Mobile Robots
(EECN30169/535307)

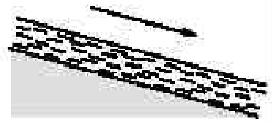
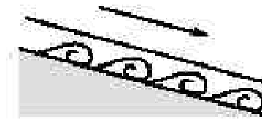
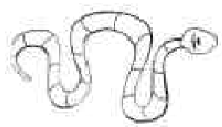
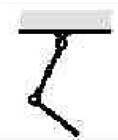
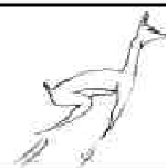
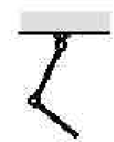
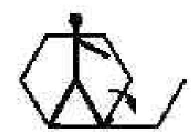
Lec. 4 Locomotion

2022/10/14

Locomotion of Mobile Robots

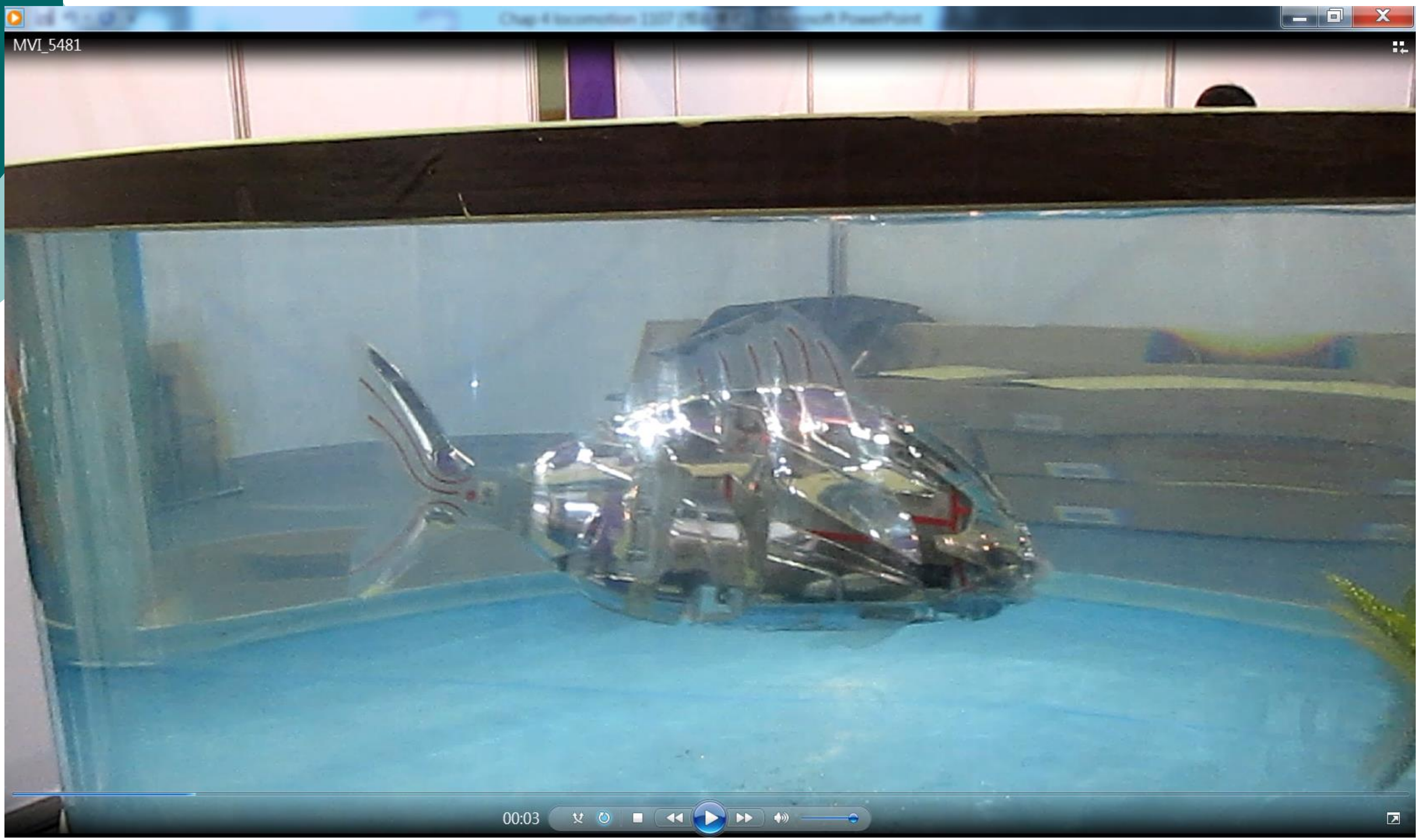
- Type of Robot Locomotion
  - Legged robots
  - Tracked robots
  - Wheeled robots
  - Omni-directional robots
  - Ballbot
- Shape of mobile robots
- Self–localization of mobile robots

Locomotion Concepts: Principles Found in Nature

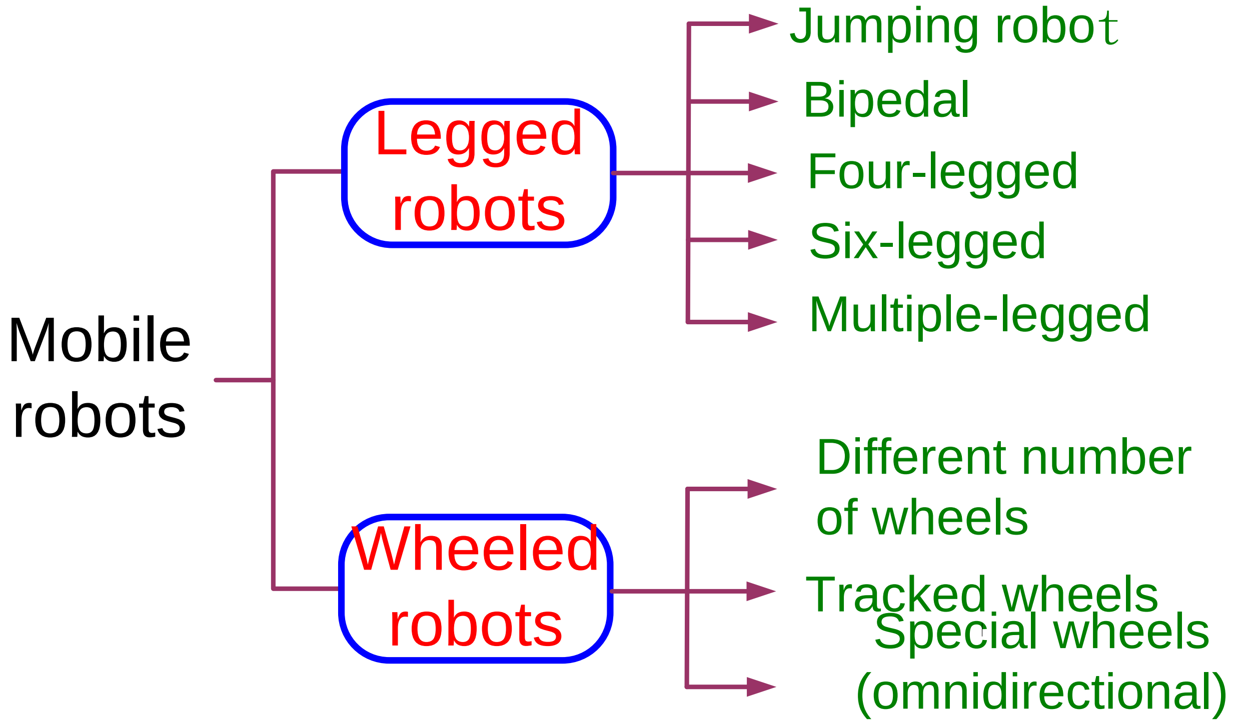
Type of motion		Resistance to motion	Basic kinematics of motion	
Flow in a Channel		Hydrodynamic forces	Eddies	
Crawl		Friction forces	Longitudinal vibration	
Sliding		Friction forces	Transverse vibration	
Running		Loss of kinetic energy	Oscillatory movement of a multi-link pendulum	
Jumping		Loss of kinetic energy	Oscillatory movement of a multi-link pendulum	
Walking		Gravitational forces	Rolling of a polygon (see figure 2.2)	

From :Introduction to autonomous mobile robots by Siegwart and Nourbakhsh , MIT Press,

