Introduction to Mobile Robotics

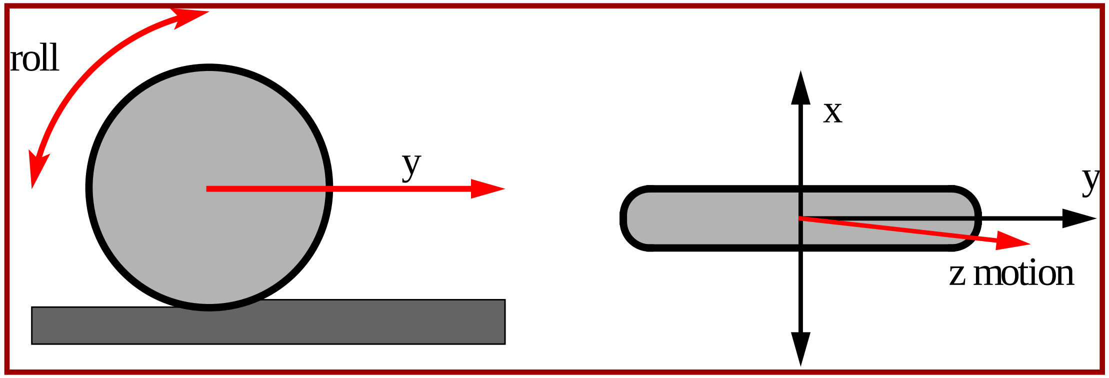
Wheeled Locomotion

Wolfram Burgard

Locomotion of Wheeled Robots

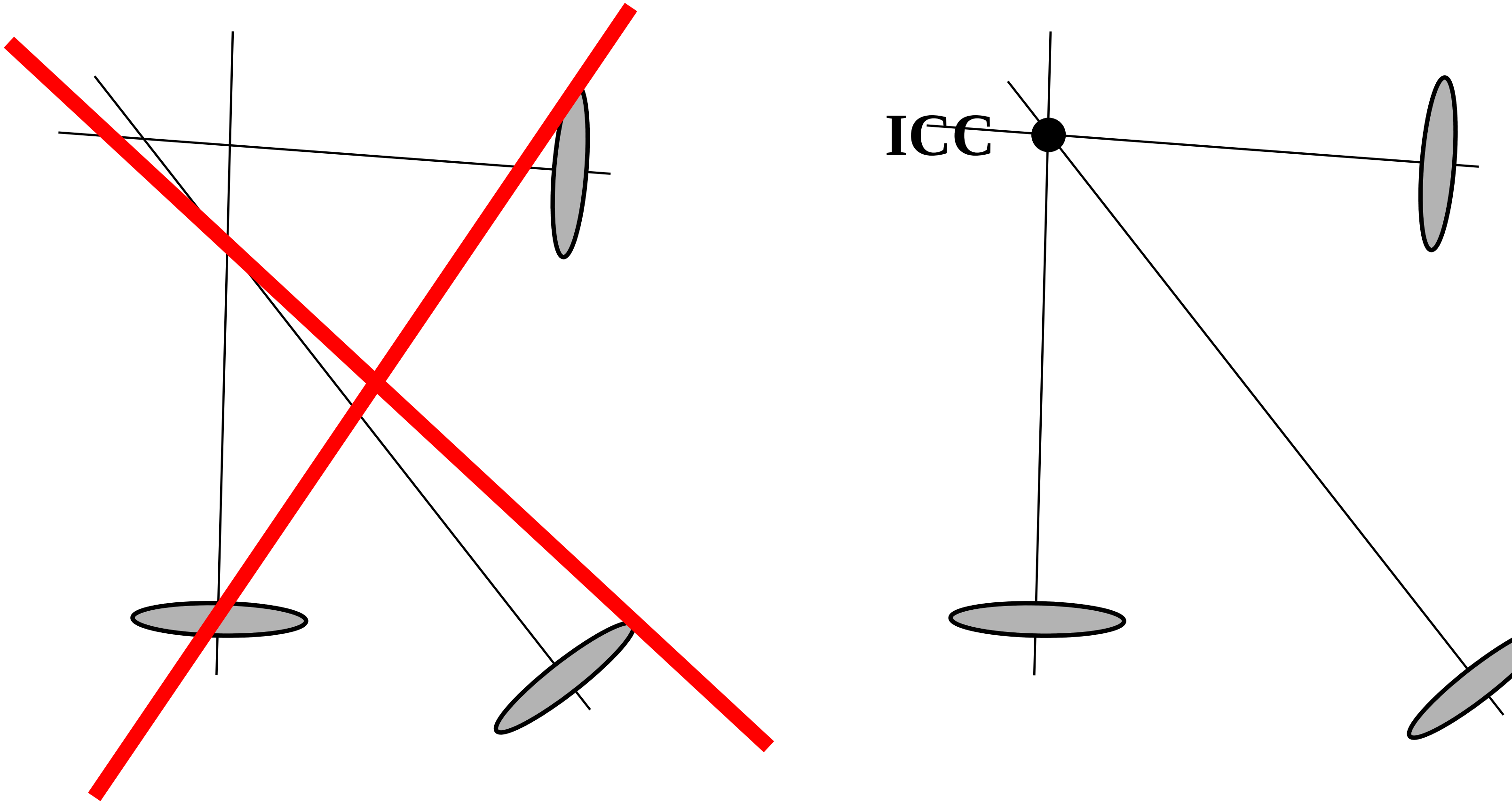
Locomotion (Oxford Dict.): Power of motion from place to place

