Tampere University

Innovations in area of off-road machinery

https://research.tuni.fi/iha/

Dr. Tatiana Minav

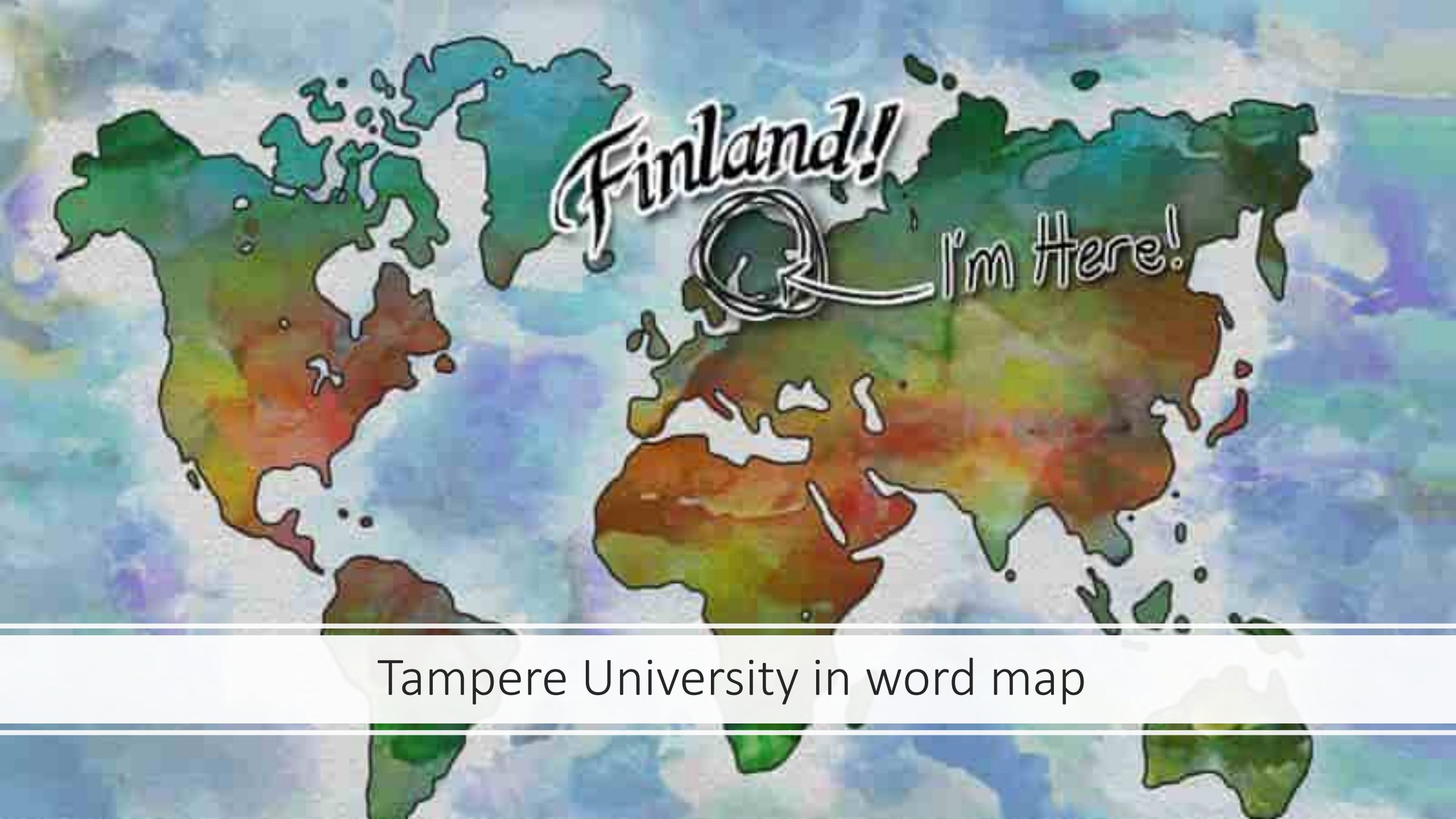
Associate Professor – Hybrid drives
TAU - Tampere University
ENS - Faculty of Engineering and Natural Sciences
IHA - Innovative Hydraulics and Automation

tatiana.minav@tuni.fi

https://www.linkedin.com/in/tatiana-minav-22306578/

Follow up IHA research group Tampere university:

#IHA_TampereUni



Tampere University in word map

Tampere University

Introduction to Tampere University

Tampereen yliopisto
Tampere University

Our purpose:

We work together to build a sustainable world

- Our university brings together scientifically excellent and high-impact research and education in **technology, health** and **society**.
- Together with our partners, we are developing solutions to improve human health and well-being, societal resilience, and environmental sustainability.
- We are creating new knowledge and expertise that stand the test of time.

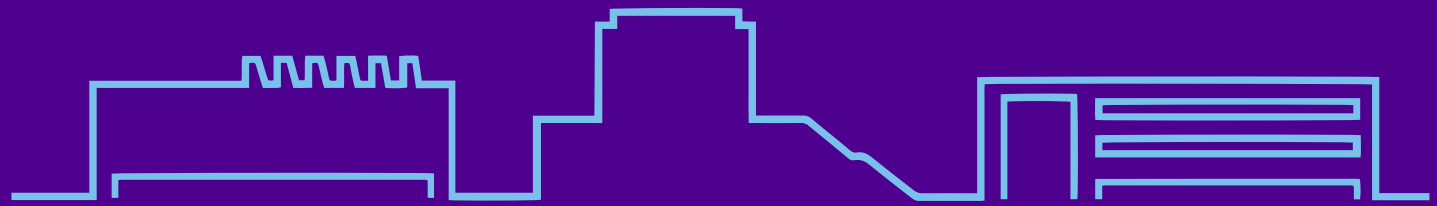
Tampere University

Our University in brief

7
faculties

10
fields of education

We are spread across three campuses in Tampere…



...and operate in the university consortia in Pori and Seinäjoki.

We are a community of 27,000 people

4,200 employees of whom **20%** are international staff

22,500 students of whom **9%** are international students

Tampere University

Our education in 2023

4,408
degrees

214
doctoral degrees

2 316
higher academic decrees (MSc, LicMed)

Students

19,742
BSc and MSc students

2,763
doctoral students

9%
international

113
nationalities

750
in fields relating to technology

568
in social sciences

213
in medical sciences or health and welfare

Tampere University

We educate future game-changers in ten fields of education

- Arts and culture
- Business, administration and law
- Education
- Engineering and technology
- Health and welfare
- Humanities
- Information and communication technologies
- Medical sciences
- Natural sciences
- Social sciences

Students

19,742
BSc and MSc students

2,763
doctoral students

Tampere University

Faculty of Engineering and Natural Sciences (ENS)

- Automation Technology and Mechanical Engineering (ATME)
    - Innovative Hydraulics and Automation (IHA)
- Materials Science and Environmental Engineering (MSEE)
- Physics

https://research.tuni.fi/iha/

Welcome to IHA - Innovative Hydraulics and Automation

#IHA_TampereUni

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Innovative Hydraulics and Automation – IHA lab

https://research.tuni.fi/iha/

IHA Key facts:
Est. 1968
Staff 60+
DSc 100+
MSc 500+

Research Profile:
- Digital hydraulics
- Zonal hydraulics
- Hybrid technology
- AI-based maintenance
- Autonomous off-road machines
- Heavy-duty robotics

Unique Research Infra
&
Top in Industry Collaboration





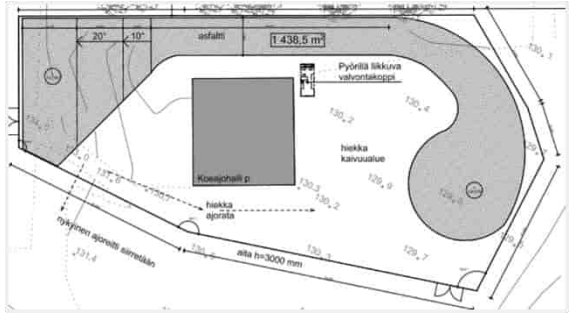
Prof. Tatiana Minav

Prof. Matti Linjama

Prof. Reza Ghabcheloo

Prof. Jouni Mattila

Prof. Kalevi Huhtala



Contact: firstname.lastname@tuni.fi

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Innovative Hydraulics and Automation – IHA lab collaborators

https://research.tuni.fi/iha/

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WE ARE IHA! Innovative Hydraulics and Automation lab!

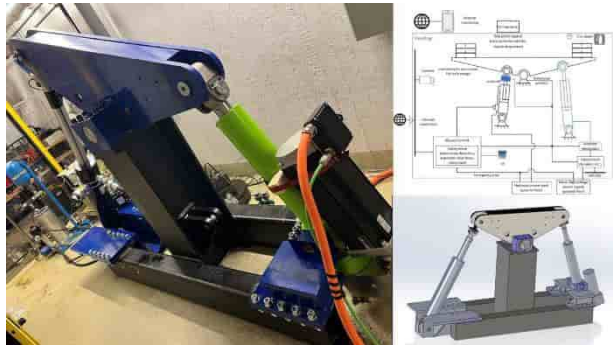
https://research.tuni.fi/iha/

Meet our Professor Tatiana Minav

Research Keywords: hybrid drives**,** electro-hydraulics, AI-based condition monitoring, energy efficiency, electrification of off-road machines

Key tasks:

- ✓ Doctoral student supervision (ENG&FIN)
- ✓ Industrial Doctoral student supervision/DSII (ENG&FIN)
- ✓ Industrial Master thesis supervision (ENG&FIN)
- ✓ Master thesis supervision (ENG & FIN)
- ✓ Bachelor thesis supervision (ENG &FIN)
- ✓ Internship (ENG &FIN)
- ✓ TET (ENG &FIN)



Main courses:

AUT 250 Hydraulic machines, fall semester,

AUT 520 Zero-emission hybrid mobile machinery, spring semester

AUT.910 Project Work in Intelligent Heavy Machines

Doctoral level course TTITO: Research Reading Circle

Ongoing projects: SAMANTHA, EMMA2 ESTV

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Associate Professor
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Meet our Professor Matti Linjama

Research Keywords: model-based control, novel hydraulic solution, digital hydraulics, energy efficiency

Key tasks:

✓ Doctoral student supervision (FIN&ENG)
✓ Industrial Doctoral student supervision/DSII (FIN&ENG)
✓ Industrial Master thesis supervision (FIN&ENG)
✓ Master thesis supervision (FIN&ENG)
✓ Bachelor thesis supervision (FIN&ENG)

Main courses:

AUT 565 Modern Control of actuation systems, spring semester
AUT.555 Modeling and control of hydraulic actuators, fall semester,