International Robot Contest KINTEX, Korea 2014



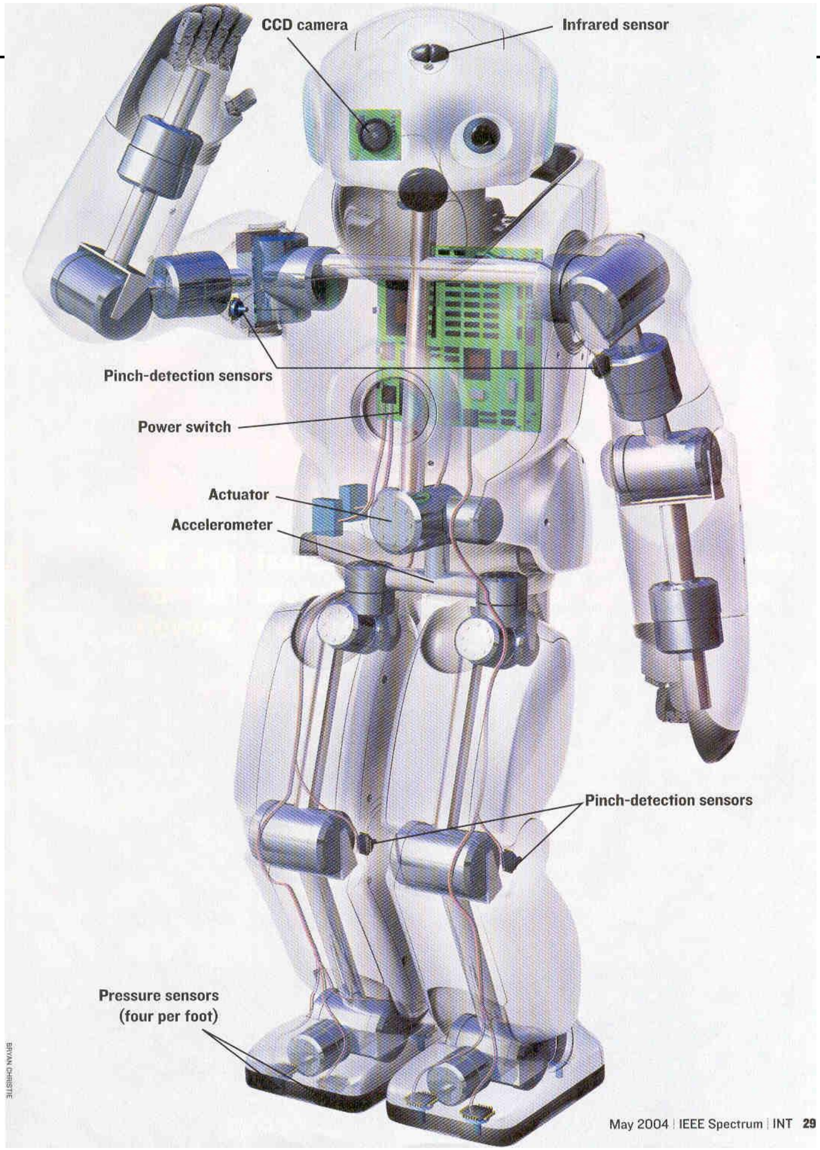
Mobile Robots Categorized by Locomotion



Legged Robots

- Legged robots can walk on uneven terrain or climb stairs.
- Dynamic stability is a major problem of bipedal robots
- More complicated mechanical structure
- Normally not fast-moving robots。

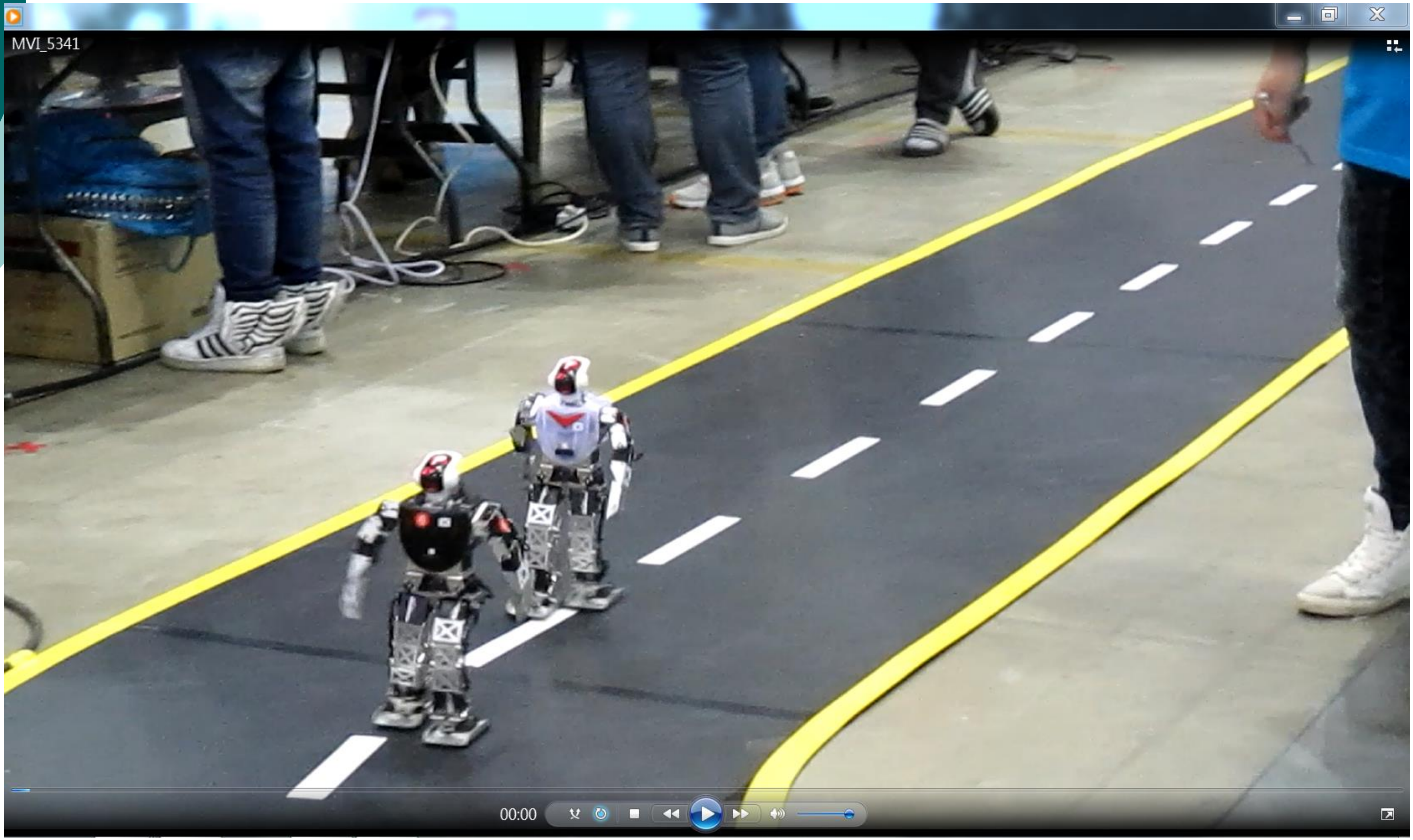
Intelligent humanoid robot



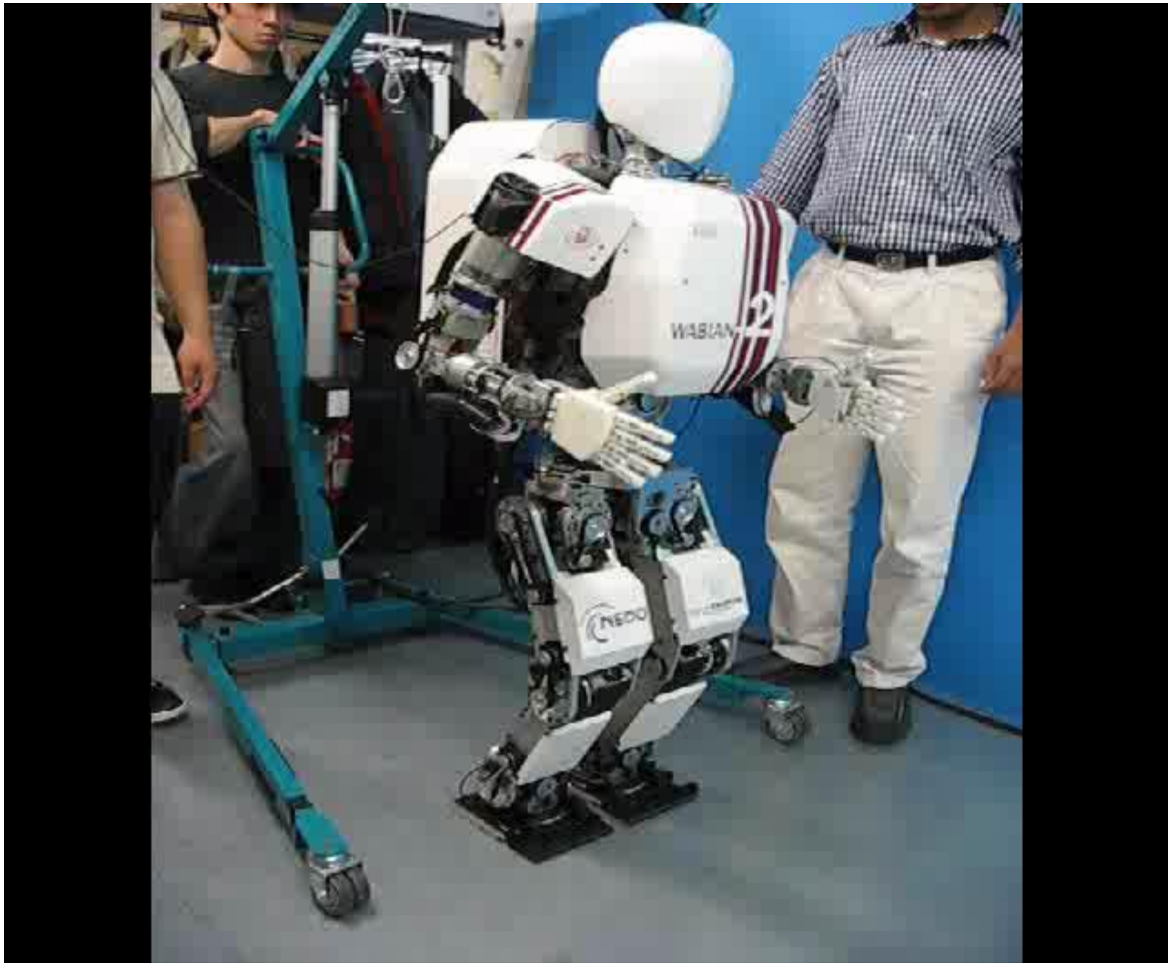
From: IEEE Spectrum, May 2004

Human-like robotic motion

International Robot Contest KINTEX, Korea 2014



WABIAN II (Waseda University)

