GEOWEB - Modernising geodesy education in Western Balkan with focus on competences and learning outcomes
Training course on modern geodetic topics
University of Mostar, Faculty of civil engineering, BIH, Oct. 16th – 20th 2017

GEOSENSOR NETWORKS
USAGE IN GEOMATICS

Aleksandar Ristić
Milan Vrtunski, Miro Govedarica

Geospatial technologies and systems center
Study programme Geodesy and geomatics
Faculty of technical sciences
University of Novi Sad, Serbia

1

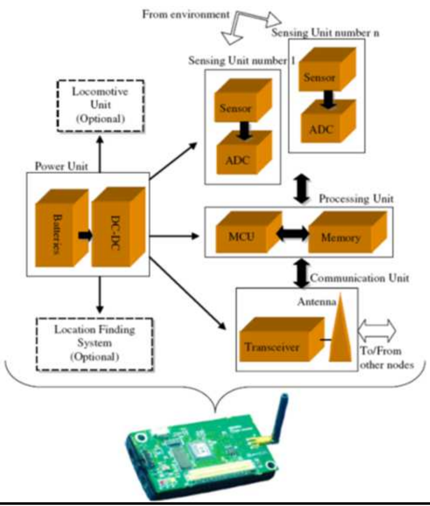
CONTENTS

- Geosensor networks – structure and tasks
- GSN – application areas in geomatics
- Realisation of GSN applications in geomatics
- GSN laboratory at the University of Novi Sad
- Conclusion

2

GEOSENSOR NETWORK – BASIC STRUCTURE

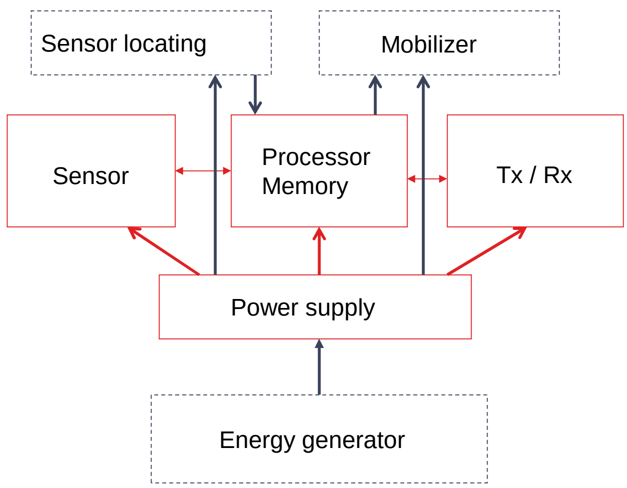
A geosensor network may be defined as a sensor network that monitors phenomena in a geographic space



- **Basic task** – is to yield a conclusion about a natural phenomenon, which would be much harder or even impossible to produce using classic measurement procedures.
- It is done by monitoring using sets of spatially distributed sensor nodes which work in a network.
- **Basic structure** – GSN is formed of individual sensor nodes (SN).

3

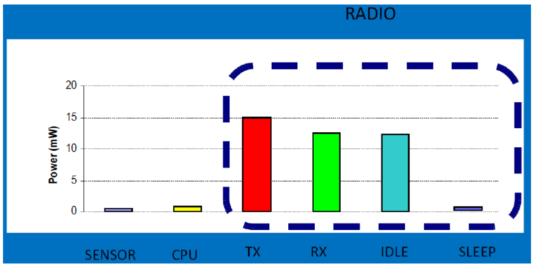
SENSOR NETWORKS – NODE ARCHITECTURE



4

WGSN – DESIGNING

- **Scalability** (spatial density of nodes within the range)
- **Price** (costs of WSN have to be smaller than the costs of installation)
- **Hardware** (SN nodes, power supply – network lifetime)
- **WSN topology** (single/multiple hop, static/adaptive, clusters, regular/non-regular)
- **Environment** (environmental influences on nodes design)
- **Communication channel** (environmet, amount of data)
- **Power consumption** (energy efficiency)



5

GS NETWORKS – SYSTEM ARCHITECTURE

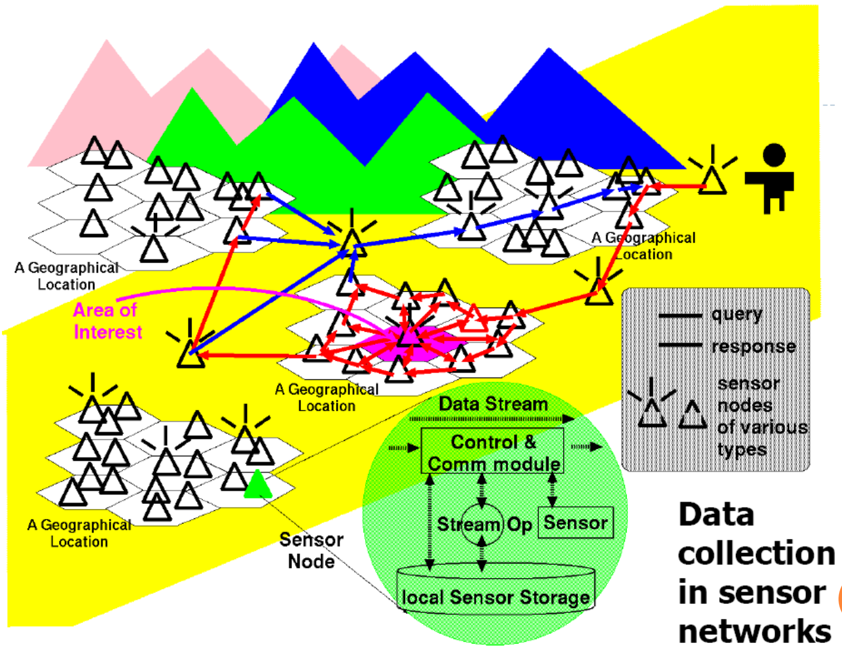
Application layer	Applications: events, reactions
Spatio-temporal DB layer	Data model, Types of queries
	Data aggregation, Query processing
Network layer	Adaptive topology, georouting
	MAC, time, location
Physical layer	Communication, sensing

6

GSN – *SENSOR* DBMS: *OBJECTS OF INTEREST*

- Information from the environment are described with:
  - **OBJECTS**: identifier, geometry (point, line polygon – **vectors**) represents the boundary, attributes
  - **REGIONS**: for all coordinate pairs (x,y): F(x,y) → v (**rasters**)
  - Both vectors and rasters are relevant in GSN: monitoring of traffic; monitoring of air quality in the city center
  - Step forward is object extraction from the region (vector from raster)
    - Example: position of toxic cloud above the chemical facility
    - Contour lines and maps
    - Monitoring of spatio-temporal changes of edges in real-time

