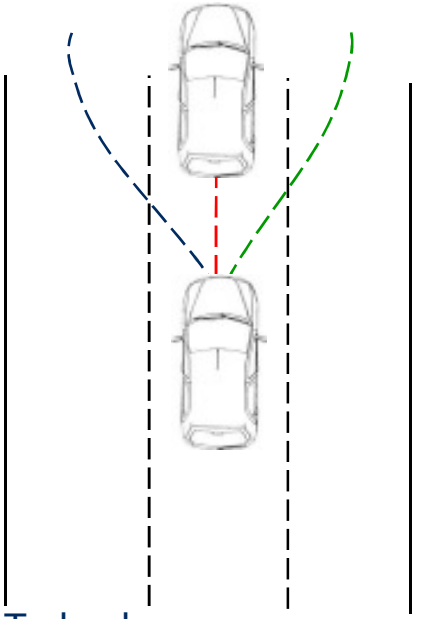
Spykerprijs 2009-2010, Maastricht

Reducing Steering Wheel Stiffness
is beneficial in Supporting Evasive Maneuvers

Mauro della Penna, M.M. van Paassen, Mark Mulder & David A. Abbink



Presentor

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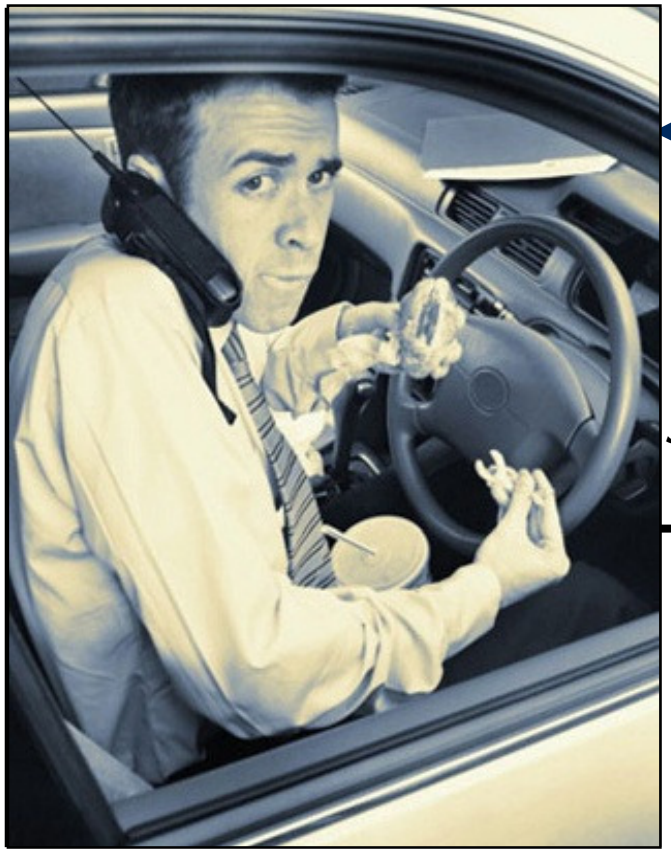
Background:

How do we combine the best of human and machine?

Automation



Slow (>200 ms)
visual feedback

Environment

Steering angle

Tasks:
Lane Keeping
Curve Negotiation
Evasive Maneuver

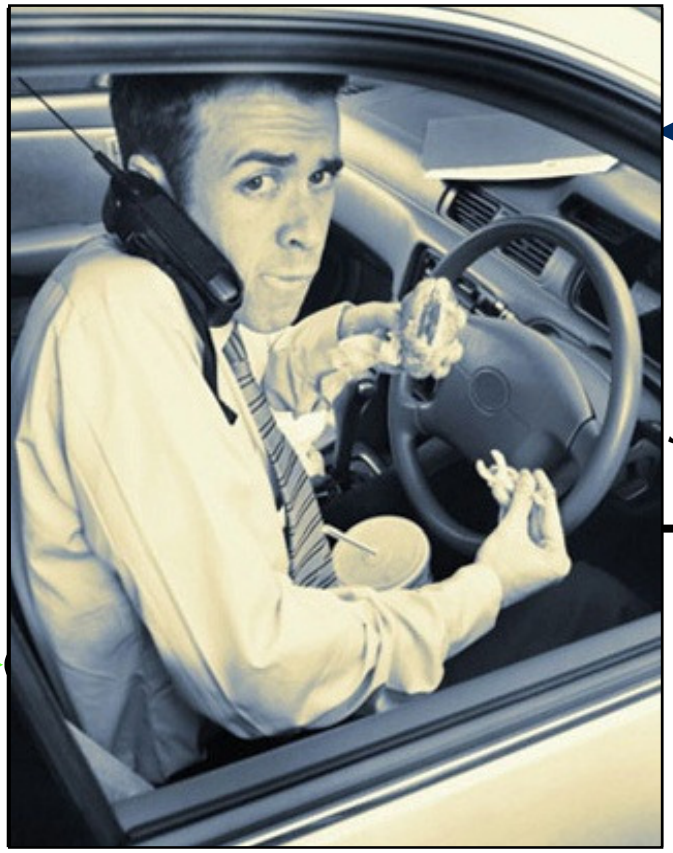
Optimal steering angle

controller

sensor

What mode am I in?
What is the system doing?
Sarter & Woods (1995)