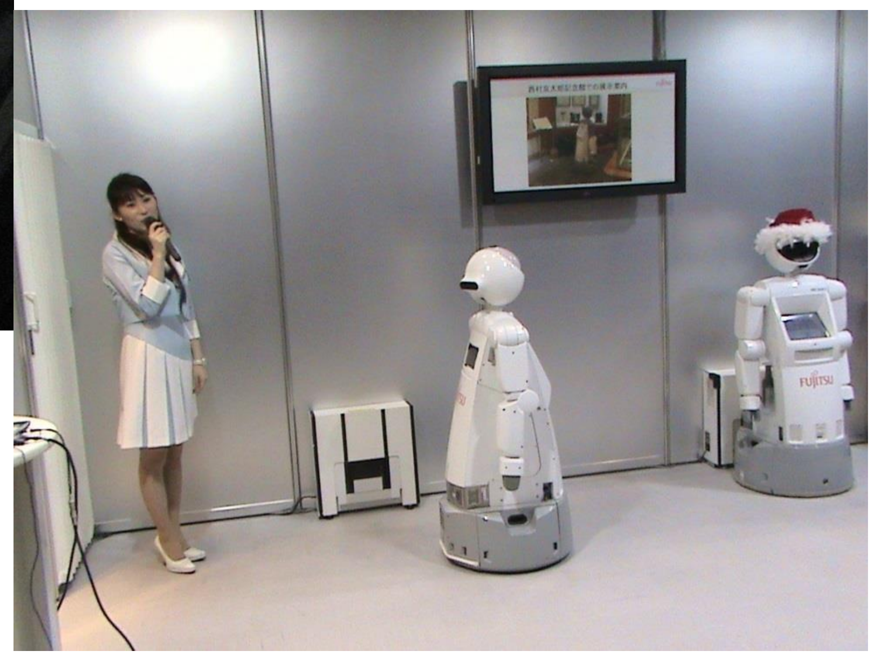


Wheeled Mobile Robots

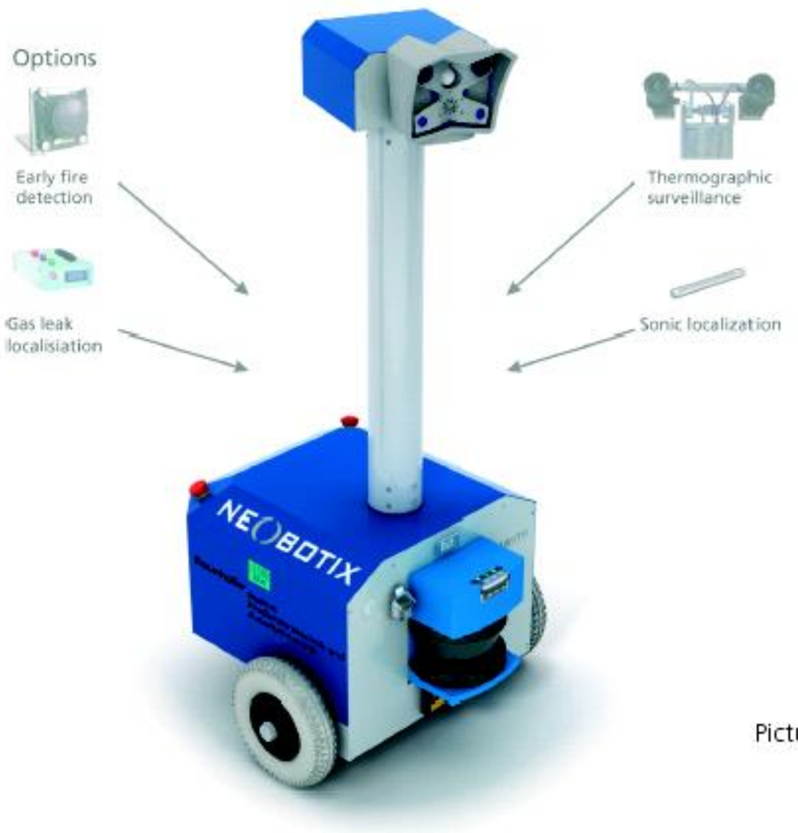
- More stable motion
- Relatively light
- Faster motion
- Easy to construct
- Easy to get parts (less expensive)

Problems:
-Soft surface
-Uneven terrains
-Stairs

Home robots



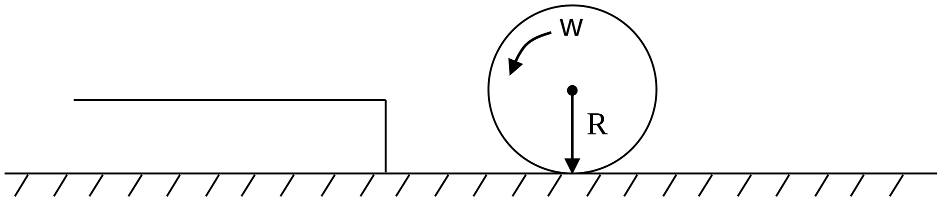
Security Robots



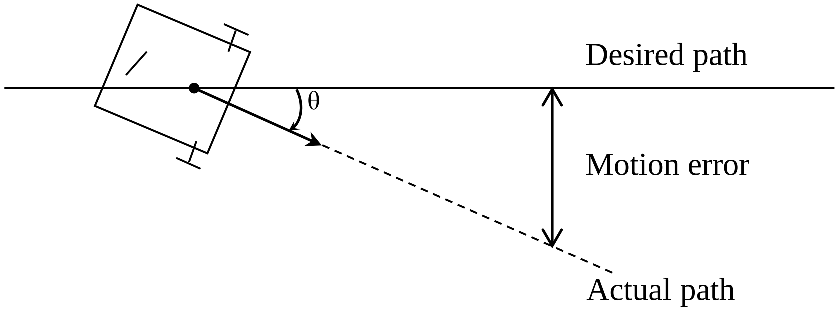
Picture 1 Security robot Secur-O-bot with a modular sensor building set.

Disadvantages of Wheeled Robots

- May perform poorly on uneven terrain.



Generally cannot go over objects higher (larger) than radius of wheel.



Wheel slip on soil, wet surfaces, especially when accelerating hard.

Accumulated error in position estimation, making dead-reckoning difficult.

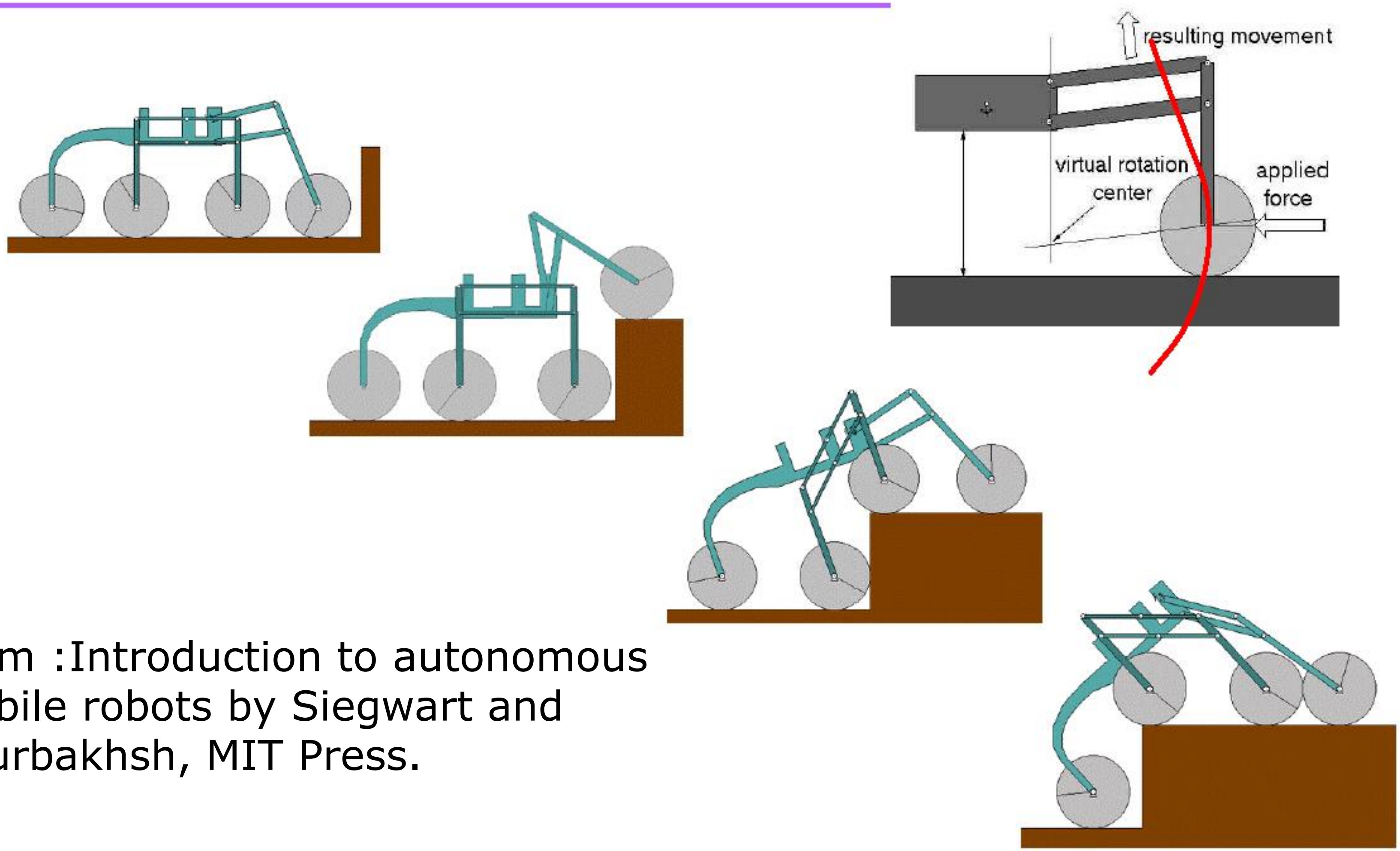
Rover for Mars exploration

Stepping / Walking with Wheels

- SpaceCat, and micro-rover for Mars, developed by Mecanex Sa and EPFL for the European Space Agency (ESA)

From :Introduction to autonomous mobile robots by Siegwart and Nourbakhsh, MIT Press.

