Telepresence: Mind the gap!

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DLR - German Aerospace Center

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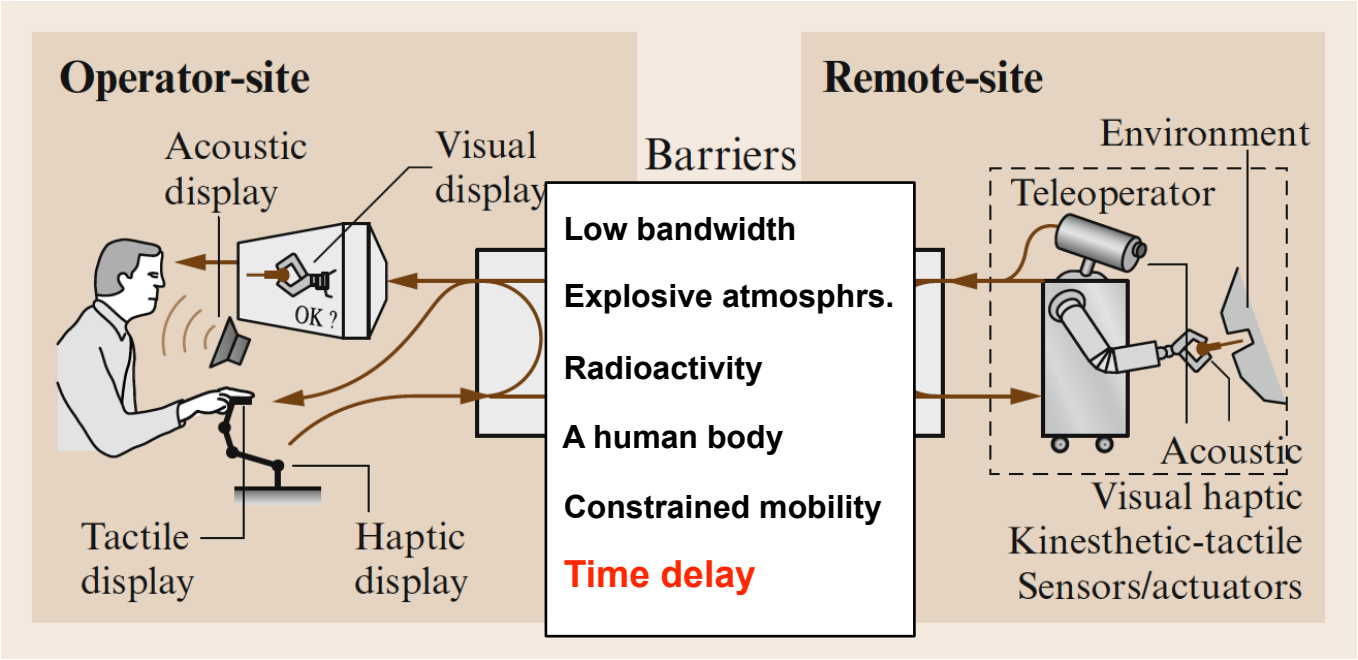
Telepresence refers to a set of ***technologies*** which allow people to ***feel*** as if they were present, to give the appearance of being present, or to have an effect, via ***telerobotics,*** at a place other than their true location.

Source: Wikipedia



Source: Handbook of Robotics (Springer)

Baseline: System stability can not be negotiated; It's a must. Delay is the main source of instability

Challenges:
- the barrier,
- human in the loop,
- unstructured environments, dynamics
- heterogenic devices,
- multi-users/robots

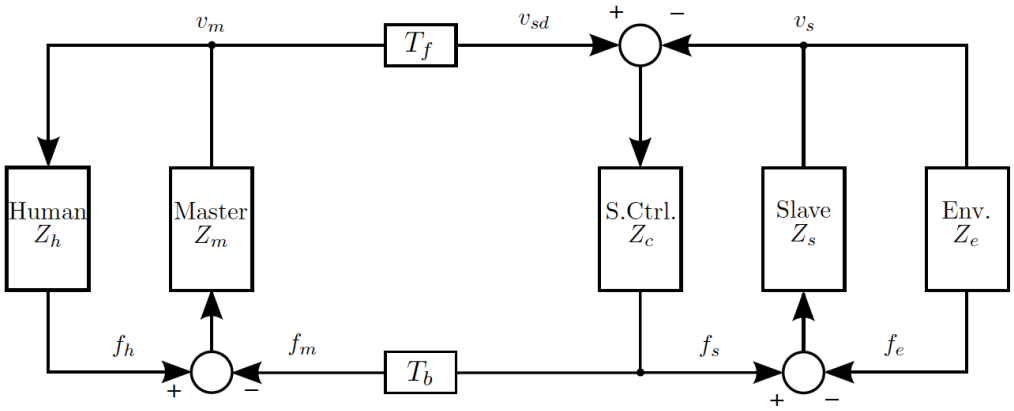
Goal: Transparency

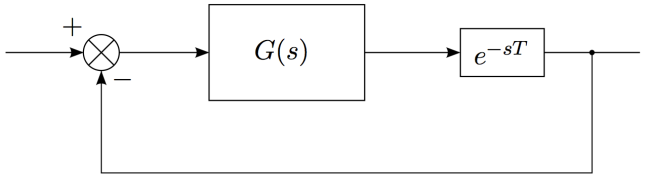
Values: Control generality → Approach feasible for any robot

PART 0: Introduction to time delayed Teleoperation

A simple example: Position-Force Architecture (1)

Stability based on transfer function and Routh-Hurwitz (classical approach)





Analogous representation as a feedback system

Assuming $Z_e = 0$ (i.e. free environment), we can write:

Open loop transfer function: $$G_{ol}(s) = G(s)e^{-2sT} = \frac{v_m(s)}{f_m(s)} = \frac{Bs + K}{ms^2 + (B+b)s + K}e^{-2sT}$$

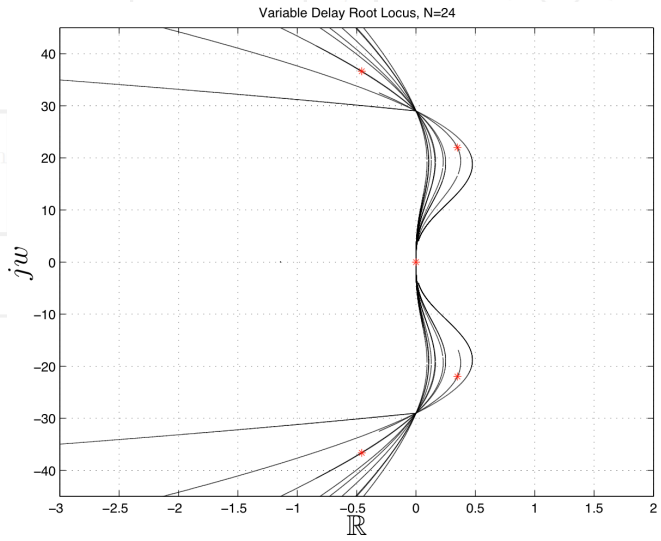
Close loop transfer function: $$G_{cl}(s) = \frac{G_{ol}(s)}{1 + G_{ol}(s)} = \frac{G(s)e^{-2sT}}{1 + G(s)e^{-2sT}}$$

Characteristic equation: $$1 + G(s)e^{-2sT} = 0$$

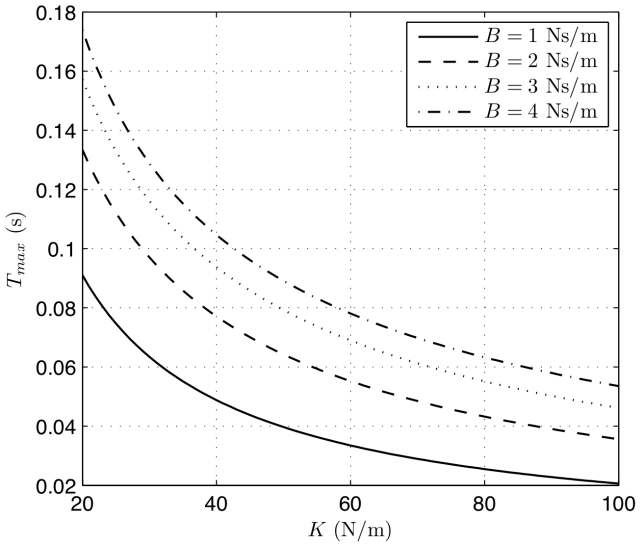
System poles, solving for T: $$T = \frac{2m}{\sqrt{-b(b+2B) + 2Km}} arctan((B+b)\sqrt{\frac{2}{mK}}).$$

