Institute of
Integrated Sensor Systems
Dept. of Electrical and Computer Engineering
Technische Universität Kaiserslautern

gefördert vom
Bundesministerium für Bildung und Forschung
VDI|VDE|IT

Prozessintegriertes autonomes Überwachungssystem für die Verfahrenstechnik auf Basis vernetzter, multifunktionaler MST-Funksensoren

(**PAC4PT**)

All PAC4PT partners:

UST Umwelt Sensor Technik, IMST, microTEC, KROHNE, ISE, Technische Universität Kaiserslautern

Ressourcen-effiziente, robuste Sensor- und Funksignalverarbeitung für autonome vernetzte Systeme in fluiden Medien

(**ROSIG,** Fkz. 16SV3604)

Ergänzungsmaterial zum Statusseminar 15.02.2011

ROSIG Project Overview

ROSIG Project Group of ISE: Prof. Dr.–Ing. Andreas König
Dipl. –Wirtsch. –Ing. Stefano Carella
M.Sc. Kuncup Iswandy

Contents:

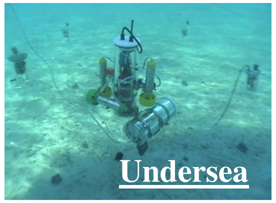
- Introduction
- Magnetic Sensor Localization
- Magnetic Sensor Synchronization
- Low Power and Self-x Issues
- Sensor Node Prototype and Test
- Conclusion and Future Work

Introduction

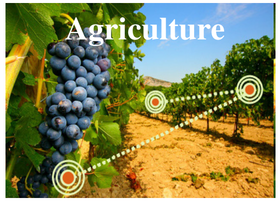
Motivation

Wireless Sensor Networks :

- Supported current advanced micro- and nano-technology
- Design: medium to tiny size
- Static and mobile nodes
- Low power
- Applied in a wide range of applications
- For measurement, monitoring, and control



http://neo.lcc.uma.es



http://www.probesrl.net/eng/

http://www.mics.org/

http://beveragemanager.net/

Important issues in WSN besides the communication and hardware design:

- ➢ Localization
- ➢ Synchronization
- ➢ Self-X and Low-power

These aspects are focused on by our research group with regard to applications of monitoring industrial process based on liquid-filled container.

Localization

Need and Challenges

- Measurement values in the context of industrial process are interpretable, when location of sensor nodes along with time information is known.

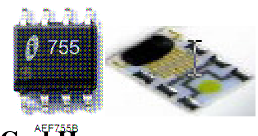
- Limitation of existing localization technologies for monitoring the industrial process in liquid-filled container (e.g., brewery industry):

Radio Frequency (RF)	Requires more energy high attenuation by materials, e.g., liquid, steel or copper
Light wave	opaque materials such as smoke, dust, or muddy liquid
Acoustic wave	effect of reflection or scattering of air bubbles

Localization
Technology

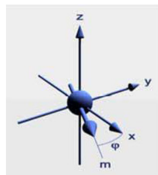
Sensors used for Localization

- **Radio base**
- **Light wave**
- **Magnetic Field**
  - **External Source**
    - **Quasi DC Field**
      - **Ascension Technology**
        www.ascension-tech.com
      - **AMR**

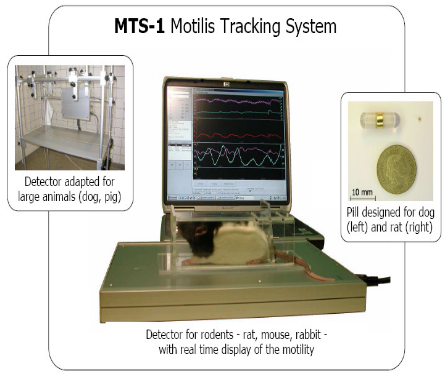


Sensitec GmbH
http://www.sensitec.com/

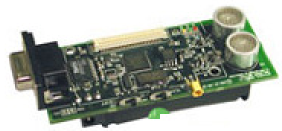
    - **AC Field**
      Polhemus
      www.polhemus.com
  - **Internal Source (ball magnet) Magnetic Marker**



Triple Sensor Technologies GmbH



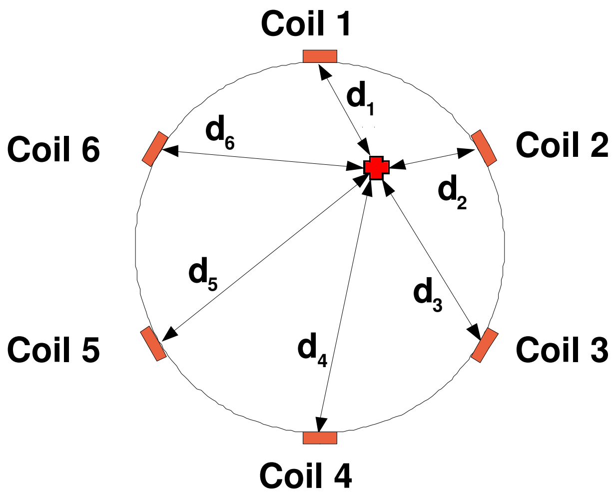
- **Ultra Sound**

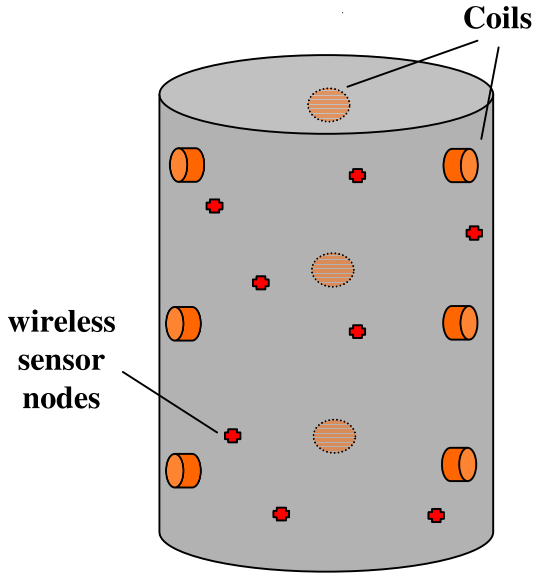


MCS410 Crossbow - Cricket
http://www.xbow.com/

Localization
Concept

- Range-based localization (coils ↔ sensor nodes)
- Fixed Anchors‘ position (coils) surrounding the measuring environment
- Scalable in size and number of coils depend on environment (see [2])
- Triaxial Anisotropic Magnetoresistive (AMR) sensor for 3D localization
- Movable sensor nodes
- Arbitrary number of sensor nodes

