

**Institut français
des sciences et technologies
des transports, de l'aménagement
et des réseaux**



SHM and NDT techniques at IFSTTAR - applications on Civil Engineering structures Challenges and new trends on wireless, smart and embedded sensors

Vincent Le Cam

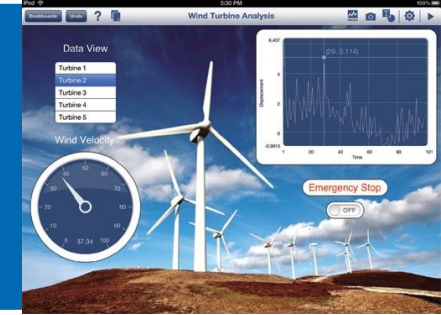
IFSTTAR - COSYS Depart.
Co-head of SII – Lab (20 pers.)

**CEFIPRA Indo-French Seminar on
Smart Systems and SHM (Structural Health Monitoring)
for structures under Harsh Environments**



IFSTTAR

Summary:



1) IFSTTAR presentation and identity

2) SHM and NDT techniques at IFSTTAR

- What and why monitoring Civil Engineering and Transportation structures ?
- How to monitor ?

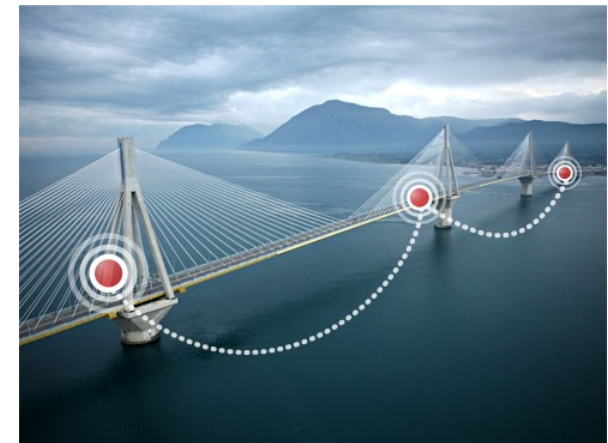
3) Focus on Wireless Sensors Network

- Context / expectations
- Bibliography / technical challenges

4) Ifsttar solution : Pegase platform

- Platform characteristics
- Practical applications

5) Conclusions – perspectives – new trends



1 - IFSTTAR

IFSTTAR : french national institute of science and technology for transport development and networks. International level.

MULTIDISCIPLINARY

**Engineers sciences
+
Human and social sciences
+
Life sciences**

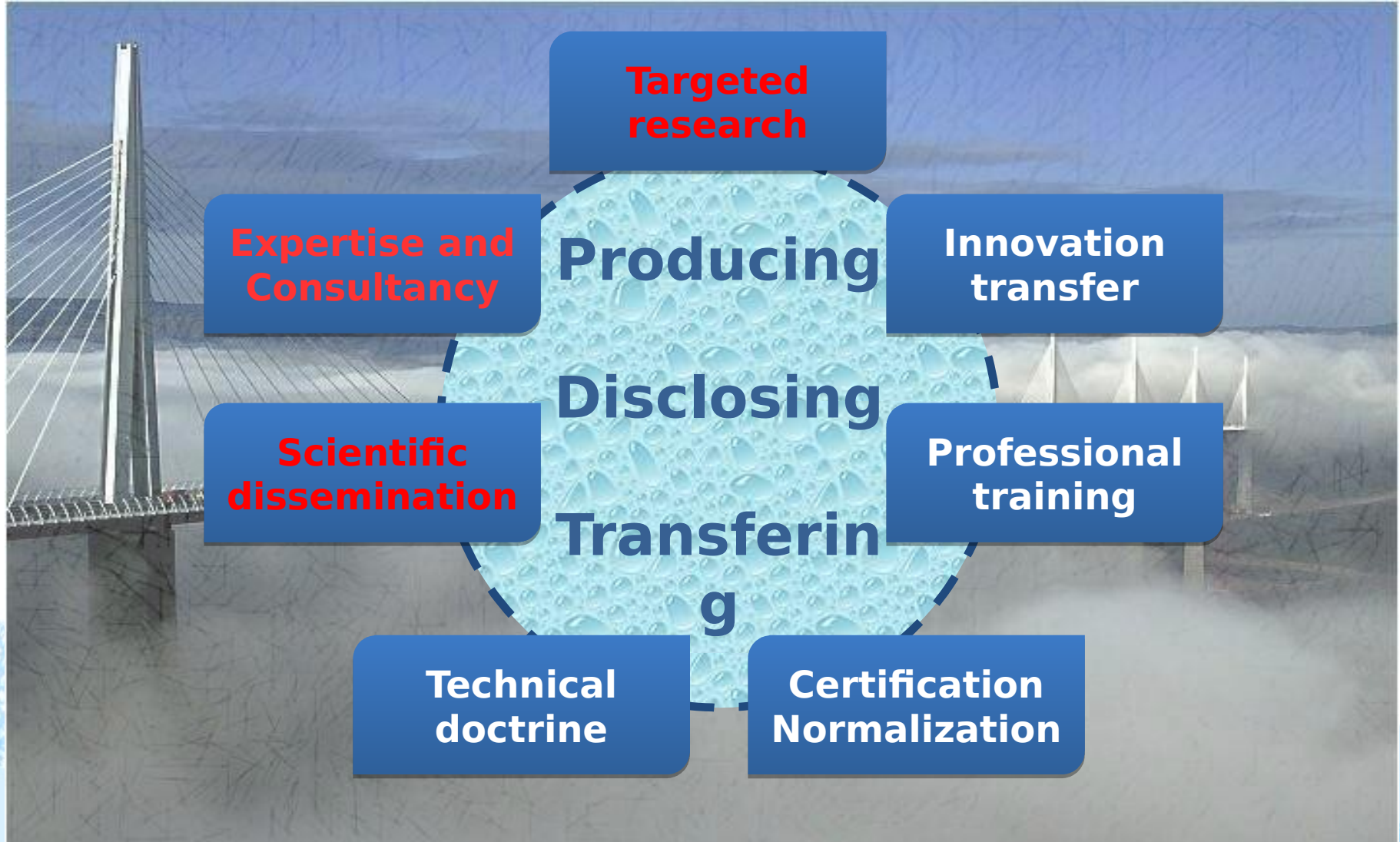
- **Civil engineering and building materials**
- **Natural hazards (characterization and impacts)**
- **People and goods mobility**
- **Safe transport systems**
- **Impacts of transport systems**



www.ifstt.fr

1 - IFSTTAR

IFSTTAR 's missions.