Haptic Shared Control



Slow (>200 ms)
visual feedback

Environment

Steering
angle

perfor-
mance

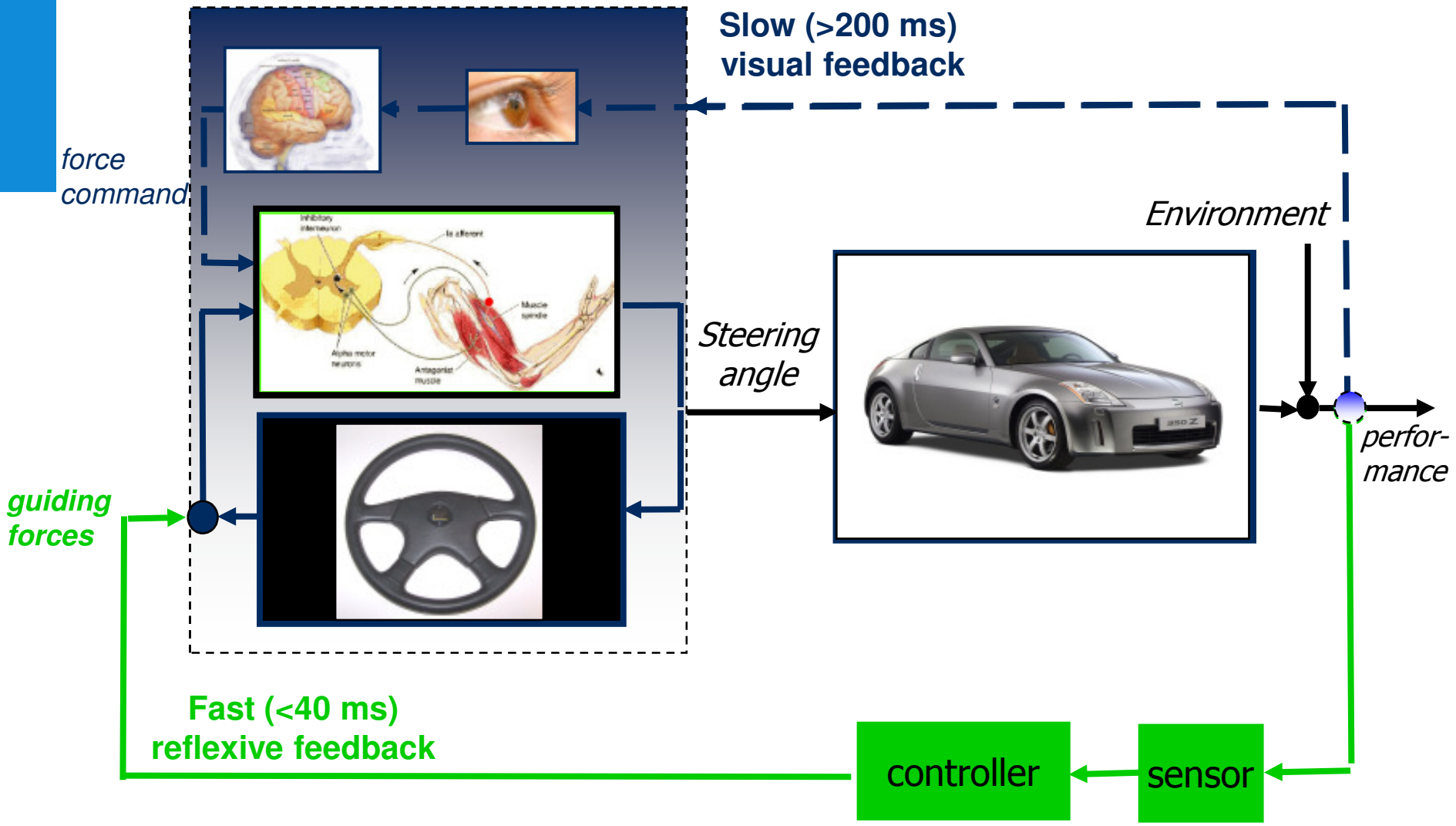
guiding
force

Optimal
steering
angle

controller

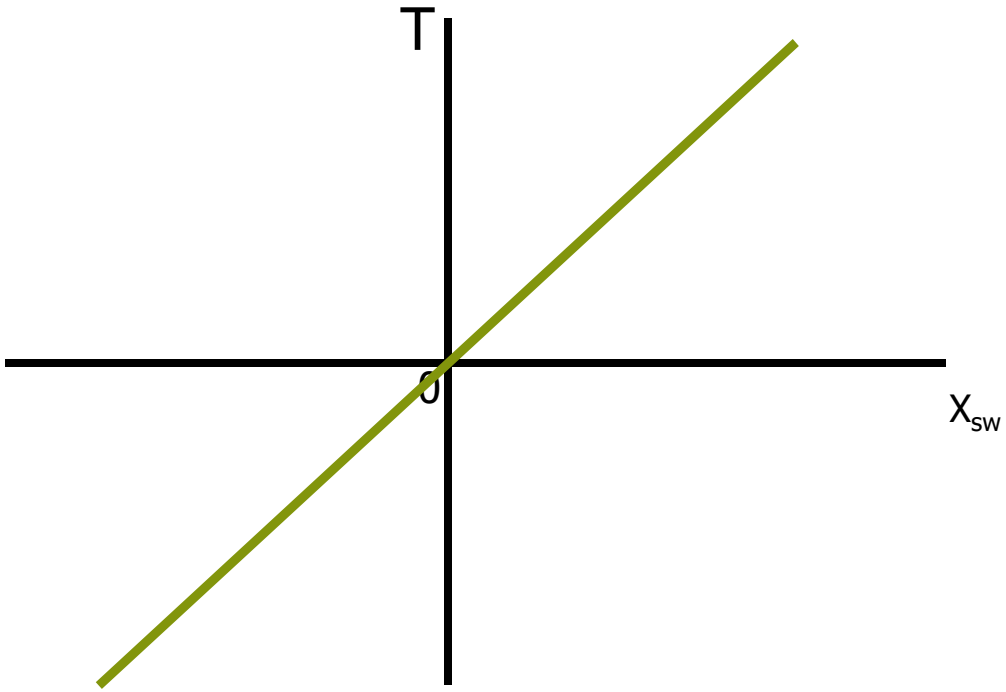
sensor

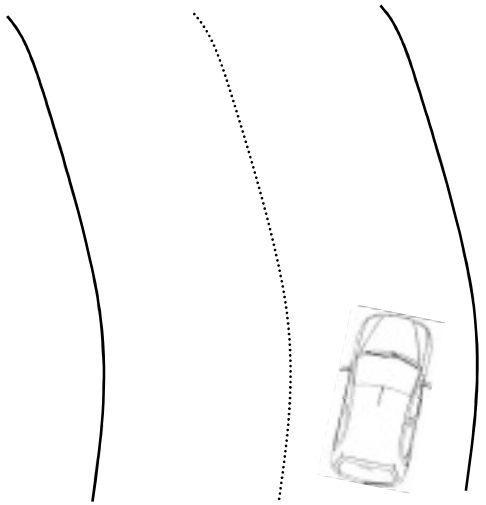
Haptic Shared Control



