RESEARCH ON FLUID POWER AND HEAVY MACHINERY IN LABORATORY OF INTELLIGENT MACHINES, LUT UNIVERSITY

Professor, D.Sc (Tech.) Heikki Handroos

LUT University

Two Campus University
7500 students
1000 staff members (400PhD students)
2 Engineering Faculties + Business School

- business and economics (176–200th)
- physical sciences (201–250th)
- engineering (251–300th)
- computer science (301–400th)

Among the world’s top universities

10

The world’s top 10 university in climate action (THE Impact Rankings, SDG 13)

11

LUT Business School is the world's second best in research quality (THE World University Rankings by subject)

40

Among the world’s top 40 in partnerships for the goals (THE Impact Rankings, SDG 17)

Technology →

Business →

Social Sciences →

BIOGRAPHY HEIKKI HANDROOS

- Prof. of Machine Automation and Head of Laboratory of Intelligent Machines since 1993.
- His research interests range from modeling, simulation and control of mechatronic systems to robotics, hybrid transmission and mobile machinery
- He has published about 300 scientific journal and conference papers in the field of mechatronics
- Supervised/co-supervised 38 Doctoral Dissertations (Lab total 40) and more than 200 M.Sc theses
- Has been responsible leader of academic and industrial R&D projects (tot. > 20M€)
- Co-founder of MeVEA Oy, Haptronics Oy, ThT Robotics Oy and Flowgait Oy
- Visiting Professor in University of Minnesota, National Defense Academy (Japan) and Peter the Great St Petersburg Polytechnic Univeristy
- Several Duties of Trust in ASME, IEEE and GFPS (FPNI)

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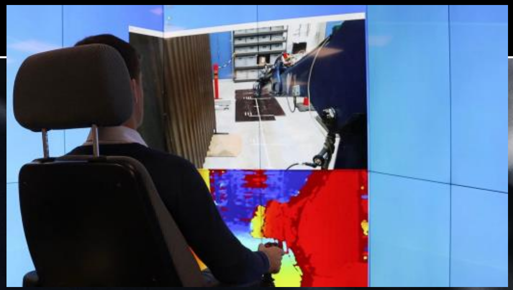
LABORATORY OF INTELLIGENT MACHINES – MOST IMPORTANT RESEARCH IMPACTS

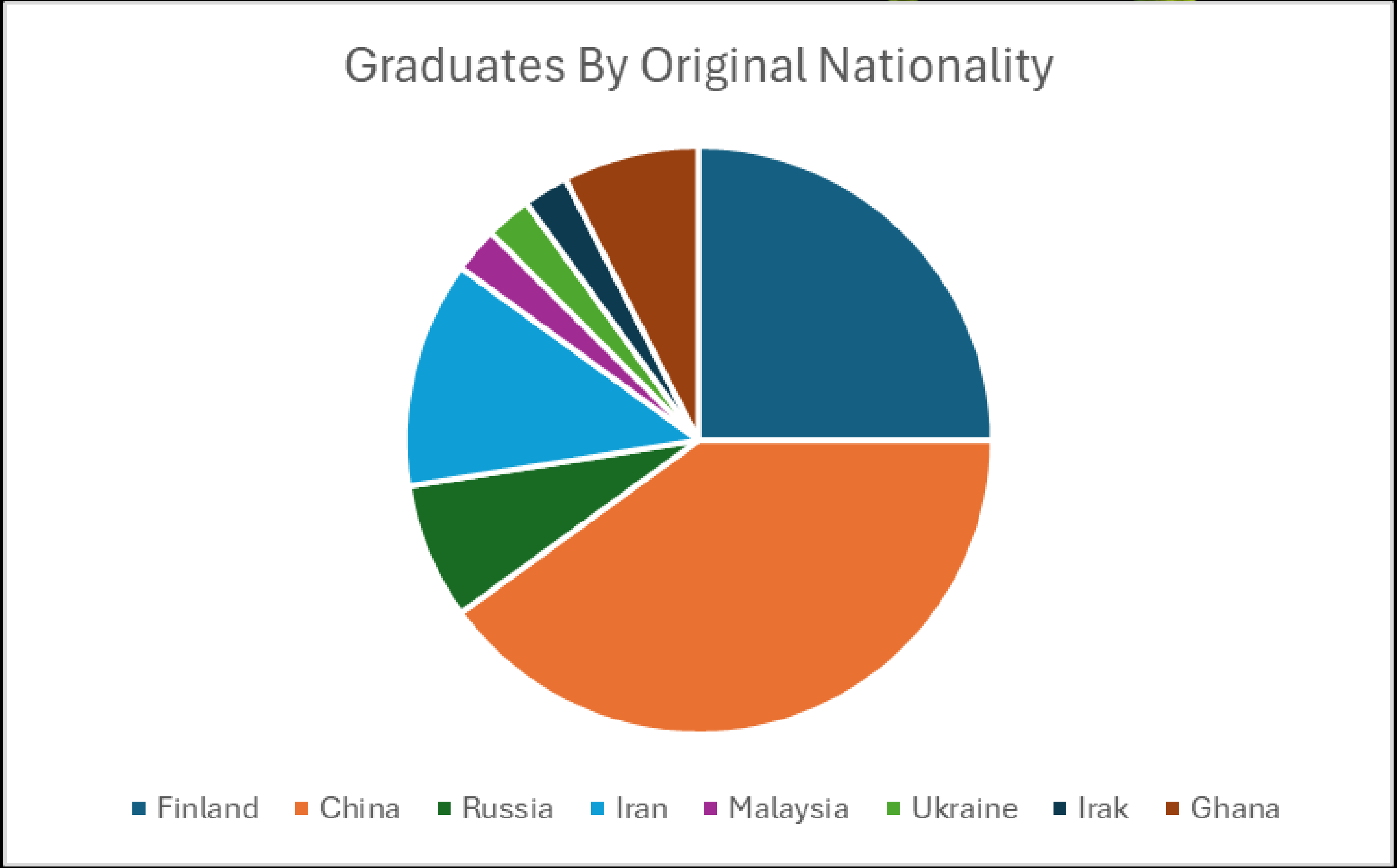
- Advance Modelling and Simulation methods for Mechatronic Systems
- Advanced Robotics technologies with Special Reference to Nuclear and Hazardous Environments (more than 20 years in EUROFusion programs)
- More than 300 scientific publications and 40 doctoral dissertations (end of 2024)
- Spin-offs
  - Mevea Oy (Training & R&D simulators)
  - THT Robotics (Robotic Handling for Web-Grocery)
  - Flowgait Oy (Horseback Riding Simulators)
  - Haptronics Oy (Haptic Interfaces for Heavy Machinery)



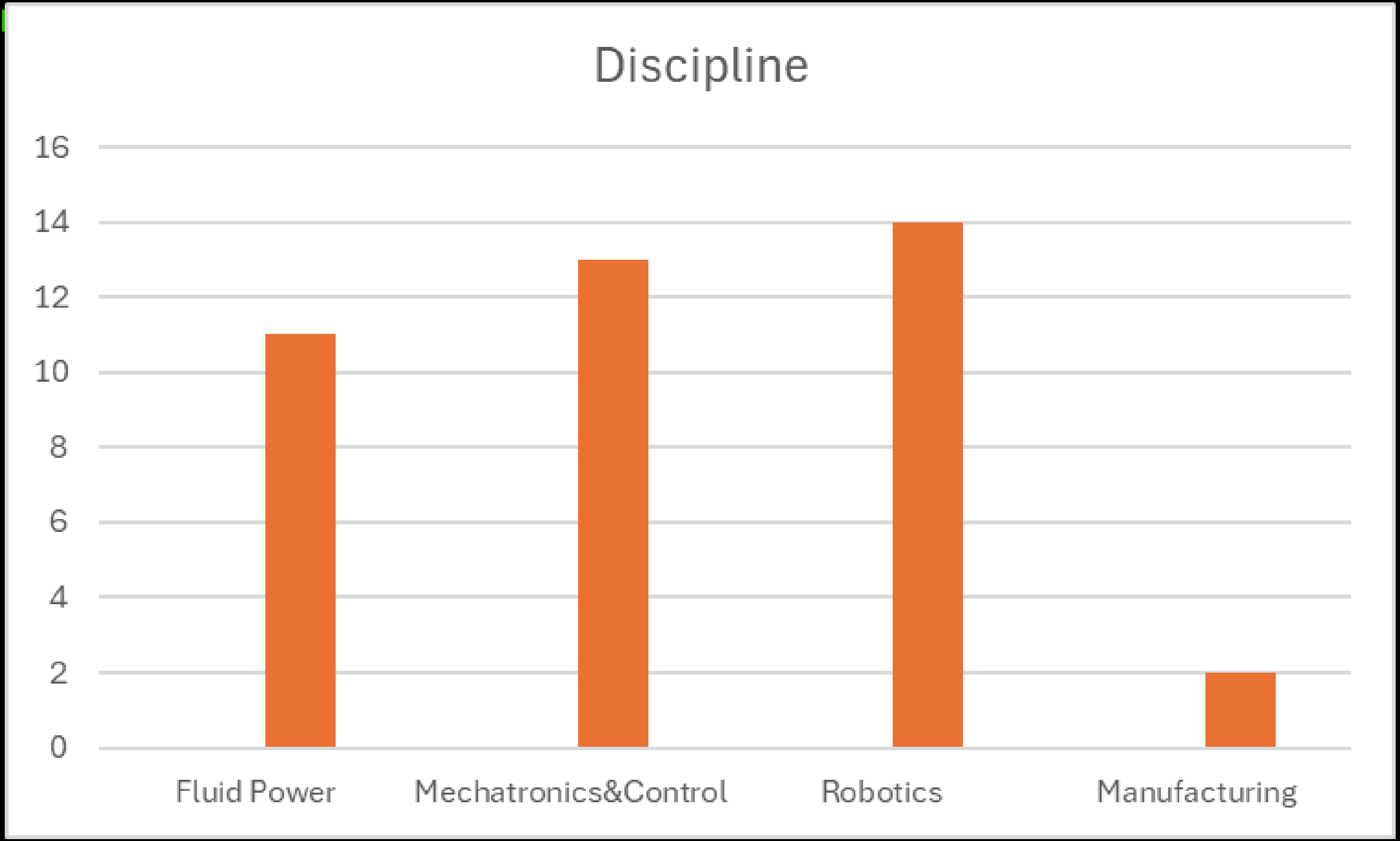
LIM PERSONNEL 12/2024

1 professor 2 associate professors, 3 post docs, 7Ph.D students + 5 research assistants

