Joint Project MoSeS-Pro

Modular Sensor Systems for real time Process Control and Smart Condition Monitoring

http://www.moses-pro.de

Source: Oliver Dietze
Funded within the research focus area 'Sensor-based electronic systems for applications for Industrie 4.0 – Selekt I4.0’

Funding period: 10/2015 – 9/2018

Project budget 3.1 Mio. €, 73 % funded by German Federal Ministry of Education and Research (BMBF)

Project management VDI/VDE Innovation + Technik, Berlin, Germany

Project partners

- Bosch Rexroth AG, Facility Homburg (associated)
- Festo AG & Co. KG, Facility St. Ingbert (associated)
- CANWAY Technology GmbH, Ostbevern
- ESR Pollmeier GmbH, Ober-Ramstadt
- Lenord, Bauer & Co. GmbH, Oberhausen
- Sensitec GmbH, Lahnau
- Fraunhofer IMS, Duisburg
- TU Kaiserslautern, ISE, Kaiserslautern
- ZeMA gGmbH, Saarbrücken (coordinator)
Contents and goals at a glance

- Modular and open sensor system kit for assembly, handling and packaging processes in Industrie 4.0
- In addition to optimized sensing functions: Extending of signal processing capabilities for intelligent condition monitoring
- Sensor principles
  - Primarily magnetoresistive (XMR) technologies with focus on TMR
    → wide range of applications (current, angle, length and position measurement)
  - Integration of further sensing principles
    → Vibration/acoustics, VIS/IR cameras, pressure, oil quality
  - Self-sensing drives: Servo control and condition monitoring
    → based on voltage & current signals with online model-based analysis
- Real time wireless communication & energy harvesting for flexible integration
- Laboratory tests of MoSeS kit based on different application scenarios
- Demonstration of sensor system kit embedded in industrial processes
  → in cooperation with Festo and Bosch Rexroth (associated partners)
Application scenario I

FESTO

- Electromechanical axes for assembly and handling systems
  - Extending available sensor technologies for improved functionality and smart condition monitoring by sensor fusion (e.g. current, angle, and vibration measurements)
  - Both for End-of-Line testing & quality assurance and for condition monitoring in customer applications
  - Establishing standardized formats for data exchange

Source: Festo
Enhancement of the existing Industrie 4.0 assembly line

- Expanding the Industrie 4.0 concept: Machining production of components, monitoring of cooling lubricants, quality control of final product after assembly
- Significant optimization and acceleration of production process based on early fault detection by correlation of process data and EoL test results

Source: Bosch Rexroth
Application scenario III

- Sensors and compact positioning drives with integrated sensors
  - e.g. format adjustment actuators for packaging machines: trend towards higher flexibility only possible with extended functionality
  - primarily partially redundant angle & current measurements → provides basis for condition monitoring
  - Also woodworking and textile machinery as further applications

Source: Lenord+Bauer
Application scenario IV

Efficient and compact drive systems

- Servo, torque or linear motors, electronics & control with customer-specific configuration for handling systems in production and R&D
- Complex and high performance test bench developed in DFG project (ZeMA)

→ Testing of optimized position and current measurement and especially self-sensing drive systems

→ Combination for condition monitoring

Source: ZeMA, group drive technology
Application scenario V

Electronic modules based on DSP/FPGA for MoSeS kit
- Realization of functional models and demonstrators within the project
  → important part of electronic systems and interface to process control
- Later: Improvement of customized measurement hardware, e.g., hardware-in-the-loop (HIL) test benches for automotive production or vibration analysis / condition monitoring

Improved sensor modules based on XMR with integrated electronics
- Industrial applications, but also automotive / consumer applications
- Self-X functionality (self diagnosis, configuration, and adaptation)
  → Helps to better fulfil customer requirements regarding functionality and robustness
XMR sensor technology: base technology in the project w focus on TMR
- Particularly small, low-power sensors with high spatial resolution and large bandwidth for measurement of current, length, position, angle, and field
- Addition of self-X components in existing sensor elements → Integration of self-monitoring and self-repair functions close to the sensor
- Simplification and acceleration of data processing on system level → reliable, valid sensor data, additional control routines can be omitted
- Evaluation of application-specific potential for miniaturization
**Technologies II**

- **Self-X sensor electronics:** generic, reconfigurable sensor electronics
  - Improved flexibility using self-monitoring and -correction
  - Integration of existing modules or circuits in the MoSeS kit as the lowest hardware-layer of the information processing architecture
  - Expansion of digital DSP/FPGA functionality with analog functions including reconfigurable devices (Field-Programmable-Analog-Arrays, FPAA)

Demonstration of modularity and openness by integration of additional sensor principles (vibration/acoustics, VIS/IR cameras, pressure, oil quality)

Source: ISE, TU-KL
Soft-Sensor condition monitoring of electrical machines

- Direct Flux Control (DFC) method allows condition monitoring without dedicated sensors, i.e., only based on a high-bandwidth current sensor
- Monitoring of magnetic flux vector, rotor position, winding currents and torque as well as mechanical eccentricity in real time
  → can be used for control and self-diagnosis

- Multi-parameter sensing requires only measurement of current and voltage
  → after A/D conversion: model-based data processing using the DSP/FPGA device
Technologies IV

**Condition monitoring using statistical data analysis**

- Promising results in previous study using sensor fusion and signal processing techniques for hydraulic systems
- Method based on existing process sensor data (pressure, temperature, flow, motor power, valve position, ...)