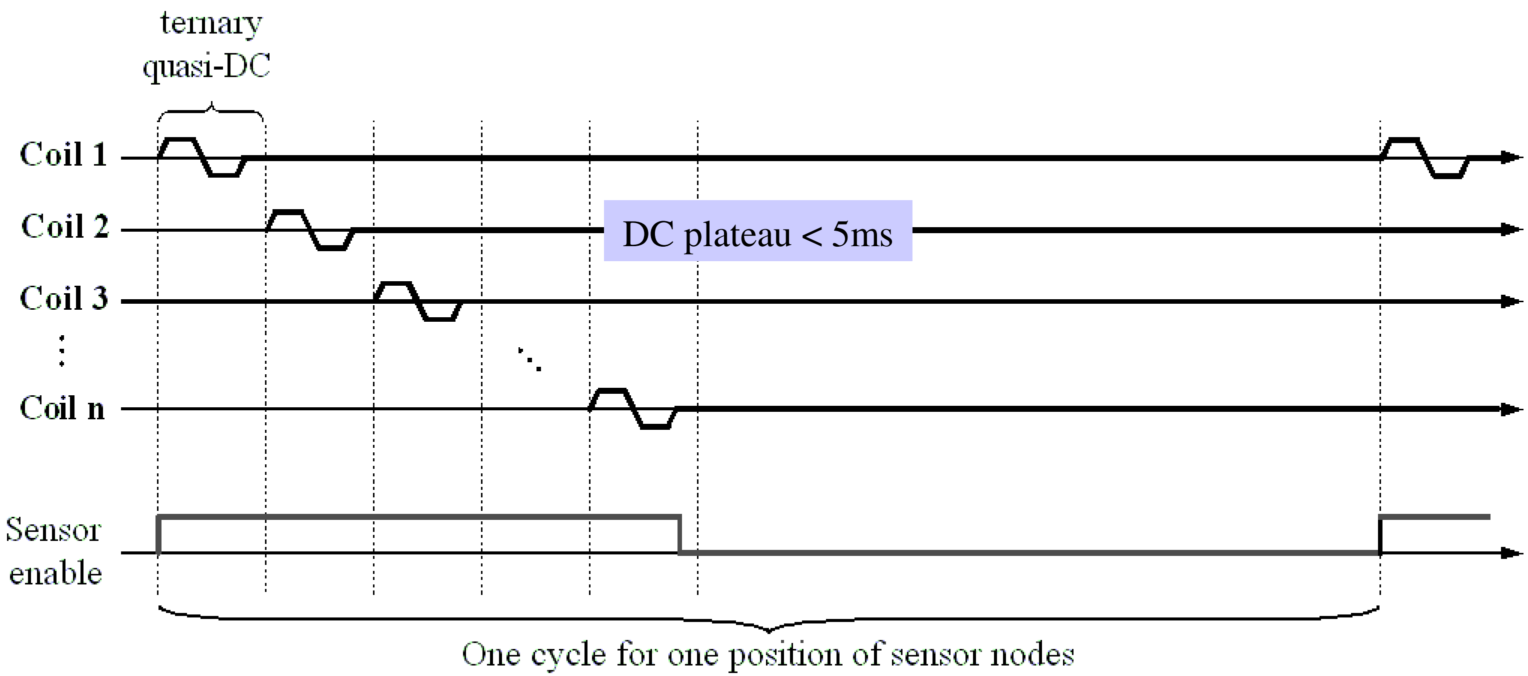




Stainless-steel container

Localization
Concept

- Emitted coils based on ternary quasi-DC alleviate need for flipping of AMR sensors (node power dissipation!)

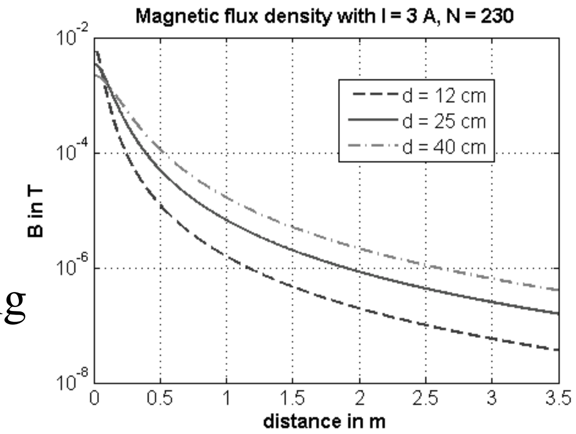


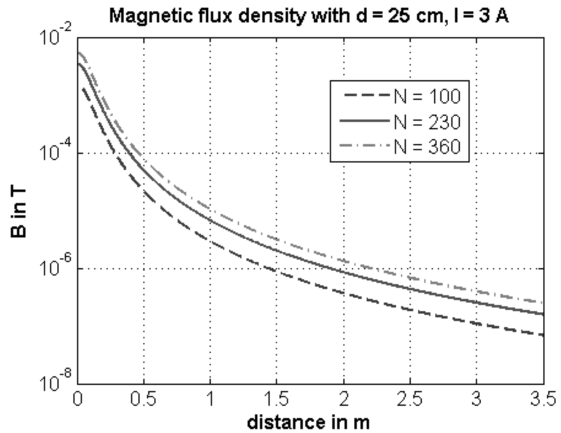
Localization

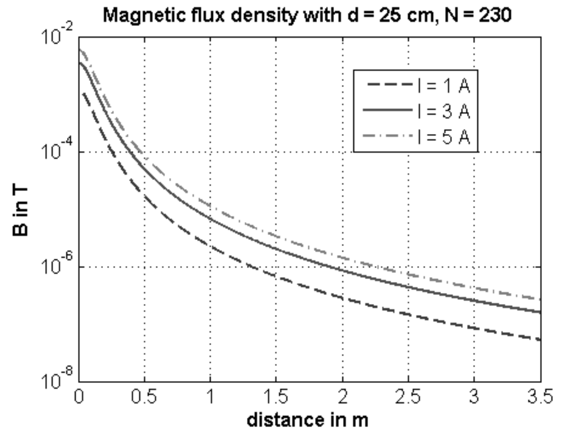
Consideration in coil design: Magnetic flux density wrt. distance

- Current supply I, diameter d of coil, and number N of windings

- Saturation due to large magnetic flux density (< 0.5 mT) must be avoided, while still allowing detection by AMR sensor (2nT) for farthest distance



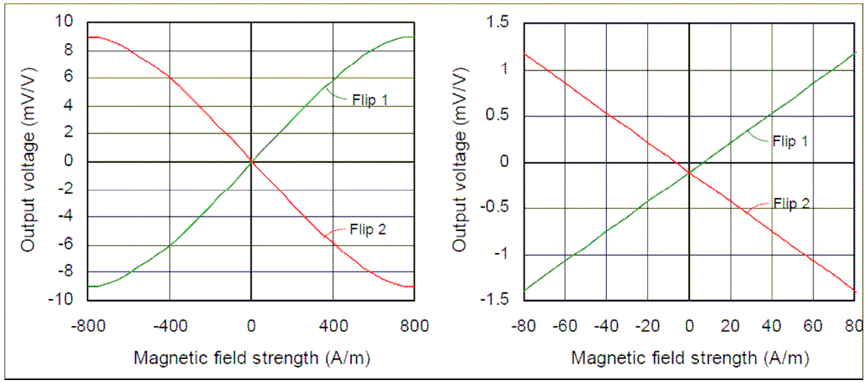




Localization

Conversion from Sensor Output to Distance Value

- AMR sensor: Sensitec AFF755B



$$V_i = \frac{V_i^p - V_i^n}{2}, \quad i = \{x, y, z\}$$

$$V_M = \left(V_x^2 + V_y^2 + V_z^2\right)^{0.5}$$

$$B_M = \left(B_x^2 + B_y^2 + B_z^2\right)^{0.5} = \frac{V_M}{S \cdot V_s \cdot G}$$

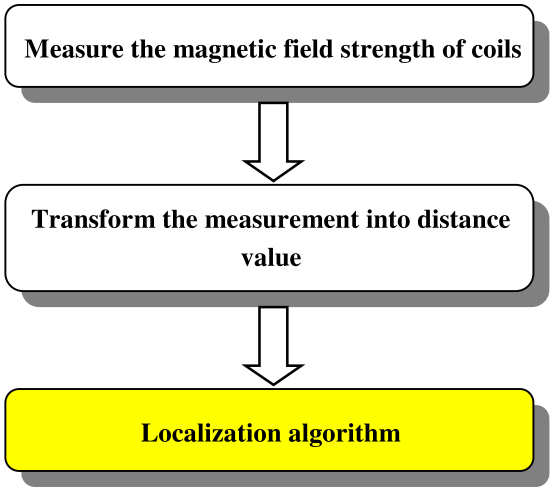
$$B_M = \frac{\mu_0}{2} \cdot \frac{n \cdot I \cdot R^2}{(R^2 + d^2)^{3/2}} \Rightarrow d = \left(\left(\frac{\frac{1}{2} \cdot \mu_0 \cdot n \cdot R^2 \cdot I}{B_M} \right)^{\frac{2}{3}} - R^2 \right)^{\frac{1}{2}}$$

where

S : sensitivity

V_s : bridge supply voltage

G : gain of amplifier



Localization
Algorithms

Localization algorithms can be categorized into

- Range-based versus range-free approach
- Centralized versus distributed
- Anchor or without anchor nodes

Centralized algorithms, e.g.

