Method to Substitute Threshold Criterion of Monitoring and Early Warning in Geotechnical Constructions

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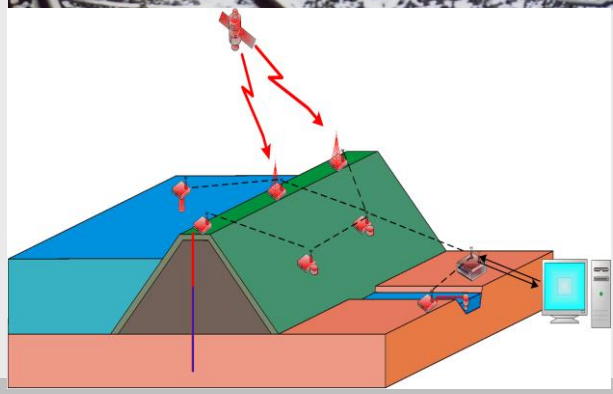
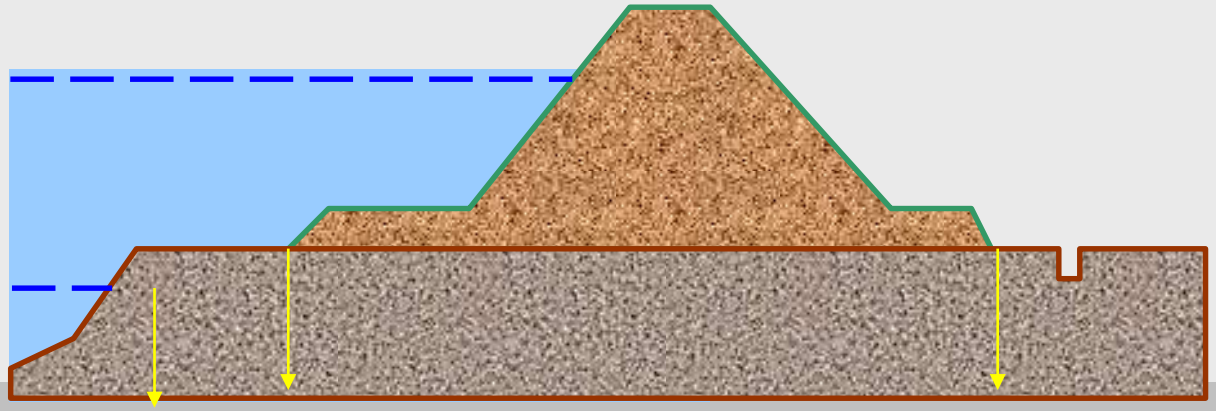
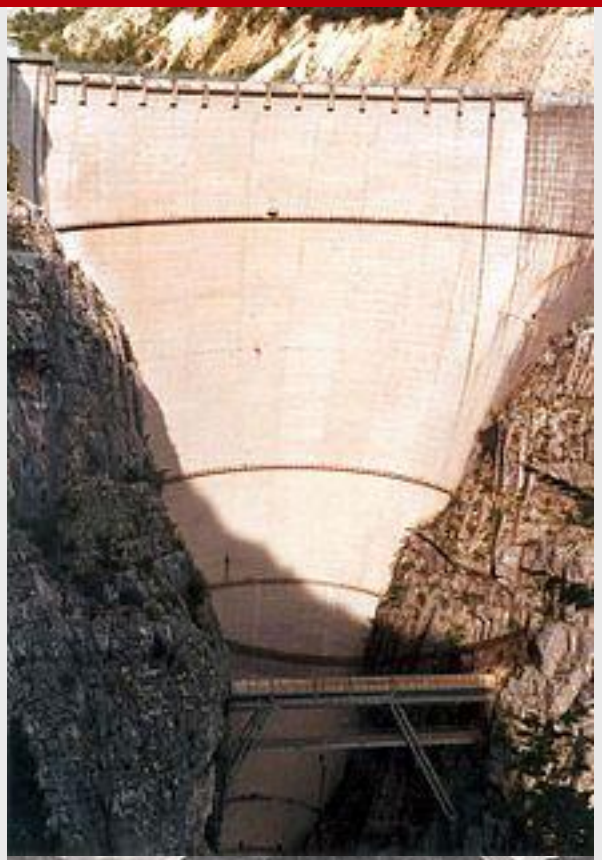


ZONA INTERDITA
PERIGO
QUEDA DE PEDRAS

Dam Monitoring System

- Vajont Dam Failure 1963





Teton Dam 1976

Monitoring Systems of Constructions

- It is important to monitor man-made constructions for safety reasons
- There are many types of monitoring systems using sensors to measure certain parameters
- Till now, all monitoring systems use a single value for the measured parameters as threshold to evaluate the safety of the construction
- Lately, self-organized wireless sensor networks have been developed and used successfully

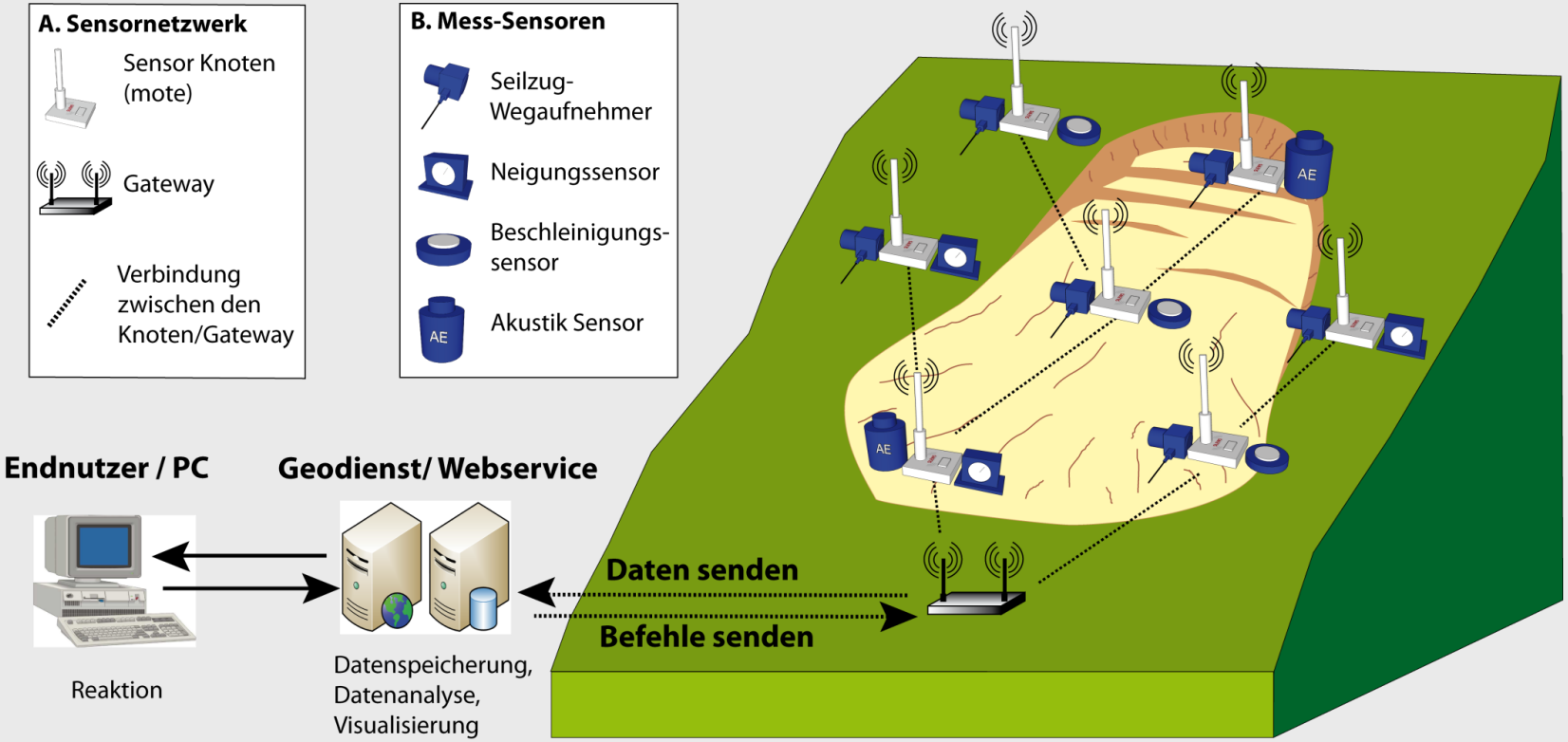
These systems can be used as monitoring system for landslides, dams, geotechnical measures, Bridges, environmental monitoring, Tunneling, etc.
Only the sensors and the data infrastructure vary according to the conditions and considering the type of monitoring.

For example:
To monitor anchors the chucking force is measured between anchor rod and screw nut.
Decreasing force is an indication for anchor creep,
Increasing force is an indication for movement in rock.

What parameters can be monitored?

1. Piezometer heads (water level)
2. 3D Acceleration
3. 3D Tilt
4. Movement by GPS
5. Flow rate e. g. down stream
6. Turbidity of water down stream
7. Water temperature
8. Water pressure
9. Chucking force on anchor head
10. Distance between points, etc.

1. Spatial Real-Time Sensor Network Monitoring



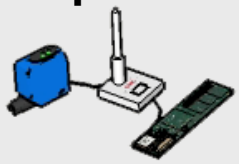
Requirements:

- Precise
- Low Maintenance Effort
- Cost Efficient,
- Remote Operable

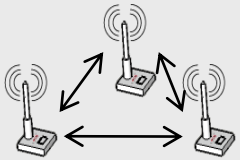
1. Spatial Real-Time Sensor Network Monitoring – *Aims of the project*

Systematic development of a prototypic alarm and early warning system for landslides, by using modern technologies and monitoring methods.

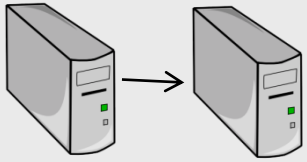
Main aspects:



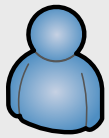
Usage of low-cost, reliable and suitable **sensor technologies**, integrated in modern self organizing **wireless sensor networks**



Advancement of data quality and reduction of false alarm rates due to **sensor-combination** and **sensor-fusion**.

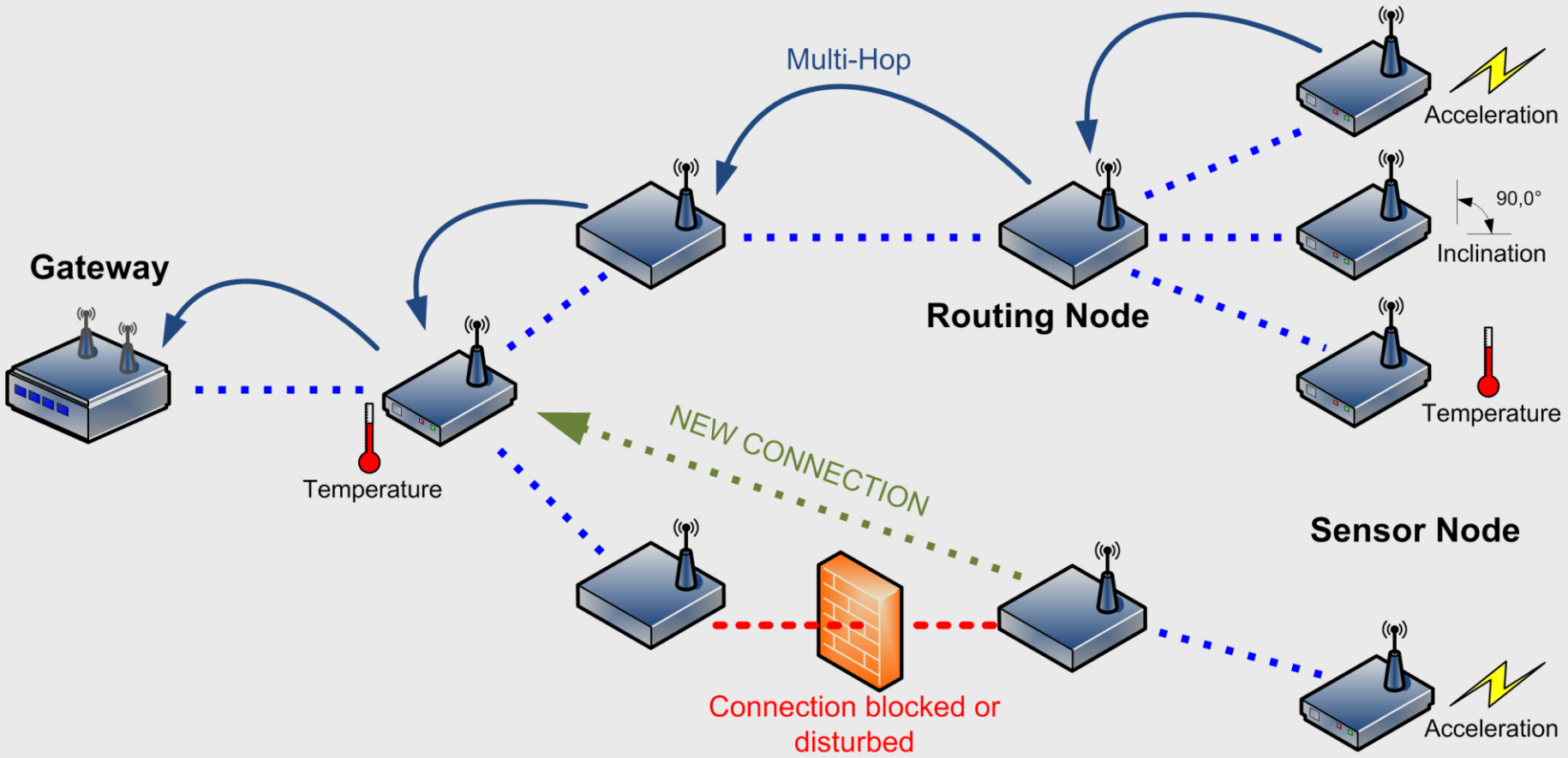


Development and configuration of a **geoservice infrastructure** for integration of realtime data and **geoprocessing**.



