Lecture 8b – Haptic Tele-operation Applications: Revolution? -> Haptic Shared Control

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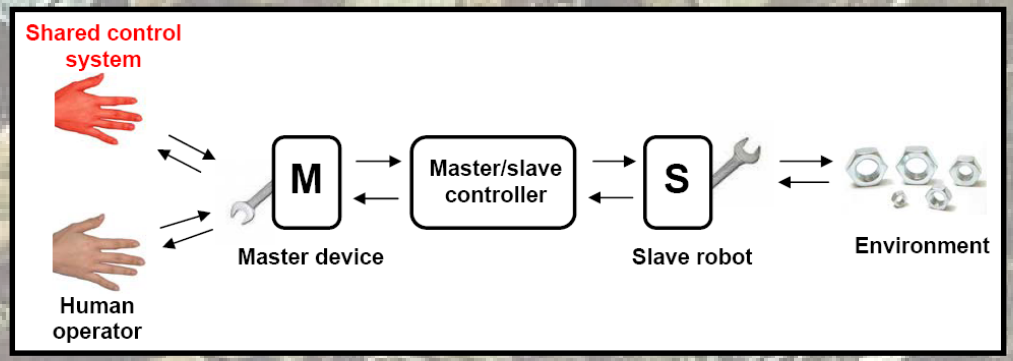

About me:

- Jan 2011

  MSc graduation, BME TU Delft

- July 2011 – current

  PhD candidate at FOM institute DIFFER/ TUe / TUD

European project: EFDA GOT RH project (ITER)

WP1.6: "Analysis and optimization of tele-operated task performance during ITER RH maintenance"

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[http://www.differ.nl/remote-handling-study-centre]

Content for next 45 min…

- Part 1: Introduction of ‘Haptic Shared Control’ in tele-manipulation
- Part 2: Research example Haptic Shared Control – *Proof of principle*
  - Human factors experiment
  - Experimental results and conclusions
- Part 3: What about a real application?! – *Maintenance at ITER*
  - A - Operational data from JET
  - B - Exploratory human factors experiment (VR)
  - C - Applied Haptic Shared Control

What to learn the next 45 min…

- Part 1: Introduction of 'Haptic Shared Control' in tele-manipulation
- Part 2: Research example Haptic Shared Control – *Proof of principle*
  - Human factors experiment
  - Experimental results and conclusions
- Part 3: What about a real application?! – *Maintenance at ITER*
  - A - Operational data from JET
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  - C - Applied Haptic Shared Control

Reproduce: *Different abilities of humans and automation and how this relates to haptic shared control*

Apply: *Extrapolate experimental results to other tele-operation situations (new hypotheses)*

Critical reflect: *Discuss possibilities & limitations of discussed experimental results.*

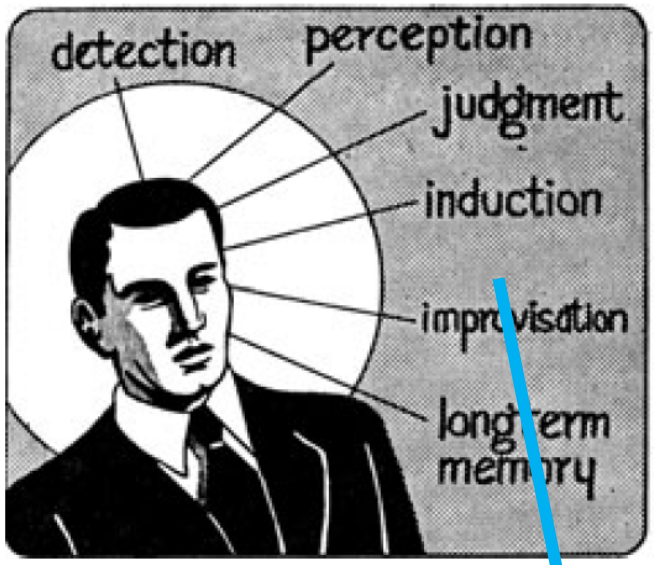
Part 1:

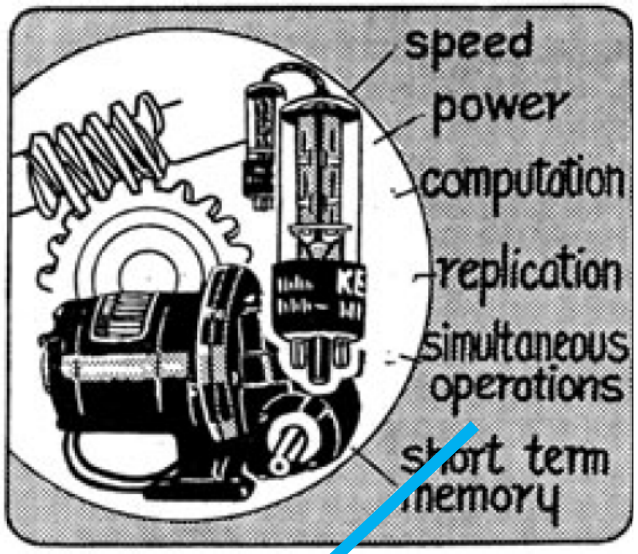
Introduction of ‘Haptic Shared Control’ in tele-manipulation

Introduction

Abilities of human <-> machine

Combine Human & Machine/automation ?





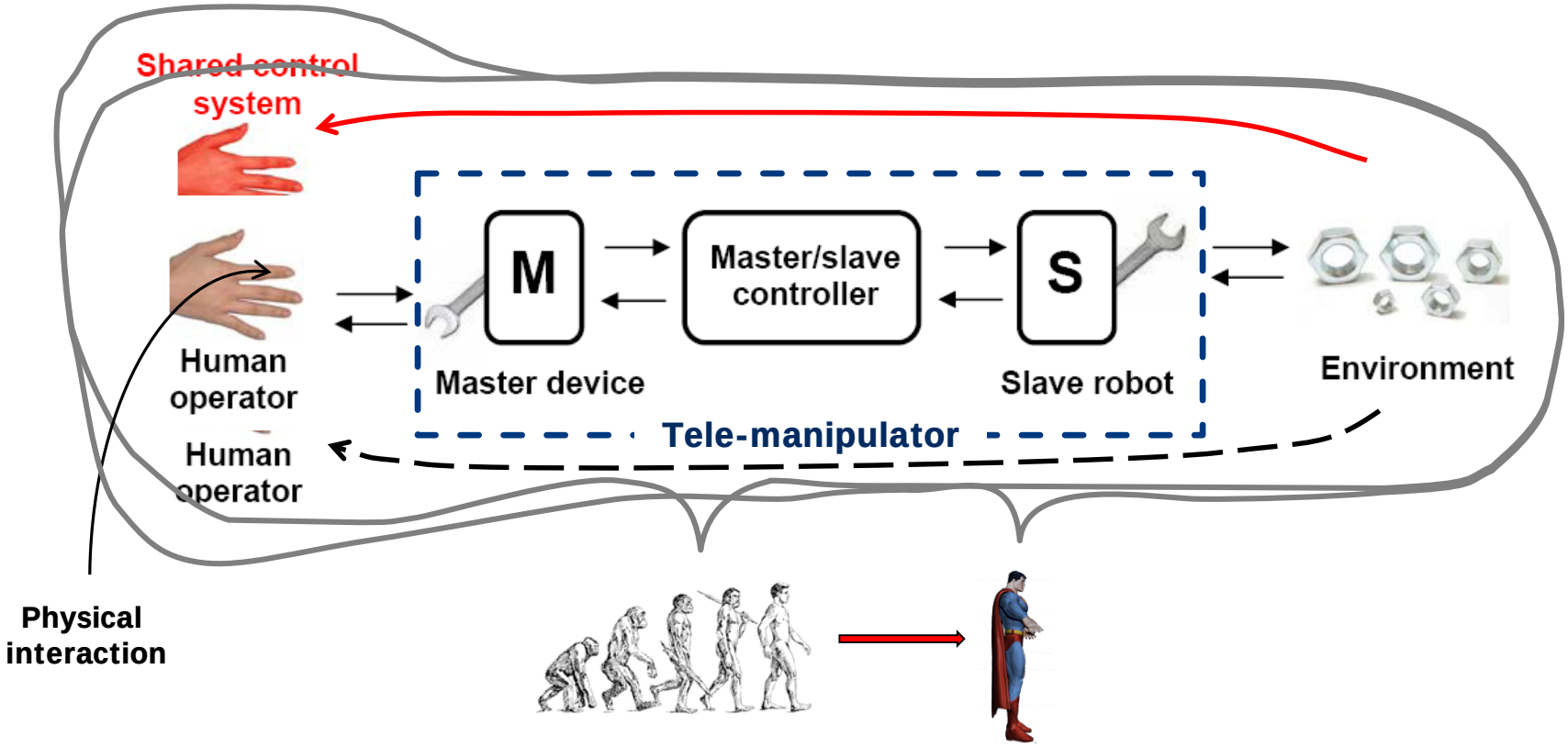
"Fitts list; [1] P.M. Fitts, 1951; [2] J.C.F. Winter and D. Dodou, 2011

But what if we need both..?

Introduction – Improvement of tele-manipulation

Evolutionary approach: Improve transparency

Assist the human with performing a task; apply guiding forces



Introduction – Improvement of tele-manipulation

Revolutionary approach: Haptic shared control

Assist the human with performing a task; apply guiding forces

→ Combination of manual control and automation

Introduction

Shared control is not new

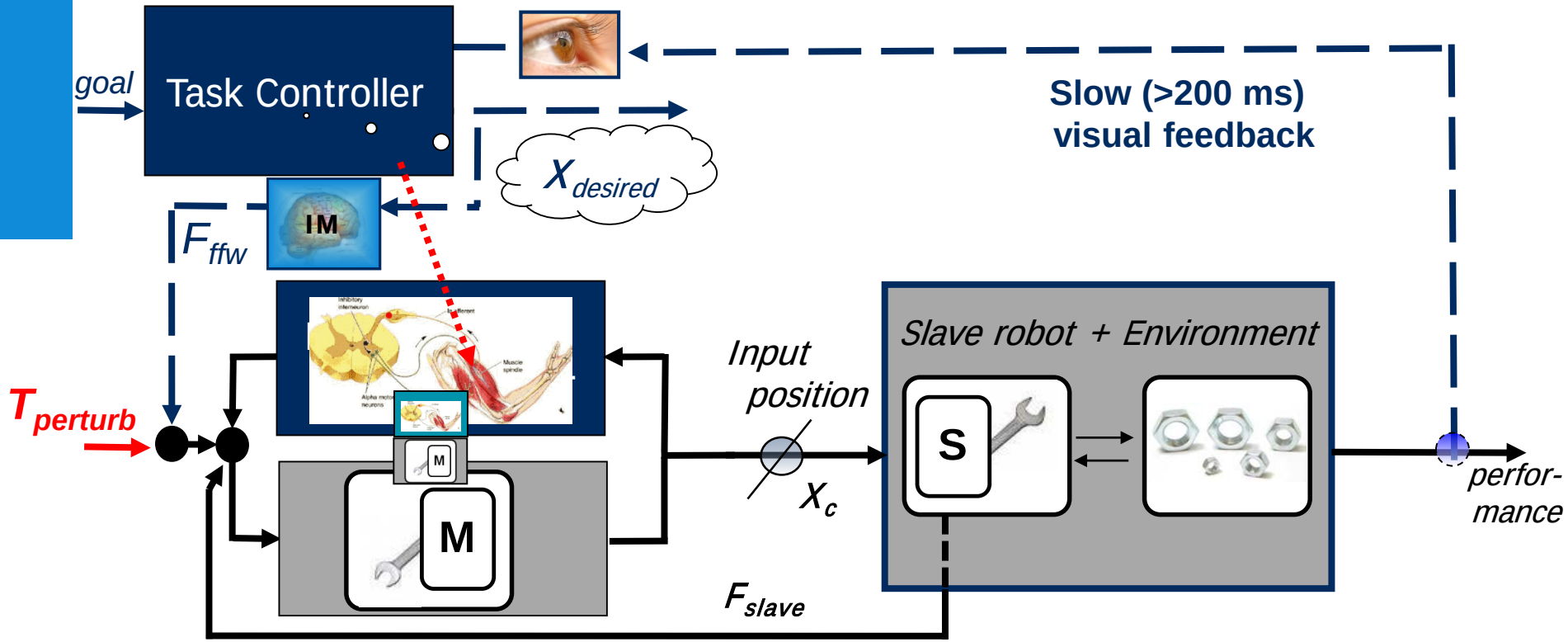
Tele-operated /cobot control tasks

- General [O'Malley et al., 2006, Feth et al., 2011, Passenberg et al., 2011]
- Gripping [Griffin et al., 2005]
- Surgery [Kragic et al., 2005, Abbot et al., 2007]
- Micro-assembly [Basdogan et al., 2007]

