GEOLOGICAL SURVEY OF IRELAND
LANDSLIDES WORKSHOP 21 APRIL 2009

Recent Developments in Geotechnologies for Landslide Monoitoring

Tim McCarthy
NUI Maynooth

email tim.mccarthy@nuim.ie

SFI (SRC-ID 07/SRC/I1168)

NUIM, Geocomputation & Geotechnologies

National Centre for Geocomputation (NCG) www.nuim.ie/ncg

- Established 2004, SFI Research Fellowship to (€2.5m) Prof. A. S. Fotheringham)
- 26 (Academic/Research/Administration/PostDoc/PostGrads) Staff

Research Areas

- Environment Monitoring, Geocomputation
- Geovisual Analytics, Geovisualisation
- Remote Sensing, Spatial Analysis, Geostatistics
- Spatial Modelling, Spatial Statistics, Handling uncertainties
- Machine Learning and Spatial Data Mining

Strategic Research Cluster in Advanced Geotechnologies (StratAG) www.stratag.ie

- Established 2008, Coordinated by NCG (1 X PI & 13 Co-PIs)
- SFI (€7m + o/h), 5 year funded research programme
- 4 X Universities (NUIM, DIT, Trinity & UCD), 9 X PostDocs, 6 (+6) X PhDs
- Industry partnership (ESRI, eSpatial, PMS, BKS-Fugro, O_2, GSi, MI, NRA, OSi)

Research Areas

- Sensors
- Spatial Algorithms
- Visualisation
- LBS

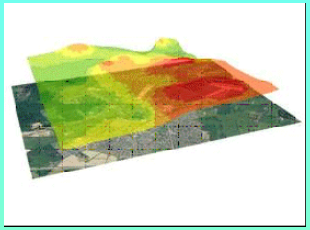
NUI MAYNOOTH NCG StratAG Strategic Research in Advanced Geotechnologies sfi NDP National Development Plan

SFI (SRC-ID 07/SRC/I1168)

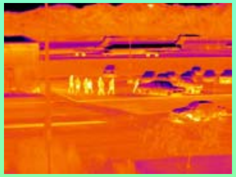
Capabilities - Research, Technology, Innovation

Geocomputation, Geotechnologies, GeoInformatics, Geomatics

- Remote Sensing/Earth Observation & in-situ WSN integration
- Intelligent Geosensors (adaptive, autonomous, self-organising) multi-platform, multi-dimensional, multi-thematic

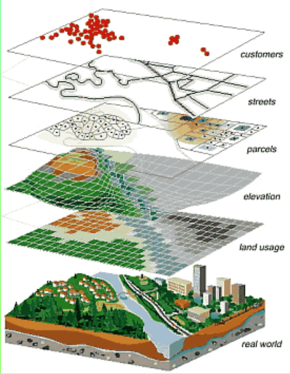


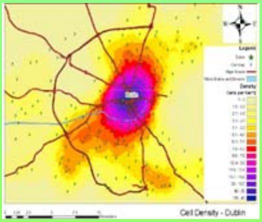
- Geospatial algorithms, analysis, statistics
- Data Fusion
- Image Processing, Machine Vision
- Machine Learning from spatio-temporal data streams
- Geovisual Analytics, Spatial data mining, knowledge discovery
- Intelligent control and decision support systems

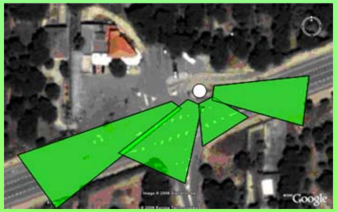


- Service orientated architectures, Sensor Web Enablement
- Geospatial data management, Interoperability (OGC)

- Seamless navigation, positioning, high-value asset tracking







NUI MAYNOOTH NCG StratAG Strategic Research in Advanced Geotechnologies sfi science foundation ireland NDP National Development Plan

SFI (SRC-ID 07/SRC/I1168)

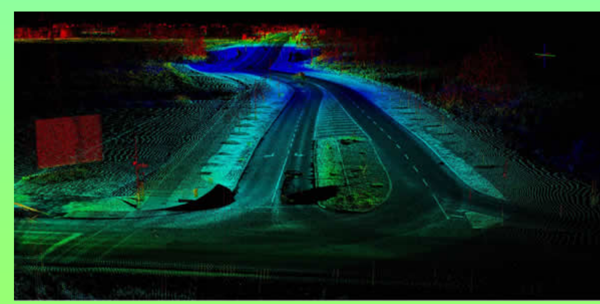
Experimental Testbeds - Mobile Mapping (XP-1)