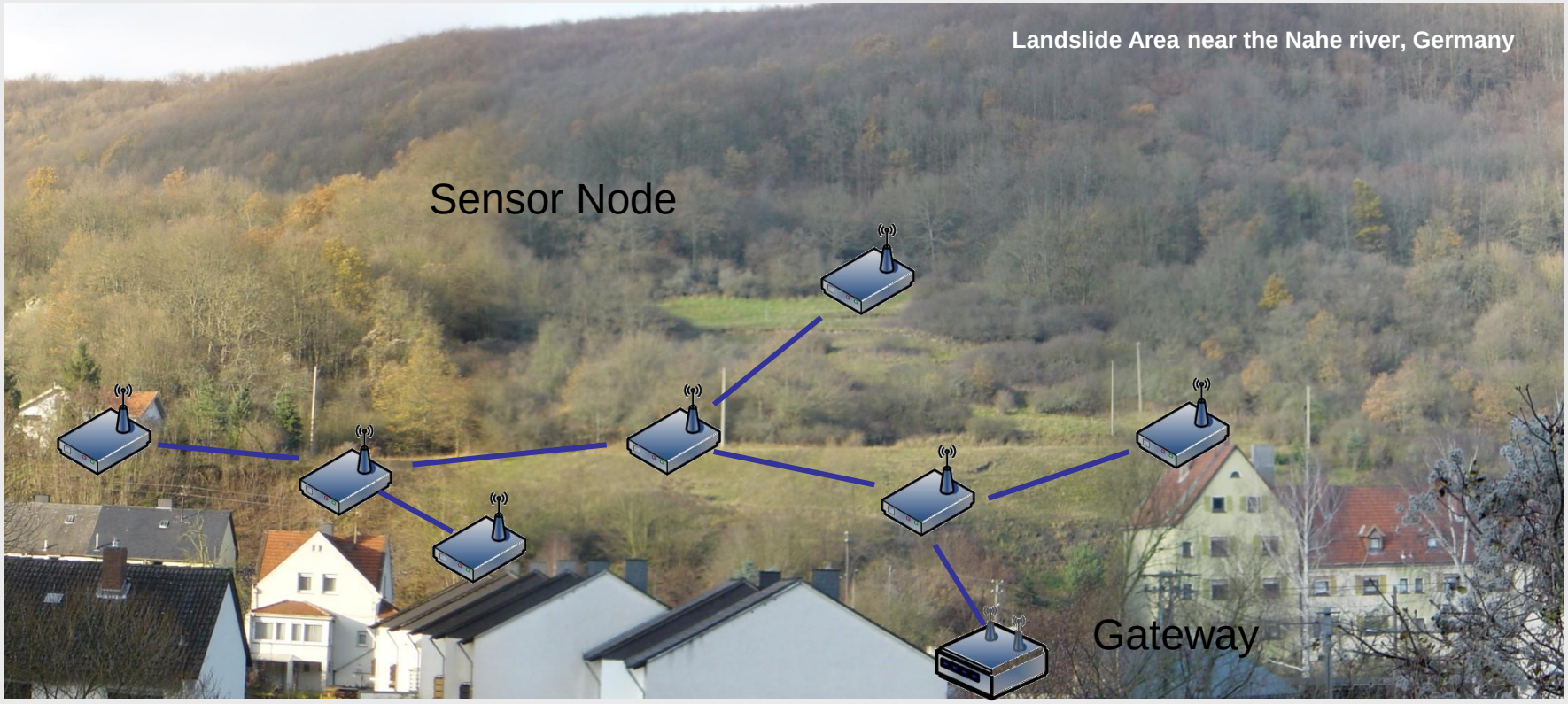
Construction and development of **user-orientated interfaces** and allocation of **user-specific information**.

1. Spatial Real-Time Sensor Network Monitoring - *Structure*



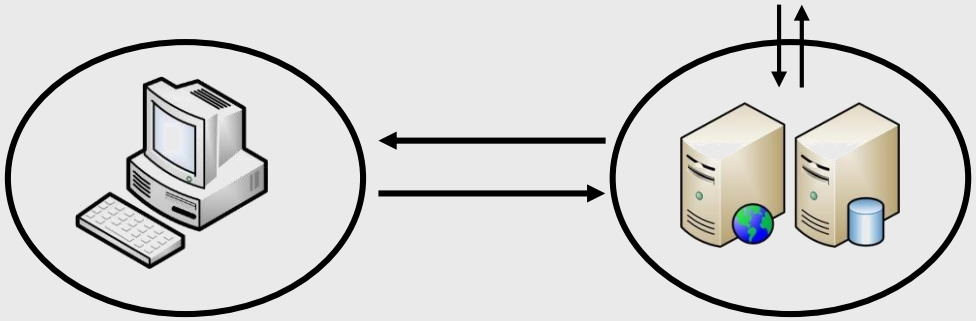
Wireless **Energy Saving** **Multi Hop** **Ad-hoc** **Bidirectional** **Self-Healing**

2. Spatial Real-Time Landslide Monitoring



Enduser

Reaction
Emergency Plans

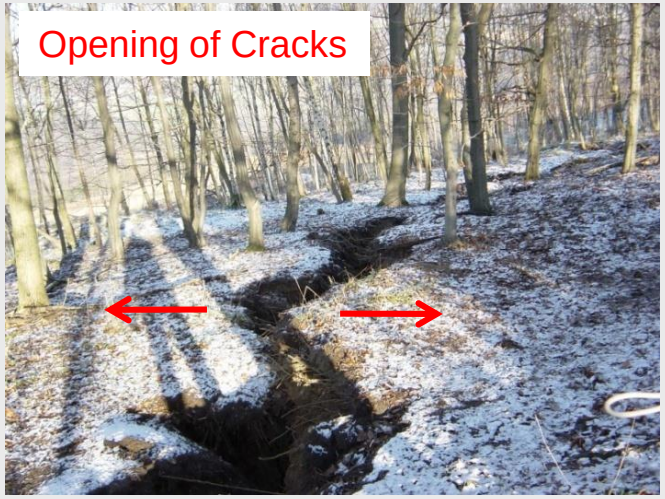


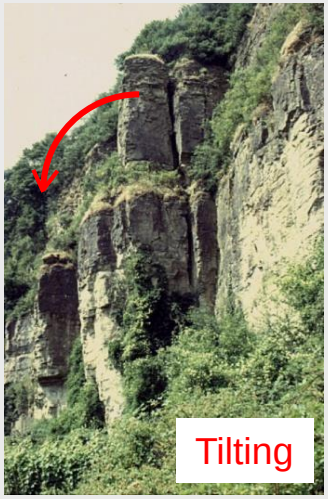
Geoservice / Webservice

Data storage
Data analysis
Visualisation

2. Spatial Real-Time Landslide Monitoring – *Deformation Structures*

Surface Deformations

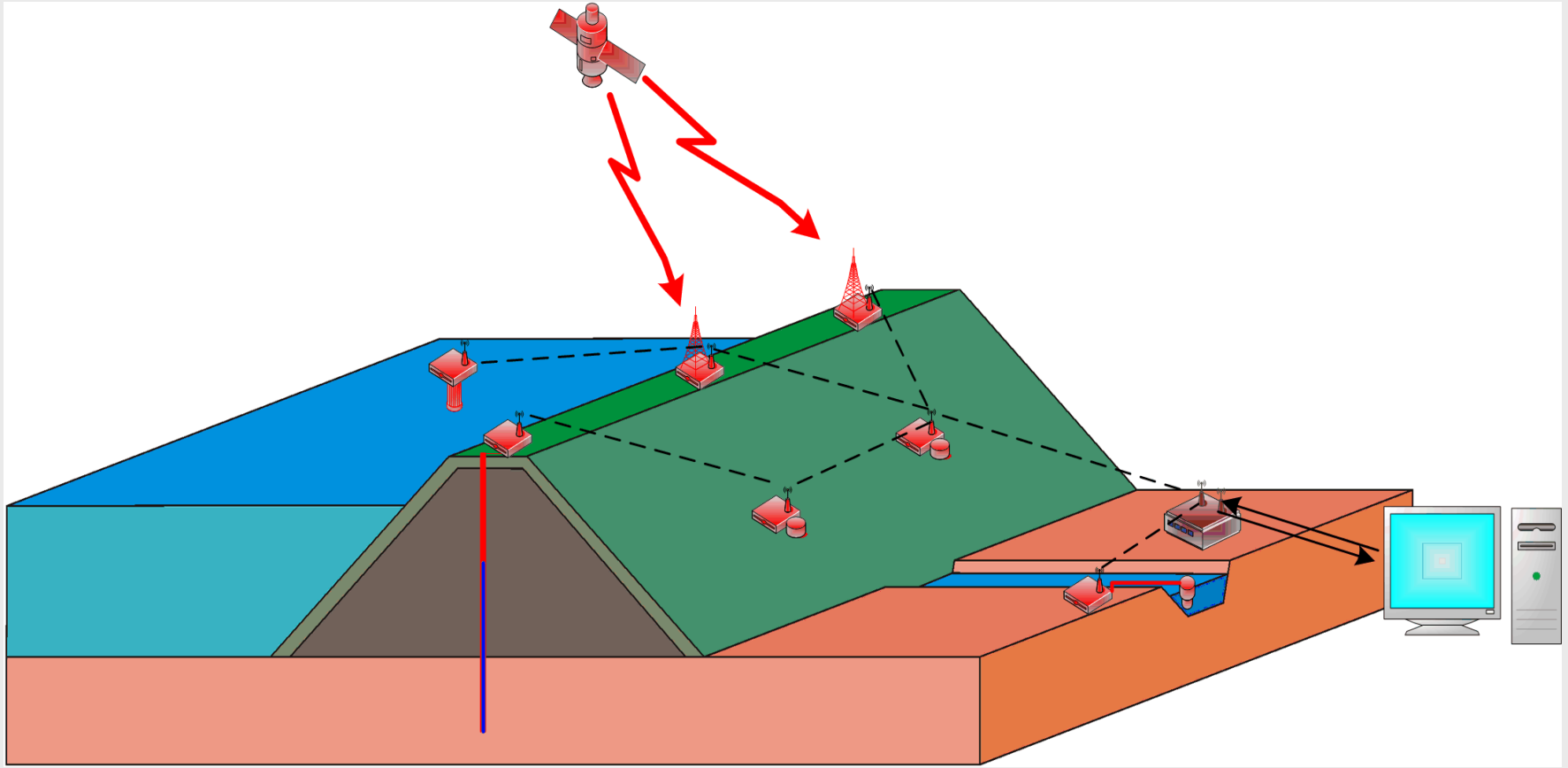




Scarps, rifts, trenches, depressions

Deformation of constructions and infrastructures

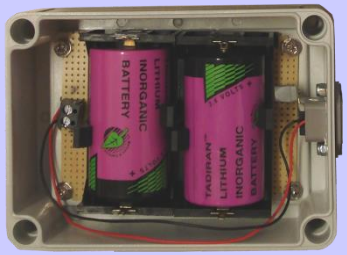
3. Monitoring of Dams



4. Sensors - Components

Sensor Node

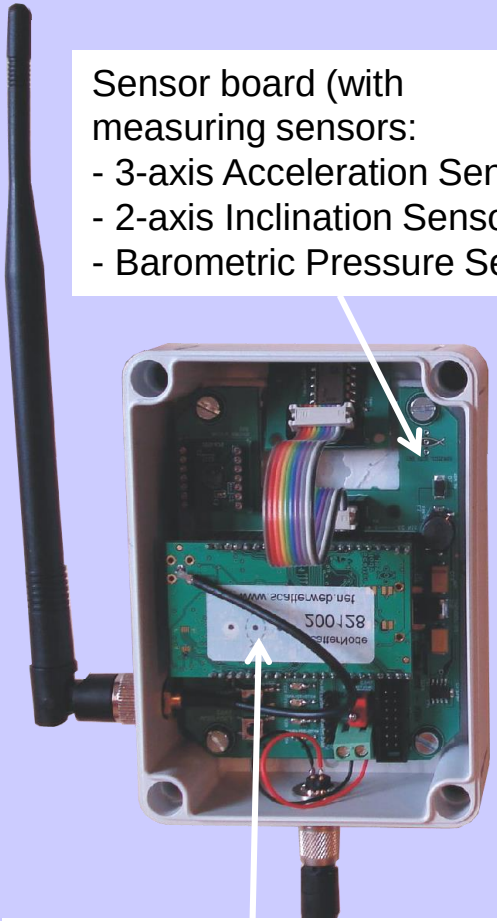
Energy Modul



Battery Pack

Solar Modul

Sensor Modul



Sensor board (with measuring sensors:
- 3-axis Acceleration Sensor
- 2-axis Inclination Sensor
- Barometric Pressure Sensor

