High Speed Differential Drive Mobile Robot Path Following Control With Bounded Wheel Speed Commands

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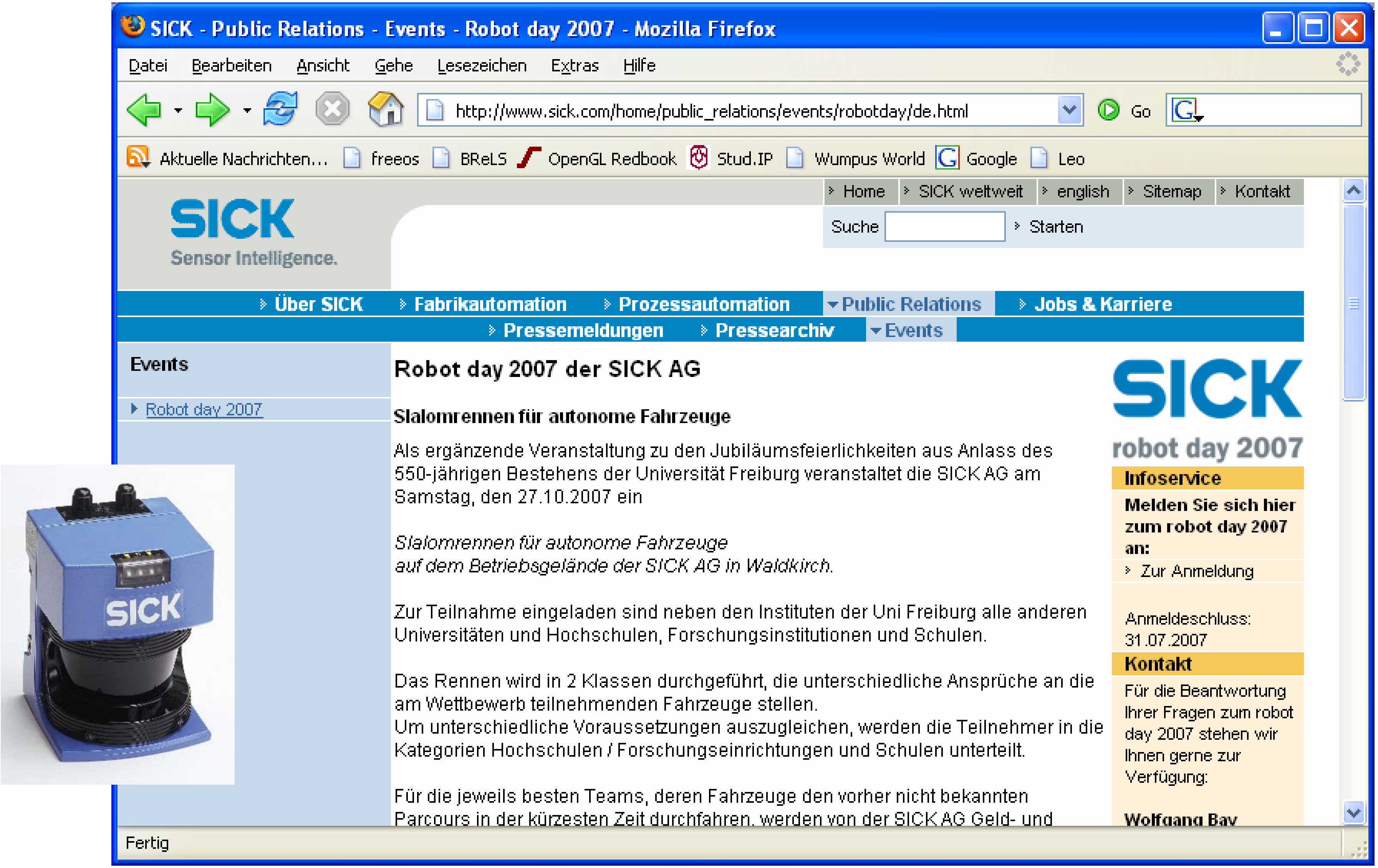
Motivation – SICK robot day

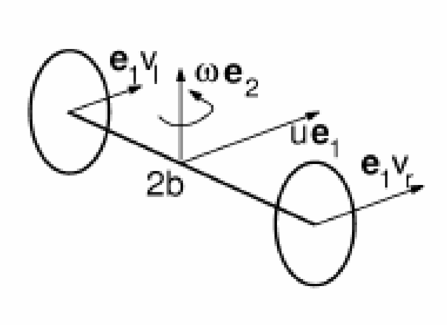


Challenges when driving fast

- Ideal actuators:
  - any control value is assumed to be instantly implemented regardless of its value.
    - Dynamical case: torque
    - Kinamatical case: speed
  - No saturation
- Real actuators:
  - Exhibit saturation in case the commanded signals should exceed given thresholds.
  - Usually the controller outputs are bounded to prevent hardware damages
- Here we consider the case of kinematical path following control for a differential drive mobile robot with actuator velocity saturation.