1 - IFSTTAR

IFSTTAR : key figures (2013)

- Staff : 1260 employees (380 PhD students)
- Annual budget : 103 M€
- > 370 scientific publications
- > 80 defended PhD
- 80 patents at intl. level
- 150 research programs (50 European projects)
- 110 technical expertise's



www.ifstt.fr

1 - IFSTTAR

Materials and Structures testing facilities



Wire rope test bench



Pavement fatigue testing facilities



Materials testing Labs: MRI , Presses, SEM, Gamma-densitometer, Micro-tomography, Fatigue testing devices



Material mixing plant



Embedded equipment for in situ inspection



Civil engineering structure testing facility

1 - IFSTTAR

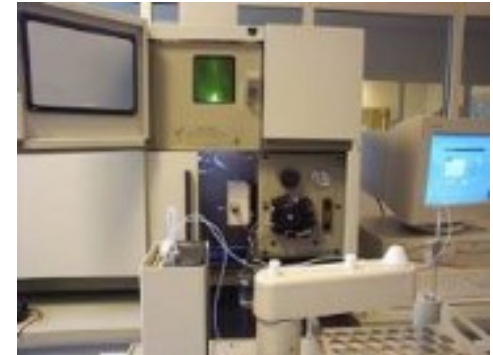
Materials and Structures testing facilities



Geotechnical centrifuge :
behaviour survey of
geotechnical structures
(foundations, off-shore
anchorages, embankment,
retaining structures) on a
small-scale



Facility for Impact
assessment of rock fall (Up
to : 20 t / 12 m)



Rock and soil analysers

Environmental
chemistry
Analysers



Dedicated sites for on field
experimentations

**Chambéry, Paris,
Nantes**

1 - IFSTTAR

Materials and Structures testing facilities

Paris,
Lyon,
Nantes



UAV : High Performance Imaging System

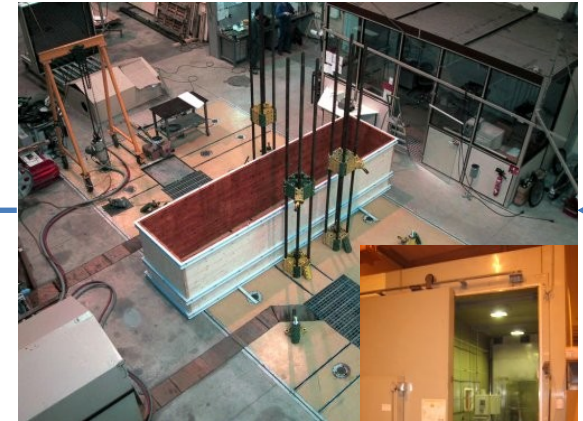
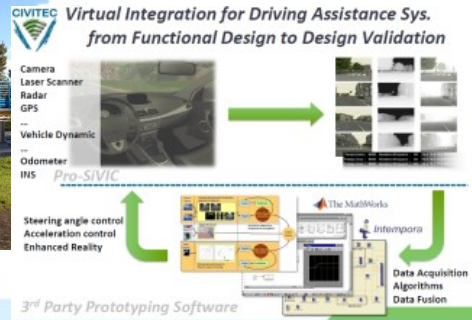


Instrumented Vehicles :
Driving and Trajectory Observation

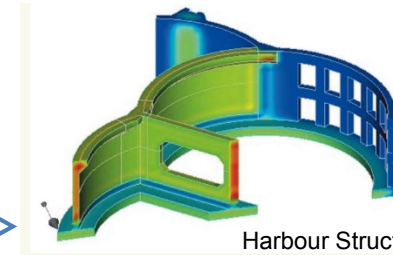
Railway traffic Simulator (ERTMS)



Large Smart Composite Experimental Bridge



Vibration test-bench
Climate Chamber



Harbour Structure's Mechanical Behaviour

Civil Engineering
Finite Element
Code



Psycho-Visual
Analysis Bench

Driving assistance simulation (E-MOTIVE)

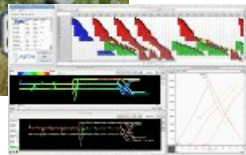
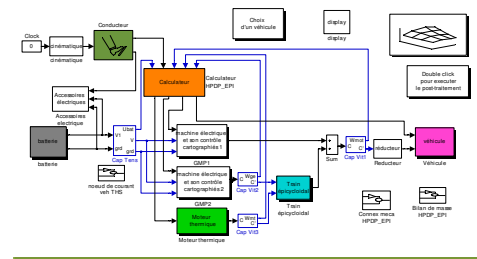
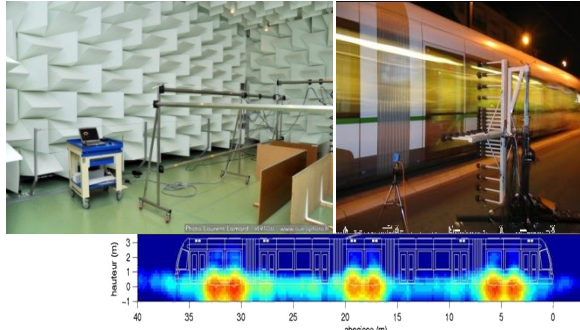
1 - IFSTTAR

Materials and Structures testing facilities

Data bases : «Travel Enquiries»

Data bases : « Goods traffic »

Acoustical analysis facilities



Railway traffic monitoring



Test benches for vehicles, engines, components (batteries....)