- Differential drive (AmigoBot, Pioneer 2-DX)
- Car drive (Ackerman steering)
- Synchronous drive (B21)
- XR4000
- Mecanum wheels



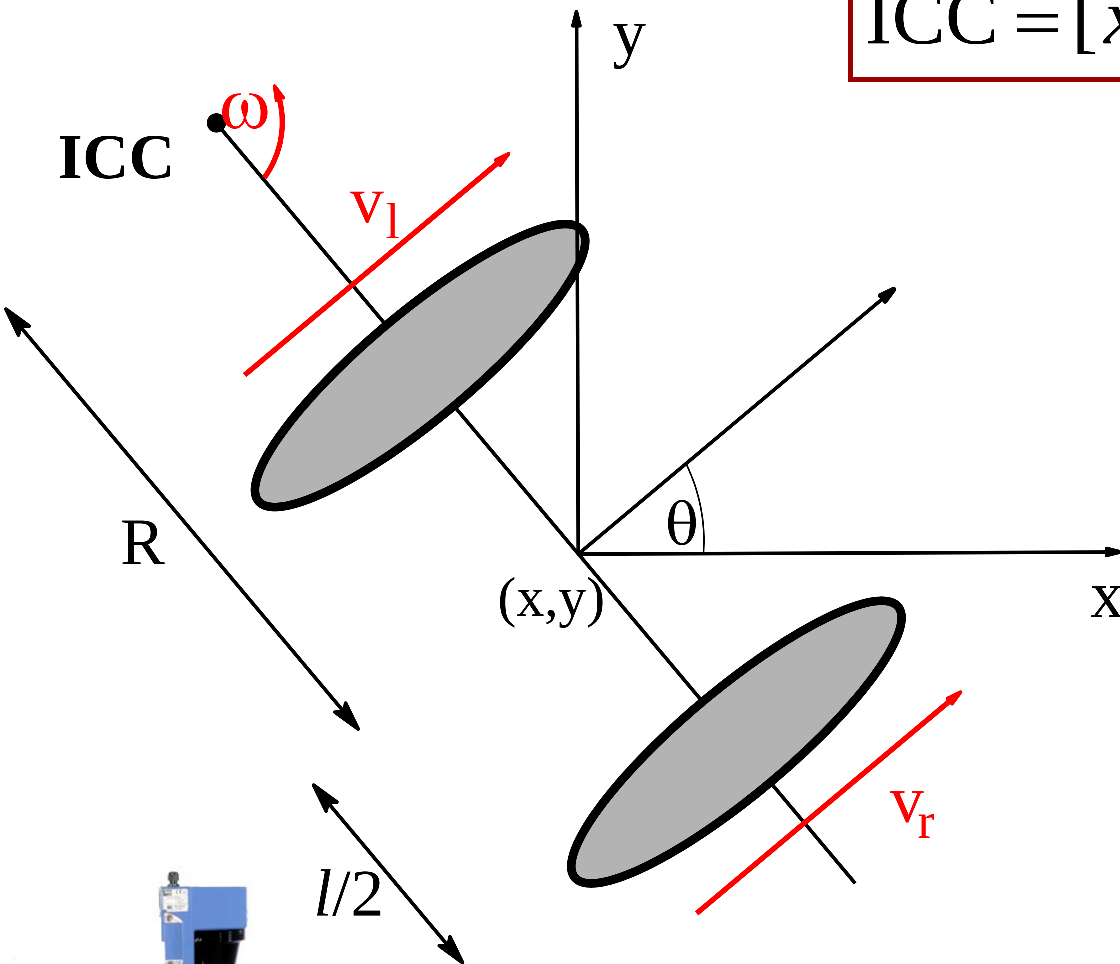
we also allow wheels to rotate around the z axis

