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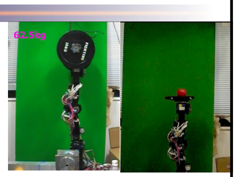
Fundamental Technology on Dependable SoC and SiP for Embedded Real-Time Systems

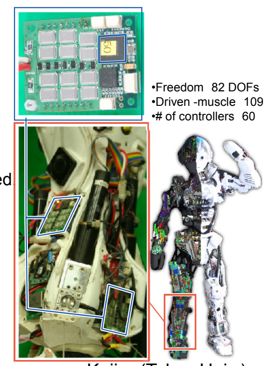
Nobuyuki Yamasaki (Keio Univ.)
Kikuo Wada (NECAT)
Masayuki Inaba (Tokyo Univ.)

Requirements in the Field of High-end Robots

- Requirements for a high power motor driver
  - Real-time processing under high speed communication
    - Motor temperature estimation processing for very high power motor driving such as 20 times overdrive rated at 200W
      - Current control cycle: 10msec → 10μsec
  - Reliability, availability, and safety on communication and control under high-stress environment
    - Huge current noise, unusual situation such as cable disconnection, etc
    - ⇒ Prevention of fatal accidents
- Requirements for a large scale distributed motor driver
  - Microminiaturization of the controller (size: 36x46x7mm)
    - Area constraint of the digital control part: 20mm square
    - Real-time communication and control under the size constraint
      - Poor processing power of current MPU (H8S/2215 16MHz)
        - Limit of control cycle: 1msec → 10μsec
        - External computation servers (Xeon 3.4GHz x 2) are required
      - High communication traffic 7.2MB/sec
        - Limit of Inter-device synchronization cycle: 8msec (USB) → 100μsec (*Responsive Link*)
    - Reliability of communication under the size limitation
      - Severe noises under the logic servo systems
  - Power saving scheme under the large scale distributed control
    - Static power of a whole logic part: 80W@idle → 1W

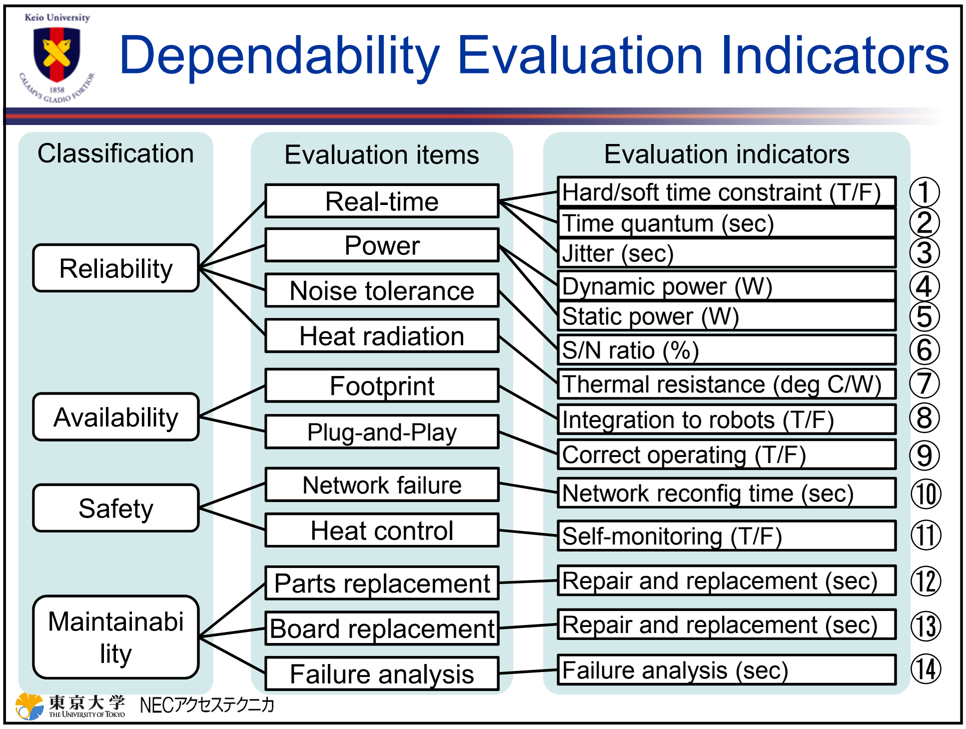


High power leg: HRP3L-JSK (Tokyo Univ.)
Continuous current 80[V],100[A],15[sec]
Peak current 80[V],200[A],10[msec]