Ongoing projects: Flex CPT- **Flexible Clean Propulsion Technologies,** https://cleanpropulsion.org/

Dr. Matti Linjama
Adjunct Professor
matti.linjama@tuni.fi

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Meet our lecturer Mikko Huova

Research Keywords: model-based control, novel hydraulic solution, multi-pressure systems, digital hydraulics, energy efficiency

Key tasks:

- ✓Doctoral student supervision (FIN&ENG)
- ✓Industrial Doctoral student supervision/DSII (FIN&ENG)
- ✓Industrial Master thesis supervision (FIN&ENG)
- ✓Master thesis supervision (FIN&ENG)
- ✓Bachelor thesis supervision (FIN&ENG)
- ✓Internship (FIN&ENG)

Main courses:

AUT 530 Drives and Actuators for mobile machinery, spring semester,

AUT.910 Project Work in Intelligent Heavy Machines

Ongoing projects: Volvo DSII, Drive forward

Dr. Mikko Huova
lecturer
mikko.huova@tuni.fi

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Meet our lecturer Petteri Multanen

Research Keywords: novel hydraulic solution, energy efficiency, condition monitoring

Key tasks:

- ✓Doctoral student supervision (FIN&ENG)
- ✓Industrial Doctoral student supervision/DSII (FIN&ENG)
- ✓Industrial Master thesis supervision (FIN&ENG)
- ✓Master thesis supervision (FIN&ENG)
- ✓Bachelor thesis supervision (FIN&ENG)
- ✓Internship (FIN&ENG)

Main courses:

AUT.240 Hydrauliikan ja Koneautomaation Perusteet, fall semester

AUT.500 Johdatus Älykkäisiin Liikkuviin Työkoneisiin, spring semester

Ongoing projects: Flex CPT

Dr. Petteri Multanen
lecturer
petteri.multanen@tuni.fi

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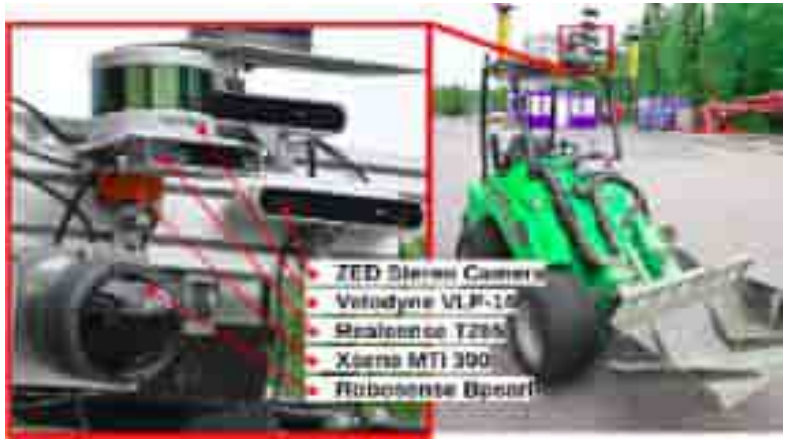
https://research.tuni.fi/iha/

Meet our Professor Reza Ghabcheloo

Research Keywords: Robotics for autonomous (heavy) working machines. Advanced control, integrated perception and control, software and safety, drive and manipulation

Key tasks:

- ✓ Doctoral student supervision (ENG)
- ✓ Industrial Doctoral student supervision/DSII (ENG)
- ✓ Industrial Master thesis supervision (ENG)
- ✓ Master thesis supervision (ENG)
- ✓ Bachelor thesis supervision (ENG)
- ✓ Internship (ENG)



Main courses:

ROBO.400 Mechatronics and Robot programming, fall semester

ROBO.710 Fundamentals of Mobile Robotics, spring semester

Ongoing projects: Aurora (Business Finland **2025-27**) Automated and Connected Machines
SenCAN (Business Finland **2025-26**) Sensor Calibrations Anywhere
XSCAVE (HE/RIA, **2025-28**) Explainable, Safe, Contact-Aware Planning and Control for Heavy Machinery Manipulation and Navigation

Dr. Reza Ghabcheloo
Professor
reza.ghabcheloo@tuni.fi
office K2229

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https://research.tuni.fi/iha/

Meet our Professor Jouni Mattila

Research Keywords: Autonomous Mobile Manipulators, Heavy-duty Robotics, all-electric heavy-duty mobile manipulators, energy-efficient and high-performance control of complex system and actuators

Key tasks:

- ✓ Doctoral student supervision (FIN&ENG)
- ✓ Industrial Doctoral student supervision/DSII (FIN&ENG)
- ✓ Industrial Master thesis supervision (FIN&ENG)
- ✓ Master thesis supervision(FIN&ENG)
- ✓ Bachelor thesis supervision (FIN&ENG)

Main courses:

AUT.540 Automation in Heavy Machines, fall semester,

AUT.580 Model-Based Design and Rapid Prototyping, spring semester

AUT.910 Project Work in Intelligent Heavy Machines

Ongoing projects: FUTURA (https://www.six.fi/futura), PDE-based control of flexible manipulators (Research Council of Finland #355664)

Dr. Jouni Mattila
Professor
jouni.mattila@tuni.fi

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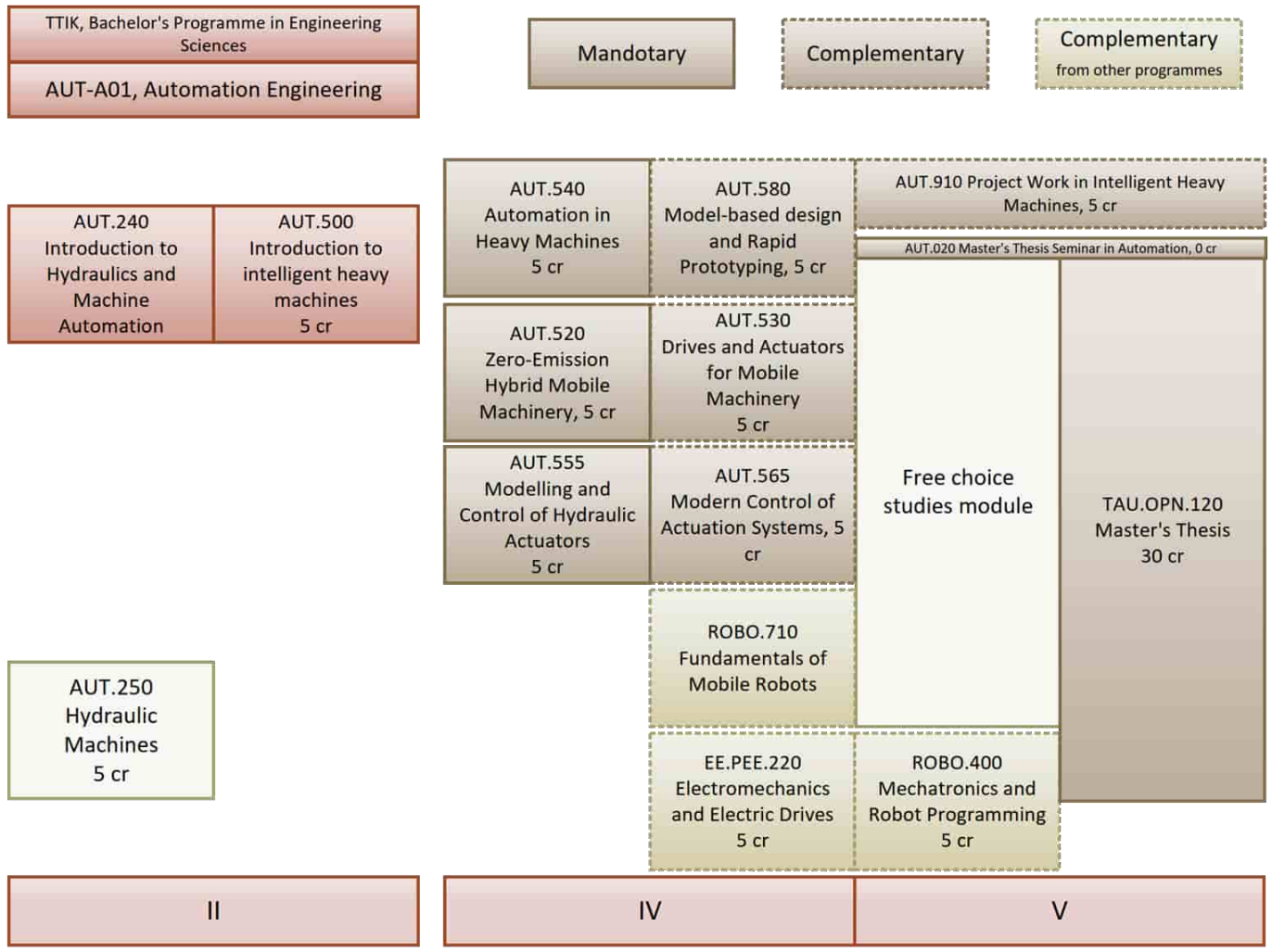
IHA courses

- ✓ AUT.240 Hydrauliikan ja koneautomaation perusteet (Introduction to Hydraulics and Machine Automation)
- ✓ AUT.250 Hydraulic Machines
- ✓ AUT.500 Johdatus älykkäisiin liikkuviin työkoneisiin (Introduction to Intelligent Heavy Machines)
- ✓ AUT.520 Zero-Emission Hybrid Mobile Machinery
- ✓ AUT.530 Drives and Actuators for mobile machinery
- ✓ AUT.540 Automation in Heavy Machines
- ✓ AUT.555 Modeling and control of hydraulic actuators
- ✓ AUT.565 Modern Control of actuation systems
- ✓ AUT.580 Model-Based Design and Rapid Prototyping
- ✓ AUT.910 Project Work in Intelligent Heavy Machines

https://research.tuni.fi/iha/



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IHA Heavy laboratory - World class and unique

Permanent staff:

3 IHA Technicians, shared: NC machinist, Purchaser, Manufacturing support with CAD design QA etc.

General facilities:

- 3-pump main unit (400 kW)
- Electric power supply (200 kW, 50-750 VDC)
- Stand-alone hydraulic power units
- 3 installation platforms (Tot: 19 m^2)
- Model-based rapid prototyping (dSpace, Speedgoat, Beckhoff…)