- Multi-Dimensional Scaling (MDS)
- Non-Linear Mapping (NLM), e.g. Sammon's Mapping [3, 4]

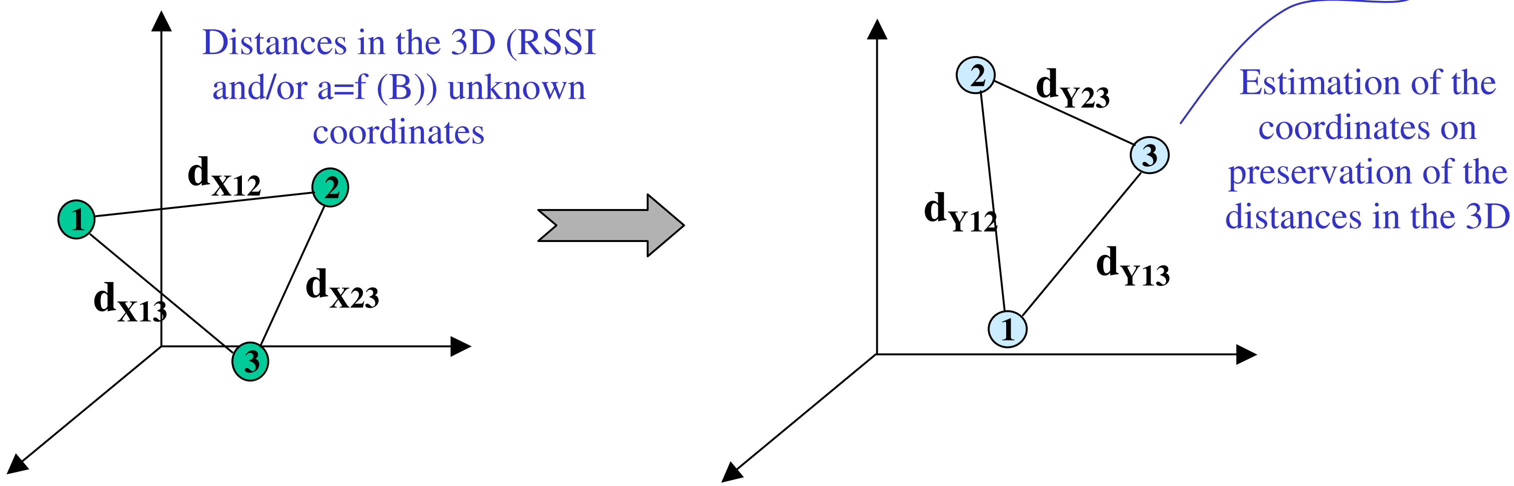
Distributed algorithms, e.g.

- Triangulation [3, 4]
- Multilateration

Localization
Iterative Non-Linear Mapping

- Basically used for dimensionality reduction and data visualization
- Sammon‘s cost function:

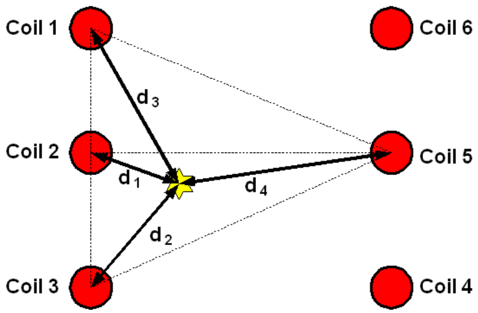
$$E(m) = \frac{1}{c} \sum_{j=1}^{N} \sum_{i=1}^{j} \frac{(d_{X_{ij}} - d_{Y_{ij}}(m))^2}{d_{X_{ij}}} \quad \text{with} \quad c = \sum_{j=1}^{N} \sum_{i=1}^{j} d_{X_{ij}} \quad \text{and} \quad \begin{cases} d_{Y_{ij}}(m) = \sqrt{\sum_{q=1}^{d} (y_{iq}(m) - y_{jq}(m))^2} \\ d_{X_{ij}} = \sqrt{\sum_{q=1}^{M} (x_{iq} - x_{jq})^2} \end{cases}$$

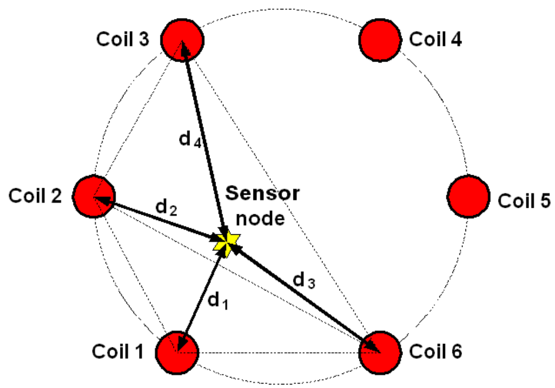


- Coordinate transformation after Sammon‘s mapping
- Robust, but computationally demanding method

Localization

Triangulation





- Faster computation compared to NLM
- Select only four nearest coils (four highest magnetic density flux values)

$$d_{s,c}^2 = (x_s - x_c)^2 + (y_s - y_c)^2 + (z_s - z_c)^2$$

$$d_{s,c_i}^2 - d_{s,c_j}^2 = (x_s - x_{c_i})^2 + (y_s - y_{c_i})^2 + (z_s - z_{c_i})^2 - (x_s - x_{c_j})^2 - (y_s - y_{c_j})^2 - (z_s - z_{c_j})^2$$

$$\underbrace{\left(d_{s,c_i}^2 - d_{s,c_j}^2\right) + \left(x_{c_j}^2 - x_{c_i}^2\right) + \left(y_{c_j}^2 - y_{c_i}^2\right) + \left(z_{c_j}^2 - z_{c_i}^2\right)}_{\mathbf{B}} \;=\; \underbrace{\left(2x_{c_j} - 2x_{c_i}\right)x_s + \left(2y_{c_j} - 2y_{c_i}\right)y_s + \left(2z_{c_j} - 2z_{c_i}\right)z_s}_{\mathbf{AX}}$$

$$\mathbf{X} = \mathbf{A}^{-1}\mathbf{B}$$

Localization
Considered Algorithms and Improvement

Open issues to be investigated for NLM improvement:

- Include weight factors of the distance information from emitting coils
- Reduce computational complexity based on NLM recall approach

Previous study considered for localization applications:

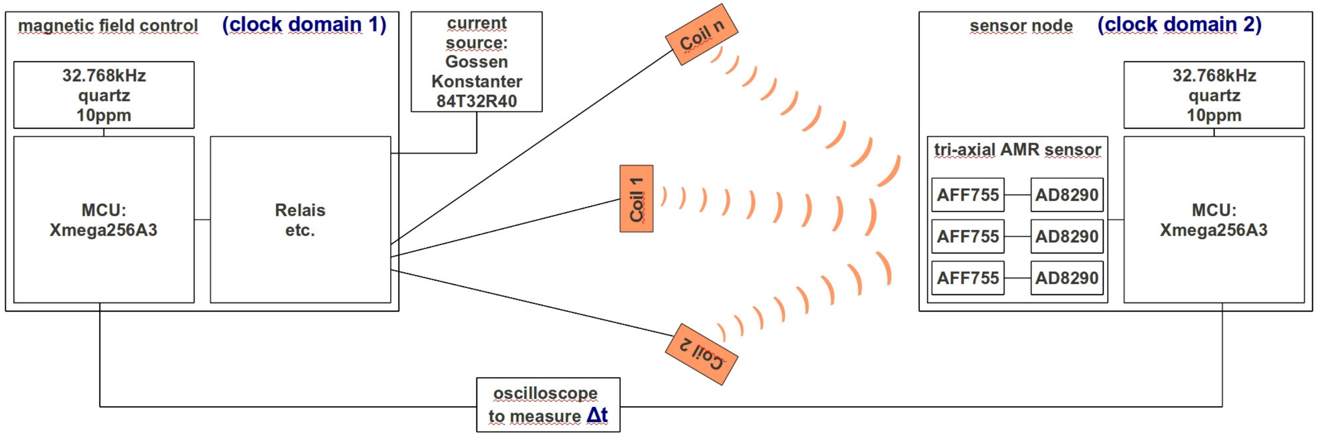
- Study of localization using incomplete distance information [1]
- Finding better minimum in optimization, e.g., by evolutionary computation