•Freedom 82 DOFs
•Driven -muscle 109
•# of controllers 60

Kojiro (Tokyo Univ.)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Dependability Evaluation Indicators
Classification
Evaluation items
Evaluation indicators
Reliability
Availability
Safety
Maintainability
Real-time
Power
Noise tolerance
Heat radiation
Footprint
Plug-and-Play
Network failure
Heat control
Parts replacement
Board replacement
Failure analysis
Hard/soft time constraint (T/F) ①
Time quantum (sec) ②
Jitter (sec) ③
Dynamic power (W) ④
Static power (W) ⑤
S/N ratio (%) ⑥
Thermal resistance (deg C/W) ⑦
Integration to robots (T/F) ⑧
Correct operating (T/F) ⑨
Network reconfig time (sec) ⑩
Self-monitoring (T/F) ⑪
Repair and replacement (sec) ⑫
Repair and replacement (sec) ⑬
Failure analysis (sec) ⑭
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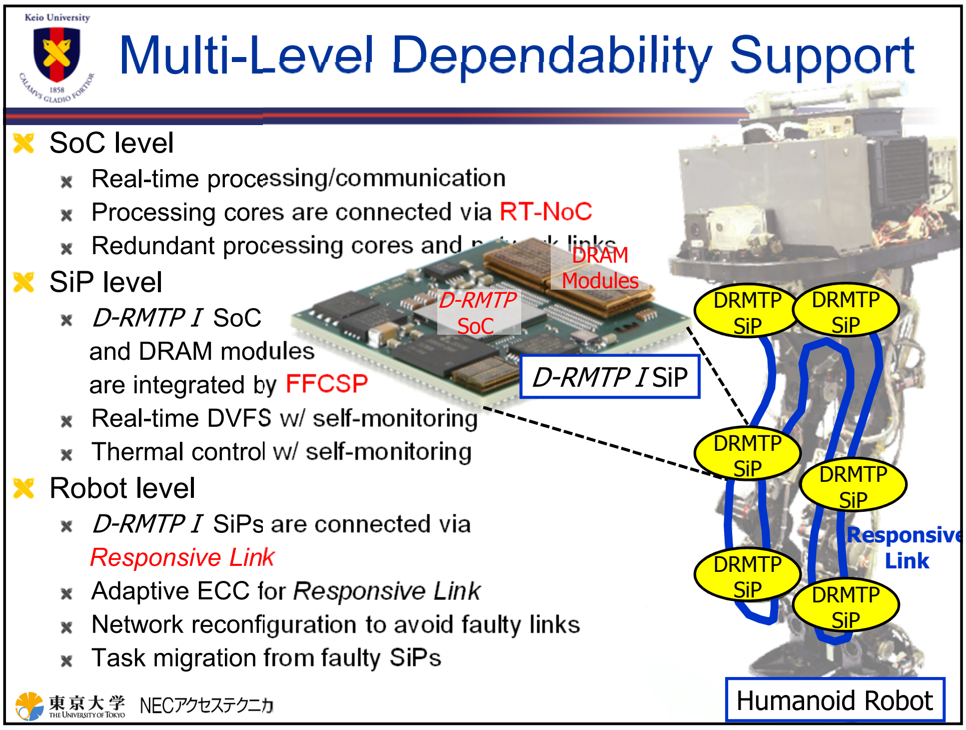
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Multi-Level Dependability Support
SoC level
Real-time processing/communication
Processing cores are connected via RT-NoC
Redundant processing cores and
SiP level
D-RMTP I SoC and DRAM modules are integrated by FFCSP
Real-time DVFS w/ self-monitoring
Thermal control w/ self-monitoring
Robot level
D-RMTP I SiPs are connected via Responsive Link
Adaptive ECC for Responsive Link
Network reconfiguration to avoid faulty links
Task migration from faulty SiPs
DRAM Modules
D-RMTP SoC
D-RMTP I SiP
DRMTP SiP
Responsive Link
Humanoid Robot
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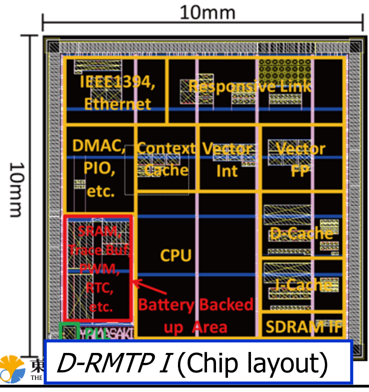
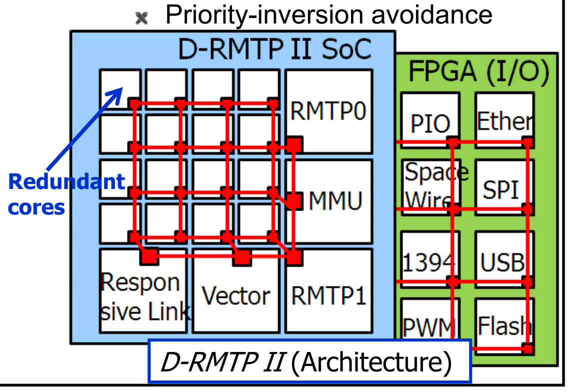
SoC Level Dependability