Instantaneous Center of Curvature



- For rolling motion to occur, each wheel has to move along its y-axis

Differential Drive



$$ICC = [x - R\sin\theta, y + R\cos\theta]$$

$$\omega(R + l/2) = v_r$$

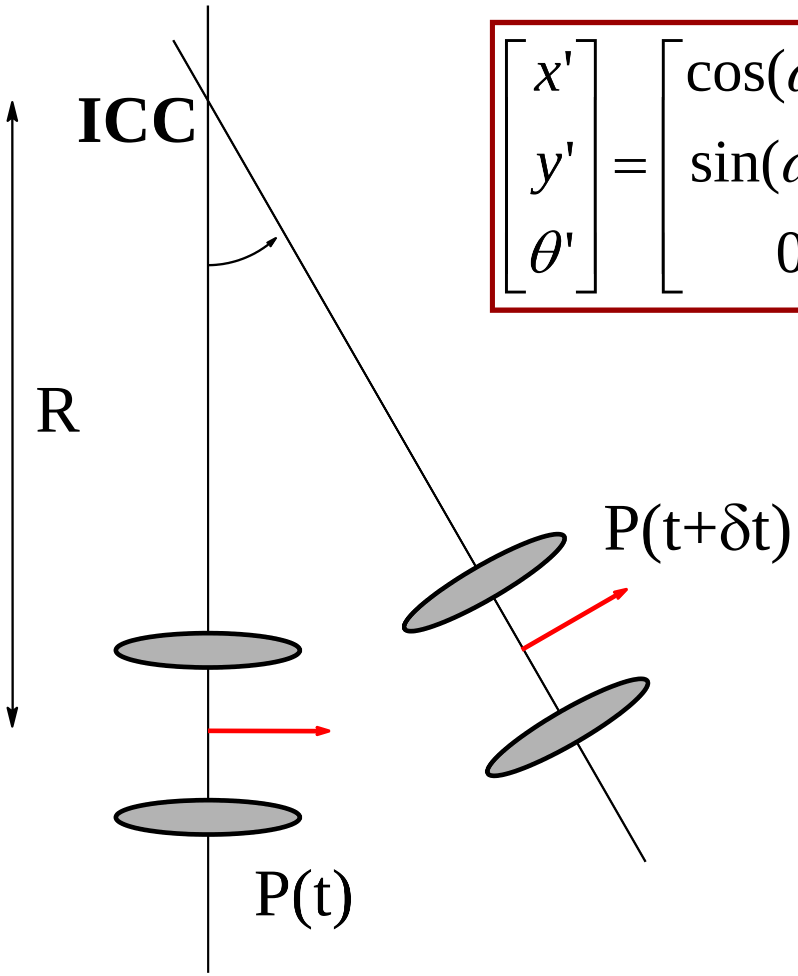
$$\omega(R - l/2) = v_l$$

$$R = \frac{l}{2}\frac{(v_l + v_r)}{(v_r - v_l)}$$

$$\omega = \frac{v_r - v_l}{l}$$

$$v = \frac{v_r + v_l}{2}$$

Differential Drive: Forward Kinematics