The SHRIMP Adapts Optimally to Rough Terrain



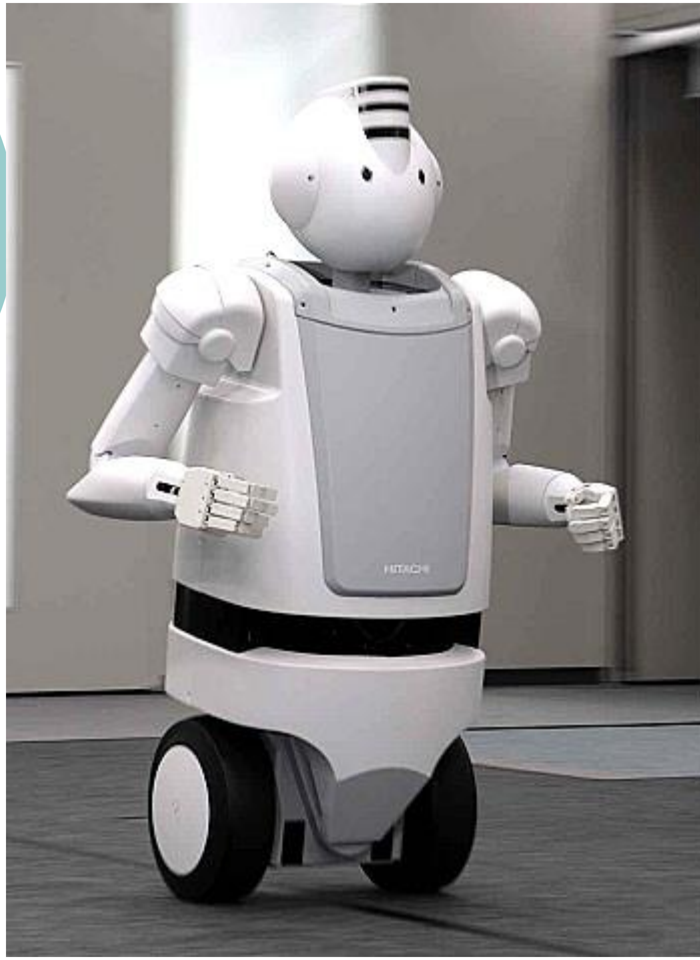
From :Introduction to autonomous mobile robots by Siegwart and Nourbakhsh, MIT Press.

Use of multiple wheels to overcome uneven terrains

Personal mover, Tokyo University

Segway: Gyros and Accelerometers are used for dynamic balance control.

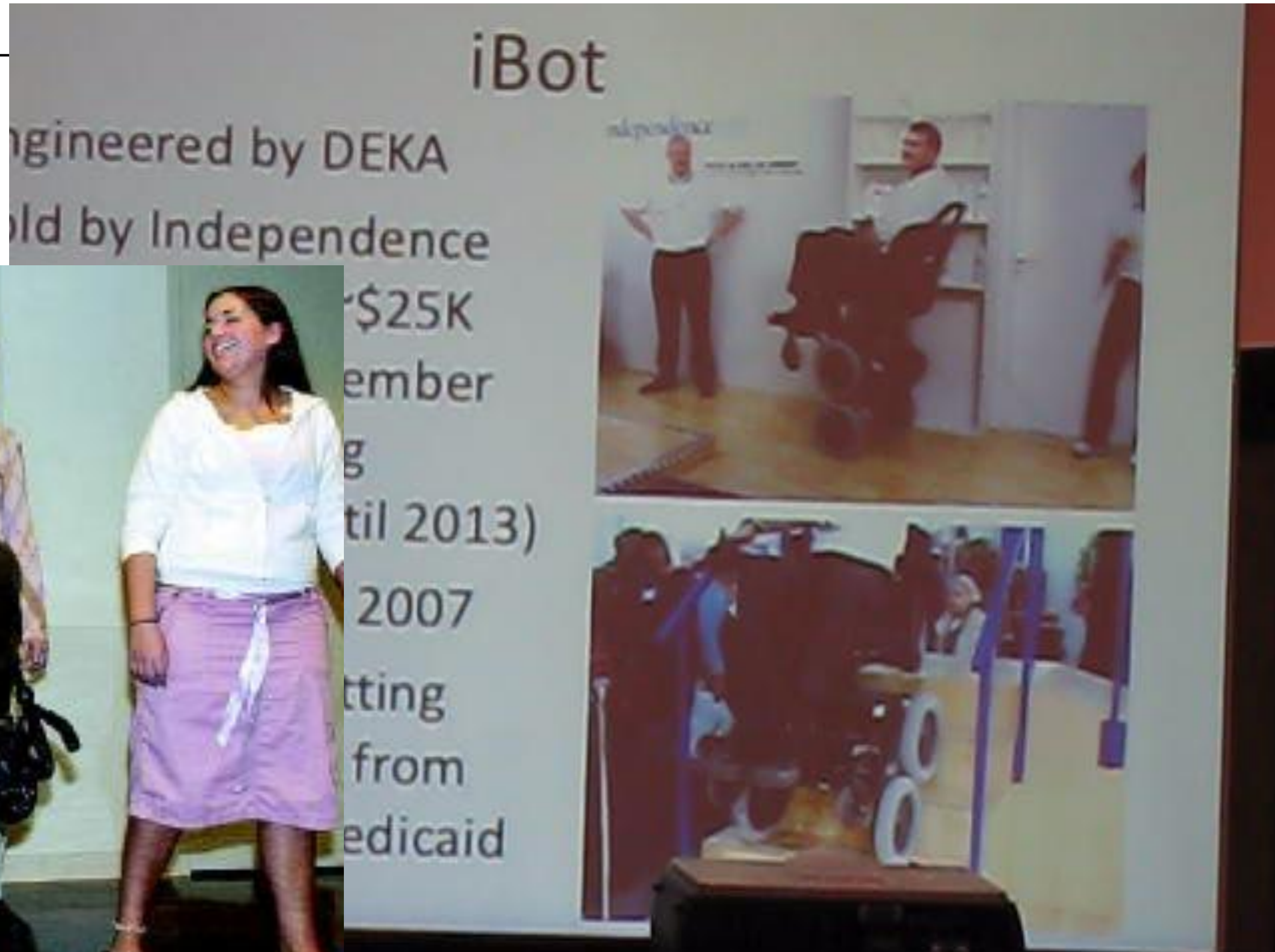
From: Times, Dec. 10, 2001


HITACHI


Winglet
Winglet
TOYOTA

iREX 2009, Japan

iBot of Dean Kamen



Dean Kamen & Robotic Wheelchair

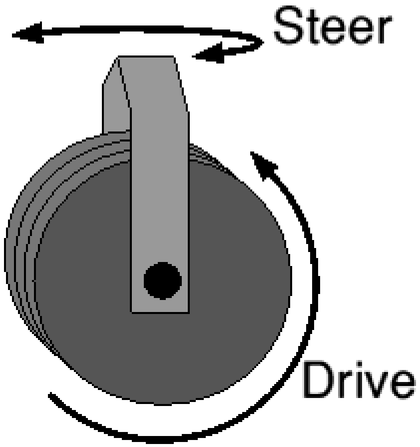
Number of Wheels

- Three-wheeled:

  Most popular is two-independent drive wheels with a caster for balance. With differential speeds of two wheels, the robot can move in straight line, turn or spin at the spot.
- In factory, a front drive and steer wheel with two passive rear wheels can give good motion control and position estimation.
- Four-wheeled configuration can carry more load, but have problem on uneven surface.
- Two-wheeled robots need a dynamic balance control

Front wheel drive and steer system

- Drive and steer on the same wheel, similar to cars
- One motor drives, another motor steers
- Dead reckoning on the other two passive wheels, because these two wheels are not powered, slippage is less likely to occur.
- 2 DOF