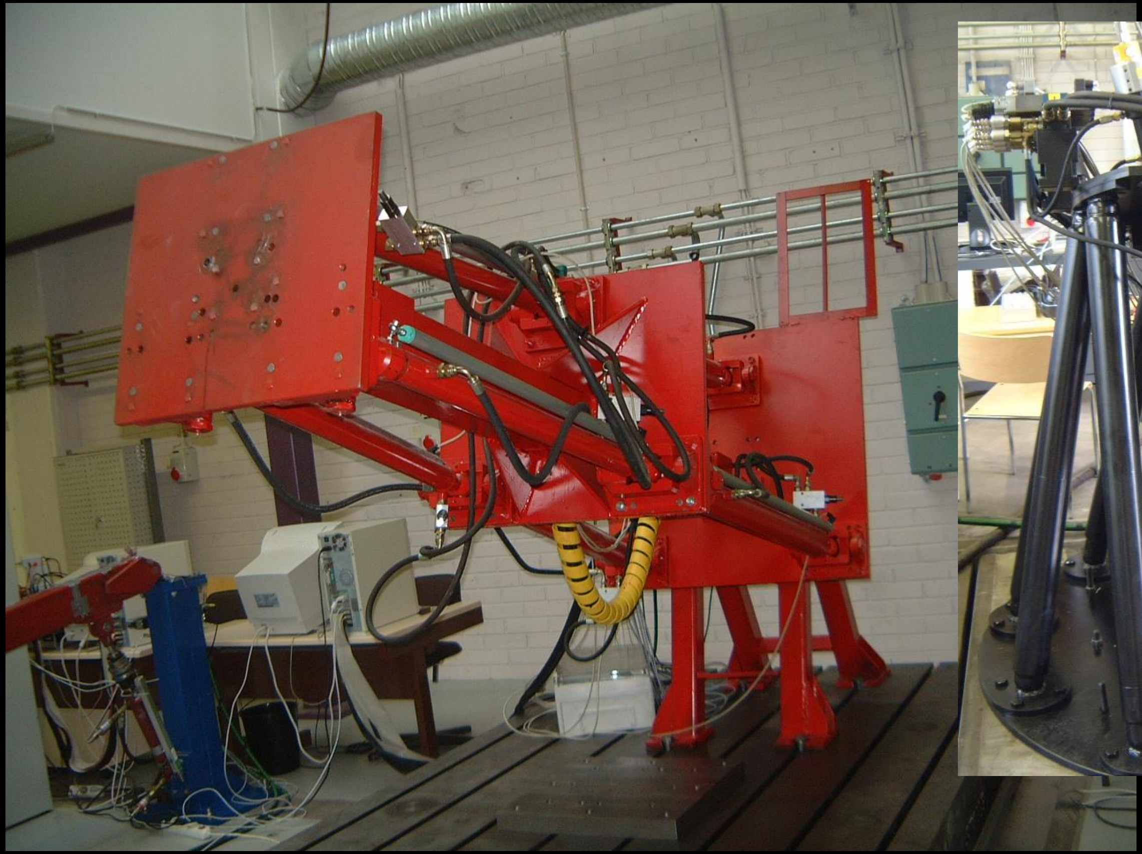
STATISTICS OF 40 PHD'S GRADUATED

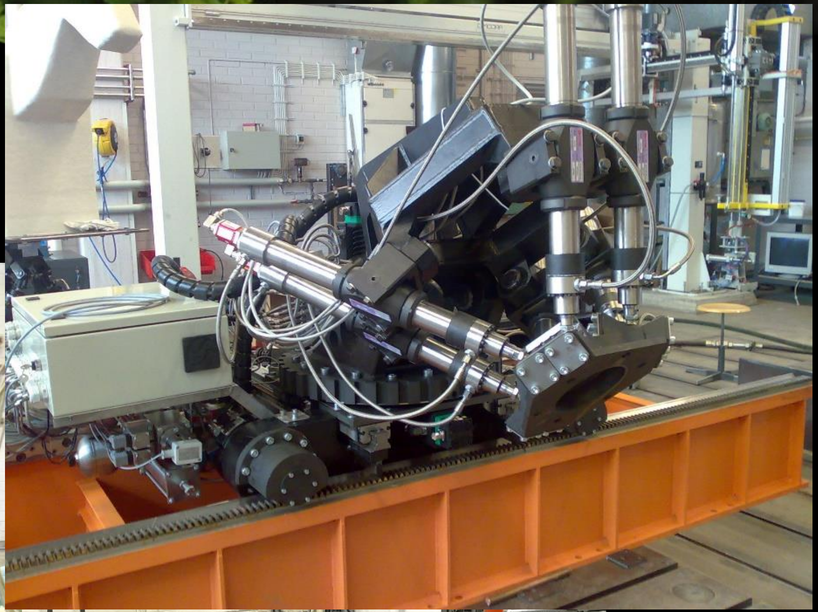


STATISTICS OF PHD'S GRADUATED



RESEARCH IN HEAVY DUTY PARALLEL ROBOTICS



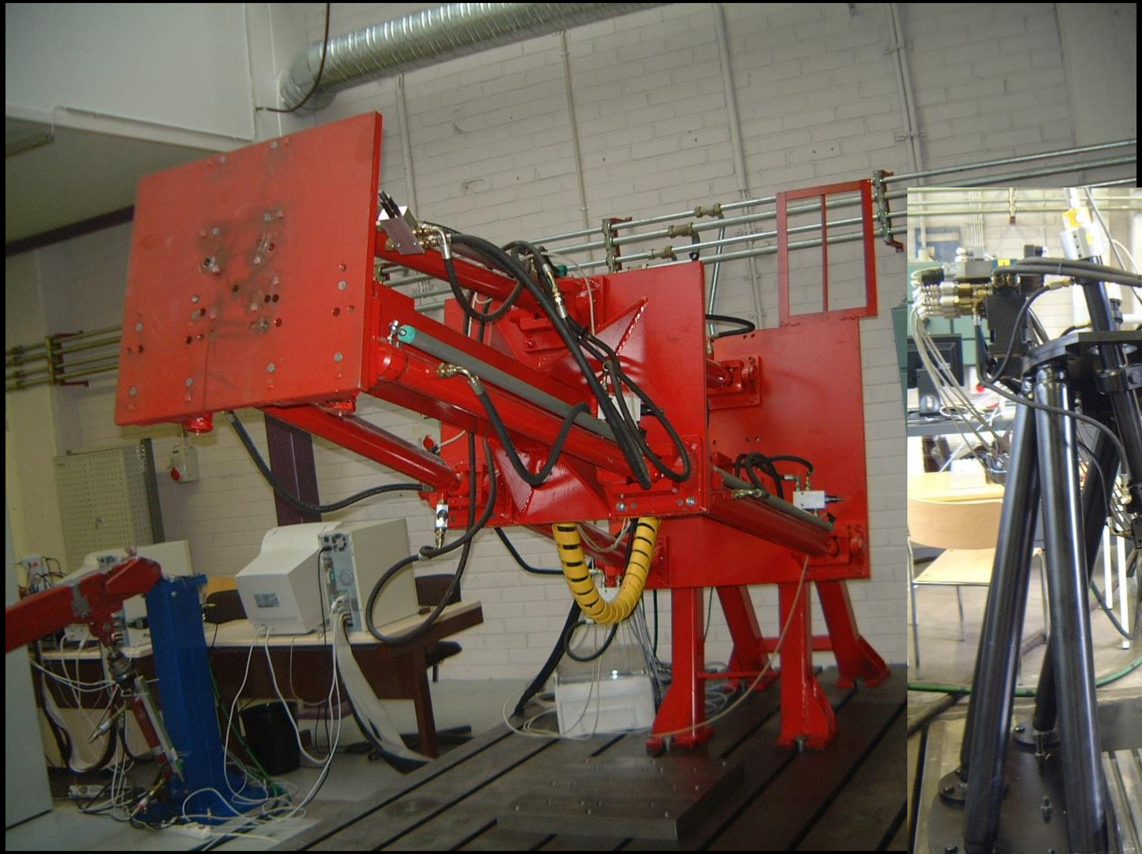


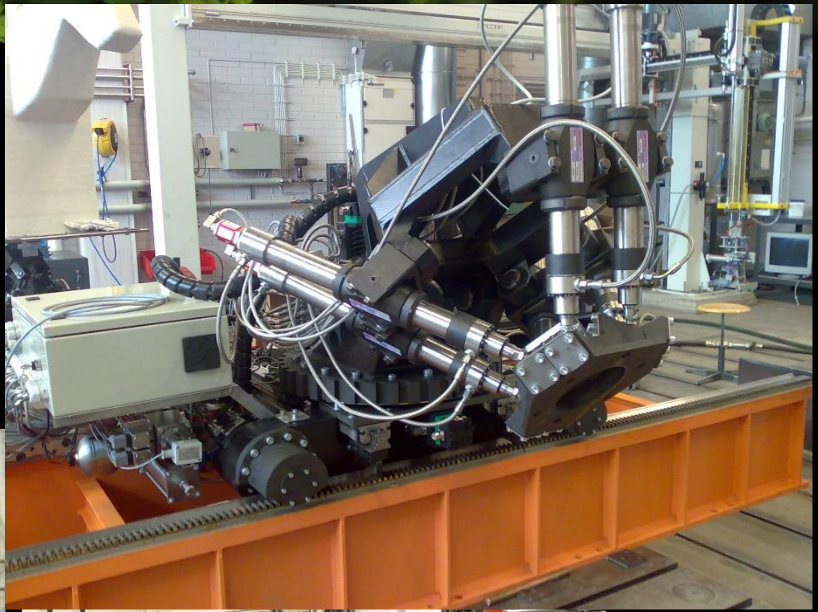
PARALLEL KINEMATIC MOTION PLATFORMS

HYDRAULIC

ELECTRIC

RESEARCH IN HEAVY DUTY PARALLEL ROBOTICS





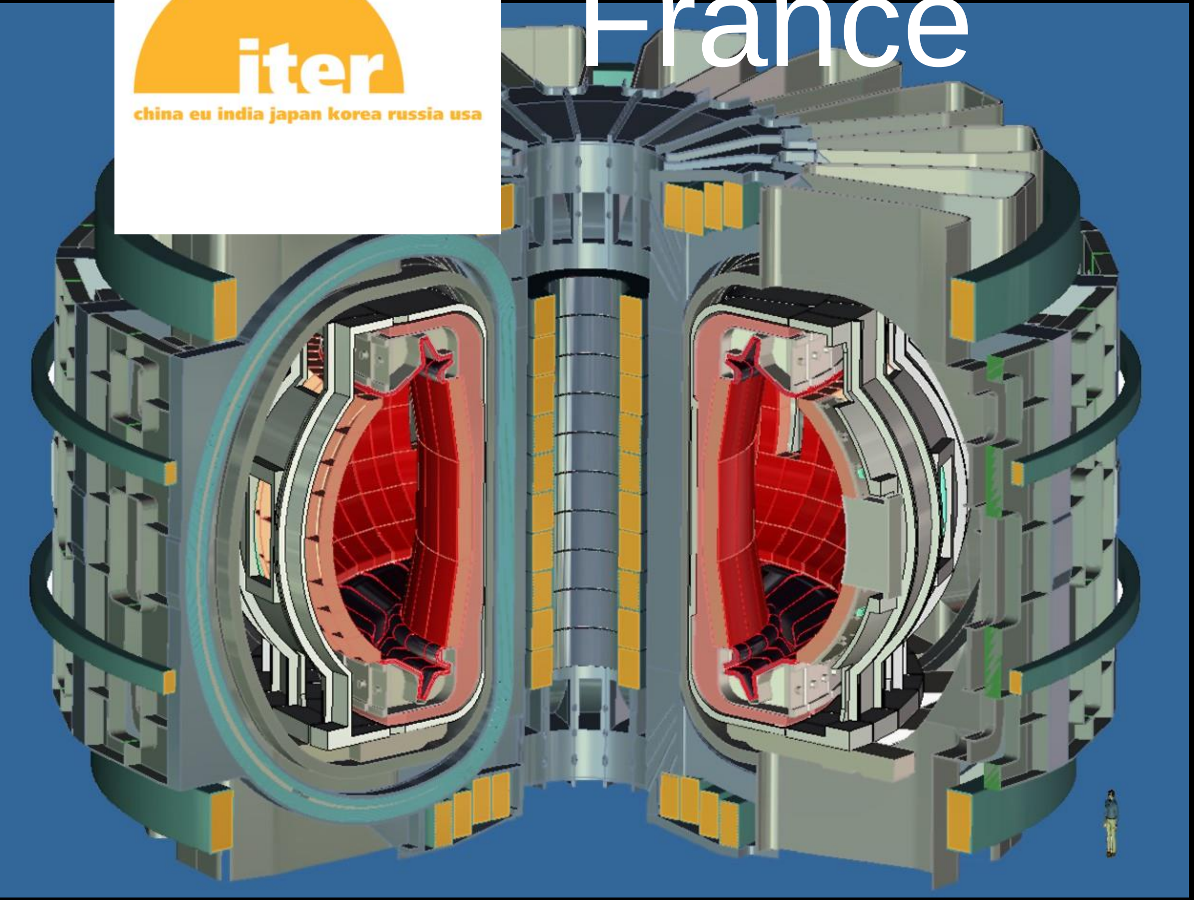

TOKAMAK EXPERIMENTS

EUROfusion

LUT University

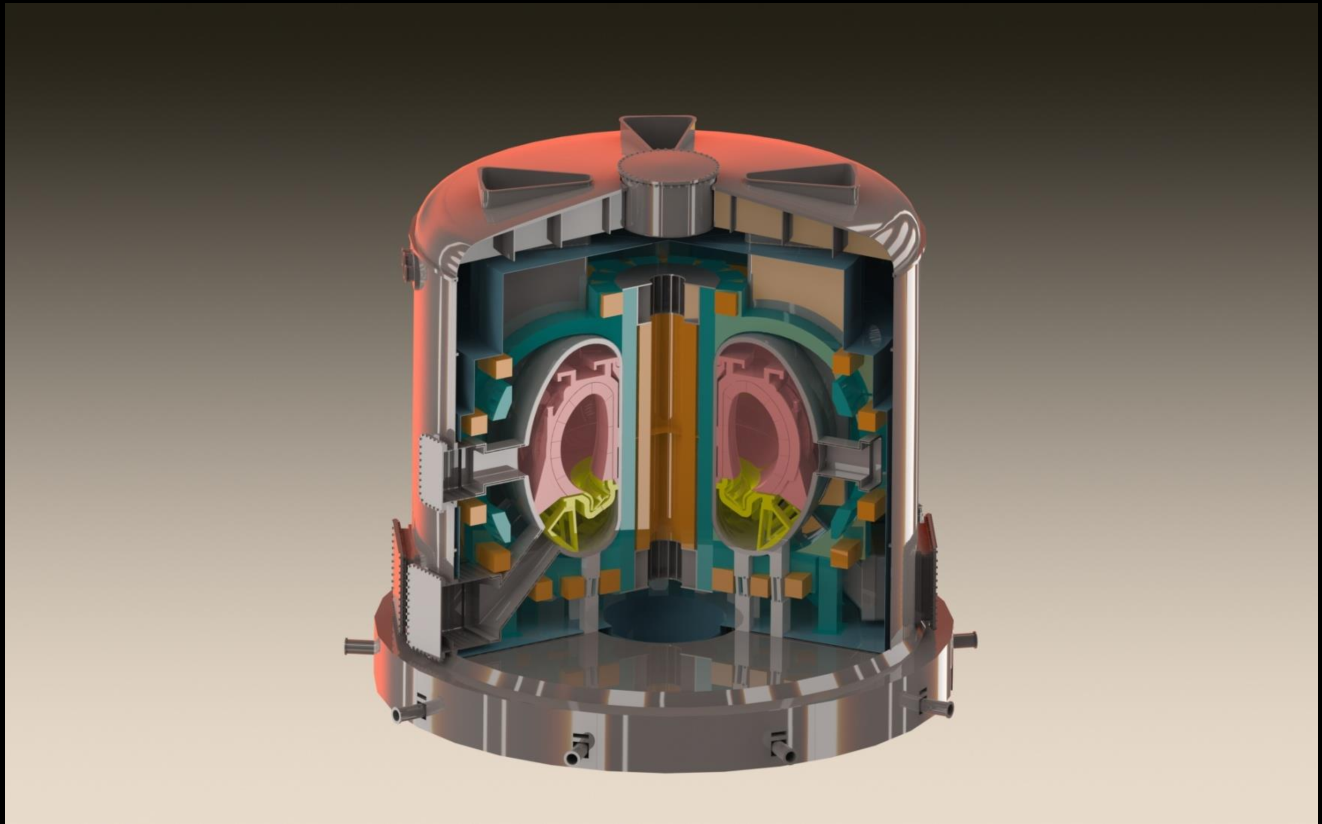
iter
china eu india japan korea russia usa

Cadarache, France

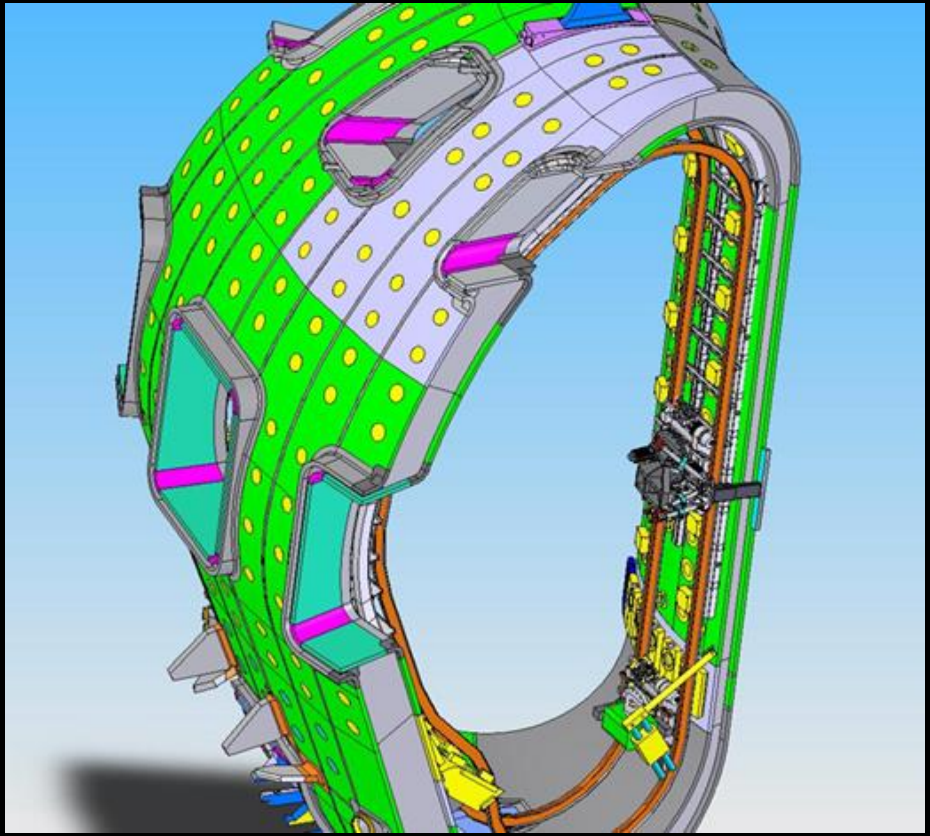