A simple example: Position-Force Architecture (2)

Stability based on transfer function and Routh-Hurwitz (i.e. classical approach)



Variable delay root locus.
The system has “stability windows” that are a function of the delay value



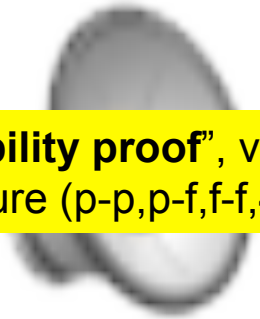
Stability regions can be drawn as a function of the delay value and the controller constants

Control engineer’s job: To select K and B such that the system remains in a stability region. However, **low practical implications** and **system dependent**

A simple example: Position-Force Architecture (5)

Stability based on transfer function and Routh-Hurwitz (i.e. classical approach)

Video of a Position-Force Architecture with a time delay of 10ms and a controller set into an unstable region

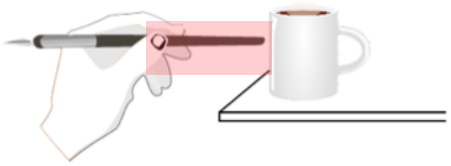


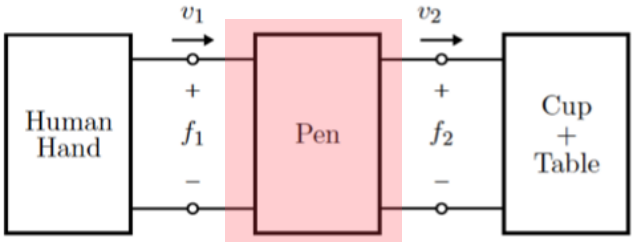
We need a practical "**stability proof**", valid for ***any*** system and ***any*** control architecture (p-p,p-f,f-f,4ch..), i.e. **general**

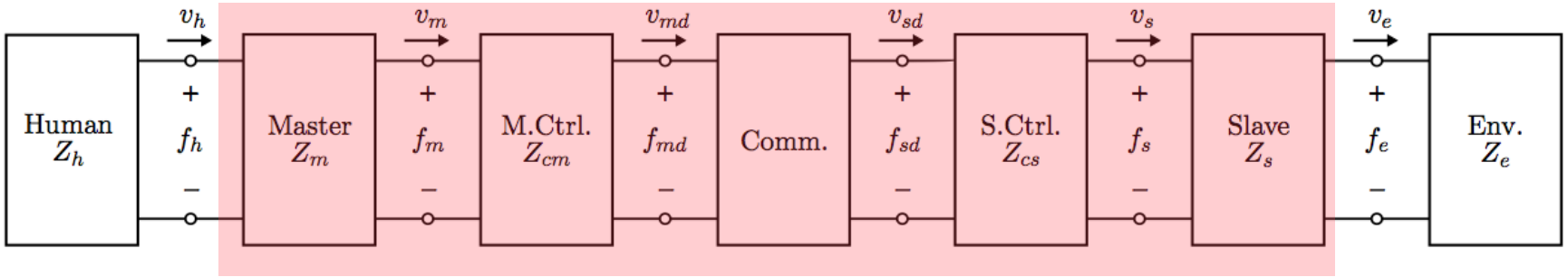
PART 1: How is energy transferred?

A stability certificate

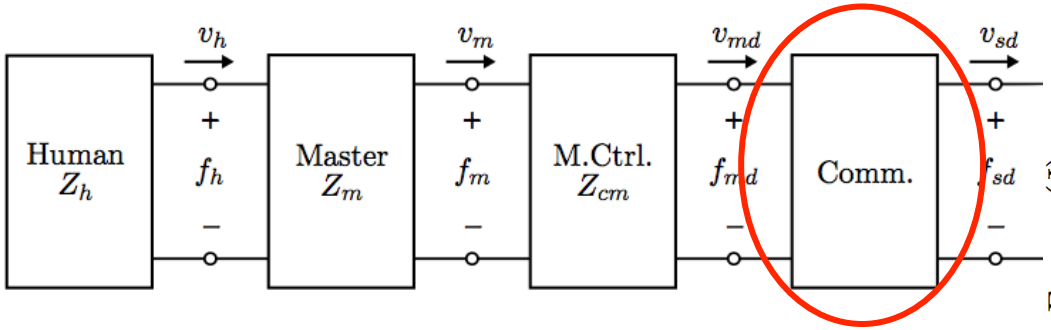
Telepresence: The Hand-Pen-Cup simile

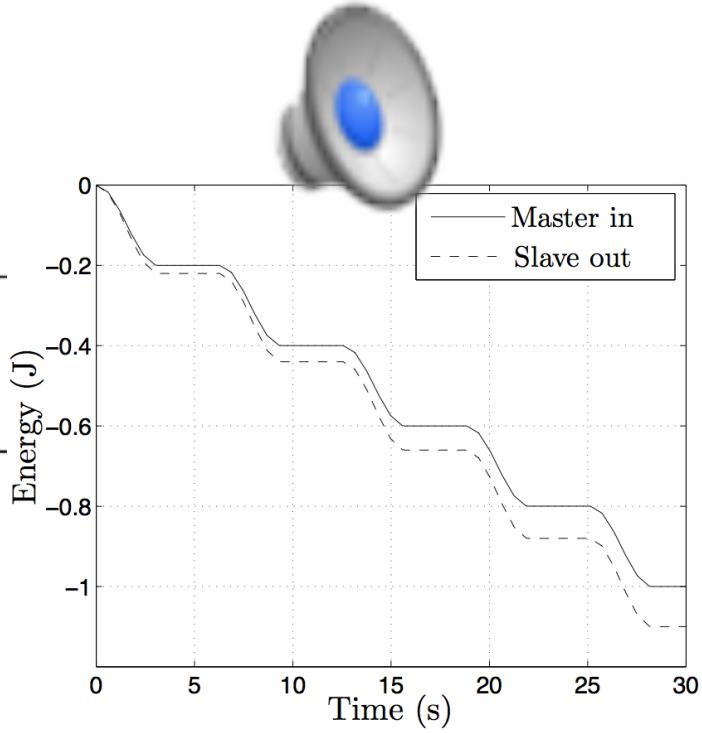






But, Communication Channel Active!





Channel Energy: $\int_0^t f_1(\tau)v_1(\tau)d\tau + f_2(\tau)v_2(\tau)d\tau$

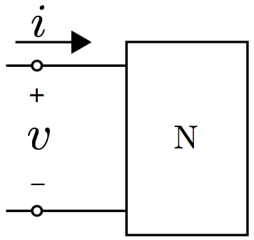
$$E_{obs}(n) = T_s \sum_{k=0}^{n} (f_1(k)v_1(k) + f_2(k)v_2(k))$$

So more energy is coming out from the slave side (Slave out) as energy injected at the master (Master in) = ACTIVE! → Unstable!

Passivity theory

Consider a one-port network with through and across signals i and v.

$$W(t_o,t) = \int_{t_0}^{t} v(\tau)i(\tau)d\tau.$$

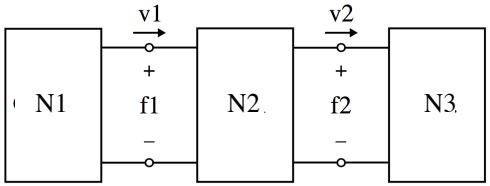


Then the maps $v \rightarrow i$, $i \rightarrow v$ are passive if:

$$W(t_o,t) + E(t_o) \geq 0 \qquad \forall t \geq 0$$

Sufficient but not necessary condition for stability

A cascade or parallel interconnection of passive systems is passive, e.g.