Example of "No Guidance Forces"

Steering Wheel Normally passive





Example of "Normal Guidance"

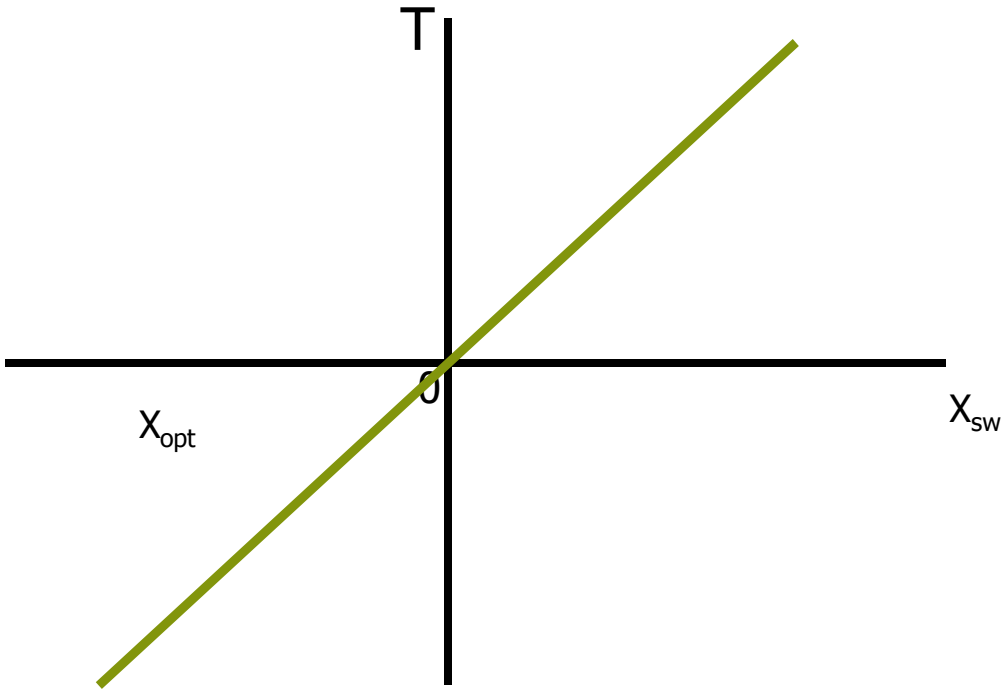
Abbink & Mulder (2009) – Exploring the dimensions of haptic feedback support in manual control

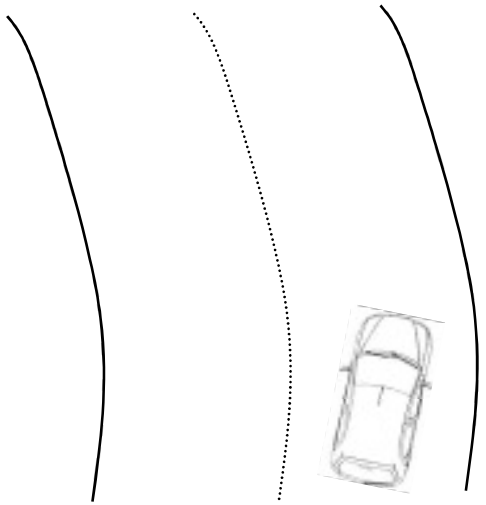
Joint patent with Nissan (2008)