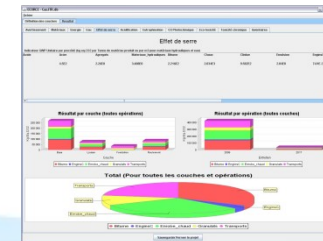


Analysis of exhaust emissions

Electric vehicle modelling software + test vehicles



Structures LCA Software



www.ifsttar.fr

1 - IFSTTAR

Example of a KEY PROJECT : the 5th generation Road !

Why do we need R5G ?

- Bad image associated to road transport
- Introducing existing innovations in the road field
- Need for technological transfers

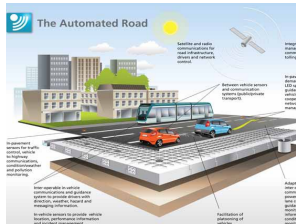
Project ambitions :

- a flexible road
- a cooperative road
- an environment friendly road
- Harvesting energy...
- an acceptable road

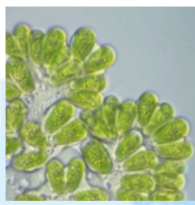


R5G is a multipurpose solution

Infrastructures for urban, suburban, structured or local networks



Forever Open Road



Workplan

The goal : To design and to realize of full scale demonstrator

2010-2014: R5G components demonstrators

2014-2018: tests of subsystems

2020 : R5G full demonstrator

1 - IFSTTAR

Ifsttar : a leading role in Europe and at International level



- **Bilateral research programs : NSF / ESF...**
- **Transfer of knowledge**
 - Major actor in international dedicated networks
 - Expertise
- **Member of normative and regulatory working groups**
- **Worldwide strategy support for SME's**
- **Contribution to prepare European research programs (member of dedicated clusters)**
 - ECTRI, FEHRL, FERSI, ERTRAC, ECTP, CEDR, JPI Urban...
- **Influence on European policies**
 - Transport, Materials, nanotechnologies, ICTS...
- **Project manager or Partner in research programs**
 - Horizon 2020, 7^{ème} PCRD

1 - IFSTTAR

Some of IFSTTAR's nat/intl. partners



2 – SHM and NDT at IFSTTAR



- **What and why monitoring Civil Engineering and Transportation structures ?**
- **How to monitor ?**



2 – SHM and NDT at IFSTTAR

Civil Engineering, Energy and Transportation Structures are strategic : human-safety, cost, environment impact, timelife, construction and maintenance costs ...

Thus, **Structural Health Monitoring (SHM)** and **NDT techniques** are expected as solutions to :

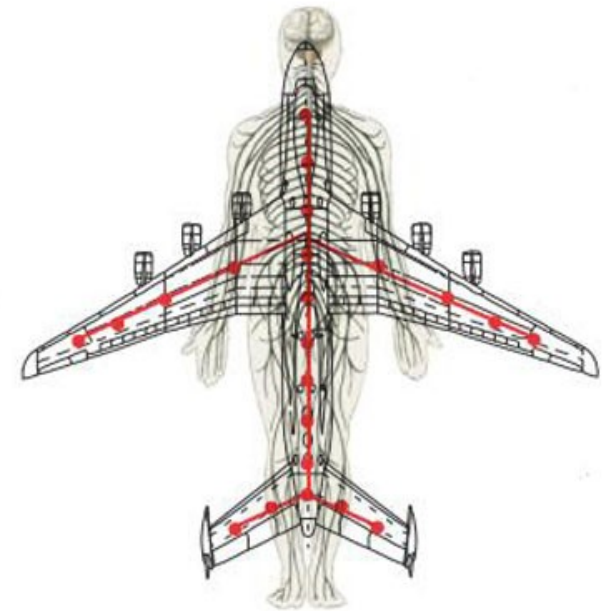
- Detect minor or major structural default
- Ensure the continuity of structure's exploitation
- Anticipate a future default / disease
- To make prognostics (PHM)
- To program repairs or structure's end of live
- ...

Strategic Structures requires Strategic informations !

SHM systems are based on following analogy :

→ **Human Body** : nervous network connected to brain that takes decisions

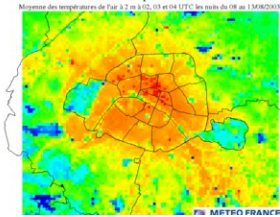
→ **A network of sensors** connected to a central Supervisor unit that compute algorithms



2 – SHM and NDT at IFSTTAR

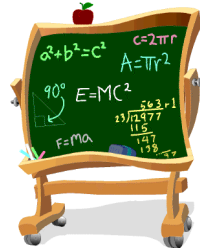
Concretely, **SHM implementation** is the sum of :

Sc. Modeling :
analytic, statistic,
inverse, finite
elements...



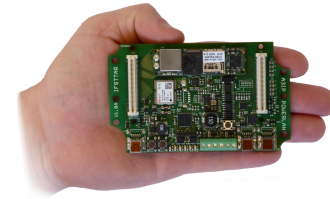
+

**Computer
Science** for model
implementation
(Matlab, C/C++...)



+

Instrumentation
based on sensors
and smart systems



=



2 – SHM and NDT at IFSTTAR

IFSTTAR's vision for **SHM** : make structures **smarter**

→ able to give a **status of their health**

→ going further than a simple metering. Data + algorithms should **provide quantitative and/or qualitative infos**, that makes sense

→ useful infos to perform dialog between measurement world and structure's managers

The crack grew up of 3 μm



So much ? Destroy bridge now !