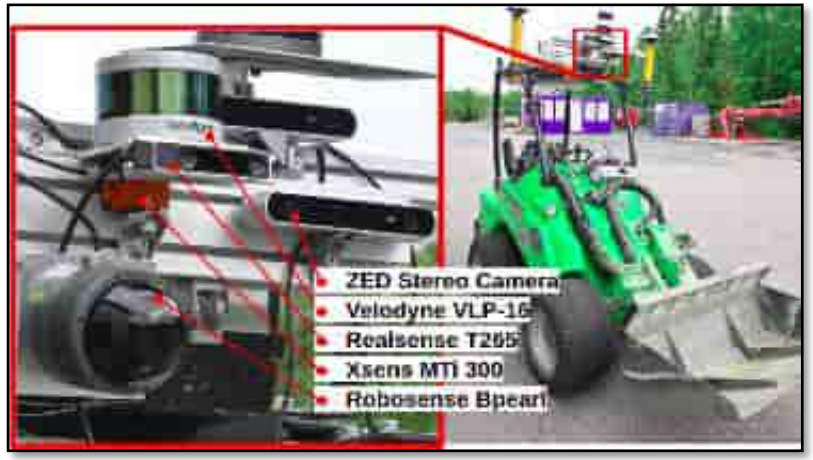
Test setups:

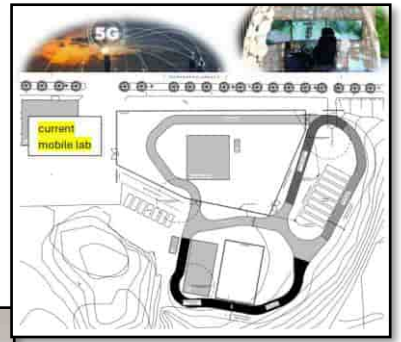
- Secondary loading unit (45 kW cont.)
- High inertia load benches (seesaws)
- 4-quadrant HIL-loading test bench for linear actuators
- Indoor diesel engine setup

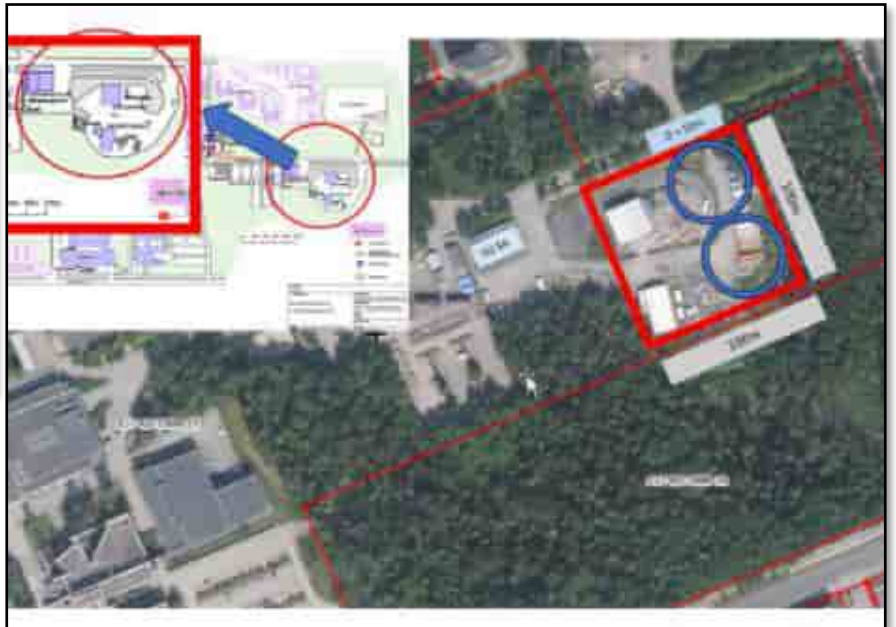
Tampere University

IHA Mobile lab

- State of art perception and computing (3 instrumented machines)
- 5+ Instrumented off-road machines + 2 Boom Bases
- 4000 sqm fenced / controlled area
- **NEW** Rough off-road test track for autonomous driving (~ 300-500 m, 8-shape) fenced / controlled area to be ready 2025
- all-electric rough terrain mobile manipulator (FUTURA-project)
- Electric Volvo EEVE excavator
- Leica 6 DOF laser tracker for data set ground truth measurements
- 5G private network







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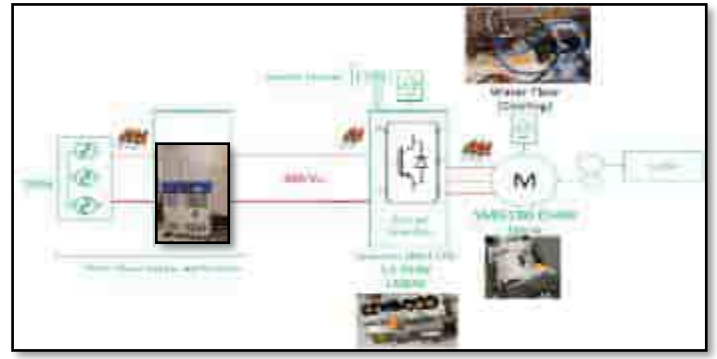
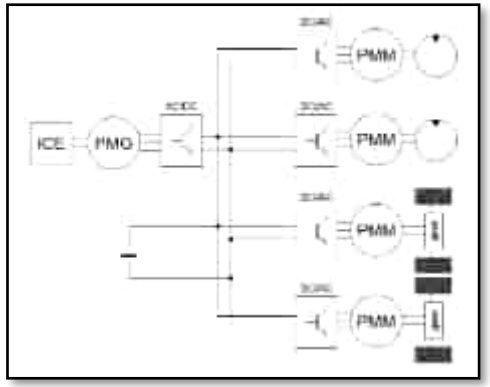
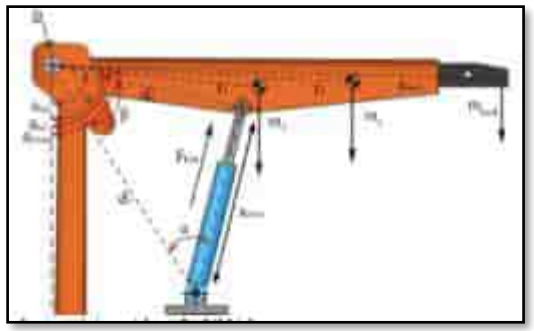
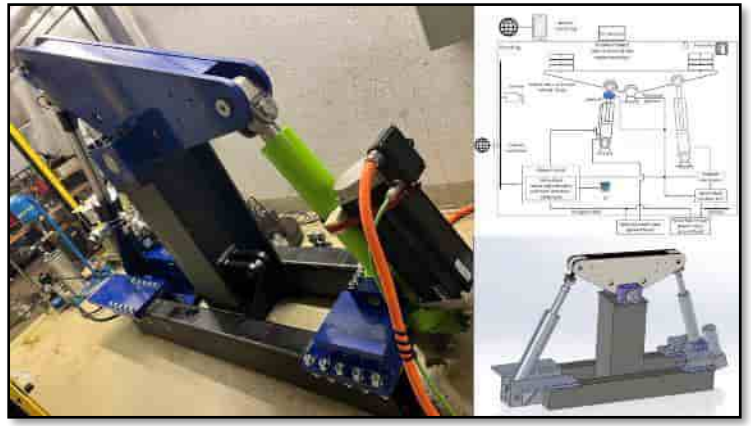
Electrification & RUL

- **High Voltage Test Rig** (50 - 750 VDC) testing EM, FC or ICE+ Gen set (hydraulic payload and external cooling)
- **Electric reach truck with AI-based health monitoring**
- **sWille hybrid wheel loader platform**
- **Crane test rig – testing of EHA, efficiency, filtering**
- **HIL Test** Rig for testing power management strategies (based on Digital twins Mevea)
- **Durability Test Rig** for testing EHA, EMA
- **Pump Degradation Test** Rig – controllable accelerated degradation of pumps, obtaining historical data for AI condition monitoring



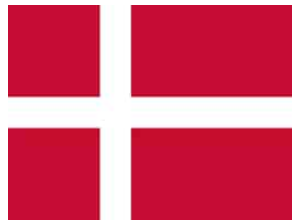






Example of research

Carbo-neutral Targets Timeline







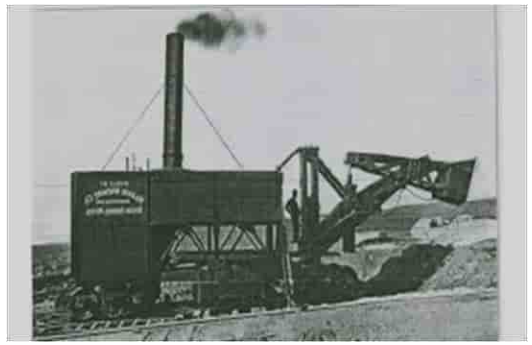
2025
Denmark

2030:
Norway

2035:
Finland

2045:
Sweden
Germany

2050:
USA



Is evolution ongoing?

Trends in heavy-duty mobile machinery

Decarbonize Off-road Machinery

- Powertrain
  - Downsize ICE
    - Hybridization
  - Remove or keep ICE
    - Electrification

Electric hybrid: ICE + Gen + En.Storage
Hydraulic hybrid: ICE+ Hydr.Accu

Electric : Gen + Energy Storage
Keep: Hydrogen based mixes

Tadano hybrid All Terrain (Concept)

Grove GMK 4100L-2 Plug in Hybrid (concept)

Hyundai, 18E Electric excavator

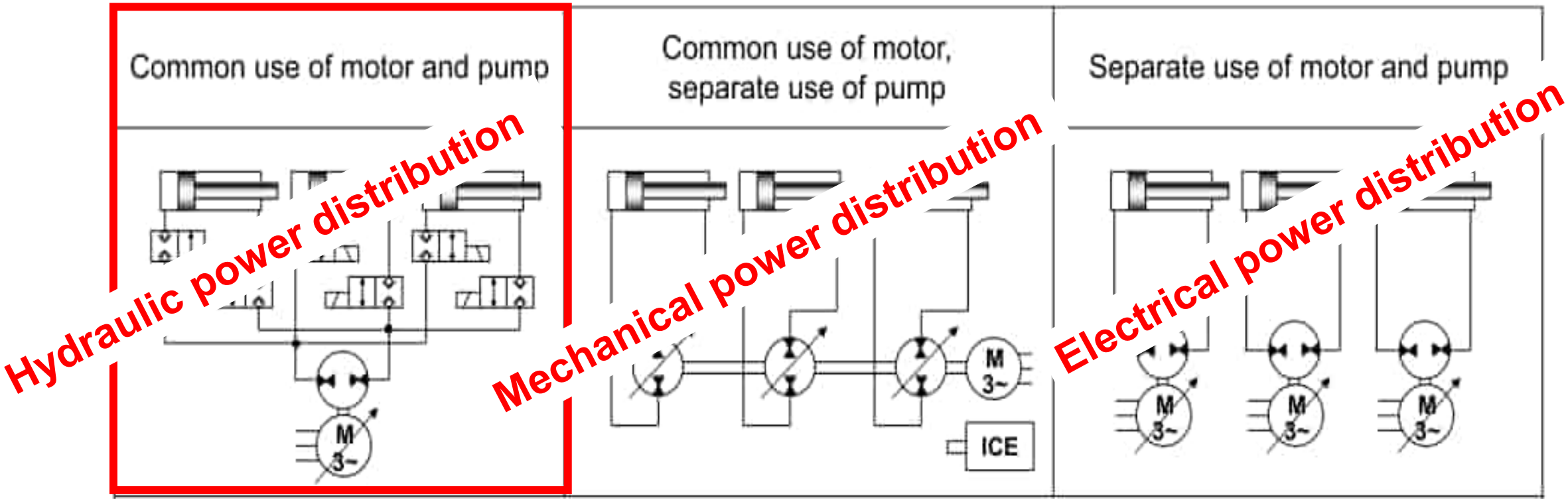
Sampierana 15x-100-electric, (Product)