ScatterNode (radio module)

Gateway

Outdoor use

Indoor use

4. Sensor Requirements

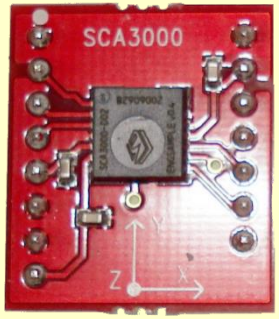
costs *< 500,- €*
(most: < 100,- €)

Displacement Transducer: ± 0,1 mm
Angle Sensor: ± 0,1°

accuracy / quality

integrability / interface compatibility

Interface: digital, absolute
(I^2C, SPI, SSI, RS232)



SENSOR

energy use

Voltage: 0,3 – 3,6 V

adaptability

Displacement Transducer → Spreading, Sliding
Angle Sensor → Toppling

weatherability

Temp.: between -20° C and +70° C
Protection Classification: IP 54

expendable

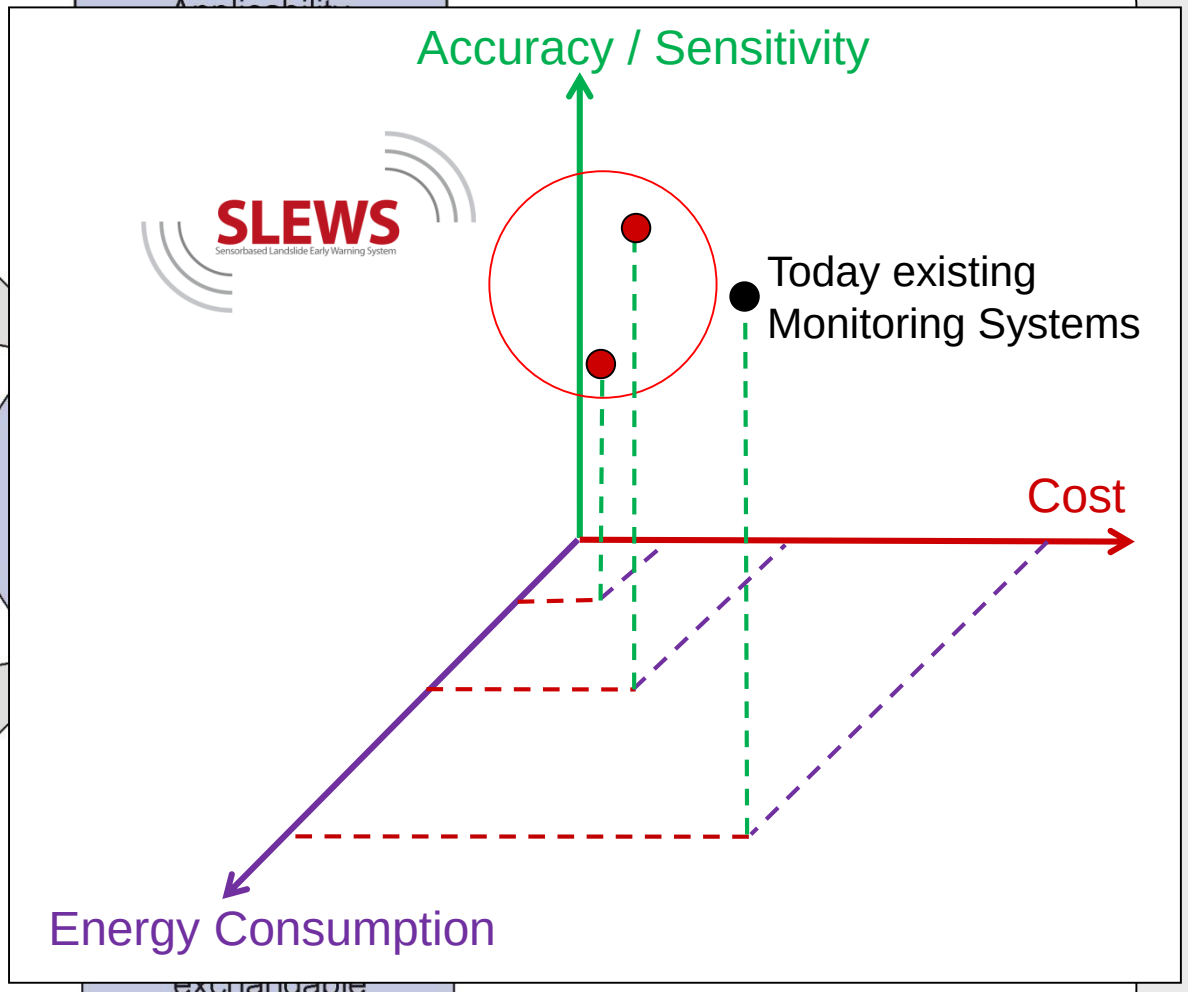
Easy integration → easy to expand

4. Sensors – Sensor Requirements

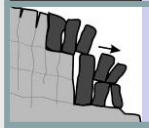
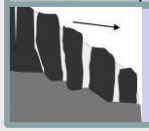
Low energy consumption

System-Integrability / Interface-Compatibility

Weatherability, solid, robust



4. Measuring Sensors – Sensor Selection

Type of Movement \ Sensors	Acceleration Sensor	Tilt Sensor	Displacemnet Transducer	Acoustic Sensor	Pressure Sensor	Temperature Sensor	Moisture Sensor	Pore water pressure Sesnor	Geophys. Sensors	GNSS/GPS	Ultra Wide Band (UWB)
Fall	✓	✓	✓	✓	✓	✗	✗	✗	✗	✓	✗
 Topple	✓	✓	✓	✓	✓	✗	✗	✗	✗	✓	✓
Slide	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
 Spread	✗	✗	✓	✓	✗	✗	✓	✓	✗	✓	✓

Relative measurement

Absolute measurement

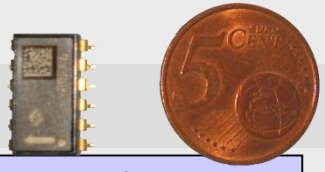
✓ : suitable

✗ : suitable to only a limited extend

4. Measuring Sensors – Sensor Selection (MEMS)

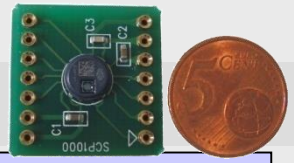
Acceleration Sensors (< 50,- €)

3-Axis Acceleration Sensor	Interface: SPI (digital)	Temp.: -20° to +85°
Range: +/- 2g	Sens./ Acc.: 1333 LSB/g	Cons.: <500 µA / 2,5V
Bandwith: up to 70 Hz	Output Data Rate: 250 Hz	buffer memory (192 values)



Inclination Sensors (Tiltmeter) (<50,- €)

2-Axis Inclination Sensor	Interface: SPI (digital)	Temp.: -20° to +85°
Range: +/- 30° (+/-90°)	Sens./ Acc.:1638 (819)LSB/g	Cons.: 4 mA / 5V
Bandwith: 8 - 28 Hz	Resolution: 0,035° /LSB	



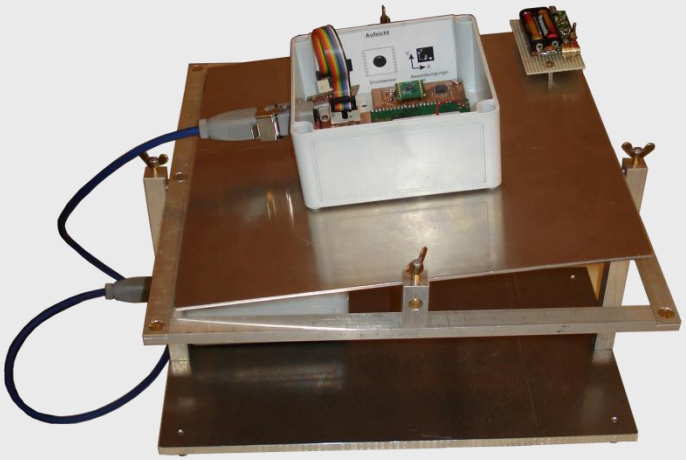
Barometric Pressure Sensors (< 50,- €)

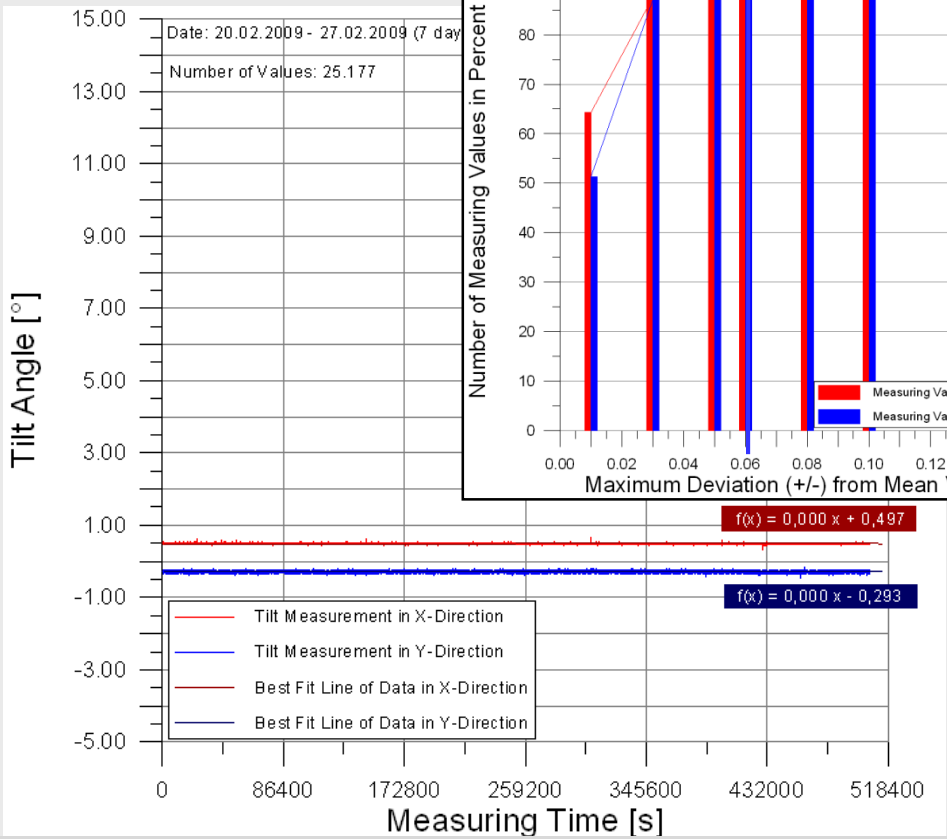
Interface: SPI (digital)	Temp.: -20° to +70°	Range: 30 kPa – 120 kPa
Bandwith: 1,8 - 9 Hz	Sens./ Acc.: ±50Pa to ±200Pa	Resolution: 1,5 Pa
Cons.: <25 µA / <3,6V		

