Enhanced PLCA for Humanoid Robots

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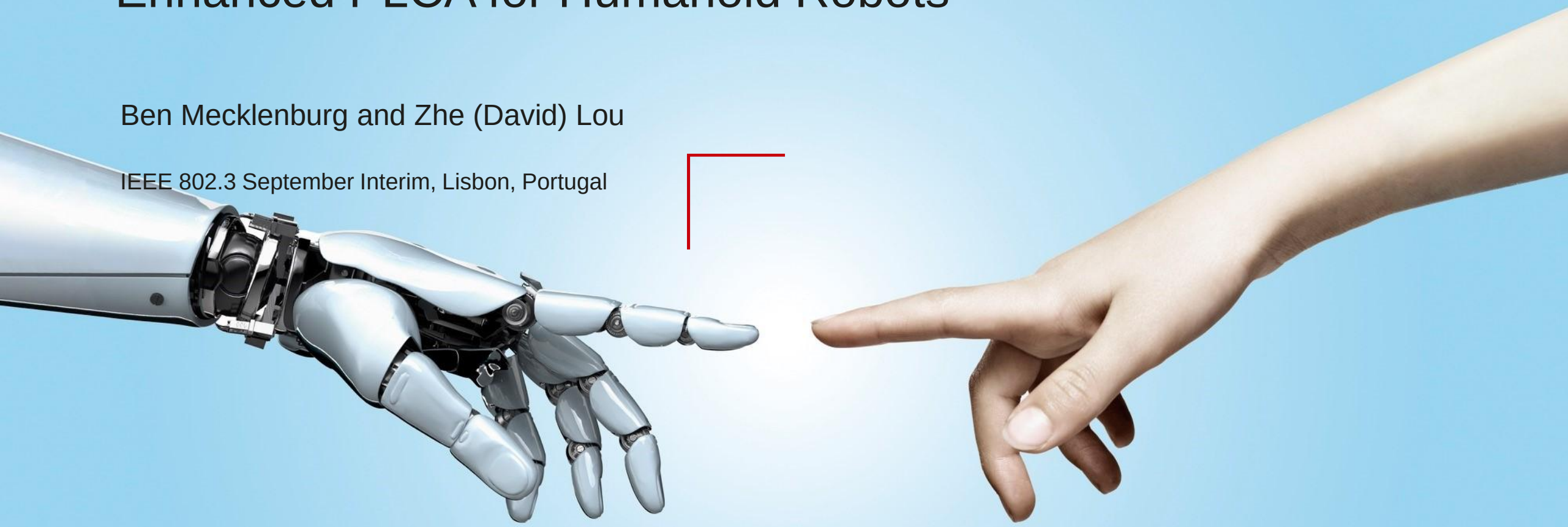

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Agenda

Goal: **Trend scouting on humanoid robotic use case(s)**

Motivation

- Growing Market
- Close to automotive network architecture but with more severe requirements

Architecture and Network Topology

- Centralized / domain architecture
- Dexterous Hand specifically challenging to solve

Early assessment of network requirements for humanoid robotics

- 1 kHz rate for motion control and sensing
- Mixed critical network segments for motion control, sensing, audio, ..