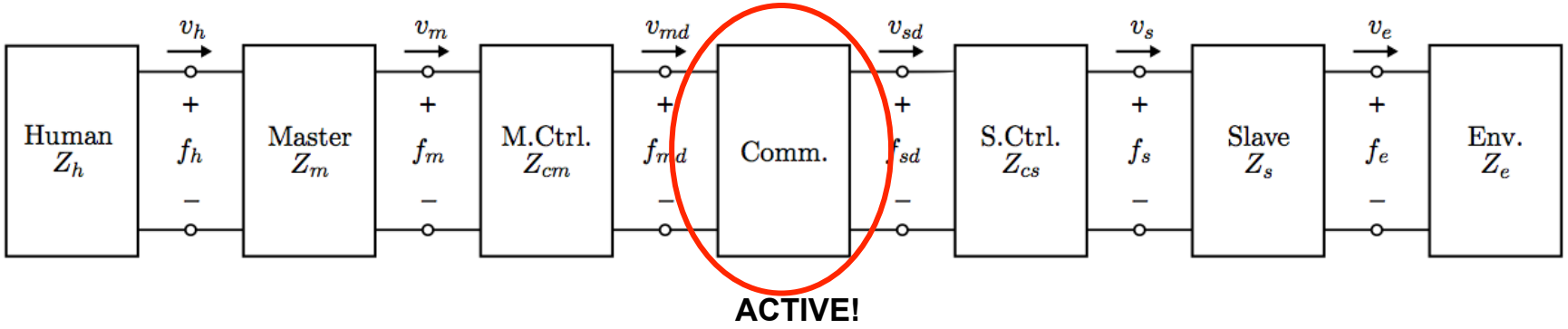


Input/output property, no specific model required

In other words: A system is passive if it does not generate energy

Passivity in Delayed Teleoperation

“ If all the networks of a system



are passive. Then the overall system is passive and therefore stable. ”

G. Raisbeck. A definition of passive linear networks in terms of time and energy. Journal of Applied Physics, 1954.

(All other elements are assumed to be passive)

But, if delay ➔ non-passive ➔ Potentially unstable

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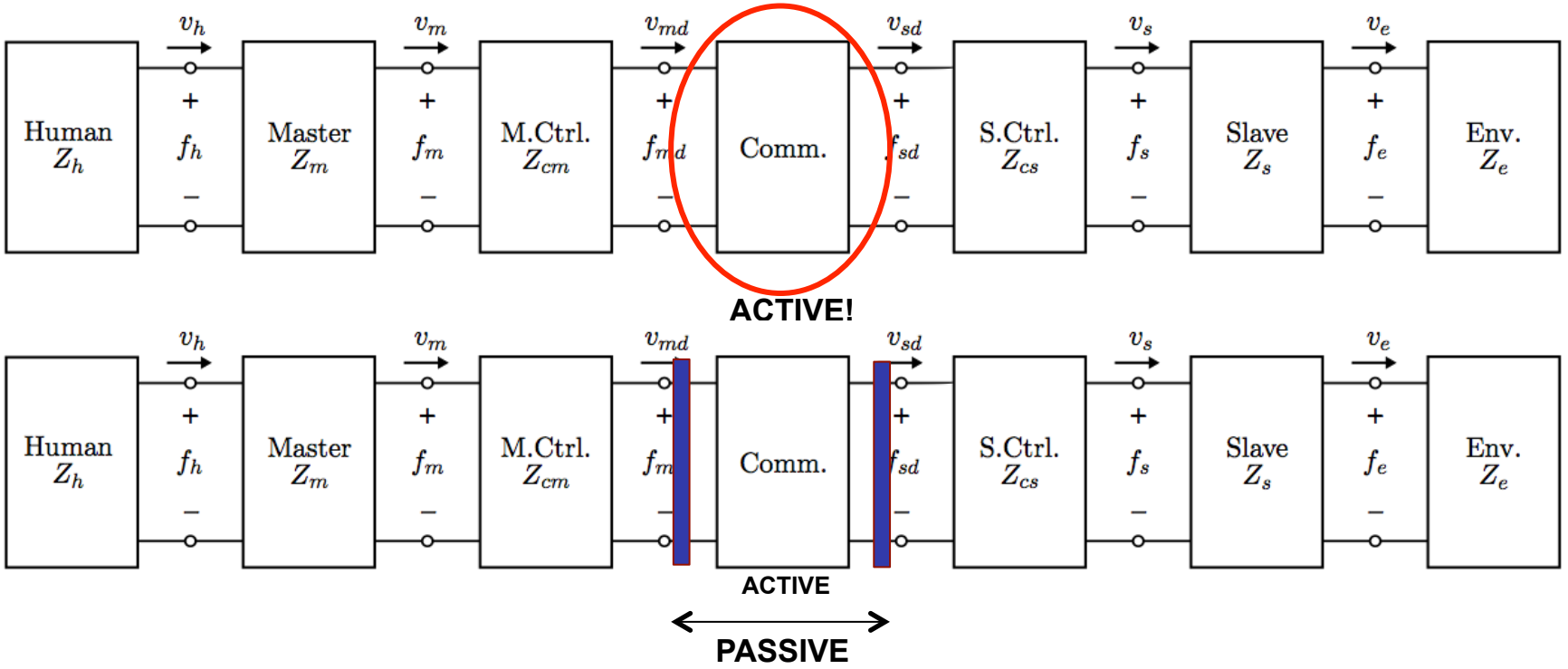
Rendering the channel passive



Time Domain Passivity Control:

1- Observe the energy of the channel in real time

2- Dissipate energy generated by the channel through a damper

J.H. Ryu, J. Artigas, and C. Preusche. “A passive bilateral control scheme for a teleoperator with time-varying communication delay”. Elsevier Journal of Mechatronics, October 2010.

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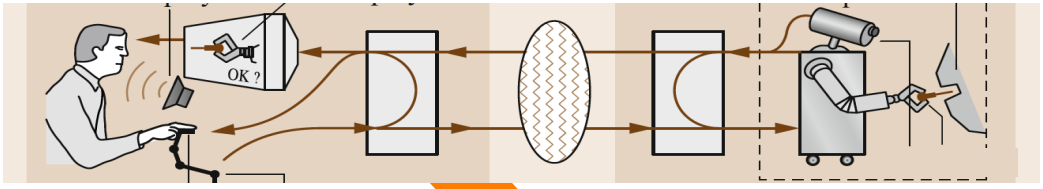
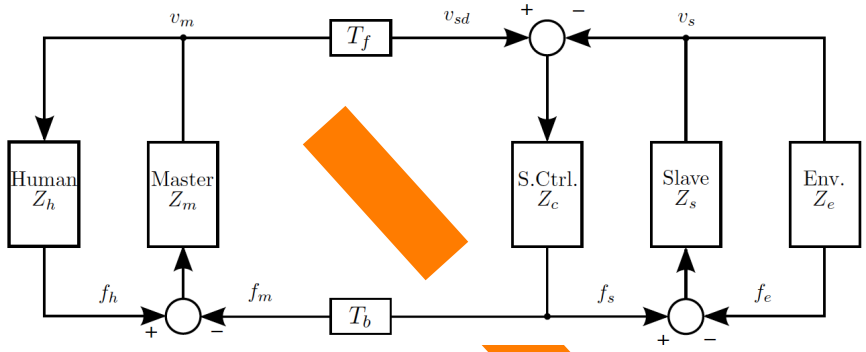
Modeling of Teleoperation Systems