Experimental Platform 1 (XP-1)

- Multipurpose, *state of the art,* mobile mapping research platform
- Navigation, 3D LiDAR, 10 X Multipsectral cameras (BGR, IR, thermal)
- Integrated IXSEA GPS inertial navigation system (INS), FOG) better than 0.05°/hr
- 3D LiDAR (200kHz, 360º)
- 3kW of onboard power

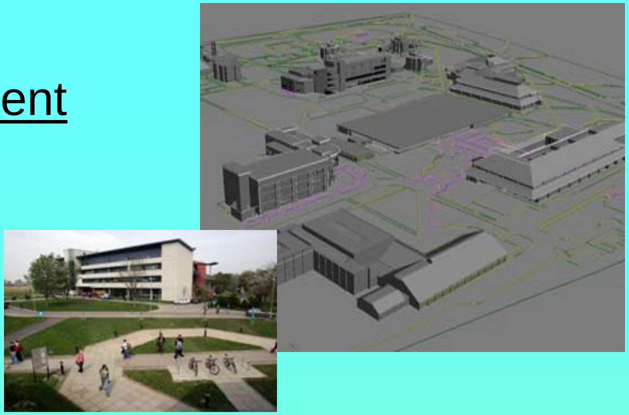
XP-1 Applications

- ITS & Telematics
- 3D reconstruction of urban areas
- Environmental Monitoring
- Infrastructure and asset inventory of route-corridors
- Real-time, dynamic signal propagation analysis



SFI (SRC-ID 07/SRC/I1168)

Experimental Testbeds - eCampus



Static 3D model of Physical Infrastructure & Environment

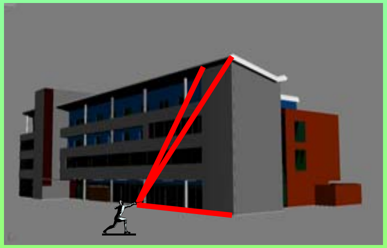
- buildings, road-ways, walk-ways
- lighting, car-parks, sports facilities
- vegetation, recreational-spaces

Autonomous monitoring using Wireless Sensor Networks (WSN)

- RFID, visual, auditory, vibration sensors
- Environmental sensors (air-quality, temp/humidity, water, soil)
- Laser, doppler sensors
- IR, magnetic sensors

LBS Testbed

- Service orientated architecture
- Support multiple positioning modes
- Bi-directional information flow



Experimental Testbed (Environmental monitoring)

SmartBay (Phase-II, Euros10m) – PRTLI5 Bid

Wide area communications and sensing infrastructure linking surface buoys and submarine cabled systems, AUVs, satellite-based sensing and shore deployed units, harsh environment. An environmental web-portal that will make the information harvested accessible to industry, general public, educators and specialists alike (Platforms, Bio-sensors, SOA/SWE, GeoInformatics)

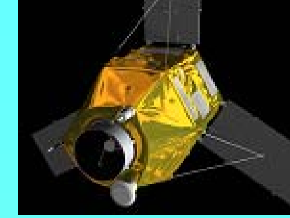
Core Partners : DCU (LEAD) , NUIG, NUIM & UCD, MI, INTEL, IBM

Aerial Survey Research

- Digital SLR Camera
- SC 660 Thermal (3 – 17 microns)
- Condor 5-CCD (1280*1024), BGR, IR-1, IR2
- Direct georeferencing (GPS/IMU)
- Role of microdrones

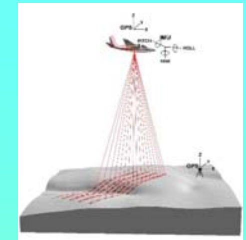
SFI (SRC-ID 07/SRC/I1168)

Monitoring & Mapping Geotechnologies - **Background**



Landslide studies can be organized into three phases

- analysis and prediction of slope failures in space and time
- monitoring activity of existing landslides
- detection and classification of landslides