Steering Wheel

Can generate feedback forces

human can relax, resist or give way



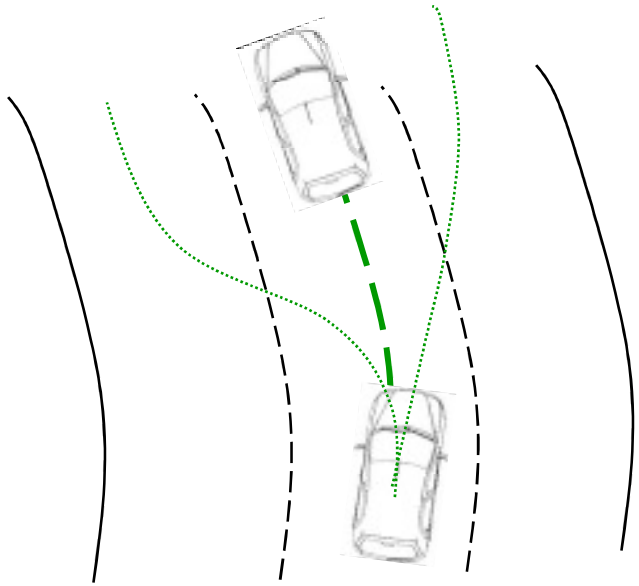


Problem Statement

Limitation: Support for only one path

Problem: How to support multiple paths?

- No automation, human should make the choice
  - Creative solutions may be needed
  - Liability
- So, design should connect to previous haptic work at Delft