7

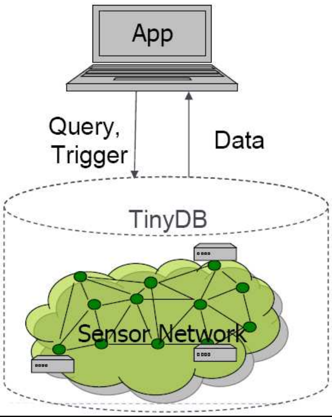


Data collection in sensor networks

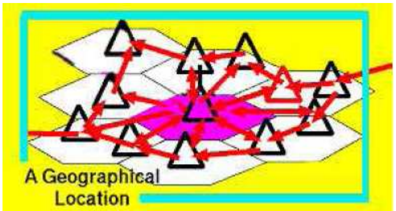
8

GSN – *Sensor **D**ata **B**ase **M**anagement **S**ystem*

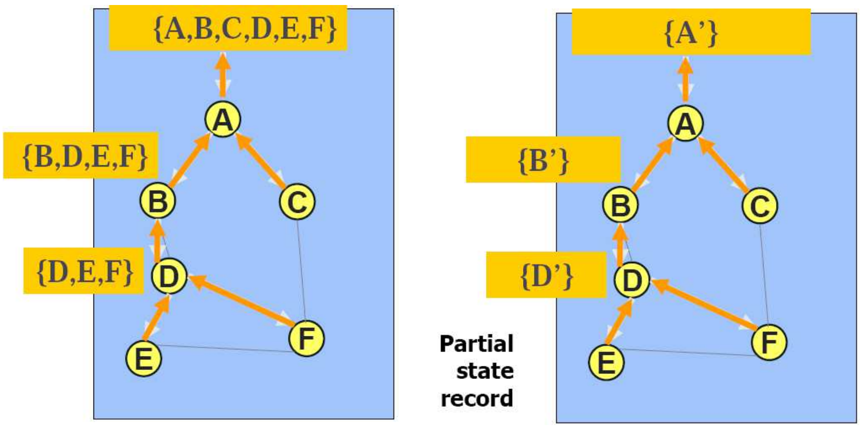
```
SELECT MAX(temperat)
FROM sensors
WHERE temperat > thresh
SAMPLE PERIOD 64ms
```




```
SELECT MAX(temperat)
FROM sensors
WHERE temperat > thresh
AND sensor.loc within
rect(p1, p2)
SAMPLE PERIOD 64ms
```



GSN – Tree topology, data flow and processing



GSN APPLICATIONS

11

CONTENTS

- Geosensor networks – structure and tasks
- GSN – application areas in geomatics
- Realisation of GSN applications in geomatics
- GSN laboratory at the University of Novi Sad
- Conclusion

12

GSN in Geomatics - Deformation Monitoring

- Monitoring of dimensions and positions of objects and/or terrain is common task in geodesy
- Deformation can be defined as a change of shape of an object (expansion, compression or some other type of distortion). Usually it occurs as a response to applied load or strain, but can be a consequence of temperature or humidity changes
- Application areas of GSNs for deformation monitoring:
  - Objects: bridges, dams, buildings…
  - Terrain: landslides, levees, tunnels, open pits mines…

13

Modern Technologies Applied for Deformation Monitoring

- Modern technology enabled the development of new methods in this area
  - Geodetic survey:
    - GPS/GNSS
    - Robotic total stations
    - Digital levels
    - Laser scanning
  - Digital geotechnical sensors
  - Communication technologies:
    - Wireless communication
    - Web technologies
- Real time and near real-time monitoring is now possible

14

System characteristics

- To monitor the deformations in real time a system has to fulfil certain requirements:
  - Accuracy – almost always at centimeter level
  - Modularity – parts of the system have to be replaced as easy as possible
  - Configurability – system has to be configurable while functioning
  - Robustness – resistivity to various influences, detection of errors

15

Sensor types

Three types of sensors:

1. Geodetic sensors
2. Geotechnical sensors
3. Other sensors

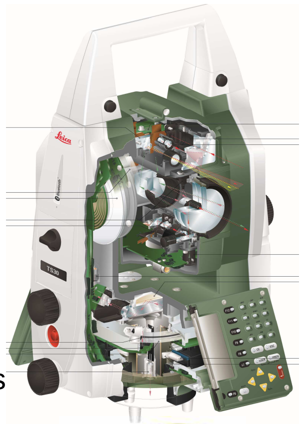
Sensors have to provide:

- Continuous measurements
- Appropriate accuracy
- Robustness (resistive to environment)
- Autonomous work

16

Geodetic sensors – Total stations

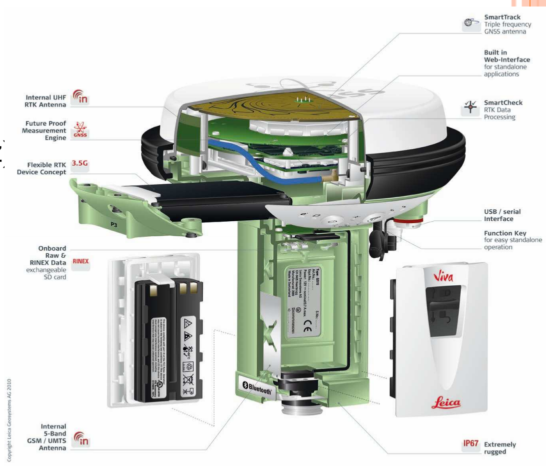
- Autonomous measuring:
  - Stations rotation around vertical and horizontal axis
  - Automatic target recognition – ATR
- Only robotic total stations are used
- High accuracy: up to 0.5” and millimeter level
- Less robust than GNSS receivers therefore are installed on concrete pillars inside measurement huts.
- Point cannot be monitored by total station if the prism is not installed on it (reflector-less measurements are not possible)



17

Geodetic sensors – GNSS receivers

- Robust construction – no optical or moving parts
- High frequency of measurements (up to 20Hz)
- Installation on stabilized points
- Several receivers can form a network – network solution
- Both single - and dual frequency receivers are used