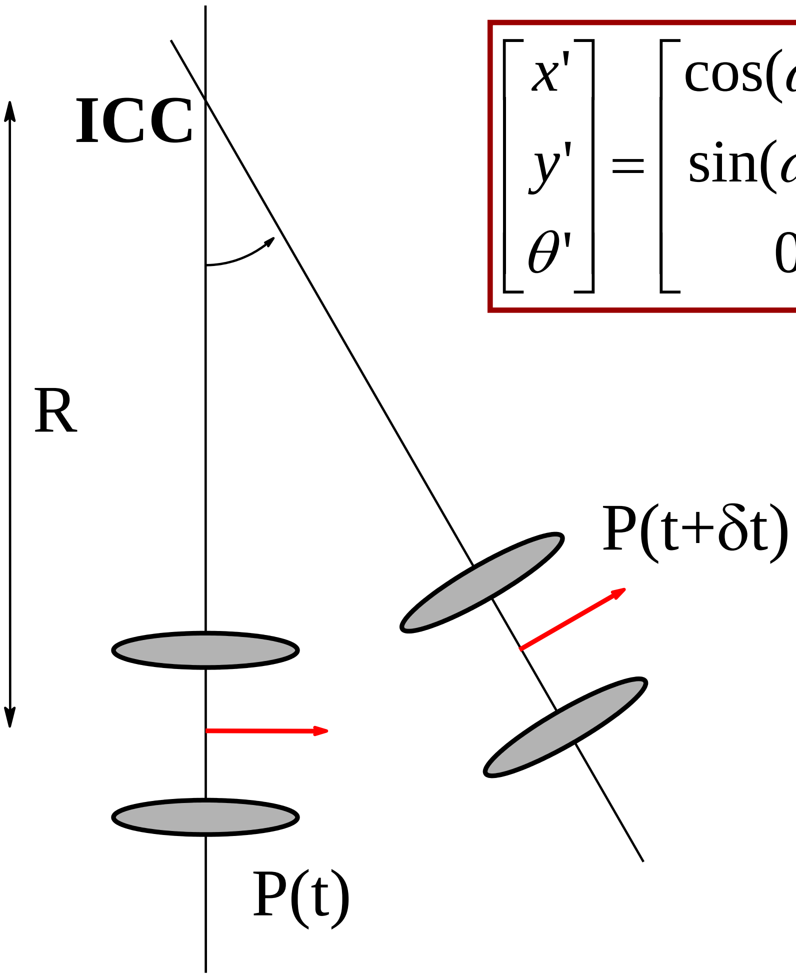
$$\begin{bmatrix} x' \\ y' \\ \theta' \end{bmatrix} = \begin{bmatrix} \cos(\omega\delta t) & -\sin(\omega\delta t) & 0 \\ \sin(\omega\delta t) & \cos(\omega\delta t) & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x - \mathrm{ICC}_x \\ y - \mathrm{ICC}_y \\ \theta \end{bmatrix} + \begin{bmatrix} \mathrm{ICC}_x \\ \mathrm{ICC}_y \\ \omega\delta t \end{bmatrix}$$