4. Measuring Sensors – Tests and Results

Tilt Measurements – Stable Conditions

100% of Data have a deviation of +/- 0,06° or less

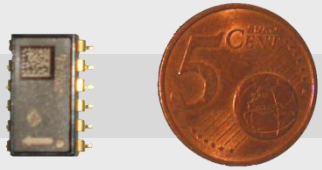


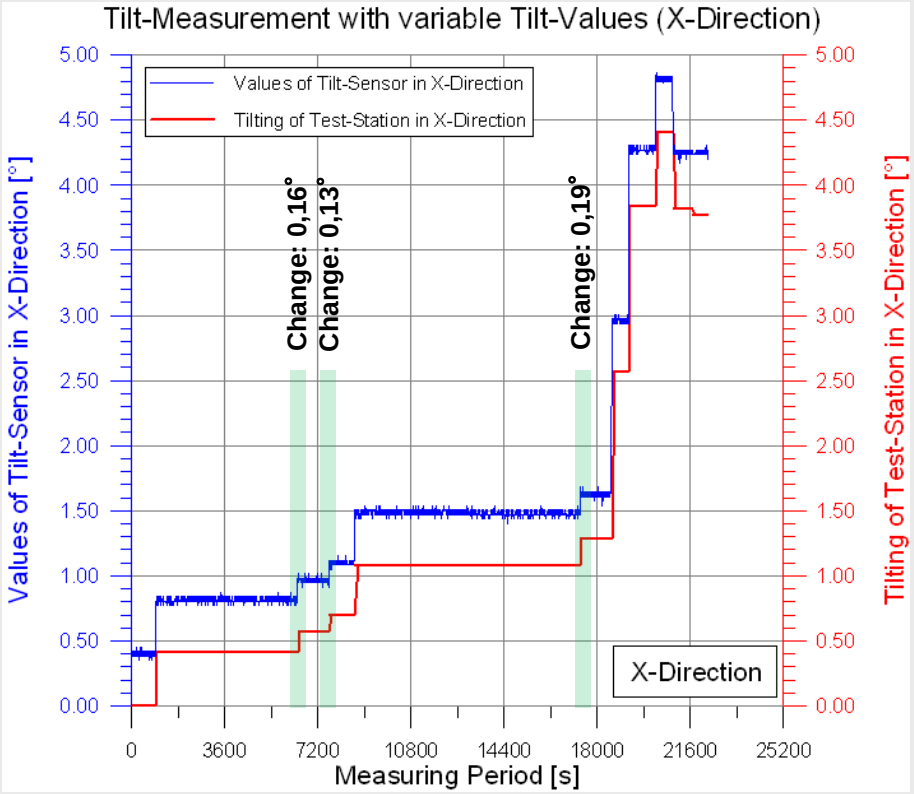


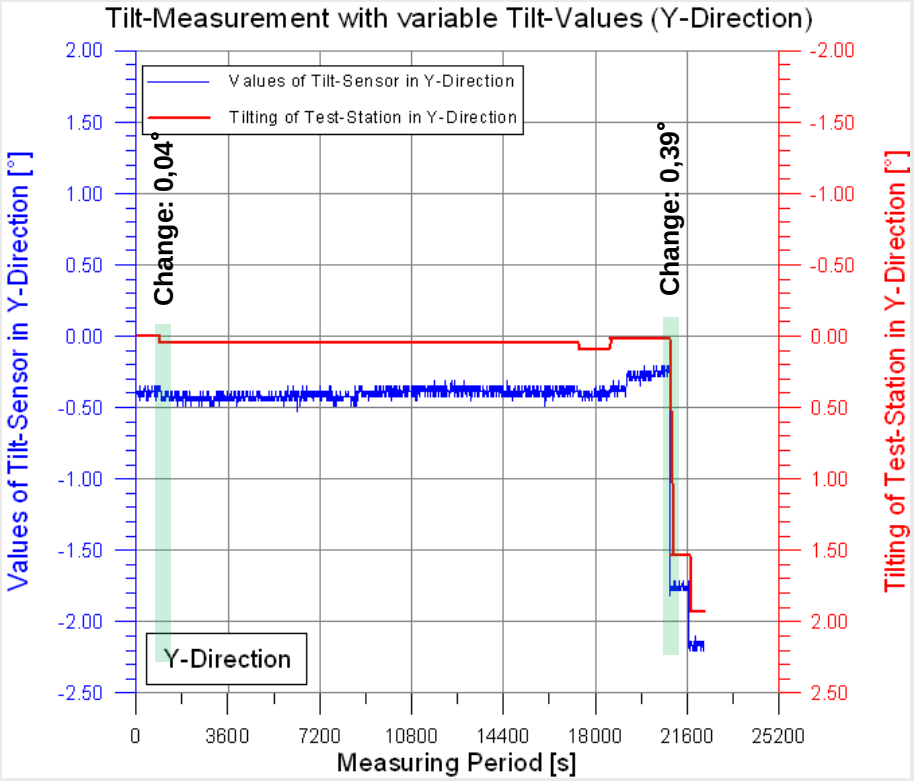
- Minor Data Spreading (Variance < 0,001)
- **Accuracy** (= maximum Deviation) under laboratory conditions: +/- 0,06°

