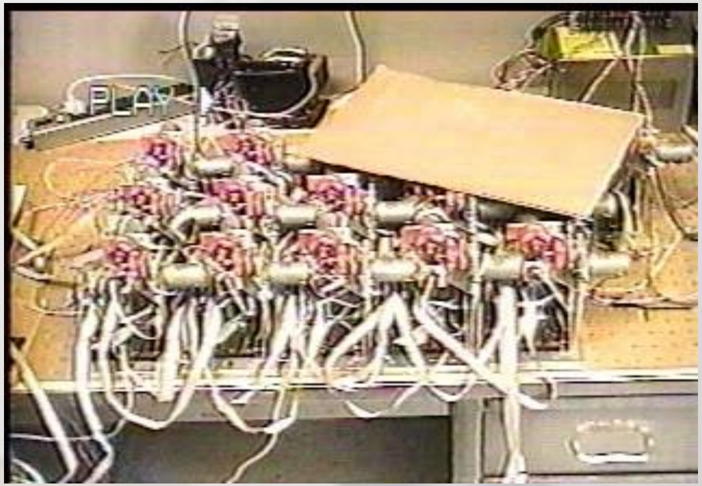
Pictures from "Navigating Mobile Robots: Systems and Techniques" Borenstein, J.

Advantages:
- Separate motors for translation and rotation makes control easier
- Straight-line motion is guaranteed mechanically

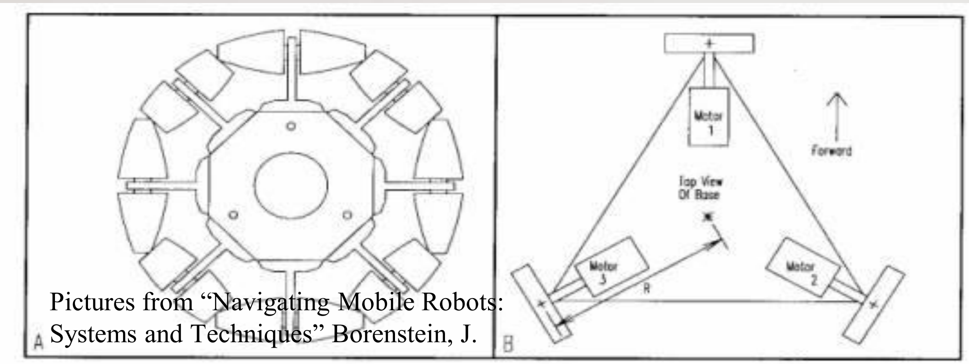
Disadvantages:
- Complex design and implementation

Distributed Actuator Arrays: Virtual Vehicle

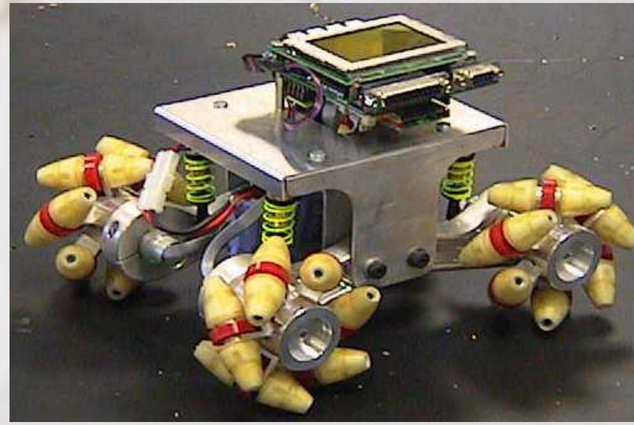
- Modular Distributed Manipulator System
- Employs use of Omni Wheels

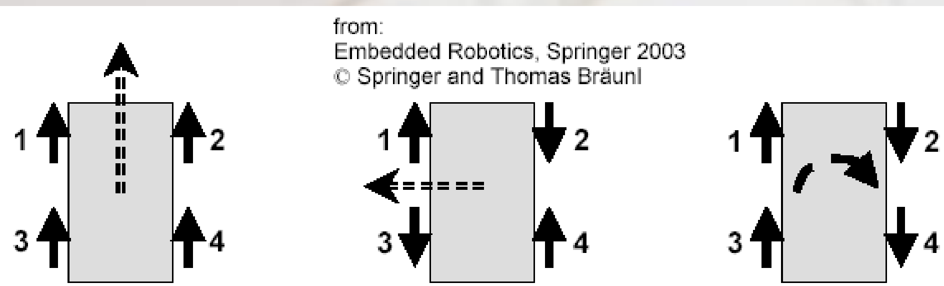


Omni Wheels



Pictures from “Navigating Mobile Robots: Systems and Techniques” Borenstein, J.