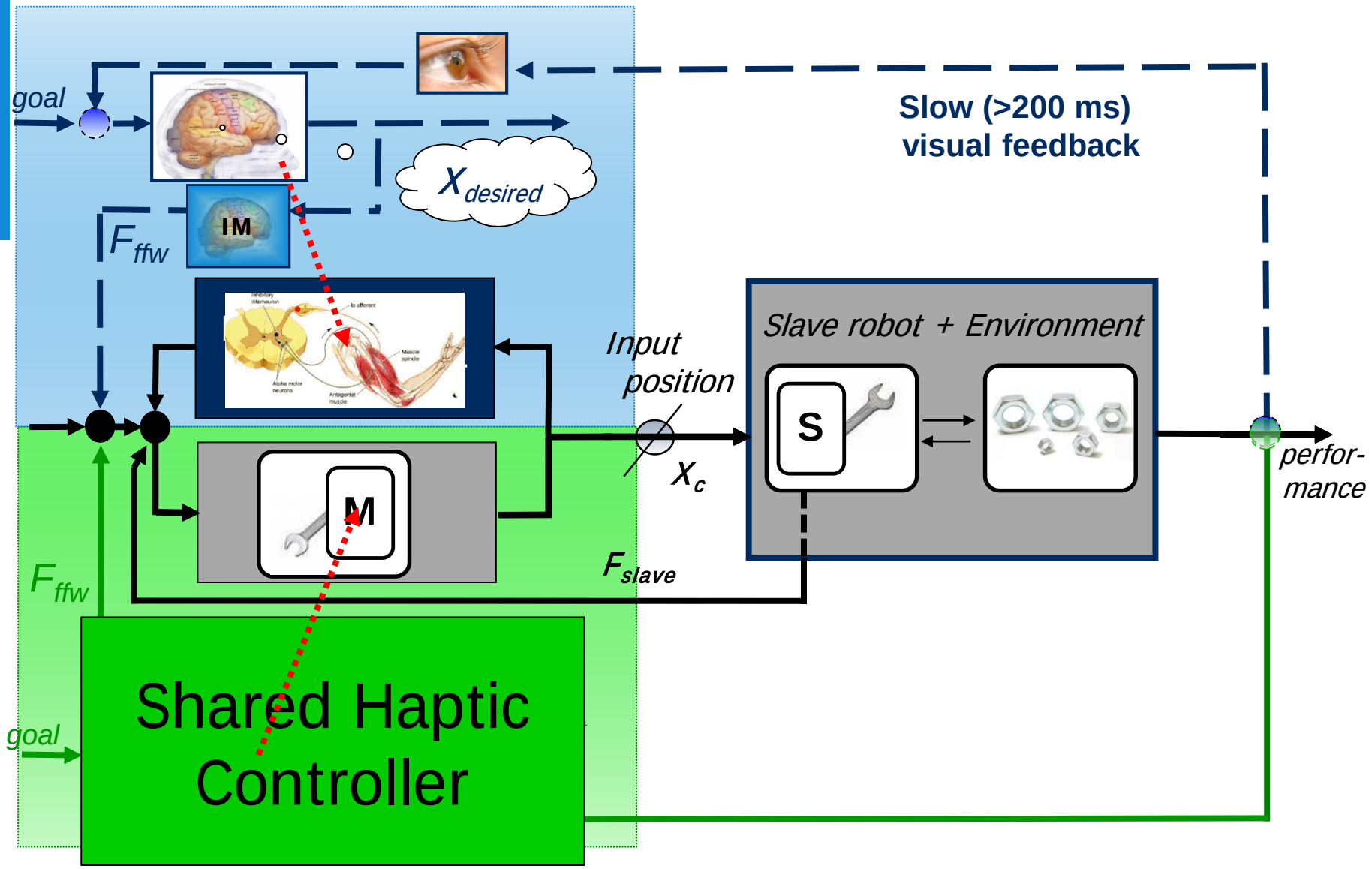
Vehicle Control

- Longitudinal automotive control (car-following)
  [Mulder et al., 2008; Abbink et al., 2011]
- Lateral automotive control (steering)
  [Griffiths & Gillespie, 2005; Brandt, 2007; Abbink & Mulder, 2008; Flemisch et al., 2011]
- Aviation [Goodrich et al., 2008; de Stigter et al., 2007]
- Wheel chair control & Brain-Machine Interfaces
  [Trieu et al., 2008; Carlson et al., 2008]

Introduction – Control by human



Introduction – Haptic Shared Control



Introduction

Does Haptic Shared Control work?

Problem statement:
Comparative improvements of ***transparency*** **vs** ***shared control*** are unknown

Goal of experiment:
Experimentally **quantify** the influence of transparency and shared control on tele-manipulated task performance.

Part 2:

Research example Haptic Shared Control – Proof of principle

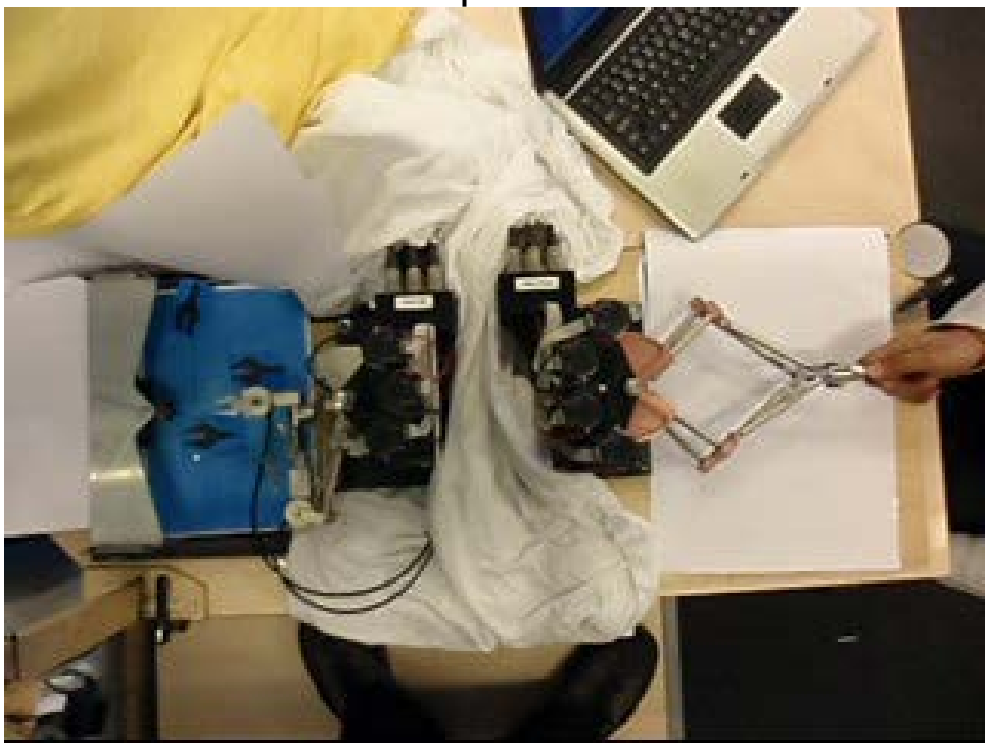
Human factors experiment

Experiment

Experimental setup

3 DOF tele-manipulator ‘Munin’ (Christiansson, 2007)

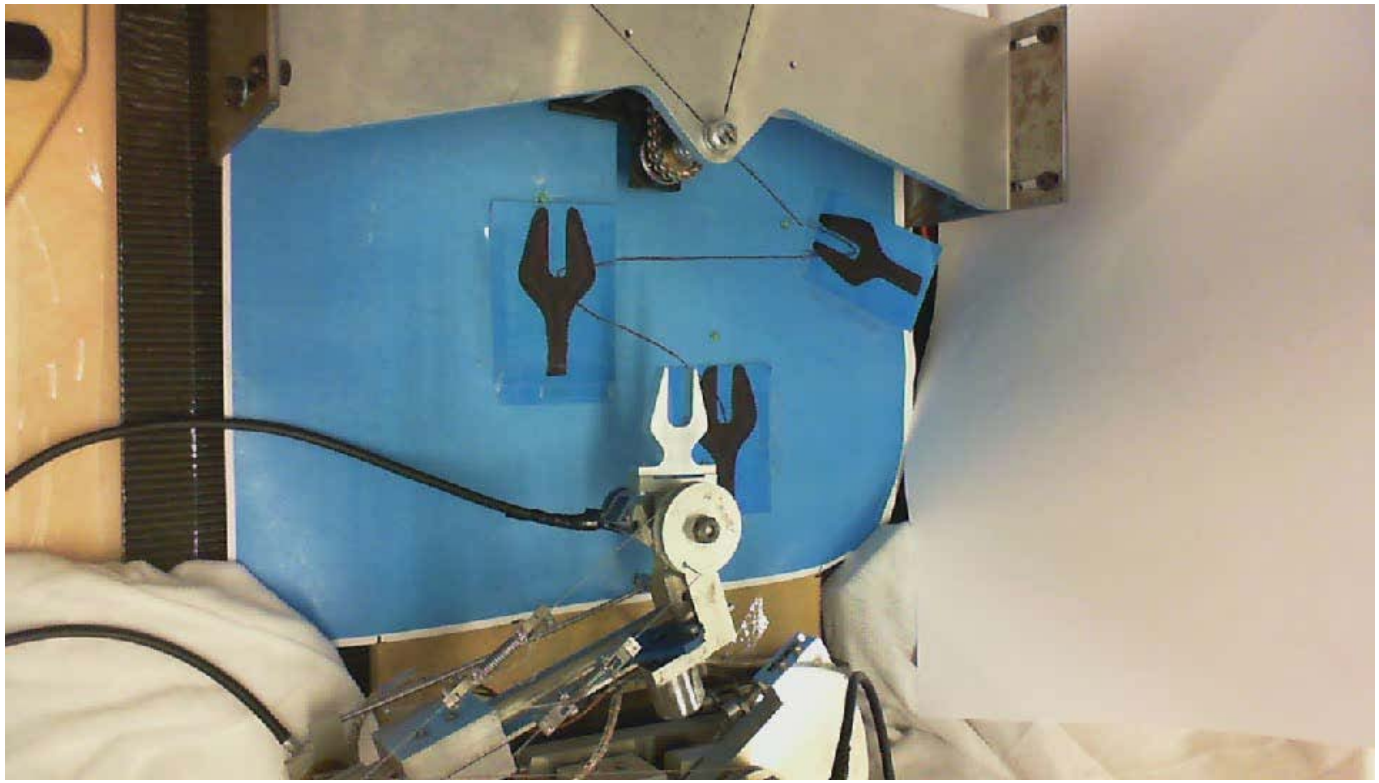
Top view



Experiment

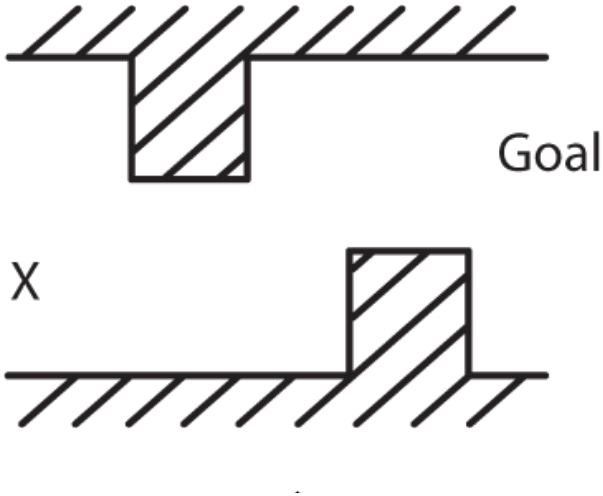
Experimental task

Camera view from remote environment



Experiment

Shared control design



- Free Air Movement:

  Predictive guiding: $F_{shared\ control} = E2^{*}\ k2$

  Based on automotive [Mulder 2010]

- Contact Motion

  Position and orientation guiding and artificial contact damping

- Constrained Translational Motion

  Position and orientation guiding, snap feature

- Constrained Rotational Motion

  Guiding forces perpendicular to force task; snap feature, virtual rotation point in NoFF condition.

