Design Considerations for Embedded Sensor Solutions in Industrial Applications

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Renesas Technology Europe

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Key Requirements and Use Cases

**Industrial Application**
- Robustness
- Reliability
- Safety
- Realtime
- Standardization

**Environment Conditions:**
- Temperature
- Electrical Noise
- Mechanical

**Life time**
- Quality Level
- Recovery

**Fail-safe**
- Redundancy

**Deterministic**

**Interoperability**

**Embedded Sensor**
- Measurement
- Intelligence
- Connectivity
- Security
- Tiny
- Low Power
- (Actuator Function)

**Data Storage**
- Pre-processing
- Adaptivity

**Response**
- Event
- Setup

**Encryption**
- Decryption
- Key Setup

**Alarm**
- Display
- Control

**Battery**
- Energy Efficient

**Accuracy**
- Realtime
- Range

**Range**

**Environment Conditions:**
- Temperature
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- Temperature
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System Concept

- Separate measurement function from other intelligence to simplify certification process?
- Separate communication interface from other intelligence for modularity?
- Or integrate everything to achieve small form factor?

Display options:
- Display has built-in display driver
- MCU has built-in display driver
- LCD SW driver, TFT Direct Drive

Non volatile memory for data storage (data flash) and adaptivity (firmware update)

Power supply
- Uncritical: Line powered or laptop size battery
- Medium: re-chargeable batteries, medium lifetime
- High: 10~20 years of lifetime (Calculation of runtime, wake-up time, sleep time needed)

Increase reliability and safety by
- self-test SW or HW (according to e.g. IEC60730)
- redundant MCU concept (watchdog MCU, asymmetric/symmetric dualcore, etc.)

Availability of development tools, application notes and sample code (as close as possible to real application) to improve time-to-market
- Mechanical aspects (Industrial housing, etc.)
MCU Selection Criteria for Industrial Sensor Applications

✓ Low Power Features
  ✓ Stop mode (wake up by external event)
  ✓ Low voltage operation (1.8V)
  ✓ Subclock
  ✓ Real Time Clock

✓ Reliability Features
  ✓ Power-On-Reset
  ✓ Low Voltage Detection (2 steps)
  ✓ On Chip Oscillator (low speed / high speed)
  ✓ Oscillator stop detection
  ✓ Watchdog
  ✓ Protected Registers

✓ Memory features
  ✓ Scalable memory variants
  ✓ Flash memory (BGO programming mode, 20 years data retention)
  ✓ Data Flash
  ✓ Protection

✓ Sensor Features
  ✓ ADC, External Interrupts, Event Counter, Input Capture, Wake-Up
  ✓ AD trigger by any external or interrupt source

✓ Actor Features
  ✓ DAC, PWM, Output Compare

✓ Performance
  ✓ Enough for data pre-processing, protocol handling, user interface
  ✓ DMA or DTC (Data Transfer Controller)

✓ Supplier
  ✓ Qualified for Industrial / Automotive applications
  ✓ Excellent quality record
  ✓ Long term supply guarantee
  ✓ toolchain
  ✓ support
### MCU proposals for intelligent sensors