Liebherr R 9XX H2 crawler excavator with hydrogen engine (prototype)

2022: HW155H Hydrogen Excavator (prototype)

Trends in heavy-duty mobile machinery

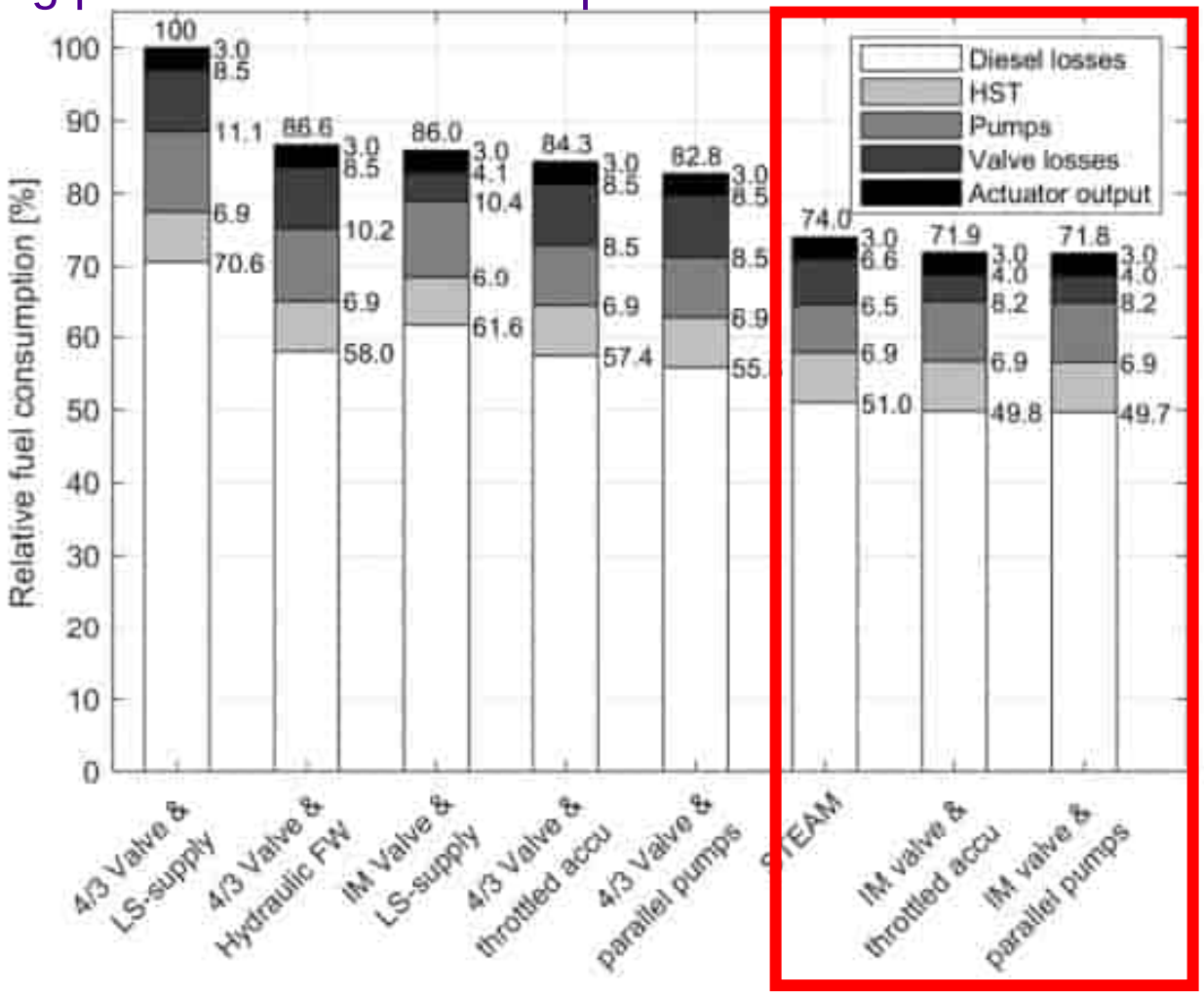
Trends in research: implements



J. Weber, at al. Novel System Architectures by Individual Drives, 8-10 March 2016, IFK-2016, Dresden, Germany

Hydraulic power distribution

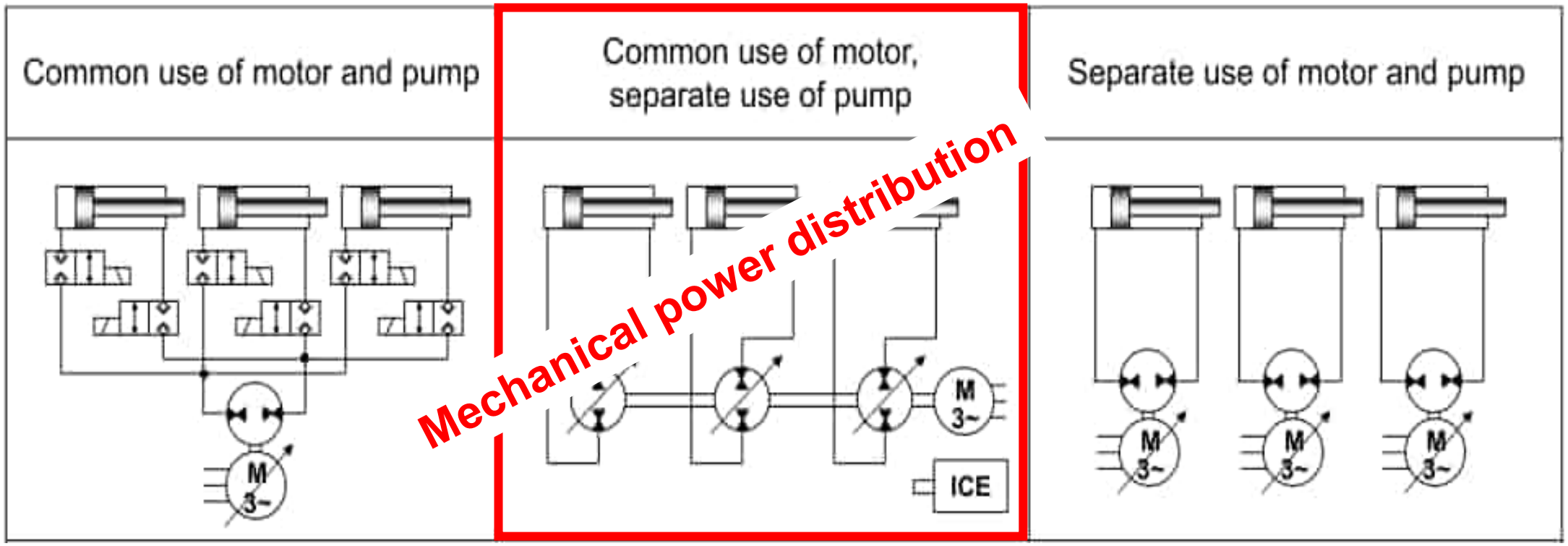
Energy saving potential of the municipal tractor



The best results are obtained with STEAM, throttled accumulator with independent metering (IM)

M.Linjama, et.al, HYDRAULIC HYBRID WORKING MACHINES PROJECT - LESSONS LEARNED, SICFP, May 22-24, 2019, Tampere, Finland