Hypotheses

Effect of haptic shared control on task performance / control effort:

Ideal ← **Transparency** → No

	Direct control (**DC**)	Tele-operation Force Feedback (**FF**)	Tele-operation No Force Feedback (**NoFF**)
No Shared Control			
Shared Control (SC)			

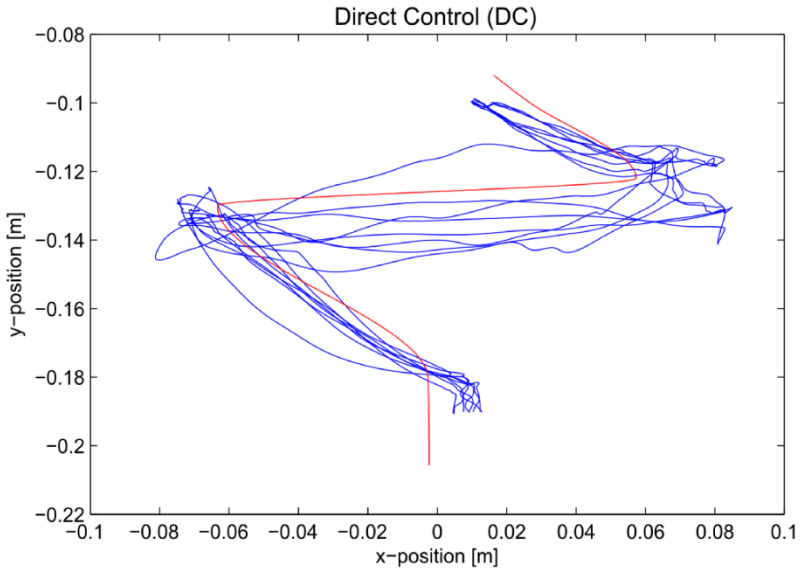
Results

Results

Trajectories

Position trajectories (8 repetitions) of a typical subject

No shared control



[H.Boessenkool , MSc thesis 2011]

Shared control

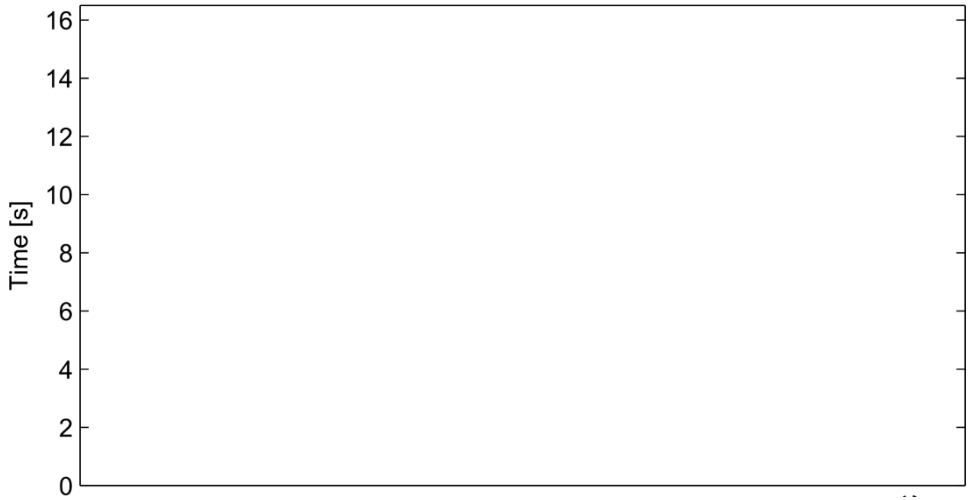
Results

Time to complete

Reduced transparency decreases performance (blue)

Shared control (red) improves DC

Shared control (red) results in faster execution without higher forces.



Experimental conditions

[H.Boessenkool , MSc thesis 2011]

[H. Boessenkool, et al., "A Task-Specific Analysis of the Benefit of Haptic Shared Control During Telemanipulation," 2013]

•	$p \leq 0.05$,
• •	$p \leq 0.01$,
• • •	$p \leq 0.001$

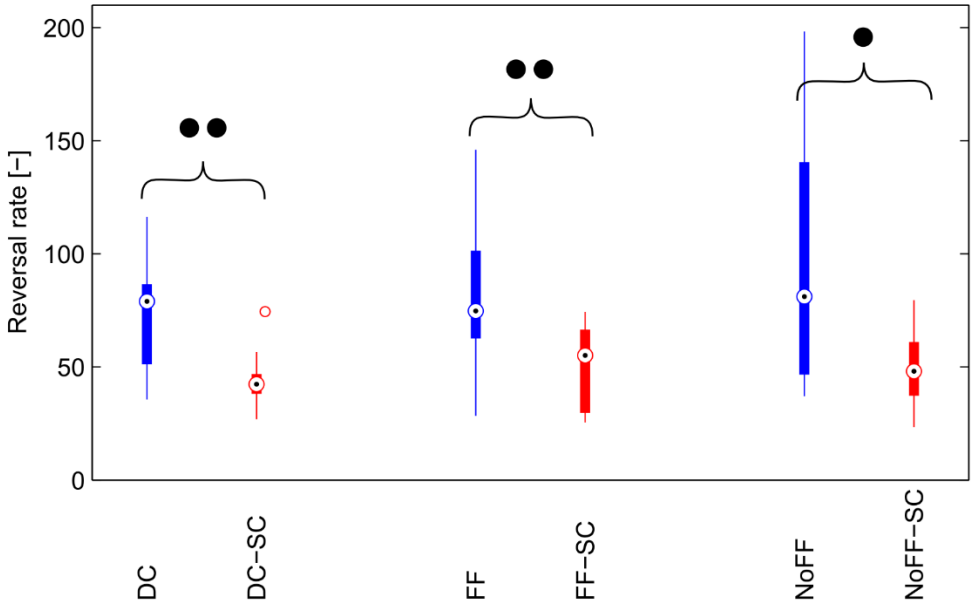
Results

Control effort

Transparency does not influence control effort (blue)

Shared control (red) improves DC

Shared control (red) improves for all transparency conditions



[H.Boessenkool , MSc thesis 2011]

[H. Boessenkool, et al., "A Task-Specific Analysis of the Benefit of Haptic Shared Control During Telemanipulation," 2013]

● $p \leq 0.05$,
●● $p \leq 0.01$,
●●● $p \leq 0.001$

Summary

Summary

- Shared Control showed improvements for:
  - Task performance (time, accuracy and exerted forces)
  - Control effort, workload
- Shared control influenced task performance much more than transparency
- Open issues: how to capture human intention? / what are the long term effects? / automation problems (misuse/disuse/abuse/..)? / ...

- **Discussion question: Do we still need transparency if we use haptic shared control?**

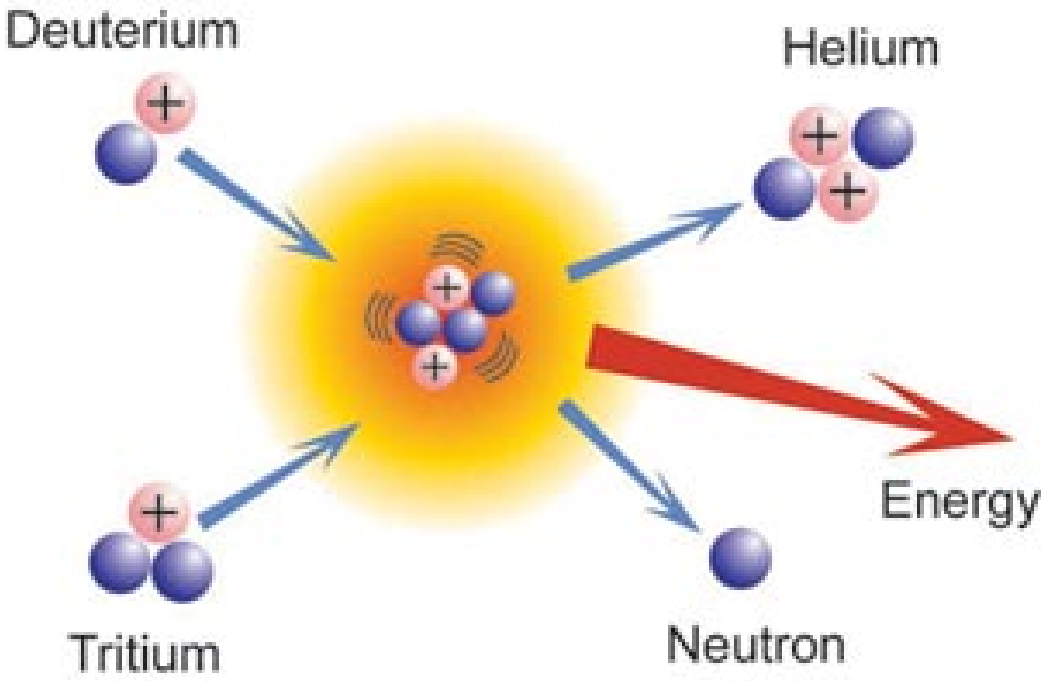
Part 3:

What about a real application?!

Maintenance at ITER

Fusion

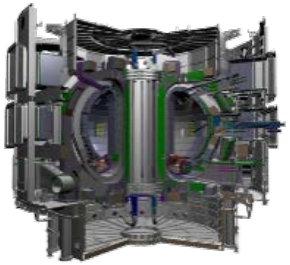
The power of the sun and the stars



ITER project

Is fusion a viable power source?