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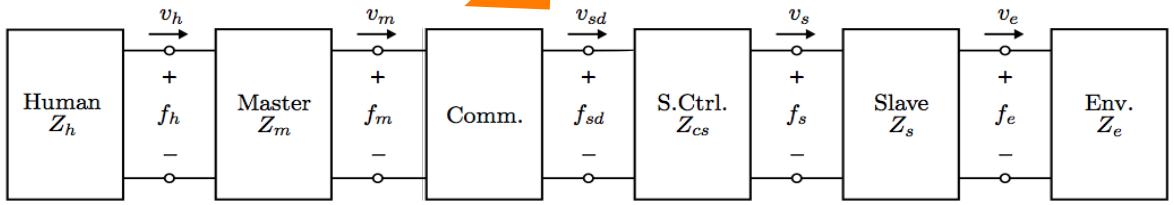

J. Artigas, J.H. Ryu, and C. Preusche.
Network representation and Passivity of Teleoperation Systems.
In IEEE ICRA 2011.

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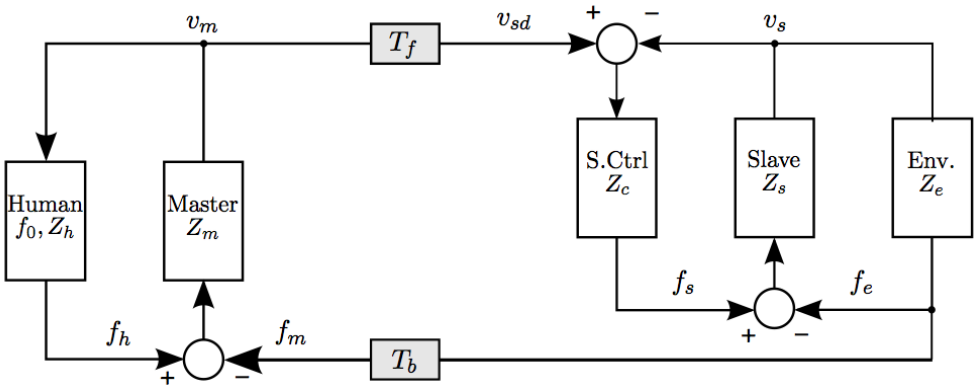
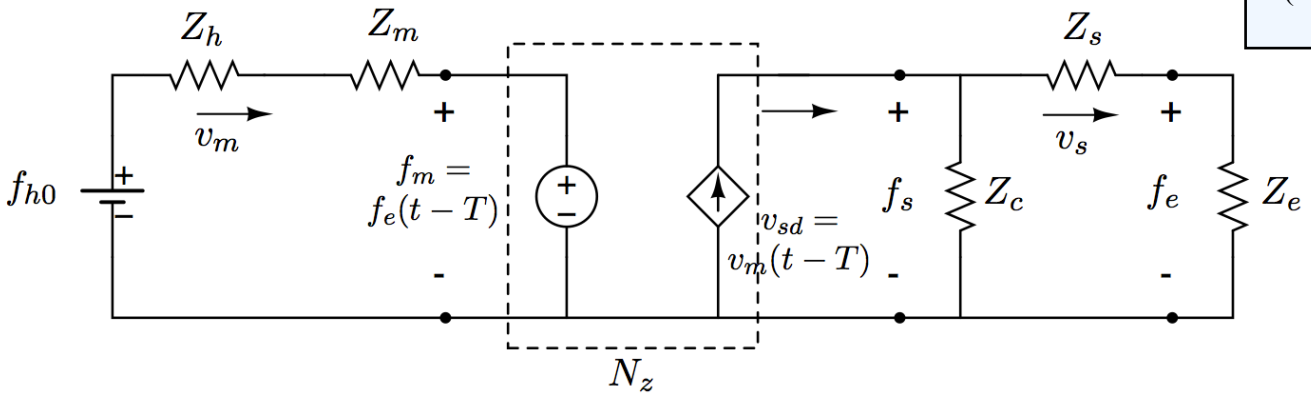
Example: Position – Force Measured
(electrical-mechanical analogy)