Differential Drive Wheels

- Two independent drive wheels
- One of the least complicated locomotion systems
- Wheels on an aligned axis, each controlled by separate motor
- 2.5 DOF motion

go straight

move in an arc

rotate in place

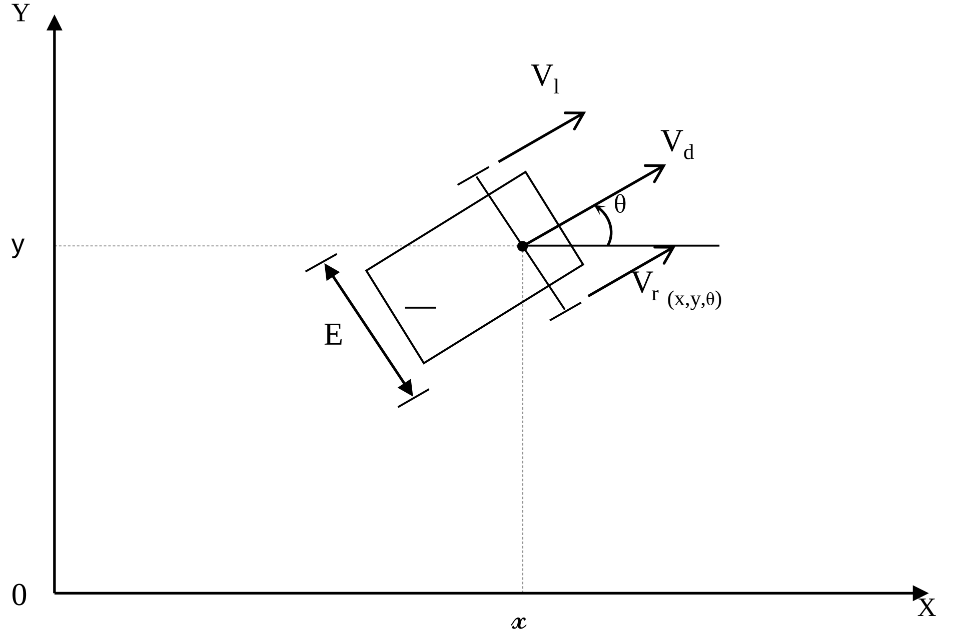
Balance

- Adds a caster
- Add two caster

  can get tighter turns

  can get trapped on uneven terrain

Kinematics of Wheeled Robot



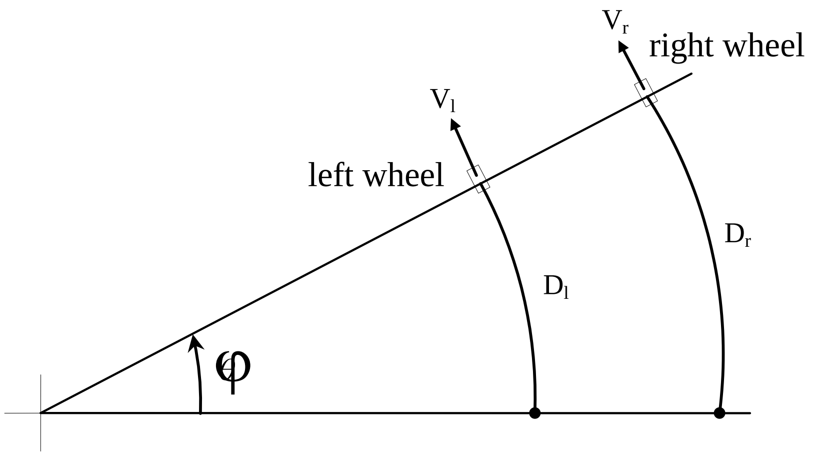
linear velocity of center point:Vd

$V_d = (V_l + V_r) / 2$

$\omega = (V_r - V_l) / E$

E : distance between two drive wheels

To make a turn



$$D_r - D_l = R_1\varphi - R_2\varphi = \varphi\,(R_1 - R_2) = E\varphi$$

$$\varphi = (D_r - D_l) / E$$

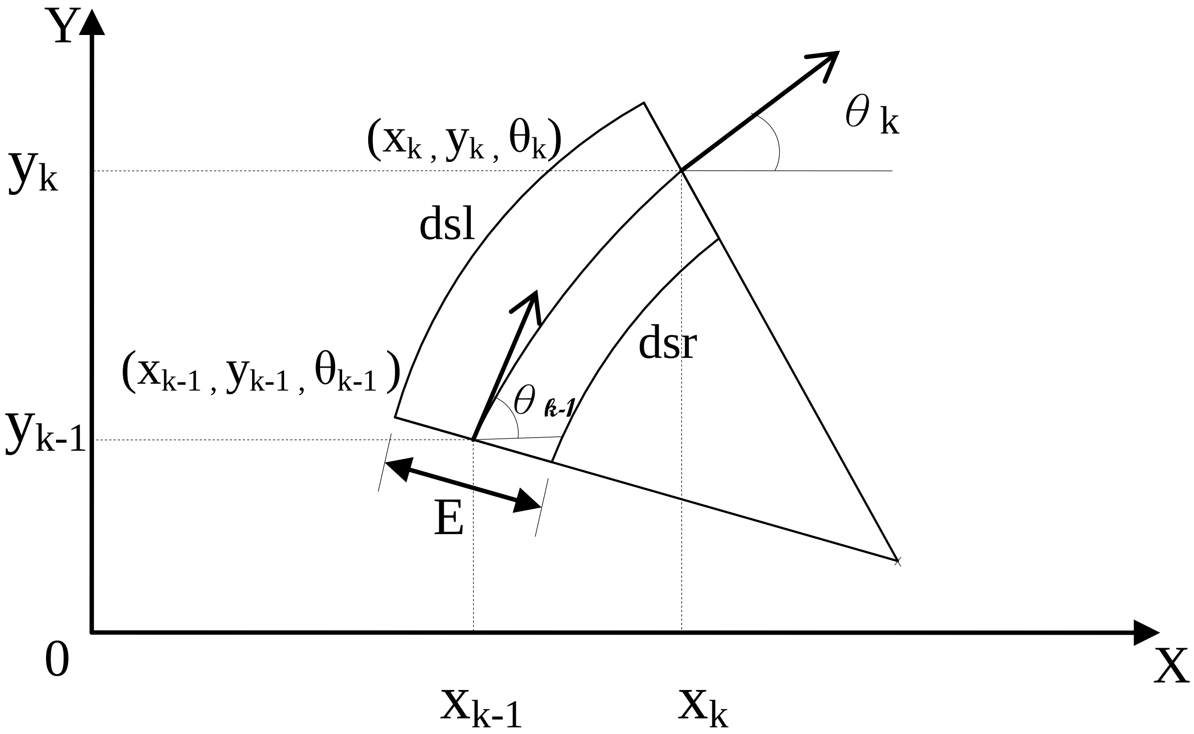
Minimize φ by maximizing E

Maximize φ by minimizing E

Self-localization and odometry

- Dead-reckoning (use internal sensors)
- Want two wheels to spin at same rate based on shaft encoders (for move straight motion)
- pulse counts to represent angular displacement of motor shaft

Odometry calculation (1/2)



Odometry calculation (2/2)

$S = R\,(\varphi)$

$d\theta_k = (dS_r - dS_l) / E$

$dS_k = (dS_l + dS_r) / 2$

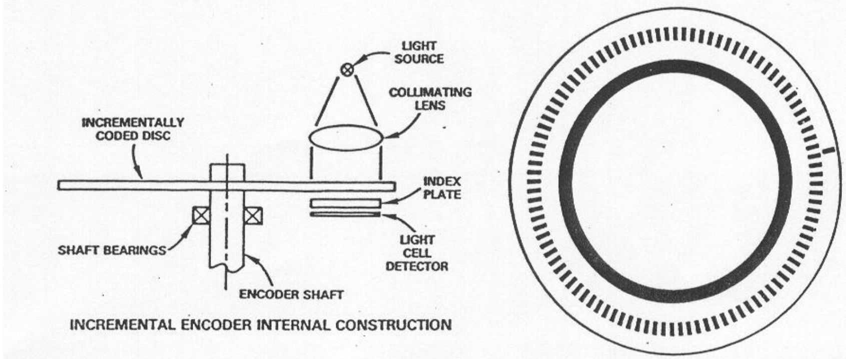
$\theta_k = \theta_{k-1} + d\theta_k$

$$x_k = x_{k-1} + dS_k \cos\left(\frac{\theta_k + \theta_{k-1}}{2}\right)$$

$$y_k = y_{k-1} + dS_k \sin\left(\frac{\theta_k + \theta_{k-1}}{2}\right)$$

Optical Encoders

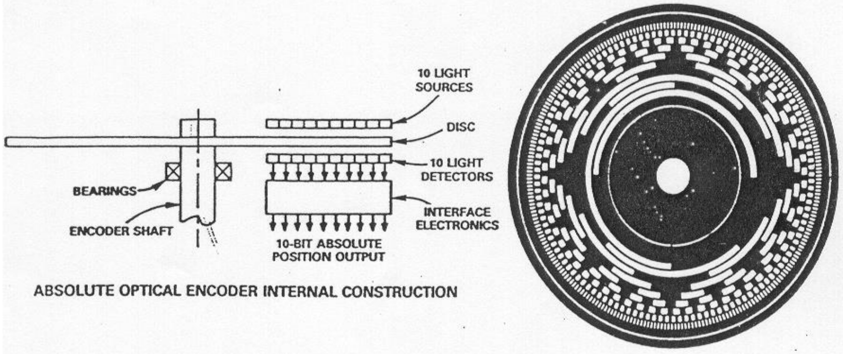
Incremental encoder



a. Incremental encoder.

Need a decoder circuit to do the pulse count.