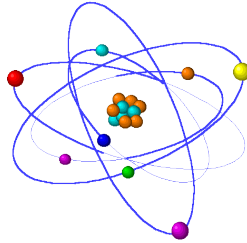


2 – SHM and NDT at IFSTTAR

IFSTTAR's topics for **SHM** :

Physics / Science :

- Modeling : structural behaviour
- Modal analysis, vibration
- Wave propagation
- Statistics
- Signal Processing, acoustic
- Electromagnetic
- ...



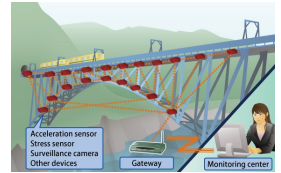
Application / feedback / experimentation :

- Energy : pipeline, power plants, wind turbine,
- Aerospace
- Marine
- Railway
- Automotive
- Civil engineering
- ...



Measurement:

- Sensors : smart, wireless, network
- Multiphysics : chemical, piezo...
- Thermography
- Micro / nano agents, MEMS
- Optic Fiber
- ...



Process, maintenance, standard

- V&V, standardization
- Strategy, theory to practise
- Homogeneisation (Aero ↔ Civil Engi)
- Benchmarking
- ...



2 – SHM and NDT at IFSTTAR

IFSTTAR : SHM in an international network

Groupement d'Intérêt Scientifique



Maîtrise des Risques en Génie Civil



IWSHM



7th European Workshop on Structural Health Monitoring

2nd European Conference of the Prognostics and Health Management (PHM) society



July, 8 - 11, 2014 - Nantes, France



2 – SHM and NDT at IFSTTAR

SHM for which diseases ?



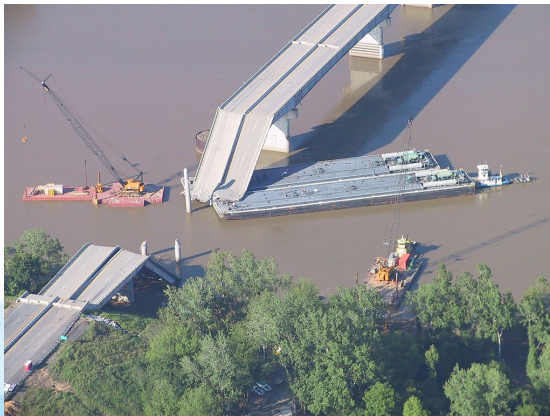
2 – SHM and NDT at IFSTTAR

SHM for which diseases ?



2 – SHM and NDT at IFSTTAR

SHM for which diseases ?



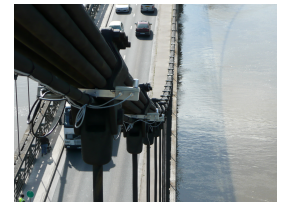
...

2 – SHM and NDT at IFSTTAR

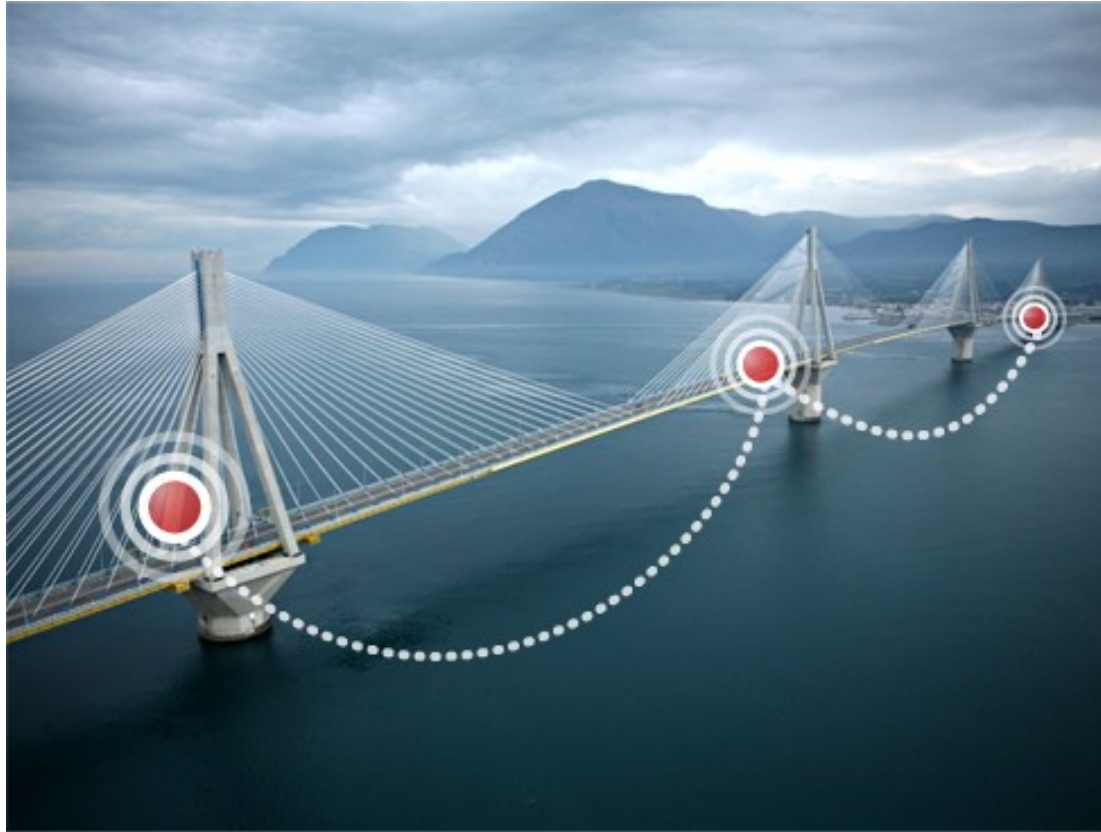
SHM solutions (non exhaustive) :

To face SHM requirements, IFSTTAR's lab develop knowledge and technologies in various domains :

- **Modal Analysis** for SHM based on structure's natural frequencies evolution
- **Signal processing** applied to structures's pictures or video
- **Fiber Optic** as long-base sensor (embeded in concrete for ex) using Bragg, Brillouin or Raman effects
- **Acoustic Monitoring** : default detections by active or passive acoustic wave propagation analysis / structural modeling
- **Thermal analysis** of bridges, buildings using IR or CMOS camera, invisible spectrum...
- **Chemical techniques** : for detection and evolution of corrosion or concrete carbonatation
- ...