4. Measuring Sensors – Tests and Results

Tilt Measurements – Variable Conditions



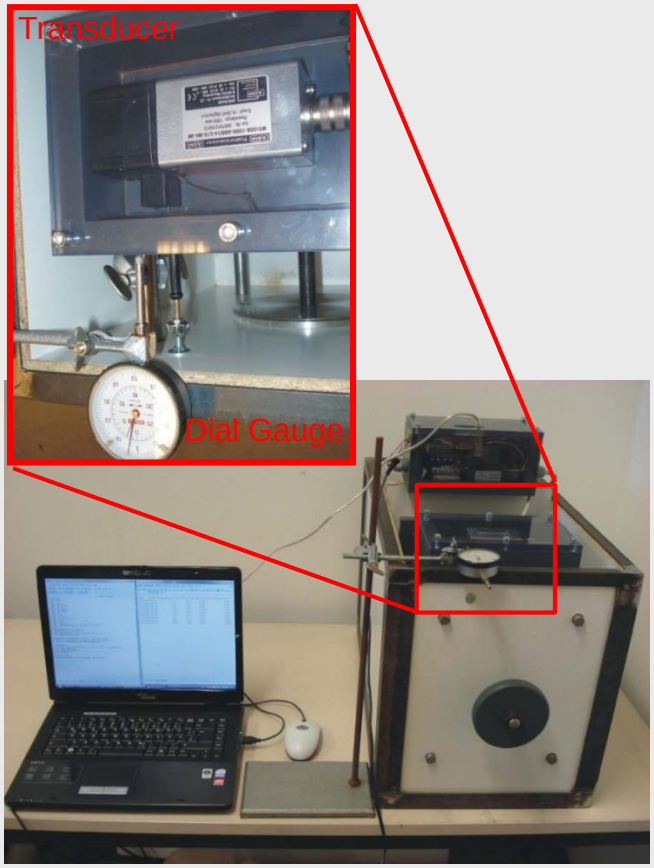


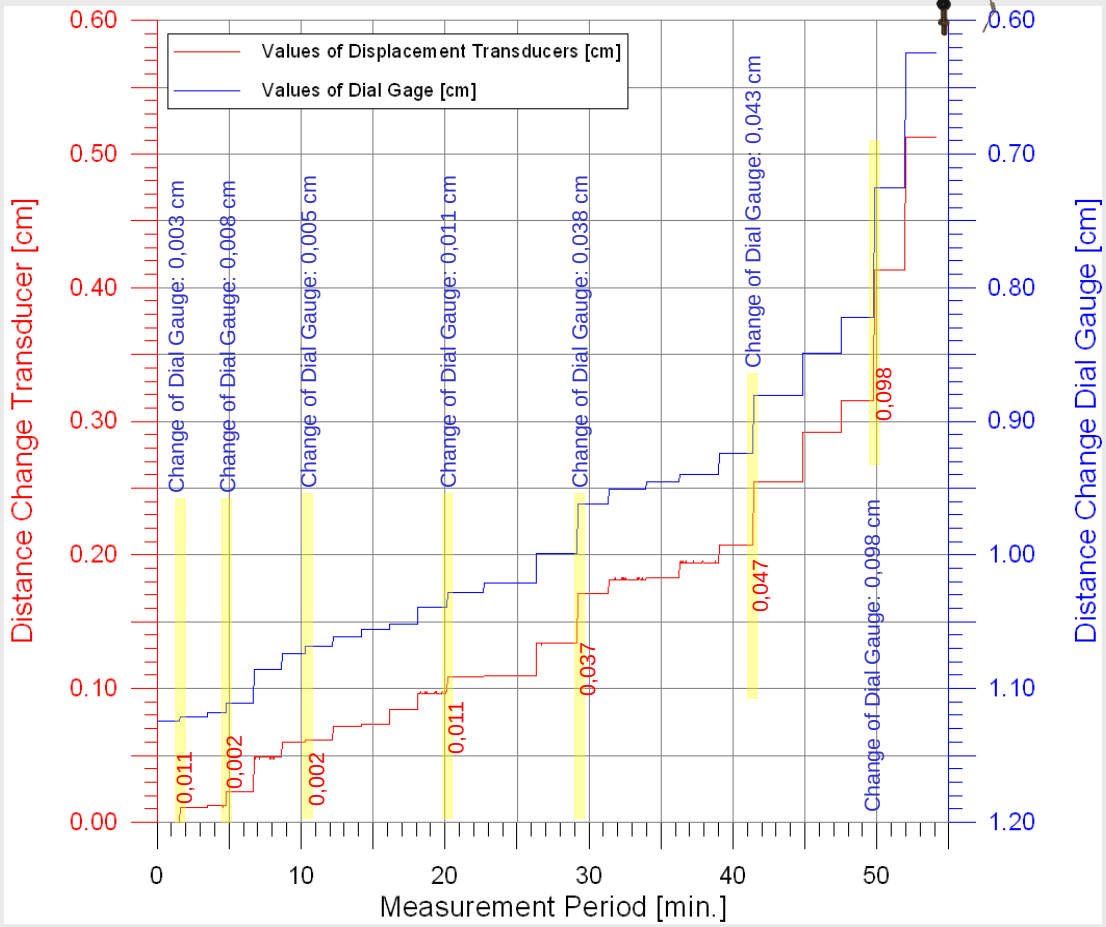


Resolution (= smallest change that can be detected) ≥ 0,1°

4. Measuring Sensors – Tests and Results

Elongation Measurements – Variable Conditions

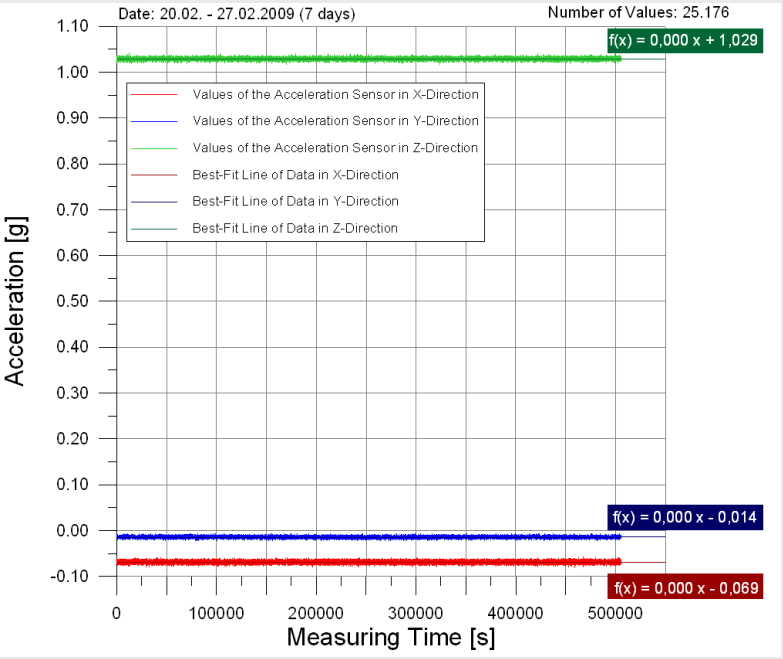


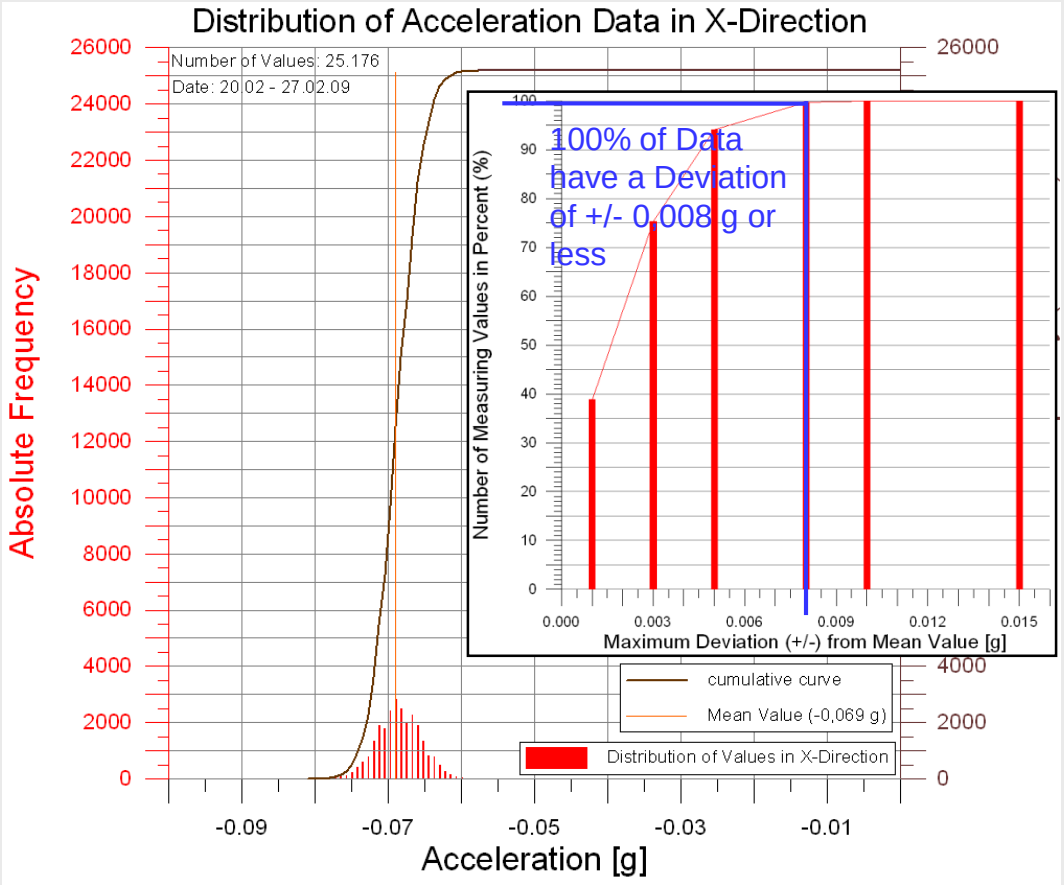


Resolution (= smallest change that can be detected) ≥ 0,01 cm

4. Measuring Sensors – Tests and Results

Acceleration Measurements – Stable Conditions



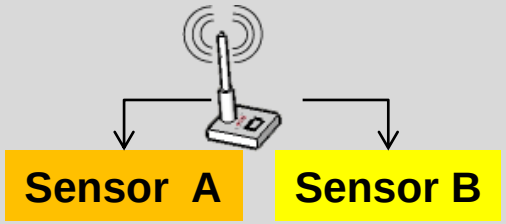


Accuracy (=maximum Deviation) under laboratory conditions: +/- 0,008 g

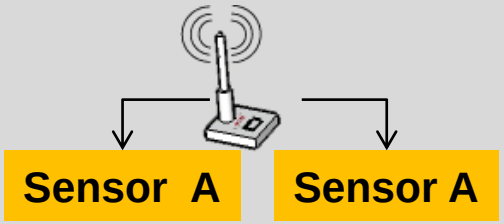
5. Sensor Combination and Data Fusion

Sensor-Combination

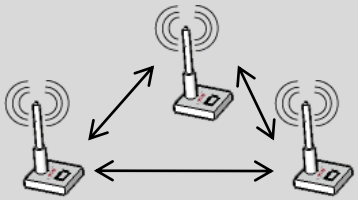
- Combination of different sensors



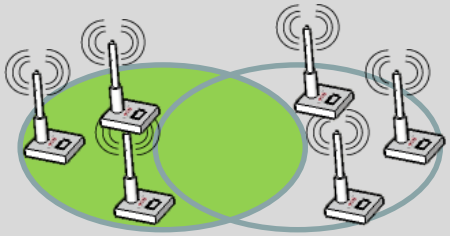
- Combination of the same sensortypes (Redundanz)



- Combination of many measuring sensors and sensor nodes



- Combination of sensornetworks



Sensor-Fusion

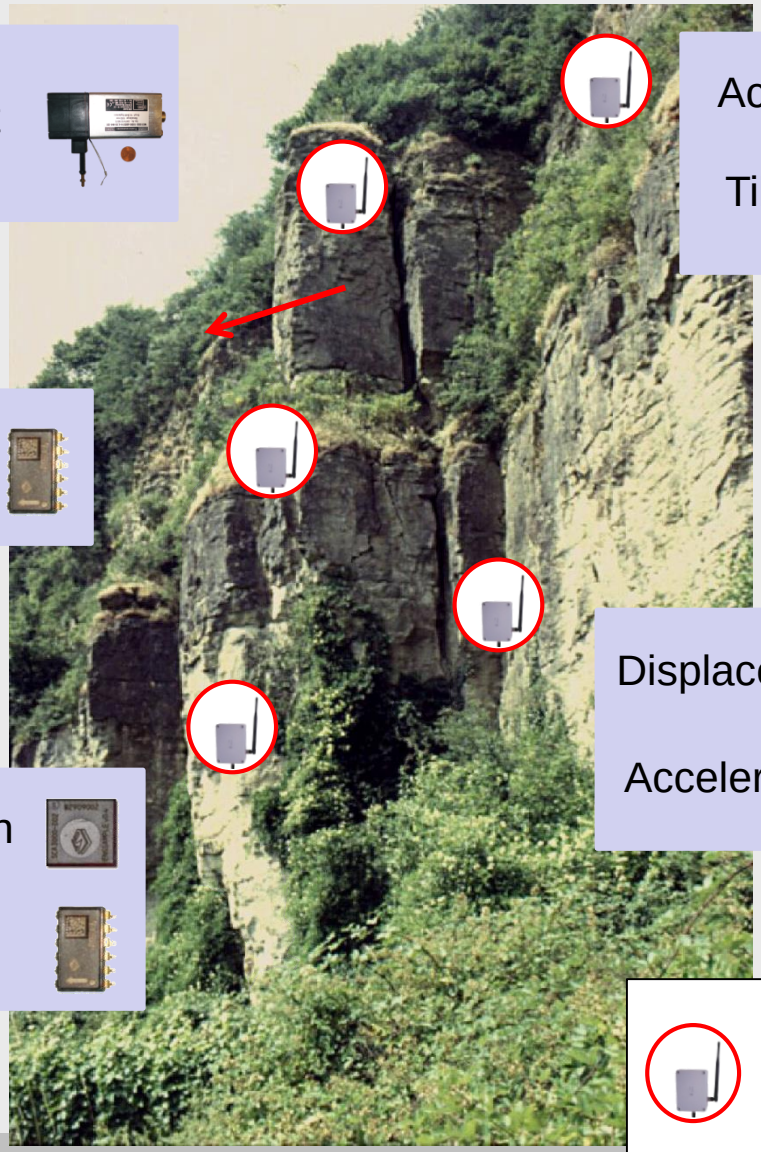
Enhancement and improvement of:

- *data quality*
- *evaluation of the failure mechanism*
- *decision-making for alarm and early warning systems*

Decrease and reduction of:

- *malfunctions and errors*
- *false alarm*

5. Sensor Combination and Data Fusion



Change — Displacement

Acceleration — No Change

Tilting — No Change

Change — Tilting

Displacement — Change

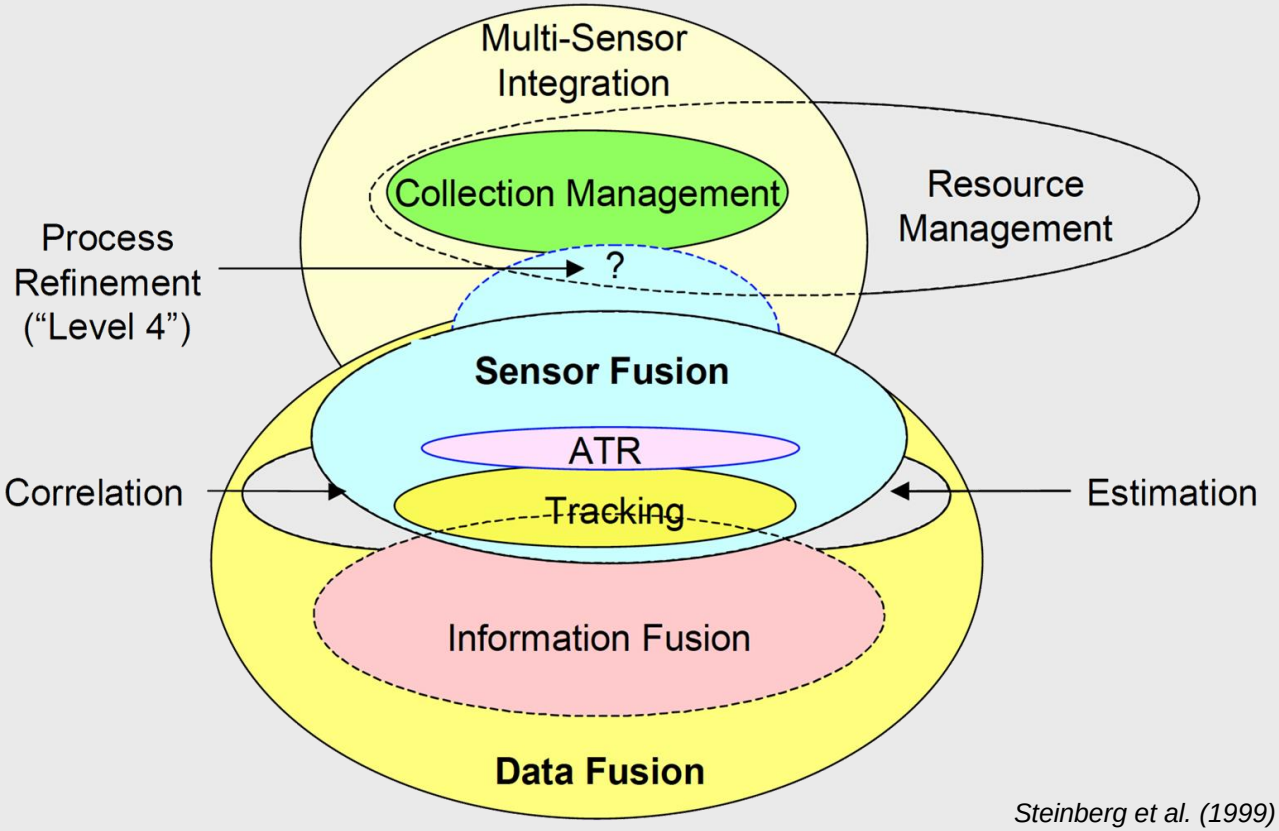
Acceleration — No Change

Change — Acceleration

Change — Tilting

Node of the Sensor Network with different or same Measuring Sensors

5. Sensor Fusion Terms

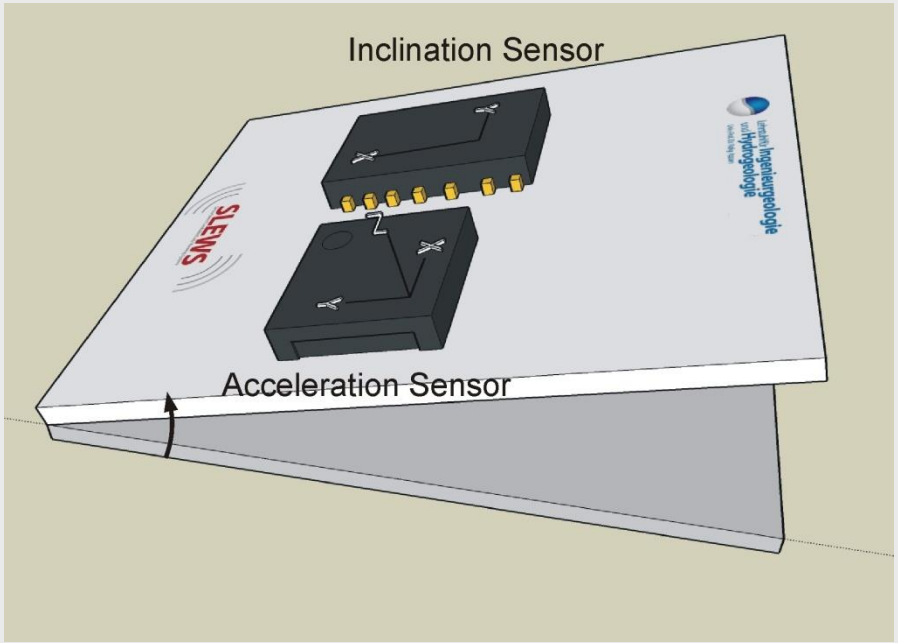


Steinberg et al. (1999)

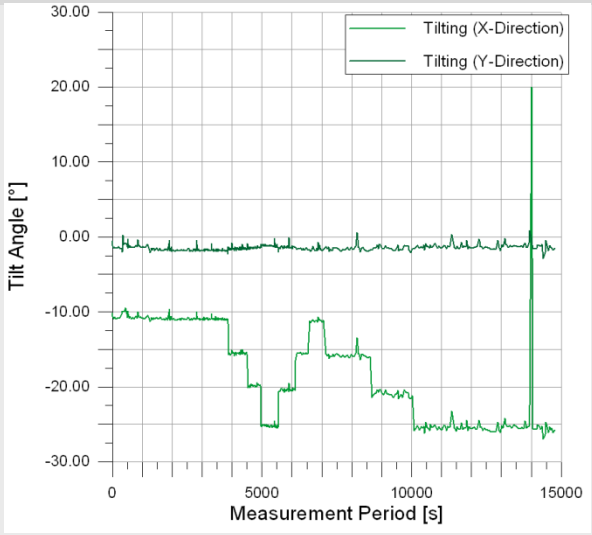
"Data fusion is the process of combining data to refine state estimates and predictions."