- Experimental reactor
- Mission: Prove that fusion is a viable power source
- Under construction in Cadarache, France
- First plasma 2023
- Plasma confined by superconducting magnets



Tokamak Building

Source: www.iter.org

Maintenance at ITER

Maintenance has to deal with radiation & toxic dust

→ Remote Handling (RH)

Characteristics:
- Complex and unforeseen tasks
- High requirements for safety and reliability

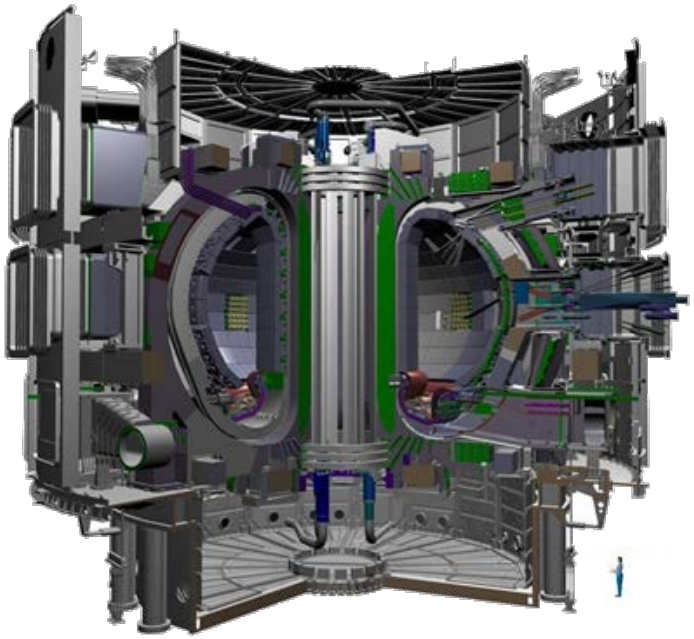
Approach:
Human in the loop, Tele-operated maintenance

Time consuming

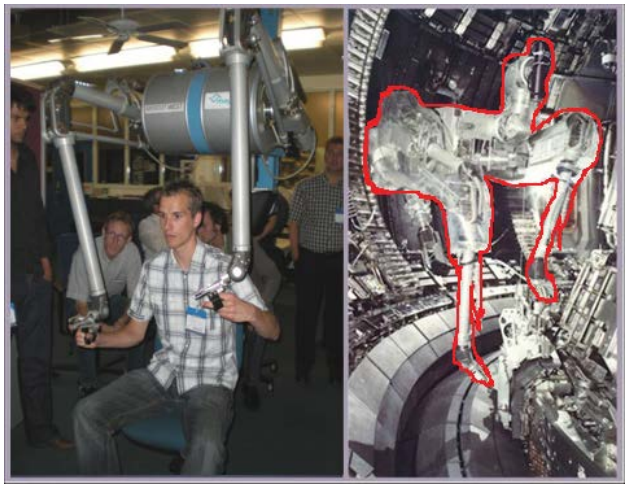
Complicated

Limits plant uptime...

Improvement in RH is important!



Source: www.iter.org



Source: www.jet.efda.org (modified)

Maintenance at ITER

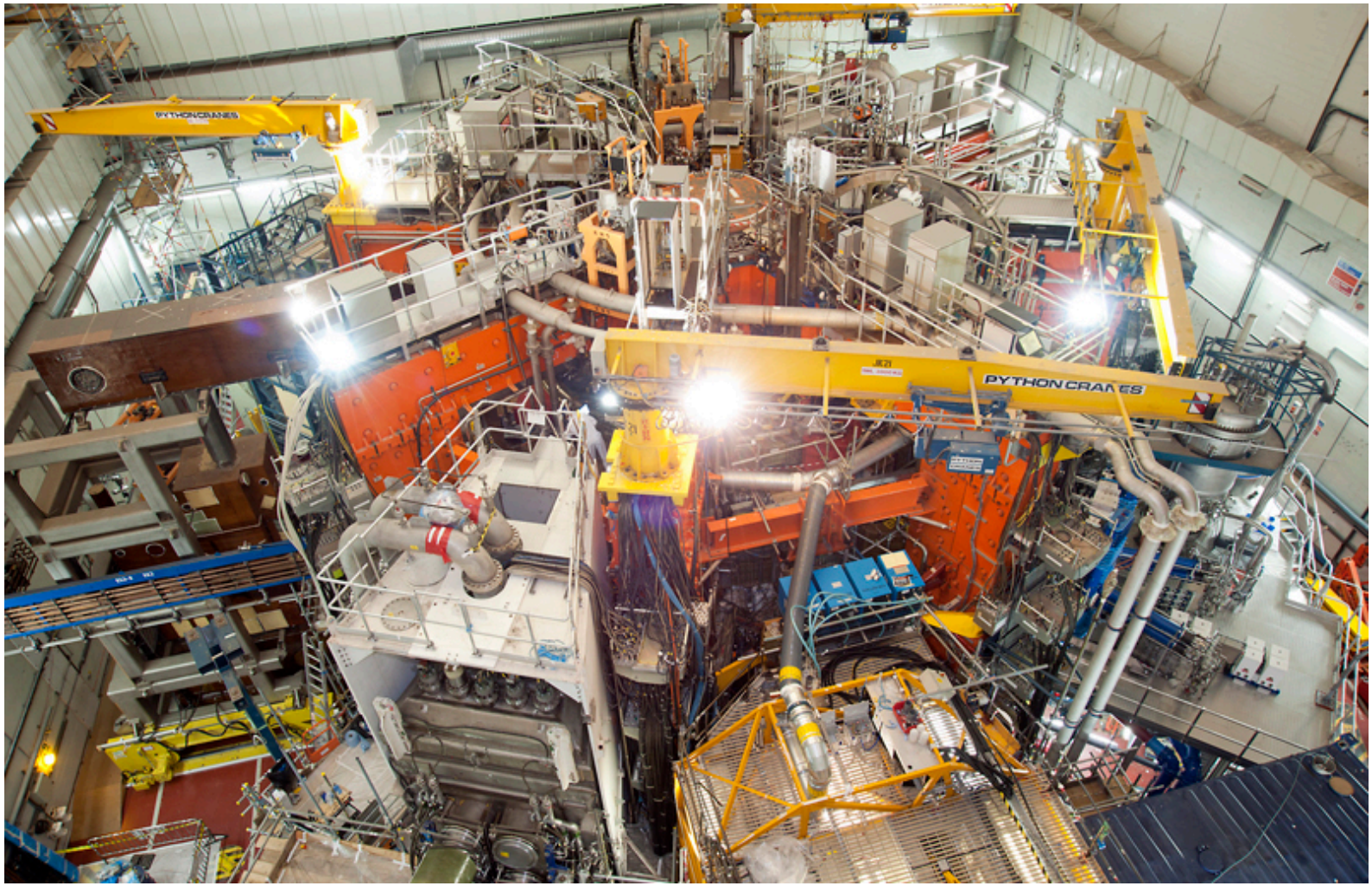
What is the problem? / Where & what to improve?

Two approaches to find out:

A - Operational data from JET

B - Exploratory human factors experiment (VR)

A – Operational data from JET



A – Operational data from JET

Goal:
Get **subjective** and **objective data** about Mascot-operator task performance.

Approach:

- Operator interviews
- Analyze logfiles/video data,
- Non conformance reports (‘skill based’ issues)

Control room JET RH

Results (in progress):

- Time / error data per task type
- Effect of operator experience/skills

→ Find focus for improvement

A – Operational data from JET

Maintenance tasks:

- Positioning/alignment:
- Bolting
- Positioning of cables (loom/small cables)
- Hovering *[http://www.youtube.com/watch?v=U0xiseBOtmA]*
- Cutting
- Inspection
- Hoisting
- (Preparing for) welding
- ...

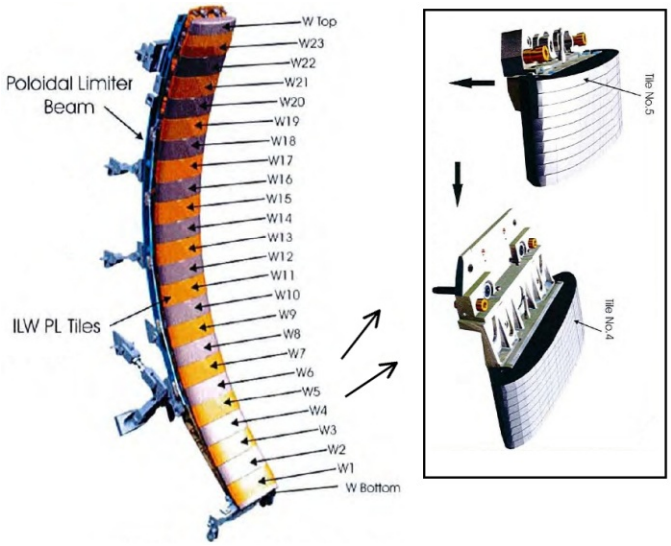
→ How to improve (what makes it difficult)?

General impression JET RH
[http://www.youtube.com/watch?v=pv8UrMUOkww]

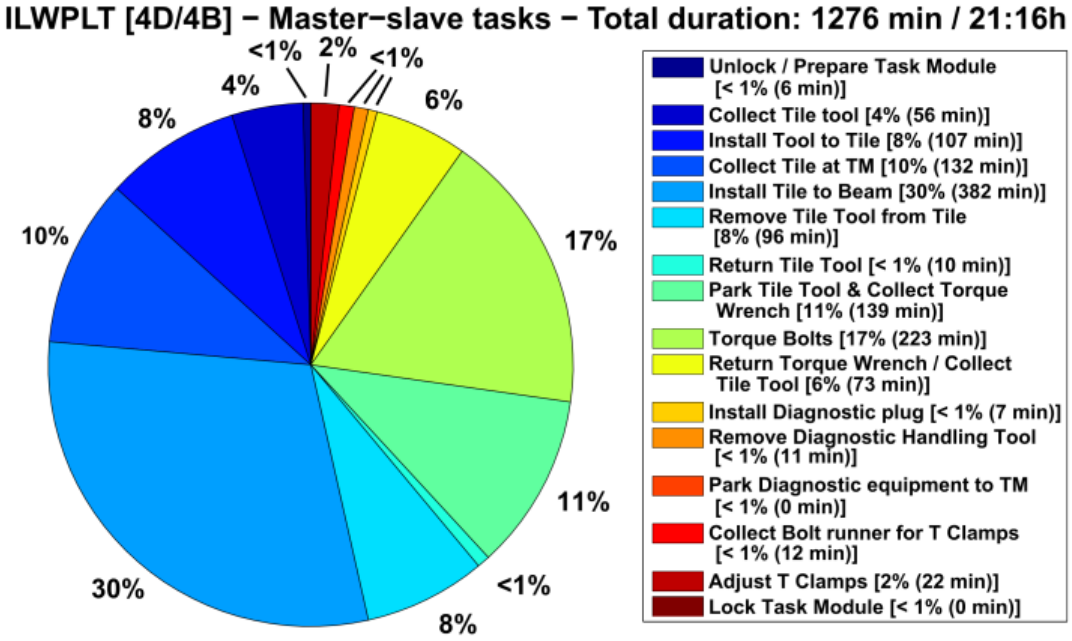
A – Operational data from JET

Where to improve? – Time data per subtask

Task: ILW PL tile placement



- 25 tiles per beam, +/-10 kg each
- Size: +/- 25 x 15 x 7 cm
- Delicate beryllium surfaces
- Small clearances



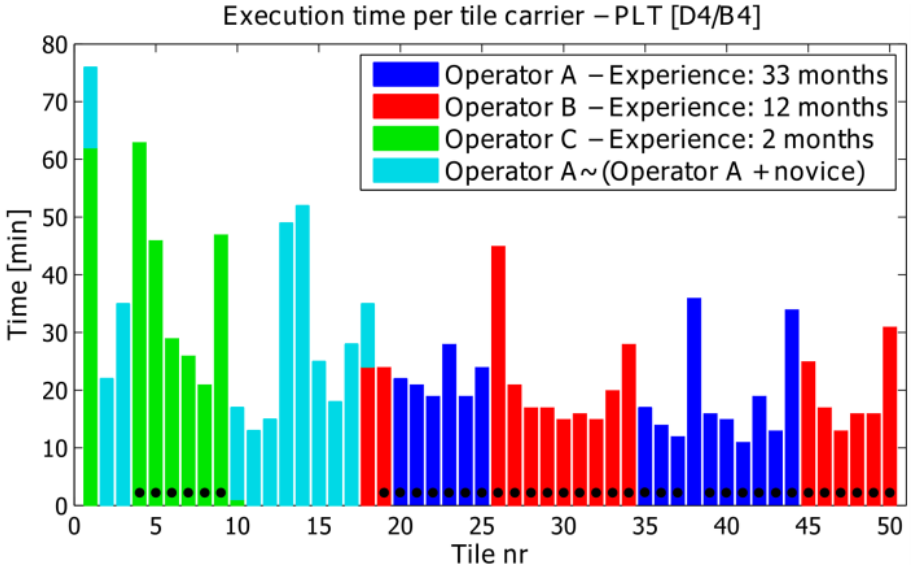
First: focus on most time consuming subtasks