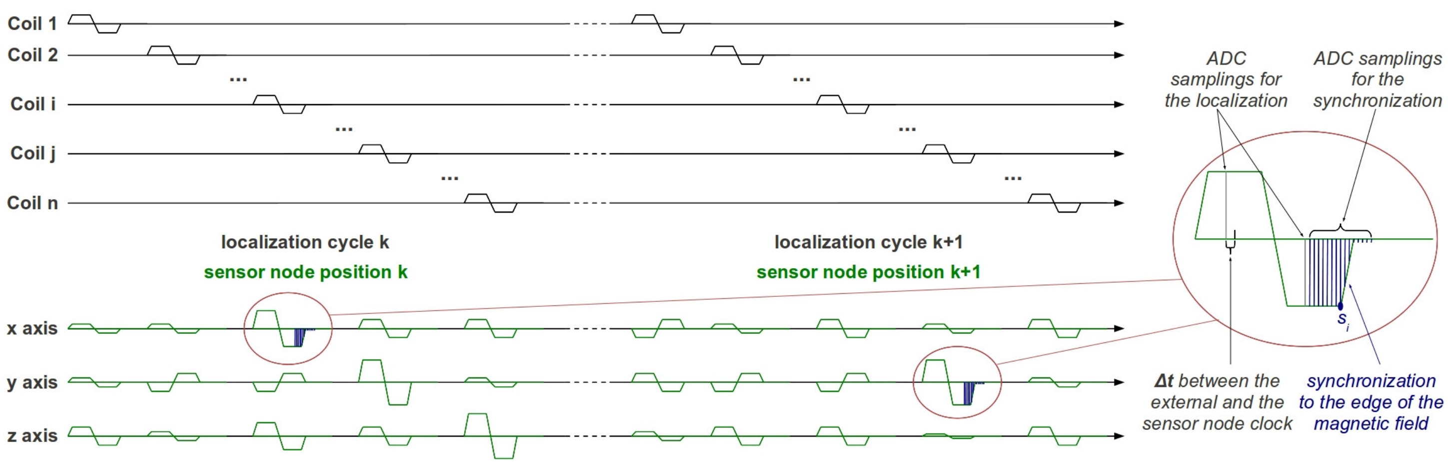
K. Iswandy and A. König. Soft-Computing Techniques to Advance Non-Linear Mappings for Multi-Variate Data Visualization and Wireless Sensor Localization. In e-Newsletter IEEE SMC Soc. , Issue #29, Dec. 2009.

K. Iswandy and A. König. Evolutionary Multidimensional Scaling for Data Visualization and Classification. In Applications of Soft Computing: Recent Trends, Tiwari et al (eds.), Springer, ISBN: 3-540-29123-7, pp. 177-186, May 18, 2006.

König, A.: Interactive Visualisation and Analysis of Hierarchical Neural Projections for Data Mining. In IEEE TNN, Special Issue on Neural Networks for Data Mining and Knowledge Discovery, pp. 615 - 624, Vol. 11, No.3, May, 2000.

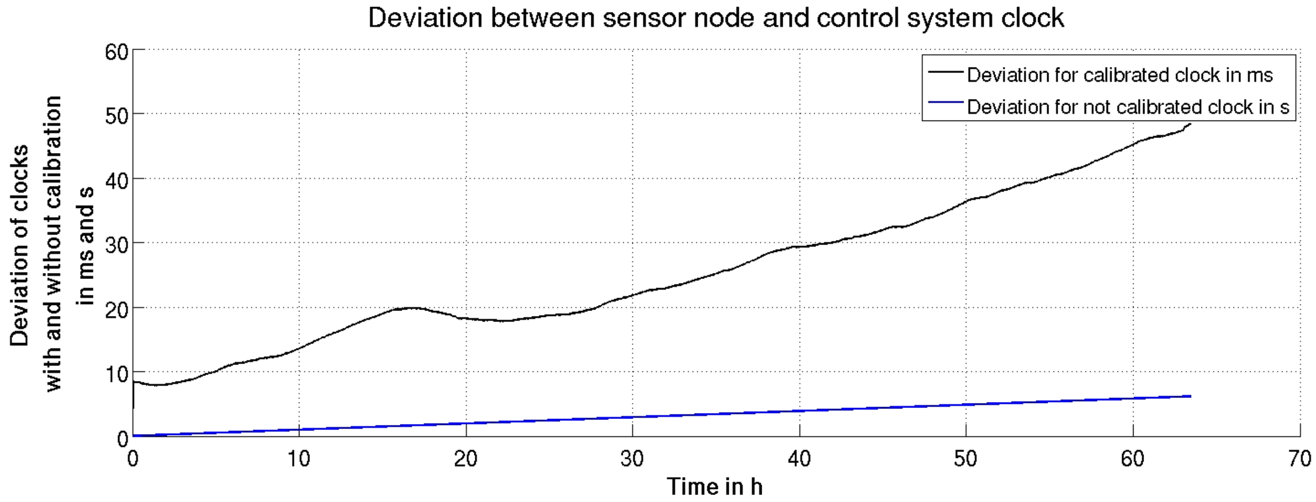
Synchronization
Methodology





Synchronization

Test Result

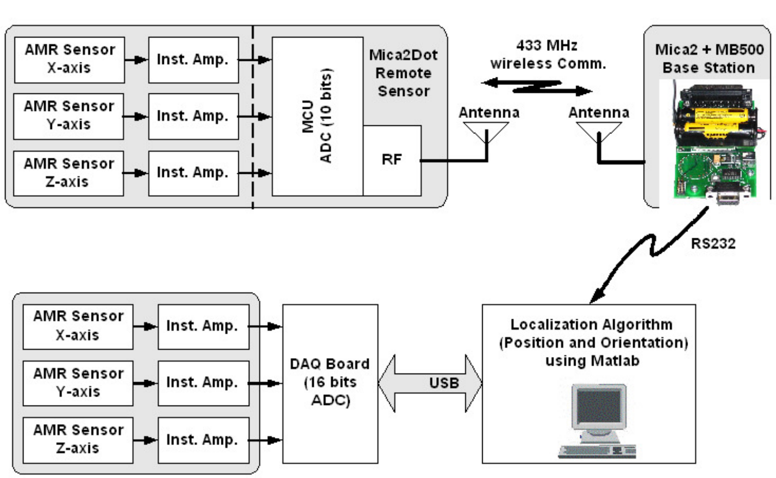


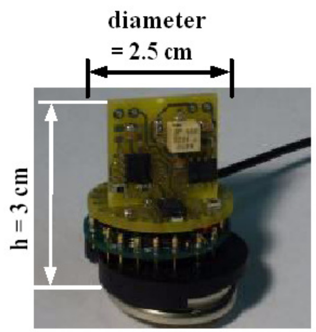
- Localization requires an accurate time base 2ms
- Localization of nodes requires time synchronization [6]
- Flank of magnetic fields for localization as a time reference
- In 60 minutes deployment time with 23 synchronizations
- Mean of synchronization error: 1.55ms and Std. deviation: 0.67ms

Low Power and Self-x Issues

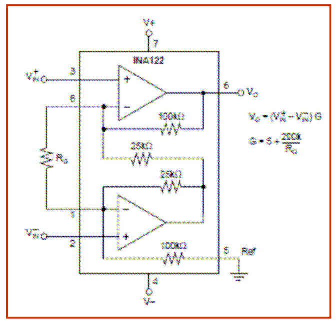
Proof-of-Principle Hardware (first prototype of wireless and wired version)

- Quiescent current (INA 122) is 60 µA, with gain is approx. set 100 V/V
- Current consumption of AMR sensor (AFF755B) is 1.2 mA (× 3 sensors)
- Voltage supply for AMR sensor and InAmp is 3V or 5V
- The power consumption is **11.34 mW @3V**