- *D-RMTP I*
  - RMT processor, I/O peripherals
- IPC control for precious real-time execution ②
- Trace buffer for fault analysis ⑭
- *D-RMTP II* (under development)
  - RMT processor & many cores
  - Redundant cores for faults ⑫⑬
- Real-time NoC ②
  - Priority-based arbitration
  - Priority-inversion avoidance



D-RMTP I (Chip layout)



D-RMTP II (Architecture)

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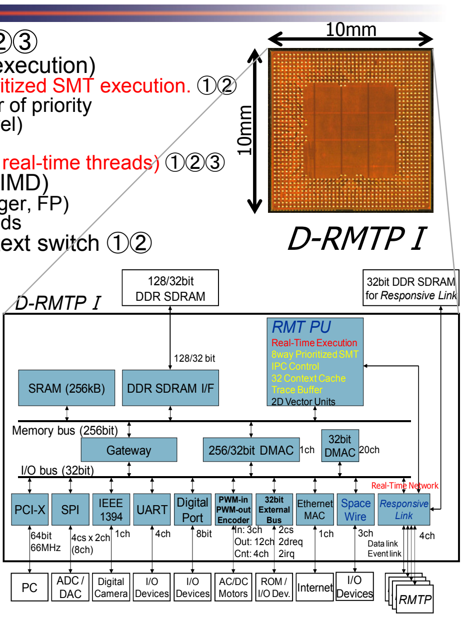
SoC for Embedded Real-Time Processing: *Responsive Multithreaded Processor (RMTP)*

- Real-time processing unit: *RMT PU* ①②③
  - Real-time execution mechanism (RMT execution)
    - A context switch is converted to the prioritized SMT execution. ①②
    - 8-thread simultaneous execution in order of priority
    - Thread control bases on priority (256-level)
    - Thread wake-up by an interrupt
    - IPC control (processing speed control of real-time threads) ①②③
  - Multimedia processing units (Vector + SIMD)
    - Flexible 2D vector processing units (Integer, FP)
    - Shared vector registers by multiple threads
  - Context cache (32threads): 4-clock context switch ①②
  - Execution trace buffer
- Real-time communication : *Responsive Link* x 5 ①②⑩
  - Preemption of communication: Packet overtaking by priority
  - Packet acceleration/deceleration: Packet priority can be replaced with new priority at each node.
  - ISO/IEC 24740
- Computer I/O peripherals
  - PCI-X, IEEE-1394, Ethernet, etc.
- Control I/O peripherals
  - SpaceWire (3-ch switch) ①
  - PWM Generators, Pulse Counters, etc.



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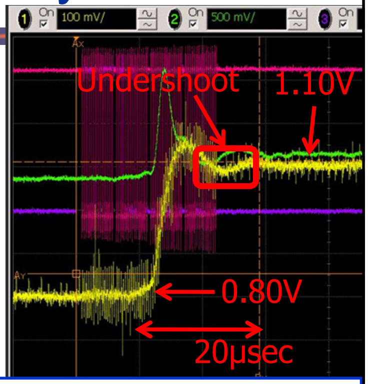
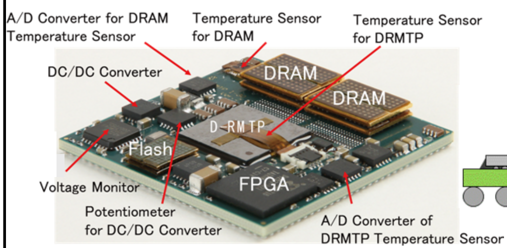
SiP Level Dependability

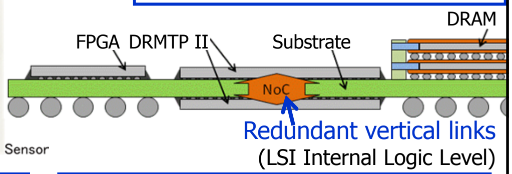
- *D-RMTP I* SoC and DRAM modules are integrated on a SiP Interposer by FFCSP
- Real-time DVFS (*D-RMTP I*) ② ④
  - Low-power while guaranteeing deadline
  - Safety voltage control w/ self-monitoring
- Prevent *D-RMTP I* & DRAM from Overheating
  - Thermal control w/ self-monitoring ⑪