Steinberg et al. (1999)

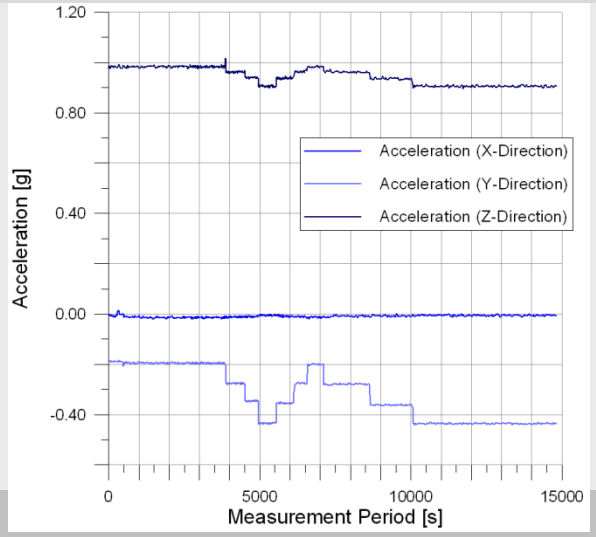
5. Sensor Combination and Fusion



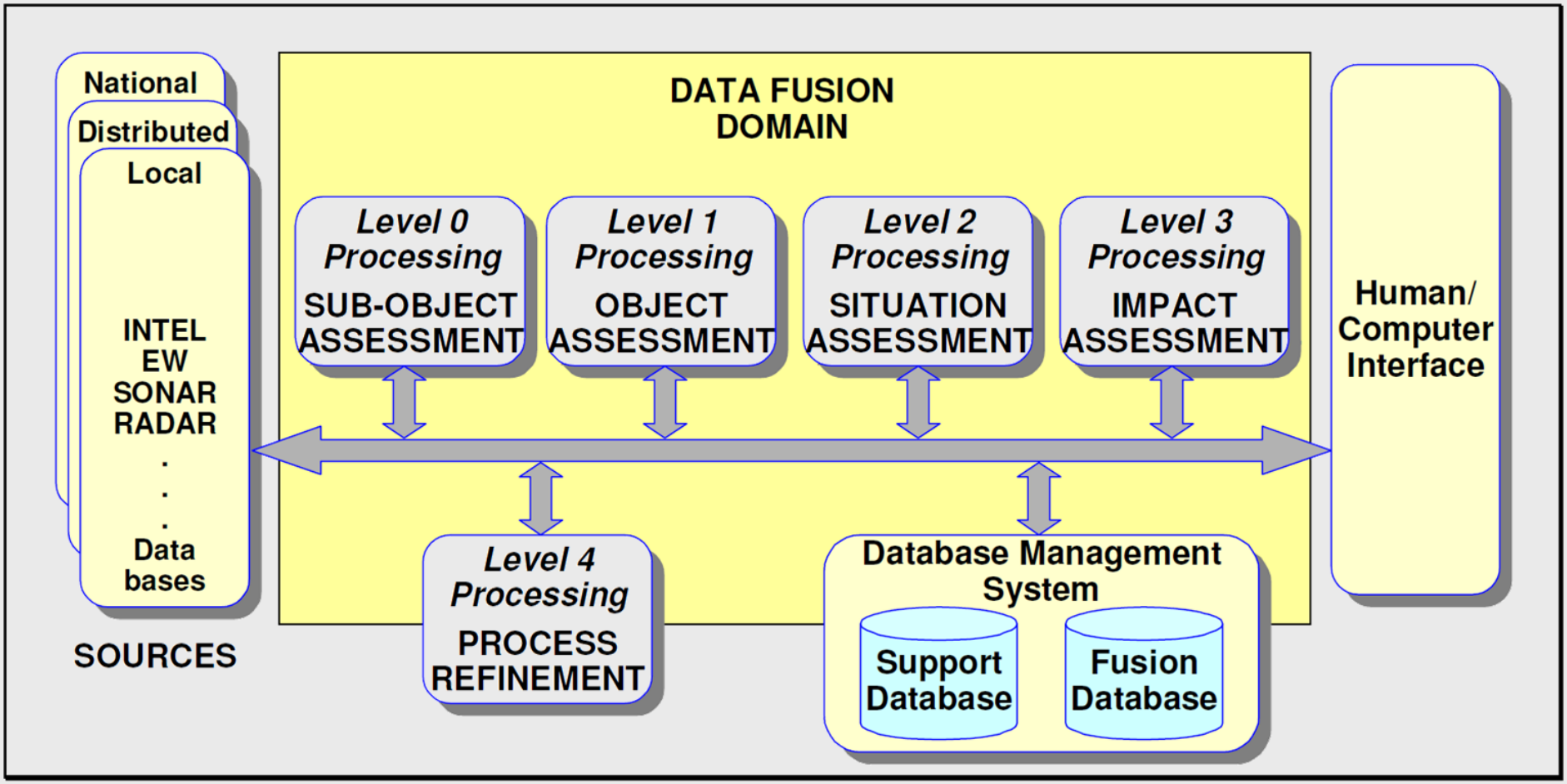
Inclination Sensor



Acceleration Sensor

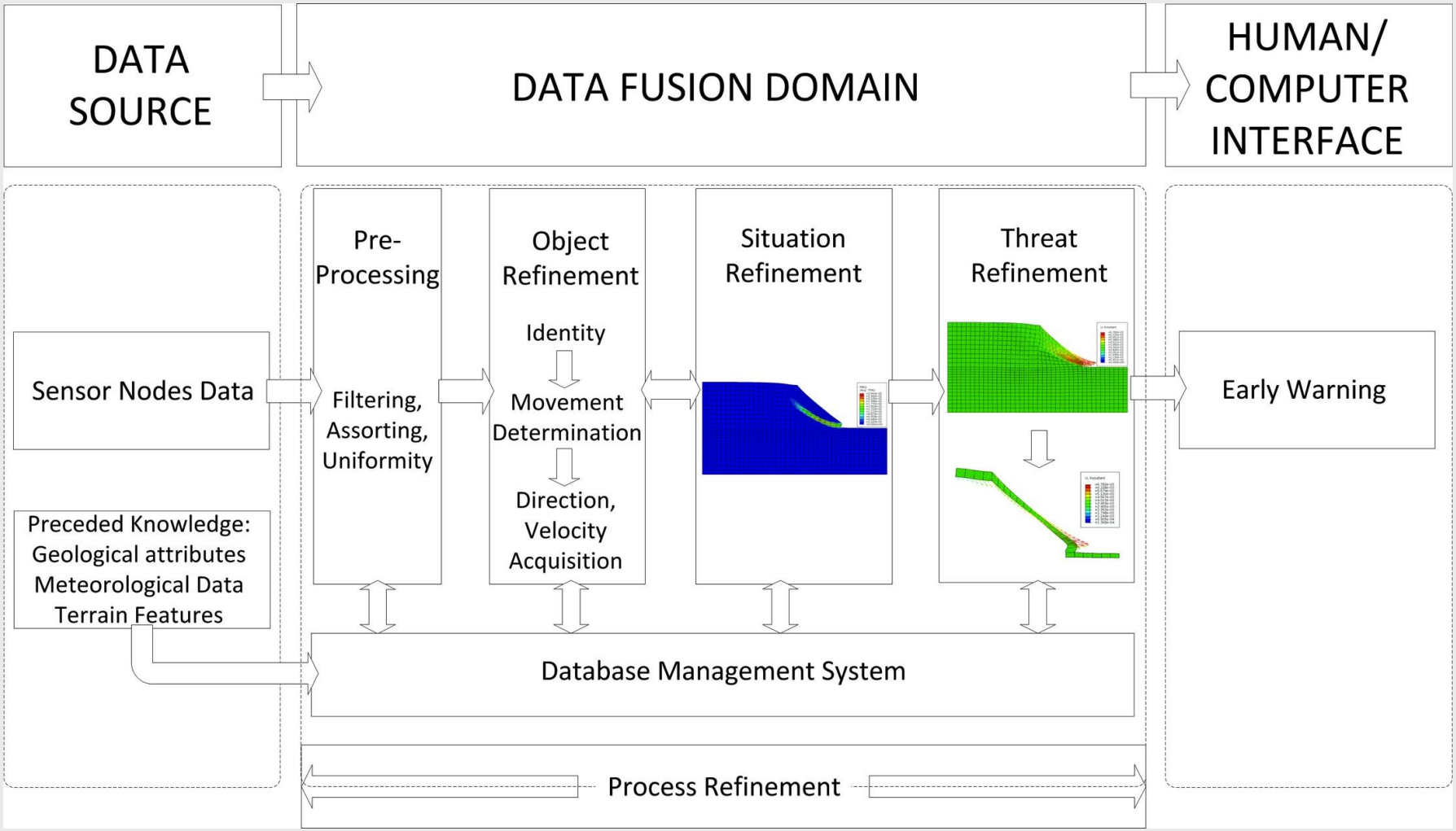


5. Data Fusion Model



Steinberg & Brown (2004)

5. General Approach for Data Processing

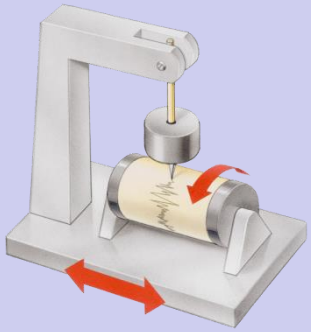


Chen et al. (2013)

5. Sensor Combination and Data Fusion– Tests and Results

Acceleration Measurements – Variable Conditions (Dynamic)