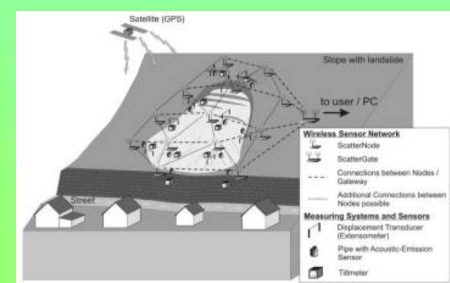
Remote Sensing

- Satellite
  - Multispectral (Landsat, SPOT, Ikonos, Quickbird, IRS CartoSat-1, ALOS)
  - Interferometric SAR (InSAR and DInSAR of Radarsat, ERS, Envisat, TerraSAR-X, Cosmo/SkyMed, ALOS)
  - Micro-satellities (Pleiades, DMC, RapidEye)
- Airborne
  - Multipsectral imaging, LiDAR

- Terrestrial
  - Ground Based SAR, LiDAR (TLS)

In-situ Mapping & Monitoring

- Wireless Sensor Networks (WSNs)



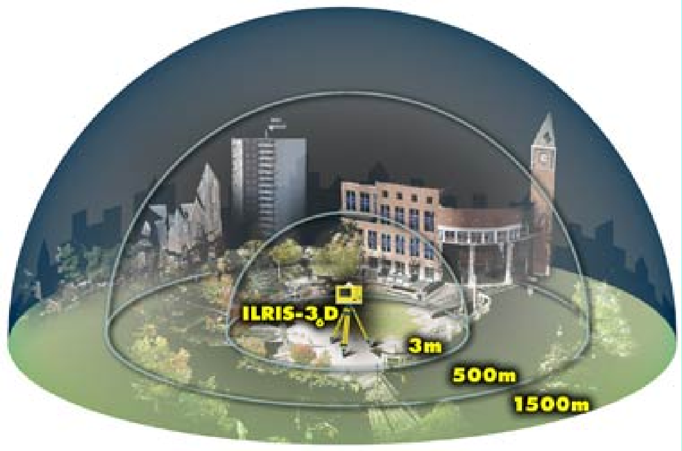
SLEWS, Arnhardt et. al., Geotechnologien 2007

SFI (SRC-ID 07/SRC/I1168)

Terrestrial Laser Scanning (TLS)

Optech ILRIS 3D

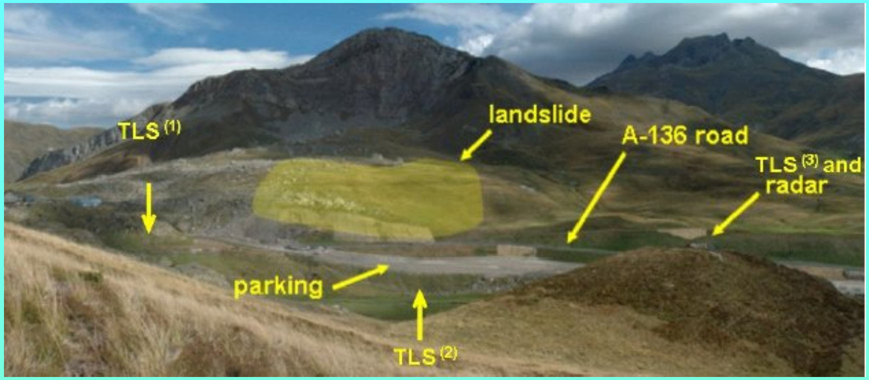
- 2.5kHz
- Beam divergence 0.00974°
- Minimum spot step (X and Y axis) 0.00115°
- Range (3m to >1km)
- Accuracy (range/position at 100m) 7mm/8mm
- Ruggedised design
- Scanner fov = ($-20^{o} + 90^{o}$ V & 360^{o} H)
- Integrated digital camera
- Weight = 13kg
- Battery life = 5 hrs (hot-swappable)
- Operation temperature (0^{o} to 40^{o} C)
- Class 1 (Eye Safe)



Source = http://www.optech.ca

SFI (SRC-ID 07/SRC/I1168)

TLS measurement parameters at Formigal landslide (source = http://www.galahad.it/Downloads.htm)



TLS MEASUREMENT PARAMETERS	
Target distances	100-1000 m
Type of TLS	Optech Ilris 3-D
Laser wavelength	1500 nm
No. of point clouds acquisition	66
No. of shots (average for each point clouds)	3.560.000
1st measurement campaign	start: 04/07/2006 at 9:00 stop: 05/07/2006 at 15:00
2nd measurement campaign	start: 03/10/2006 at 13:00 stop for rain start: 04/10/2006 at 16:00 stop: 05/10/2006 at 14:00
3rd measurement campaign	start: 24/07/2007 at 12:00 stop: 25/07/2006 at 15:00
Data sampling rate	2500 points per second
Spot spacing	from 2 cm to 20 cm
Duration of an acquisition	from 20 min to 1h 30 min