Motivation

Markets

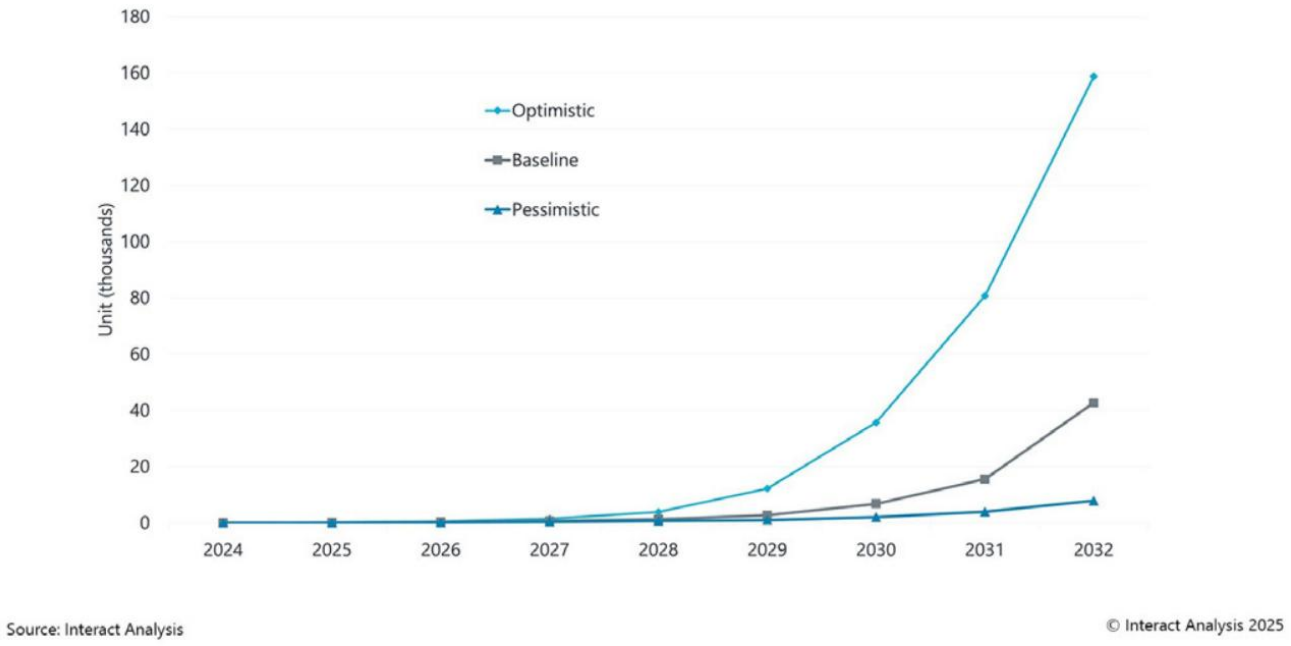


Figure 1: Global Humanoid Robot Shipment by Scenarios [5]

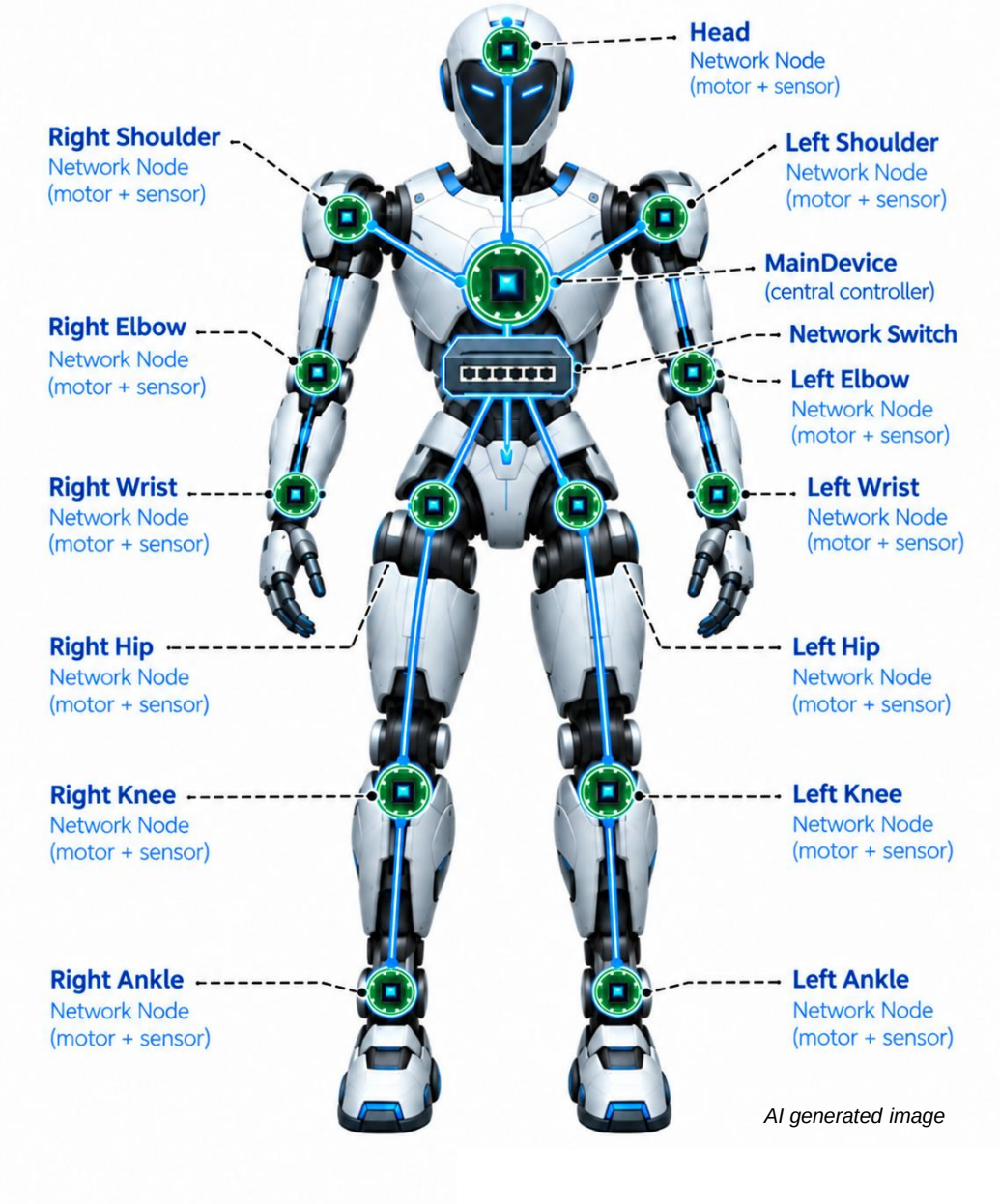
- Rapidly growing market
- non-transparent and rapidly changing, hence difficult to predict