Institute Of Plasma Physics
Chinese Academy Of Sciences

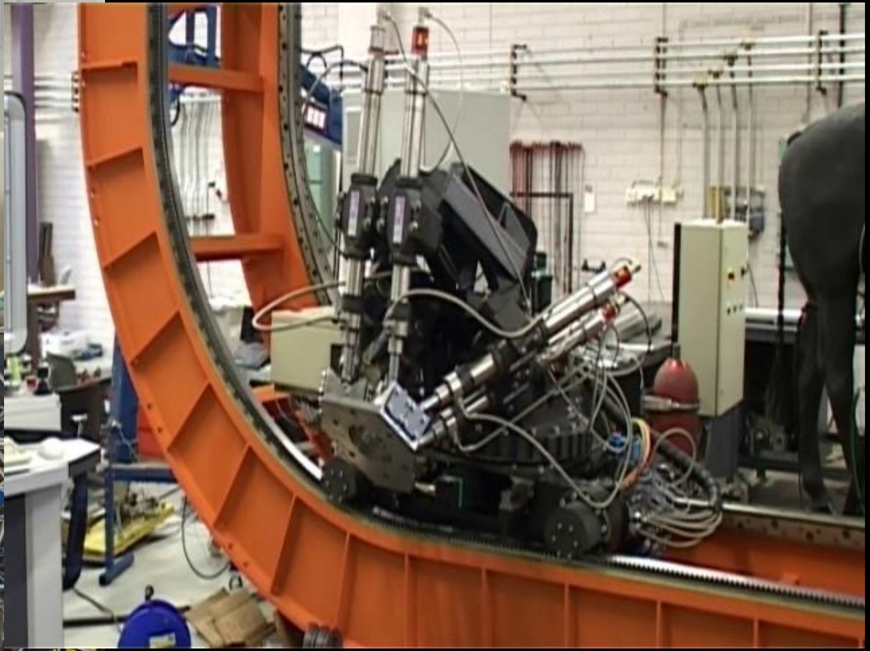
CFETR, Hefei



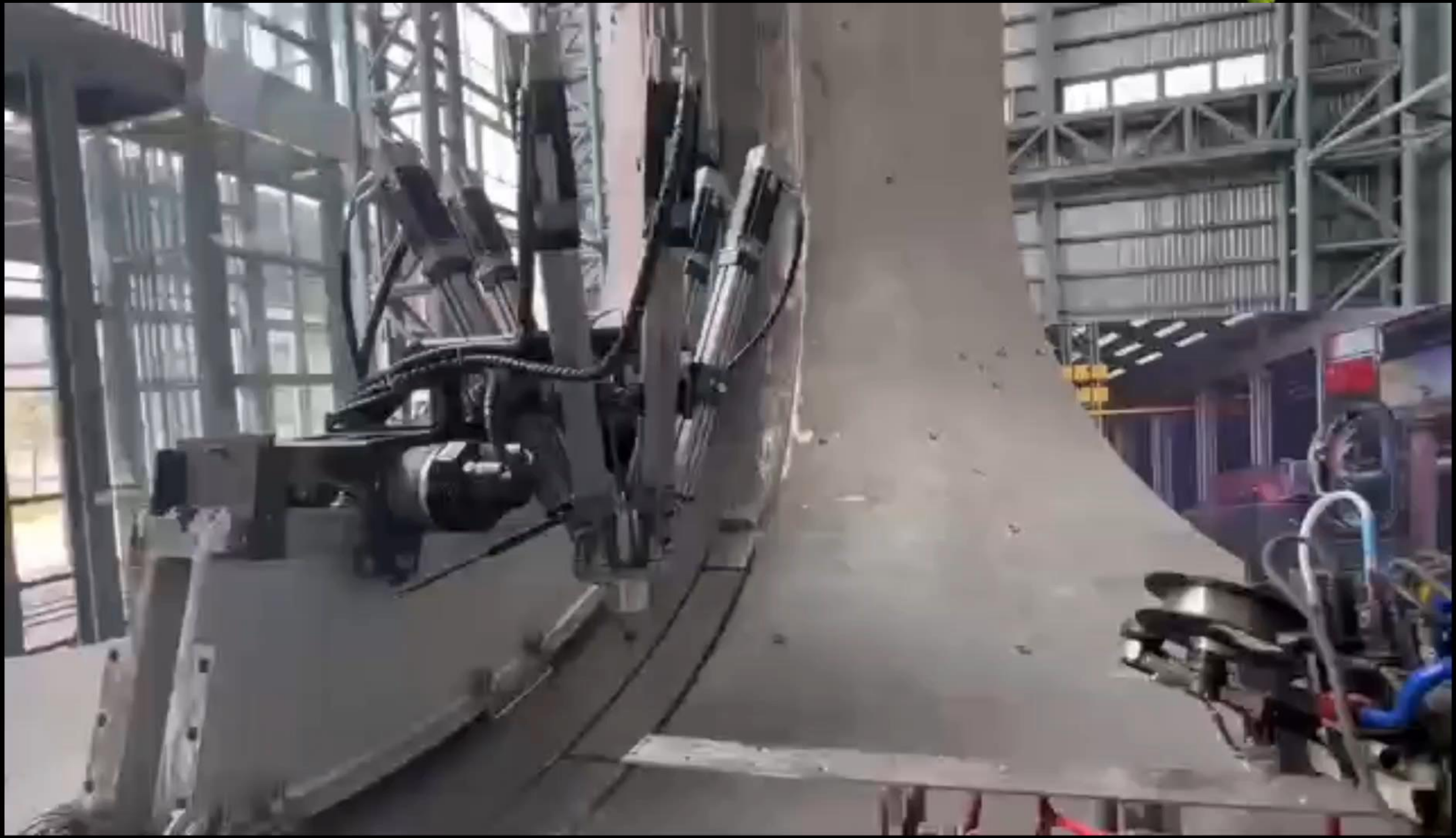
1. OILHYDRAULIC PROTOTYPE OF INTERSECTOR WELD/CUT ROBOT



2. 10-AXIS WATERHYDRAULIC PROTOTYPE



3. 10-AXIS ELECTRICALLY ACTUATED IWR



RESEARCH ON MODELLING, IDENTIFICATION, OBSERVATION AND CONTROL OF HYDRAULIC SERVOSYSTEMS

- Robust control (Sliding Mode, Backstepping)
- Identification (Differential Evolution, Monte Carlo Markov Chain)
- Observation (Extended and uncentered Kalman Filters, Particle Filters)
- Fuzzy and neural control
- Tuning of controllers by AI