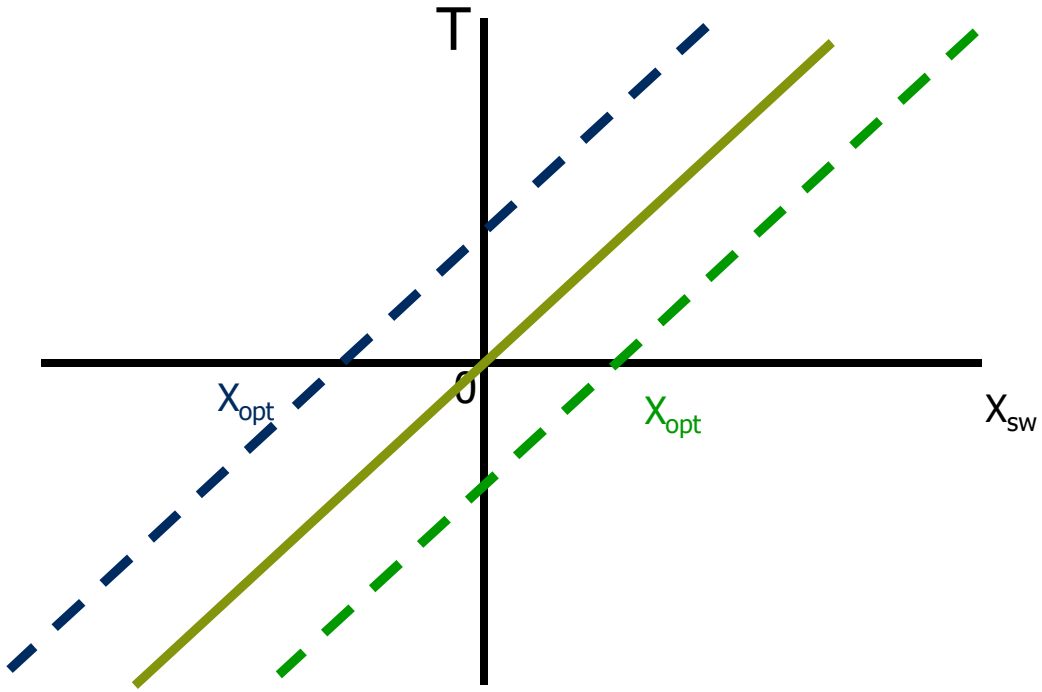
System Design

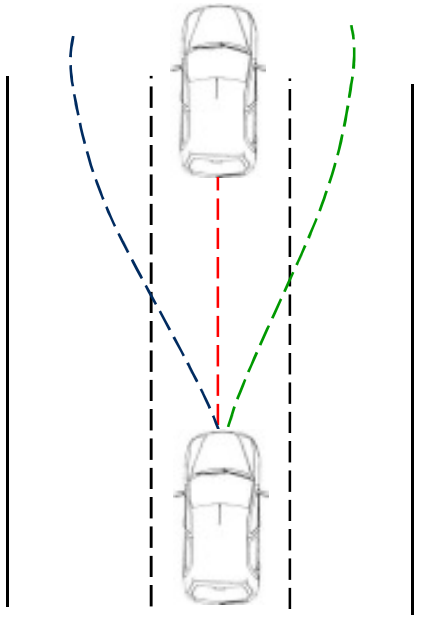
Design Concept: Reducing Stiffness

Idea

Reduce stiffness

- criticality will be felt when trying to steer
- easier to steer left or right



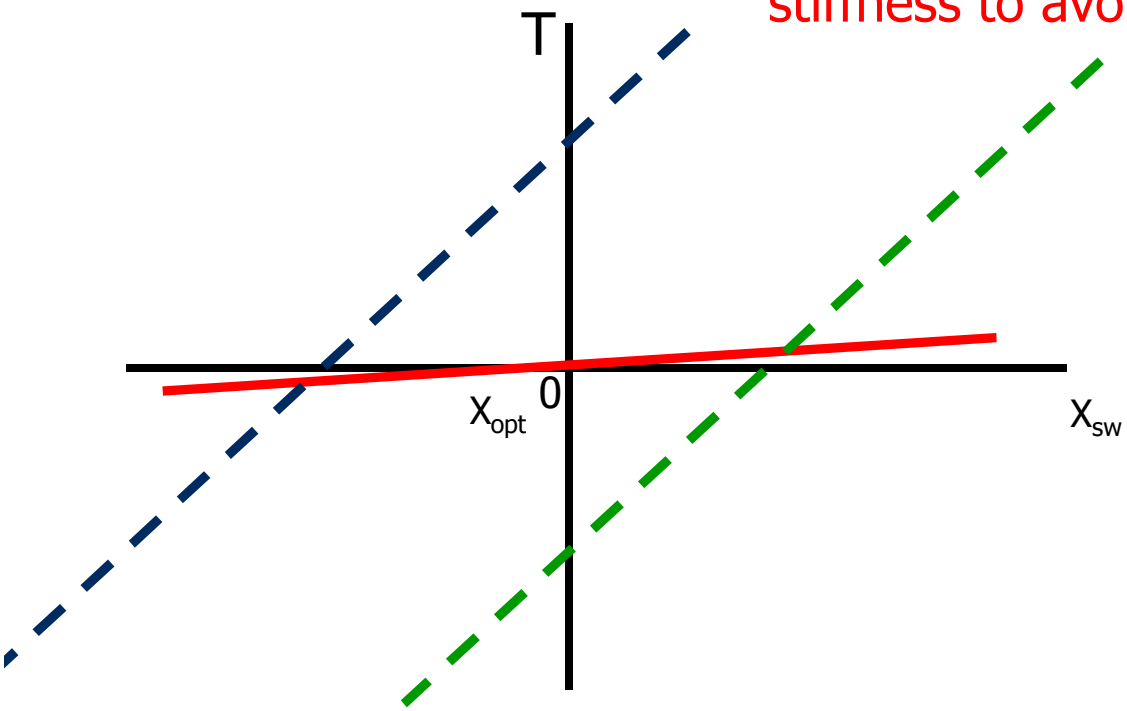


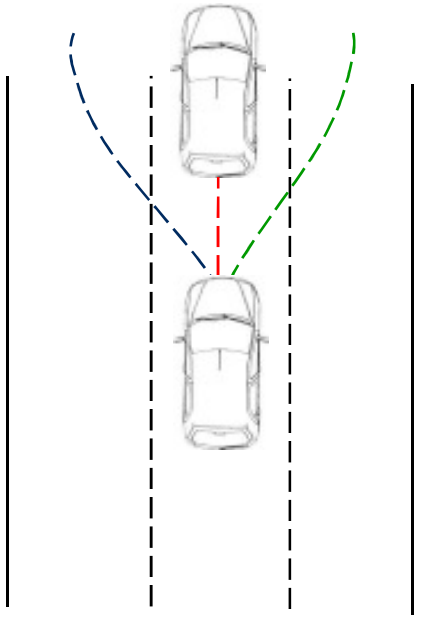
Design Concept: Reducing Stiffness

Stiffness

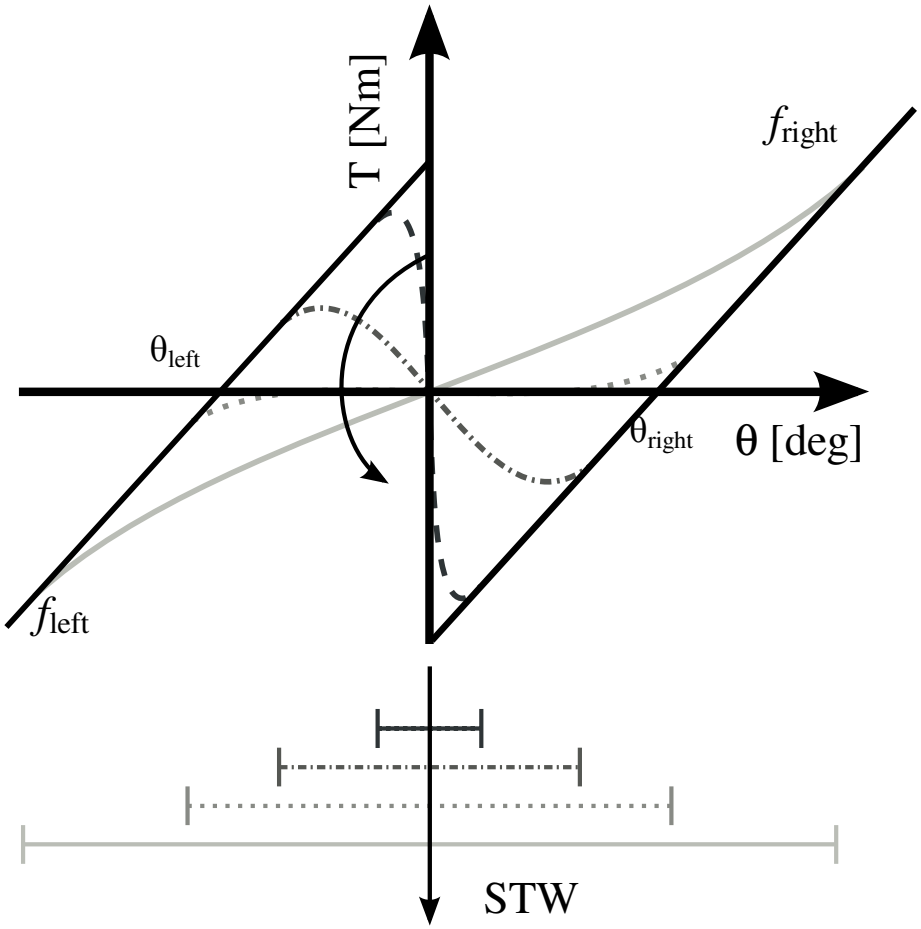
Can become negative in extreme cases

- a choosing human is supported to avoid obstacle, and is then "caught" by the support
- a stubborn human needs to increase own stiffness to avoid steering left or right





Final System Design

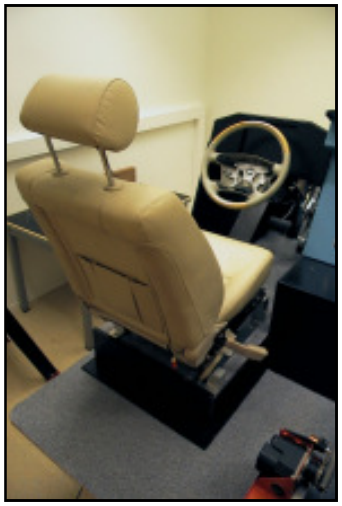


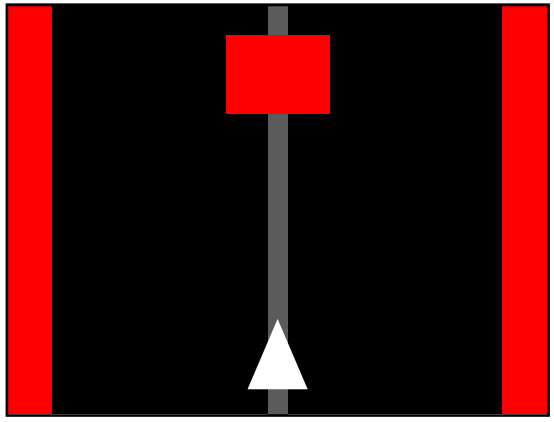
- Algorithm makes a smooth transition between the three lines
- Shape adapts online, depending on available time to choose (Steering Time Window)