18

Geodetic sensors – Digital levels

- Automated readings of bar-coded staff
- High accuracy measurements of deformations in vertical plane (sub-millimeter)
- Not motorized – one instrument reads only one staff
- Staff has to be lighted so it can be read in the dark

19

Geodetic sensors – Terrestrial laser scanner

- Measures a large number of points and forming of digital 3D model
- Recently introduced as instrument for real time deformation monitoring
- Integrated solutions – total stations with some functionalities of laser scanners

20

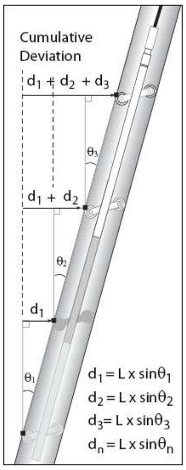
GEOTECHNICAL SENSORS

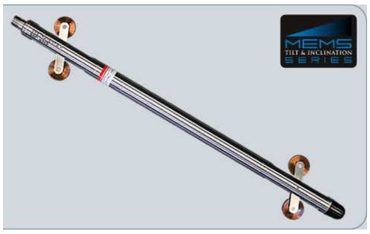
- Geotechnical sensors are used to measure non-georeferenced displacements, as well as some other quantities.
- Conditions to use geotechnical sensors:
  - Measurements of relative displacements directly on the object
  - Sub-surface measurements
  - Target is not visible
  - Sub-millimeter accuracy
  - High frequency of measurements (>1Hz)
- Types of geotechnical sensors:
  - Inclinometers/tiltmeters
  - Piezometers
  - Extensometers
  - Strain gauges
  - ...

21

INCLINOMETERS

- Angular displacement from the vertical axis
- Depending on application:
  - *In-place*, for placing in boreholes
  - Inclinometers for installation on objects
- Uniaxial – measurements in one plane
- Biaxial – measurements in two orthogonal planes

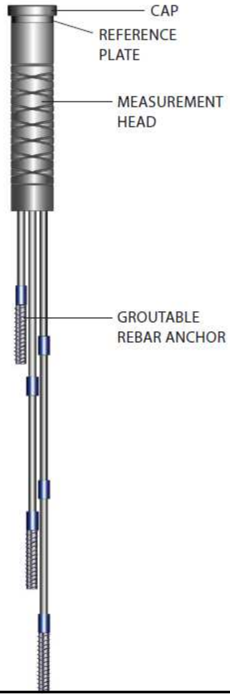




22

EXTENSOMETERS

- Measure longitudinal displacement in the soil
- Three main parts: measurement head, bars and anchors
- Usually sensor has three anchors, connected to the head with steel or fiberglass bars.
- Bars are of different length, so that displacements at different depths can be measured
- Anchors are fixed in the soil and their longitudinal displacement relative to the head is measured
- Accuracy ~μm
- Maximum measurable displacements: 50-100mm



CRACKMETERS

- Crackmeter is a type of extensometer. Instead of being placed in boreholes, its ends are fixed on two sides of a crack.
- Width of the crack is measured.
- Easy to install, sub-millimeter accuracy
- Applications:
  - Landslides
  - Rockfalls
  - Open mine pits...

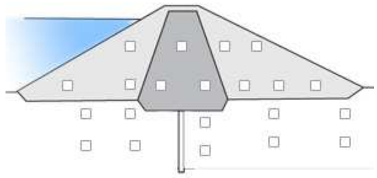
24

PIEZOMETERS

- Sensors that are placed in the soil and measure the water pressure and the level of underground water
- Types:
  - Standpipe
  - Vibrating wire
  - Pneumatic
  - Interferometric
- Applications:
  - Landslides
  - Dams
  - Levees
  - Earthwork preparation...



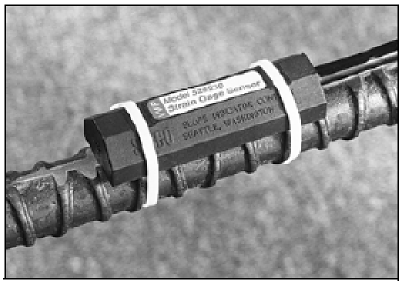
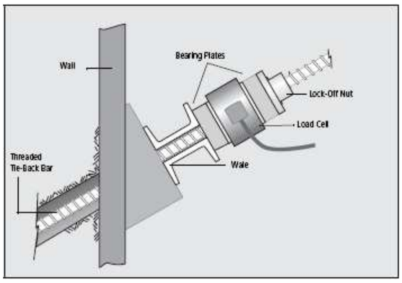




25

FORCE MEASUREMENTS

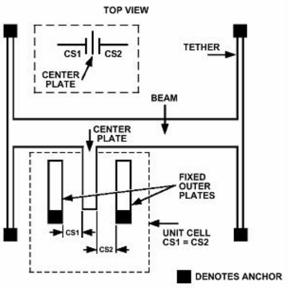
- Two types of sensors are used to measure force:
  - Strain gauges
  - Load cells
- Convert force induced deformation into the change of electric quantity (most commonly electric resistance)
- Strain gauges are used on rebar, cables, metal and concrete construction elements
- Cells can measure higher values of force and are used on support walls, pillars, etc.

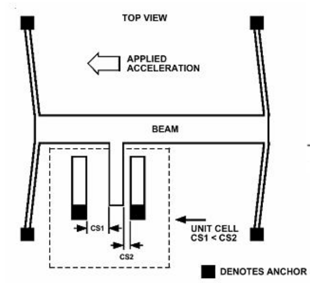



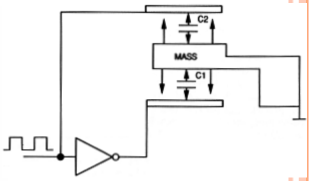
26

Accelerometers

- Inertial element causes the change of capacitance (movements of capacitors plates)
- Movement of inertial element within a range of ±20μm
- Measuring range from 1μg to 100g, frequency range 10kHz
- **MEMS (Micro Electro Mechanical System)** technology – entire system in one IC, semiconductor microtechnology



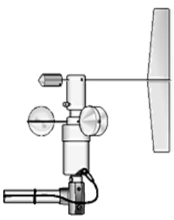




27

Other sensors

- Meteorological sensors:
  - Thermometers - measuring of temperature
  - Barometers – atmospheric pressure
  - Humidity sensors
  - Rain gauge – amount of rainfalls
  - Anemometers – speed and direction of wind
- Air pollution sensors
- Cameras – visual inspection, burglary protection
- Other sensors, mainly for protection services (e.g. IR motion detection sensors)