Seismometer



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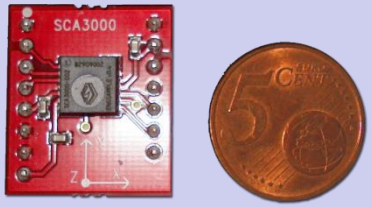
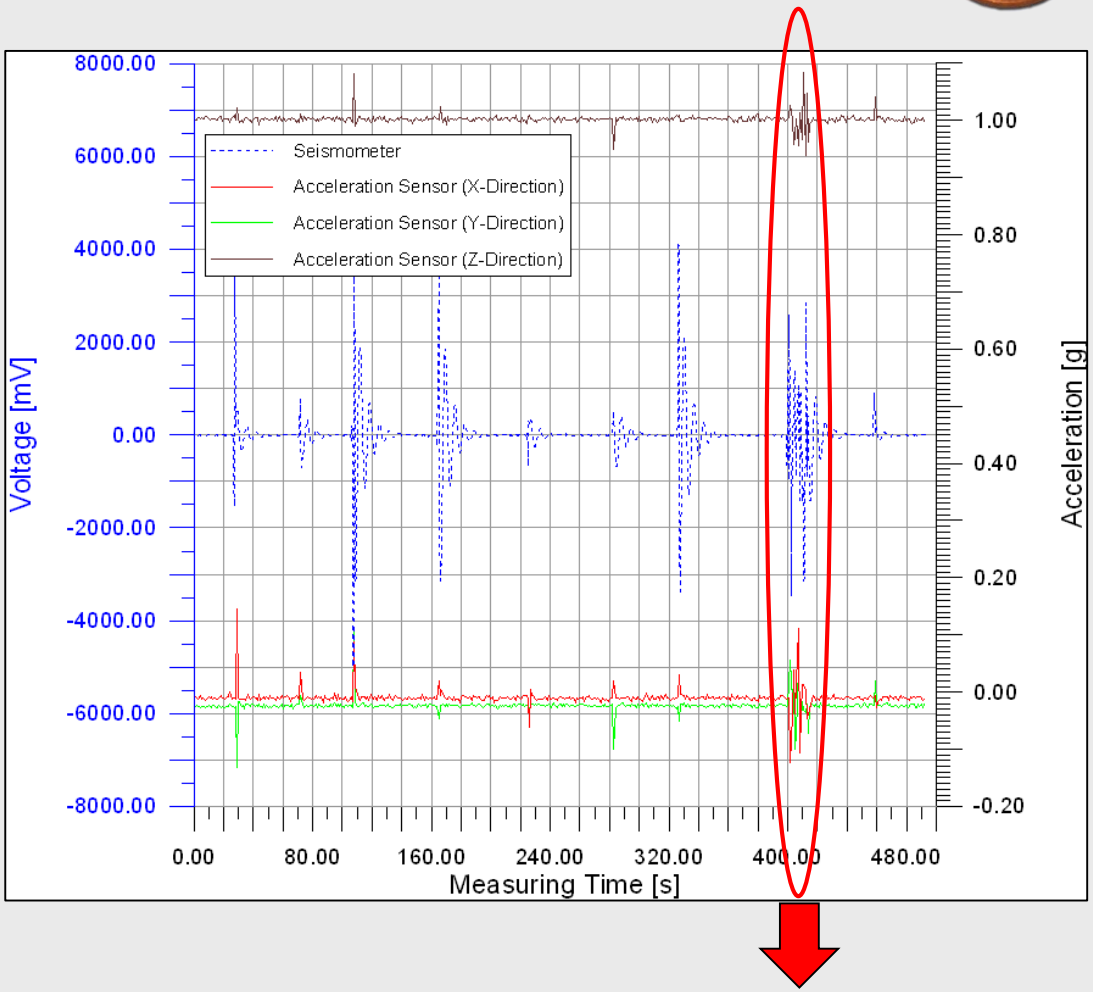
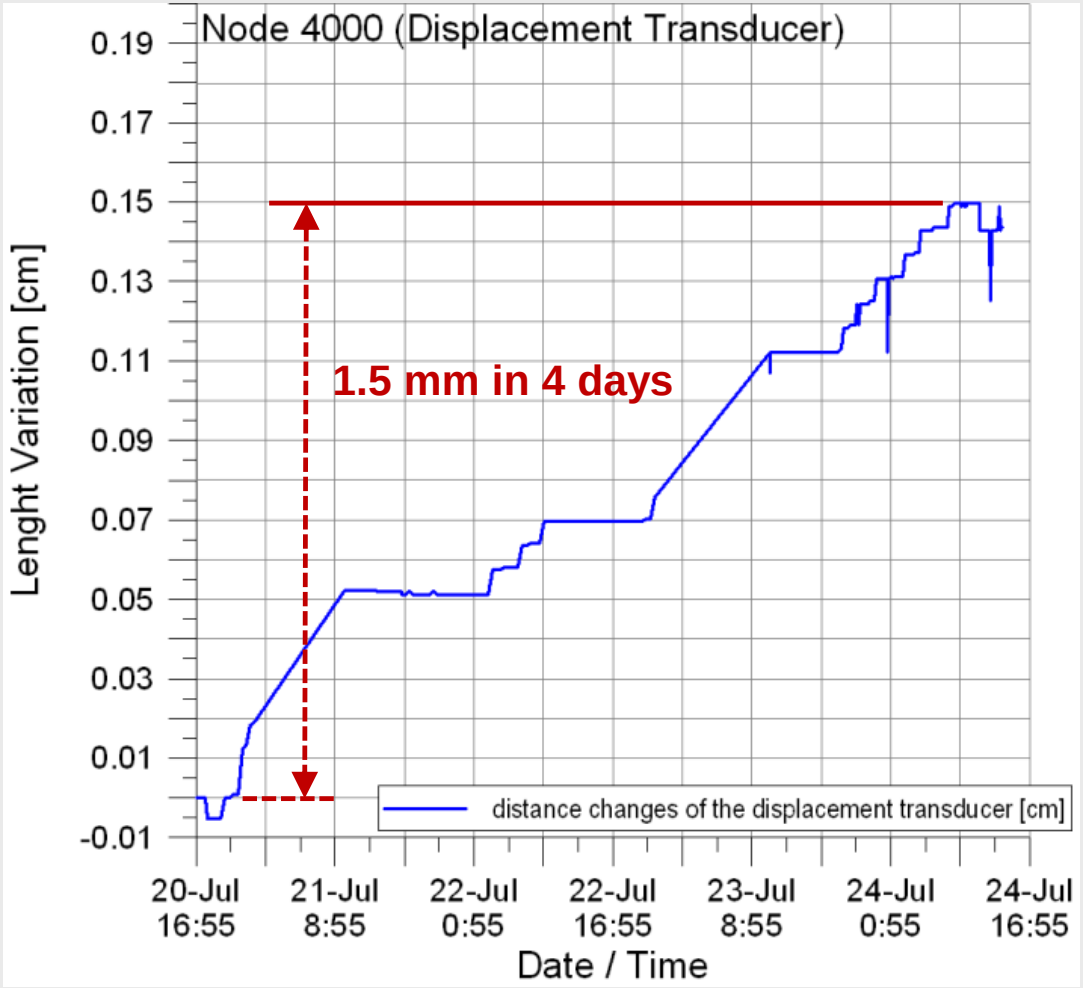