- Also takes into account the initial heading, velocity and position of the vehicle with respect to the object
- For details, see publication:

  Della Penna (2010) – "Reducing Steering Wheel Stiffness is beneficial in Supporting Evasive Maneuvers". IEEE SMC Conference Istanbul

Experimental Study

Experimental Setup





- Fixed-base driving simulator at Delft
- Subject controls and receives feedback by active steering wheel
- Controlled vehicle dynamics are a second-order system

- Visualization by beamer
- Simplified scenario in order to generalize findings

- **Task** avoid obstacle, and avoid red bounds
  - left or right does not matter

Experimental Conditions

Subjects

- Ten subjects (2 female)

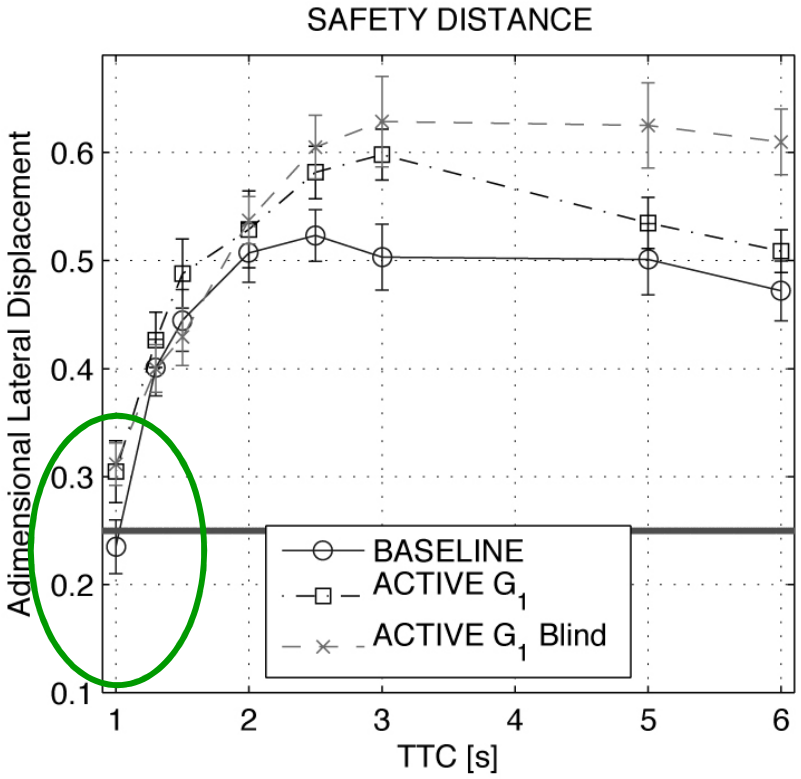
Condition: Obstacle time-to-contact (TTC)