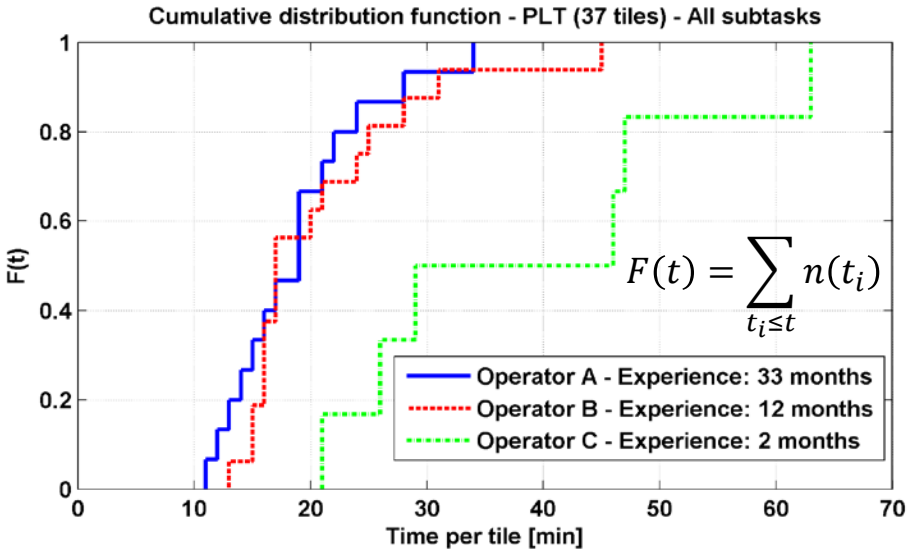
[http://www.youtube.com/watch?v=HPfRIc4acHI]

A – Operational data from JET

What to improve? – Time data per tile

Task: ILW PL tile placement





- Large variation within and between operators

Can we decrease the variation?

- If all operators worked on level A → 26% time improvement
- If all operators worked as fastest trial A → 57% time improvement

Maintenance at ITER

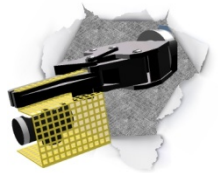
What is the problem? / Where & what to improve?

Two approaches to find out:

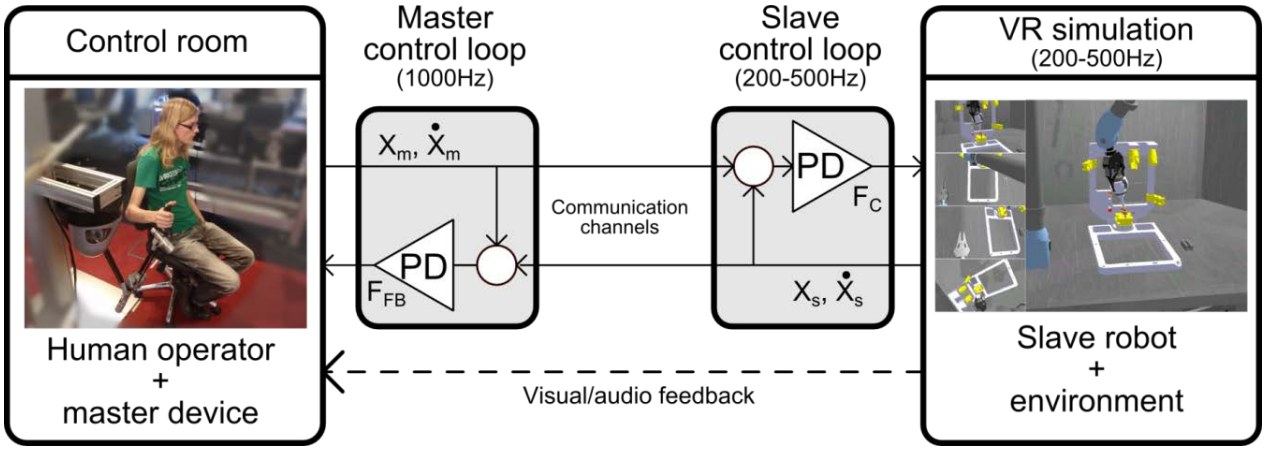
A – Operational data from JET

B – Exploratory human factors experiment (VR)

B – Exploratory experiment

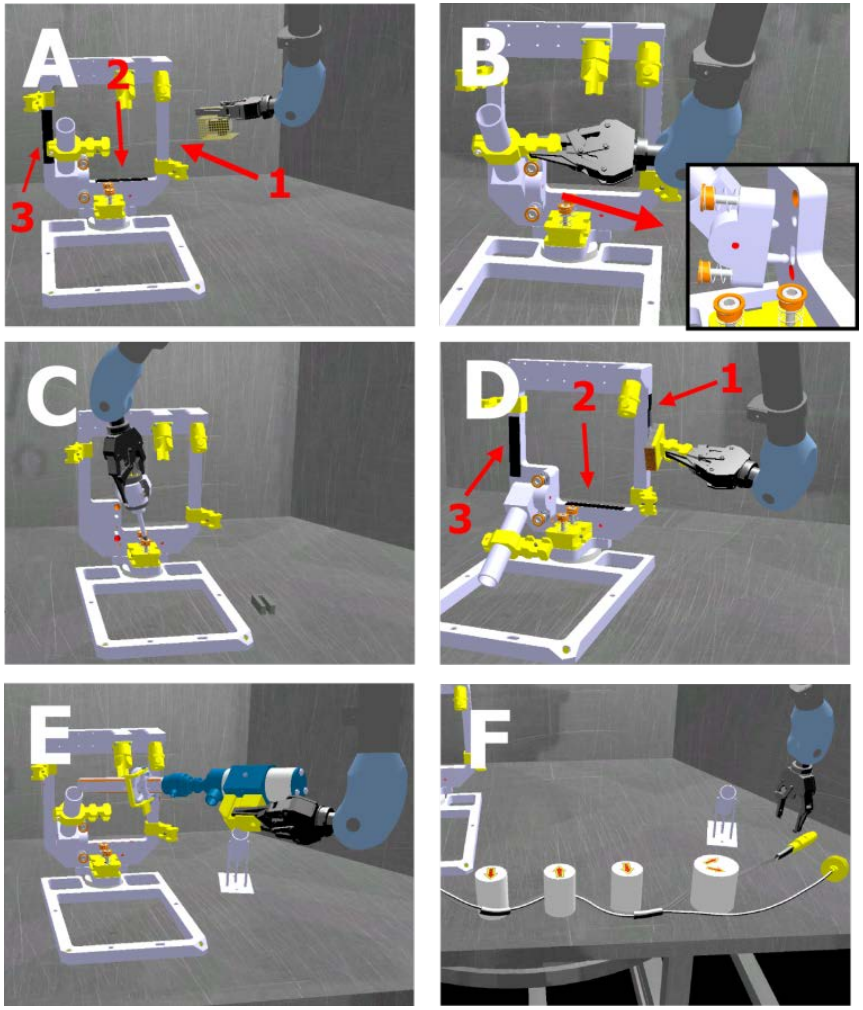


- **Question:** What are the exact problems in RH?
- **Approach:** Exploratory human factors experiment



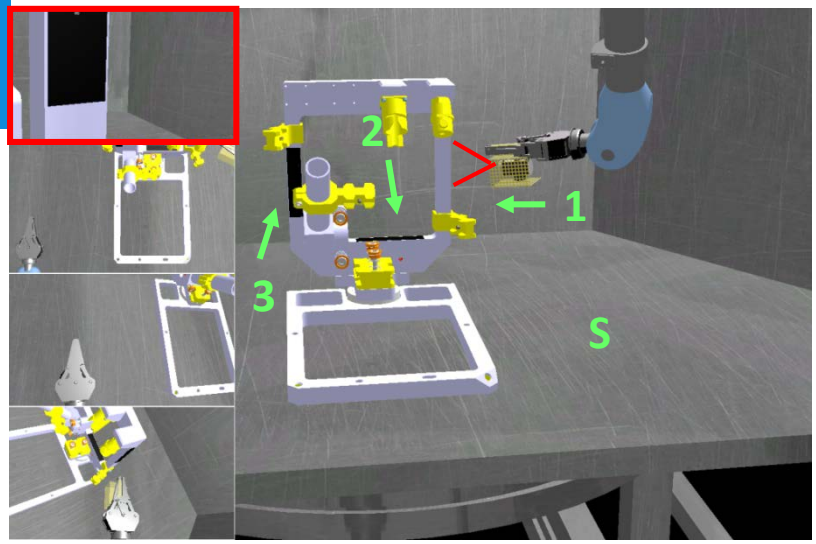
Experimental tasks: Selection of 6 diverse RH tasks

B – Experimental tasks



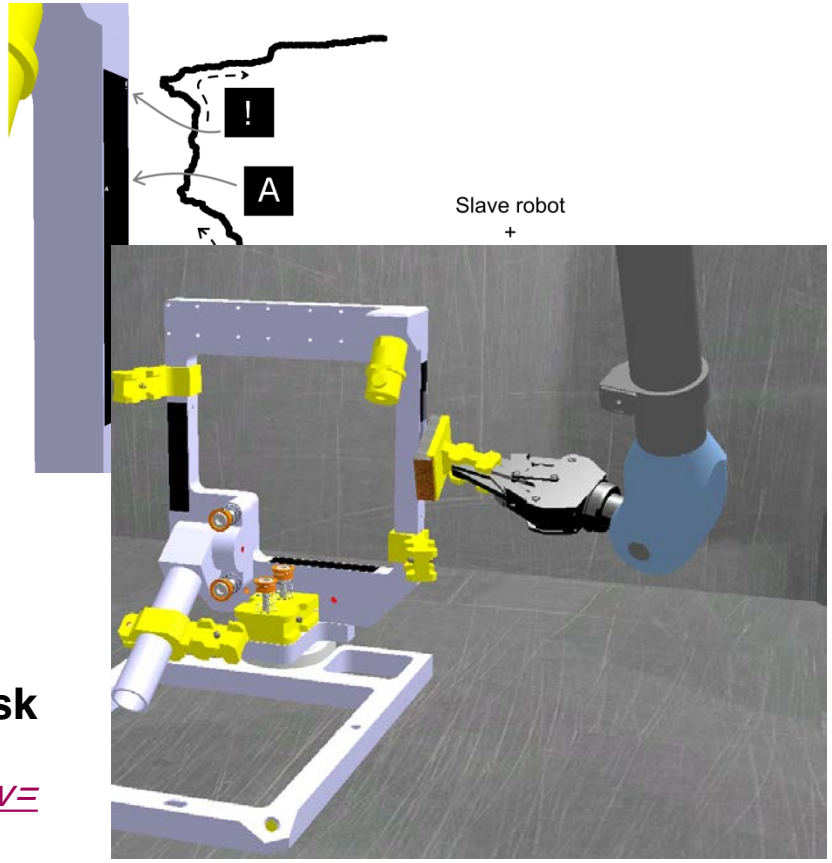
A. Visual inspection
B. Assembly task
C. Bolting
D. Polishing
E. Peg-in-hole
F. Cable placement

B – Experimental tasks (2 of 6)



[http://www.youtube.com/watch?v=6zUURuA3B5s]