Source = GALAHAD (FP6 Project) Advanced Remote Monitoring Techniques for Glaciers, Avalanches and Landslides Hazard Mitigation

Ground Based Synthetic Aperture Radar (GB SAR)

<u>One example from Tohuku University, Japan</u>

- Vector Network Analyser
- Dual polarised antenna
- Antenna positioner
- Operational frequency = 50MHz – 20 GHz
- Scanning aperture = 20m(H), 1.5m(V)
- Full polarimetric and interferometric functions
- Usually can operate under all weather, but can be affected by atmospheric conditions

<u>Operation</u>

GB SAR radiates microwave and records amplitude and phase of the backscattered information

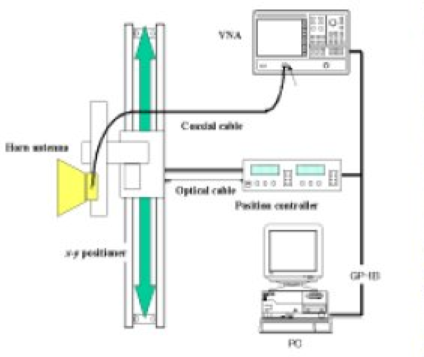


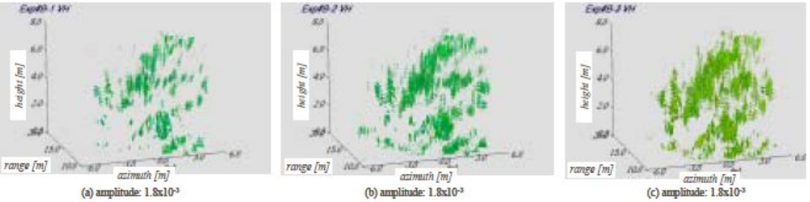
Fig.1 System diagram of the GB-SAR


Fig. 2 GB-SAR system

GB SAR, Tohuku University, Japan


(a) March (b) April (c) May

Fig.4 Cherry tree


(a) amplitude: 1.8×10^{-3} (b) amplitude: 1.8×10^{-3} (c) amplitude: 1.8×10^{-3}

(a) March (b) April (c) May

Fig.5 3D SAR image of a cherry tree (V-H polarization)

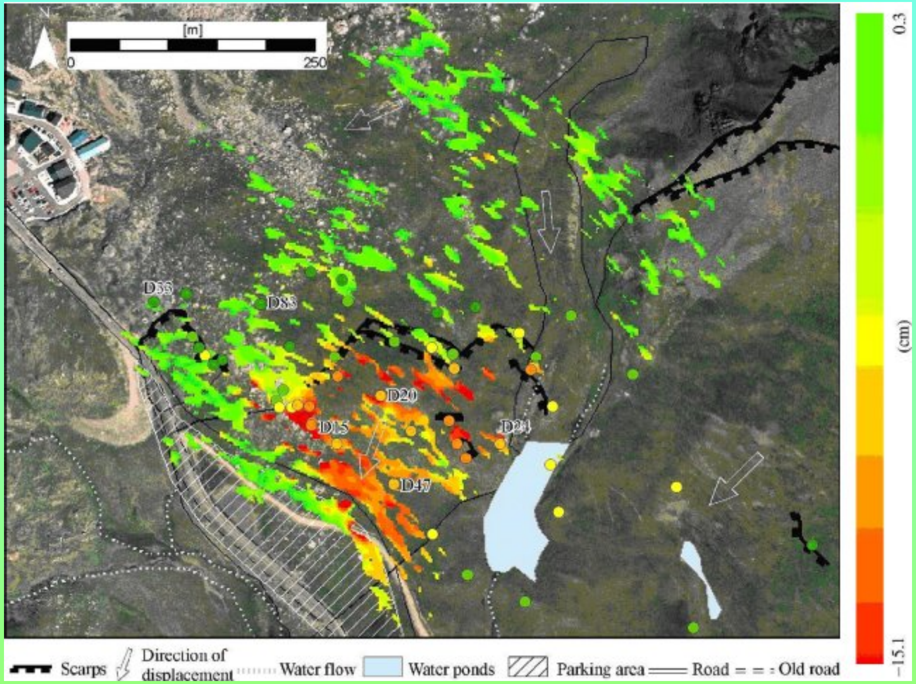
Source : Motoyuki Sato, Zheng-Shu Zhou, Tadashi Hamasaki and Wolfgang-Martin Boerner. 2005. DEVELOPMENT OF A GROUND-BASED SYNTHETIC APERTURE RADAR (GB-SAR) SYSTEM AND ITS APPLICATIONS TO ENVIRONMENT MONITORING AND DISASTER PREVENTION. ESA Workshop.http://earth.esa.int/workshops/polinsar2005/participants/67/paper_GB-SAR_proceedingss.pdf