- Seven TTC levels were chosen between
  - TTC = 1 sec (extremely critical)
  - TTC = 6 sec (relaxed avoidance possible)

Condition: Feedback provided to the driver

- Visual only (baseline)
- Visual and haptic feedback (normal system use)
- Haptic feedback only (visual inattention)

Experimental Results - Performance



System improved safety distance

- Baseline: often unable to avoid objects
- Support system: with or without visual feedback – objects more often avoided, with a larger safe distance

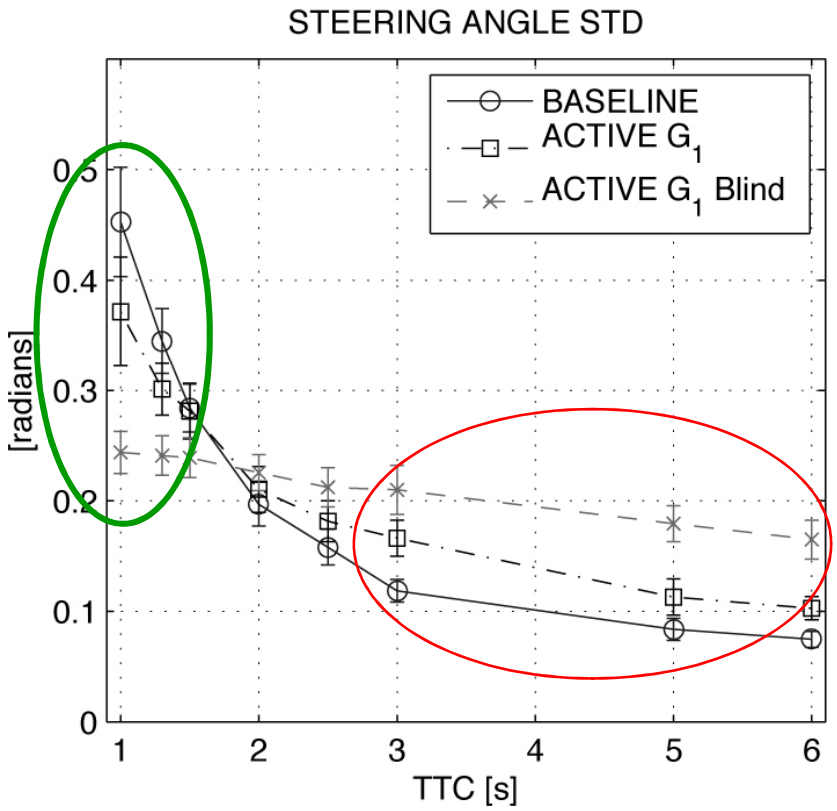
System reduced crashes

- (45% -> 15%)

System caused smaller response time

- (500 ms -> 250 ms)

Experimental Results – Control Effort



Control effort

STD of angle and torques

- Decreased in critical situations
- Increased slightly in non-critical situations
  - Better path generation for human is needed when they have more time to choose

Conclusions

System is very beneficial in critical cases

- Design keeps keeps human fully in the loop
  - Allows human to choose best escape route
    - Then supports that choice, avoiding overshoot
  - If no choice is made, reduced stiffness facilitates a choice
    - Then supports that choice, avoiding overshoot
- Experimental results show that the system:
  - Substantially reduced the amount of crashes
  - Reduced control activity and control effort
  - Did not deteriate overshoot after the initial maneuver
  - Decreased the response time to appearing object
    - Suggests it allows the use of reflexive response

2010 Apr - A patent on this idea was filed

2010 Oct - A conference publication at IEEE SMC

Journal publication in progress

Questions & Discussion?

You can also email me!

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Haptic Shared Control Metaphor

"Horse Metaphor", by Frank Flemisch & Ken Goodrich

Flemisch et al. (2003). Nasa Report about the H-mode.

