Blade Intelligence

Phoenix Contact – Solutions for Wind Energy
Blade Intelligence

Agenda

- Global scope
- Sensor Systems
  - LM-S
  - ID-S
  - RM-S
- Data fusion
Blade Intelligence

Motivation

Tasks:
- Model predictive control
- Detect misalignment
- etc.
- Predictive maintenance
- Observing remaining lifetime
- Active load control
- Predictive maintenance
- Active load control

Need Measurement Data & Computing
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Existent Sensor Systems

- LM-S
- ID-S
- RM-S
PLCnext Technology
enhance your automation thinking
Blade Intelligence

Software – PLC.next in a nutshell

PLCnext is a lean and open development platform for working with data streams from multiple sources in a real-time environment that ensures integrity and security.
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Hardware - AXC F 2152

- Cyclone 5 ARM Cortex-A9 CPU 2 x 800 MHz
- 512 Mbytes RAM
- SD Flash card slot
- 1 x ETH-MAC interface switched
- Micro-USB type C
- Axio field bus for up to 63 modules
- Left side extension capability
- Trusted platform module (TPM) for security
- Temperature range: -25°C up to +60°C
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Edge Computing Platform

- Lean engineering
- Security
- Open platform
- A priori consistent data
- Flexible IOs

PLCnext Technology

- Task 1 (1ms)
  - Prg 1 IEC 61131-3
- Task 2 (3ms)
  - Prg 2 Simulink
  - Prg 4 C++
  - Prg 5 IEC 61131-3
- Task 3 (10ms)
  - Prg 3 C++

GDS

- PROFINET
- Axioline
- ...

Open platform
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Measurements

- Blade acceleration sensor
- RM-S-SGI strain gauge sensors
- Shaft acceleration/ inertial sensor
- Several temperature sensors
- LM-S Lightening sensors
- ID-S Ice sensors
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Calculation

Raw Data → Transform → Data

Sensor Fusion

NN

Kalman

Filter

Usable Data
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Data
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Subsysteme – LM-S
Blade Intelligence

Subsysteme – LM-S
Blade Intelligence

Subsysteme– LM-S
Blade Intelligence

Subsysteme – LM-S
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System components

Sensor  FOC  Analyzer / Web interface  Blade Intelligence
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Sensor

- Robust sensor (IP67)
- Easy installation directly on the down conductor
- Push-Pull-Connector for easy and safe connection of fiber optical cable

+ Purely optical measuring and signal transmission
+ No disturbances caused by the electrical field
+ No galvanic connection between sensor and electronics

LM-S-LS-H 2800616
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**Optical cable with protective tube**

- Robust variant for laying in very harsh environment like wind turbines
- With pre-installed protective tube
- Good UV- / oil-resistance
- Other length on request
- Cable labeling possible as required
Main features

- Live monitoring system for permanent recording and analysis of lightning strikes
- Detailed analysis of lightning currents $I_{\text{max}}, \frac{\text{di}}{\text{dt}}, \text{Charge and Specific Energy}$
- Surge current measuring range: +/- 5 kA to 400 kA
- Exact determination of past lightning events
- Network access via Ethernet
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**Customer benefit**

- Gaining detailed information about lightning currents and their impact
- Allows the evaluation of the system’s actual load
- Possible system damages can be inferred from analyzed lightning strikes
  - Predictive maintenance of system reduces downtimes
  - Reduction of unnecessary maintenance services
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Subsysteme – ID-S
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Subsysteme – ID-S

- Wireless data transfer
- Ice and temperature measurement
- Energy harvesting
- Energy buffer
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Subsysteme – ID-S
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Ice & Temperature Measurement

- surface status is indicated by 4 levels:
  - 4: ice > ~ 10 mm
  - 3: ice > ~ 1 - 2 mm
  - 2: "activity" (very thin layer < 1 mm or wet)
  - 1: free surface

- temperature measurement:
  - accuracy: +/- 0.25 °C integrated
Icing Wind Tunnel Test
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**Simplified stand alone system**

- No initializing process at turbine start up
  → Simplified initializing
- No turbine controller information needed
  → Simplified integration
- Nondependent from blade characteristics and resonance frequency
  → Simplified installation
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**Rotorblade heating**

- Temperature measurement directly on the blade
- Feedback for the blade heating
- Build up reliable control loop to improve heating system
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Subsysteme – RM-S
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Subsystem – RM-S
Blade Intelligence

Subsystem – RM-S

\[ \varepsilon_1 = \varepsilon \]

\[ \varepsilon_2 \approx -\varepsilon \]

\[ \varepsilon_3 \approx \varepsilon \]

\[ \varepsilon_4 \approx -\varepsilon \]

\[ \Delta U_d = \frac{k}{4} (\varepsilon_1 - \varepsilon_2 + \varepsilon_3 - \varepsilon_4) \approx k \cdot \varepsilon \]
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RM-S-SGI – Strain gauge sensor

- Robust design
- Excellent force flow
- Low price
- Temperature compensated
- Fast and easy installation.

- Normal elongation ± 1000 µm/m → Fatigue life >> $10^8$
- Normal elongation ± 1500 µm/m → Fatigue life >> $10^7$
- High load version ± 5000 µm/m → Fatigue life >> $10^8$ currently in development
- Maximum elongation 50000 µm/m (fatal)
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Methodik – FAST & Simulink
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Methodik – Subsystem „Simulation“
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Methodik – Exemplarisches Rauschen „Gyro“

Rauschen [deg/s]

Time (seconds)
Beispiel – Pitchwinkel

Prinzipielle Komponenten 1..3
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Beispiel – Pitchwinkel

Prinzipielle Komponenten 4..6

Pareto Darstellung der Varianz je Komponente

Prozent der Gesamtvarianz

12
10
8
6
4
2
0

100%
83%
67%
50%
33%
17%
9%

1
2
3
4
5
6

Prinzipielle Komponente
Beispiel – Pitchwinkel

Prinzipielle Komponenten 7..9

Pareto Darstellung der Varianz je Komponente

Prinzipielle Komponente

Komponente 7

Komponente 8

Komponente 9
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Beispiel – Pitchwinkel
Beispiel – Pitchwinkel
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Beispiel – Pitchwinkel

Response of Output Element 1 for Time-Series 1

- Training Targets
- Training Outputs
- Validation Targets
- Validation Outputs
- Test Targets
- Test Outputs
- Errors
- Response
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Thank you