NUI MAYNOOTH
SFI (SRC-ID 07/SRC/I1168)

GB-SAR at Formigal landslide (source = http://www.galahad.it/Downloads.htm)

Range : ~1km
Monitoring : 1 image per hour 47 days
Oct/Nov 2006
Instrument control : GPRS
Images captures = ~1000 complex SAR

GB-SAR MEASUREMENT PARAMETERS	
Target distance	200-1300 m
Transmitted Power	20 dBm
Central frequency	5.955 GHz
Range Resolution	1.7 m
Azimuth Resolution	0.74°
Start date / end date	5 Oct – 21 Nov, 2006
Measurement time (1 acquisition)	1 hour
No. of SAR images collected	1002



Source = GALAHAD (FP6 Project) Advanced Remote Monitoring Techniques for Glaciers, Avalanches and Landslides Hazard Mitigation

SFI (SRC-ID 07/SRC/I1168)

TLS - Some conclusions at Formigal landslide (source = http://www.galahad.it/Downloads.htm)

TLS is particularly recommended for study of un-stable rock slopes

- Extraction of geomechanical features
- Assessment of potential sliding mechanisms
- Evaluating extent of potentially un-stable rock volumes
- Geometrical information for trajectographic analyses
- Choice and dimensioning of remedial work
- Better suited to long term discontinuous monitoring
- Suited to remote monitoring
- Required of natural targets

TLS can be used under following conditions

- Minimum estimated displacement higher >2cm
- Presence of recognisable features on surveyed surface
- 1km range
- Little vegetation
- Good weather conditions only

TLS for DEM construction

- High spatial resolution (1cm to 10s of cm)
- Vegetation reduce accuracy

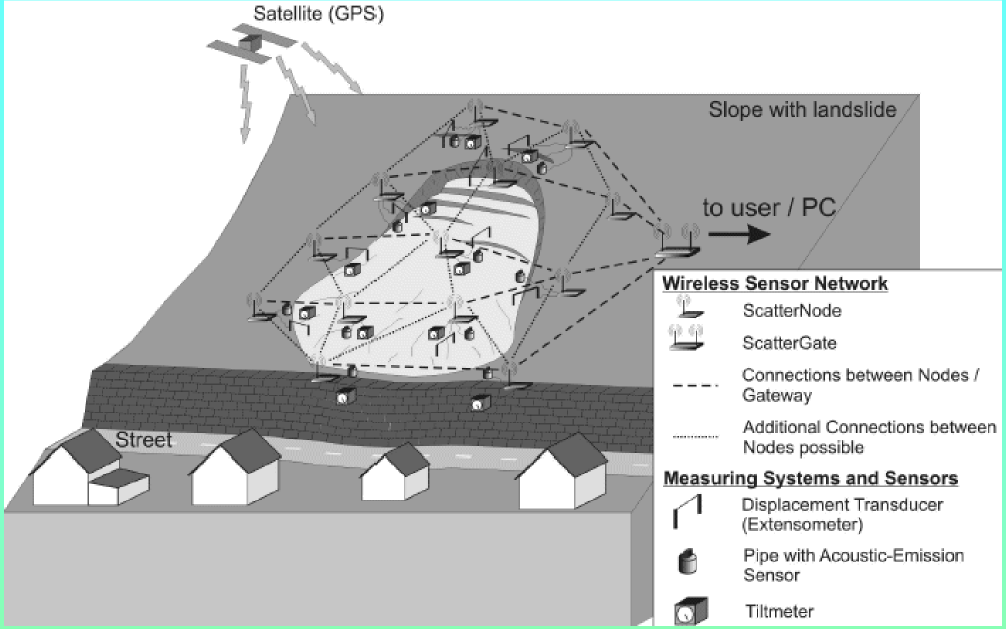
Source = GALAHAD (FP6 Project) Advanced Remote Monitoring Techniques for Glaciers, Avalanches and Landslides Hazard Mitigation

GB SAR - Some conclusions at Formigal landslide (source = http://www.galahad.it/Downloads.htm)