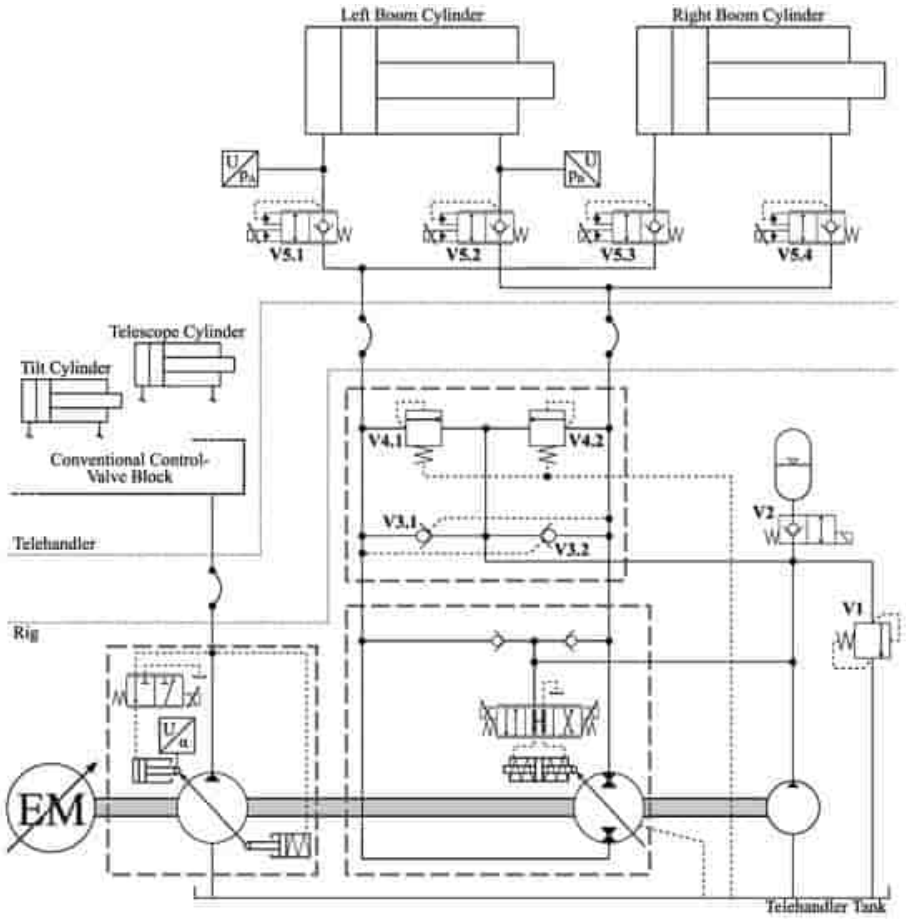
Trends in research



J. Weber, at al. Novel System Architectures by Individual Drives, 8-10 March 2016, IFK-2016, Dresden, Germany

Mechanical power distribution

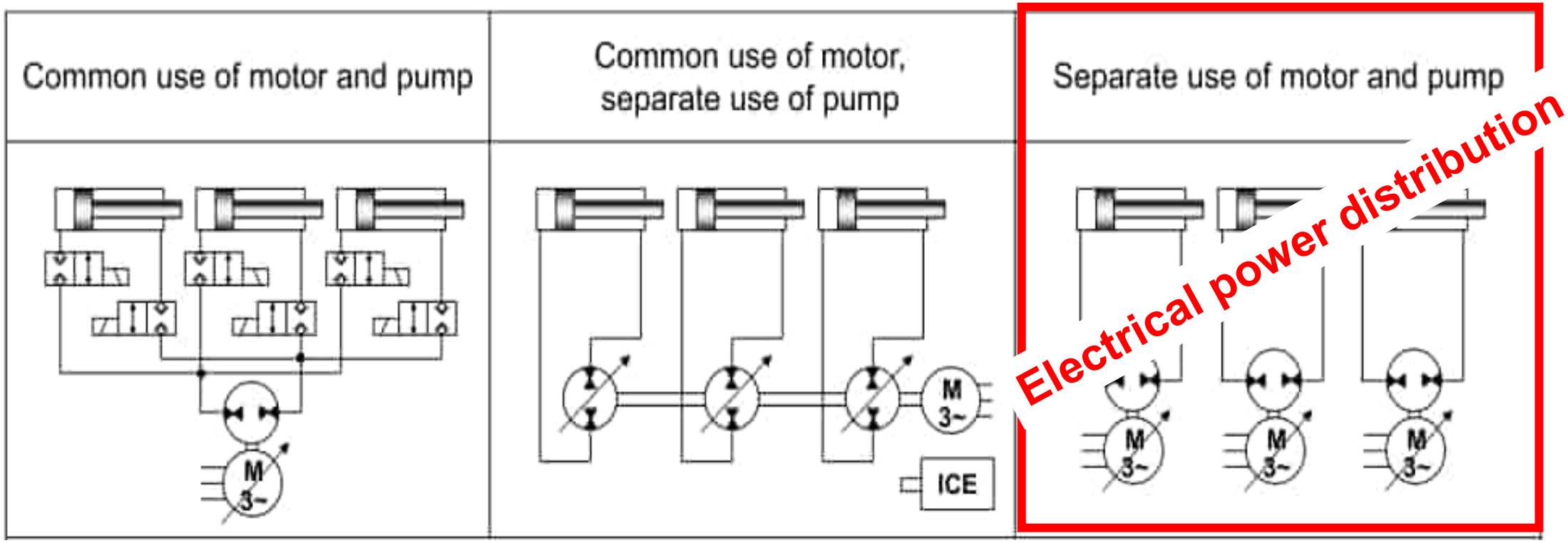
Partially Valve- and Displacement-Controlled Electrified Telehandler Implements



Cycle	Pile Work	Truck Loading (serial movements)	Truck Loading (simultaneous movements)	Pallet Lifting – Empty Lowering	Empty Lifting – Pallet Lowering
Consumption Reduction [%] (compared to pure valve control)	21 (±10)	3 (±6)	29 (±4)	23 (±4)	31 (±5)

Fassbender, D.; Brach, C.; Minav, T. Experimental Investigations of Partially Valve-, Partially Displacement-Controlled Electrified Telehandler Implements. *Actuators* **2023**, *12*, 50. https://doi.org/10.3390/act12020050

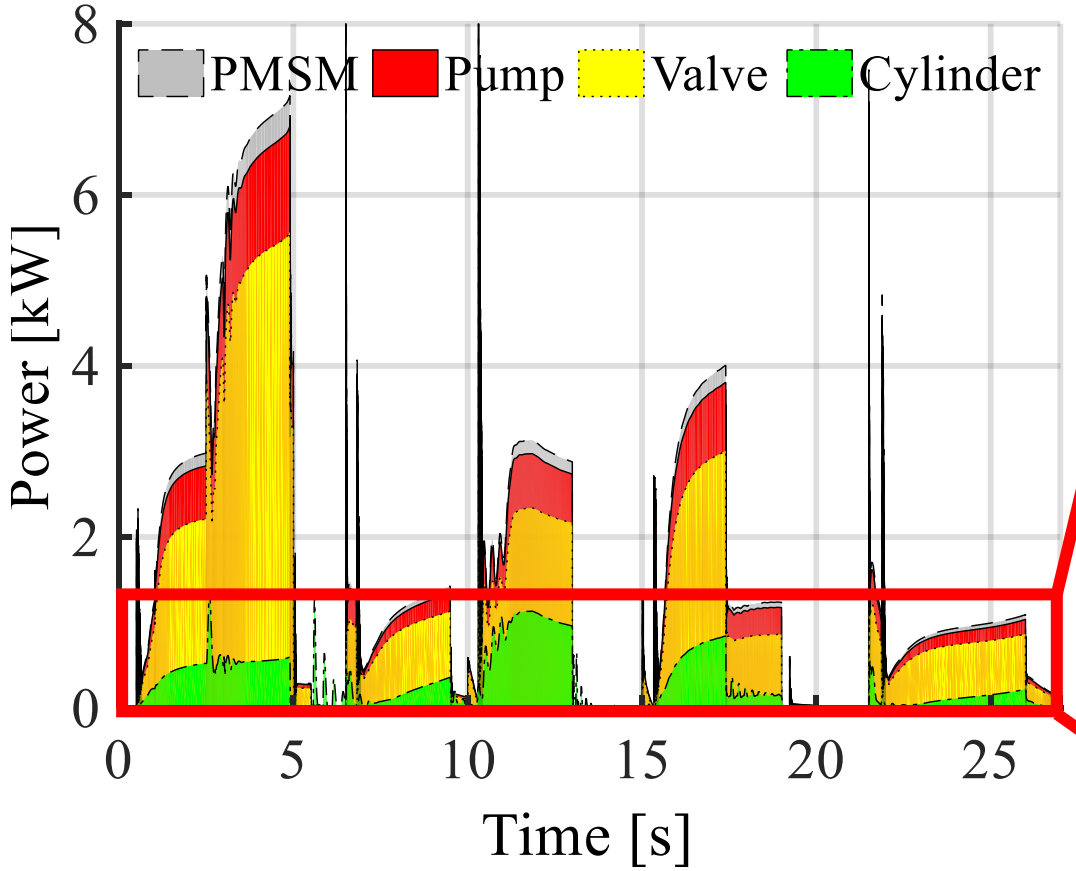
Trends in research



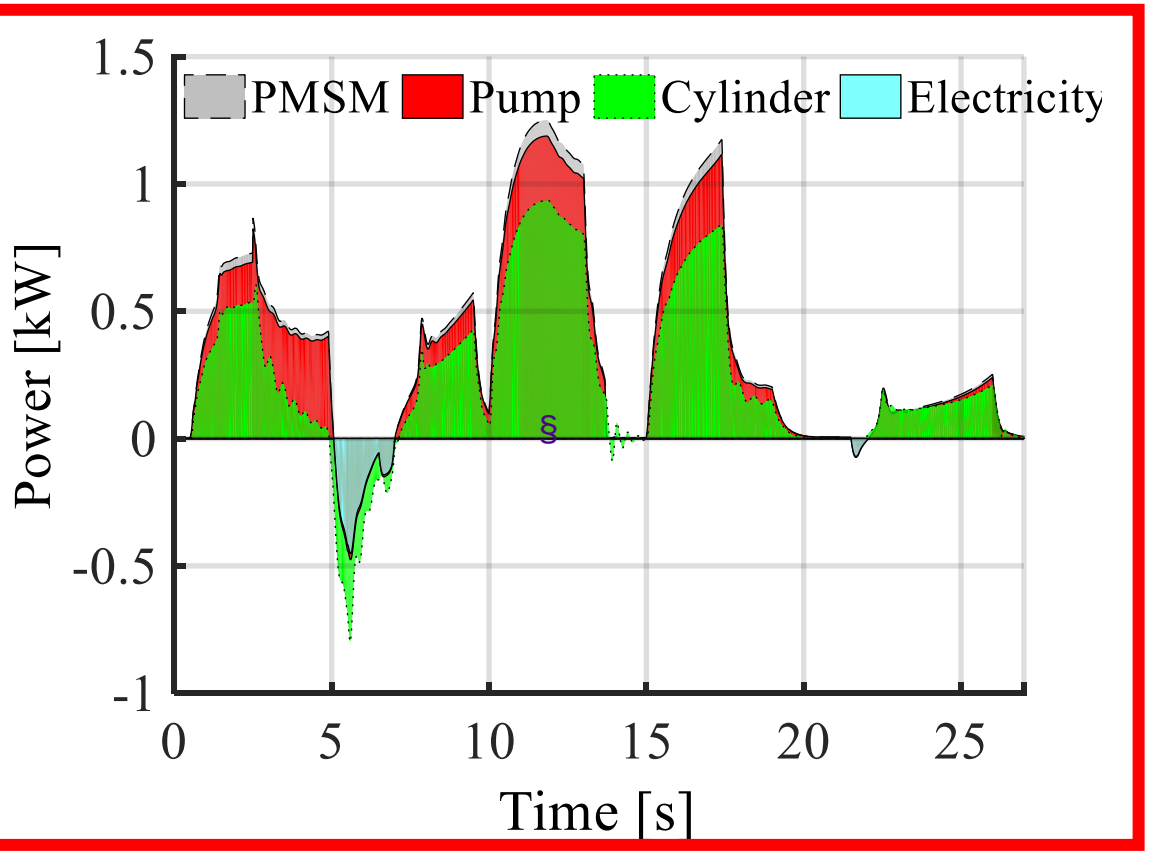
J. Weber, at al. Novel System Architectures by Individual Drives, 8-10 March 2016, IFK-2016, Dresden, Germany