$$x(t) = \int_0^t v(t') \cos[\theta(t')] dt'$$

$$y(t) = \int_0^t v(t') \sin[\theta(t')] dt'$$

$$\theta(t) = \int_0^t \omega(t')\, dt'$$

Differential Drive: Forward Kinematics



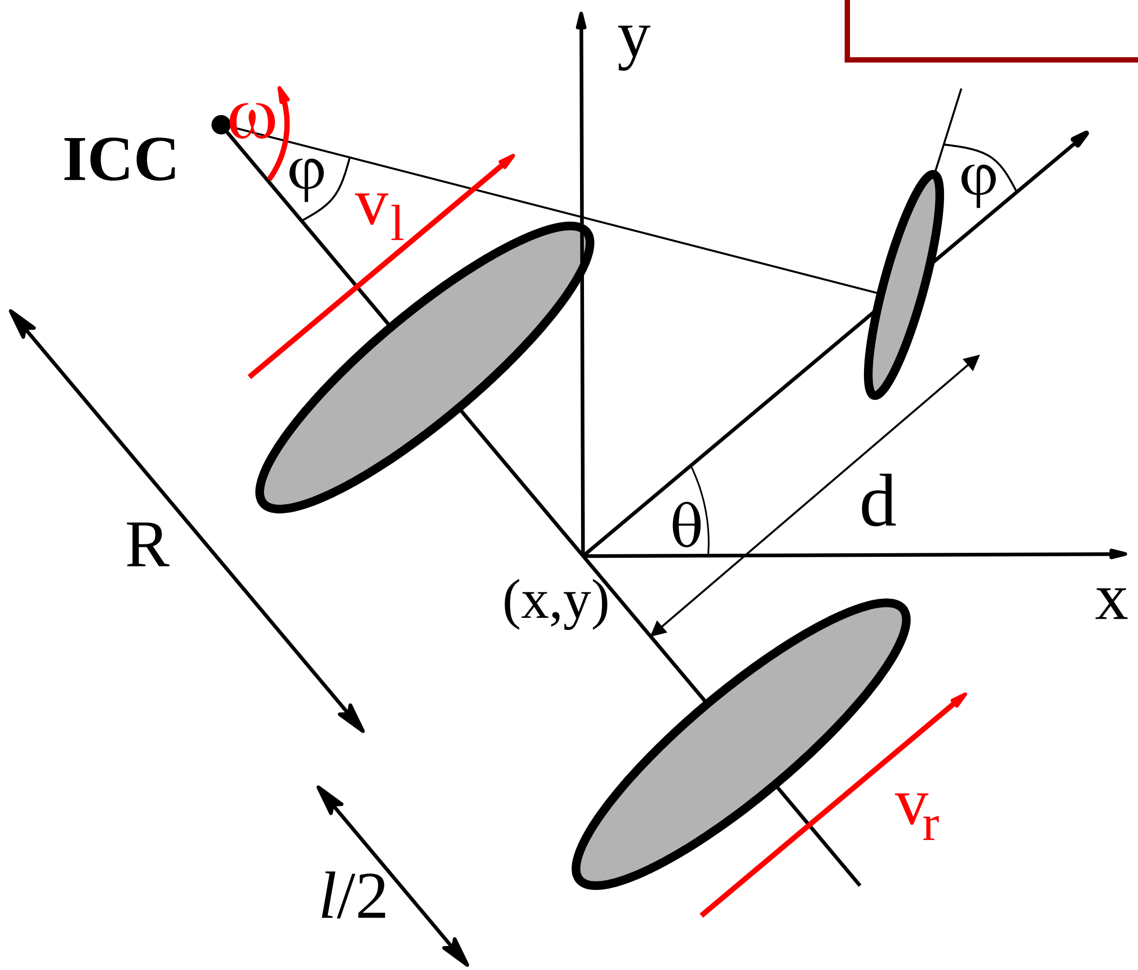
$$\begin{bmatrix} x' \\ y' \\ \theta' \end{bmatrix} = \begin{bmatrix} \cos(\omega\delta t) & -\sin(\omega\delta t) & 0 \\ \sin(\omega\delta t) & \cos(\omega\delta t) & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x - ICC_x \\ y - ICC_y \\ \theta \end{bmatrix} + \begin{bmatrix} ICC_x \\ ICC_y \\ \omega\delta t \end{bmatrix}$$