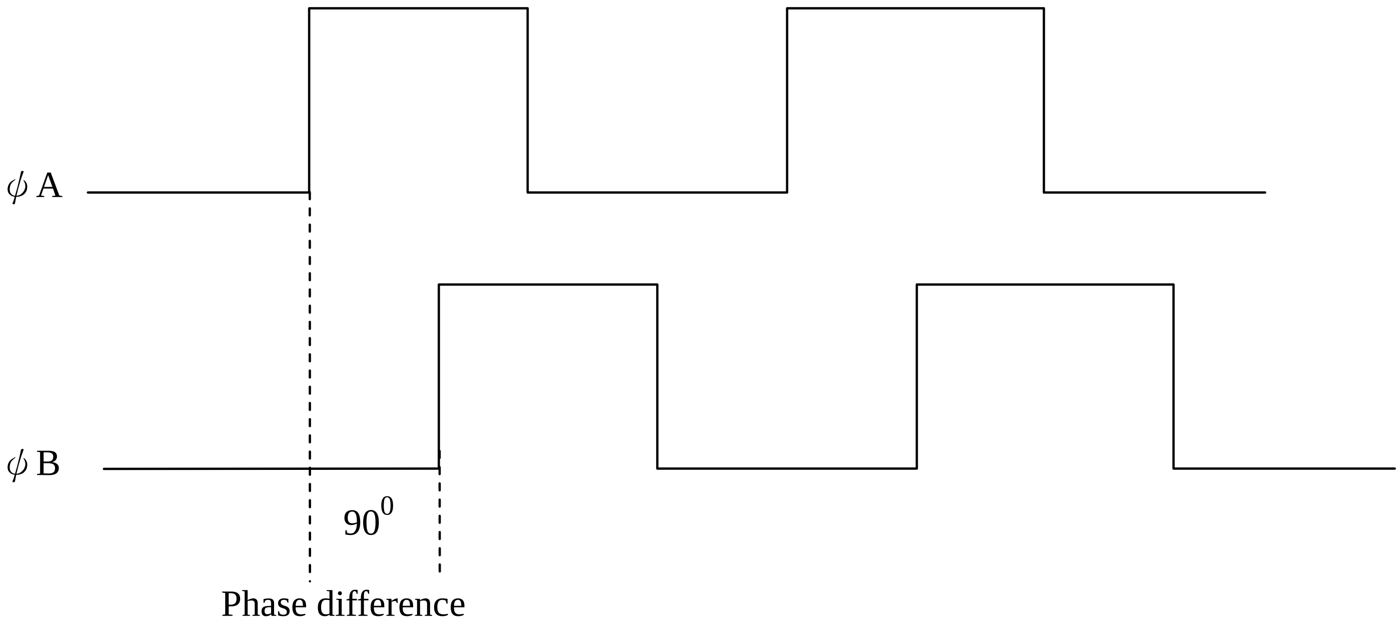
Absolute encoder



b. Absolute encoder.

Figure 14.3. Optical encoders.

Signal from shaft encoders



Problems with dead-reckoning

1) we sample the pulse counts of left and right motor periodically to calculate the pose of robot (x_k, y_k, θ_k) at time instant k.

2) the estimated pose is relative to the motor shaft, but not absolute relative to the world coordinate system.

3)Because the pulse counts from the motor shaft do not represent the actual speed of the left and right wheels, while slippage occurs or error due to sampling, it will cause odometry error which will accumulate.

Major Difficulty – to make a robot go straightline

- Motors with the same signal have different speeds – the robot go straight only if two wheels with the same speed
- Two independent servo loops –the disturbance in any loop will cause a transient speed variation

  1)different resistance in gear trains

  2)different surface conditions for each wheel

  3)solution : cross–coupling dynamic control

Test run for straight-line motion

Sensor-based motion control

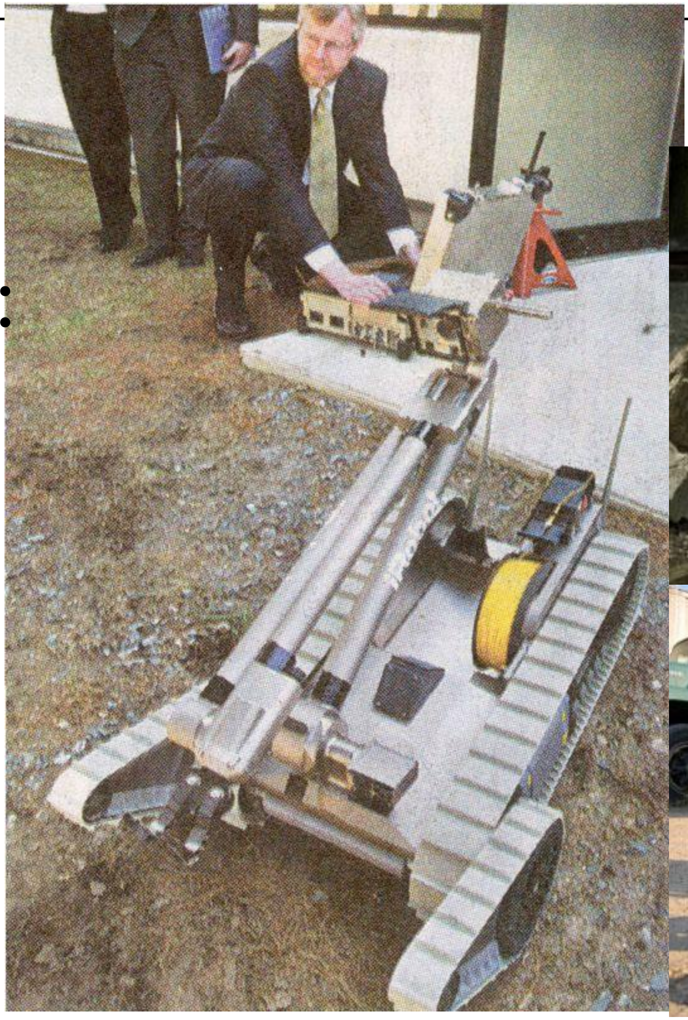
Tracked Robots

- More suitable for outdoor environments
- Tracked wheels allow the robot to move on a slope or small step.
- The track on each side can be adjusted for tightness. Each track is servo controlled for driving.
- The robot direction is steered by changing the speed of two tracks.

Track-wheeled robot

Unmanned combat robot: Stryker

－iRobot



From:路透社

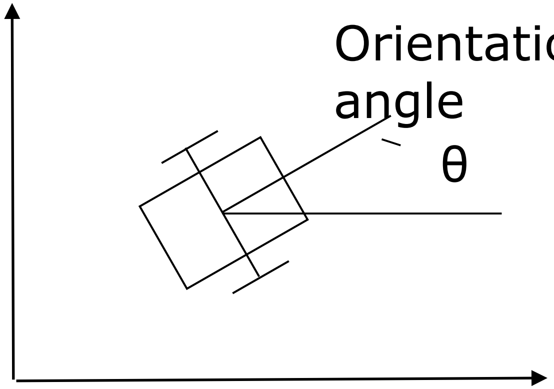
Tracked robot with stereo camera

Limitations of Car-like Mobile Robots

- Can we position and orient our robot any where on the plane? If we give it (x,y,θ), can the robot be able to move to that location?
- The robot's orientation and position are coupled. In order to turn, it must move forward or backward.
- only have two DOF : nonholonomic constraint

Nonholonomic System

- The mobile robot can only move in the direction perpendicular to the drive wheel's axis



$$\frac{dy}{dx} = \tan\theta \qquad \frac{Vy}{Vx} = \tan\theta$$

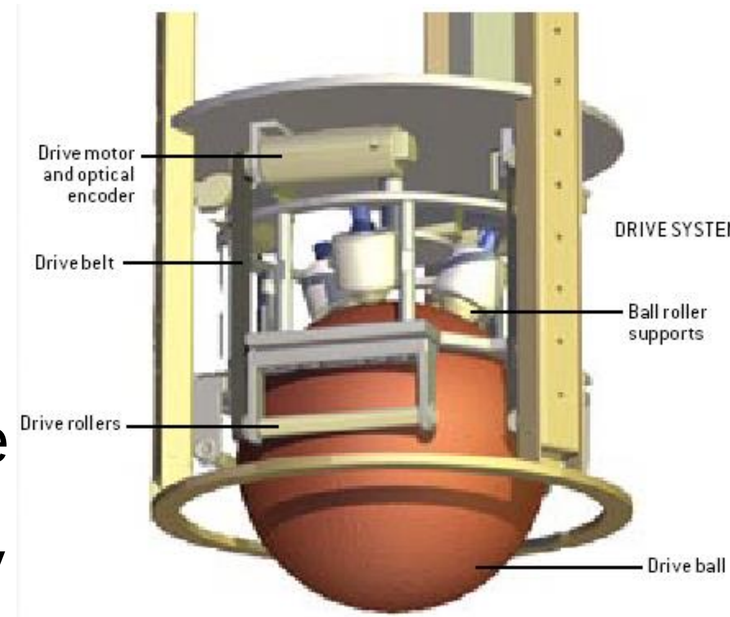
The traveling direction of the vehicle is always tangent to the trajectory of its center point.