Voltage transition (0.8→1.1V)



Voltage & thermal control (*D-RMTP I*)



Vertical chip stacking (*D-RMTP II*)

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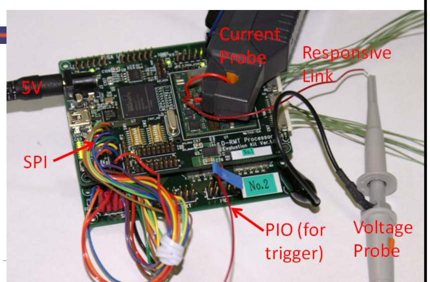
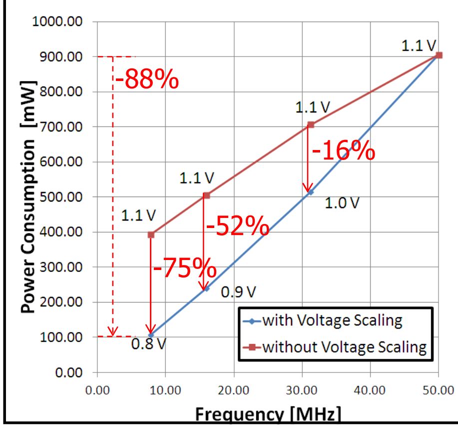
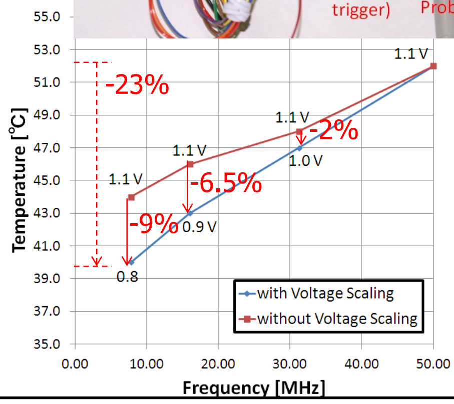
RT-DVFS on *D-RMTP I* SiP

- Power consumption [mW] ④
- Temperature [°C] ⑪
- Measured by voltage and thermal sensors on *D-RMTP I* SiP at run-time







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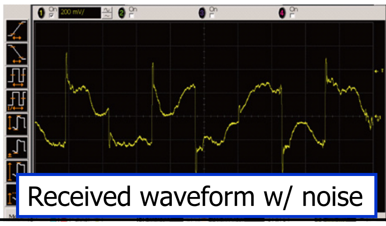
Robot Level Dependability

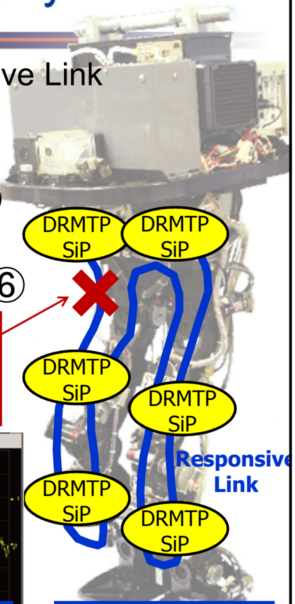
- *D-RMTP I* SiPs are connected via Responsive Link
- Permanent faults (links & boards)
  - Network reconfiguration to avoid faulty links ⑩
  - Task migration from faulty *D-RMTP I* SiPs ⑫⑬
- Transient faults (links)
  - Adaptive ECC & line codes for Responsive Link ⑥

ECC code (4Byte)	ECC code (1Byte)	Line code
Reed-Solomon (48, 32)	BCH (16, 8)	BS+NRZI (9, 8)
		8b10b (10, 8)
		4b10b (10, 4)
	Hamming (12, 8)	BS+NRZI (9, 8)
		8b10b (10, 8)
		4b10b (10, 4)
	None	8b10b (10, 8)
		4b10b (10, 4)
None	BCH (16, 8)	BS+NRZI (9, 8)
		8b10b (10, 8)
		4b10b (10, 4)

(1) Permanent faults by link disconnection
(2) Transient faults by motor noise



Received waveform w/ noise



Humanoid Robot

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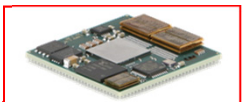
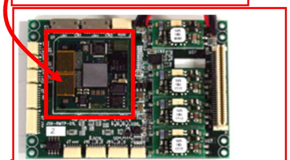
Basic Experiments of High-power Actuation

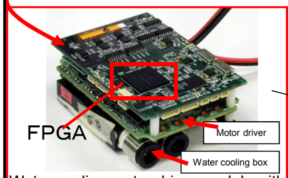
- Testing environment for real-time dependability verification