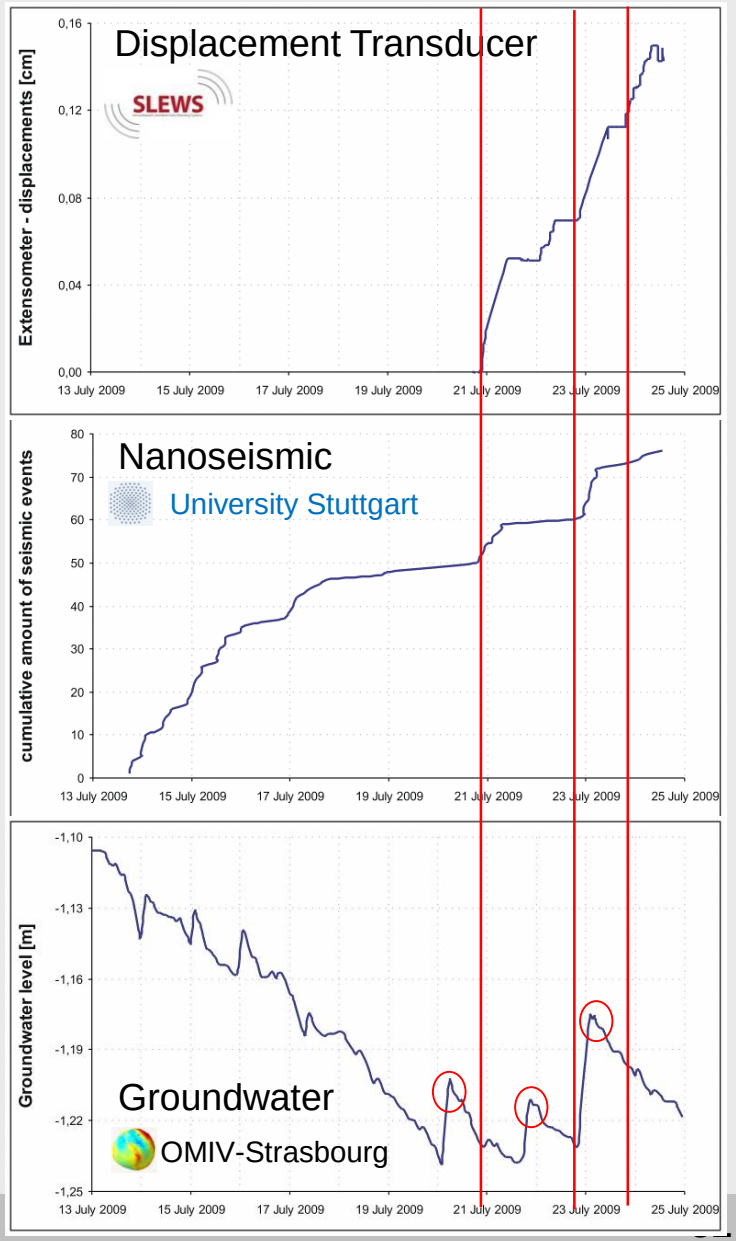
Acceleration Sensor



MOVEMENT

5. Sensor Combination and Data Fusion -example

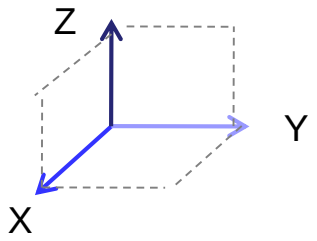




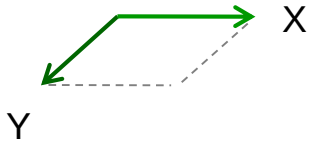
4. Sensor Combination and Data Fusion

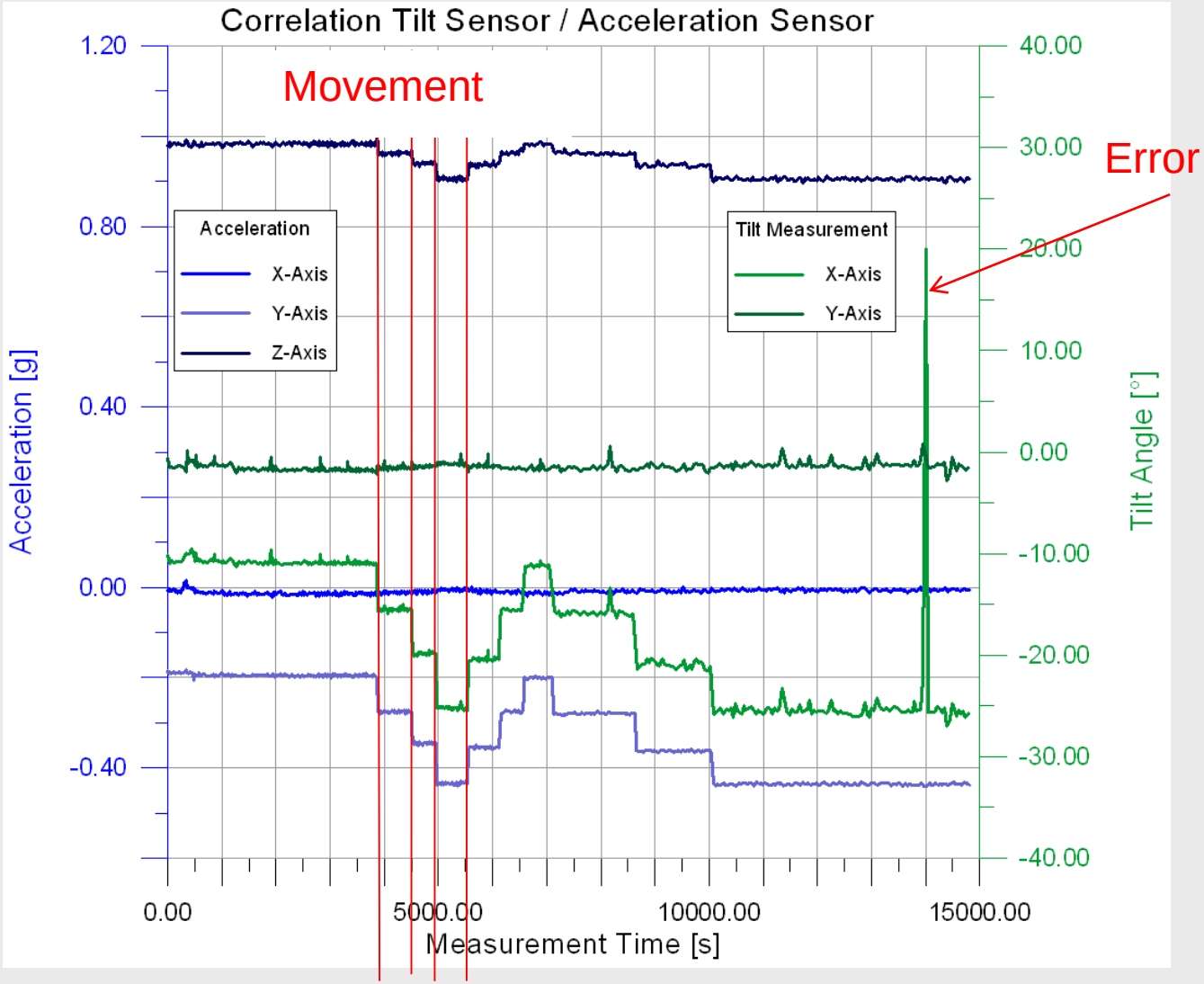
Legend

Acceleration



Tilting

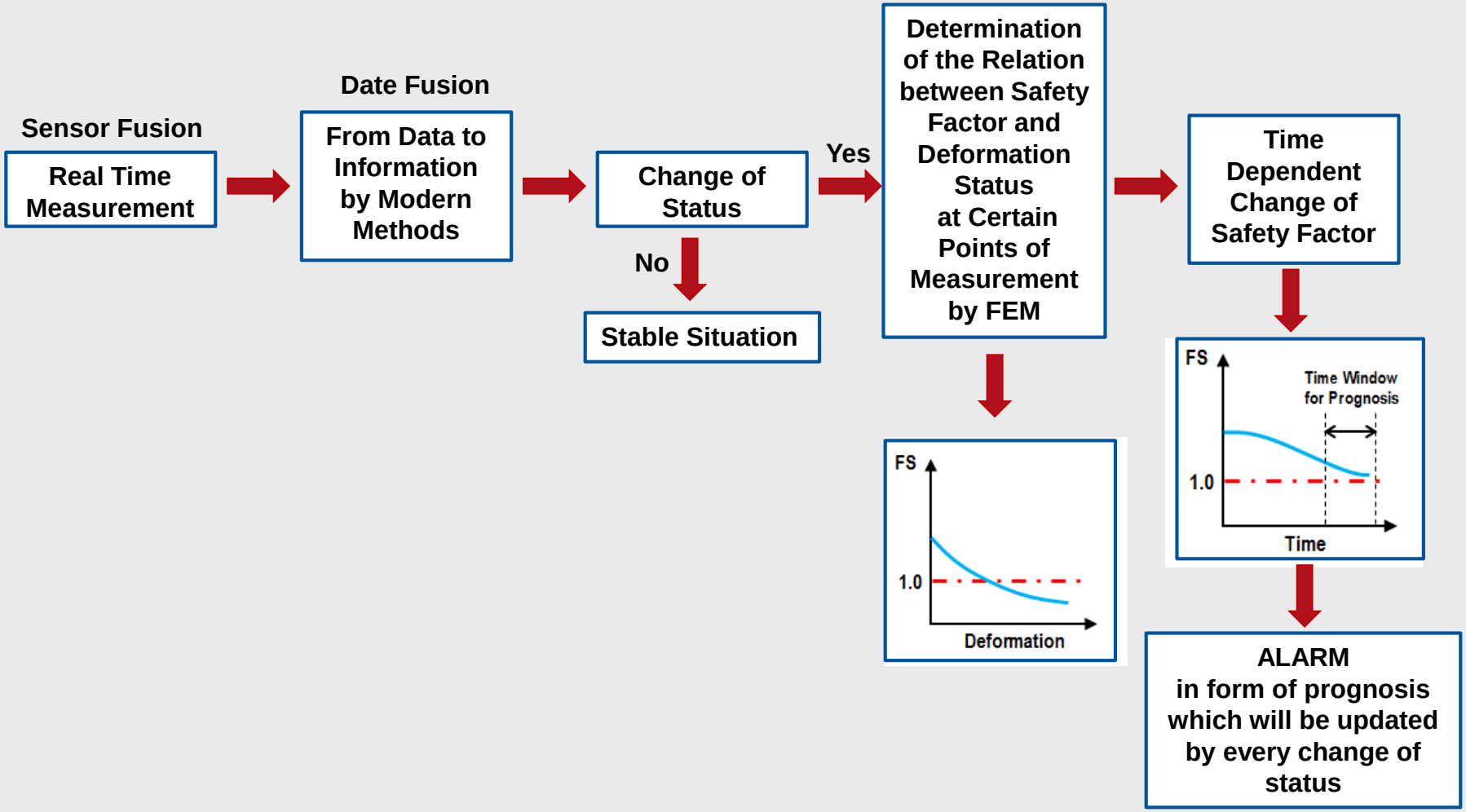




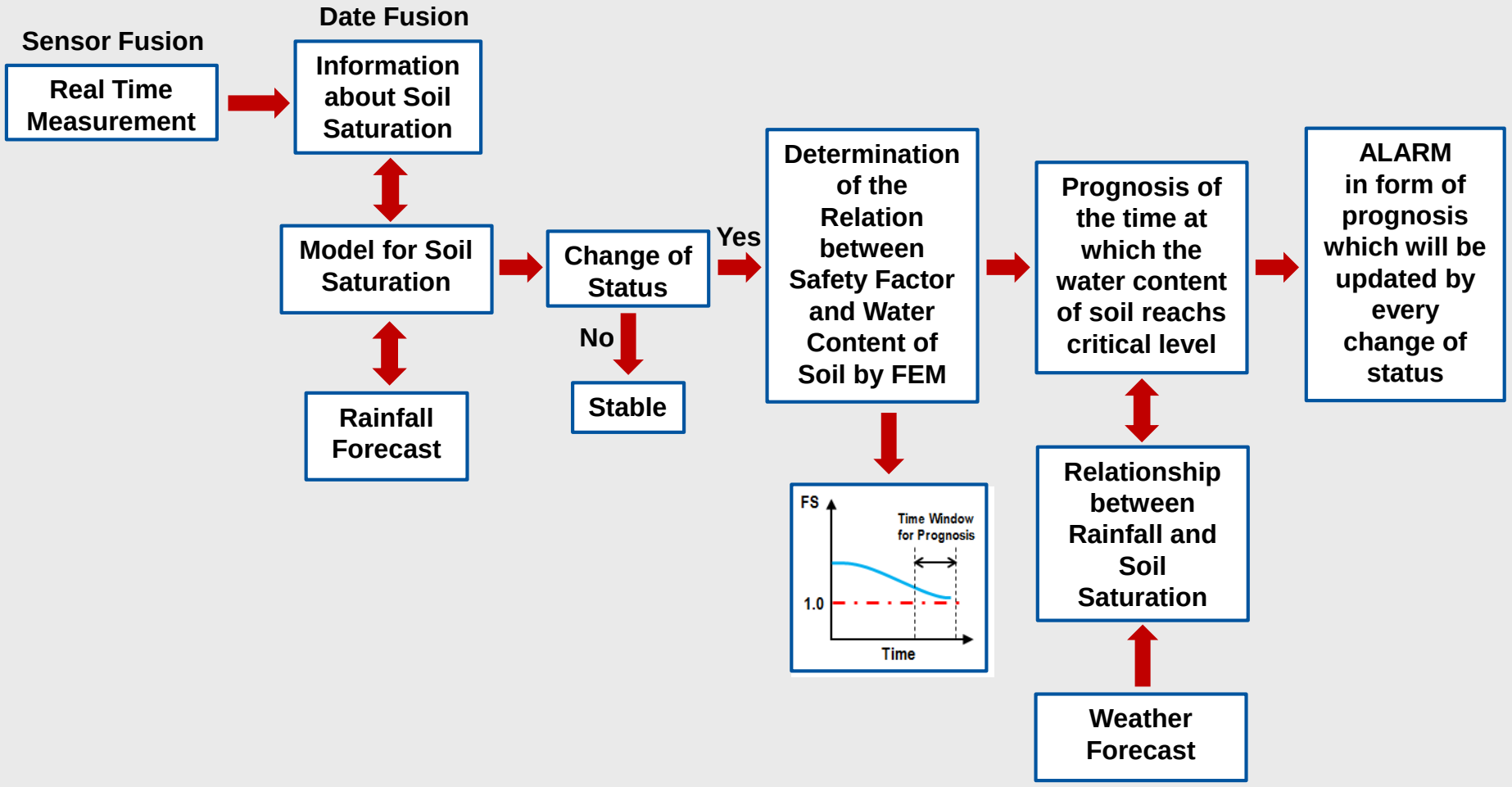
6. Method to substitute the threshold Criterion

Up today criteria for alarms in geo-management focus on threshold evaluation of a certain parameter.
But what does it mean if we measure a certain deformation, does it mean that the slope will fail, and when it would fail.
How do we know that the measured deformation is dangerous?
If we give always false alarms, would the people trust us after a while?
Do we have other options to deal with this problem?

6. Criteria for alarm
-Destabilization Process in Slow Motion-



6. Criteria for alarm
-Destabilization by Rainfall-



7. Summary

New method for the evaluation of the safety in managing geotechnical construction and a Monitoring and Early Warning Systems for real-time observation are needed.

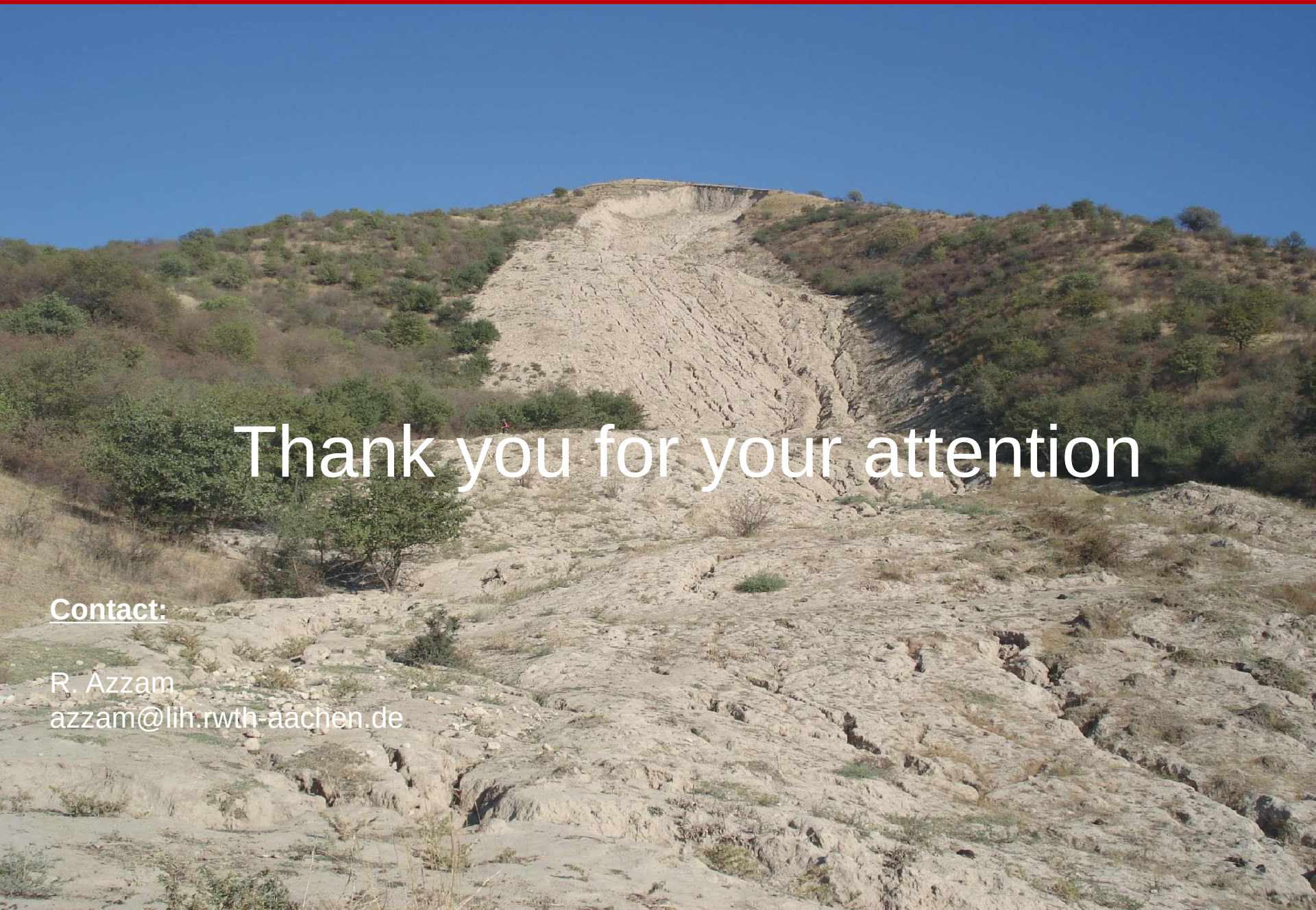
Aims: Cost Efficient, Precise, Easy to Set Up (Deployable), Interoperable

Modern Technologies: Wireless Sensor Network and Measuring Sensors with an appropriate data infrastructure and processing technology

Integration of small low-cost Sensors (MEMS)

Sensor-Combination and Sensor-Fusion for improvement of data quality and reduction of false alarm rates

Combination of modern methods for data processing and modelling using real time data, stationary data, and forecast data can lead to high quality safety evaluation and reduction of false alarm rates



Thank you for your attention

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