1. Visual inspection task

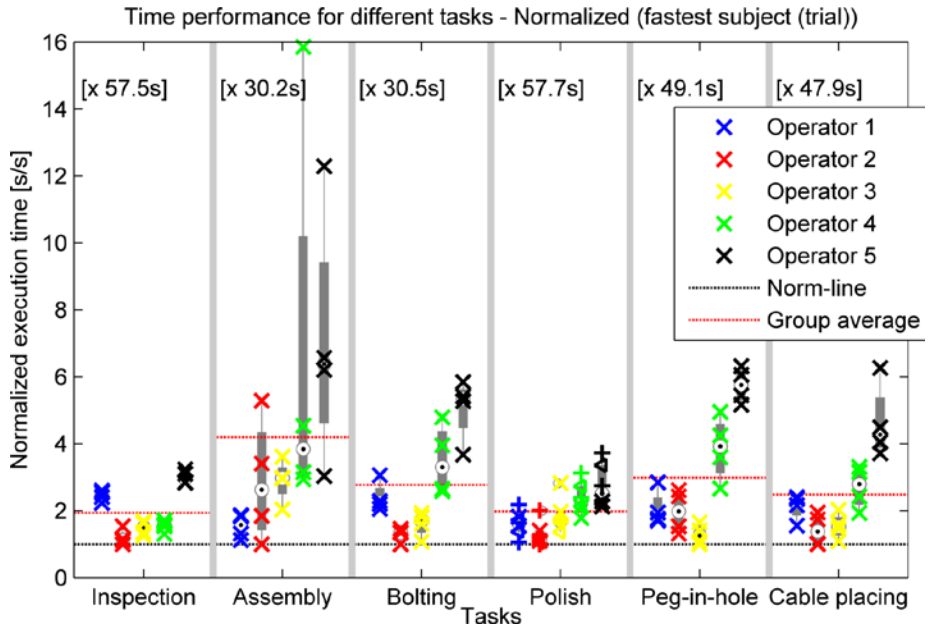


4. Polish frame task

[http://www.youtube.com/watch?v=7ycslbPqMAo]

B – Results

- Large variation in time performance between and within subjects
- Tool orientation/constant force level difficult in contact situation
- Higher operator workload for T2 & T4 (NASA TLX)



A/B – General conclusions

- Improvement of subtasks *placement & tightening bolts* is most effective (resp. 30% and 17% of total time ILW PLT placement)
- A substantial amount of time (up to 57% (JET) / up to 76% (VR)) can be saved if operators are assisted to behave like an expert operator's best trial.
- Baseline tasks that are especially difficult (show large time variation):
  - Picking up non-fixed tools,
  - Assembly task (average->fastest: 76%)
  - Peg-in-hole task (average->fastest: 66.5%)
- Baseline task that show especially little within subject variation:
  - Visual inspection

Maintenance at ITER

What is the problem? / Where & what to improve?

Two approaches to find out:

A – Operational data from JET

B – Exploratory human factors experiment (VR)

→ Would ‘haptic shared control’ be a solution in a more realistic case like ITER?

C – Applied haptic shared control (VR)

C – Applied Haptic Shared Control

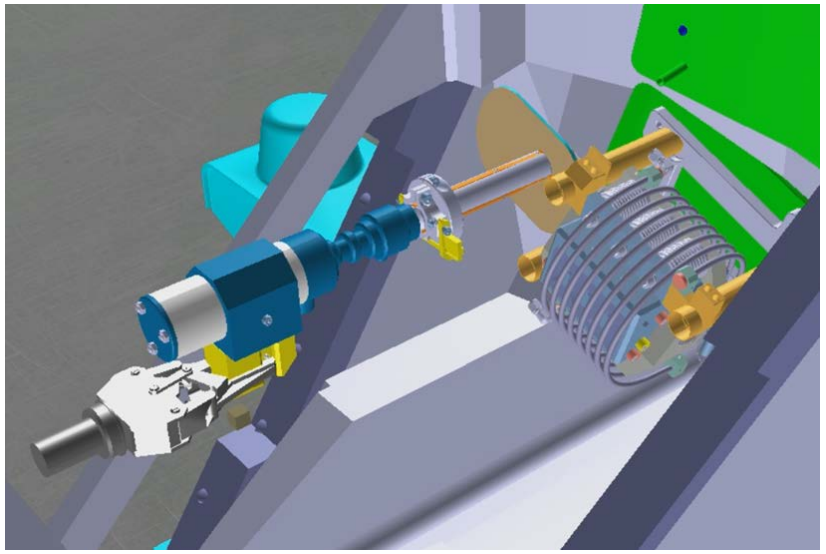
[J. van Oosterhout, MSc thesis 2012]

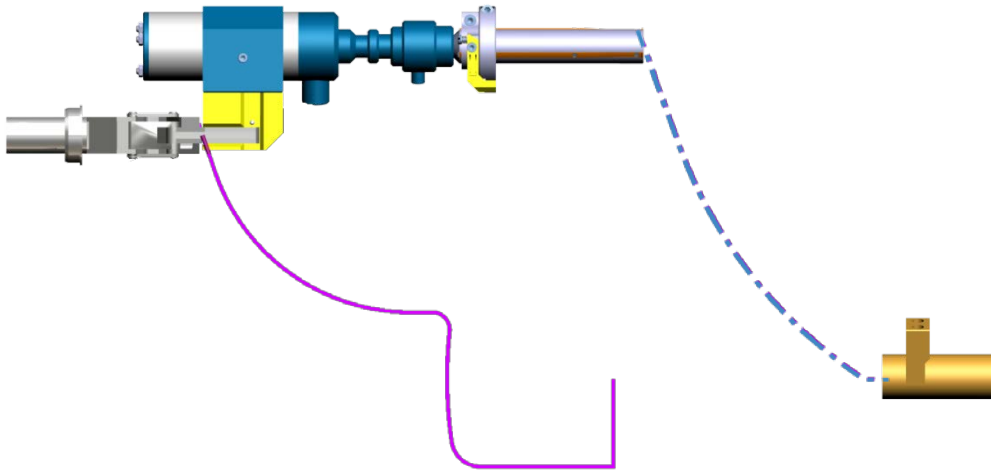
Question: “How do guiding errors influence teleoperated task performance?”

C – Methods – Experimental setup

Task

- Peg-in-hole type task (ITER RH)
- Virtual reality simulation
- Four fundamental subtask to span wide task space[1]
  - Free Space Movement
  - Contact Transition
  - Constrained Translation
  - Constrained Rotation





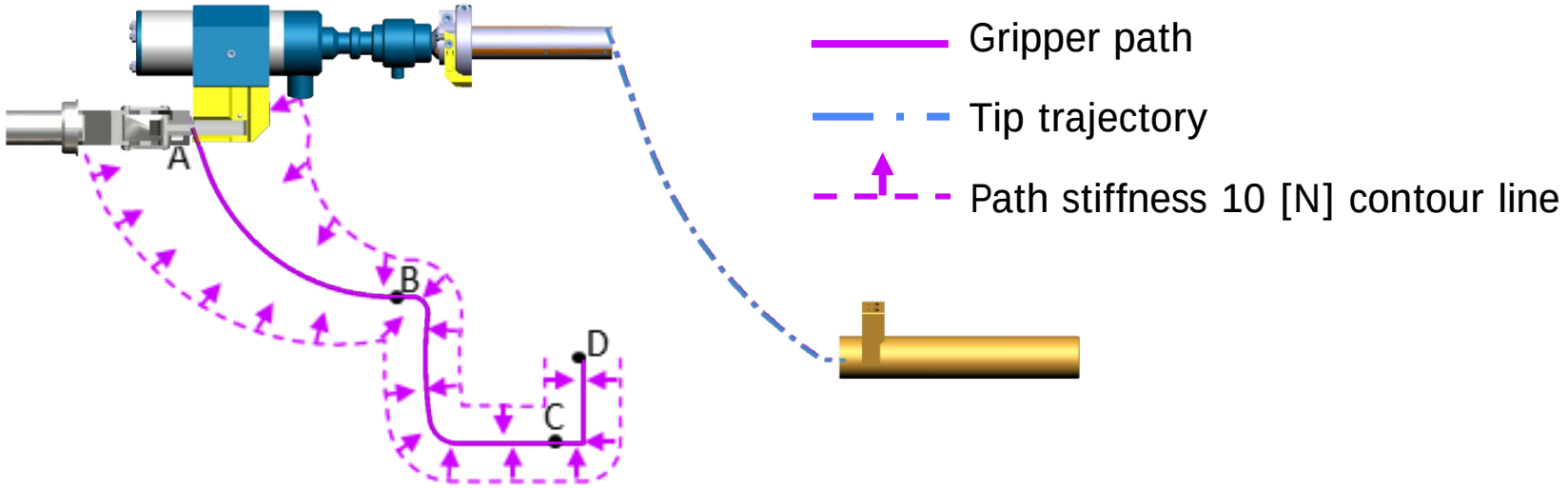
[1] *J.G.W. Wildenbeest et al., 2012,*

C – Methods – Experimental setup

Haptic shared control

Guide gripper along path[1]

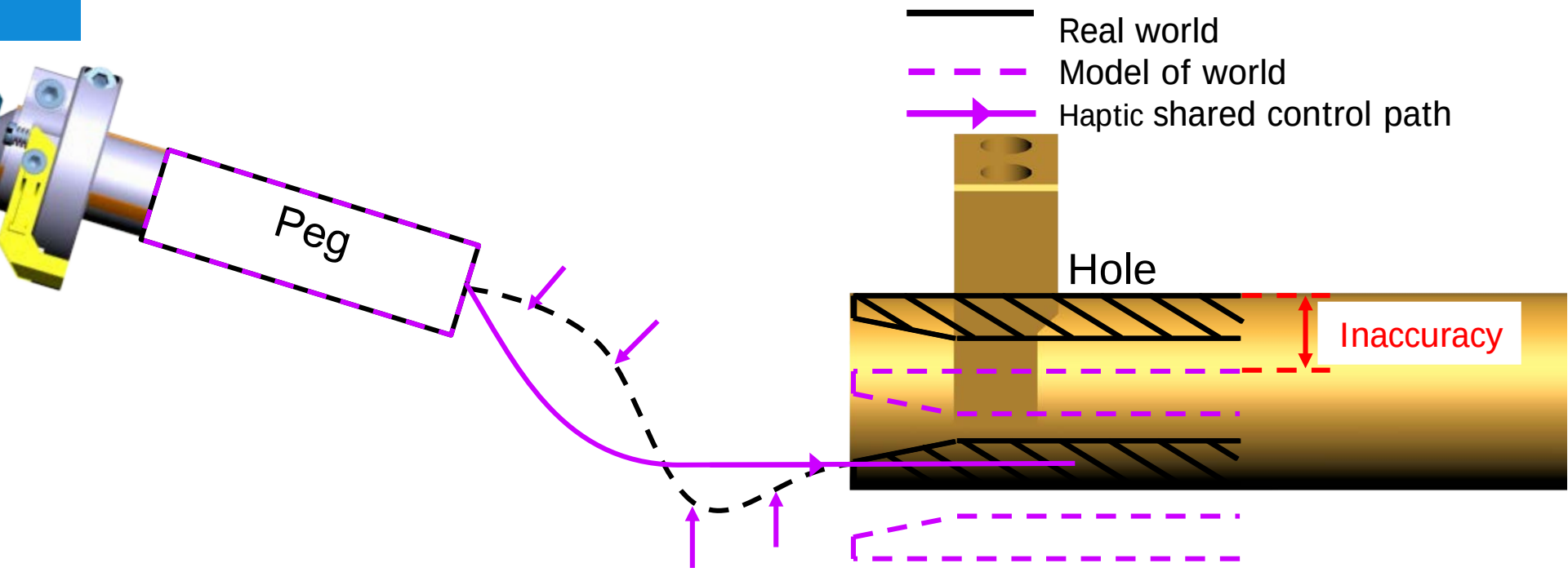
- Guiding force/torque depends on distance to path
- Max 10 [N] force
- Max 1 [Nm] torque