Mechanical / electrical analogy

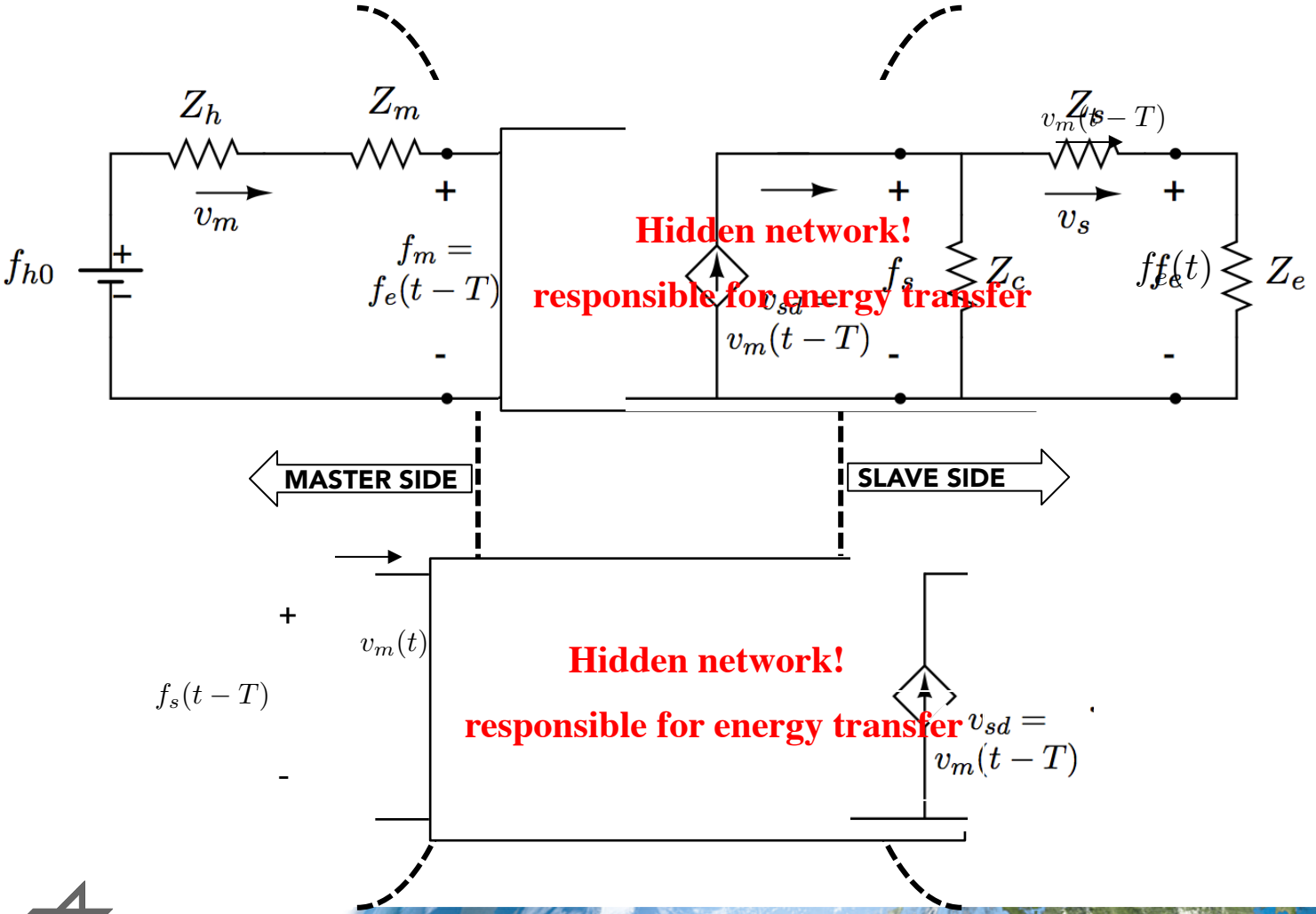




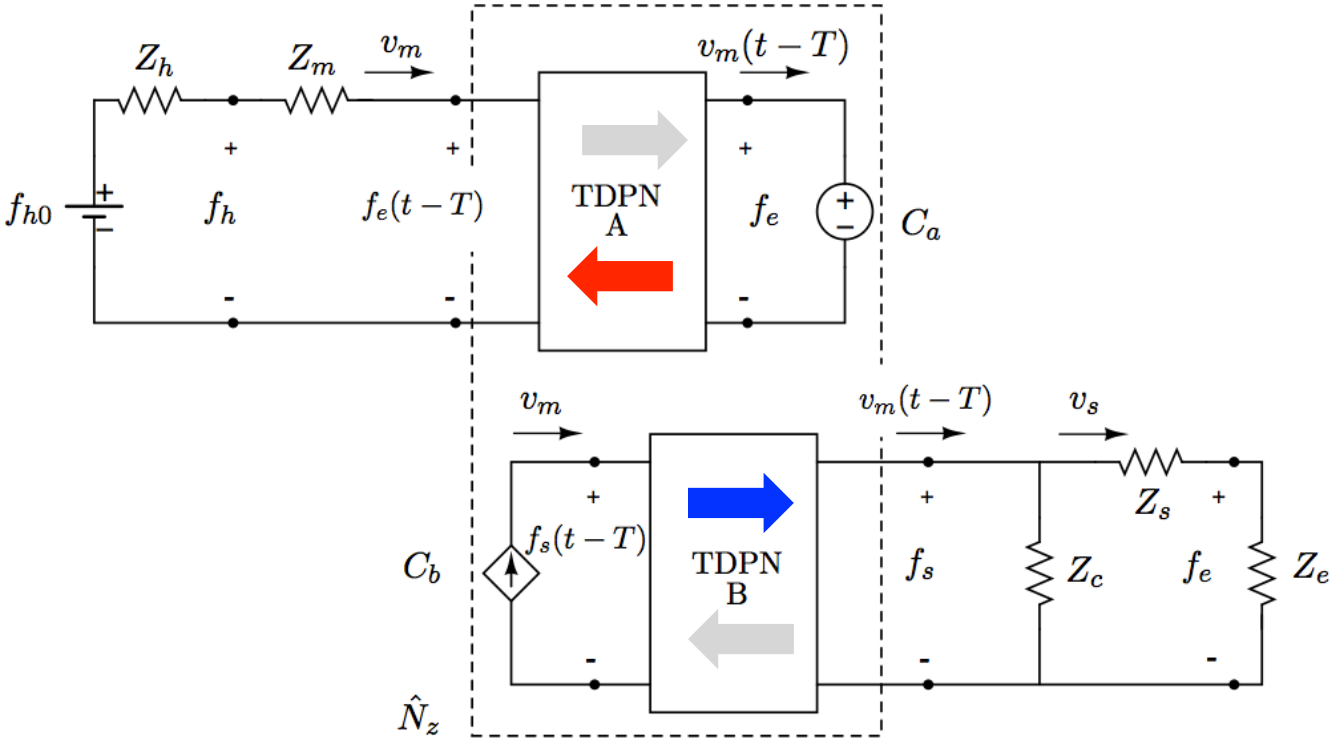
Mechanical Electrical Analogy:

F (Force)	V (Voltage)
V (Velocity)	I (Current)

Disambiguation: Time Delay Power Networks (TDPN)



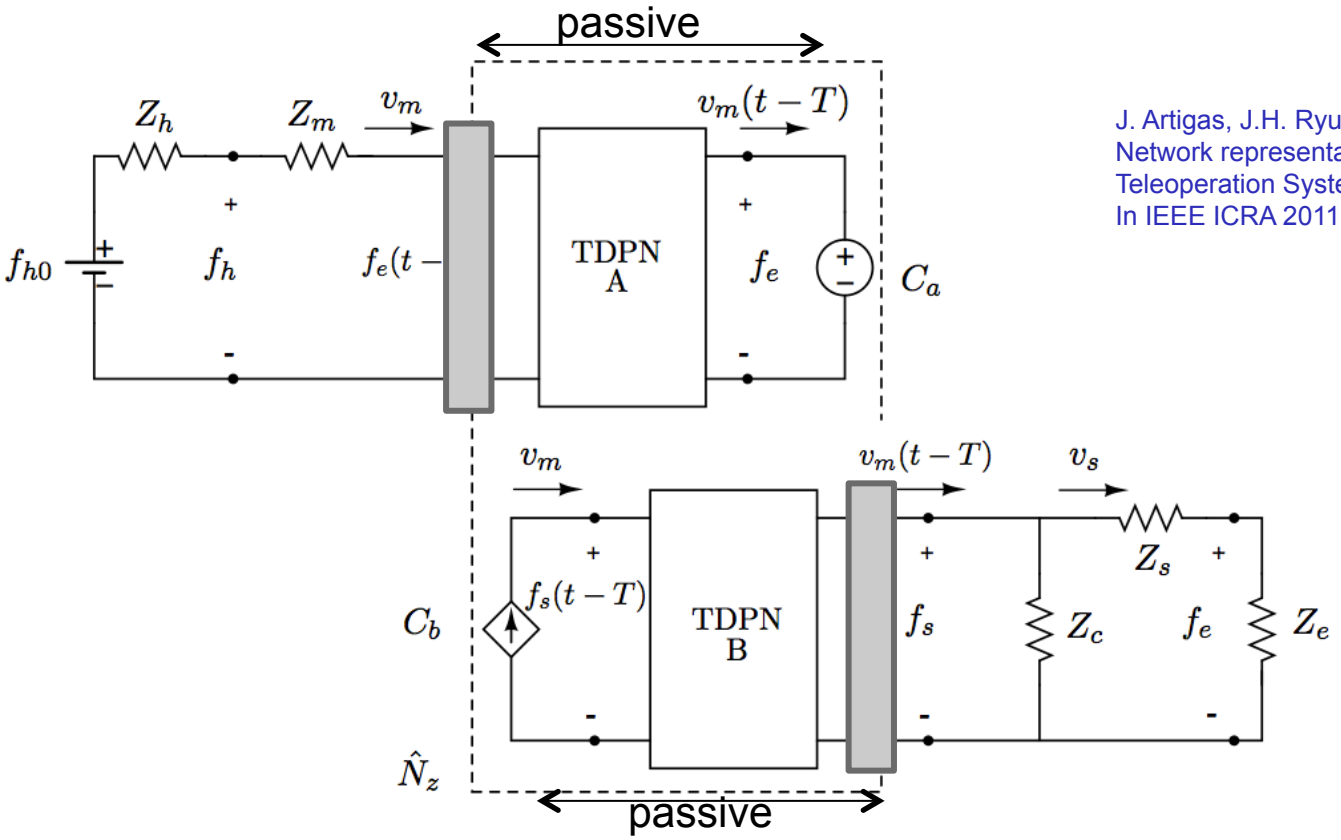
Energy transfer between Master and Slave (TDPNs)



Remarks:

- Signal flow is unmodified since original port variables remain untouched
- **The hidden TDPNs unveil the actual energy transfer**