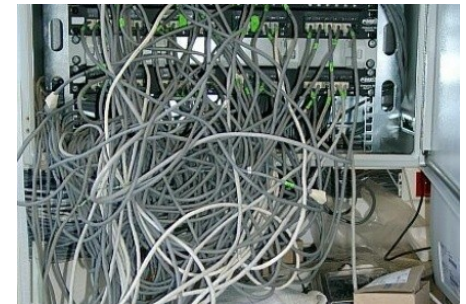
3 – Wireless Sensor Network (WSN)



3 – Wireless Sensor Network (WSN)

Context and expectations :

- Actual structural instrumentation is mostly wired ... (or non-existent) !
- Structural instrumentation is not mandatory or well standardized in Civil Engineering
- Few incitations to go to wireless. Opportunistic or one-shot solutions
- Few technical standards in instrumentation
However wires are very vulnerable : fatigue, corrosion, sealing, E.M. effects, lightning, *skin or antenna* effects, robbery...
- Thus, wired solutions are **very expensive** (or non-existent) !



3 – Wireless Sensor Network (WSN)

Even if a real market exist...

- Structural Managers express their needs (ex. Europe / FERHL)...not always answered !
- Some companies are only focused on Instrumentation...
- **But are waiting for strong innovations**



Advitam

diadeS
Diagnostic et durabilité des structures



VCE
Vienna Consulting
Engineers ZT GmbH



acogec

mageba
Switzerland www.mageba.ch

27

www.ifstt

3 – Wireless Sensor Network (WSN)



Definition of what a Smart Wireless Sensor should be

Able to sample and condition physical data



Mesure
Conditionnement
Conversion



Processeur
Traitement
de signal
Stockage

Able to process data / to apply SHM algorithms

Able to communicate in an existing wireless network



Radio
Communication



Energie:
- gestion batterie
- récupération

Able to manage energy from saving to harvesting

And able to :

- Geotag its position
- Synchronise data and process
- ...

3 – Wireless Sensor Network (WSN)

Bibliography : emerging solutions



Airbean



Formic



Newsteo



Microstrain



Vantage



Michigan



PEGASE



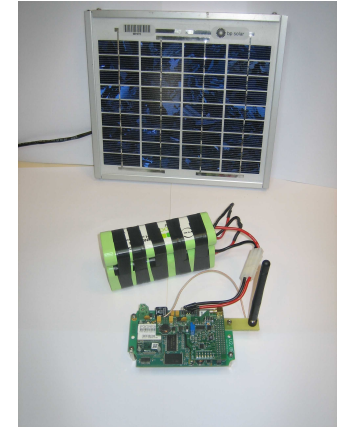
Pioneer

3 – Wireless Sensor Network (WSN)

Bibliography : emerging solutions

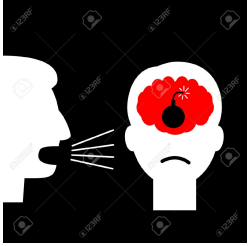


3. Wireless sensors are used to measure long-term stress and strain in civil engineering structures like buildings and bridges. (Courtesy: Microstrain Inc.)

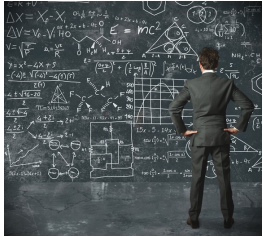


3 – Wireless Sensor Network (WSN)

But let note that :



Practical Wireless instrumentations often give bad feedback



« Wireless Sensor Networks » gives 6 540 000 results under google ... but

How many managers you know, have really deploy a WSN ?



3 – Wireless Sensor Network (WSN)



→ WSN technologies have to improve to jump from theoretical to practical world !

→ what are the challenges ?

Let focus on 4 main challenges for WSN :

1 – Energy

2 – Wireless Communications

3 – Need of synchronization

4 – Missing end-user tools



3 – Wireless Sensor Network (WSN)



1 – Energy

- Make a WS autonomous on a battery for years isn't realistic...
- Or often ask to reduce/degrade sensor capacities (precision, sampling...)
- Most often an **external source** is necessary to harvest local energy

~100 mW to
W / m²



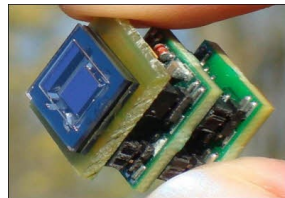
Solar

~10ths W



Wind

~ 10ths μ W



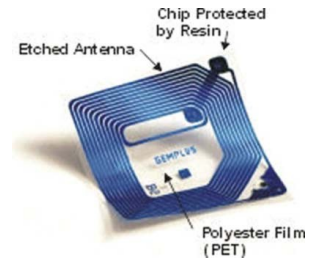
Vibration

~ μ W



Heat -
seebeck

W = 0



External
E.M. /
RFID

www.ifstt

3 – Wireless Sensor Network (WSN)



1 – Energy

In Civil Engineering world the *winner* is often solar source.



What for aero world ? Probably vibration dedicated MEMs sensors...



3 – Wireless Sensor Network (WSN)



2 - Wireless Communications

- Wireless communications is what ask for more energy in a WS node
- Standardization is a good trend...
- A lot / a jungle of wireless protocoles :

LAN protocoles :

Diagram illustrating LAN protocols. It features logos for ZigBee, WiFi, and Bluetooth. A detailed diagram shows the 802.15.4 architecture, including the upper layers (Zigbee), IEEE 802.15.4 LLC (Type 1), IEEE 802.15.4 MAC, and IEEE 802.15.4 PHY (868/915 MHz and 2400 MHz). It also shows the ISM band and the M-Bus wireless logo. The power consumption is noted as 10 / 150 mW.