Electrical power distribution

Conventional LS hydraulics



Electrical power distribution



Significant reduction of maximum power requirement

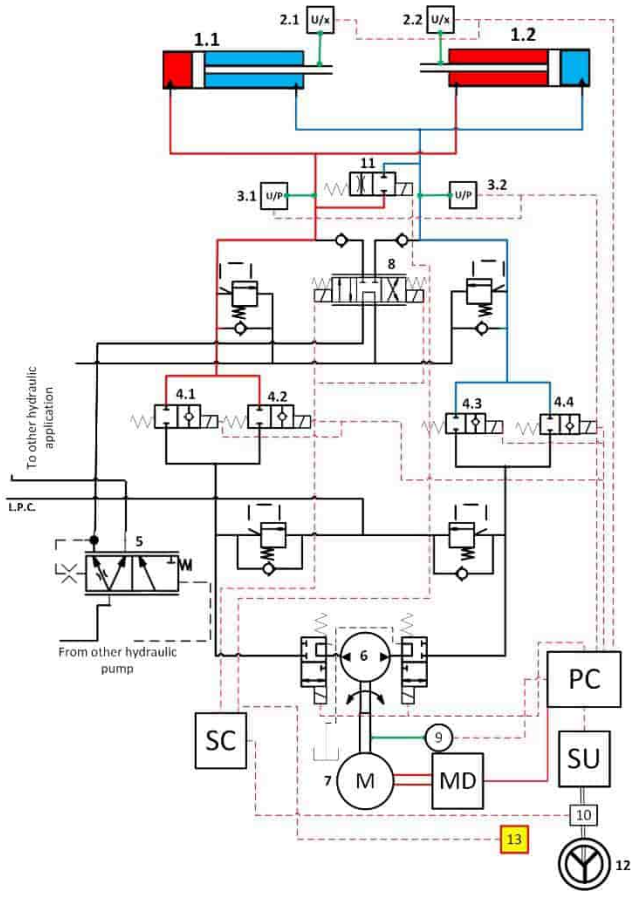
From 7 kW ➔ to 1.2 kW

For more details refer to Zhang S., T. Minav, Pietola M., (2017), Decentralized Hydraulics for Micro Excavator, SICFP'17

Electrical power distribution: EHA

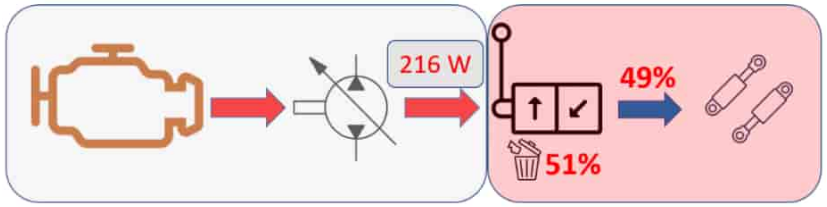
EM/MA-2

EHA-based Steering analyzed against conventional wheel loader realized in Mevea&Simulink.

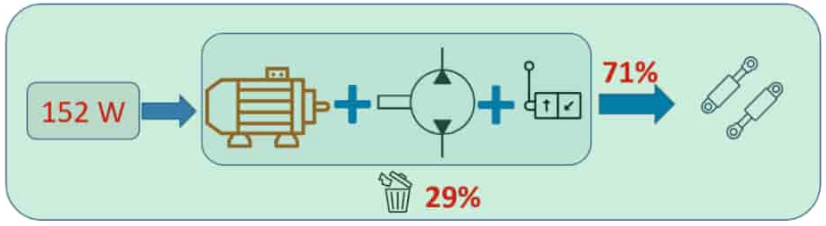


Energy consumption/Loss

Conventional steering



EHA-based steering



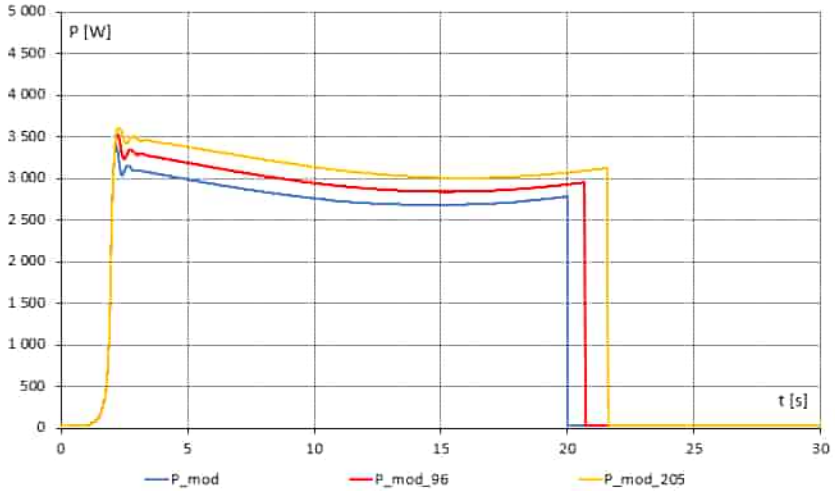
More details refer to the publication in SICFP 2023 by Vinay Singh.

Electrical power distribution: EMA

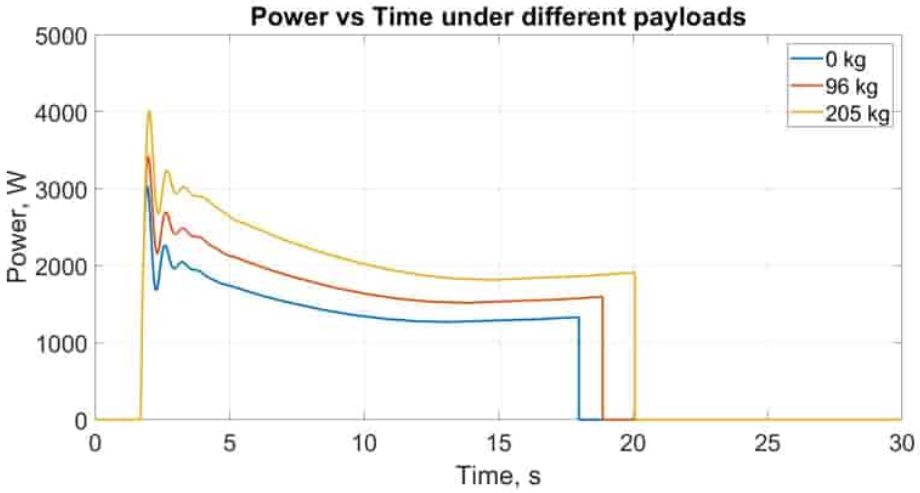
EMA lifting cycle analysed against conventional scissor lift.

Prototype study by Norrhydro (Motiomax)

Conventional hydraulics



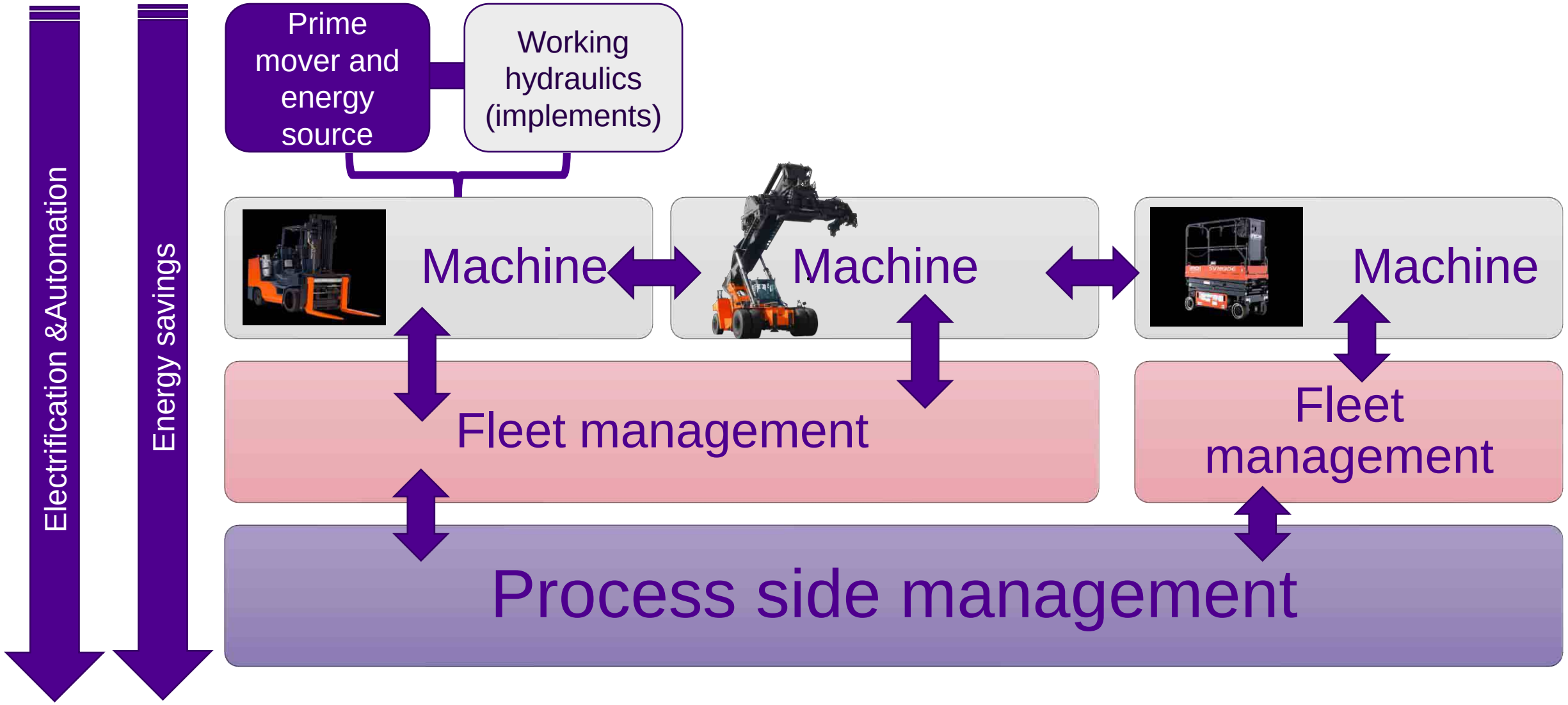
EMA-based



More details refer to the publication by Viacheslav Zakharov https://www.mdpi.com/2076-0825/12/10/394

Zakharov, Ł. Stawiński, T. Minav and A. Kosucki, (2023). ENERGY HARVESTING ANALYSIS OF ELECTRIFIED SCISSOR-LIFT , SICFP23

How to maximize energy savings?