RESEARCH ON MORE ELECTRIC TRANSMISSION

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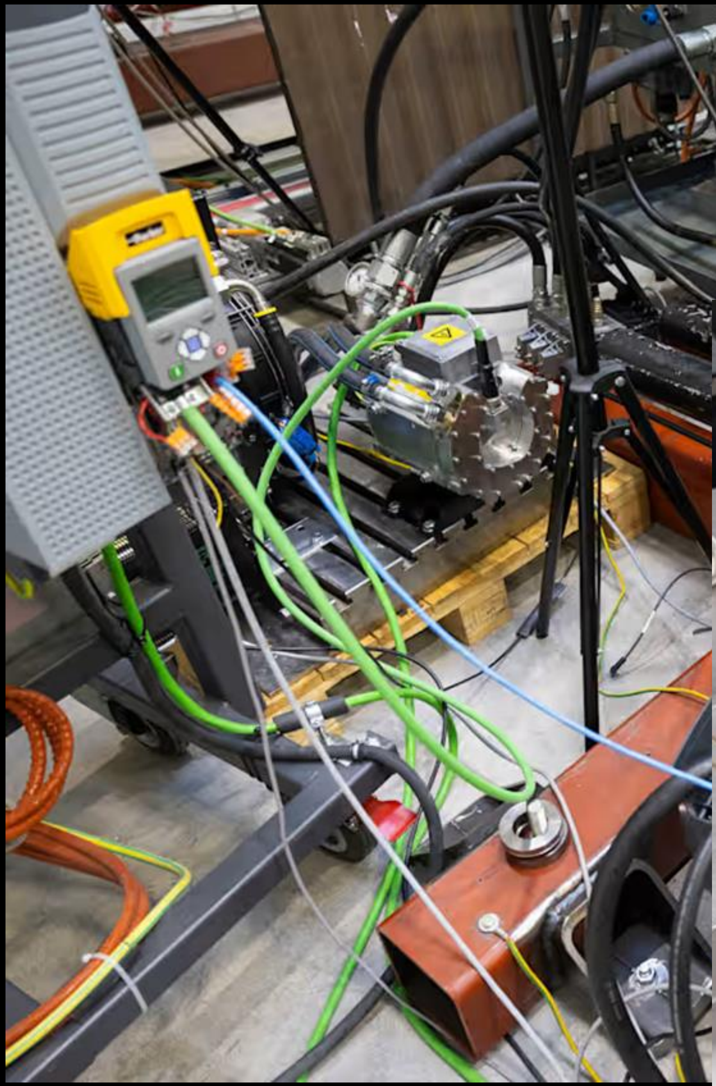

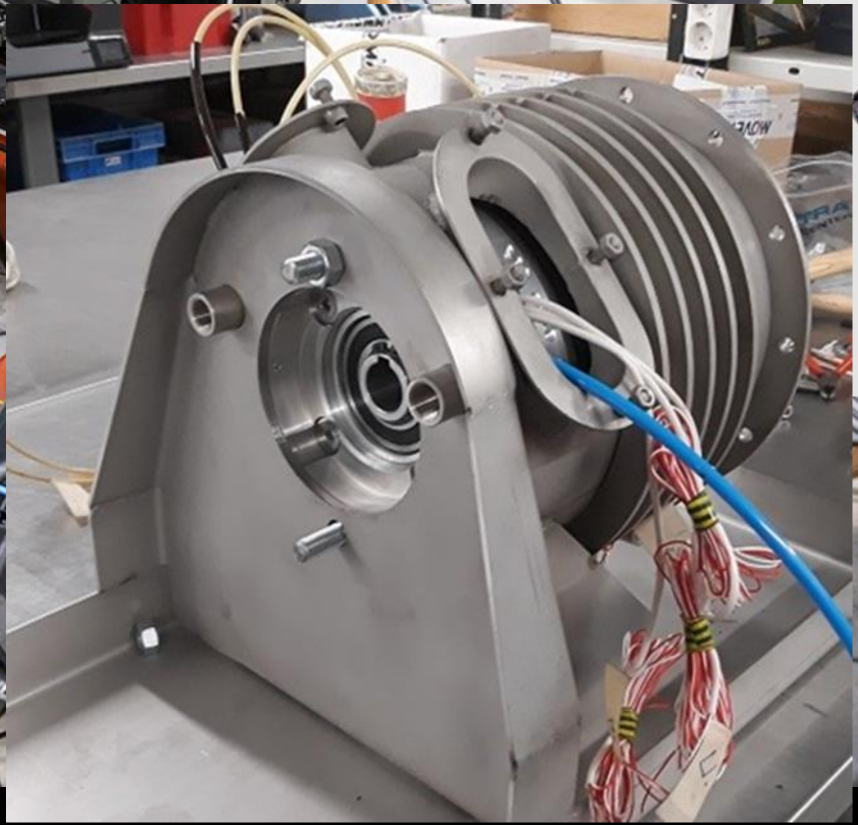

INTEGRATED ELECTRO-HYDRAULIC ENERGY CONVERTERS – LUT IEHEC

- Supply hydraulic circuit with hydraulic power
- Energy regeneration (hydraulic energy → electrical energy)
- Maximum efficiency up to 90 %. Inverter efficiency is not included.

Parameter	**Value**
Output power	30 kW
Flow rate	100 lpm
Speed max	3000 rpm
Pressure max	380 bar
Weight	110 kg

INTEGRATED ELECTRO-HYDRAULIC ENERGY CONVERTERS – LUT COMEHEC

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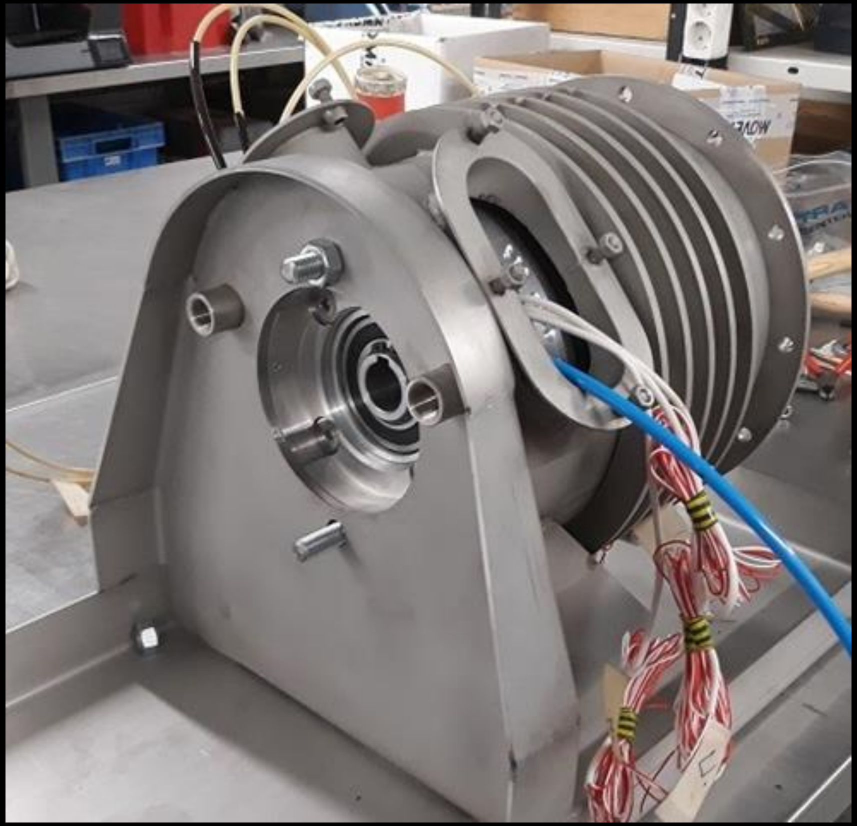
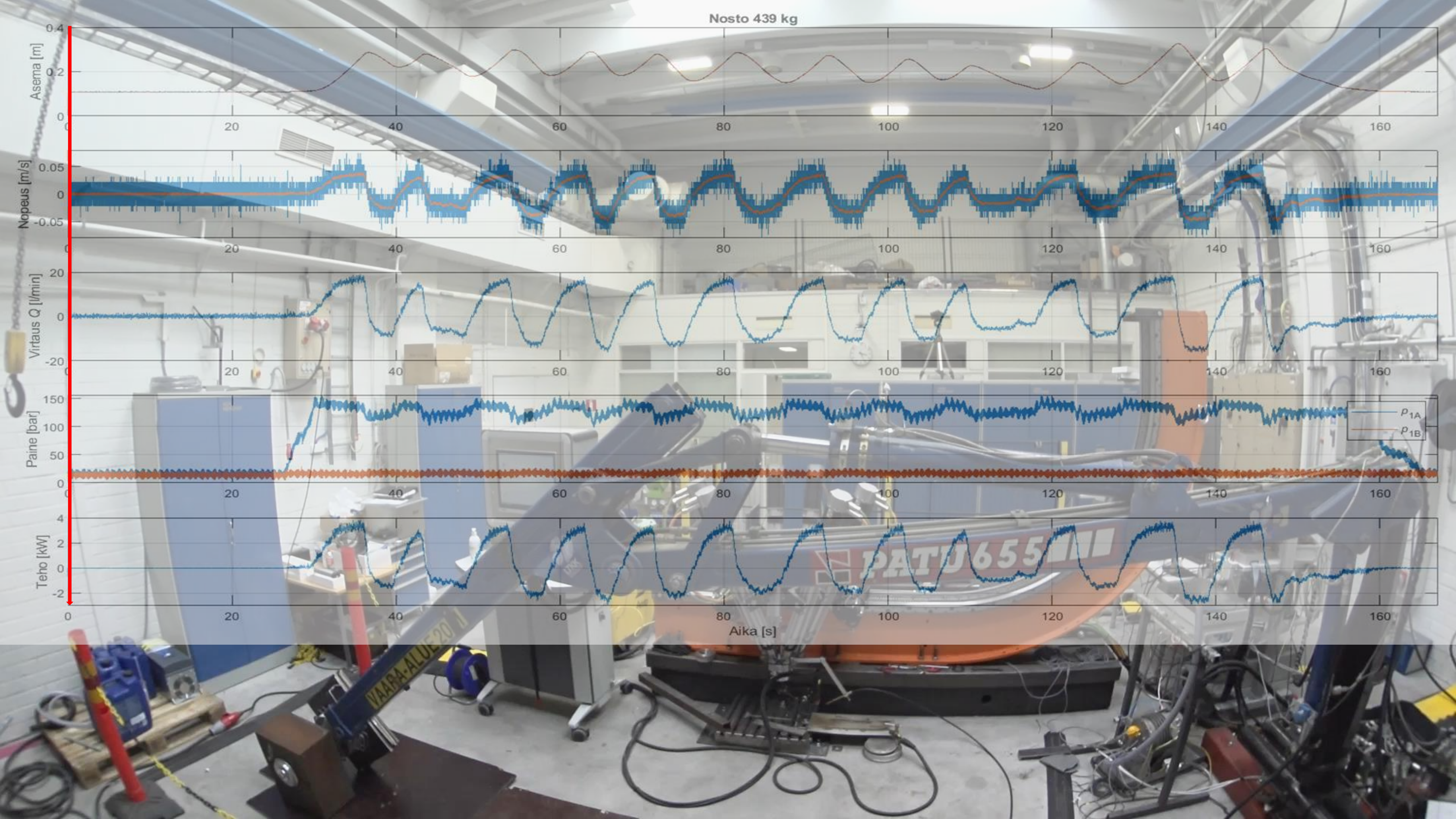
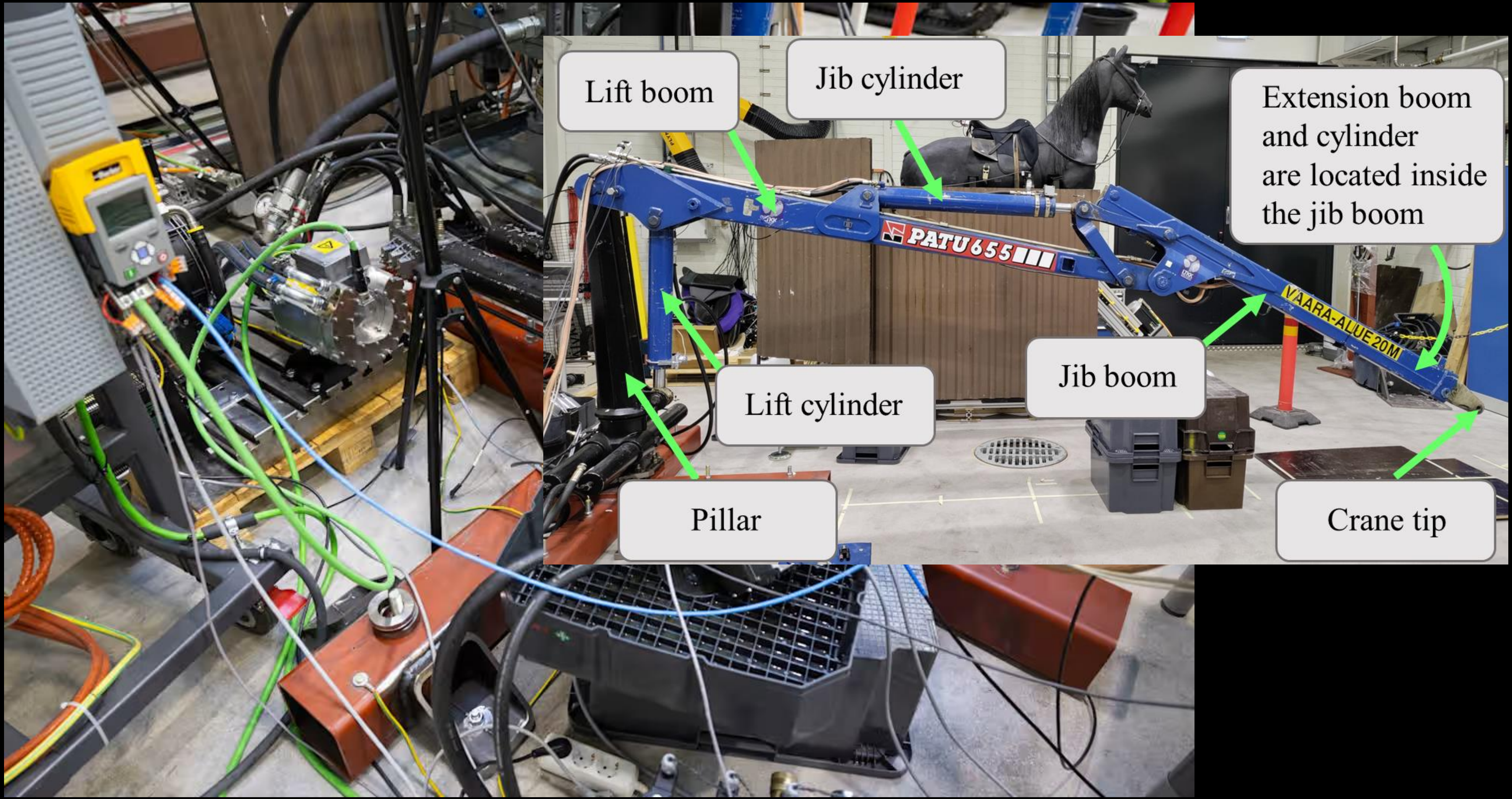