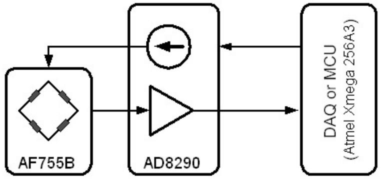
INA 122
Package SO-8

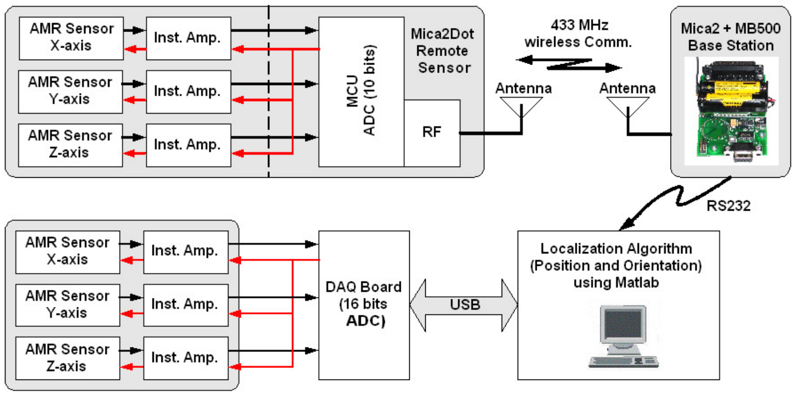


Low Power and Self-x Issues

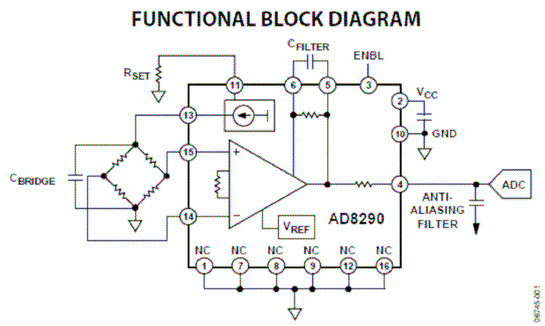
Proof-of-Principle Hardware (Second prototype of wireless and wired version)

- InAmp AD8290, enable pin is available (for shut down), and gain is 50 V/V
- Available current source to supply the AMR sensor
- Current consumption during measurement is 3.6 mA (× 3 InAmp)
- In shut-down mode, the current is 1.5 µA
- Voltage supply only for InAmp is 4.5 V





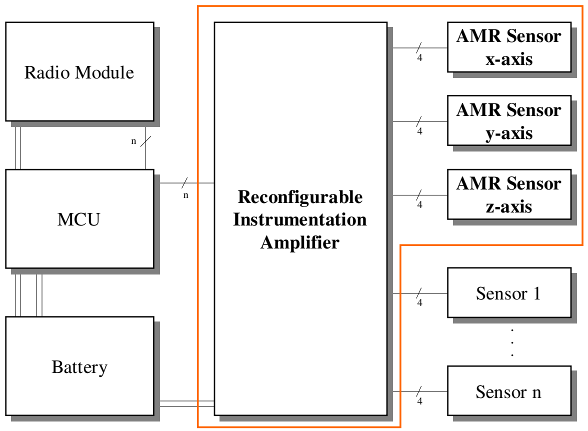
- The mean power consumption (6s ON per minute) is **4.87 mW @4.5V**

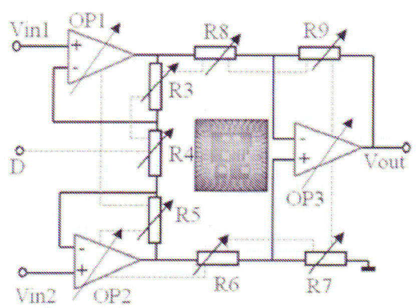


Low Power and Self-x Issues

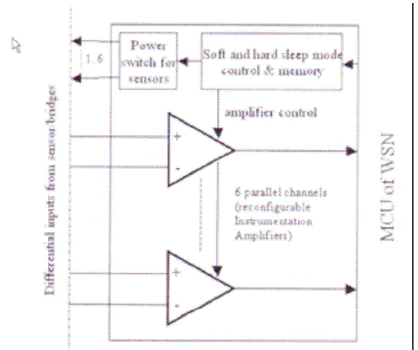
Reconfigurable and Self –Repairing and -Calibration

- Future reconfigurable hardware and sensor electronics [2]

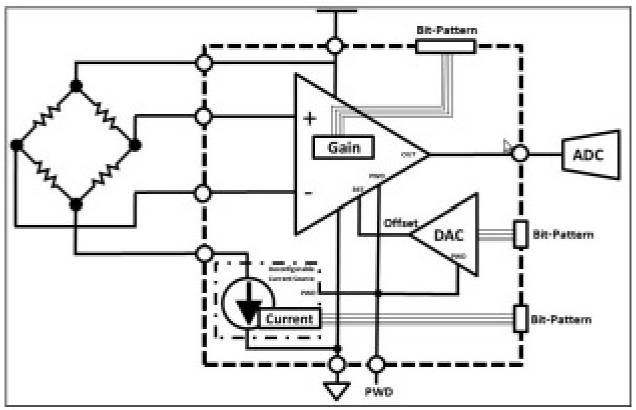




Existing prototype



New case study [2]



- Allow to some extent switched sensor-bridge, amplifier operation, and minimize on-time
- Self -repairing and -calibration for sensor adaptation and improved dependability in deployment and run-time

Low Power and Self-x Issues

Case Study

K. Lutz, A. König. Minimizing power consumption in wireless sensor networks by duty-cycled reconfigurable sensor electronics. In 2010 8th Workshop on Intelligent Solutions in Embedded Systems (WISES), 8.-9. July, pp. 97-102, 2010.

K. Lutz, R. Freier, A. König. Studie zur Optimierung des Verlustleistungsbedarfs autonomer, drahtloser, integrierter Sensornetzwerke durch Erweiterung des Ruhemodus auf die Sensorik. In Tagungsband XXIV. Messtechnisches Symposium des AHMT, 23.-25. September, pp. 135-144, 2010.