from:
Embedded Robotics, Springer 2003
© Springer and Thomas Bräunl

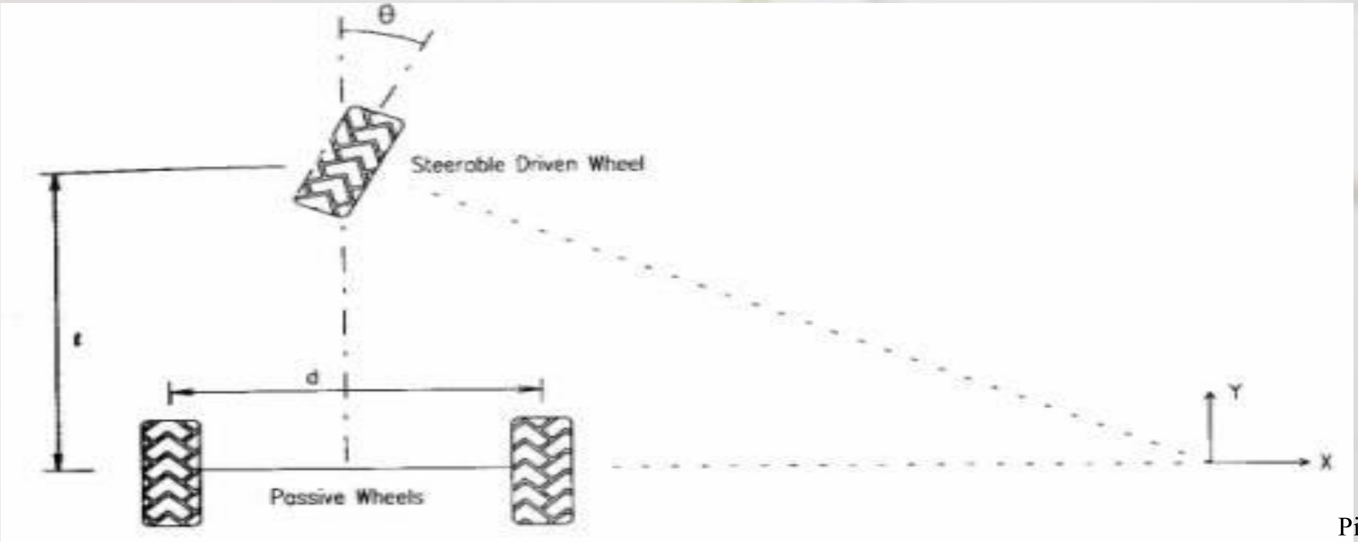
Advantages:

- Allows complicated motions

Disadvantages:

- No mechanical constraints to require straight-line motion
- Complicated implementation

Tricycle



Pictures from “Navigating Mobile Robots: Systems and Techniques” Borenstein, J.

Advantages:
- No sliding

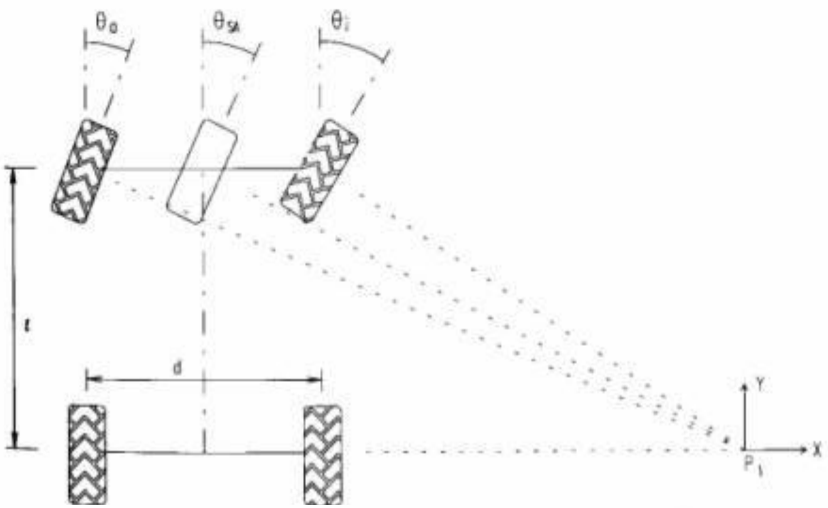
Disadvantages:
- Non-holonomic planning required

Ackerman Steering

$$\cot\theta_i - \cot\theta_o = \frac{d}{l}$$

where:

θ_i = relative steering angle of inner wheel
θ_o = relative steering angle of outer wheel
l = longitudinal wheel separation
d = lateral wheel separation.