Nominal pressure, bar	200
Hydraulic machine displacement cm3/rev	19
Nominal flow rated, l/min	34.2
Hydraulic machine speed, n r/min	2000
Hydraulic machine rated power	7 kW (1000 r/min)
Hydraulic machine type	Fixed displacement bent axis motor/pump
Rated hydraulic machine Torque, TN	68 Nm
Gear ratio	1:3
Gear efficiency estimate	0.95
Electric motor power	7 kW, S3 70 %
Electric motor speed range	0 – 6000 r/min
Electric motor type	24-20 tooth-coil PMSM
Pole pair number, p	10
Electric motor max speed nNmax, r/min	6000
Rated line-to-line voltage U	300 V @ 3000 r/min 400 V in field weakn.

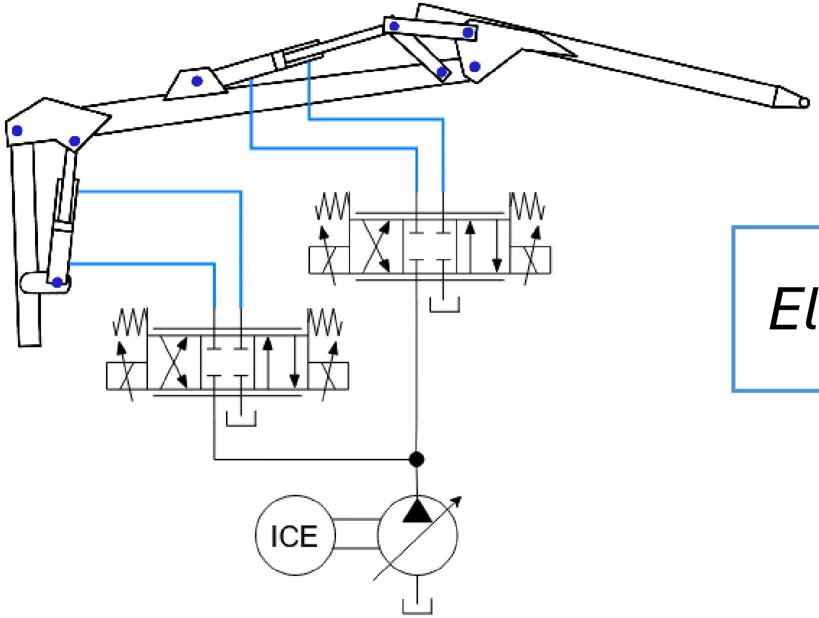


Nosto 439 kg
Asema [m]
Nopeus [m/s]
Virtaus Q [l/min]
Paine [bar]
Teho [kW]
Aika [s]
p_{1A}
p_{1B}
PATU655
VAARA-ALUE 20

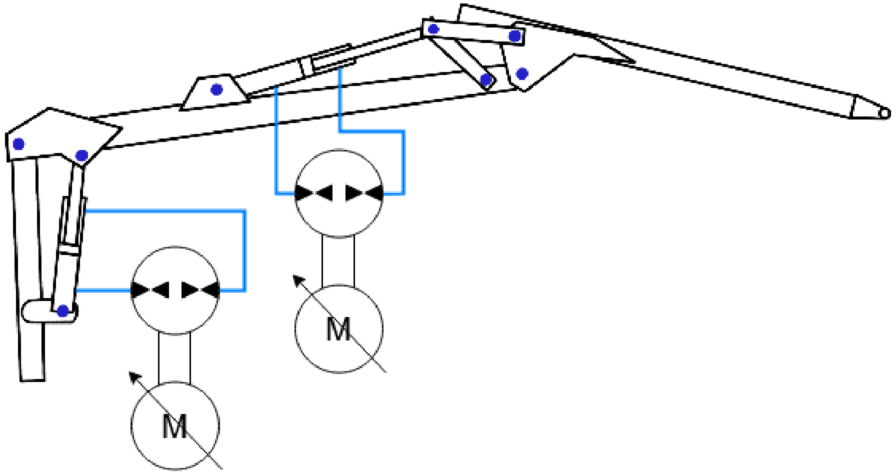
Electro-hydraulic Actuator (Parker) under test



Electrification is the key, but



Electrification



Conventional hydraulic system
~35% efficiency

Electro-hydraulic system
~80% efficiency

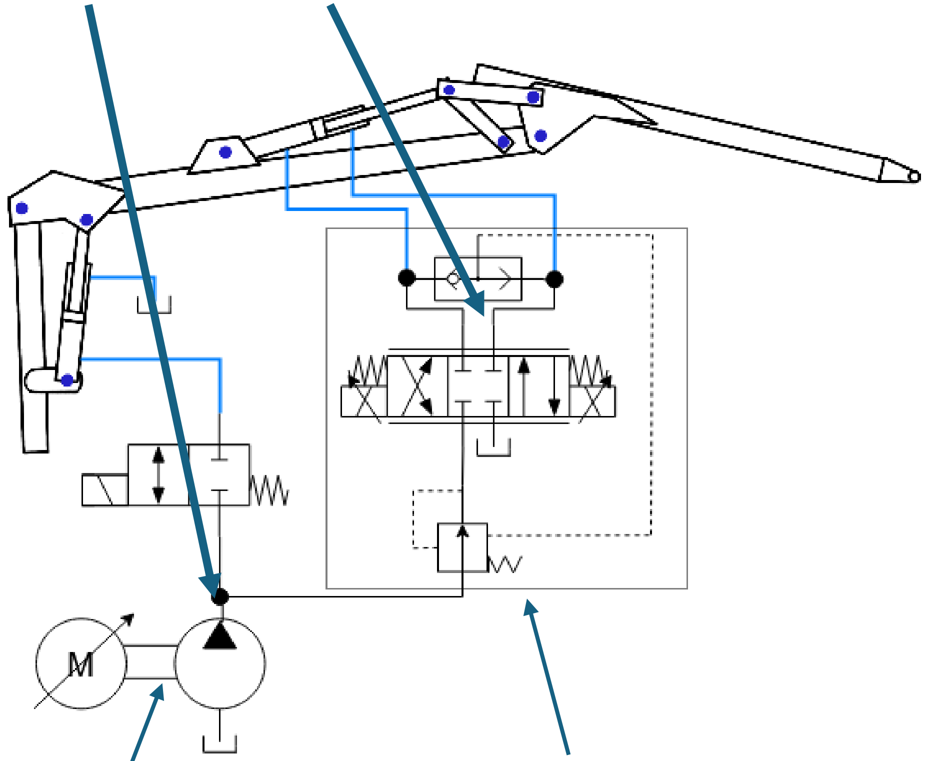
Up to 8 actuators → Up to 8 pump-motor units

Costly and massive. How to optimize it?

Solution 1: Valveless actuation of the lift cylinder

Limitation:

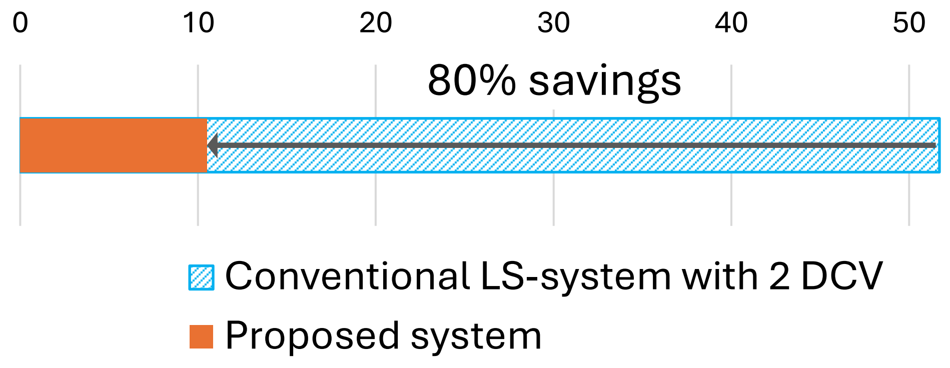
Ps > Ptilt



Pressure-compensated DCV

EHA

Energy consumption, kJ



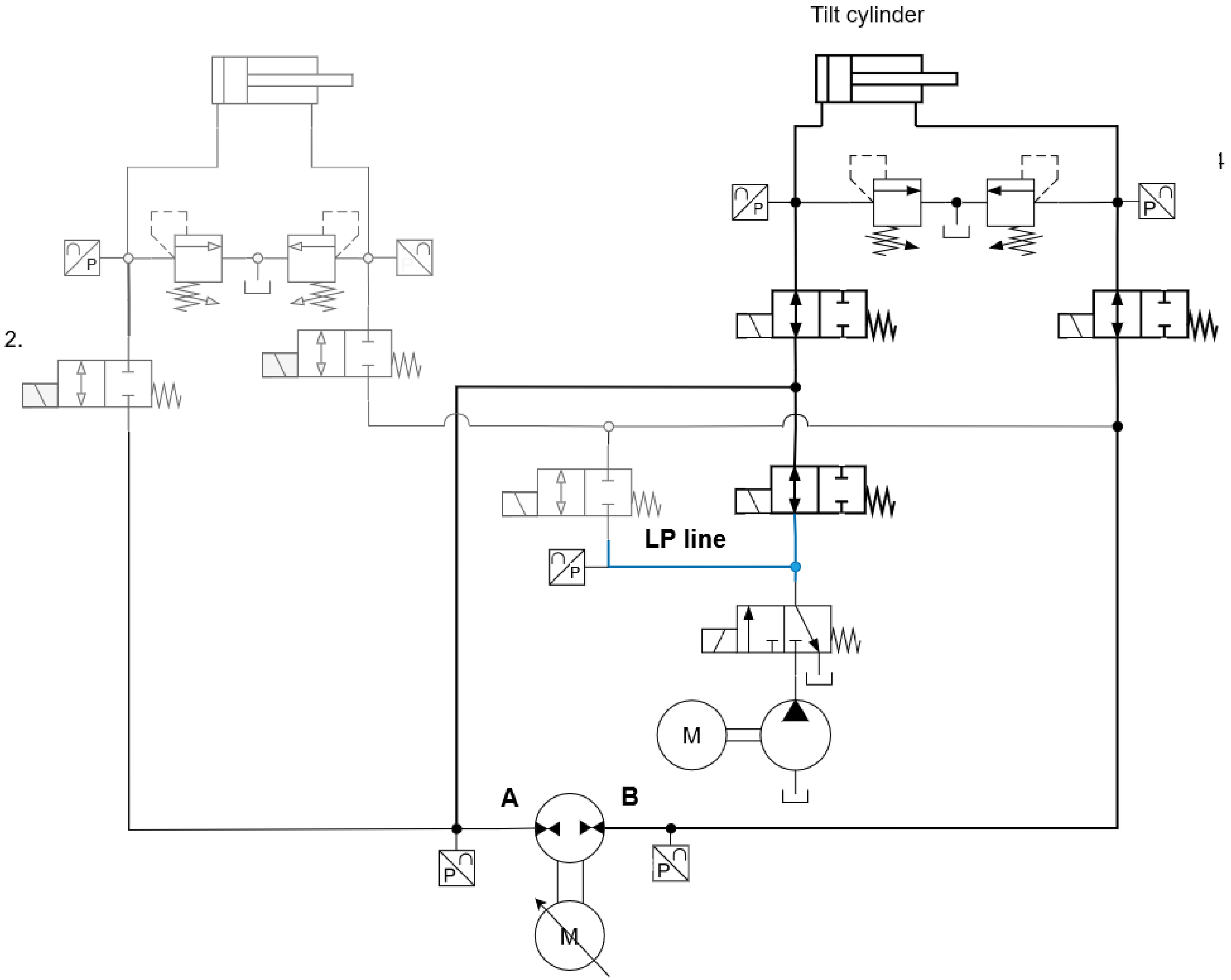
Advantages:

- Simplicity
- Compactness
- High efficiency
- Recuperation capabilities

Disadvantages:

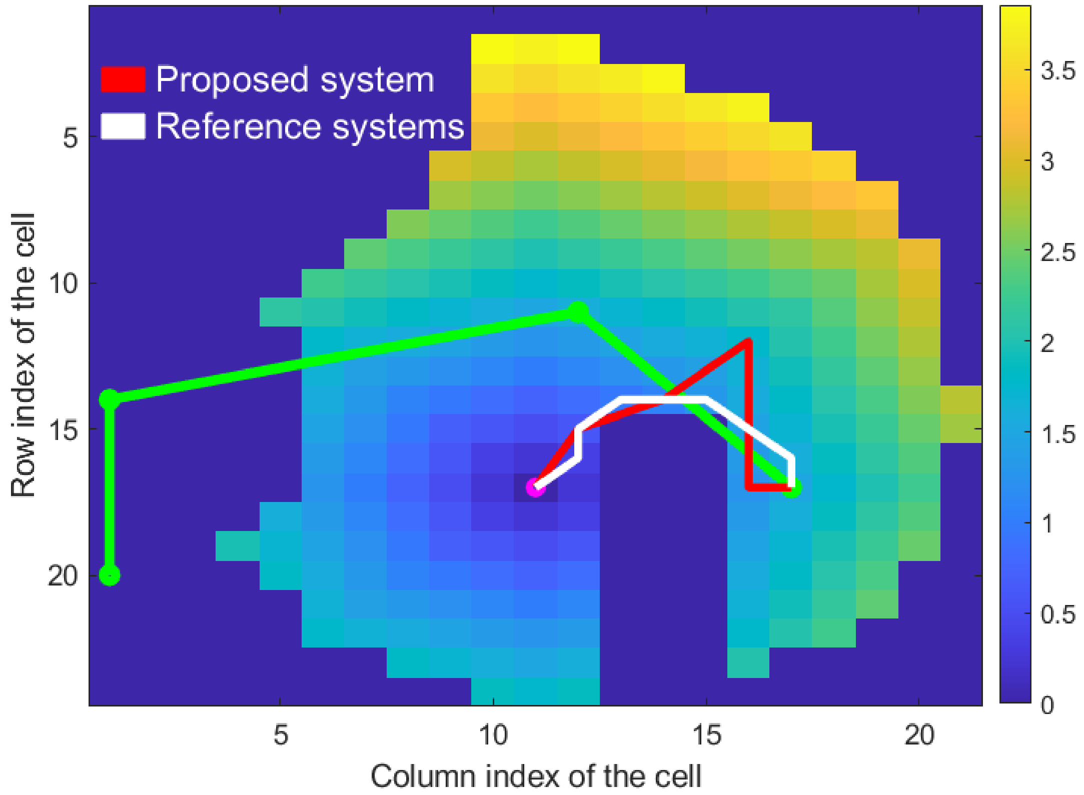
- DCV throttling losses
- Puts a limitation on system pressure

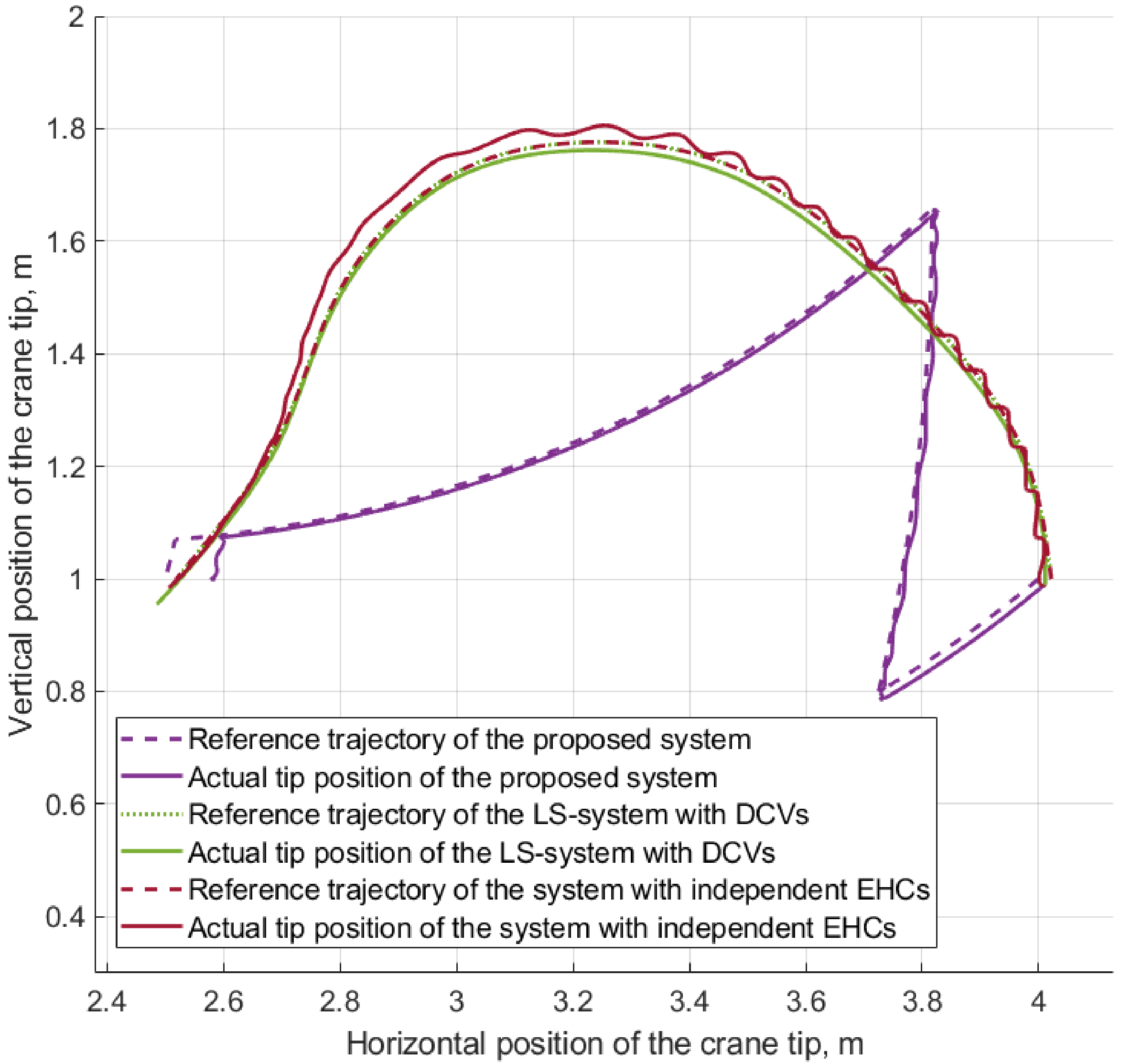
Solution 2: Sequential actuation



1 – EHA
2 – On/off valve
3 – Lift cylinder
4 – Tilt cylinder
5 – Pressure sensor
6 – Pressure-relief valve
7 – Directional control valve
8 – Boost pump

Solution 2: Sequential actuation





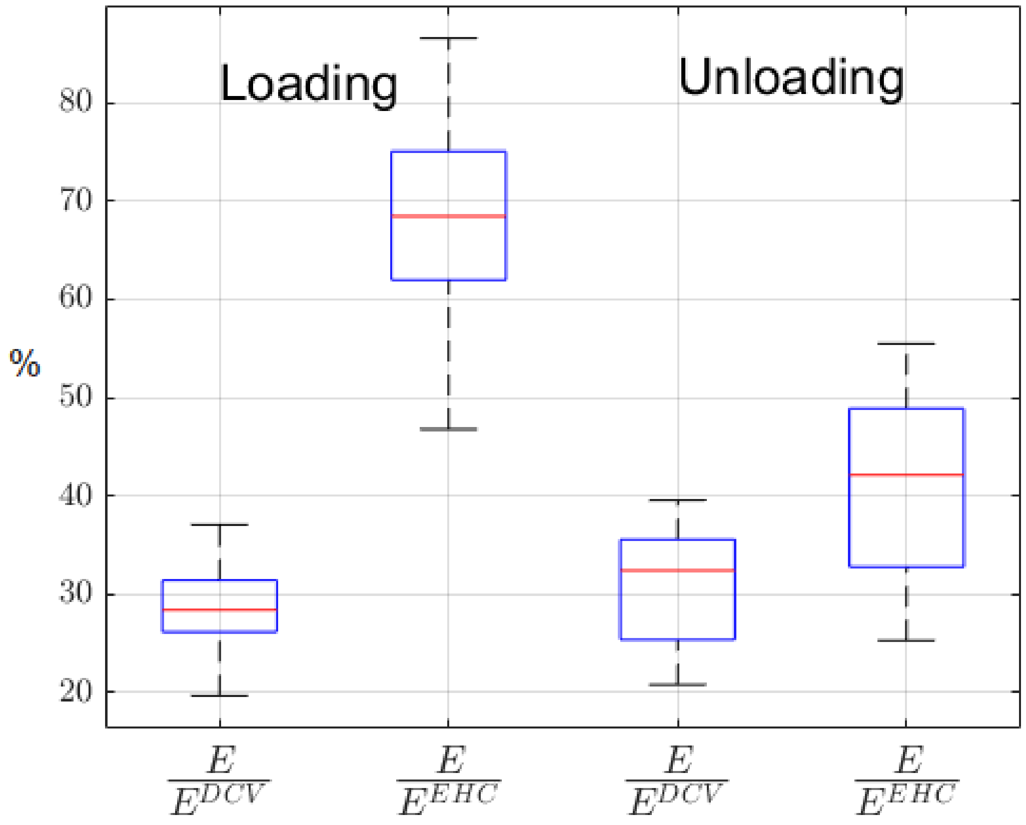
Solution 2: Sequential actuation with a single EHA

Energy consumption per cycle

E - proposed system

E^{DCV} - LS-system with DCVs

E^{EHC} - system with independent EHCs



Advantages:

- Compactness
- High efficiency
- EHA operation within high-efficiency range

Disadvantages:

- Cycle duration increases without switching optimization.