WAN protocoles :

Diagram illustrating WAN protocols. It features logos for W@P, GPRS, 3G, and 4G. The power consumption is noted as 500 / 1000 ... mW.

~ made for WSN

Not made for WSN !

www.ifstt.fr

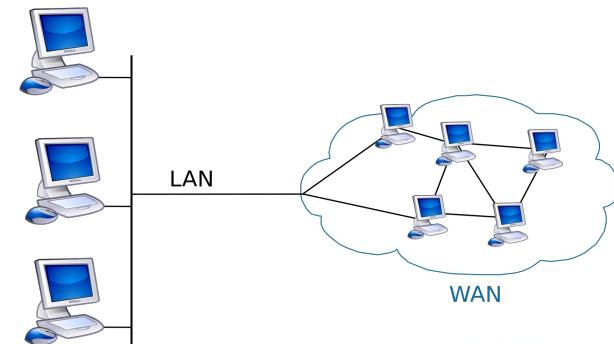
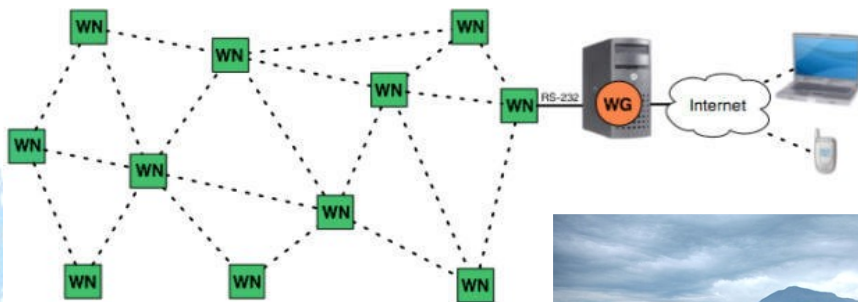
3 – Wireless Sensor Network (WSN)



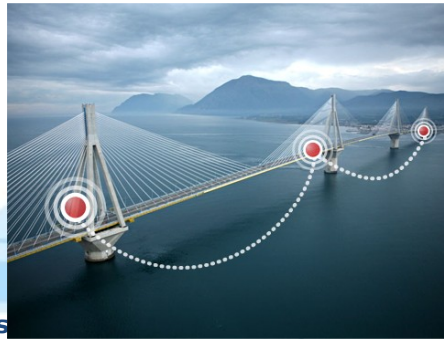
2 - Wireless Communications

Challenges & improvements :

- **Better use of wireless module** : RDV mechanism, set RF module ON only when needed, more embeded algorithms for less data to transmit
- Relative **defeat of Multihop protocoles** (Zigbee, 802.15.4...) : chaining wireless sensors **makes critical path**. Not viable in 'real life'
- Face the need to push data on a server/Internet : how to bridge the **LAN to the WAN ?**



**Théorie vs
Pratique**



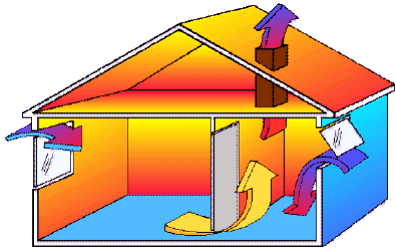
3 – Wireless Sensor Network (WSN)



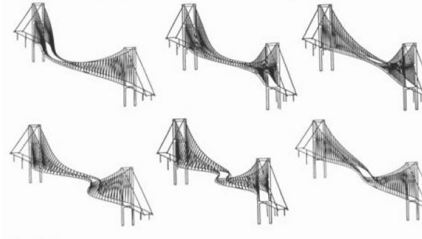
3 – Need of synchronization

Human needs to sample data in a function (time).

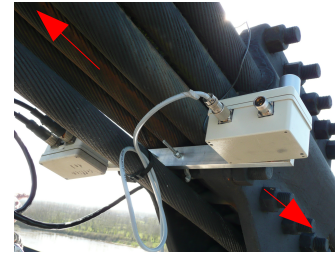
Time-stamping requirement could be low or very high :



Temperature → S - mn



Vibration → mS



Acoustic wave → μ S



Electric wave → nS

Each **electronic device has a time-base that drift** because of quartz differences, quartz aging, different conditions (temperature)... In wired instrumentation a simple cable with a synchronization pulse is a solution.

But in Wireless World : **how to ensure a good time stamping between a network of wireless sensors up to some μ S ?**

3 – Wireless Sensor Network (WSN)



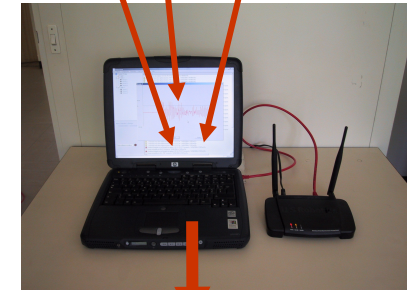
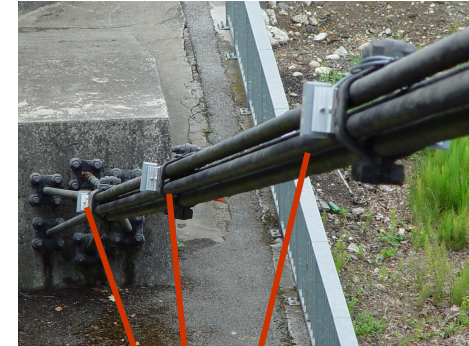
3 – Need of synchronization

Most of existing solution forget synchronization or uses :