28

COMMUNICATION

- Communication port provides:
  - Transfer of measurement results
  - Transfer of measurement parameters
  - Fault and error detection
- Instrument can be connected by cable or wireless.
- Cable connection standards:
  - Serial communication (RS232, RS485, USB)
  - Network communication (ethernet)
  - Analogue signals (electrical current or voltage)
- Wireless connection:
  - Bluetooth
  - Long-range bluetooth
  - Radio modems

29

CONTENTS

- Geosensor networks – structure and tasks
- GSN – application areas in geomatics
- Realisation of GSN applications in geomatics
- GSN laboratory at the University of Novi Sad
- Conclusion

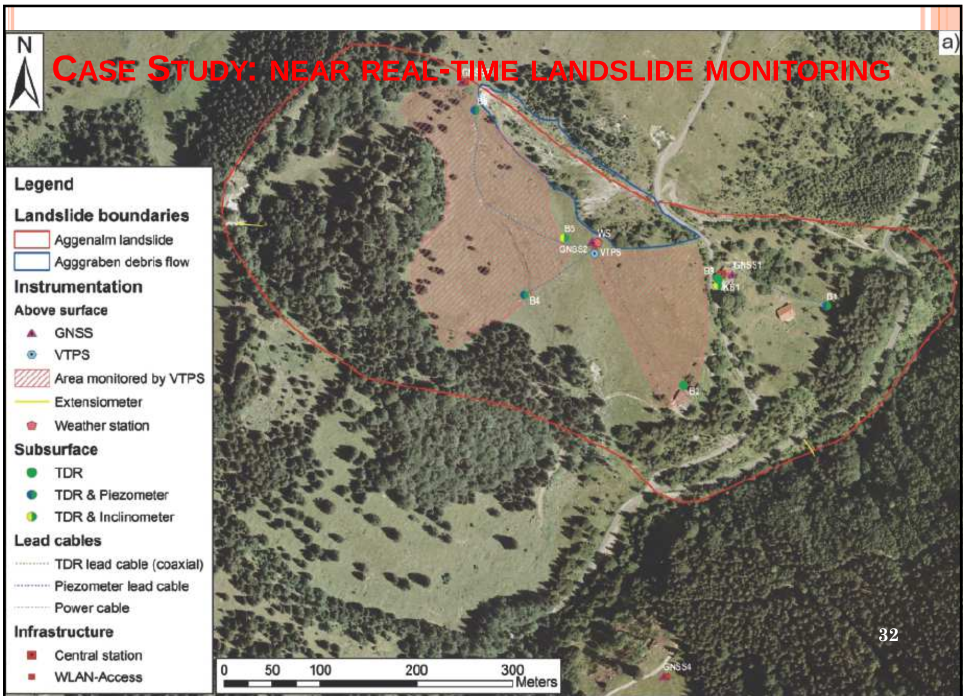
30

CASE STUDY: NEAR REAL-TIME LANDSLIDE MONITORING

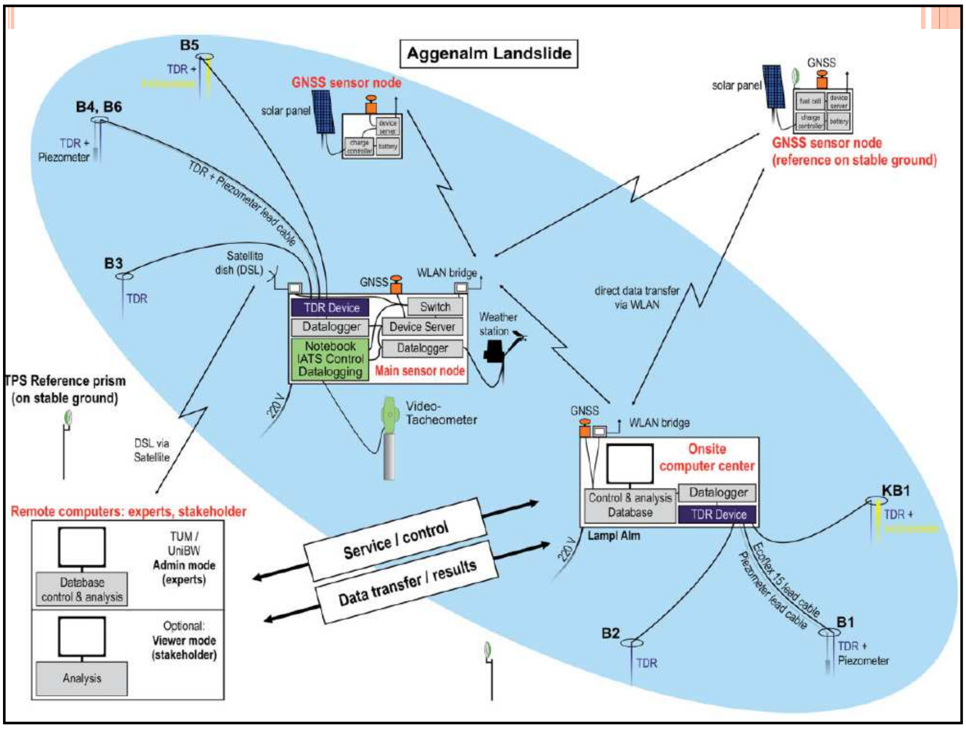
- Landslide Aggenalm in Bavarian Alps, Germany
- Average movement of landslide: 2cm per year; history of two major activations
- 5 stages of alpEWAS project: 1. location selection; 2. installation; 3. setup and configuration; 4. test period; 5. automation of aquisition
- Geosensor network consists of 3 groups of active instruments localy+ integration with external meteo station+analysis of underground water level (piezometers)
  1. Low-cost GNSS receivers for monitoring (GPS+GLONASS enabled),
  2. TDR (***Time Domain Reflectrometry***) probes – detection of movements along the sliding plane
  3. VTPS (***Video Tacheometry Positioning System***) – high accuracy monitoring of surface movements
- WebGIS interface, for data visualization