<table>
<thead>
<tr>
<th>Type</th>
<th>R8C/18</th>
<th>R8C/24</th>
<th>H8/38602RF</th>
<th>H8/38076RF</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>R8C/19</td>
<td>R8C/25</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>R8C/1A</td>
<td>R8C/2A</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>R8C/1B</td>
<td>R8C/2B</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Package</td>
<td>20pin SSOP 4.4x6.5mm 0.65mm pitch or 28pin QFN 5x5x0.75mm 0.5mm pitch</td>
<td>64pin LGA 6x6x6mm 0.66mm pitch</td>
<td>32pin QFN 5x5x6mm 0.5mm pitch</td>
<td>TLP85 7x7x7mm 0.65mm pitch</td>
</tr>
<tr>
<td>Performance</td>
<td>16bit CPU 20MHz</td>
<td>16bit CPU 40MHz</td>
<td>16bit CPU 10MHz</td>
<td>16bit CPU 10MHz</td>
</tr>
<tr>
<td>Low Power Modes</td>
<td>Stop Mode: 0.8µA Low Speed-OCO mode: 110µA</td>
<td>Stop mode: 0.8µA Low Speed-OCO mode: 110µA</td>
<td>Watch mode: 0.45µA/1.8V Subactive: 6µA/2V/32kHz Active: 1mA/2V/2MHz</td>
<td>Watch mode: 0.5µA/1.8V Subactive: 5µA/1.8V/32kHz Active: 1mA/1.8V/2MHz</td>
</tr>
<tr>
<td>Special Feature Highlights</td>
<td>I2C, SSI, UART, ADC, DAC Easy migration path to M16C,M32C,R32C</td>
<td>CAN, LIN, DTC 40MHz OCO Easy migration path to M16C,M32C,R32C</td>
<td>2.4kbps UART in subactive mode (38.4kHz) ADC @ 32kHz Fast wake-up IrDA</td>
<td>Low power communication Low power measurement Fast wake-up IrDa LCD driver and charge pump 14bit ADC (H838086)</td>
</tr>
<tr>
<td>Starter Kit</td>
<td>RSKR8C1B</td>
<td>RSKR8C23, 25, 27 RSKR8C2D, 2F</td>
<td>RSKH836079 RSKH838099</td>
<td>RSKH836079 RSKH838099</td>
</tr>
<tr>
<td>Example Sensor Application</td>
<td>Dirt Sensors for White Goods</td>
<td>Gas Sensors Smoke Sensors</td>
<td>Glucose Meters Electricity Meters Gas Meters Water Meters</td>
<td></td>
</tr>
</tbody>
</table>
## MCU proposals for intelligent sensors

<table>
<thead>
<tr>
<th>Type</th>
<th>H8SX/1622</th>
<th>SH7083</th>
<th>SH7125</th>
</tr>
</thead>
<tbody>
<tr>
<td>Package</td>
<td>TLP145 9mmx9mm 0,65mm pitch</td>
<td>112pin BGA 10mmx10mm 0,8mm pitch</td>
<td>QFN52 7,2x7,2mm, 0,4mm pitch or QFN64 8mmx8mm, 0,4mm pitch</td>
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<tr>
<td>Performance</td>
<td>32bit CPU 50MHz Onchip MUL/DIV</td>
<td>32 bit RISC 104MIPS@80MHz</td>
<td>32 bit RISC FPU 200MFLOPS peak performance Double/Single precision Sinus: 680ns double precision</td>
</tr>
<tr>
<td>Low Power Modes</td>
<td>6 low power modes HW standby: 3uA Deep standby: 4uA Deep standby (keep RAM): 19uA</td>
<td>Deep standby: 5uA SW standby: 10mA</td>
<td>SW standby: 5mA</td>
</tr>
<tr>
<td>Special Feature Highlights</td>
<td>16bit ADC (6 ch) Power cut off Smart Card IF</td>
<td>Most powerful MCU in smallest package</td>
<td>Easy migration path up to 480DMIPS/4.2GFlops MPUs (e.g. SH7722 for multimedia applications)</td>
</tr>
<tr>
<td>Starter Kit</td>
<td>RSKH8SX1622</td>
<td>RSKSH7086 RSKSH7286</td>
<td>RSKSH7124</td>
</tr>
<tr>
<td>Example Sensor Application</td>
<td>Humidity Sensor Thermo Sensor</td>
<td>Cameras Motor Drives Compact Health Goods</td>
<td>Cameras Inverters Compact Health Goods</td>
</tr>
</tbody>
</table>
How to combine MCU and sensor

✓ Application Notes

✓ Connecting a **pyroelectric infrared sensor** to H8/300 Tiny series (rej06b0121.pdf)
✓ Connecting a semiconductor type **acceleration sensor** to H8/300 Tiny series (rej06b0129.pdf)
✓ Connecting a **pressure sensor** to H8/300 Tiny series (rej06b0130.pdf)
✓ Connecting a **gas sensor** for detecting air contaminants to H8/300 SLP (rej06b0194.pdf)
✓ Connecting a **angular velocity sensor** to H8/300 Tiny series (rej06b0221.pdf)
✓ Connecting an **acceleration sensor** to H8/300 SLP (rej06b0290.pdf)
✓ Connecting a **pressure sensor** to H8/300 SLP (rej06b0291.pdf)
✓ **Sensor connection** with low supply current using comparator and A/D converter (rej06b0644_h8300hslpap.pdf)
✓ **Lux meter** for M16C/26A (rej05b0811_m16cap.pdf)
✓ **Sensor's output impedance** under A-D conversion for M16C/62 (rej05b0278_m16cap.pdf)
✓ **Detailed usage guidelines of ADC** for H8/300 SLP (res0007_h8300slp.pdf)
✓ **Ultrasonic range finder** using H8/300 SLP (res0009_h8300slp.pdf)
✓ Direction finder using **hall effect sensor** with H8/300 SLP (res0010_h8300slp.pdf)
✓ **Safety Software** according to IEC60730 Class B (app22330.pdf)