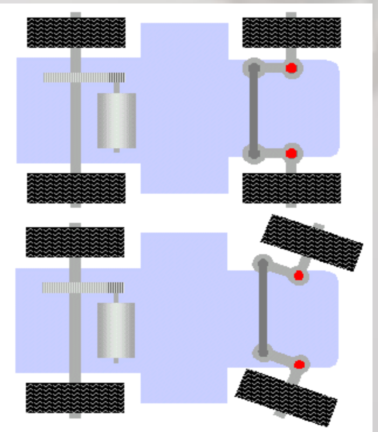
$$\cot\theta_{SA} = \frac{d}{2l} + \cot\theta_i \quad \text{or alternatively:} \quad \cot\theta_{SA} = \cot\theta_o - \frac{d}{2l}.$$

Pictures from “Navigating Mobile Robots: Systems and Techniques” Borenstein, J.

Advantages:

Simple to implement

- Simple 4 bar linkage controls front wheels



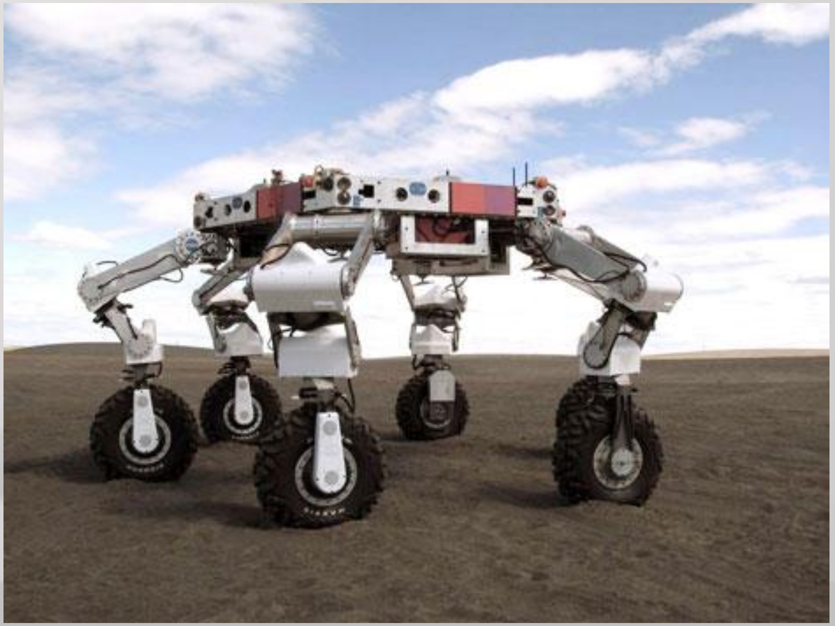
Disadvantages:

- Non-holonomic planning required

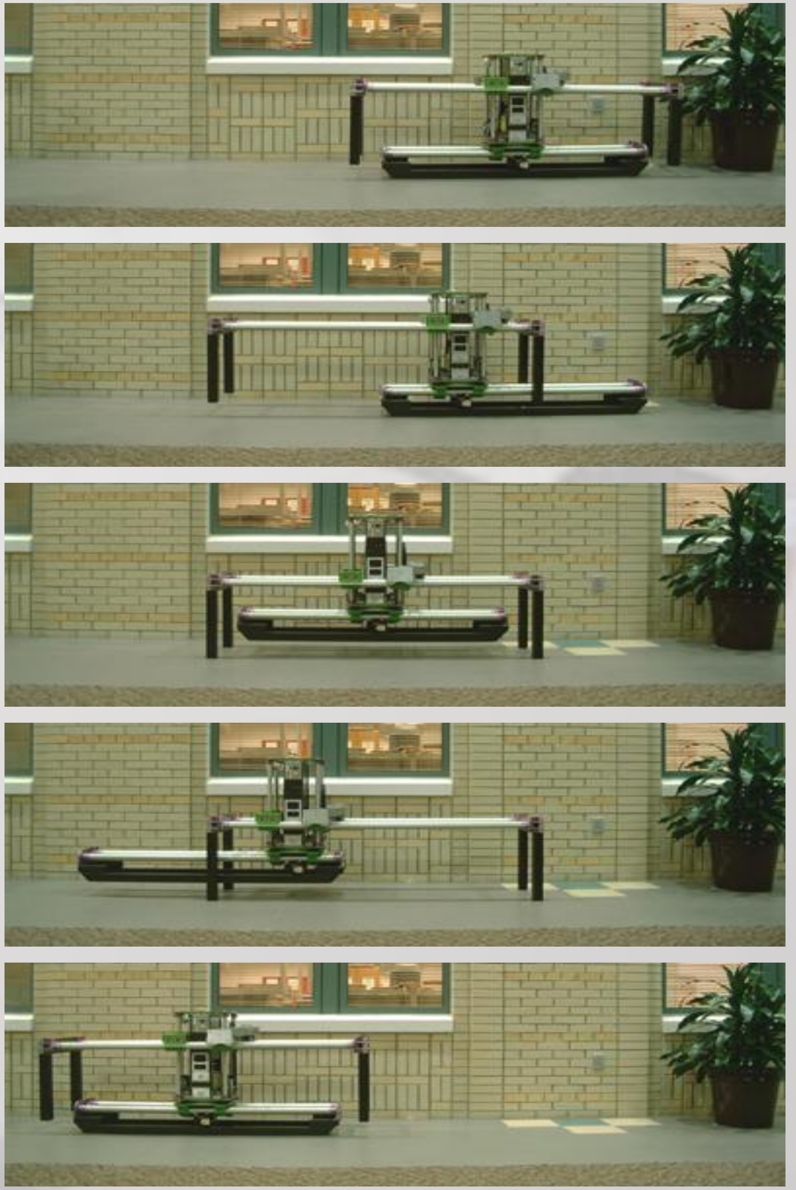
Articulated Drive: Nomad

Advantages:
•Simple to implement except for turning mechanism

Disadvantages:
•Non-holonomic planning is required



Framewalker: Jim2



Advantages:

•Separate actuation of translation and rotation

•Straight-line motion is guaranteed mechanically

Disadvantages:

•Complex design and implementation

•Translation and rotation are excusive

Snake Robots

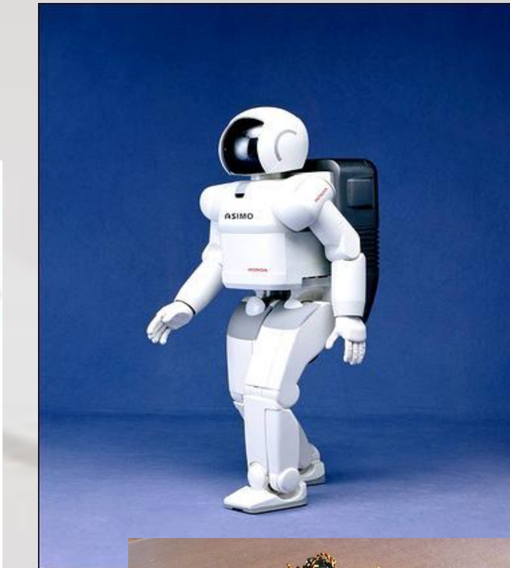
Advantages:
•Many applications
•Hyper-redundant

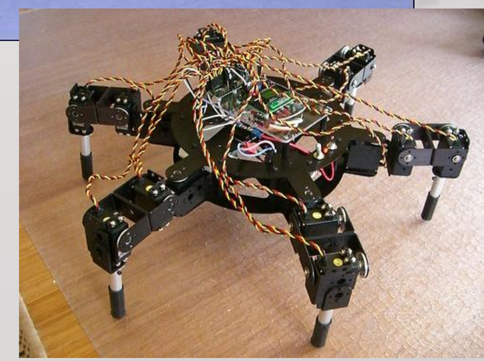
Disadvantages:
•Complex control and
planning

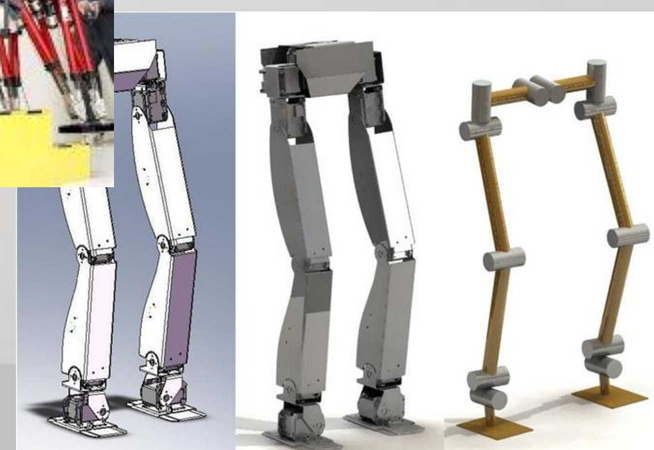
Legged Robots

Advantages:
•Can traverse any terrain a human can

Disadvantages:
•Large number of degrees of freedom
•Maintaining stability is complicated







Are legs better than wheels?