31

CASE STUDY: NEAR REAL-TIME LANDSLIDE MONITORING



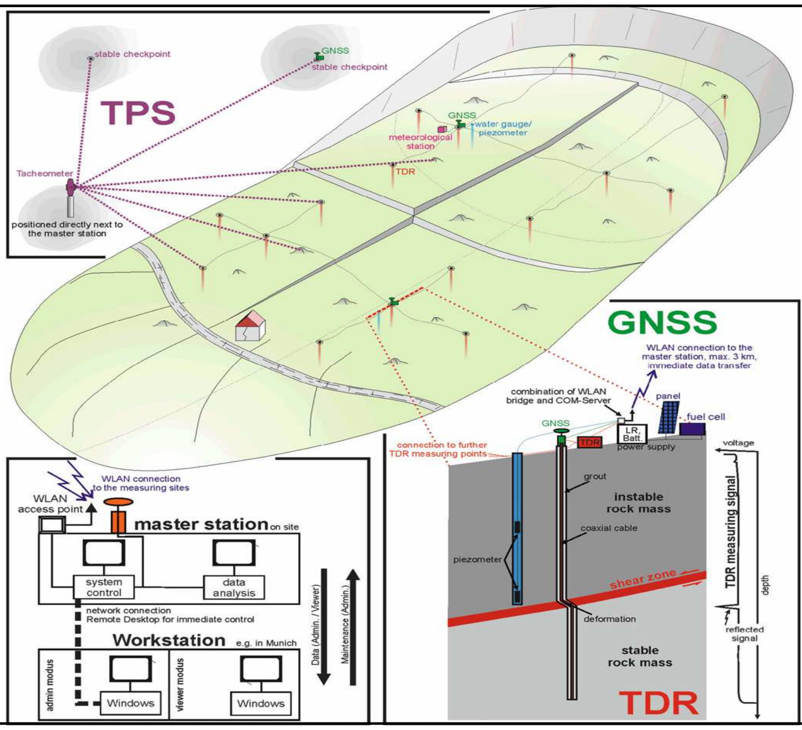
32



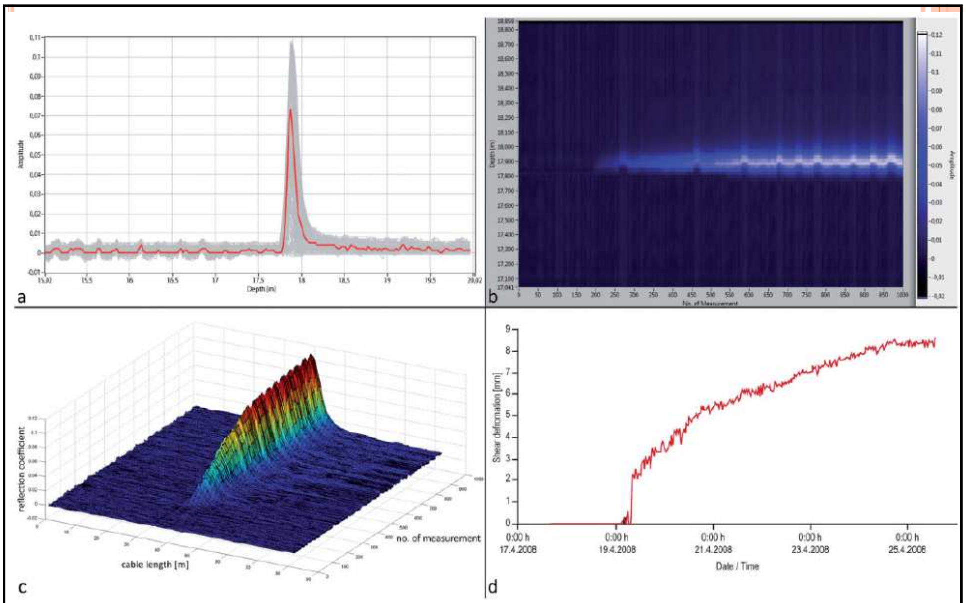
CASE STUDY: TDR

- 3 parts of sensor:
  - Measuring device (TDR cable tester + data logger + multiplexer)
  - Measuring cable (coaxial cable)
  - Cable connector (coaxial cable including connectors)
- Measuring cable is placed into the hole, at depth bigger than the sliding plane. Movement of soil layers causes deformation of the cable and voltage peak is generated at the depth of deformation
- Depth is calculated from determined two-way travel time of the impulse
- Movements up to 10cm can be measured
- Lower costs than when using inclinometers

34


stable checkpoint
GNSS
stable checkpoint
TPS
Tacheometer
positioned directly next to the master station
GNSS
meteorological station
water gauge/ piezometer
TDR
GNSS
WLAN connection to the master station, max. 3 km, immediate data transfer
combination of WLAN bridge and COM-Server
panel
fuel cell
GNSS
TDR
LR Batt.
power supply
connection to further TDR measuring points
voltage
grout
instable rock mass
coaxial cable
piezometer
shear zone
deformation
stable rock mass
TDR measuring signal
depth
reflected signal
TDR
WLAN connection to the measuring sites
WLAN access point
master station on site
system control
data analysis
network connection
Remote Desktop for immediate control
Workstation e.g. in Munich
Data (Admin / Viewer)
Maintenance (Admin)
admin modus
Windows
viewer modus
Windows

35


a
Depth (m)
b
c
reflection coefficient
cable length [m]
no. of measurement
d
Shear deformation [mm]
Date / Time

36

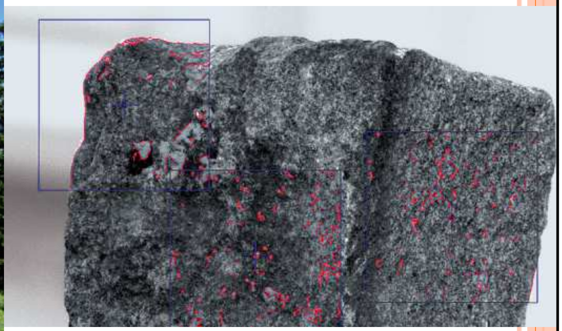
Functionality	TDR	Inclinometer	Inclinometer chain
Localization of deformation (Accuracy)	✓ mm - cm	✓ dm - m	✓ dm - m
Quantification of deformation (Accuracy)	✓ mm - cm	✓ mm	✓ mm
Orientation of movement	×	✓	✓
Max. deformation amount (localized shear deformation)	cm - dm	cm	cm
Continuous measurements	✓	×	✓
Remote data access, maintenance	✓	×	✓
Multiplexing	✓	(✓)	×
Restrictions	limited to localized shearing	none	none
Costs (1 site, 20 m depth)*	**TDR**	**Inclinometer**	**Inclinometer chain**
Drilling (exclusive drilling site setup, travel expenses etc.)	€ 1200	€ 1600	€ 1600
Installation costs (material only)	Coaxial cable, connectors, accessories € 150	Inclinometer casing, lids, accessories € 250	Inclinometer casing, lids, cables, accessories € 300
Hardware (measurement equipment only)	TDR device, data logger, Multiplexer € 6000	Inclinometer probe, cables € 12000	Inclinometer chain, data logger > € 20000
Maintenance (electricity, data transmission)	< € 100 / month	Several 100 € per measurement	< € 100 / month