D-RMTP I SoC/SiP(30x30mm)

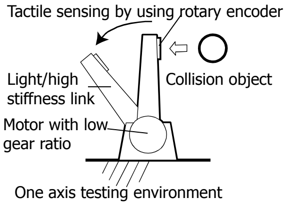


Control board with D-RMTPI SoC/SiP

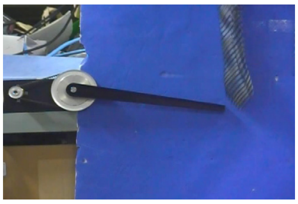


Water cooling motor driver module with *D-RMTP I* SoC/SiP(85x60x34mm) ⑧

- Experiment of motor control on *RMTP* ④⑤⑥
  - Real-time control thread: 1msec
  - Transmitter/Receiver communication thread: 100msec

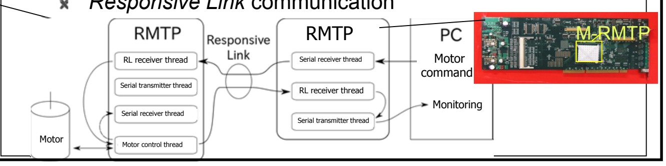


One axis testing environment



Demonstration of avoiding collision object

- Experiment of communication between multi-*RMTPs* ①②③
  - Driver board with *RMPT* - PCI testing board with *RMTP*
  - *Responsive Link* communication



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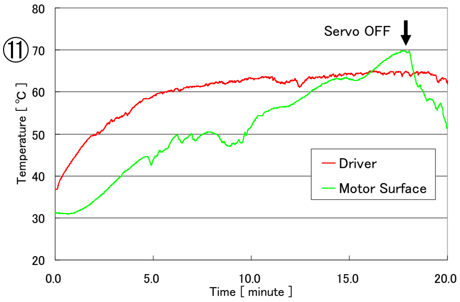
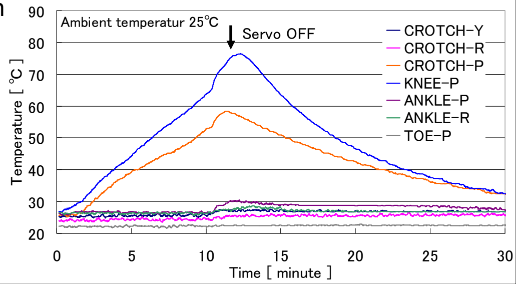
Dependability Verification for Robot Thermal Monitoring *RMTP* Motor Driver

- Temperature of *RMTP* Motor Driver ⑪
  - Temperature of motor surface and motor driver
  - Maximum 7A motor current



- Measurement of Actual Robot Temperature (HRP-2 Leg) ⑪
  - Motor temperature on squat down pose (Measured by external thermometer)
  - Integration of thermometer into motor driver should be
  - Temperature of inside motor should be estimated from outside temperature



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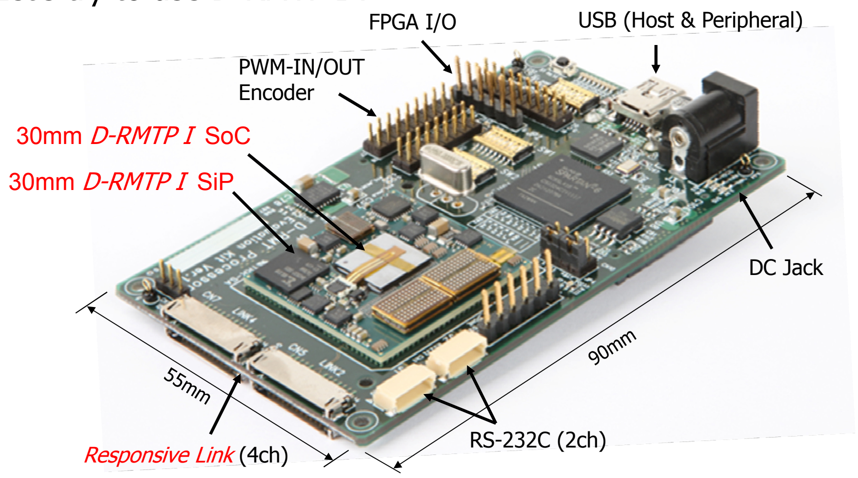
D-RMTP I Evaluation Kit

Let's try to use *D-RMTP I* !



For more information, please contact:
Yamasaki-Matsutani lab., Keio Univ.
http://www.ny.ics.keio.ac.jp/

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