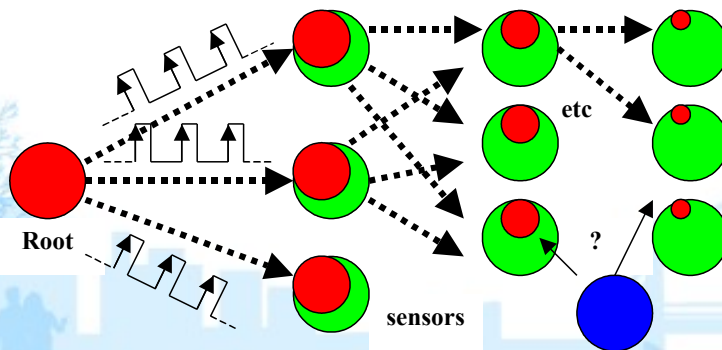
- **Data stamped at reception** : no precision, lot of power
- **NTP** (Network Time Protocol) : made for IP networks, precision up to 1 mS, ask for a lot exchanges, power-consuming
- **RBS protocol** : similar to NTP, up to 10 μ S, not deterministic !
- **TPSN** (Timing-sync Protocol for Sensor Network): similar to RBS
- ...

→ **Most of solution are** : not deterministic and/or not standard and/or not accurate and/or ask for power-consuming due to network dialog...

→ **Need of another method** to synchronize WSN



Alert !



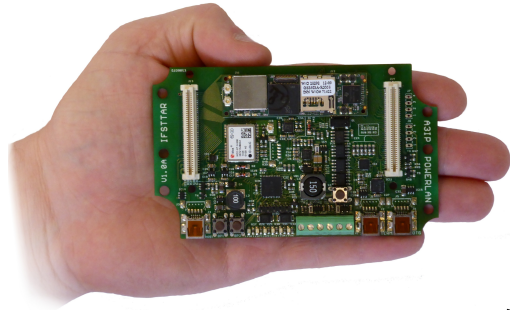
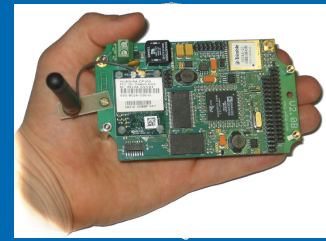
3 – Wireless Sensor Network (WSN)

4 – Missing end-user tools

See in conclusion / perspectives...

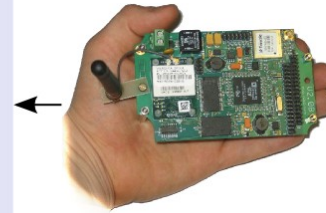
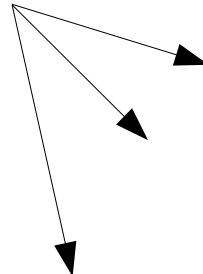


4 – IFSTTAR : PEGASE platform

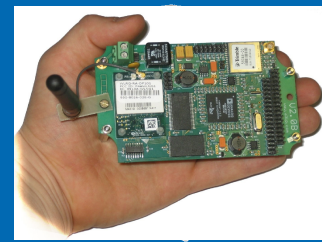


PEGASE

PEGASE - **Contrôle Non Destructif**



4 – IFSTTAR : PEGASE platform



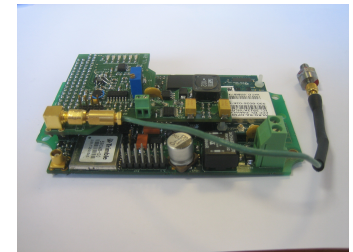
PEGASE : Generic Platform for Wireless Embedded Applications

Genericity :

in two main principes :

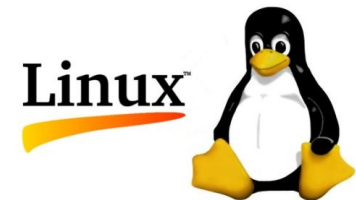
1) Hardware genericity

- PEGASE = a **mother board** comprising redundant functions in wireless monitoring
- A set of available **daughter boards** to interface sensors : gauges, accelerometer, inclinometer, PT100, acoustic...

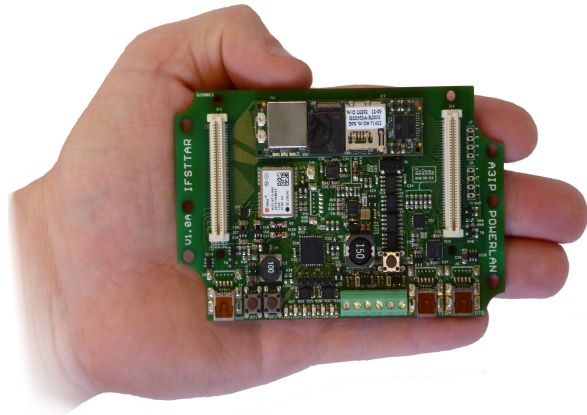
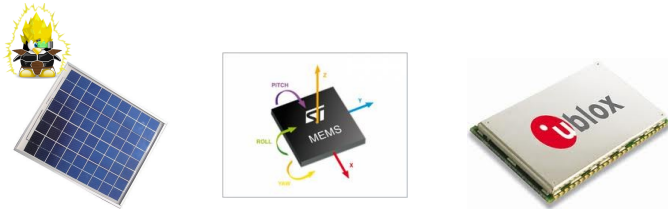
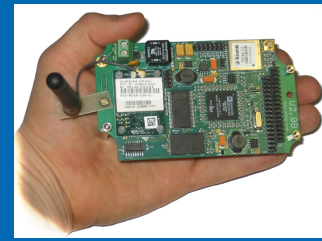


2) Software genericity

- Operating System (OS) **Linux embedded**
- Easy to program trough **C ou C++ standard** (as simple as a PC)



4 – IFSTTAR : PEGASE platform



Technical characteristics :

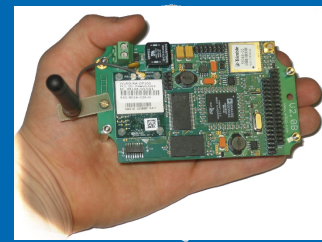
- Wireless Com : **WiFi** or 3G
- **Linux** inside (Debian kernel) , Gumstix board
- 512 Mo RAM + 8 Go Flash μ SD
- Native energy management : solar, MPPT...
- Embede MEMS : 3D accelero + gyro
- Synchronisation using GPS/PPS up to 12 nS
- **Precision GPS receiver** : UBLOX NEO 6T
- Connectivity: I2C, **USB**, SPI, Bluetooth...