37

Case Study: Video Tacheometry

- Continuous monitoring of characteristic objects on the surface, with added camera
- Movable axes of total station are used to position the camera so each pixel can be georeferenced
- Laser distance measurement
- Angular resolution 0.1mm at 100m distance
- Problems:
  - Reflection and flickering in the air (averaging of few short measurements)
  - Low light conditions during storms and heavy snowfalls
- Advantage: simple remote monitoring of landslide edges and scars
- 3D surface model is generated, which later can be used for movement detection

38



39

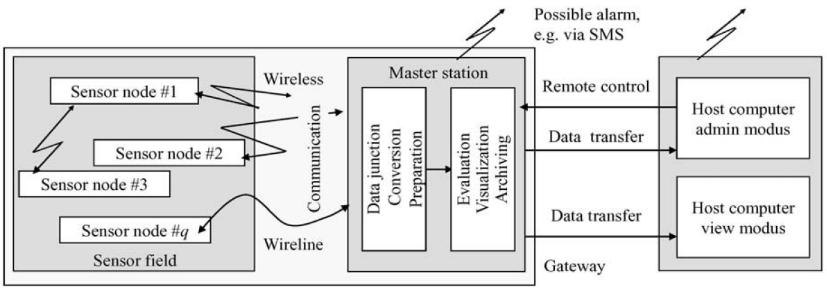
CASE STUDY: GNSS RECEIVERS

- 1+3 system: one receiver in stable zone, with baselines to 3 receivers on the landslide body. Millimeter accuracy can be achieved.
- Single frequency receivers
- 15 minutes epochs. Rough antenna construction is required due to difficult conditions in the mountains
- Antennas are placed on pillars 2m tall. WLAN communication.
- Near real time automated processing NRTP
- Positioning accuracy: 1.5cm (0.48cm when filters are applied)
- Position and height accuracy: 2.5cm (0.86cm height accuracy when filters are applied)

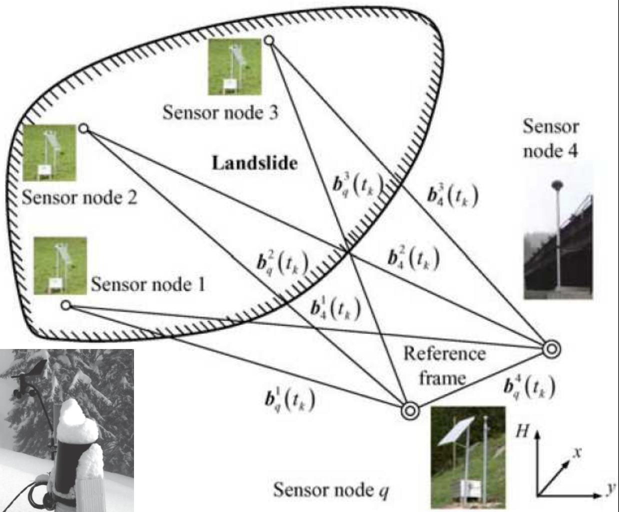
40

Weight: 575 g
Size: 115 mm diameter
90 mm height

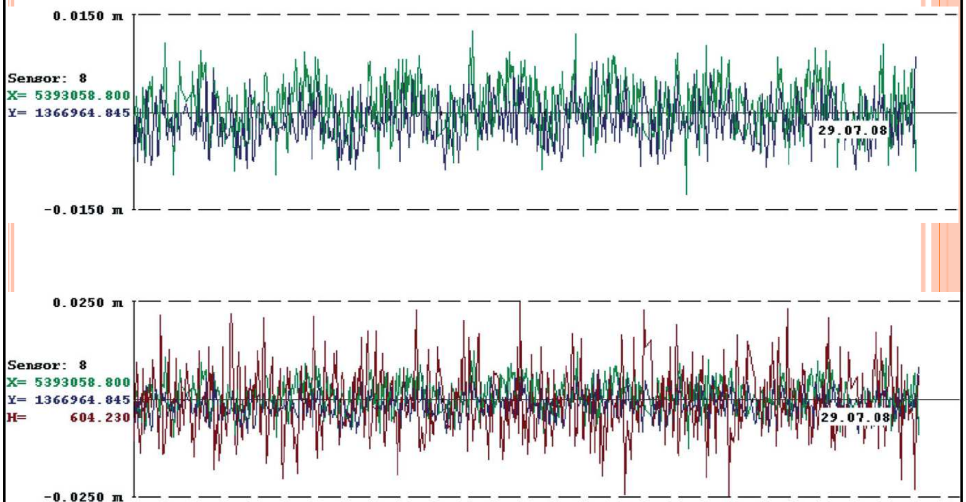
Model	Novatel Smart Antenna	Novatel Smart-V1G Antenna
GNSS	GPS	GPS + Glonass
Receiver type	Superstar II	OEMV-1G
No. of channels	12 L1 GPS	14 L1 GPS, 12 L1 Glonass
Accuracy carrier phase	1 cm rms	0,15 cm rms
Power	9-24 V; 1.4 W	9-24 V; 1.2 W
Interfaces	RS-232, RS-422	RS-232, RS-422, USB
Environmental	MIL-STD-810E	MIL-STD-810F
Price	~ 800 €	~ 1200 €



41

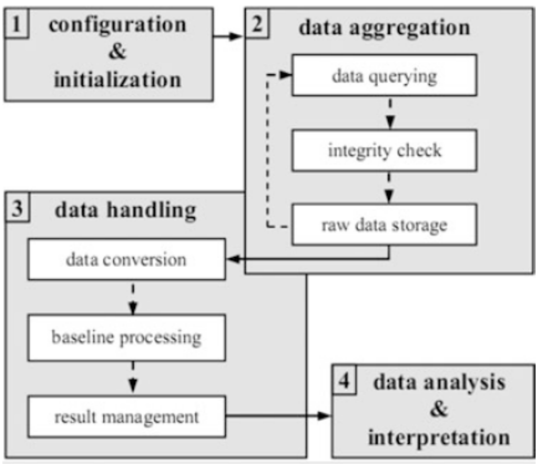


42



43

GNSS control: Central Control Application



44

CASE STUDY: SOFTWARE SOLUTION

- Modular solution, open source MySQL Database is used
- *Sensor plugin* procedures for nodes connection
- Tasks of control software:
  - Addition of sensors
  - Monitoring of sensor status
  - Raw data acquisition (communication protocols)
  - Preliminary analysis (threshold values check)
  - Data publication on the web (for deformation analysis, data exchange, alarms and warnings…)
    - Database replication from master to slave server for processing, multi-user access…
    - Multi-computer shared analysis
    - Usage of standard interfaces for data exchange with other systems
    - *Open Geospatial Consortium Sensor Web Enablement* (OGC SWE) is supported