Rich Selection of Small Sensors

- Silicon Micro Sensor
- Compression sensor
- Gyro Sensor (Angle Sensor)
- Temperature Sensor
- Acceleration Sensor
ADC Considerations: Traditional Approaches

Layout Considerations

- Use "Star" topology
- Avoid loops within a domain
- Avoid loops between domains
- Avoid crossing of domains
- Special care for all signals >0.5MHz (clock, SPI, etc.)
- Follow guidelines for all unused pins (connect to GND or unconnected output to "Low")

ADC Range and Resolution: SW controlled AGC

Choose from a selection of AD channels depending on signal energy

- HW AGC (G=2)
- AGC Control
- AN0(G=1)
- AN1(G=2)
- AN2(G=4)
- AN0(G=8)

ADC accuracy optimization: Dithering

Add Noise Level of ½ LSB to signal
Average over number of samples

(by Bob Maastra, Interstellar Research)
H8SX/1622 with full featured high precision ADC

- 16bit ΣΔ-ADC
- Offset Cancel DAC
- Differential/Single Ended Input
- Reference Voltages
- BIOS Circuit

![Diagram of H8SX/1622 with full featured high precision ADC](image)
H8SX/1622 with full featured high precision ADC

built in AGC

Voltage

Input Analog Signal (symmetric wave pattern case)

DSADDR
Max: H'7FFF
H'0001
H'0000
H'FFFF
Min: H'8000

Input Analog Signal is larger

Gain setting
x8
x4
x2
x1

Voltage Gain setting x8 x4 x2 x1

Input Analog Signal (symmetric wave pattern case)

DSADDR
Max: H'7FFF
Min: H'8000

DSADDR
Max: H'7FFF
Min: H'8000

DSADDR
Max: H'7FFF
Min: H'8000

DSADDR
Max: H'7FFF
Min: H'8000
H8SX/1622 with full featured high precision ADC

Built In Offset Control (Single Ended)

Voltage(V)

Max: H'7FFF
Min: H'8000

Input Analog Signal

Gain: x8
DOF = 0V (Default)

Gain: x8
DOF = Vin

Gain: x2
DOF = Vin

Condition:
AVccP=AVccD=AVccA=AVrefT= 3.0V
AVssP=AVssD=AVssA=AVrefB= 0V

* DOF: Analog level for offset cancellation (V)
* Vin: Center value of input Analog Signal
* DSADOF: Register value set in DSADOFn[9:0] for the corresponding channel
* AVrefT: ΔΣ reference voltage (high) (V), AVrefT <= AVccA
* AVrefB: ΔΣ reference voltage (low), AVrefB = AVssA

*DOF = DSADOF/2^10 x (AVrefT - AVrefB)
Industrial Networks
Industrial sensor networks: Industrial Ethernet

- Industrial Ethernet
  - Class A
    - Completely TCP/IP and UDP based
    - Ordinary ethernet Controller, Realtime handling by application layer
    - Candidates: Profinet, Modbus
  - Class B
    - Parallel channel for process data, TCP/IP timing controlled by process data driver
    - Ordinary Ethernet Controller
    - Candidates: Profinet-RT, Powerlink, Ethernet/IP
  - Class C
    - Parallel channel for process data, TCP/IP timing controlled by process data driver
    - Special Realtime Ethernet Controller
    - Candidates: Ethercat, Sercos, Profinet-IRT

H8S/2472:
- 176pin BGA, 13mmx13mm, 0,8mm pitch
- 512KB Flash, 40KB RAM
- USB 2.0 Full Speed (480Mbps)
- Ethernet MAC/PHY on chip
- CRC (choice of 3 polynomials)
- 34MHz @ 3V operation
- RSKH8S2472
Industrial sensor networks: CAN based

