

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

Among the world's top universities

10

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

Business

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

business and economics (176–200th)

- physical sciences (201–250th)
- engineering (251–300th)
- computer science (301–400th)

40

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



Technology







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 University
- Several Duties of Trust in ASME, IEEE and GFPS (FPNI)





FLOWGAIT

Mevea

Simulation solutions

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

Graduates By Original Nationality





STATISTICS OF PHD'S GRADUATED



RESEARCH IN HEAVY DUTY PARALLEL ROBOTICS







PARALLEL KINEMATIC MOTION PLATFORMS

HYDRAULIC

ELECTRIC





RESEARCH IN HEAVY DUTY PARALLEL ROBOTICS













Cadarache,



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





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





Nominal pressure, bar 200 Hydraulic machine displacement cm3/rev 19 Nominal flow rated, I/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 1:3Gear efficiency estimate 0.95 Electric motor power 7 kW, S3 70 % Electric motor speed range0 – 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.





Electro-hydraulic Actuator (Parker) under test



Electrification is the key, but



~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:



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 highefficiency range

Disadvantages:

• Cycle duration increases without switching optimization.

Path planning algorithm (modified A*) Learning phase f(n) = g(n) + h(n)**Evaluation function:** Energy consumed by a cylinder: Cost of the Heuristic $E_{cyl} = \int_0^T P(t)Q(t) dt$ (distance to the goal) path 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 26 3D matrices containing 2) Mesh the space 3) Obtain energy matrices using simulations energy needed to move to a neighbor cell



THE MOST EFFICIENT PATH IN MANIPULATION





3-D Experiment example



ASME

The American Society of Mechanical Engineers ® ASME [®]



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



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SampleName (0.0): Sim Time	120
SampleName (0.0): Input BoomLift	-0
SampleName (0.0): Mass in Hopper	1200
SampleName (0.0): Input Bucket	0
SampleName (0.0): Input Slew	-0
SampleName (0.0): Marker Left	-0
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5SR: GSR Conductance (Shimmer GSR 600B)	4,8
SSR Peaks (Shimmer GSR 6008); Tonic signal (microSiemens)	4,8
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SSR Peaks (Shimmer GSR_600B): Peak detected (binary)	-0
CG Heart Rate (6C54 ECG): Heart Rate	-72
ICG Momentary HRV (6C54 ECG): SDNN	40
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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



CFI

Use case: mobile log crane









LFI









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

- >> 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

Note: Note: <th< th=""><th>IATLAB R2024b - academic use</th><th>e</th><th></th><th></th><th></th><th></th><th></th></th<>	IATLAB R2024b - academic use	e					
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CAD Model, Laboratory of Intelligent Machines, LUT University

REMOTE OPERATION





HAPTIC INTERFACE

- 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



HAPTIC INTERFACE







Thank you for your attention!



LUT University

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