Step by step to autonomous operation

6. Health Management

5. Process Automation

4. Local navigation

3. Obstacle avoidance

2. Vehicle control

1. Route planning

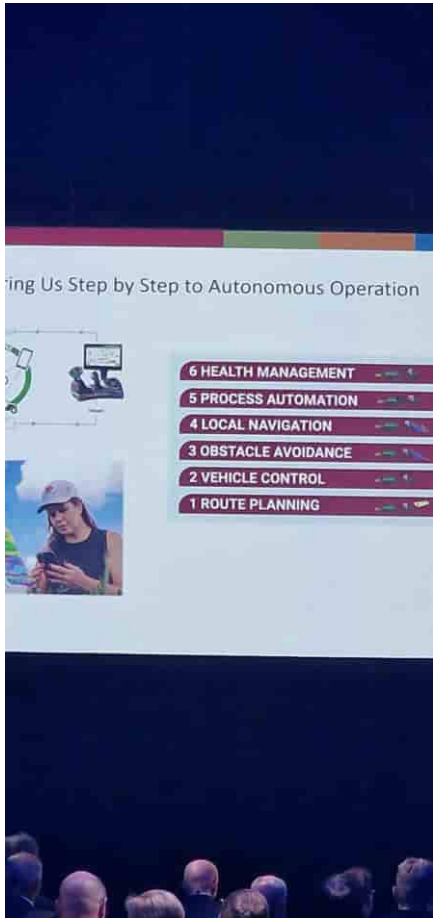


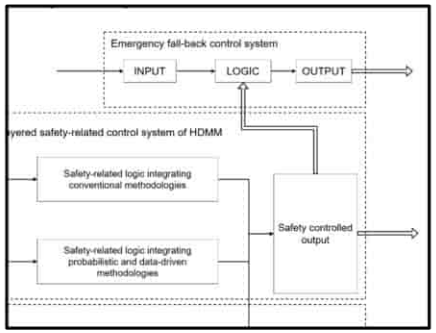
Photo from Future Mobile Machine event,
By SIX Tampere, May 2024

Example research topics

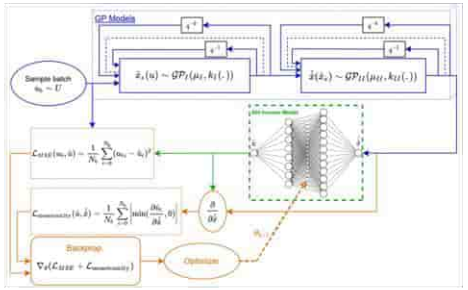
Example: Complex, safety aware autonomous operation of heavy working machines.

Example: AI driven, data efficient models of hydraulic actuators for high-precision motion control.

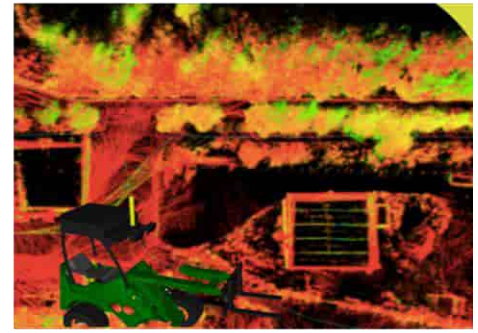
Software engineering & safety



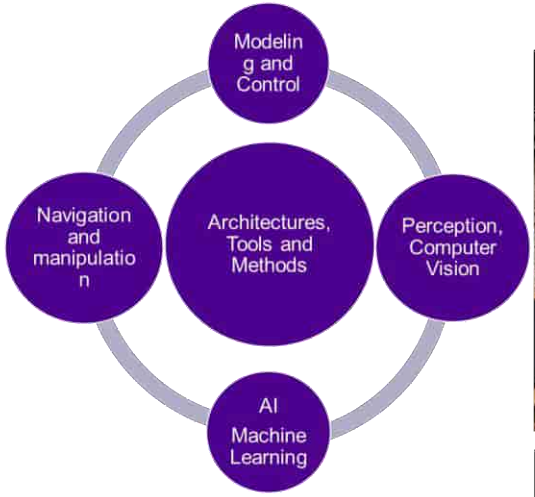
Machine learning for control



ROS2 platform, Simulation



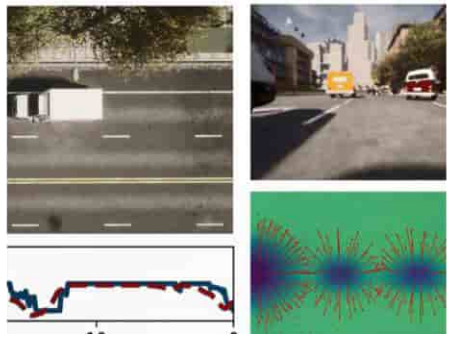
Autonomous bucket filling



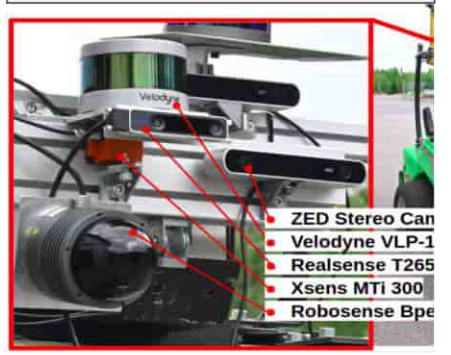
Autonomous pallet picking

Autonomous forklift

Carla sim, learning to drive



Perception, SLAM, calibration



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Heavy-duty mobile robot tackling harsh, slippery, and rough terrains with precision and reliability

This demonstration highlights the efficacy, robustness, and tracking performance of our proposed control approach by prof. Jouni Mattila

M. H. Shahna, M. Bahari and J. Mattila, "Robustness-Guaranteed Observer-Based Control Strategy With Modularity for Cleantech EMLA-Driven Heavy-Duty Robotic Manipulator," in IEEE Transactions on Automation Science and Engineering, doi: 10.1109/TASE.2024.3520638.

Tampere University

Health Management: AI-based condition monitoring for hydraulics via electric motor signals

Valve failure

Table 3 Classifiers rated based on p
f1-score, and accuracy s

Classifier	Precision	Recall		
Decision Tree	0.6	0.6		
Random Forest	0.06	0.06		
K Nearest Neighbors	0.06	0.06		
Support Vector Machine	0.06	0.06		
Naive Bayes	0.06	0.06		
XgBoost	0.57	0.58		
Gradient Boosting	0.46	0.48		
Multi-Layer Perceptron	0.69	0.70	0.69	0.70

70 % accuracy to detect valve fault

A.Azeez, X. Han, V. Zakharov, T.Minav, (2021), AI-based condition monitoring of hydraulic valves in zonal hydraulics using simulated electric motor signals, ASME/Bath FPMC 2021, USA

Pump failure

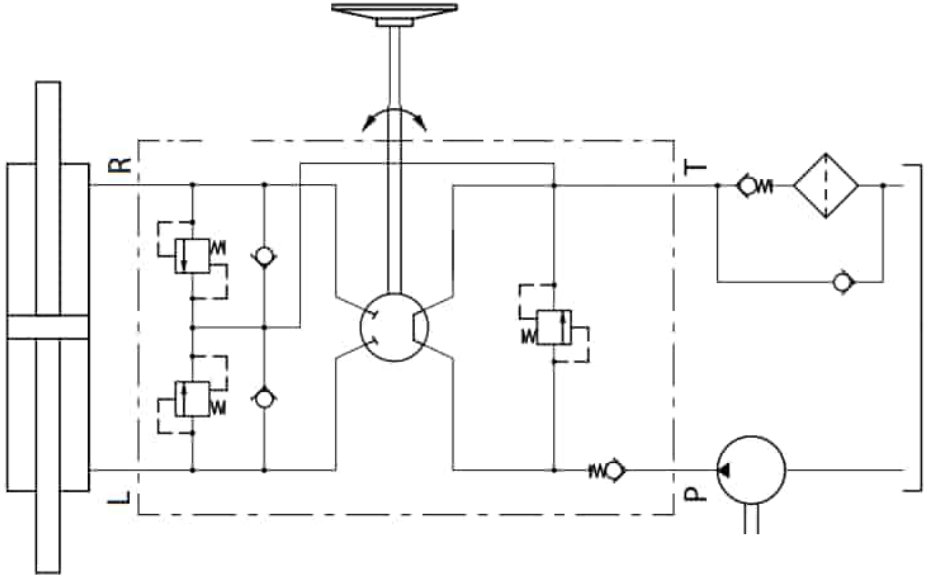
			F1-score	Accuracy Score	Data Type
			0.84	0.887	Experimental
			0.98		
			0.84		
			0.6	0.701	Simulation
			0.91		
			0.56		
Fault I (F-I)	0.72	0.44	0.55	0.757	Augmented Simulation
Fault II (F-II)	1	0.97	0.98		
Healthy (H)	0.61	0.86	0.71		

70 - 88 % accuracy to detect pump fault

A.Azeez, E.Vuorinen, T. Minav, P.Casoli, AI-based condition monitoring of a variable displacement axial piston pump, IFK 2022, Germany

Improve Functional Safety of Articulated Steering

EM/MA-2

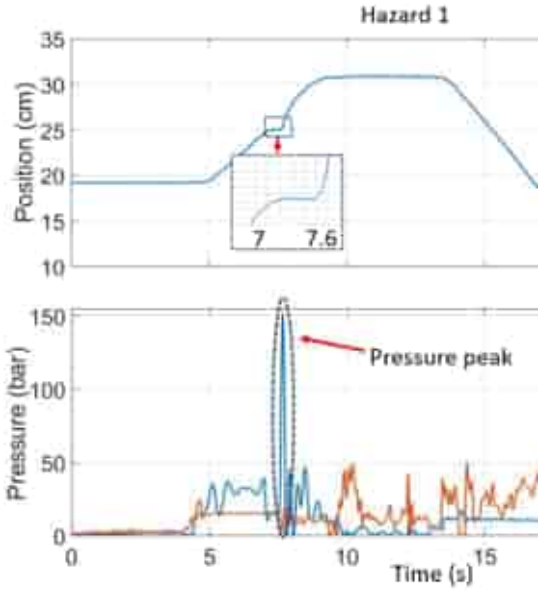


Machine Performance Level required for steering ‘a, b, c, d, e’
[ISO 13849]

V.Singh et. al. "Simulation Study of a Fail-Safe Steer-by-Wire for Heavy Earth Moving Machinery." Fluid Power Systems Technology. Vol. 87431. ASME, 2023.