Kinematical model

- We build our solution on the C. Canudas de Wit et al. [3] and D. Soetanto et al. [10] control for differential drive robots.



- Velocity and angular velocity

$$
\begin{aligned}
u &= \frac{1}{2}(v_r + v_l) \\
\omega &= \frac{1}{2b}(v_r - v_l)
\end{aligned}
$$

- Can move on a path with arbitraty curvature

$$\kappa = \frac{1}{b}\,\frac{v_r - v_l}{v_r + v_l}.$$

$$\kappa \in \left[-\frac{1}{b}, \frac{1}{b}\right] \quad \text{if} \quad v_l, v_r \in [0, V_m]$$

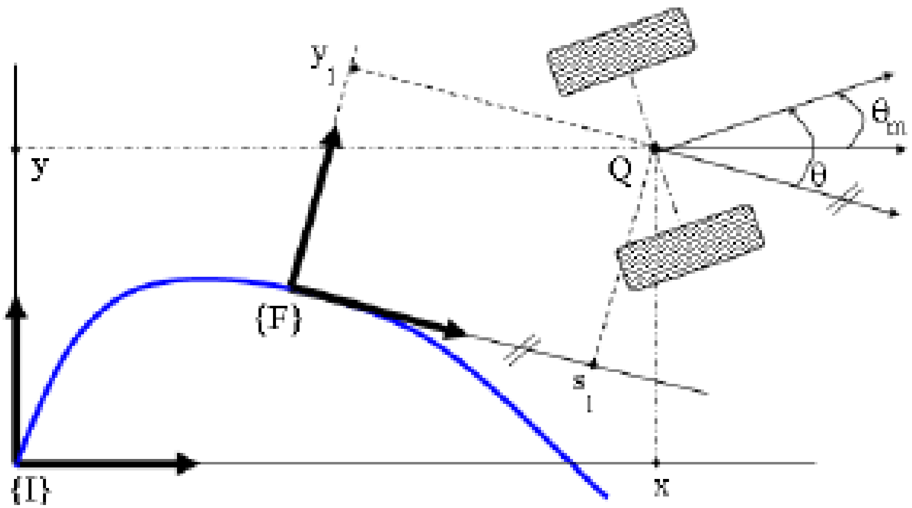
Deriving the Control Law

- Kinematics of Q is given by

$$\begin{aligned}\dot{x} &= u\cos\theta_m\\ \dot{y} &= u\sin\theta_m\\ \dot{\theta}_m &= \omega\end{aligned}$$

and

$$\begin{aligned}\dot{s}_1 &= -\dot{s}\,(1-\kappa_r\,y_1) + u\cos\theta\\ \dot{y}_1 &= -\kappa_r\,\dot{s}\,s_1 + u\sin\theta\\ \dot{\theta} &= \omega - \kappa_r\,\dot{s}\end{aligned}$$



- Lyapunov candidate function

$$V_1 = \frac{1}{2}\left(s_1^2 + y_1^2\right) + \frac{1}{2\gamma}\left(\theta - \delta(y_1,u)\right)^2$$

Deriving the Control Law (cont.)

- D. Soetanto et al. derived the follwoing control law

$$\begin{aligned}\dot{\theta} &= \dot{\delta} - \gamma\, y_1\, u\, \frac{\sin\theta - \sin\delta}{\theta - \delta} - k_2\,(\theta - \delta) \\ \dot{s} &= u\cos\theta + k_1\, s_1 \quad : \quad k_1 > 0,\ k_2 > 0\end{aligned}$$

$$\begin{aligned}v_r &= u + b\left(\kappa_r \dot{s} + \dot{\theta}\right) \\ v_l &= u - b\left(\kappa_r \dot{s} + \dot{\theta}\right)\end{aligned}$$

$$\kappa_{\text{closed loop}} = \frac{\kappa_r\, \dot{s} + \dot{\theta}}{u}.$$

$$V_1 = \frac{1}{2}\left(s_1^2 + y_1^2\right) + \frac{1}{2\gamma}\left(\theta - \delta(y_1, u)\right)^2$$

High speed path following

- Skipping …

$$\kappa_{\text{closed loop}} \quad = \quad \kappa_r \cos\theta + T(\cdot)$$

- Command wheel velocities corresponding to the highest possible linear velocity should satisfy:

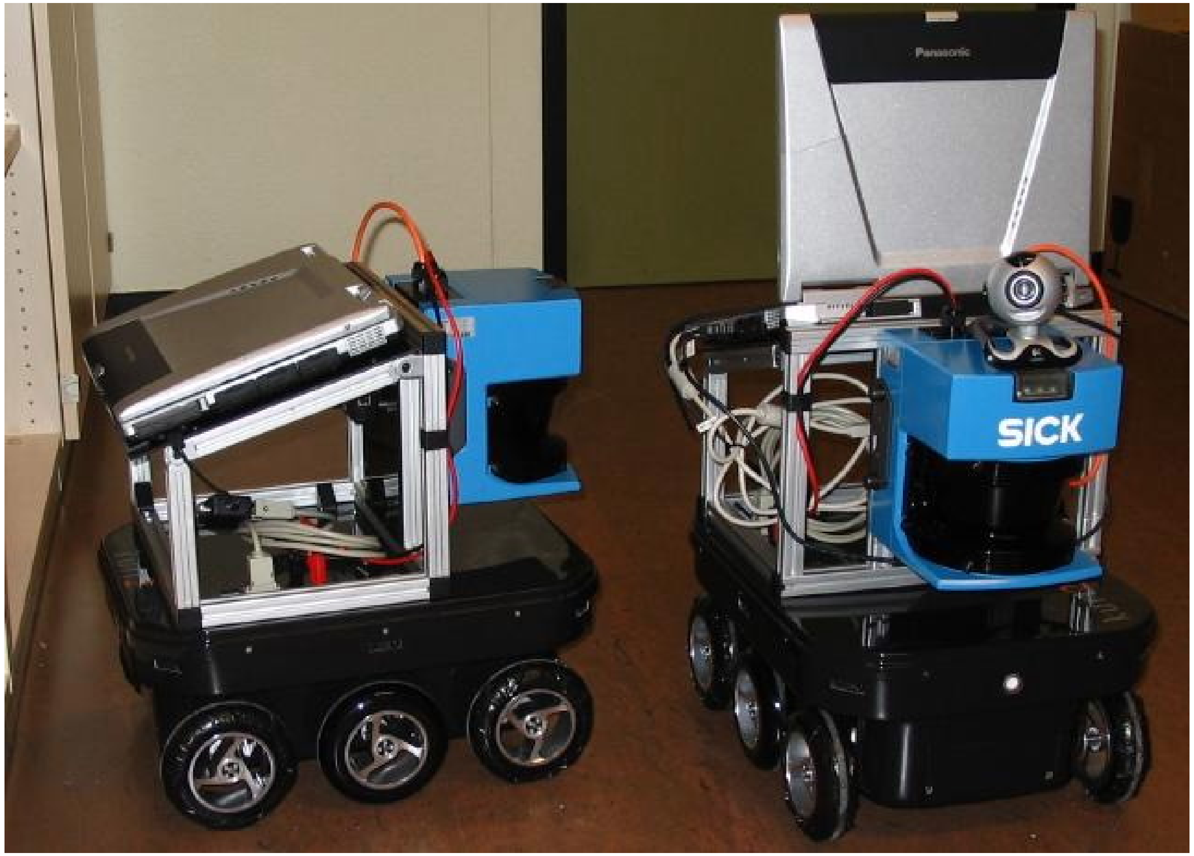
$$\max\{v_l, v_r\} = |u|\left(1 + b\left|\kappa_{\text{closed loop}}\right|\right) = V_m \Longrightarrow$$
$$u = \frac{V_m}{\left(1 + b\left|\kappa_{\text{closed loop}}\right|\right)}.$$

- From this we derive:

$$u = \begin{cases} V_m/2 & \text{if} \quad V_1 \geq \varepsilon \\ V_m/(1 + b|\kappa_r(s)|) & \text{if} \quad V_1 < \varepsilon \end{cases}$$

Implementation on a real robot

- Two 90W (200W) motors
- 48 NiMH a 4500mAh
- C167 Micro-controller
- CAN Interface
- PIV-1400 Notebook
- The robot KURT2 is a leightweight (22.5 kg).