CONTENTS

- **Geosensor networks – structure and tasks**
- **GSN – application areas in geomatics**
- **Realisation of GSN applications in geomatics**
- **GSN laboratory at the University of Novi Sad**
- **Conclusion**

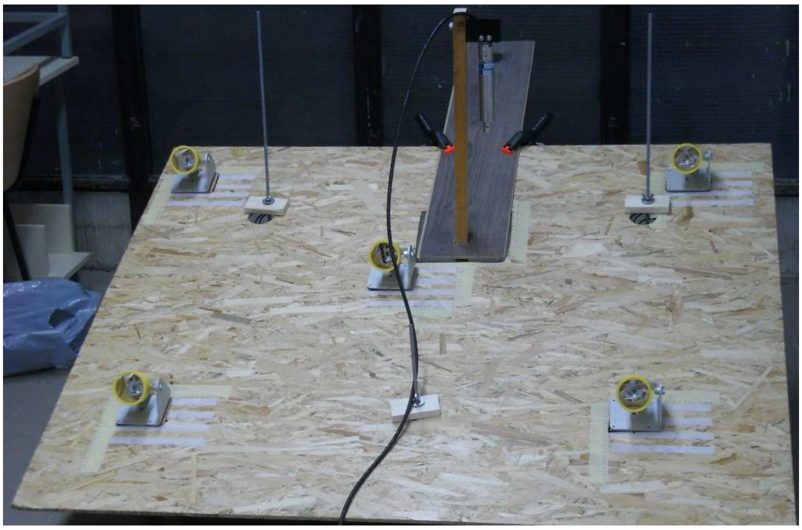
Experiments in Laboratory Environment (1)

- A small-scale system for deformation monitoring was assembled in laboratory environment.
- An experiment was done as a simulation of monitoring of slope process.
- Sensors:
  - Robotic total station (Leica TCRP1201+)
  - Tiltmeter Geokon Model 6160
  - Virtual sensor (movements down the slopes were calculated from tiltmeter measurements)
- Communication:
  - Campbell Scientific Data logger CR1000
  - COM server Moxa Nport
- Software:
  - Leica GeoMos

47

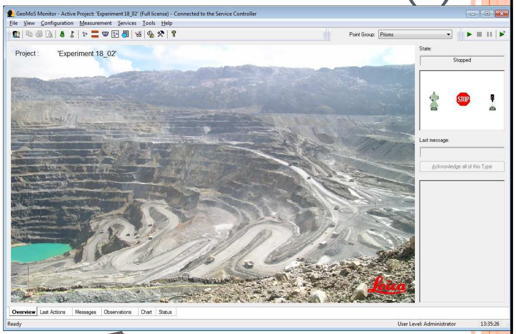
Experiments in Laboratory Environment (2)

- Physical model of slope movements



48

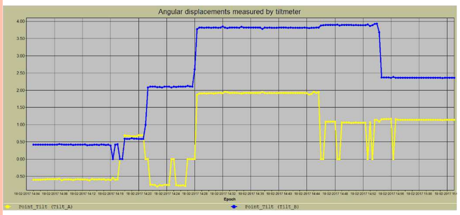
Experiments in laboratory environment (3)



49

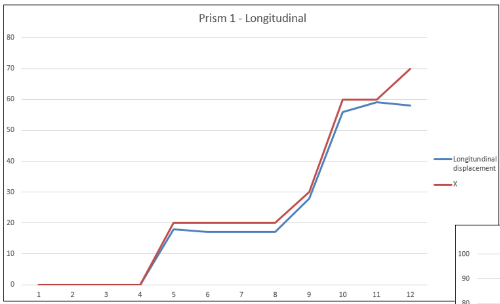
Experiments in laboratory environment (4)

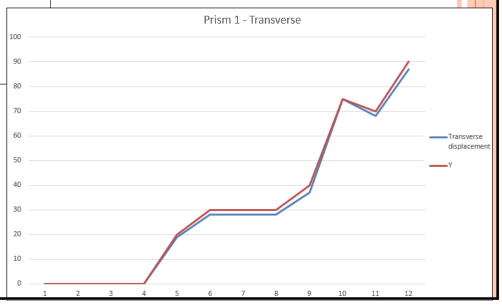
- In total, 12 series of measurements was done.
- Measured values:
  - Displacements of prisms (longitudinal, transverse, height)
  - Angular displacement
  - Displacement down the slope plane



EXPERIMENTS IN LABORATORY ENVIRONMENT (5)

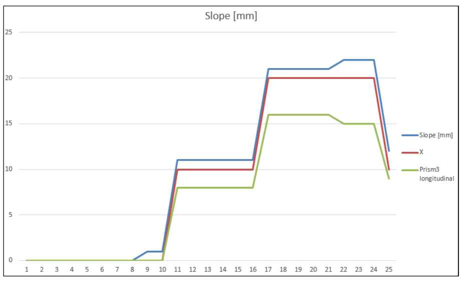
- Measured values of displacements of the prisms (blue) were compared to known, given displacement (red).

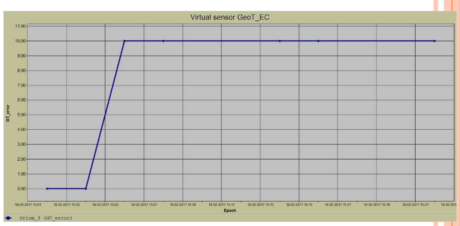




EXPERIMENTS IN LABORATORY ENVIRONMENT (6)

- Values of displacements down the slope plane calculated by virtual sensor (blue) were compared to known, given displacement (red) and also with longitudinal displacement of prism 3 (green).
- Virtual sensor was also used to check error: if a value measured by the tiltmeter if above the limit, and longitudinal displacement of prism 3 (closest to the tiltmeter) is not above the limit it means that measurement is false.