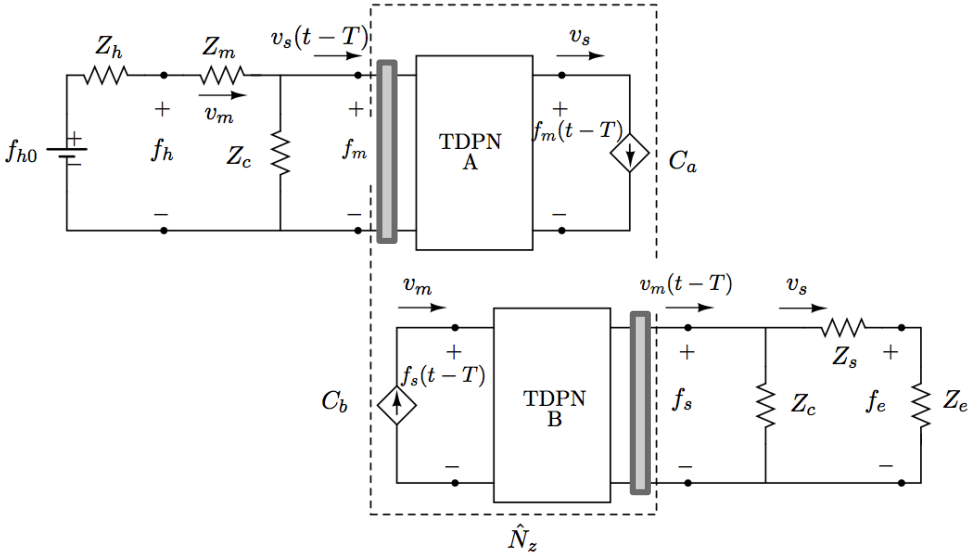
Passive TDPN based scheme



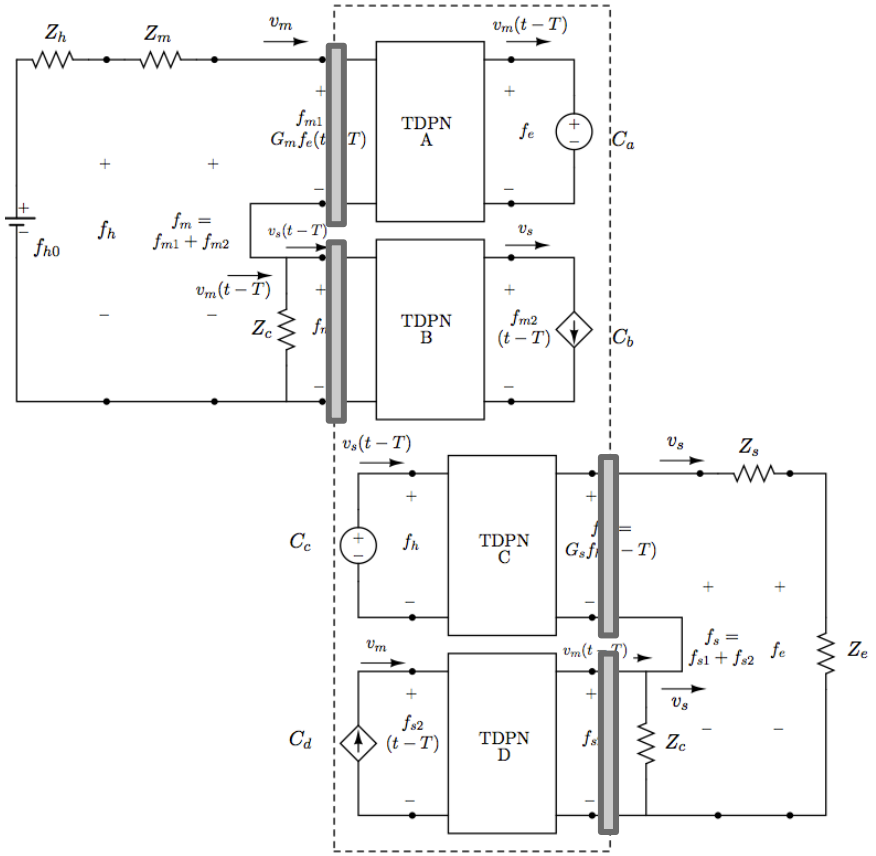
J. Artigas, J.H. Ryu, and C. Preusche.
Network representation and Passivity of Teleoperation Systems.
In IEEE ICRA 2011.

- In the TPDN representation, placing the passivity controllers is straightforward
- Robustness for arbitrary time delays and **package loss**