GB SAR is particularly recommended for study of un-stable rock slopes

- Line of sight can be orientated approx. along displacement vector
- GB SAR only provides 1D whereas TLS provides 3D displacement measurement
- Useful in real-time monitoring or in emergencies
- Affected by phase ambiguity (1cm to 2.5cm for Ku & C band respectively)
- GB SAR must be used carefully in fast moving landslide monitoring
- Long term non-continuous monitoring is limited by loss of coherence
- Persistent Scatterers approach improves GB SAR performance
- Recommended for long range distances, upto 4km
- Measurements affected by vegetation and bad weather conditions
- Spatial resolution depends on freq. and range (5m/12m C/Ku bands at 1km)
- May be used for DEM, but coarser resolution
- Requires a vehicle or helicopter to port instrument in the field
- Installation time required, e.g. concrete stable base for rail (synthetic antenna)

Autonomous wireless sensor networks (WSNs)



Landslide Projects

- SLEWS (Germany)
- Senslide (USA – India)
- WINSOC (EU- India)

Sensors for landslides

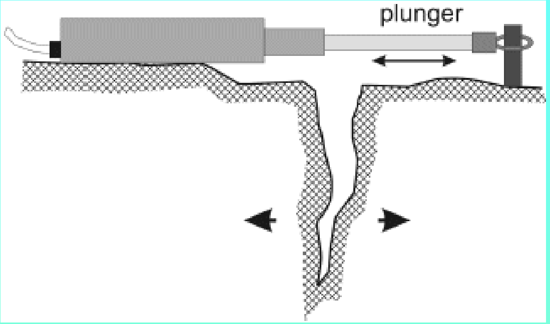
- temperature & humidity,
- high-precision displacement, acceleration transducers
- tilt-meters, geophysical
- acoustic
- GPS

SLEWS, Arnhardt et. al., Geotechnologien 2007

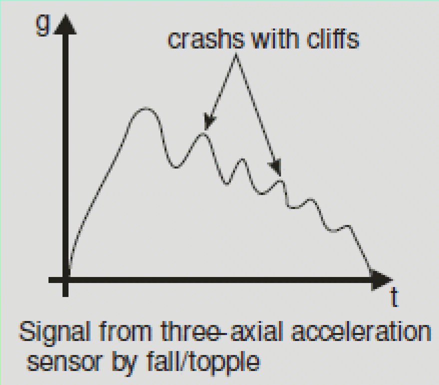
Autonomous wireless sensor networks (WSNs)

	Acceleration Transducer	Displacement Transducer	Angle Sensor
Falling	Yes	No	maybe
Topple	Yes	Yes	Yes
Rockslide	Yes	Yes	No
Rotational slide	Yes	Yes	No
Shallow translation	Yes	Yes	No

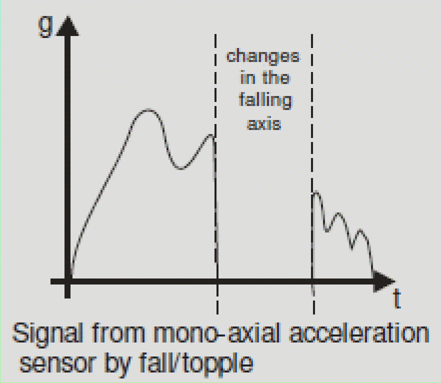
Failure mechanisms & sensors



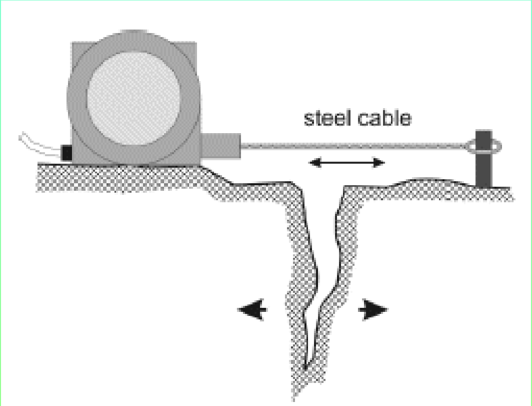
Linear displacement transducer



Mono-axial accelerometer



Tri-axial accelerometer



Draw-wire displacement transducer

SLEWS, Arnhardt et. al., Geotechnologien 2007

SFI (SRC-ID 07/SRC/I1168)

Autonomous wireless sensor networks (WSNs)