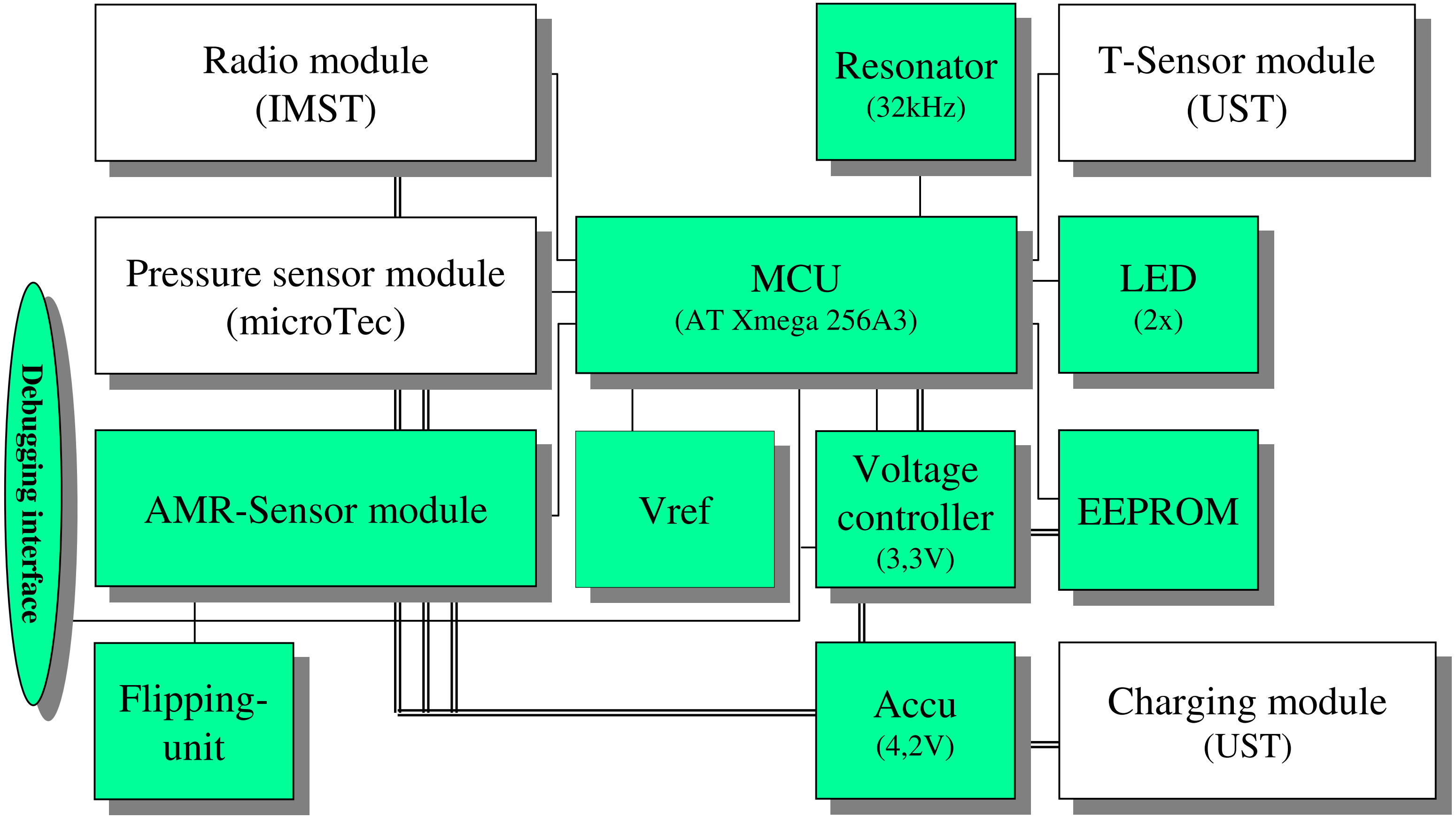
M. A. Johar and A. König. Case Study of an Intelligent AMR Sensor System with Self-x Properties. In Proc. of 15th Online World Conference on Soft Computing in Industrial Applications WSC15, November 15-27, 2010.

Senthil Kumar Lakshmanan and Andreas König, "Statistical Analysis of Compensating properties of Reconfigurable Analog Circuits for Generic Self-X Sensor Interface" In Proc. Of the 14th Int. Conf. Sensors, Technology, Electronics and Applications, SENSOR+TEST 2009, Nürnberg, Germany, 22-28 May 2009**.**

Senthil Kumar Lakshmanan and Andreas König, "Hybrid Intelligent and Adaptive Sensor Systems with Improved Noise Invulnerability by Dynamically Reconfigurable Matched Sensor Electronics.", in Int. Journal of Hybrid Intelligent Systems, pp. 71-82, Vol. 5, Number 2, 2008.

Sensor Node Prototype and Test

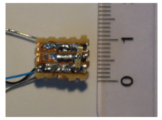
Block Diagram (components of wireless sensor node)



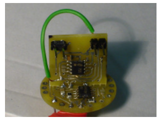
Sensor Node Prototype and Test

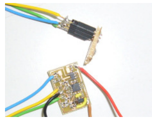
Capabilities of demonstrator

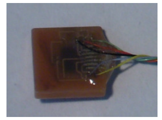
- RTC (Real Time Counter) for time-base
- Measuring cycle (i.e., AMR-Sensors, T-Sensor, p-Sensor)



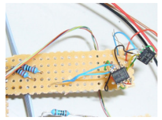
- Storage of measured value
- Power Management



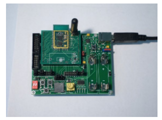




  - Wake-up through LED
    (no consumption of LED)



  - Focused on switch on and off analog components

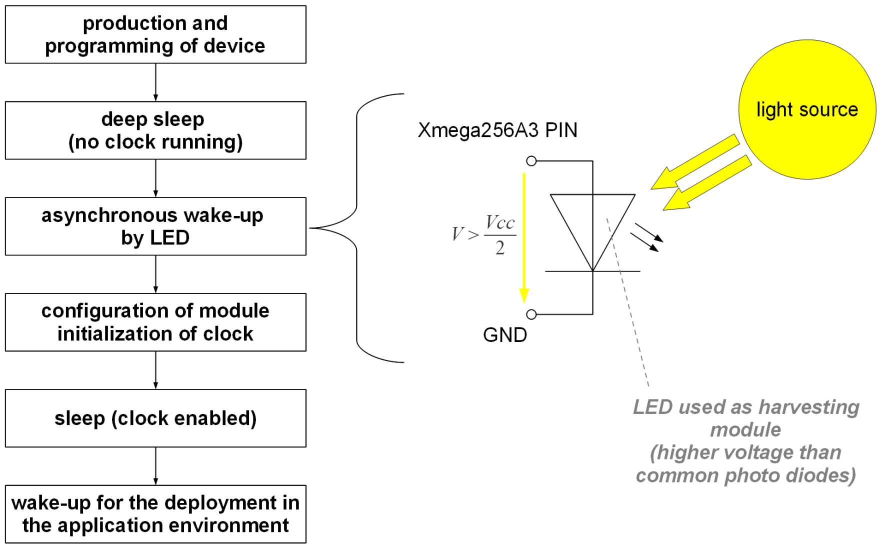


  - Xmega Sleep Mode
- Communicate the values to the base-station

Sensor Node Prototype and Test
Power Management

Reduce energy consumption by:

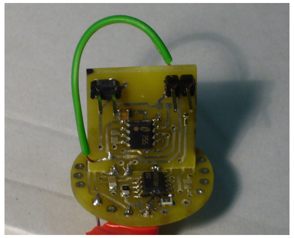
- Wake-up through LED
- Efficient use of sleep mode
- Switchable sensor electronics on/off
- Uncompensated 32768Hz crystal as a clock for the time



Sensor Node Prototype and Test

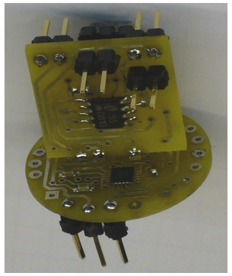
Design Roadmap

December 2009



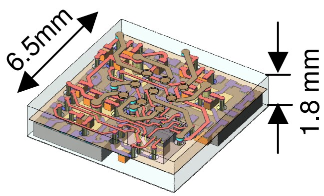
- First PCB-level module
- Three AMR sensors in three-axis
- Three Inst. Amp. (INA 122 – no shut-down)
- No flipping circuit

Juli 2010



- Second PCB-level module, same size with ver.1
- Three AMR sensors in three-axis
- Three Inst. Amp. (AD 8290 – shut-down pin)
- Additional flipping circuit

April - Mai 2011

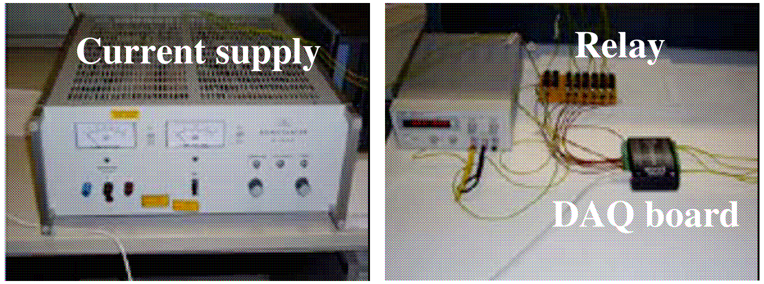


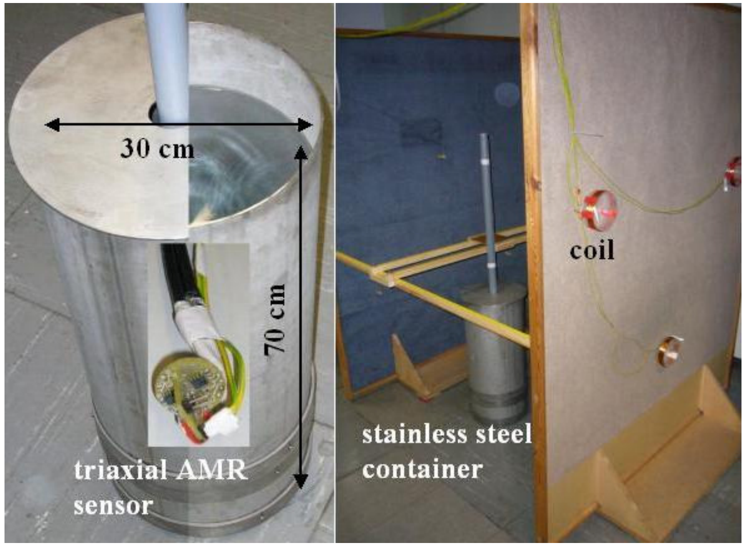
- Based on 3D-CSP integration (by microTec GmbH)
- Three Dies of AMR sensors in three-axis
- Three Inst. Amp. (AD 8290 – shut-down pin)
- Including of flipping circuit