- **DeviceNet**
  - Open Standard (Open DeviceNet Vendor Association)
  - Developed by Allen-Bradley / Rockwell Automation
  - Strong in USA and Asia
  - Based on CIP „Common Industrial Protocol“ (same as Ethernet/IP)

- **CANOpen**
  - Developed by Bosch
  - Maintained by CiA (CAN in Automation)
  - European Standard (EN50325-4)
  - Strong in Europe

<table>
<thead>
<tr>
<th>Renesas product selection</th>
<th>R8C/22,23</th>
<th>M16C/29</th>
<th>M16C/6N4,N5, M16C/6NLN, KM</th>
<th>M32C/87</th>
<th>R32C/117*</th>
<th>R32C/118*</th>
<th>SH7286</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAN channels</td>
<td>1</td>
<td>1</td>
<td>Up to 2</td>
<td>Up to 2</td>
<td>Up to 3</td>
<td>Up to 3</td>
<td>1</td>
</tr>
<tr>
<td>On Chip Flash</td>
<td>64KB</td>
<td>128KB</td>
<td>256KB</td>
<td>1MB</td>
<td>1MB</td>
<td>1MB</td>
<td>1MB</td>
</tr>
<tr>
<td>Pin</td>
<td>48</td>
<td>64~80</td>
<td>100</td>
<td>100~144</td>
<td>100~144</td>
<td>176</td>
<td></td>
</tr>
<tr>
<td>RSK</td>
<td>RSKR8C23</td>
<td>RSKM16C29</td>
<td>RSKM16C6NK, RSKM32C87</td>
<td>RSKR32C118*</td>
<td>RSK2SH7286*</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Industrial sensor networks: 802.15.4 based

• WiHART
  – Wireless Highway Addressable Remote Transducer
  – developed 2007
  – Based on 802.15.4 in ISM (2.4G band)
  – DSSS, channel access by TDMA/CSMA
  – down compatible to wired standard HART (developed 1980’s)

• IEEE1451
  – Smart Transducer Protocol
  – Unified data format (TEDS format)
  – Different standard cover different available protocols
    » DOT 0: Basic format
    » DOT 5: Bluetooth, ZigBee, WiFi, RFID, 6LowPAN, etc.
  – Unified compiler and unified compliance testing
  – Seemless internet addressing by gateway

• ISA100.11a
  – Created by industry for process automation
  – based on 802.15.4, ISM band (2.4GHz), time sync’d channel hopping
  – NWL frame format compatible to 6LowPAN, easy gatewaying to TCP/IP world
  – Can tunnel any protocol

<table>
<thead>
<tr>
<th>Renesas product selection</th>
<th>RZB-CC16C-ZDK</th>
<th>Small IEEE 802.15.4 MAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Description</td>
<td><strong>ZigBee Development Kit, 2.4GHz RF, M16C/2x MCU</strong></td>
<td><strong>802.15.4 simple MAC Software</strong></td>
</tr>
</tbody>
</table>
RUN-M: PLC/RF Hybrid protocol for metering

Full seamless hybrid approach
No gateway approach

802.15.4 enhancements for low power

<table>
<thead>
<tr>
<th>Renesas product selection</th>
<th>M16C/6S</th>
<th>RUN-M</th>
</tr>
</thead>
<tbody>
<tr>
<td>Description</td>
<td>M16C CPU Built-In PLC modem based on extreme robust DCSK modulation</td>
<td>RUN-M Software Evaluation Version Full Version</td>
</tr>
</tbody>
</table>
802.15.4 Device as Locating Sensor

Student Thesis by Mrs. Fanny Abrahamse, Poltech Clermont-Ferrand, France
At Renesas Ratingen, Germany
5~7/2008

![Graph showing RSN in dBm vs distance in meters](image)

![Diagram illustrating the concept of locating sensor](image)
Summary

- Sensor networks for industrial applications have different requirements to sensor networks for consumer applications.
- System concept and component selection must be tuned to the specific sensor application.
- Expert knowhow is needed to achieve extreme low power consumption and high sensor resolution.
- Modern industrial sensor networks must be able to "wrap" a number of protocols and must offer a selection of PHY layers.
- Renesas offers microcontrollers, software and solutions for many industrial sensor network applications.