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)
- 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
### Dependability Evaluation Indicators

<table>
<thead>
<tr>
<th>Classification</th>
<th>Evaluation items</th>
<th>Evaluation indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reliability</td>
<td>Real-time</td>
<td>Hard/soft time constraint (T/F)</td>
</tr>
<tr>
<td></td>
<td>Power</td>
<td>Time quantum (sec)</td>
</tr>
<tr>
<td></td>
<td>Noise tolerance</td>
<td>Jitter (sec)</td>
</tr>
<tr>
<td></td>
<td>Heat radiation</td>
<td>Dynamic power (W)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Static power (W)</td>
</tr>
<tr>
<td></td>
<td>Footprint</td>
<td>S/N ratio (%)</td>
</tr>
<tr>
<td>Availability</td>
<td></td>
<td>Thermal resistance (deg C/W)</td>
</tr>
<tr>
<td>Safety</td>
<td>Plug-and-Play</td>
<td>Integration to robots (T/F)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Correct operating (T/F)</td>
</tr>
<tr>
<td>Maintainability</td>
<td></td>
<td>Network reconfig time (sec)</td>
</tr>
<tr>
<td></td>
<td>Parts replacement</td>
<td>Repair and replacement (sec)</td>
</tr>
<tr>
<td></td>
<td>Board replacement</td>
<td>Repair and replacement (sec)</td>
</tr>
<tr>
<td></td>
<td>Failure analysis</td>
<td>Failure analysis (sec)</td>
</tr>
</tbody>
</table>

### Multi-Level Dependability Support

**SoC level**
- Real-time processing/communication
- Processing cores are connected via RT-NoC
- Redundant processing cores and network links

**SIP level**
- D-RMTP I SoC
- 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

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Humanoid Robot
SoC Level Dependability

- D-RMTP I
  - RMT processor, I/O peripherals
  - IPC control for precious real-time execution
  - Trace buffer for fault analysis

- D-RMTP II (under development)
  - RMT processor & many cores
  - Redundant cores for faults
  - Real-time NoC
  - Priority-based arbitration
  - Priority-inversion avoidance

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

- Real-time processing unit: RMT PU
  - Real-time execution mechanism (RMT execution)
    - A context switch is converted to the prioritized SMT execution
    - 8-thread simultaneous execution in order of priority
    - Thread control bases on priority (256-level)
  - IPC control (processing speed control of real-time threads)
  - Multimedia processing units (Vector + SIMD)
    - Flexible 2D vector processing units (Integer, FP)
    - Shared vector registers by multiple threads
  - Real-time execution mechanism (RMT execution)
  - 32 Context Cache
  - Trace Buffer
  - Execution trace buffer

- Real-time communication:
  - Responsive Link x 5
  - Preemption of communication
  - 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)
  - PWM Generators, Pulse Counters, etc.
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 & thermal control (D-RMTP I)

Vertical chip stacking (D-RMTP II)

RT-DVFS on D-RMTP I SiP

- Power consumption [mW] ④
- Temperature [°C] ⑪
- Measured by voltage and thermal sensors on D-RMTP ISiP at run-time
Robot Level Dependability

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

### ECC code

<table>
<thead>
<tr>
<th>ECC code (4Byte)</th>
<th>ECC code (1Byte)</th>
<th>Line code</th>
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<tbody>
<tr>
<td>BCH (16, 8)</td>
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<td>BS+NRZ (9, 8)</td>
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<td>Reed-Solomon (48, 32)</td>
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</table>

Received waveform w/ noise

### Basic Experiments of High-power Actuation

- Testing environment for real-time dependability verification
- Experiment of motor control on RMTP
  - Real-time control thread: 1msec
  - Transmitter/Receiver communication thread: 100msec
- Tactile sensing by using rotary encoder
- Motor with low/gear ratio
- Collision object
- Demonstration of avoiding collision object

- Experiment of communication between multi-RMTPs
  - Driver board with RMPT - PCI testing board with RMTP
  - Responsive Link communication
Dependability Verification for Robot Thermal Monitoring RMTP Motor Driver

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

- Measurement of Actual Robot Temperature (HRP-2 Leg)
  - 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

Let’s try to use D-RMTP I!

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