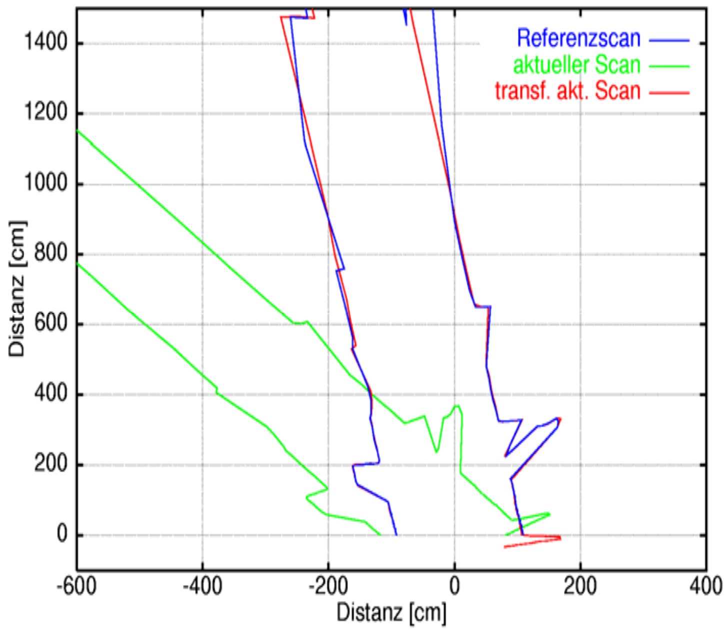
Path Following depends on pose estimation!!!

Pose estimation

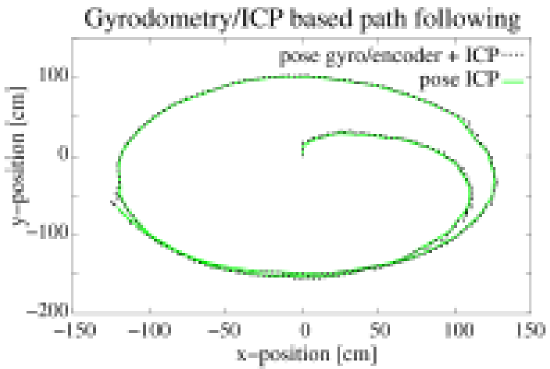
- Revival of Gyrodometry as formulated by Brenstein/Feng ICRA 1996
- Iterative Closest Point (ICP) Scan Matching in near Real Time (timing issues) for precise pose estimation

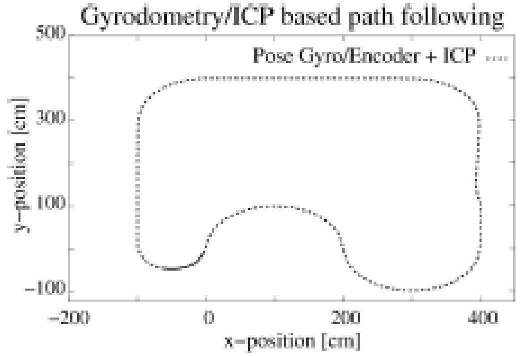
Algorithm 1 Gyrodometry

if $|\Delta\theta_{\text{odo}}| > c_1$ **then**
  $\theta \leftarrow \theta + \Delta\theta_{\text{gyro}} - e$
else if $|\delta\theta_{\text{gyro}} - e| > c_2$ **then**
  $\theta \leftarrow \theta + \Delta\theta_{\text{gyro}} - e$
else
  $e \leftarrow \lambda\, e + ((1-\lambda)\,(\Delta\theta_{\text{gyro}} - \Delta\theta_{\text{odo}}))$
  $\theta \leftarrow \theta + \Delta\theta_{\text{odo}}$
end if



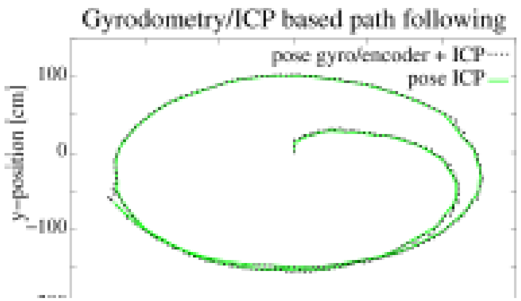
- Reference Paths

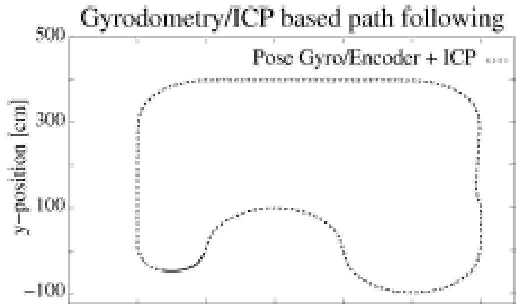




Results

(Video low speed) **(Video high speed)**





Conclusions and Future Work

- We have presented
  - An path following scheme for differential drive / skid steered robots
  - Actuator saturation
  - Fast localization for path following
- Future work
  - Participation in robot race
  - Considering dynamics

Thank you for your attention!