Path planning algorithm (modified A*)

Learning phase

Evaluation function: $f(n) = g(n) + h(n)$

Cost of the path

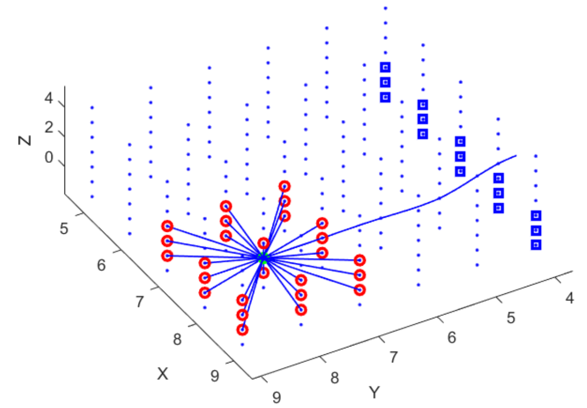
Heuristic (distance to the goal)

Energy consumed by a cylinder:

$$E_{cyl} = \int_0^T P(t)Q(t)\,dt$$

Normalized energy:

$$E_{K,R,L}[i,j,k] = \frac{E_{K,R,L}[i,j,k] + |\min_{\forall K,R,L}(E_{K,R,L})|}{|\min_{\forall K,R,L}(E_{K,R,L})| + \max_{\forall K,R,L}(E_{K,R,L})}$$



1) Define the space of the possible crane tip positions

2) Mesh the space

3) Obtain energy matrices using simulations

26 3D matrices containing energy needed to move to a neighbor cell

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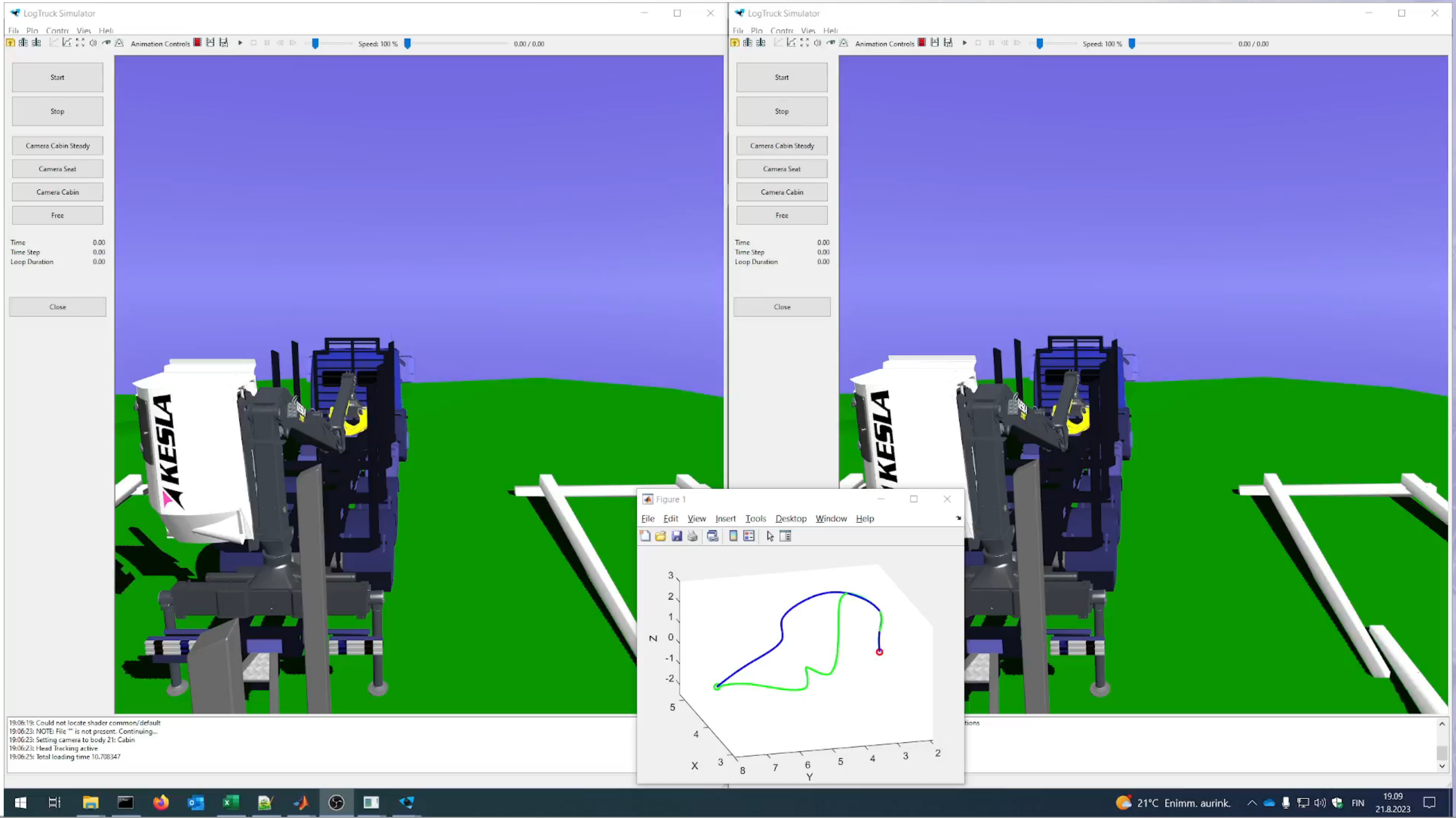
THE MOST EFFICIENT PATH IN MANIPULATION

ASME FPMC 2023
ASME/BATH Symposium on Fluid Power and Motion Control

3-D Experiment example

Efficient path



Shortest path

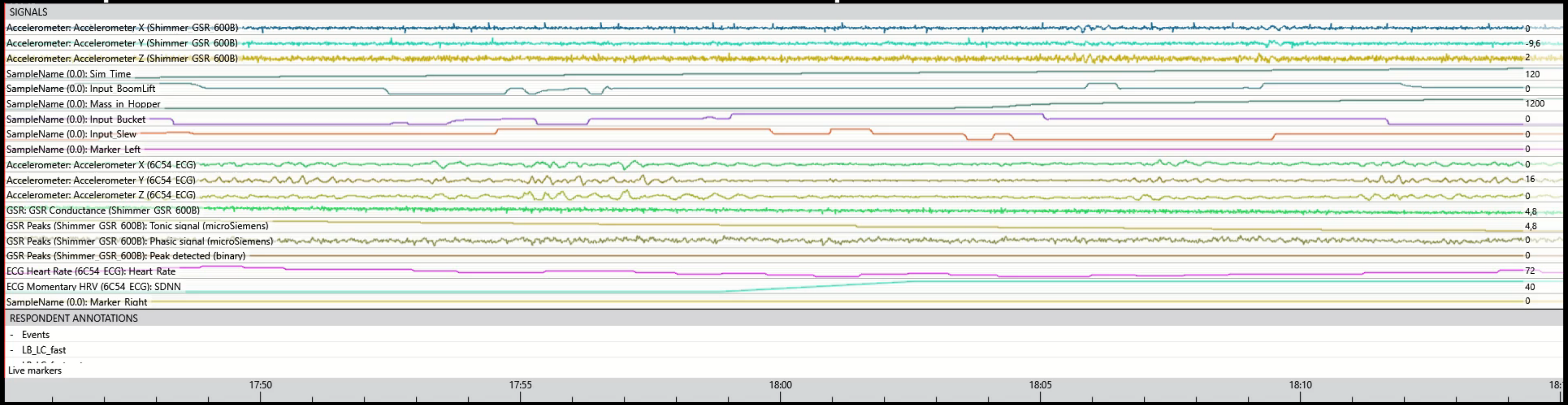
RESEARCH ON MODELLING AND SIMULATION OF HEAVY MACHINES

- Development of computational efficient models for hydraulic components
- Development of computational efficient models for electric components
- Combining multibody models and hydraulic/electric system models
- Hardware-in-the-loop simulation

RESEARCH ON MODELLING AND SIMULATION OF HEAVY MACHINES

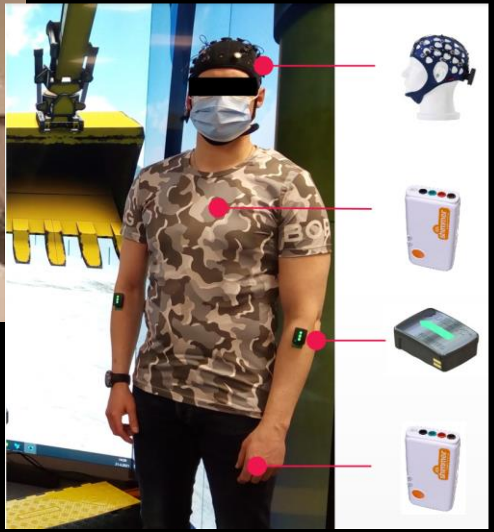
- Embedded simulators in IIoT-systems
- Machine design by real-time digital twins
- Usability and Human-Machine-interface design
- Training AI with simulated data
- Mental and physical load assessment by using bio-signals and AI

LUTERGO LABORATORY R&D INCLUDING USABILITY



LUTERGO LABORATORY

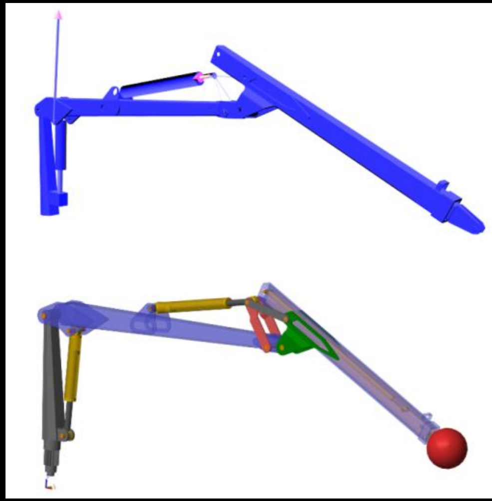
- Studying multimodal feedback for remote operation (haptic and vibrational)
- Human-centric HMI-UX development using bio-signals (EMG, ECG, EEG etc.)
- Log crane and mini-excavator remote operation demonstrators