Experiments and Results

Demonstrator and Stainless-Steel Container (First Prototype)

- Relay board for switching purpose
- DAQ board: Data Translation 9816
- Current supply is 5A

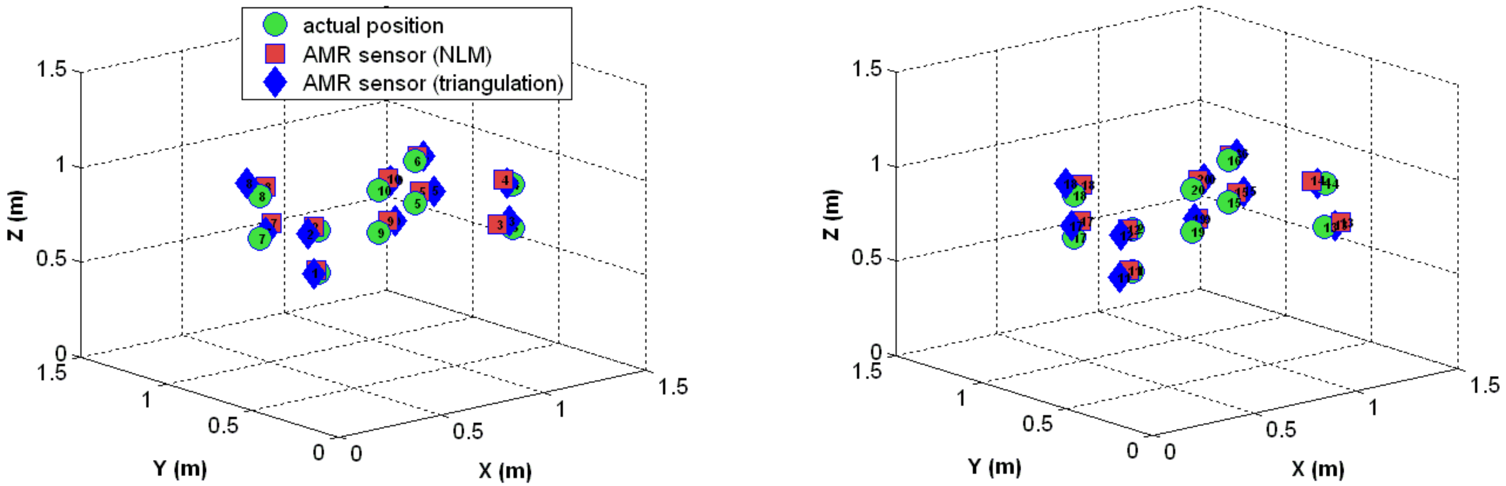




- The cubic volume used is 1.5m x 1.5m x 1.5m
- Applying 6 coils with diameter of 13cm and 100 windings
- Both versions have been tested in the air: mean error 2.92cm for 30 samples
- The error of wireless MICA2 version currently is max. 10cm higher per axis
- Deficiency of wireless version´s ADC: 10 vs. 16 bits ADC

Experiments and Results

Localization Error (in Stainless-Steel Container Filled by Water)

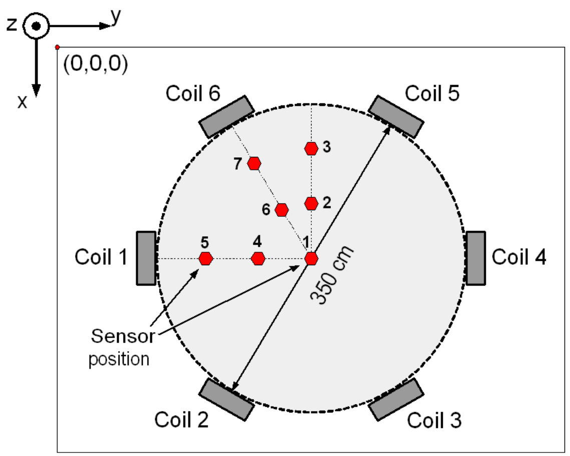


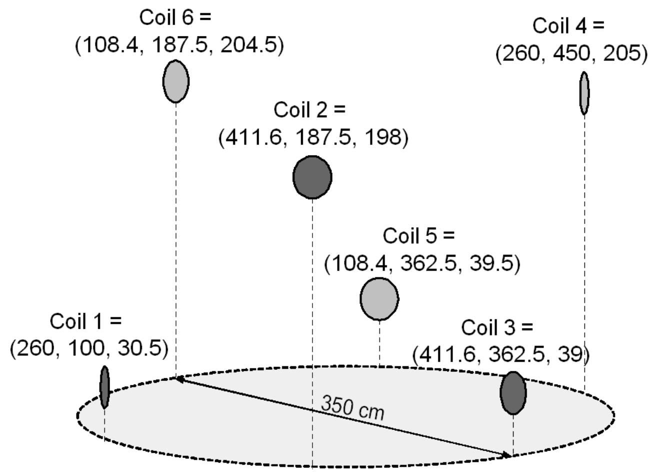
- Sensor node tested in 10 positions and each position with 2 different angles in the range of [25°, 45°]

Loc. Error	$\overline{\lvert\Delta x\rvert}$ (σ_x) in [cm]	$\overline{\lvert\Delta y\rvert}$ (σ_y) in [cm]	$\overline{\lvert\Delta z\rvert}$ (σ_z) in [cm]
NLM	2.6 (2.1)	1.4 (1.0)	4.1 (2.5)
Triangulation	3.7 (1.6)	1.6 (1.1)	3.7 (2.5)

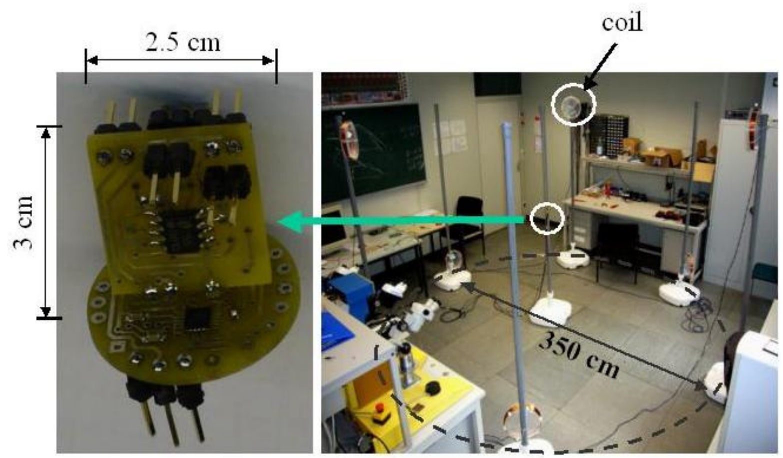
Experiments and Results

Current Sensor Module (Second Scaled-up Prototype)