Generality

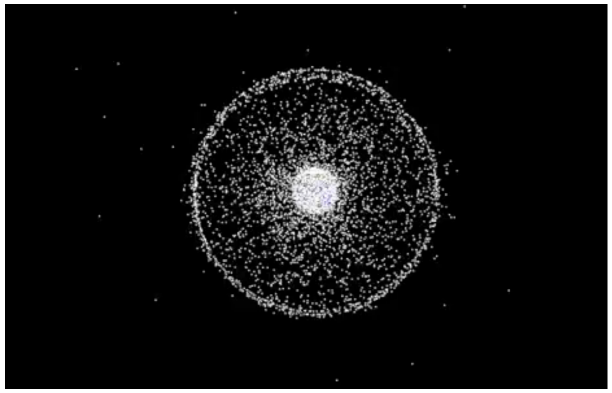


Position-Position

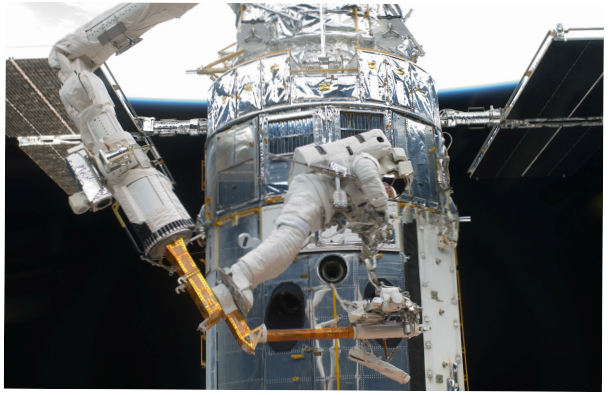


4 Channels

PART 2: Application Domains



Space Debris

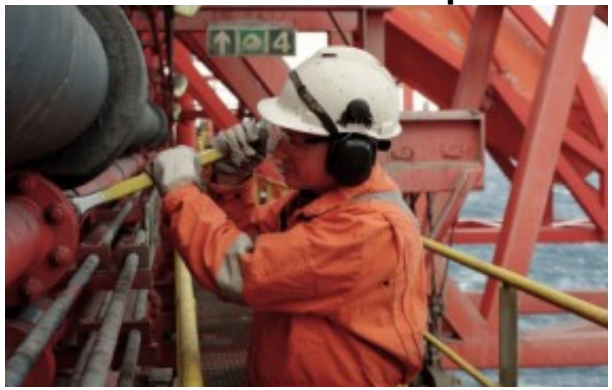


On-Orbit Servicing

Planetary Exploration

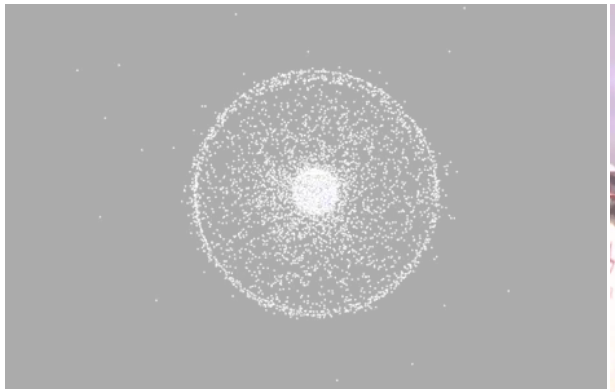
APPLICATION DOMAINS

Maintenance and Repair



Underwater

Health Care



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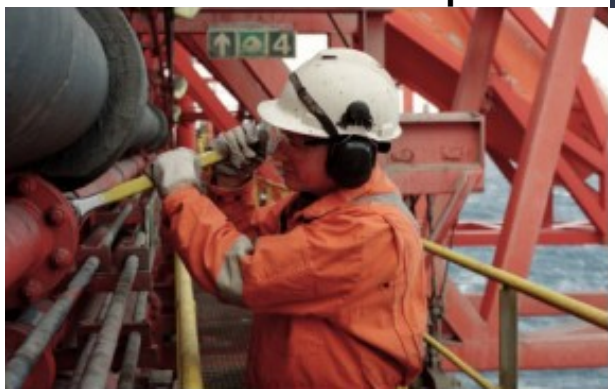
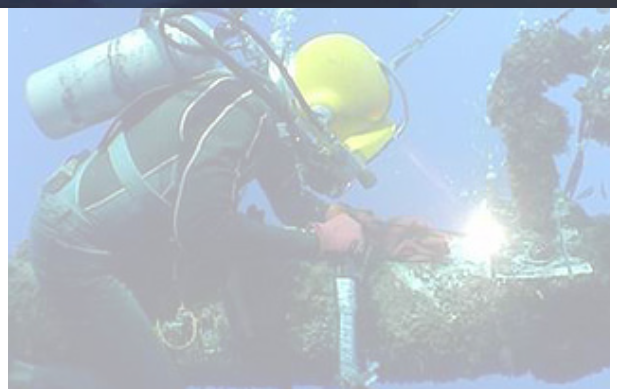
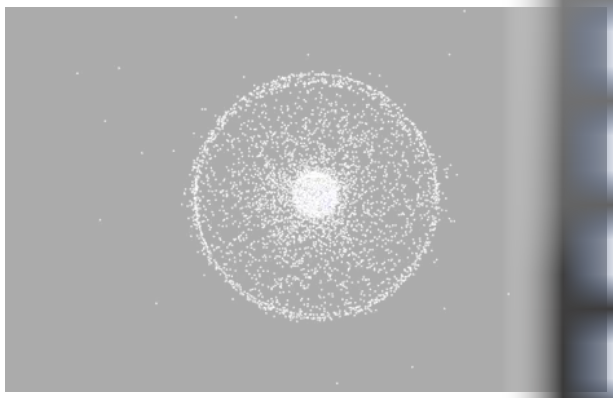
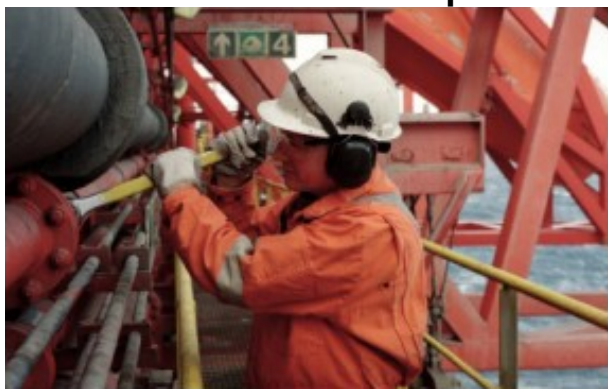
Maintenance and Repair