NEW SENSORS (1)

- Within the framework of GEOWEB project new geotechnical sensors were purchased:
  - 1 piezometer – Geokon Model 3400-2

  - 3 strain gauges – BDI ST350

  - 3 accelerometers – Analog Devices ADXL203EB

53

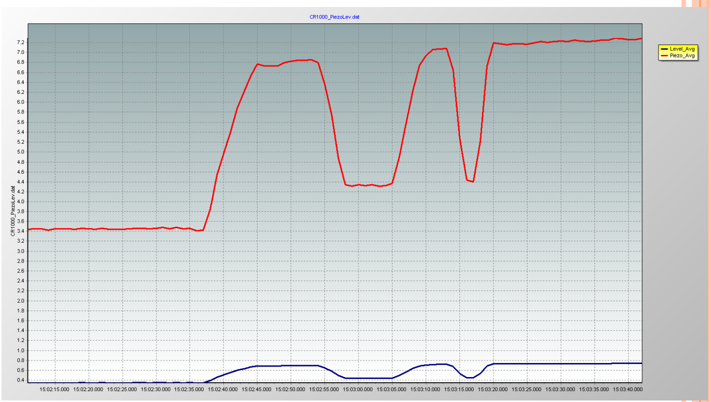
NEW SENSORS (2)

- **Piezometer Geokon Model 3400-2**
  - Measures the pressure of water in the soil and the level of underground water.
  - Typical applications: landslides, levees, dams etc.
  - Based on MEMS technology (Micro Electro Mechanical Sensor).
- **Strain gauge BDI ST350**
  - Used to record dynamic and static stress on structures.
  - Resistor-based sensor which output depends on the force applied on the object to which gauge is attached.
  - Typical applications: stress evaluation, structure modal analysis, construction stress monitoring, overload vehicle monitoring, seismic monitoring, vibration monitoring, etc.
- **Accelerometer Analog Devices ADXL203EB**
  - ADXL203EB is evaluation board with mounted ADXL203 circuit and with contacts for signal and power supply.
  - High precision, low power, dual-axis accelerometer.
  - Measures acceleration with a full-scale range of ±1.7 g.
  - Measures both dynamic acceleration (for example, vibration) and static acceleration (for example, gravity).

54

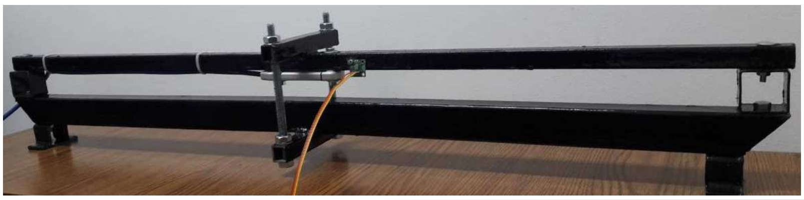
New sensors, tests (1)

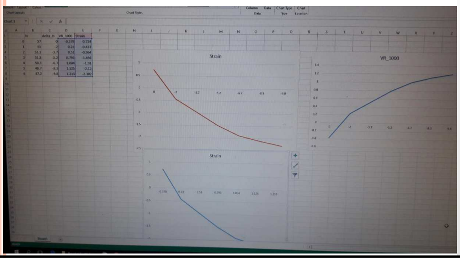
- Peizometer was tested by submerging it into the bucket of water.
- Output voltage of the sensor was read by data logger and two values are calculated by a program: pressure ([kPa], red) and height of the water column ([m], blue).

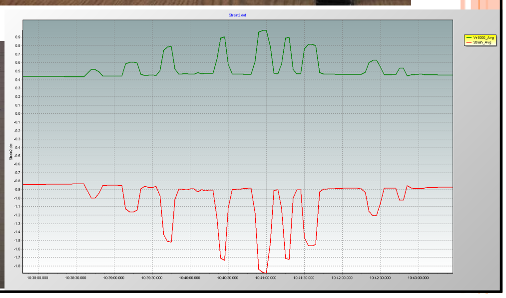


New sensors, tests (2)

- To test the strain gauge a small construction of metal bars was made, as a small-scale physical model of the beam.
- Strain gauge was attached to the bar which was put under the increasing load.

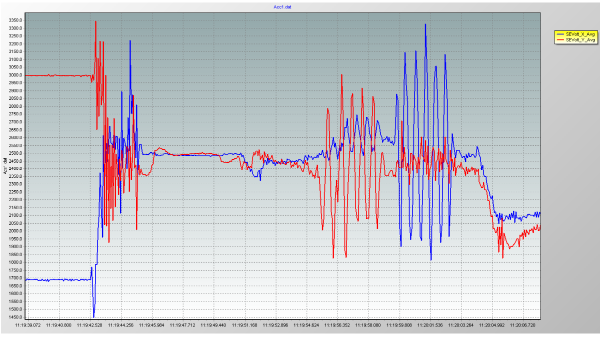


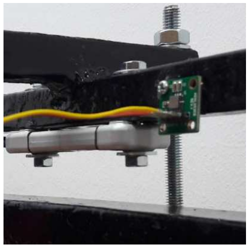




New sensors, tests (3)

- An accelerometer was also attached to the bar. It enabled testing vibrations of the bar when it is quickly put and released from the load ([mg], X-axis blue, Y-axis red).





CONTENTS

CONCLUSION

- Area of GSN applications in geomatics is **very wide**
- Application of GSNs enables **continuous** data **acquisition** and better decision making
- Adaptation of GSN based solutions on large scale requires:
  - Development of **low cost** and rugged sensor/actuator nodes
  - **Generalized solutions** to different problems
  - Complete **frameworks** to develop systems from acquisition to the modeling and the decision support
  - Solutions for particular problems should be **integrable** into more generalized solution
- Since GSN are relatively new technology there are no standards now for applications in geomatics defined

59

What will Wireless Sensor Networks Look Like in the Near Future?

- Large scale deployments
- Heterogeneous sensors
- Mobile sensors
- General Purpose sensors
- Overlapping coverage areas
- Mixture of wired and wireless
- Ubiquitous applications (mobile phones, surveillance cameras, GPS receivers, motion and light sensors)
- Integration of Internet and Intranet with GSN

60

THANK YOU FOR YOUR ATTENTION!

Aleksandar Ristić
aristic@uns.ac.rs

Geospatial technologies and systems center
Study programme Geodesy and geomatics
Faculty of technical sciences
University of Novi Sad, Serbia