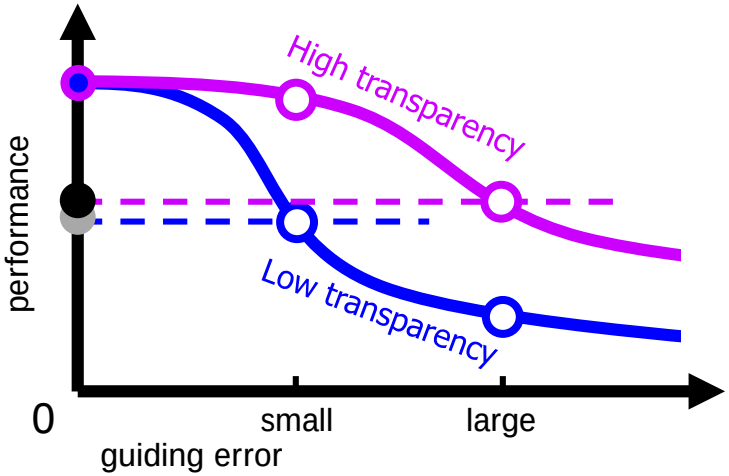
[1] *H. Boessenkool et al., 2012,*

C – Methods – Experimental design

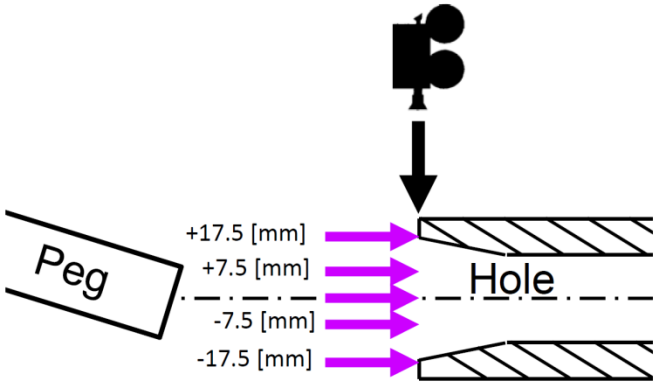
Inaccuracies



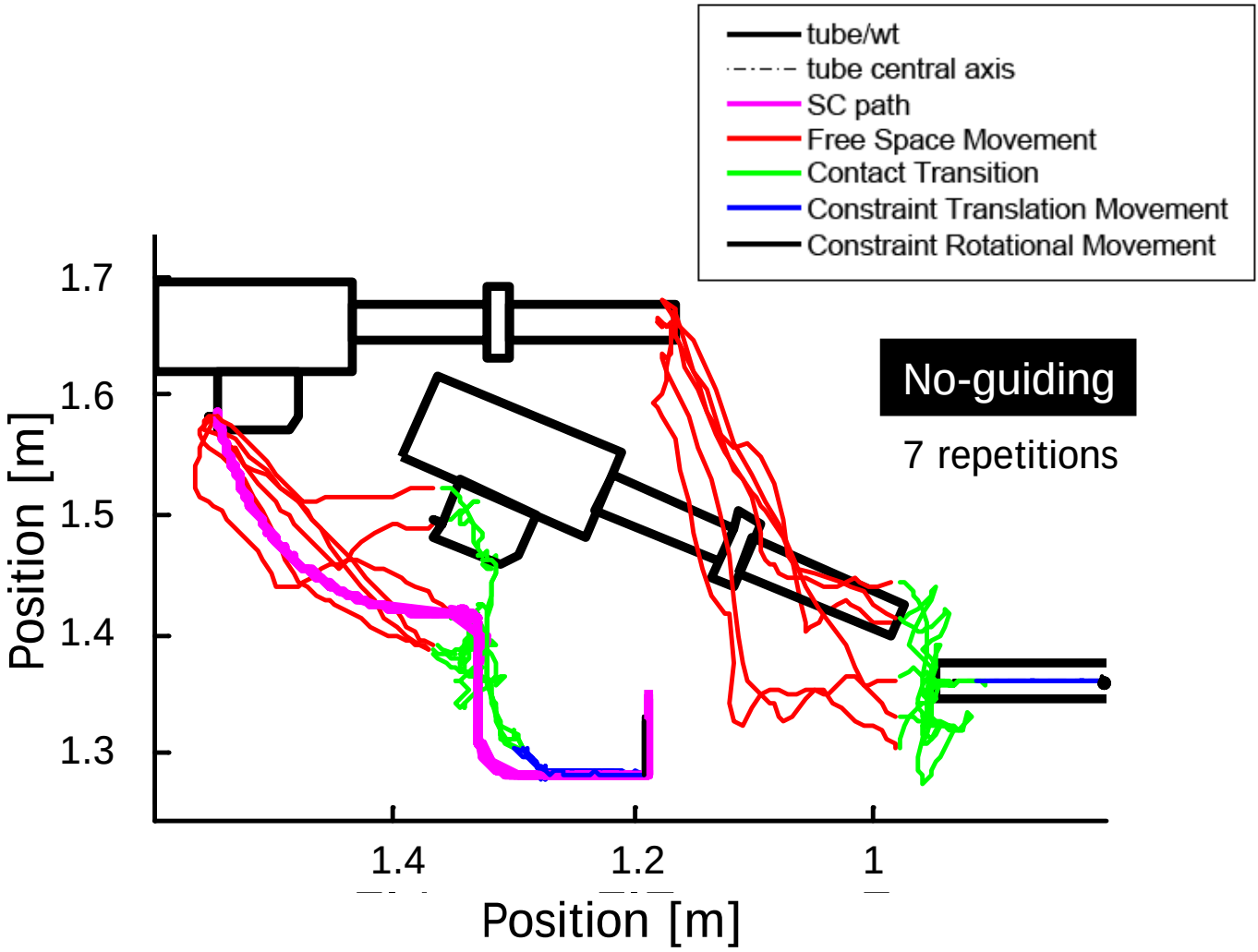
C – Hypothesis



Guiding \ Transparency	High	Low
Non	0	0
Perfect	++	++
Small error	+	0
Large error	0	--/(not)



C – Results – Travelled paths



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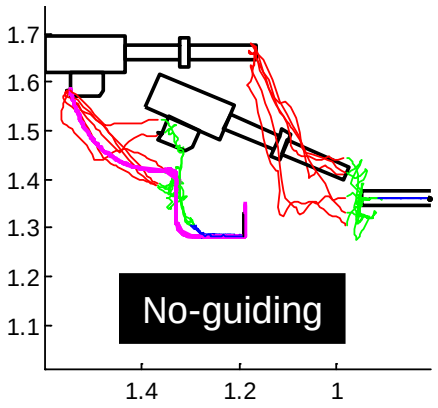
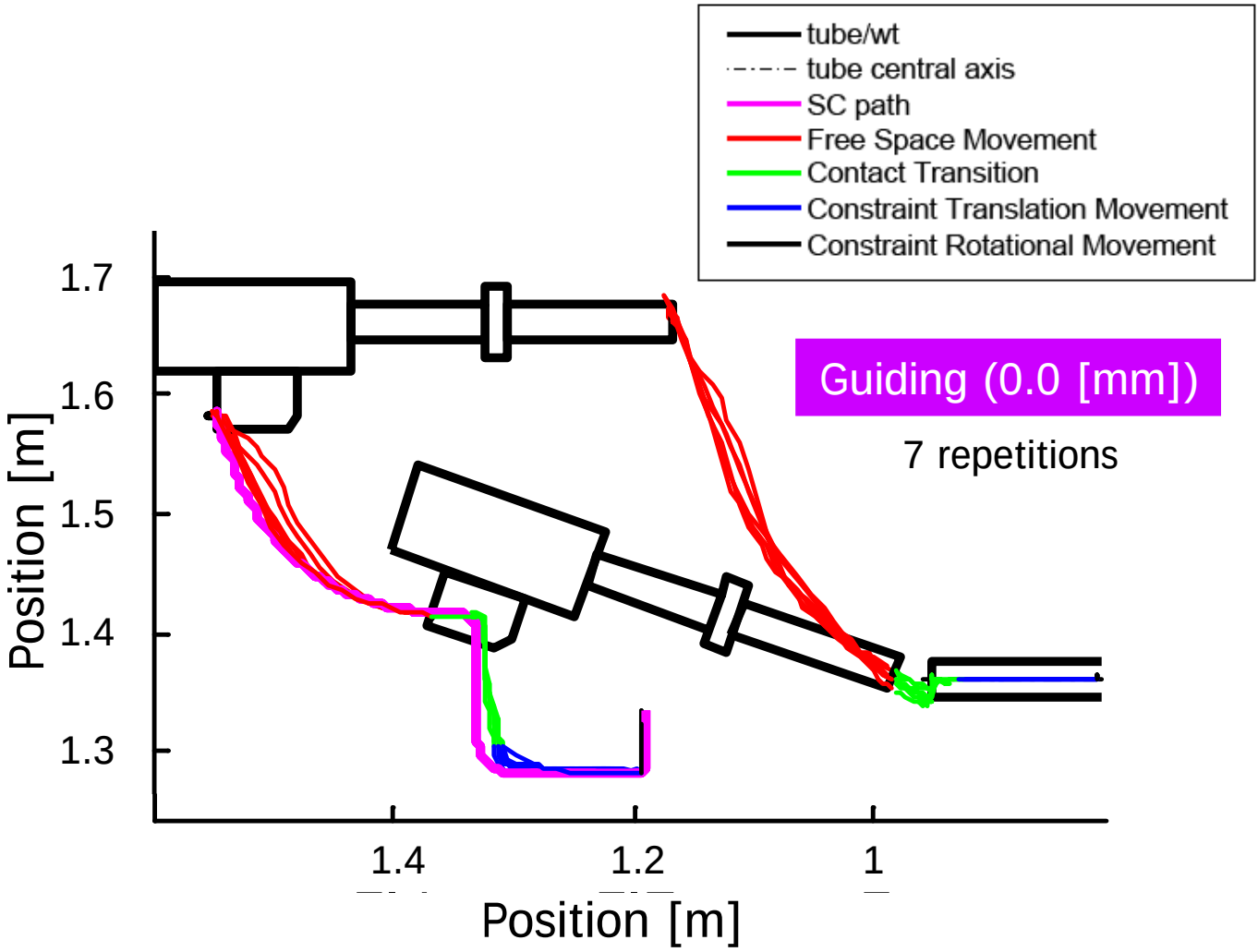
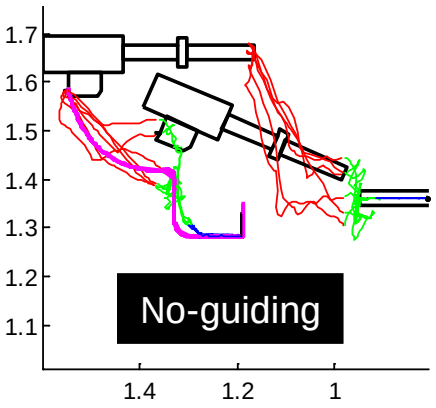
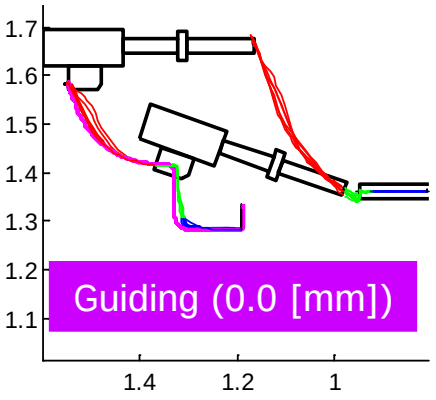
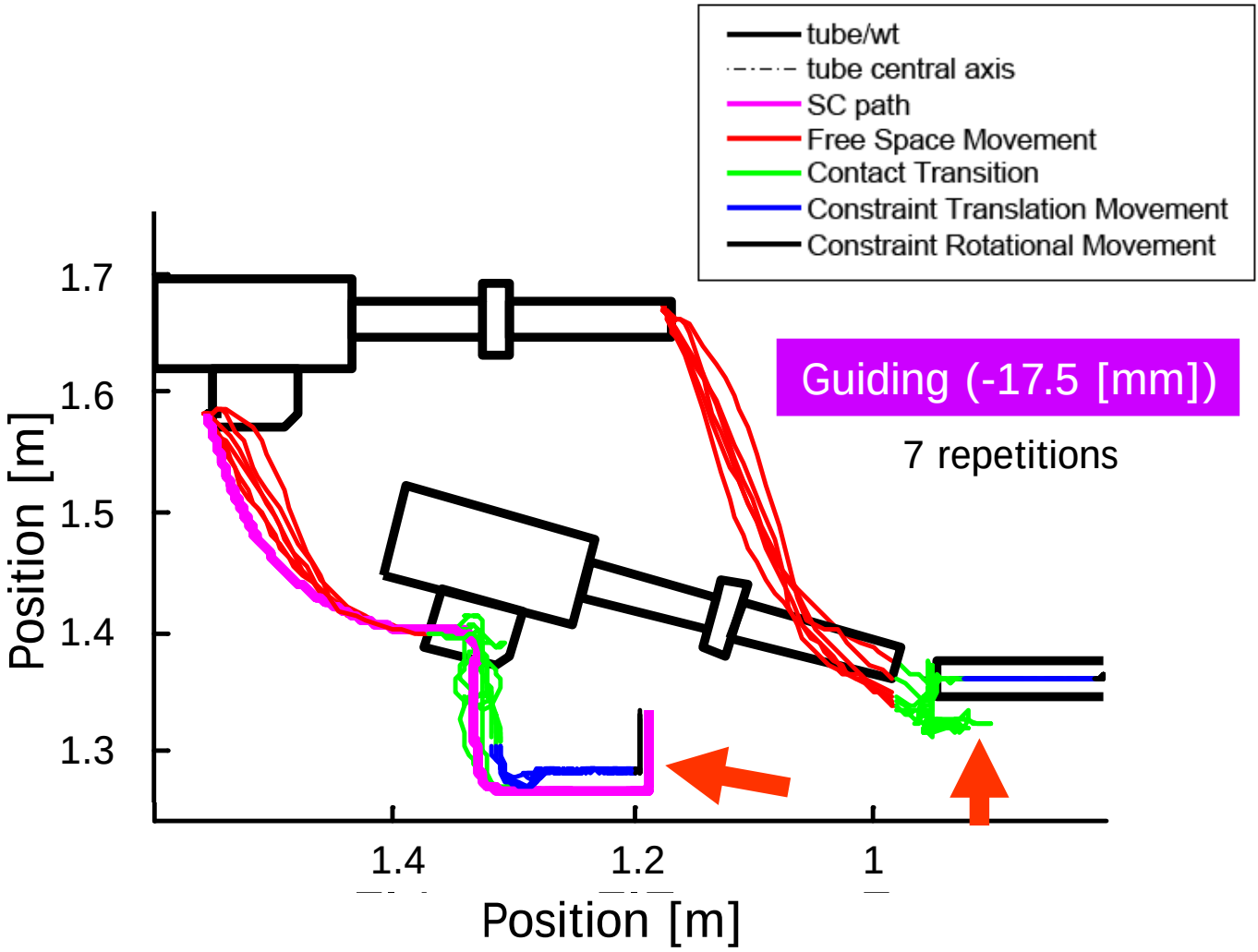