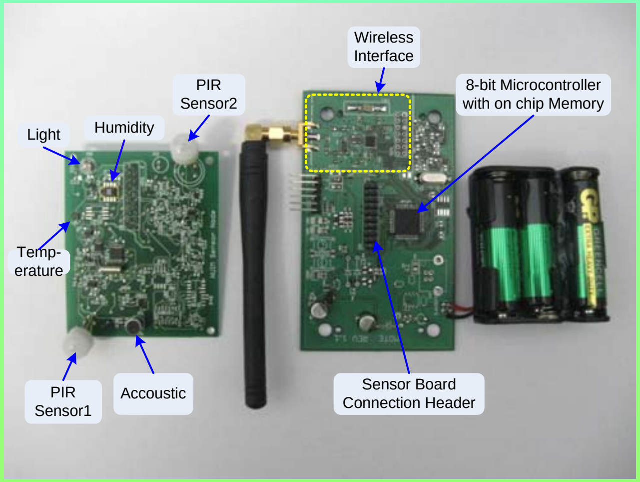
Constraints (cost/size/performance)

- power (comms & computing, triggering, energy harvesting, sustainability)
- comms (GPRS, UMTS, LTE, WiMax, WiFi, Zigbee, Bluetooth, UWB, VHF)
- computing (local processing at node or network level, OS eg TinyOS)

Intelligent behaviour

- autonomous/adaptive
- self-organising, auto-location, positioning
- distributed processing
- collaborative (common goal, failure, clustering)
- decision making (local/central)

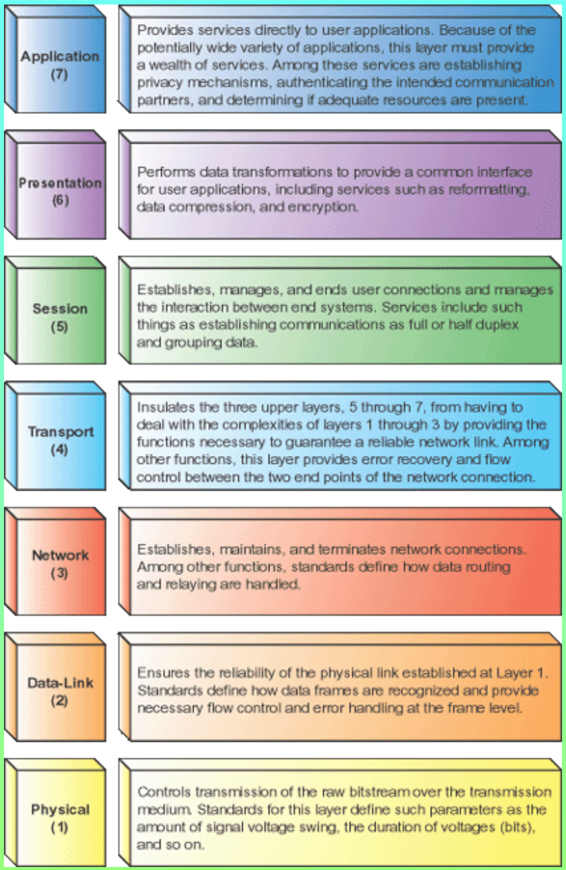
WSN Research at StratAG, NUIM



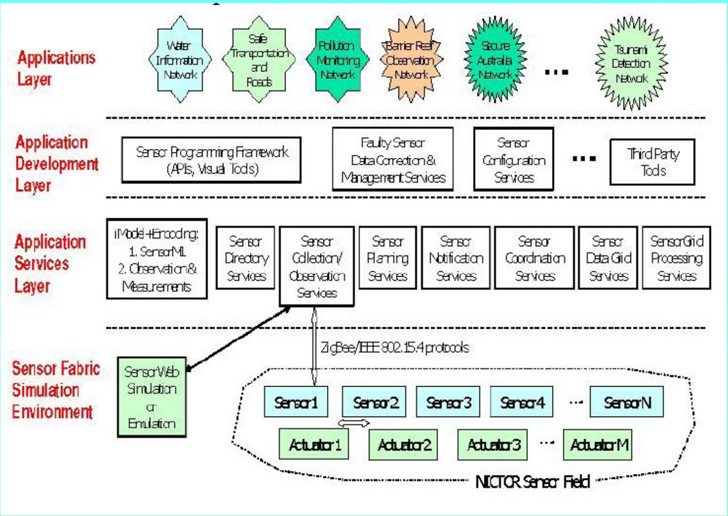
NUIM Sensor Node (M. Tahir, StratAG, 2009)