$$x(t) = \frac{1}{2}\int_0^t [v_r(t') + v_l(t')] \cos[\theta(t')]dt'$$

$$y(t) = \frac{1}{2}\int_0^t [v_r(t') + v_l(t')] \sin[\theta(t')]dt'$$

$$\theta(t) = \frac{1}{l}\int_0^t [v_r(t') - v_l(t')]\, dt'$$

Ackermann Drive



$$\mathrm{ICC} = [x - R\sin\theta,\ y + R\cos\theta]$$

$$R = \frac{d}{\tan\varphi}$$

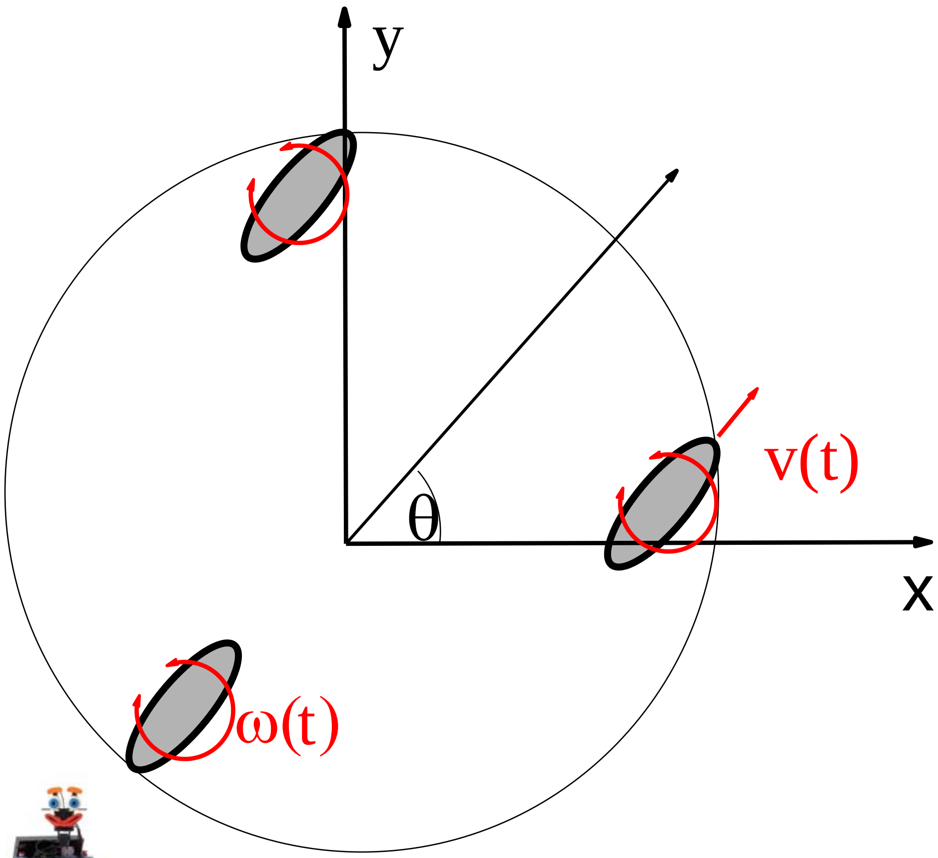