Mass production market with similarities to automotive:

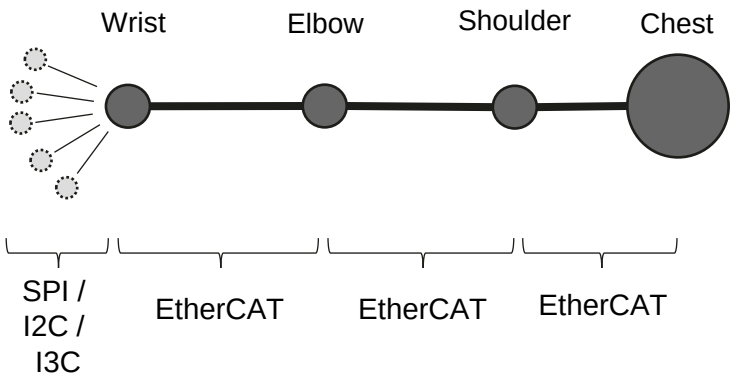
- Highly complex distributed system
- Very cost sensitive
- Weight reduction and power consumption is essential
- Humanoid robotic networks are similar to automotive networks but have even stricter requirements (limited hardware footprint, cycle time, ..)

Network Topology

- Current humanoid robots are build on a centralized / domain architecture
- Applications include vision, tactile, motion control, audio, diagnostics, ..
- Most humanoid robots use EtherCAT, Ethernet, CAN, RS-485, ..
- Dexterous robotic hand as a major challenge
  - high sensitivity,
  - strong force/torque,
  - very small form factor,
  - high real-time requirements



Dexterous Robotics Hands – A Glimpse



- Dexterous hand is a single network node that uses SPI / I2C / I3C to operate motors with a compute node in the wrist (also sending position information to the main compute node in the chest)

Two Architectures:

- In-hand actuation
  - Motors located at each joint of each finger
  - Low- and mid priced hands
- Remote / tendon-based actuation
  - Motors located in the forearm connected to joints via tendons (human-like)
  - Mid- and high-priced hands

(Potential) trends:

- Towards modularization of fingers [9]
- Towards exchange of tools

Advantages and Requirements of SPE for Humanoid Robots

General advantages:

- Thin SPE cables reduce mass and hardware footprint
- Efficient power delivery (PoDL)
- One unified Ethernet network (simplified network architecture for complex distributed systems)

Requirements:

- Multiple sources state a 1 ms cycle for motion control as requirements [1][7] ..
- .. other sensor/actuation loops typically have lower requirements (e.g., 2ms, 4 ms, 8ms cycles)
- Multitude of sensors require mixed-criticality network segments (tactile / robot state sensing, motion control and sensing, audio, ..)

Example Requirements and Traffic Classes*

Traffic class	Example	Rate / bandwidth	Latency
Tactile and force, sparse	skin patches; contact and slip detection [6]	50 to 100 Hz per node; raster-scanned arrays rarely exceed 100 Hz [6]	Latency-critical for slip reaction, tolerant of single-sample loss
Diagnostics and maintenance	Health telemetry, firmware download in maintenance mode [1]	Aperiodic, bulk	None / Best-Effort
Audio	Single or few microphones, command interface	4 microphones ~1.02 Mbps [8][10] (e.g., 0.26 Mbit/s per microphone for 16 kHz sampling with 16-bit per sample per microphone)	10’s of ms delay tolerable
Motion control, fast loop	Dexterous hand joint position control [1][7]	500 Hz to 1 kHz rate [1][7]; kbps to 10 Mbps, rare cases 100 Mbps [3]	1 ms – 2 ms [2]
Tactile and force, dense	Shadow Tactile Fingertip, 2+ tips per hand [1]	1 kHz; ~1.63 Mbps for two tips (per hand)	1 ms [2]
Vision and perception	Cameras, lidar, radar; vision-based [3][4]	100 Mbps to above 1 Gbps [3][4]	Relaxed relative to control

*to be verified with humanoid robotics companies

Conclusion and Next Steps

- Humanoid Robotic market is predicted to grow quickly, rapidly changing and non-transparent

- This presentation serves as trend scouting with some intermediate requirements

- Multiple sources state a 1 ms cycle for motion control as requirements [1][7]
- .. other sensor/actuation loops typically have lower requirements (e.g., 2ms, 4 ms, 8ms cycles)
- Multitude of devices and sensors require mixed-criticality network segments (tactile / robot state sensing, motion control, audio, ..)

- T1S is a potential solution within the dexterous robotic hand [9] and as connection between central node and legs and arms

- Trends:
  - (Automotive) zonal network architecture could be a logical next step [5]
  - Dexterous robotics hand: towards modularization of fingers or exchange of tools during runtime [9]

- We are currently discussing and verifying the requirements of humanoid robots with partners

Looking Forward to your Comments!

References

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