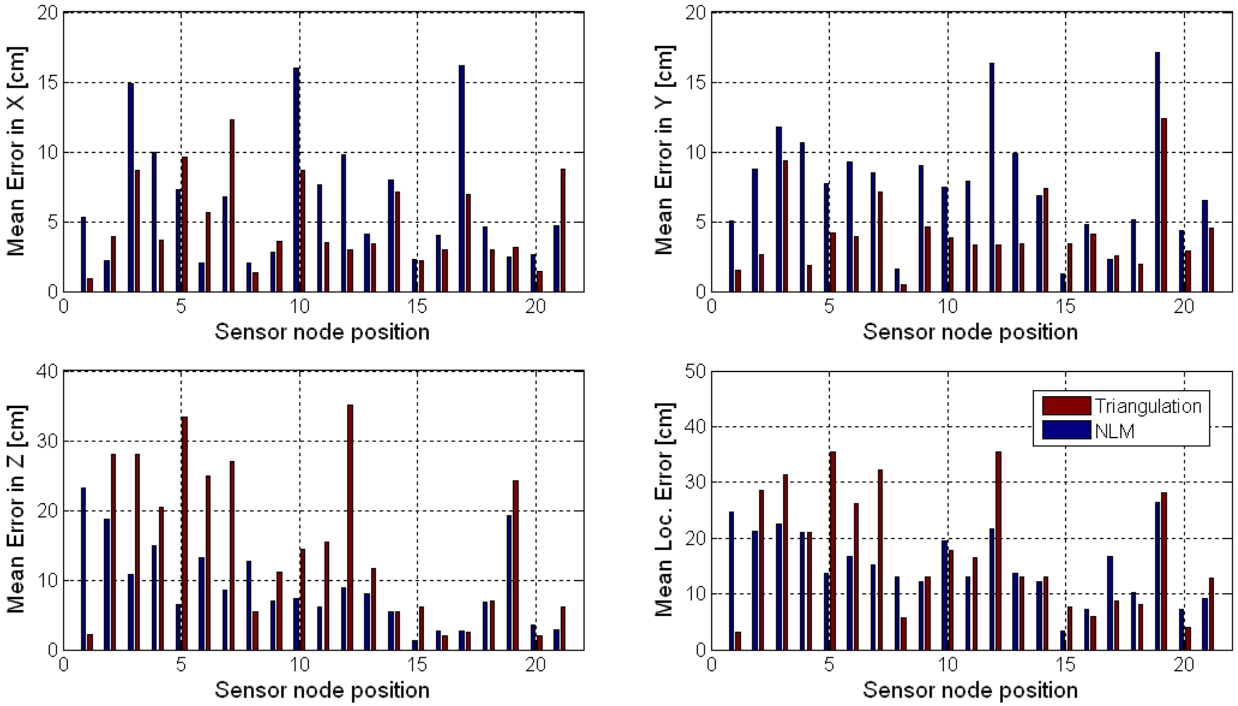
- Medium size of volume with Ø=3.5 m and h= 2.5 m
- Applying 6 coils with diameter 25 cm and 230 windings
- Current supply is 3A



Experiments and Results

Localization Error in New Sensor Module (without container)

- Test 7 planar positions with 3 different heights (40 cm, 80 cm, 120 cm)
- Each position is tested with 3 different rotations (0°, 30°, 45°)
- Overall mean of loc. error for NLM: 15.3 cm and triangulation: 17.5 cm

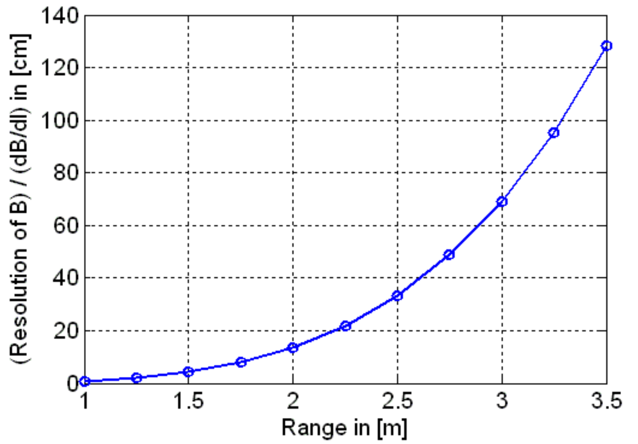


Experiments and Results

Error Sources

- The achieved mean localization error is acceptable for current specification

- Main sources of measurement error:
  - ✓ Orthogonal placement of triaxial AMR sensors
  - ✓ AMR sensors calibration pending
  - ✓ Non-linearity of AMR sensor and InAmp
  - ✓ Bit resolution and non-linearity of ADC (1 LSB : 0.305 mV or 176 nT)
  - ✓ Geometry and position of coils



Sensor Node Prototype and Test

Consideration for Result Improvement

Next step of development:

- Fermentation tank size: Ø=6m, h=25m
- Overall mean of loc. error <10cm
- Duration per loc. cycle <300ms

Small size of a real industrial stainless-steel container

Potential improvement:

- Proper adjustment of sensors and sensor electronics
- Enhanced algorithms
- Optimized design and placement of emitting coils

Conclusion

- An application-specific scalable localization concept in WSN deployed in industrial containers was presented and extended:
  - ✓ Scale-up of the demonstrator
  - ✓ Low power sensor electronics
  - ✓ First power savings of approx. factor 2.5
- Arbitrary number of wireless sensor nodes can be deployed
- NLM for host-based accurate post mortem position computation
- Triangulation for local implementation and on-line position computation
- Synchronization of coil switching and sensor node timing for accuration
- Sensor node verification by discrete prototype due to lack of complete simulation model

List of Project Publications

Pending patent application:

- Verfahren und Vorrichtung zur Ermittlung der räumlichen Koordinaten mindestens eines Sensorknotens in einem Behältnis, filing date: 18.05.2010.

Publications:

[1] Rao, L., Iswandy, K., König., A.: "Cost Effective 3D Localization for Low-Power WSN Based on Modified Sammon's Stress Function with Incomplete Distance Information". Soft Computing in Industrial Applications: Algorithms, Integration, and Success Stories, AISC 75, X.Z. Gao et al. (Eds.), pp.149-156, Springer, 2010.

[2] Carrella, S., Iswandy, K., Lutz, K., König, A.: 3D-Localization of Low- Power Wireless Sensor Nodes Based on AMR Sensors in Industrial and AmI Applications. In: 15. ITG-/GMA-Fachtagung Sensoren und Messsysteme, Nürnberg, pp. 522-529, May 2010.

[3] Iswandy, K., Carrella, S., König, A.: Intelligent Magnetic Sensing System for Low Power WSN Localization Immersed in Liquid-Filled Industrial Containers. In: Setchi, R; Jordanov, I.; Howlett, R. J.; Jain, L. C. (Eds.): Knowledge-Based and Intelligent Information and Engineering Systems, LNCS, Vol. 6277, pp. 361-370, Springer, 2010.

[4] Iswandy, K., Carrella, S., König, A.: Localization System for Low Power Sensor Nodes Deployed in Liquid-Filled Industrial Containers Based on Magnetic Sensing. In: 24. Messtechnisches Symposium des Arbeitskreises der Hochschullehrer für Messtechnik e.V., Hamburg, pp.108-121, Sept 2010.

List of Project Publications

Accepted Publications:

[5] *Carrella, S., Iswandy, K., König, A.: A System for Localization of Wireless Sensor Nodes in Industrial Applications Based on Sequentially Emitted Magnetic Fields Sensed by Tri-axial AMR Sensors. In: 11th Symposium 'Magnetoresistive Sensors and Magnetic Systems', Mar. 2011.*

[6] *Carrella, S., Iswandy, K., König, A.: System for 3D Localization and Synchronization of Embedded Wireless Sensor Nodes Based on AMR Sensors in Industrial Environments. In: 16. ITG-/GMA-Fachtagung Sensoren und Messsysteme, Nürnberg, Jun. 2011.*

Vielen Dank

gefördert vom

Bundesministerium
für Bildung
und Forschung

VDI | VDE | IT

Wir danken dem BMBF für die Förderung und dem Projektträger VDE/VDI-IT.

Zum Gesamtvortrag:

http://www.mstonline.de/mikrosystemtechnik/mst-fuer-energie/vortraegeeas