SFI (SRC-ID 07/SRC/I1168)

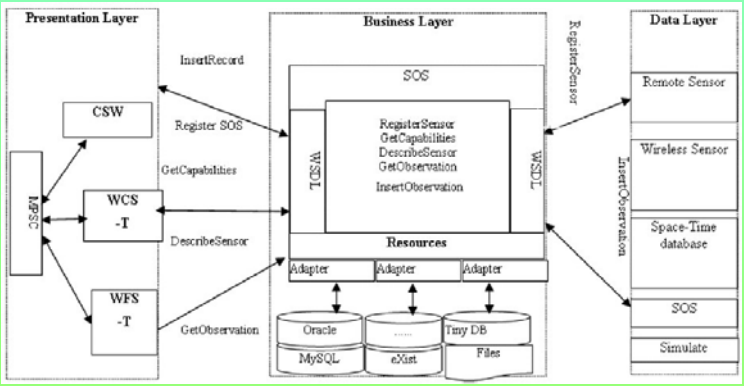
Autonomous wireless sensor networks (WSNs)
High level architectures



ISO/OSI Model



High level view of Open Sensor Web Architecture (OGC compliant) after Chu et. al. (IEEE, 2006)



Service orientated architecture (SOA),

(N. Chen et. al., ISPRS 2009)

SFI (SRC-ID 07/SRC/I1168)

Autonomous wireless sensor networks (WSNs)
Sensor Web Enablement/Web Services/OGC Languages

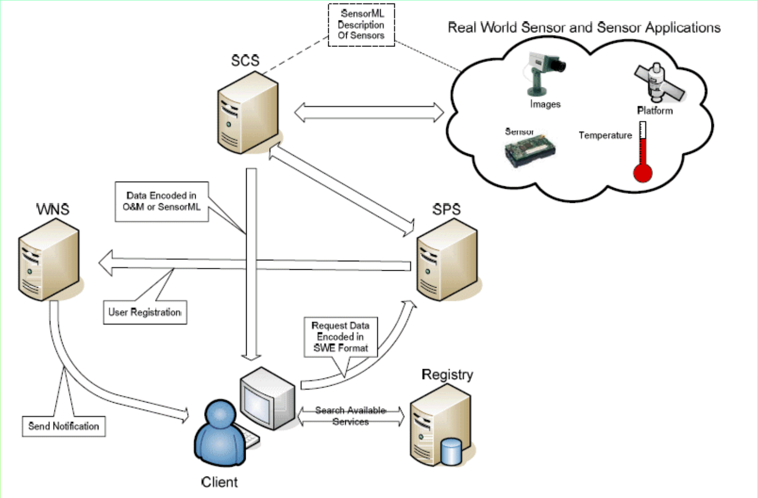
Sensor Web Enablement (SWE) - standard developed by OGC that encompasses specifications for interfaces, protocols and encodings that enable discovering, accessing, obtaining sensor data as well as sensor-processing services

Web Services

- Catalogue Service for the Web (CSW),
- Transactional Web Feature Service (WFS-T)
- Transactional Web Coverage Service (WCS-T)
- Web Coordinate Transformation Service (WCTS)
- Sensor Observation Service (SOS)
- Sensor Alert Service (SAS)
- Sensor Collection Service (SCS)
- Sensor Planning Service (SPS)
- Sensor Notification Service (SNS)
- Web Notification Service (WNS)

OGC Languages

- TranducerML
- O&M
- SensorML



NUI MAYNOOTH
SFI (SRC-ID 07/SRC/I1168)

Some Conclusions

- Global environmental technology market is a high-value sector area, forecast to double by 2020 to some €2.3T. Current EU T/O €227B
- Range of sensing technologies (RS/in-situ), Satellite, Airborne, Terrestrial for Landslide monitoring
- Increasingly multi-platform, multi-thematic, multi-dimensional
- Range of research issues to be tackled including;
    - WSNs for Landslide Monitoring/early warning/wide-area/harsh env.
    - Autonomous WSN (Power/Comms/Computing)
    - RS/WSN integration (synoptic/*in-situ*)
    - Data Fusion
    - SWE/SOA
    - Intelligent decision making (machine based) systems
- Opportunities for Irish R&D (Gov. agencies/Research Inst./Industry) in forming partnerships and developing these new Smart sensing geotechnologies

email tim.mccarthy@nuim.ie

SFI (SRC-ID 07/SRC/I1168)