Goodrich et al. (2008). Piloted evaluation of the H-mode. AIAA Conference

Delft Approach to Haptic Shared Control

Human

Can generate forces

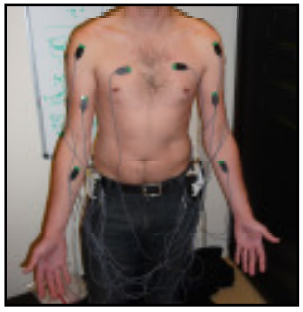
Can modify impedance

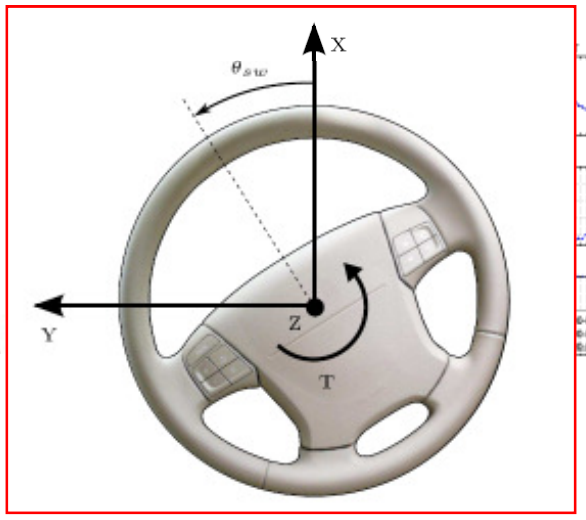
resist forces, relax, give way to forces

Machine

Can generate feedback forces

Should also modify impedance?





Abbink (2006) – Phd Thesis on Neuromuscular Analysis of Haptic Feedback

Mugge & Abbink (2010) – Experimental Brain Research

Delft Approach to Haptic Shared Control

Abbink & Mulder (2009) – Exploring the dimensions of haptic feedback support in manual control

Joint patent with Nissan (2008)

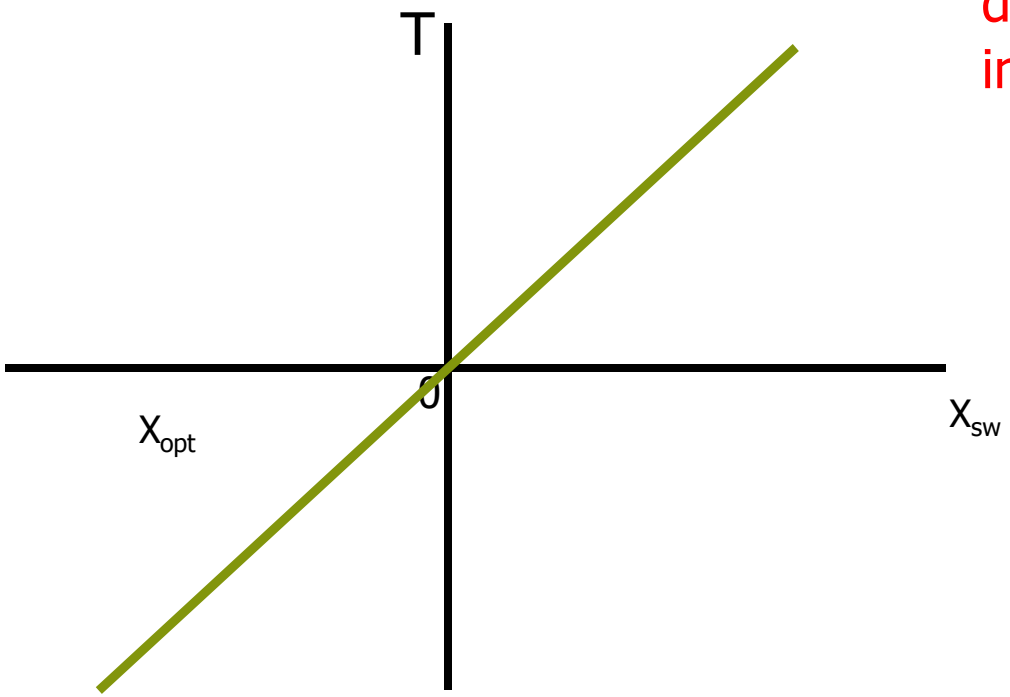
Steering Wheel

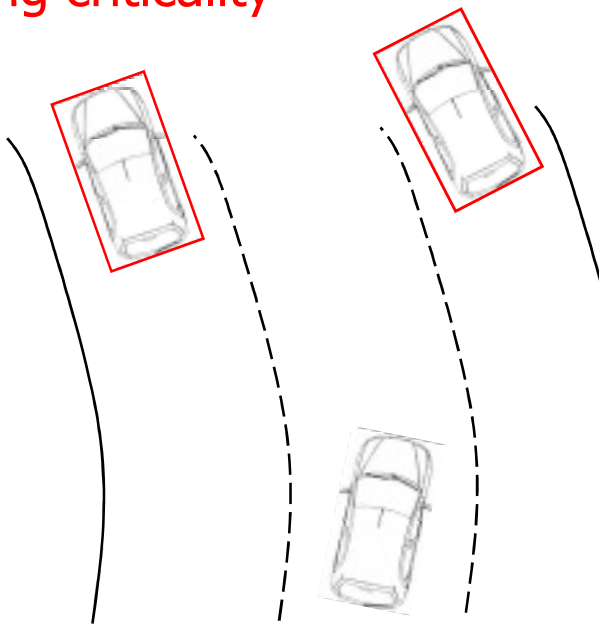
Can generate feedback forces

Can modify impedance

dynamically shift authority

in changing criticality





Experimental Results – response time

Response Time