$$\omega(R + l/2) = v_r$$

$$\omega(R - l/2) = v_l$$

$$R = \frac{l}{2}\frac{(v_l + v_r)}{(v_r - v_l)}$$

$$\omega = \frac{v_r - v_l}{l}$$

Synchronous Drive



$$x(t) = \int_0^t v(t') \ \cos[\theta(t')] dt'$$

$$y(t) = \int_0^t v(t') \ \sin[\theta(t')] dt'$$

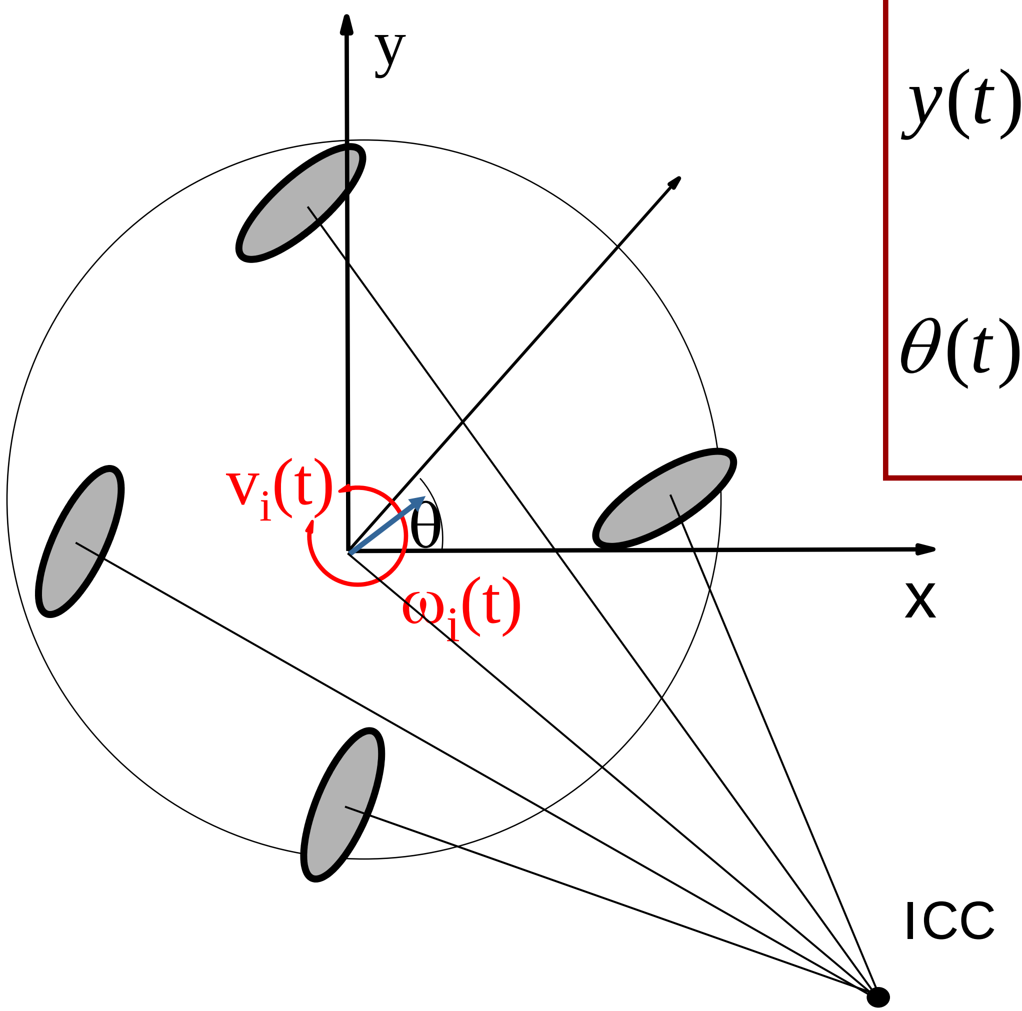
$$\theta(t) = \int_0^t \omega(t') \, dt'$$