C – Results – Travelled paths

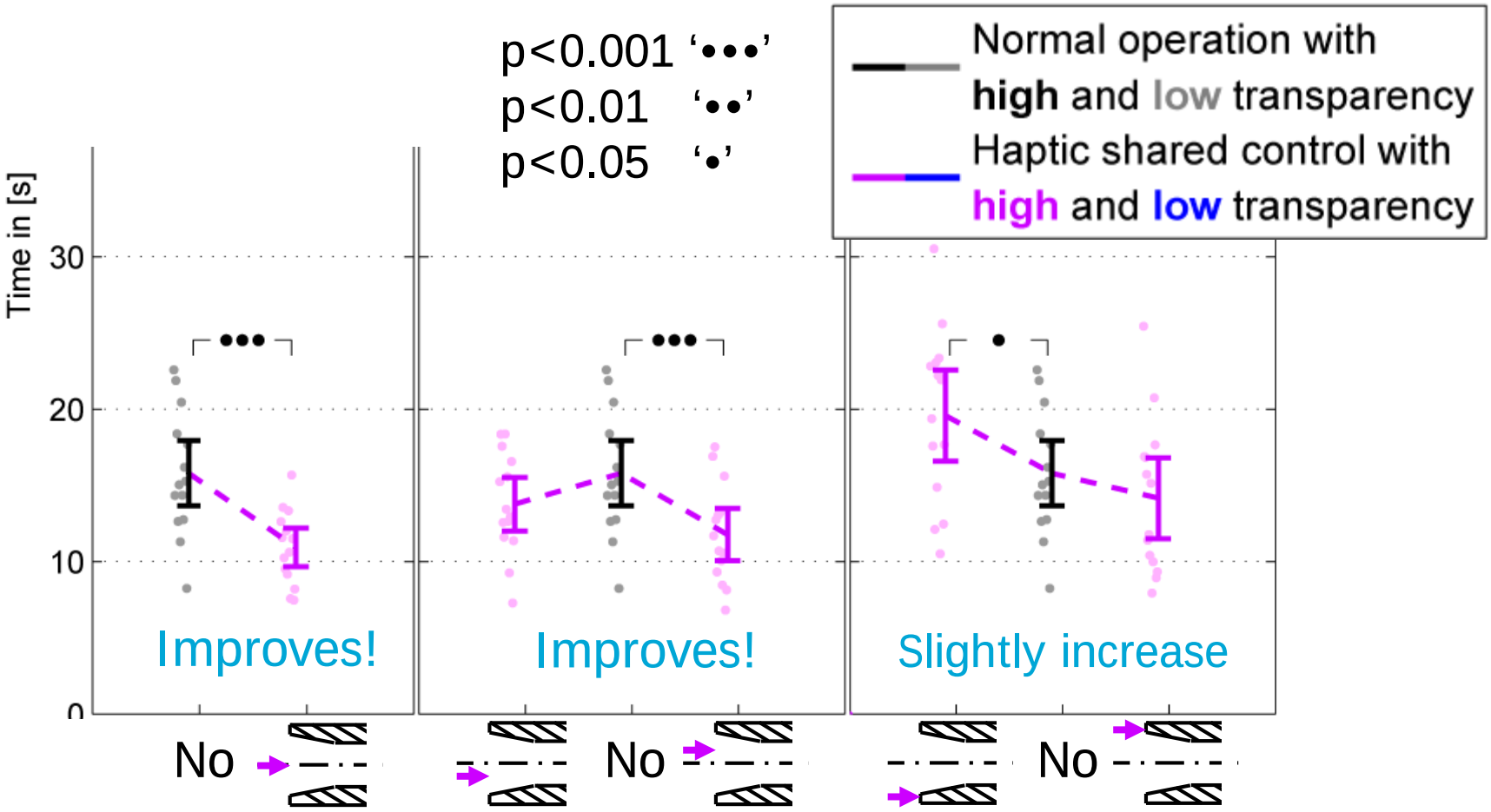






C – Results – Time to Complete

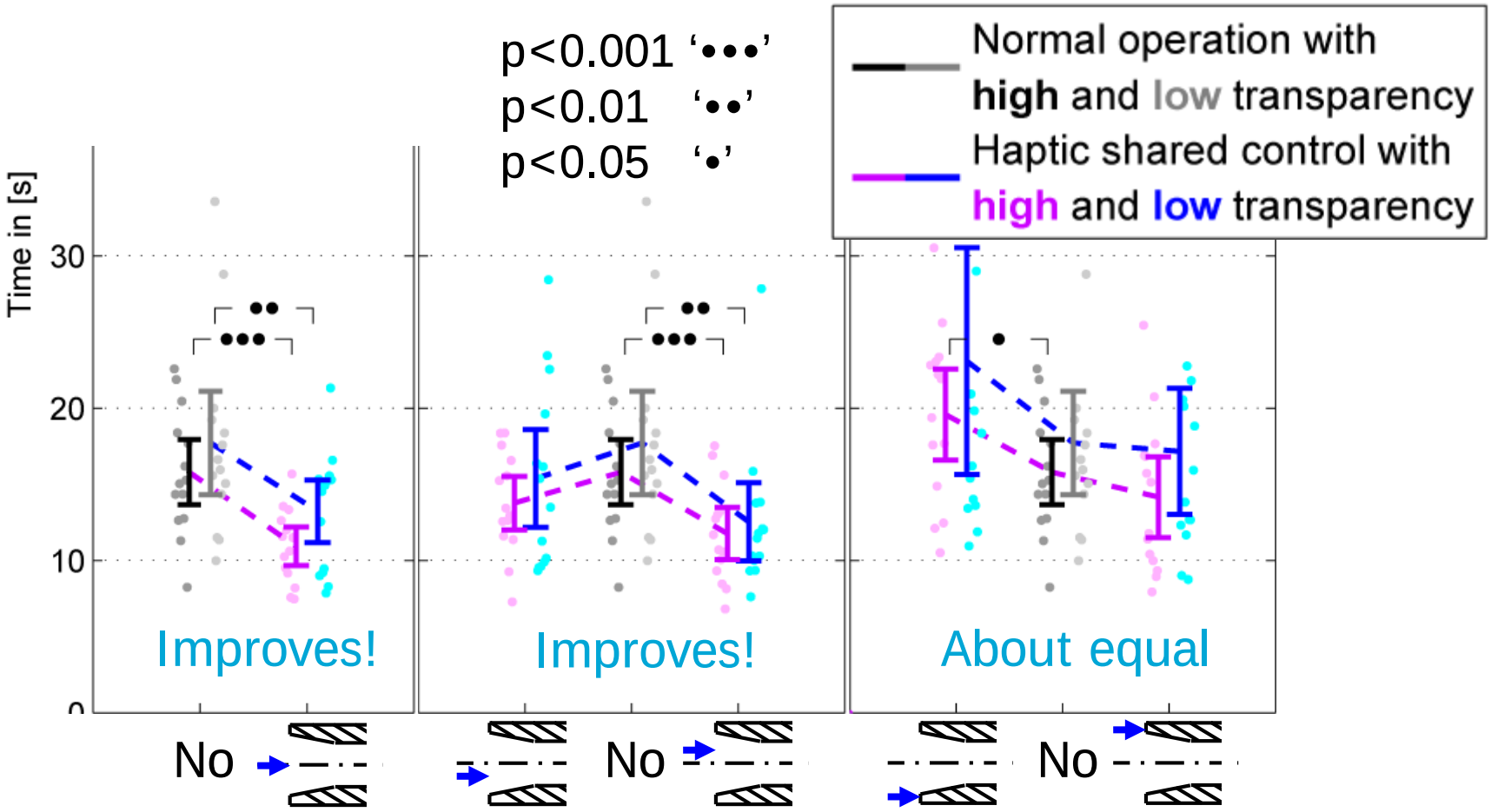
High transparency



[J. van Oosterhout, MSc thesis 2011]

C – Results – Time to Complete

Low transparency



[J. van Oosterhout, MSc thesis 2011]

C – Conclusion

“How do guiding errors influence teleoperated task performance?“

Overall:

- Haptic shared control still aids teleoperated tasks despite small translational guiding inaccuracies.

- Low transparency does not magnify the effect of translational guiding inaccuracies.

Lecture summary

Lecture summary

- Shared Control showed improvements for:
  - Task performance (time, accuracy and exerted forces)
  - Control effort, workload

- Shared control is promising for the ITER RH application, even if it contains small errors.

- Open issues: optimal HSC design? / how to capture human intention? / what are the long term effects? / automation problems (misuse/disuse/abuse/..)? / ...

Take home message

Haptic shared control seems very beneficial ...

But more research is necessary!