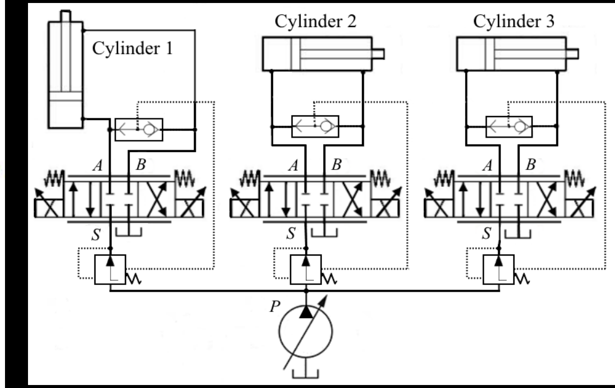
EMBEDDED DIGITAL TWINS IN IIOT-SYSTEMS

Use case: mobile log crane

Multi-body models



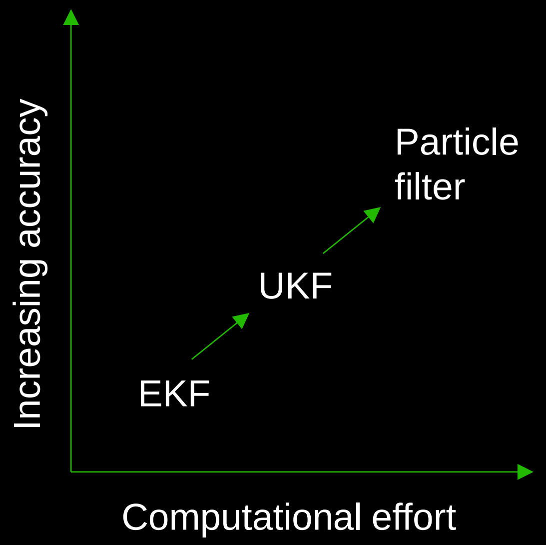
Hydraulic system model

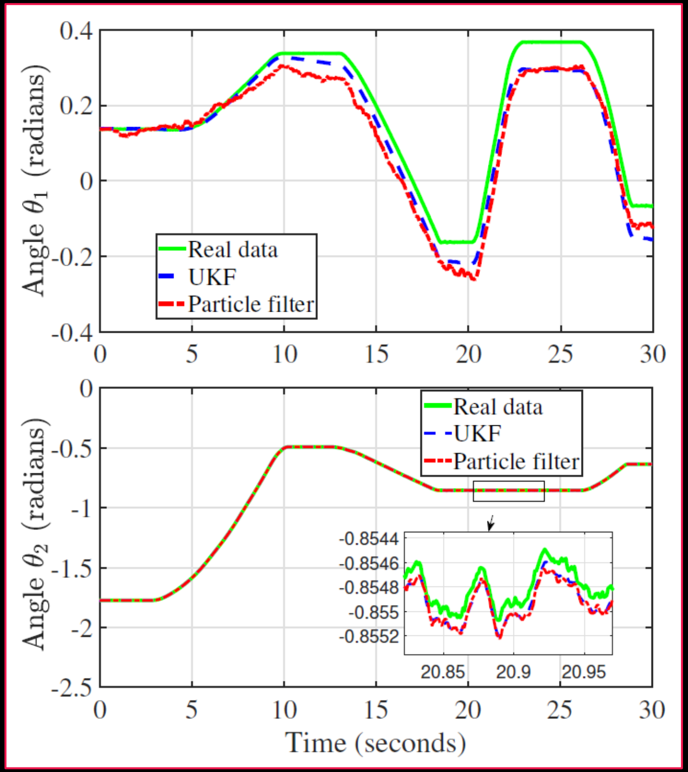


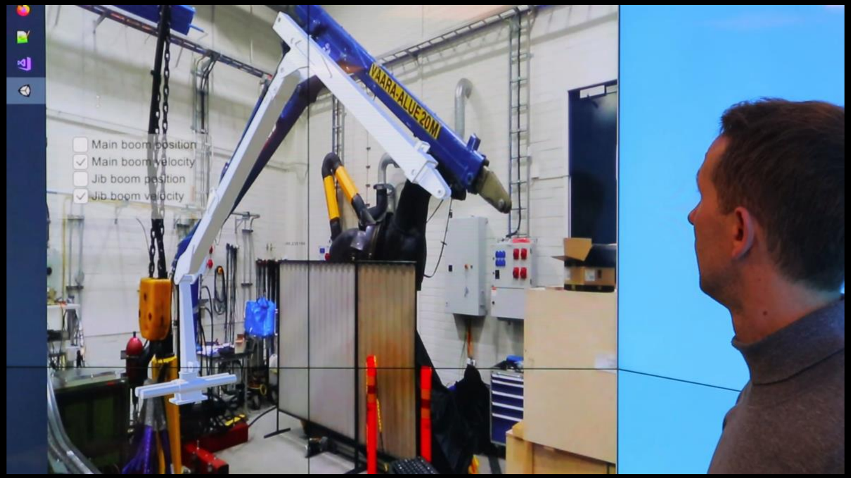
Digital twin

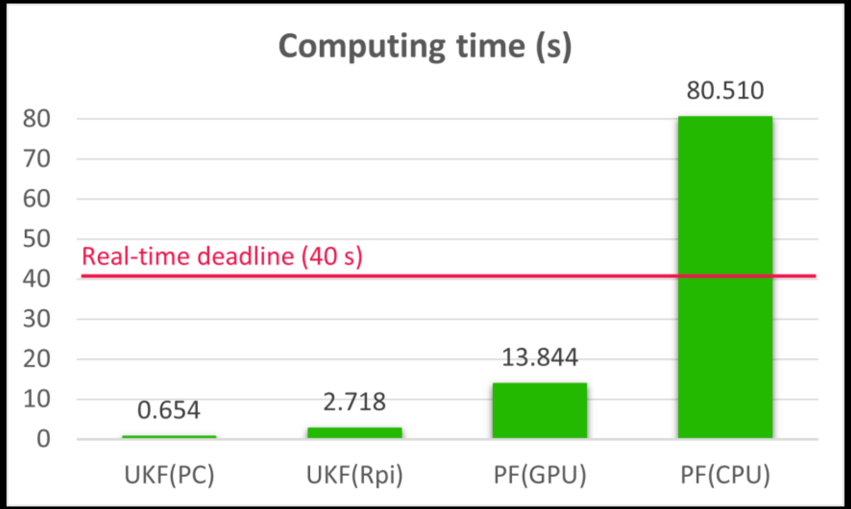
DigiBuzz project (2019-2021)

NONLINEAR FILTERING

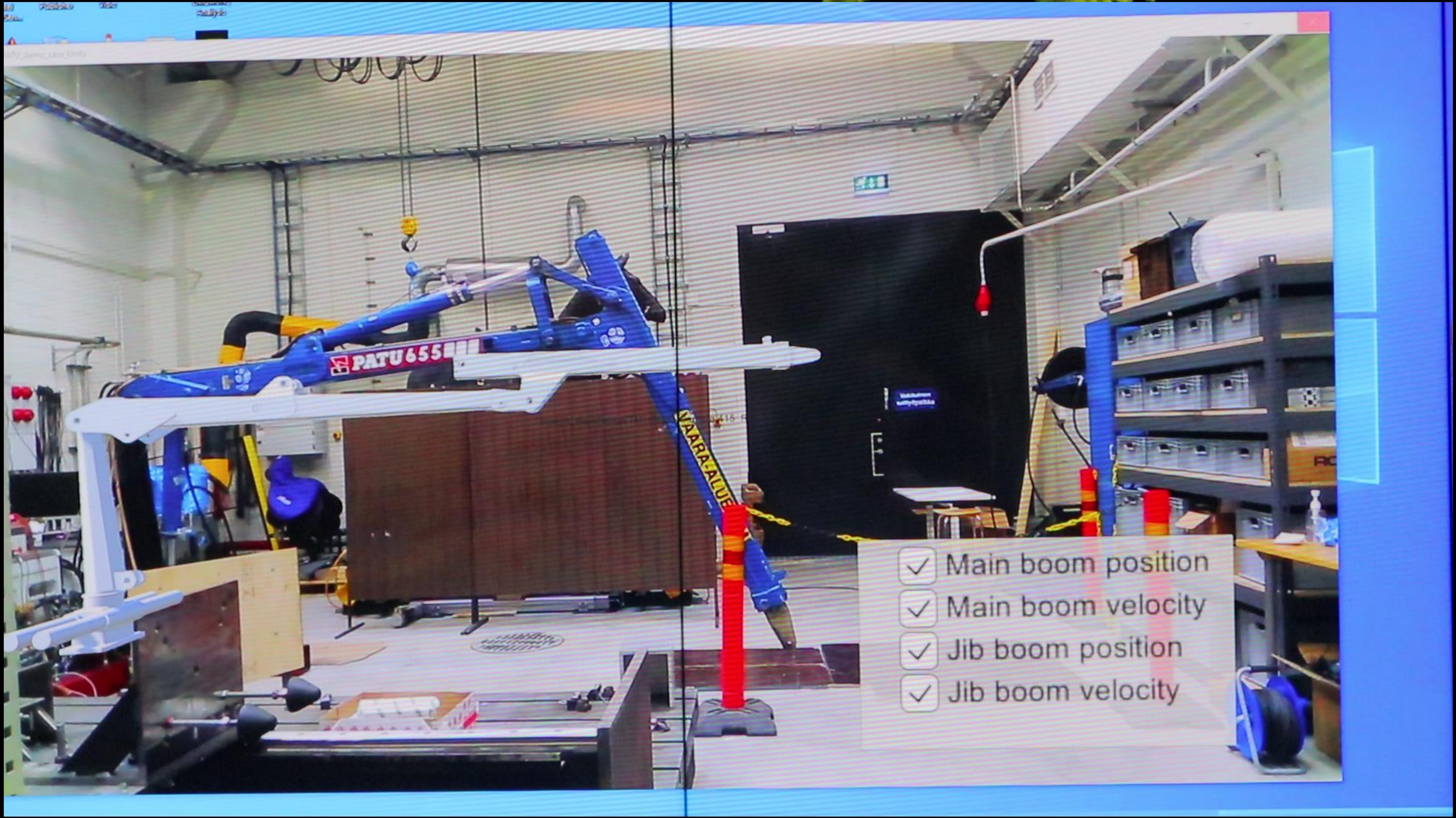








DIGITAL TWIN WITH PARTICLE FILTER



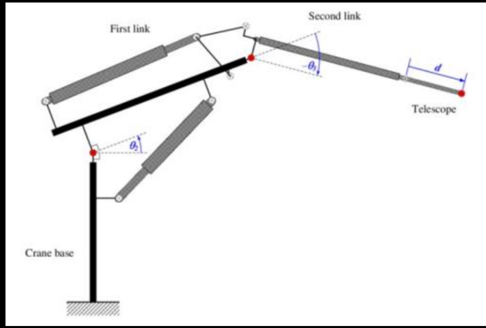
DYNAMIC MODELLING & REAL – TIME SIMULATION OF ELECTRO-HYDRAULIC ACTUATORS

Nitin Panwar

Doctoral Researcher

Supervisors: Prof. Heikki Handroos

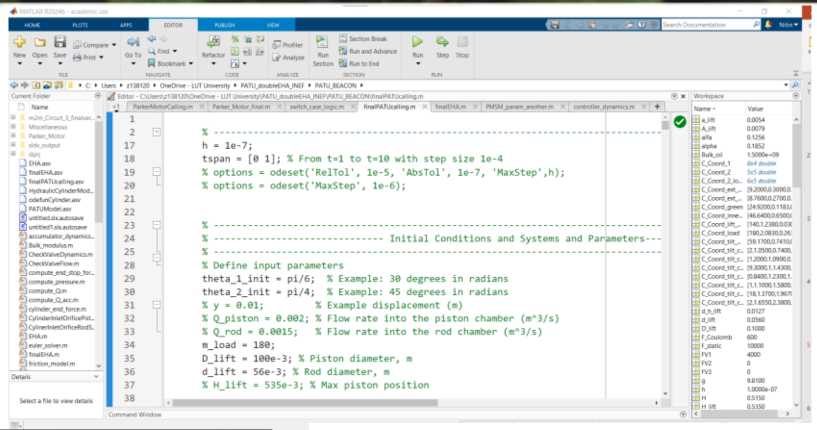
(DSc.) Victor Zhidhchenko



Research Outlook and Applications

REAL-TIME MODELS FOR EHAS

- Current Focus:
  - Building high-fidelity real-time models of EHAs
  - Integrating PMSM models with hydraulic subsystems
  - Preparing for future HIL simulation
- Applications:
  - Off – road construction equipment (e.g. PATU Crane)
  - Energy – efficient hybrid systems
- Next Steps:
  - Experimental validation with real hardware
  - Integration with machine learning for adaptive control



CAD Model, Laboratory of Intelligent Machines, LUT University

REMOTE OPERATION

HAPTIC INTERFACE

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- Haptic joystics with user interface
- Adjustable vibration frequency and amplitude
- Adjustable continuous force feedback
- Can be used in simulators and real machine control
- Blindfolded operation of a log crane demonstrated

Haptronics

LUT University

HAPTIC INTERFACE

Haptronics

Thank you for your attention!

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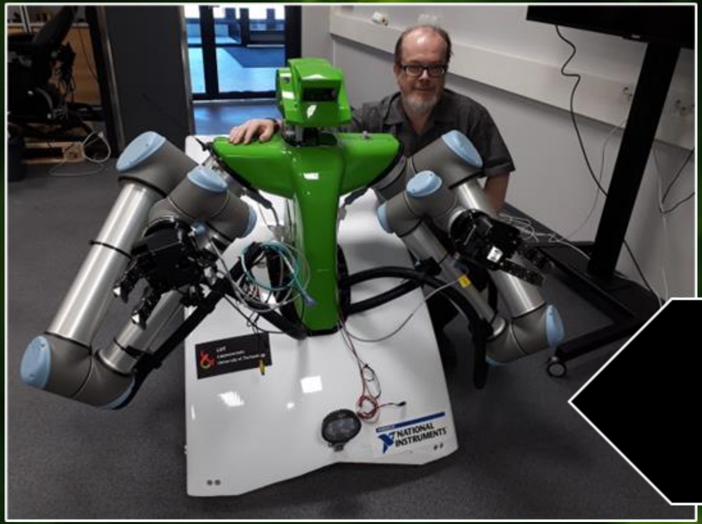

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