XR4000 Drive

$$x(t) = \int_0^t v(t') \;\; \cos[\theta(t')] dt'$$

$$y(t) = \int_0^t v(t') \;\; \sin[\theta(t')] dt'$$

$$\theta(t) = \int_0^t \omega(t') \, dt'$$



Mecanum Wheels

$$v_y = (v_0 + v_1 + v_2 + v_3)/4$$

$$v_x = (v_0 - v_1 + v_2 - v_3)/4$$

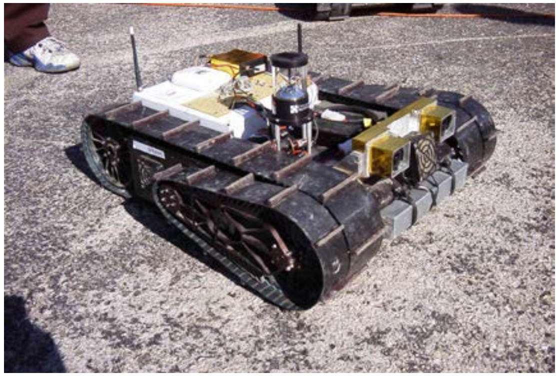
$$v_\theta = (v_0 + v_1 - v_2 - v_3)/4$$

$$v_{error} = (v_0 - v_1 - v_2 + v_3)/4$$

The Kuka OmniRob Platform

Example: KUKA youBot

Tracked Vehicles



Other Robots: OmniTread

[courtesy by Johann Borenstein]

Non-Holonomic Constraints

- Non-holonomic constraints limit the possible incremental movements within the configuration space of the robot.
- Robots with differential drive or synchro-drive move on a circular trajectory and cannot move sideways.
- Mecanum-wheeled robots can move sideways (they have no non-holonomic constraints).

Holonomic vs. Non-Holonomic

- Non-holonomic constraints reduce the control space with respect to the current configuration
  - E.g., moving sideways is impossible.

- Holonomic constraints reduce the configuration space.
  - E.g., a train on tracks (not all positions and orientations are possible)

Drives with Non-Holonomic Constraints

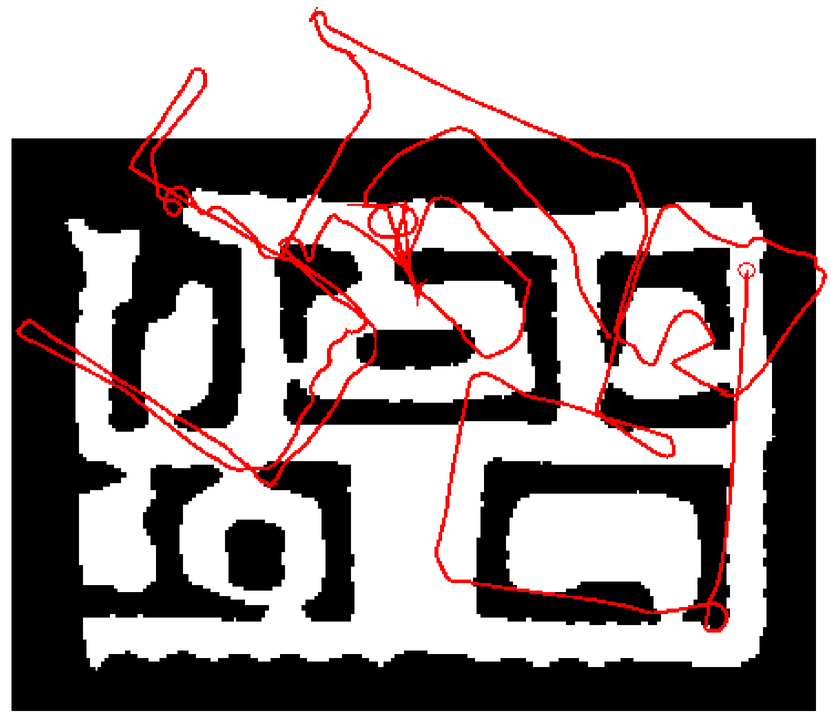
- Synchro-drive
- Differential drive
- Ackermann drive

Drives without Non-Holonomic Constraints

- Mecanum wheels

Dead Reckoning and Odometry

- Estimating the motion based on the issued controls/wheel encoder readings
- Integrated over time



Summary

- Introduced different types of drives for wheeled robots
- Math to describe the motion of the basic drives given the speed of the wheels
- Non-holonomic constraints
- Odometry and dead reckoning