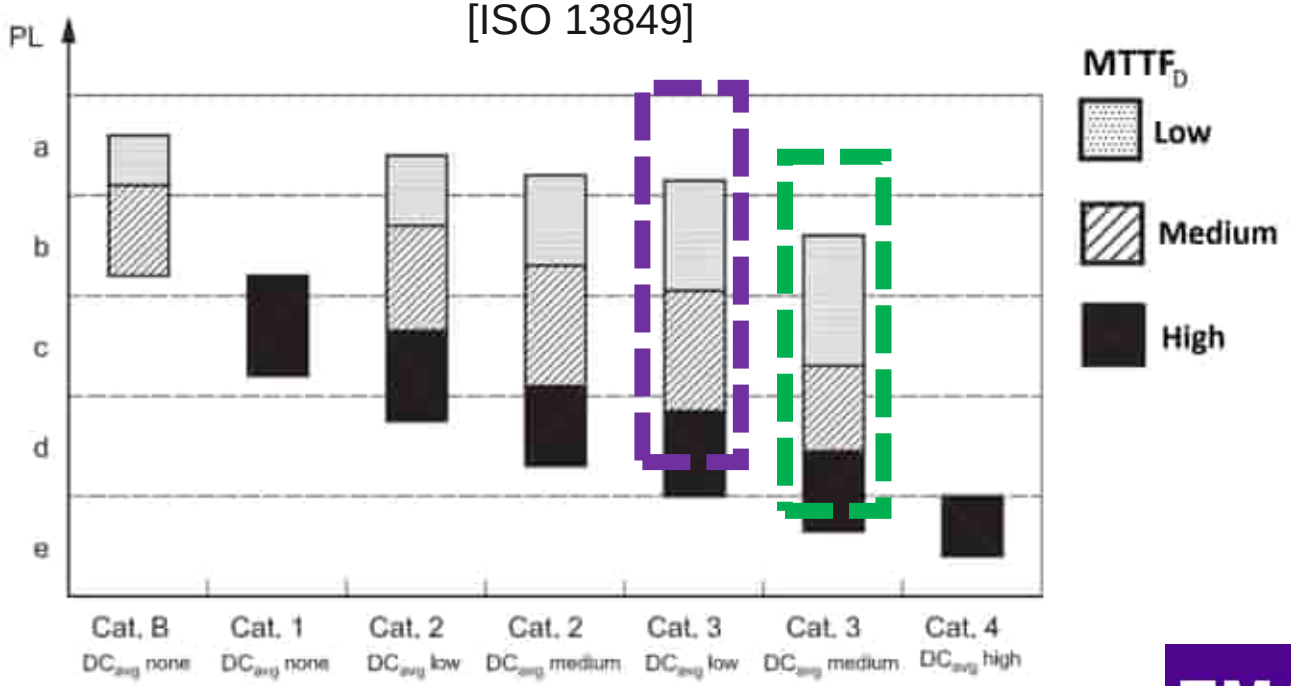
Tampereen yliopisto

Improve Functional Safety of Articulated Steering



Example: loss of power in primary steering (Hazard 1) at t = 7s **

[ISO 13849]



EM/MA-2

Even Low Diagnostic Coverage (60%-90%) results in Performance Level 'd' *
EHA: Backup steering activates within 600ms for most critical hazards**

Performance level of 'e' possible with higher Diagnostic Coverage.
EHA+AI-based solution: Average time for fault detection in tested cases is 155ms for uncommanded steering, while 307ms for loss of power in primary steering***

V.Singh et. al. "Simulation Study of a Fail-Safe Steer-by-Wire for Heavy Earth Moving Machinery." Fluid Power Systems Technology. Vol. 87431. ASME, 2023
***Vinay Partap Singh et. al.,"Hazard-free Steer-by-wire In Articulated Heavy Earth Moving Machinery Using Co-simulation Model." 14th IFK Dresden, Germany (March 2024).*
****Vinay Partap Singh et. al., "Intelligent Approach to Enhance Redundancy in Novel Steer-by-Wire for Heavy Earth Moving Machinery." (GFPS 2024) June 17-20, Sweden.*

Finnish Road Map

2025

Start point

2028

Results of Academic projecs

2031

Results of Company Development

2035

Finland Net Neutral Target

Contact Tatiana for details!
tel. +358 50 5940496,
tatiana.minav@tuni.fi

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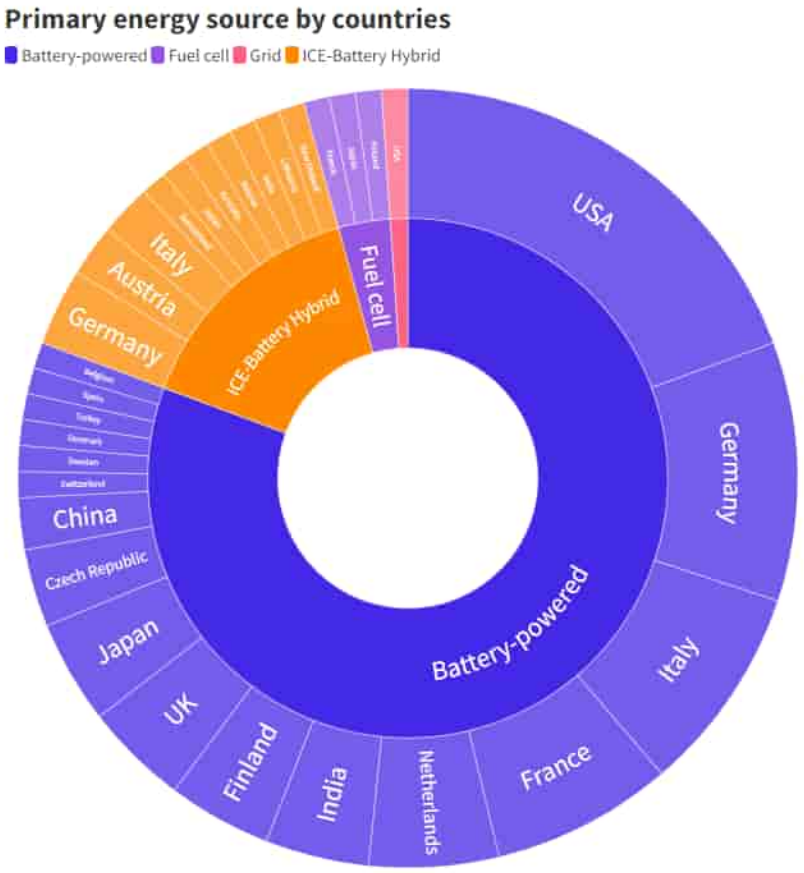
Open science

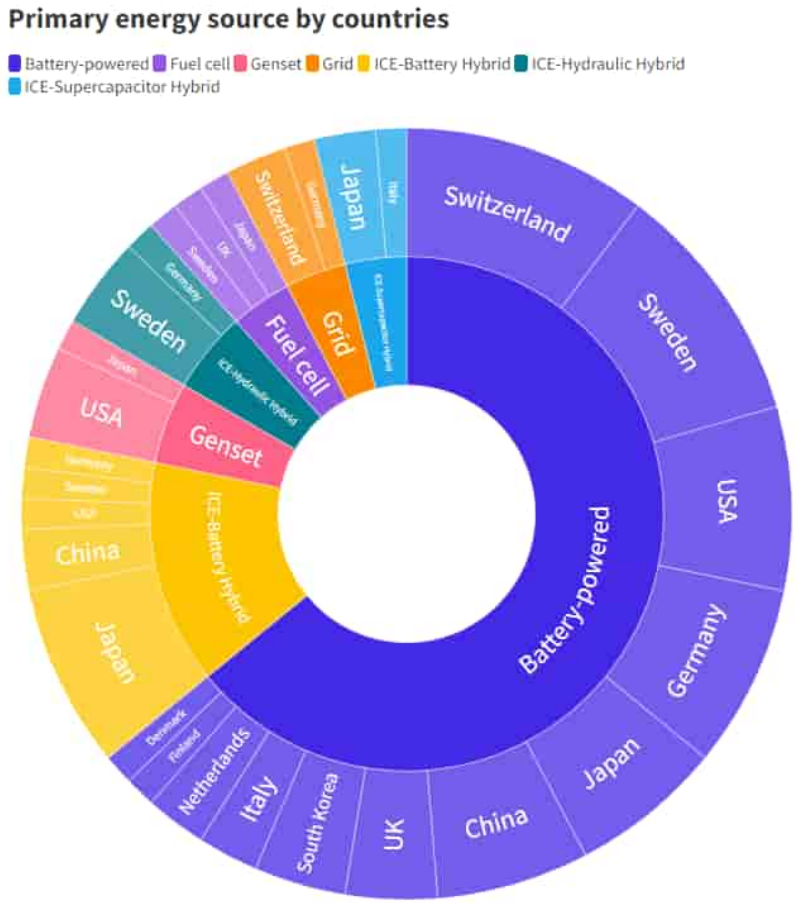
Check Machinopedia!

Learn about market state-of-the-art of hybrid and electric off-road machinery

https://research.tuni.fi/iha/



Agricultural machinery



Construction machinery

Machinopedia

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https://research.tuni.fi/iha/

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Open code

https://research.tuni.fi/iha/

Our Doctoral Student, **Abid Abdul Azeez** has created a gitHub repository regarding Time-Series Multi-Class Classification on the topic "Optimizing Time-Series Multi-Class Classification Utilizing Feature Evaluation Methods". The repository demonstrates the methodology implemented to enable hydraulic check valve fault classification in a Pump-controlled Electro-Hydrostatic actuator for Crane system. The methodology can be implemented on any time-series data to process raw data and prepare it to train several Machine Learning/ Deep Learning algorithms to perform the required classification task. The optimizing technique enables to reduce computational power requirements and provide better prediction accuracies.
Get Involved! 🤝 Check out the repository, give it a star ⭐, and feel free to fork and contribute.

Your feedback and contributions are invaluable in making this project even better!

The link to the repository:

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esearch.tuni.fi/iha/

Work cycle data is available (open access)

- Measured work cycle data of a 6-ton wheel loader type machine
- Short Y-cycle for loading gravel
- 440 second data in .mat format
- The data contains e.g.:
  - pressures,
  - piston positions,
  - flow rates,
  - engine RPM,
  - fuel rate,
  - machine speed
- Please use and cite:
  https://doi.org/10.5281/zenodo.10639199

🚜 Measured Y work cycle data for 6-Ton Wheel Loader
Available for Download!

Tampere University

Coming Phds defence

https://research.tuni.fi/iha/

Public defence

Abid Abdul Azeez: AI-based fault detection reduces downtime of off-road machines

Tampere University

Korkeakoulunkatu 6, Tampere

Hervanta campus, in Konetalo, auditorium K1702 and remote connection (link to be added)

21.2.2025 12.00–16.00 (UTC+2)

English

http://urn.fi/URN:ISBN:978-952-03-3796-4

Free of charge

Tampere University

Save the date!

https://research.tuni.fi/iha/

See you in Tampere, Finland for **Scandinavian International Conference on Fluid Power (SICFP)**

SICFP27 will be hosted by #IHA_TampereUni!

- **Days: 1-3 June 2027**
- **Location: Tampere Talo**

https://research.tuni.fi/iha/

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Welcome to IHA - Innovative Hydraulics and Automation

Tampere University

Answers are coming!
Open for collaboration

https://research.tuni.fi/iha/

Tatiana Minav

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IHA - Innovative Hydraulics and Automation

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