Omni-directional Wheel System

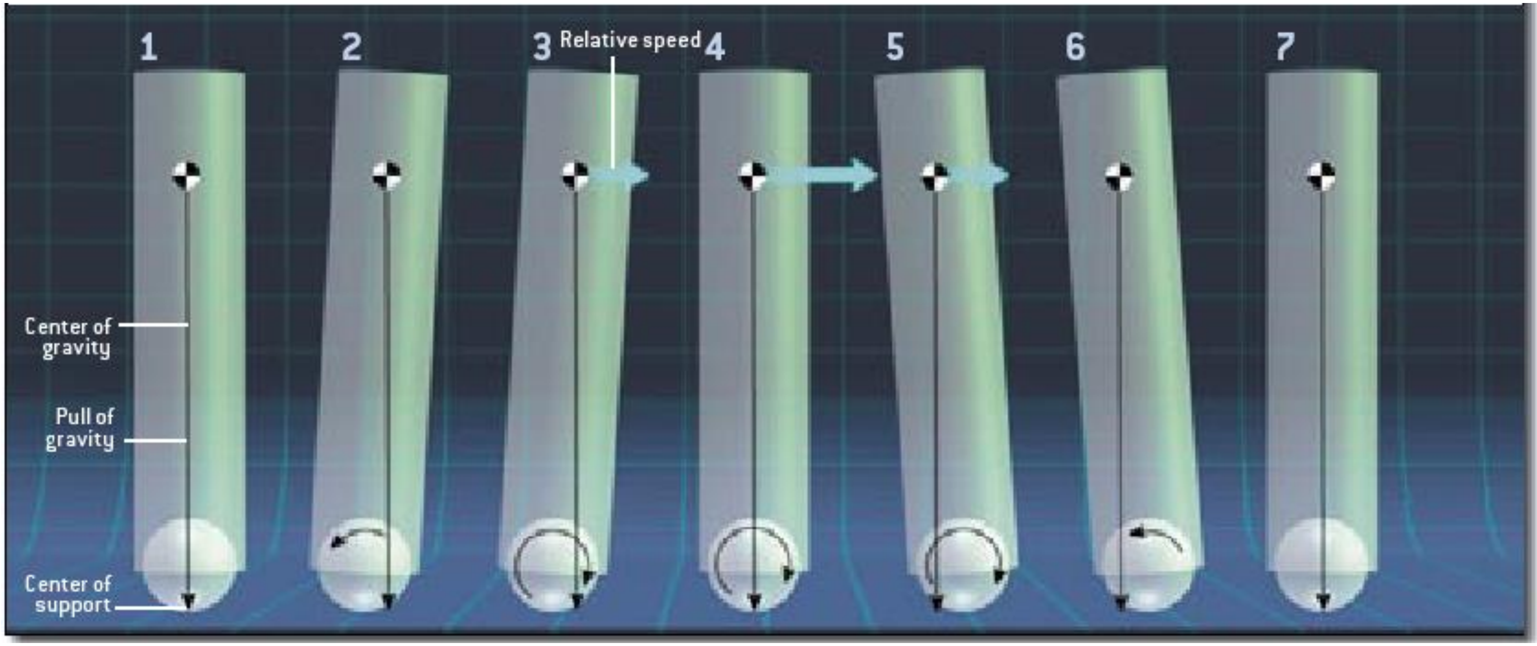
- In a world coordinated system, a robot location is specified by (x,y,θ), robot pose has three degrees of freedom.
- Independent control three degree-of-freedom(x,y,θ)
- Three drive wheels that can demonstrate real three degrees of freedom motion in a plane

BallBot

- Invented by Dr. Ralph Hollis, Cannege-Mellon University, USA
- The idea is to design a slender omni-directional robot. With a tall body and flexible motion is a narrow space, the robot can be more practically used for human-robot interaction.
- Dr. Hollis used a ball as the mobile platform. Two shaft encoders and gyros are attached to the ball body for balance control.
- An adaptive controller is required for dynamic balance control during robot motion.



Motion control of BallBot



Problem of Fall Over

- Current mobile robots adopt three or four wheeled configuration with large footprint area for stability
- The robot can not be tall with small footprint, otherwise it will fall over under relative large velocity change.
- In many applications, a slander robot is required for human robot interaction. It poses a challenge for robot locomotion design.

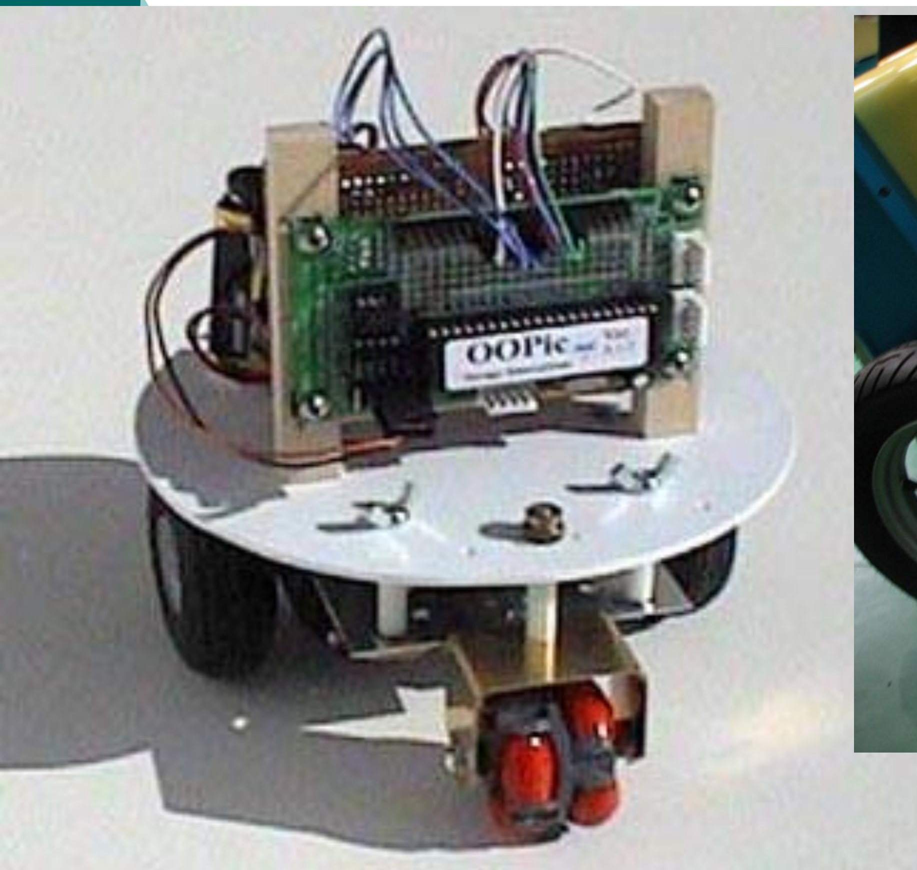
Omni-Directional Robots

- To have complete 3 Degree-of-freedom on a plane.
- Special wheels are used for omni-directional motion.
- An omni-directional wheel consists of multiple passive rollers on a circular shape. The roller provides free side motion as the wheel rotates.
- With three or four omni-directional wheels on the mobile platform, the robot can have three-directional motion on a plane.