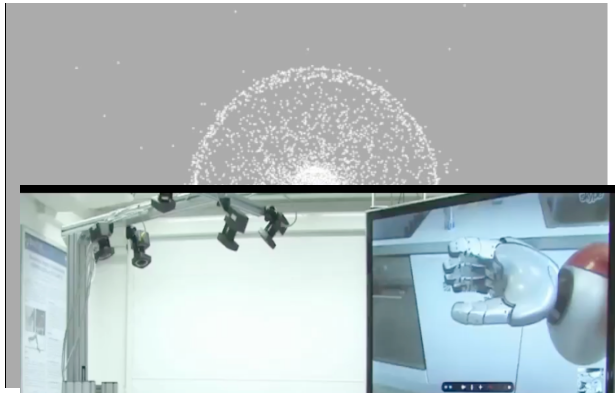


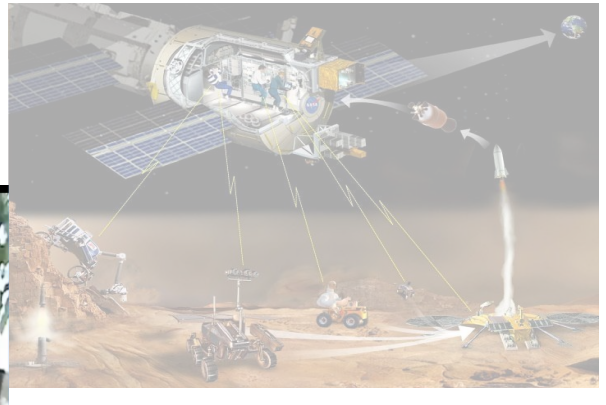




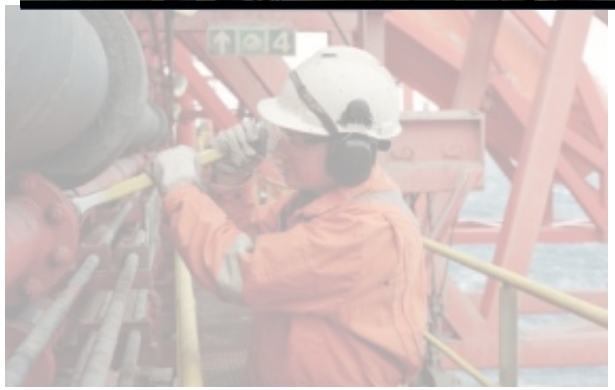
Maintenance and Repair

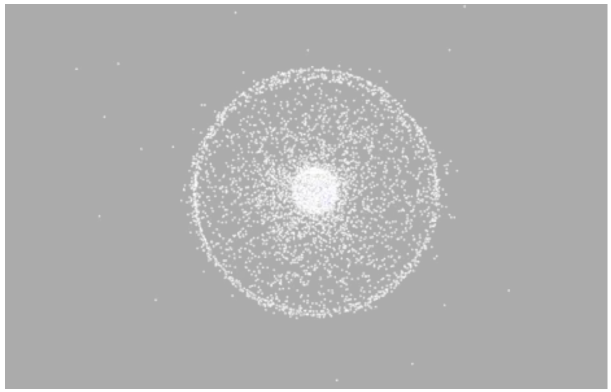


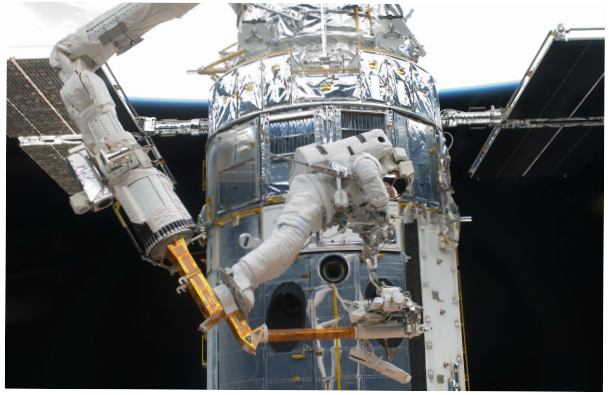


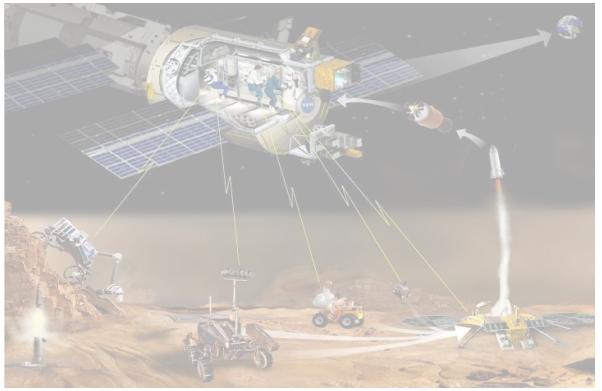


Health Care

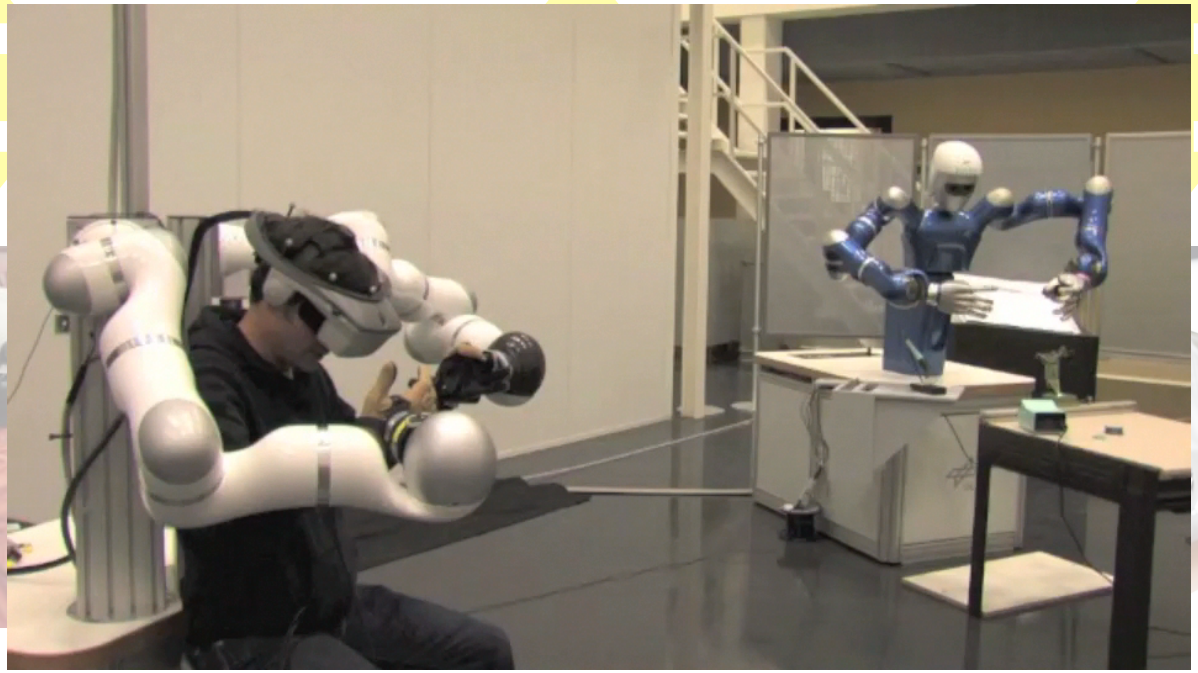


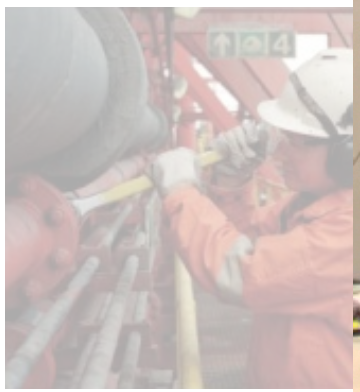


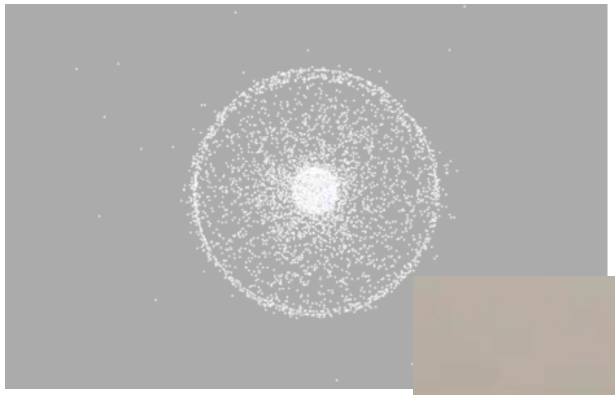
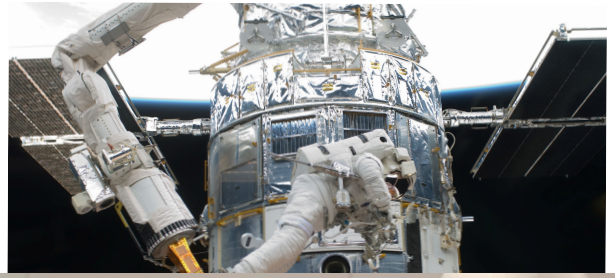
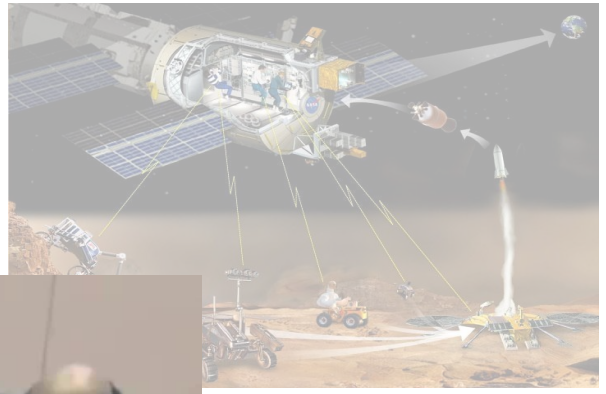
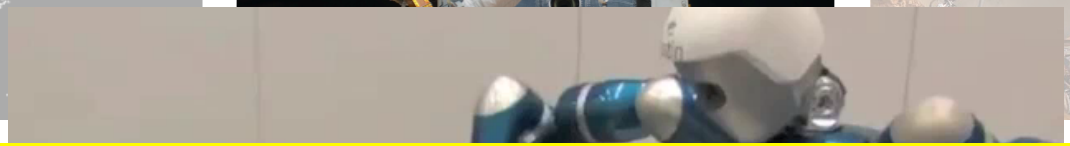




On-Orbit Servicing





With proper robotic technology and controllers, the human can achieve at least the same dexterity levels through the distance.



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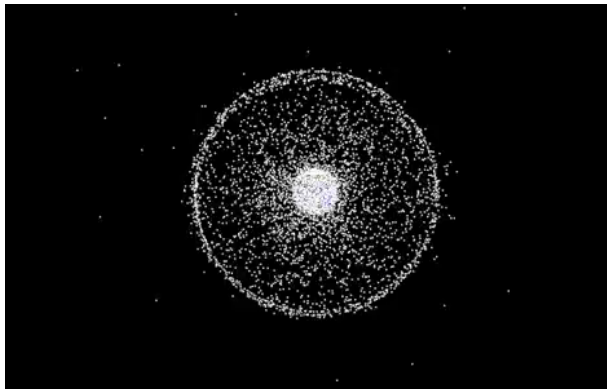
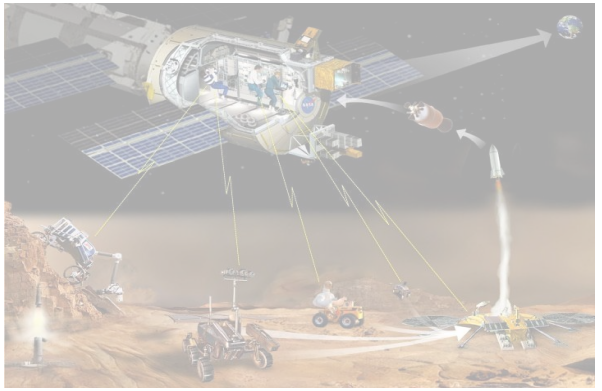
PART 3: What comes next?



Space Debris



APPLICATION DOMAINS

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Remarks

Mind the gaps!

From the User to the Environment

Explained in terms of energy flows

From the Lab to the Field

High technology readiness but still missing real world applications

Bonus!

"Satellite interaction with humanoid robots through force-feedback Teleoperation"

euRobotics Forum

Vienna, Austria
11-13 March 2015

The European Robotics Forum 2015 in Vienna, Austria, is the event you should not miss.

The sixth edition of European Robotics Forum will take place in Vienna, Austria from March 11-13, 2015.

This 3-day event, from **March 11-13, 2015**, is a meeting point for at least 350 scientists, companies and robotics officials from the European Commission. The program is designed to provide an opportunity for the companies and researchers to meet and interact in workshops and seminars in order to expand their networks, gather the latest relevant information, and build new business and collaborations thereby strengthening the potential of European robotics.

13 March 2015

	Plenary Room	Room 2	Room 3	Room 4
8h30 - 10h00	Robots as Helpers and Companions for Assisted Living	Networking & Communiaction for robots,	Mobile manipulation in manufacturing	Support for startups
10h00 - 10h45	Coffee Break			
10h45 - 12h15	Replicable robotics research and benchmarking	Model-Driven Knowledge Engineering	Robots in the laboratory	Market place for open innovation between European SMEs
12h15 - 14h00	Lunch break + Awards			
14h00 - 15h30	Health care in robotics	Towards new Robotics Software Markets for SMEs	Tactile Sensing - Down to Earth Lessons Learned from Research to Industry	Operator assisted mobile robtos For inspection of harsh
15h30 - 16h15	ERF Feedback discussion	Coffee Break		
16h15 - 17h45	Civil robotics networking	ROS Community Workshop	Inspection and Maintenance	New applications and opportunities in

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