- Compensation of defective sensors without degrading condition monitoring capability
  → improved robustness and customer acceptance
- In this project extension towards sensor elements with higher bandwidth
  → Signal pre-processing integrated in sensor modules required
Wireless communication / energy harvesting technologies

- Improved flexibility required
  → Wireless real time data transmission in addition to wire-based signal transmission (IO-Link wireless planned)
  → Realization of a self-sufficient power supply

- Safe and secure data transmission

- Reference: Self-sustaining wireless sensor (Monitoring of cooling media in steel plant)

Source: Fraunhofer IMS

Source: IO-Link, system description

Source: Fraunhofer IMS

Source: IO-Link system description
DSP/FPGA-based electronic modules

- Powerful signal acquisition, preprocessing and feature extraction close to sensor, especially for periodic signals
  → Connection between sensor and process layer
- Highly modular: variable signals, sampling rates and interfaces
- Subsequent transfer of electronic demonstrators into series production

Source: Canway Technology
Project consortium: Interfaces and topical clusters

- **Self-X sensor electronics**: Realization along process chain
  - ZeMA
  - SENSITEC
  - CANWAY
  - Fraunhofer IMS
  - Festo
  - Lenord + Bauer
  - Rexroth Bosch Group

- **Self-sensing drive systems**: Core partners
  - ZeMA
  - ESR Pollmeier GmbH Servo-Antriebstechnik
  - Lenord + Bauer
  - Group drive technology

- **Condition Monitoring**: Realization along process chain
  - ZeMA
  - SENSITEC
  - CANWAY
  - Fraunhofer IMS
  - ESR Pollmeier GmbH Servo-Antriebstechnik
  - Festo
  - Lenord + Bauer
  - Rexroth Bosch Group
  - Group measurement technology

- **Group measurement technology** + X?
Overview: Planned work and milestones

1\textsuperscript{st} milestone (month 6): MoSeS system kit and interfaces defined
2\textsuperscript{nd} milestone (month 15): 1\textsuperscript{st} generation of sensor, electronics and software modules
3\textsuperscript{rd} milestone (month 27): 2\textsuperscript{nd} generation of sensor, electronics and software modules, 1\textsuperscript{st} generation of integrated sensor systems
4\textsuperscript{th} milestone (month 36): Laboratory tests & process-integrated demonstrations completed
Methodology: Definition of application-specific data acquisition chains

Example: **Application Festo**

- Test bench specific sensors (light gray)
- Planned sensors (blue)
- Optional sensors (dark gray)

**Measured quantity**

- drive
- load

<table>
<thead>
<tr>
<th>Measured quantity</th>
<th>Sensor data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solution Canway</td>
<td>ADC, sync. DC-coupling</td>
</tr>
<tr>
<td>Rectangle A/B TTL, differential</td>
<td>Digital In, sync.</td>
</tr>
<tr>
<td>1 x voltage, range -5...5V, single ended</td>
<td>ADC DC-coupling</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Measurand</th>
<th>Sensor element</th>
<th>Wiring</th>
<th>Conversion</th>
<th>Interface module</th>
<th>Data rate</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Motor/Motor controller</strong></td>
<td><strong>P, cos p Inverter</strong></td>
<td></td>
<td></td>
<td></td>
<td>Ch=7, fs=? Hz, res=? bit → 7 MB/s</td>
</tr>
<tr>
<td></td>
<td><strong>currents I1, I2, I3 Motor</strong></td>
<td></td>
<td></td>
<td></td>
<td>Ch=3, fs=500 kHz, res=16 bit → 3 MB/s</td>
</tr>
<tr>
<td></td>
<td><strong>Angular deflection Motor</strong></td>
<td></td>
<td></td>
<td></td>
<td>Ch=2, fs=3,55 MHz, res=1 bit → 0,89 MB/s</td>
</tr>
<tr>
<td></td>
<td><strong>Torque Motor</strong></td>
<td></td>
<td></td>
<td></td>
<td>Ch=1, fs=10 kHz, res=16 bit → 0,02 MB/s</td>
</tr>
</tbody>
</table>

**Data rate**

- Ch=7, fs=? Hz, res=? bit → 7 MB/s
- Ch=3, fs=500 kHz, res=16 bit → 3 MB/s
- Ch=2, fs=3,55 MHz, res=1 bit → 0,89 MB/s
- Ch=1, fs=10 kHz, res=16 bit → 0,02 MB/s
Methodology: Measured quantities & sampling rates

Example: Application Festo

- Temperatures (3-5x)
- IR emission (2-3x)
- Magnetic field (1x)
- Vibrations (7x)
- Ultrasonic (1x)
- Motor current (3x)
- Encoder signals (2x)
  - Linear/rotatory
- Sampling rates:
  - ~1 Hz: < 500 S/s
  - ~100 Hz: < 100 kS/s
  - ~50 kHz: < 5 MS/s
  - ~500 kHz: ~ x MHz
  - fs: Sensor data raw volume
Project MoSeS-Pro

Modular Sensor Systems for real time Process Control and Smart Condition Monitoring

Coordination:

Prof. Dr. Andreas Schütze,
ZeMA, group measurement technology

Contact: schuetze@zema.de

http://www.moses-pro.de