Wheels with passive rollers

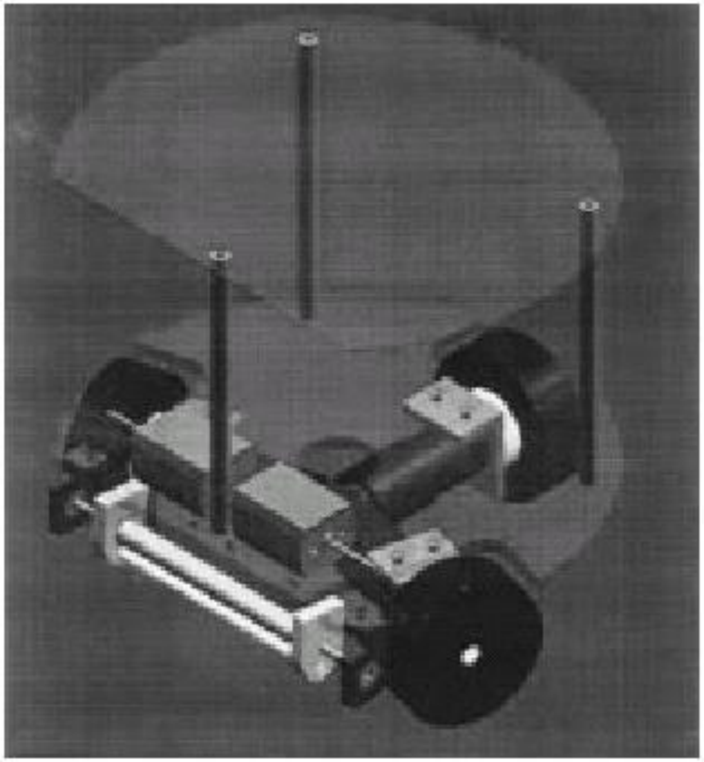
From Acroname

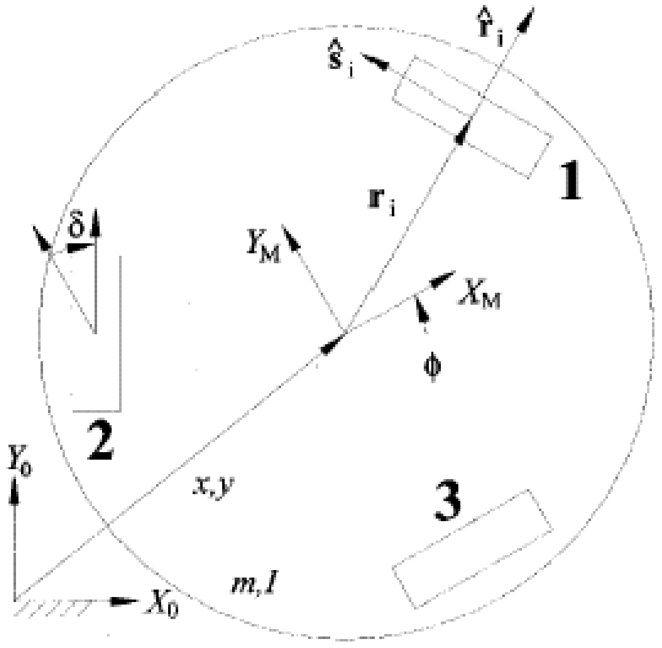
Omni-directional Caster



From Acroname

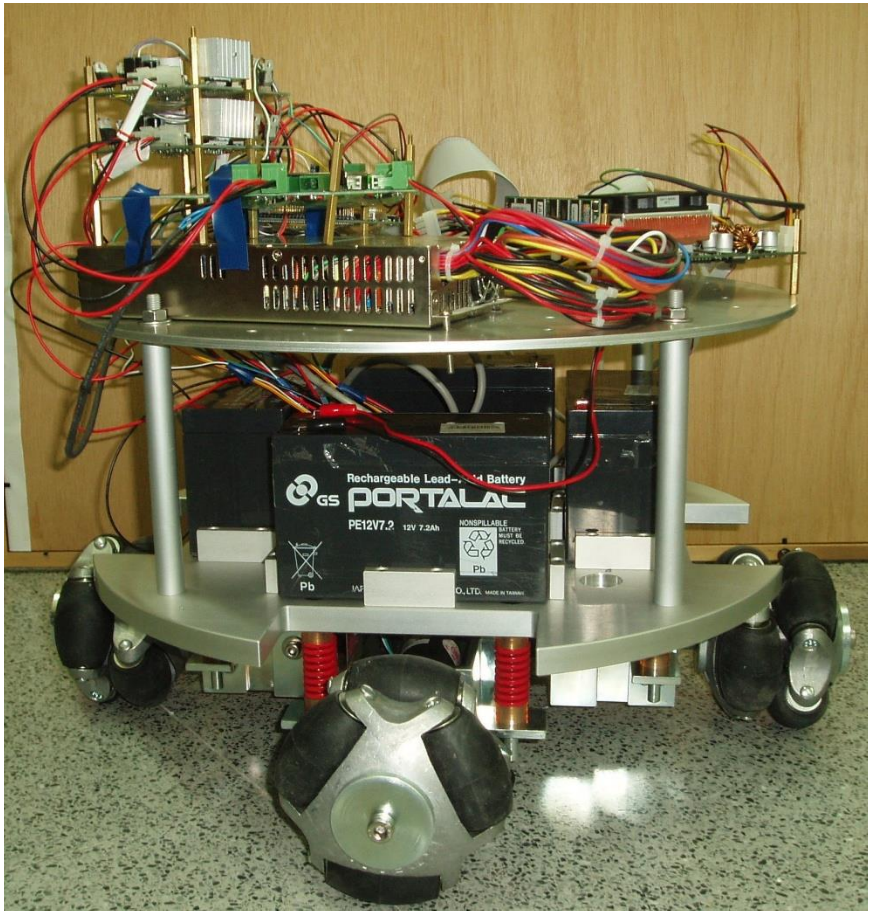
Three-wheeled Omni-directional Robot



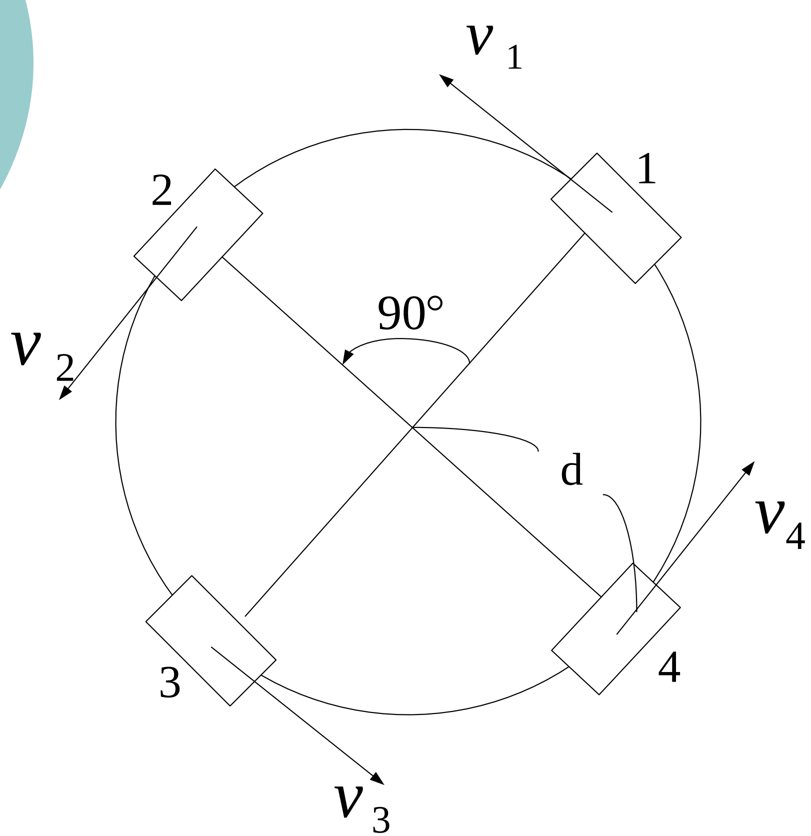


Robert L. Williams *et al,* “Dynamic model with slip for wheeled omnidirectional ro0bots,” *IEEE Trans. Robotics and Automation*, Vol.18, No. 3, 2002, pp.285-293

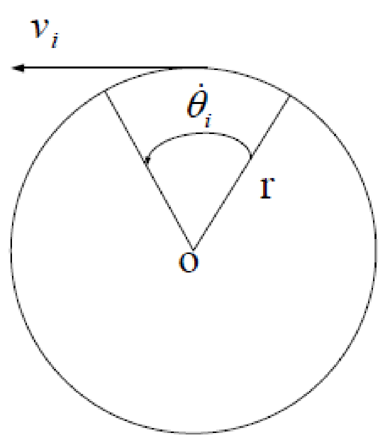
Four-wheeled Omni-directional Robot



Wheel velocity kinematics



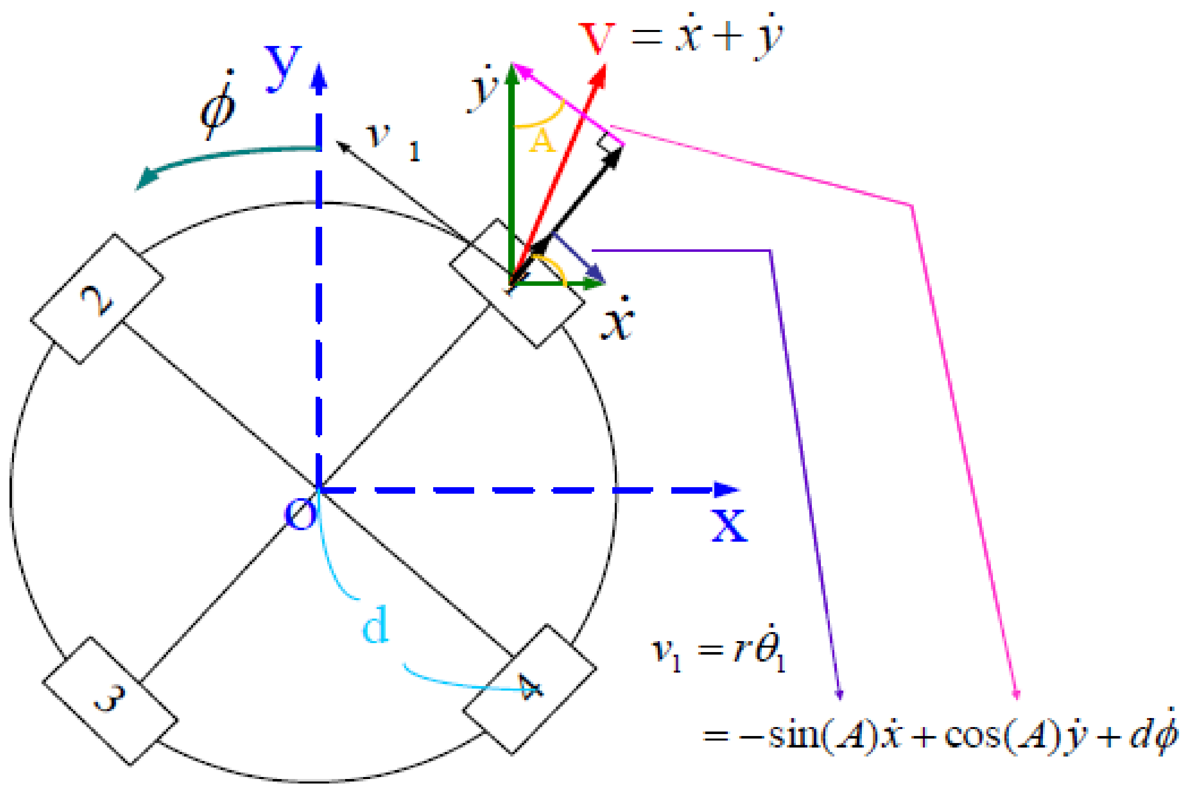
Robot Platform



$$v_i = r\dot{\theta}_i \quad , \quad i = 1, \sim 4$$

Wheel

Determine wheel velocity from platform velocity



r : wheel radius

Θ : wheel rotation angle

Inverse kinematics of omni-directional mobile robots

$$\begin{bmatrix} v_1 \\ v_2 \\ v_3 \\ v_4 \end{bmatrix} = \begin{bmatrix} -\sin(A) & \cos(A) & d \\ -\sin(A) & -\cos(A) & d \\ \sin(A) & -\cos(A) & d \\ \sin(A) & \cos(A) & d \end{bmatrix} \cdot \begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\phi} \end{bmatrix}$$

1. The mobile platform can be controlled to move in any direction by giving four wheel velocities
2. As the linear and angular velocities of the platform is given, the velocities of four wheels can be calculated and executed for provide the motion.

Video: Omni-directional Surveillance Robot

Steer-and-drive Omni-directional Mobile Platform

Robot Shape

- Circular

  1) can rotate while in contact with object
  2) can be represented as a point (shrink to a point)

  3) can mimic the shape of a human being
- Square

  1) must back-up then rotate

  2) not clear how for and what to do if has 2nd collision while backing-up

What is the Best Locomotion Type?

- It depends on applications
- Possible mixed configuration of legs and wheels
- For service robots, a soft robot is required for safety interaction with human and objects in daily-life environments