- **For SHM and NDT applications :**
 - **A complete SDK C++**
 - **DSP Core** : signal processing, complex algorithms (ex : SSI), statistics, matrix...

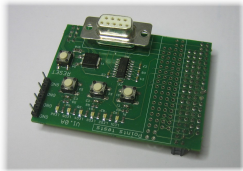


« A PC that is not a PC »

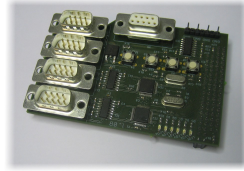
4 – IFSTTAR : PEGASE platform



A set of available daughter boards :



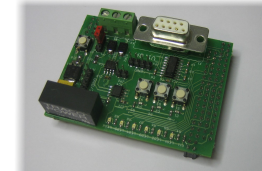
Debug



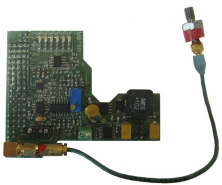
*5 UART /
RS232*



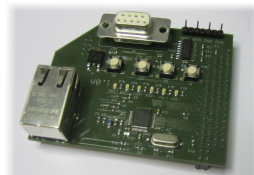
*8 generic analog
channels
24 bits / 50 kHz*



CANBus



Acoustic 250 kHz



Ethernet



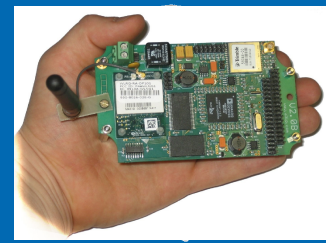
3D Accelero 3D +
PT100



3D acceleration + Gyro +
Temperature

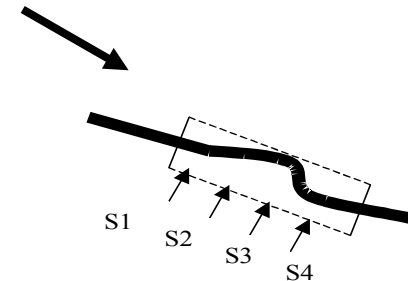
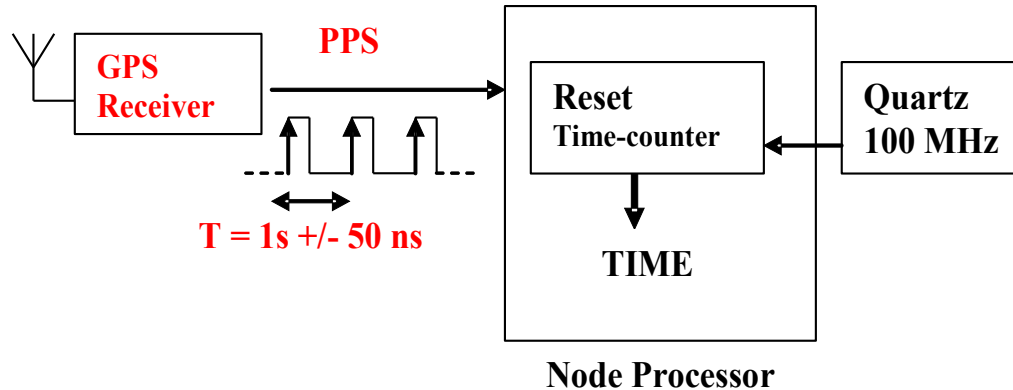
etc...

4 – IFSTTAR : PEGASE platform



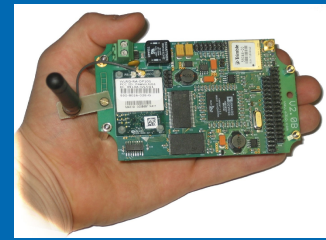
Focus on PEGASE **SYNCHRONIZATION** solution:

- Need of a real common synch. source : using a GPS receiver on each WS → each Sec a very accurate PPS signal provides an accurate edge of some nS
- Kernel Algorithms compute natural quartz drift k , integrate temperature effect...
- Each Time Stamp is corrected in real time : $T_i' = T_i * 1000\ 000 (1000\ 000 - k)$
- Synchronisation gives **up to 12 nS of common time base in UTC**



- Temperature inerty + algorithms determinism : allow GPS to be turned OFF (power)

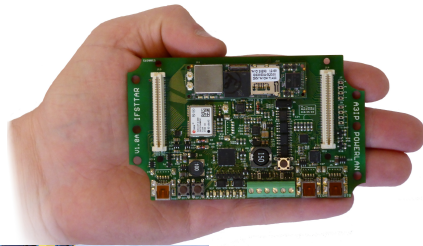
4 – IFSTTAR : PEGASE platform



PEGASE 2 concept:

Also includes a **Generic Webserver** in Cloud :

- Configuration of devices
- Start /stop
- View and store data / Big Data => Mongo DB
- Export data to third-partner program...
- Alarm, SMS...
- ...



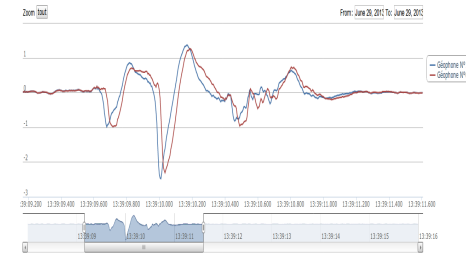
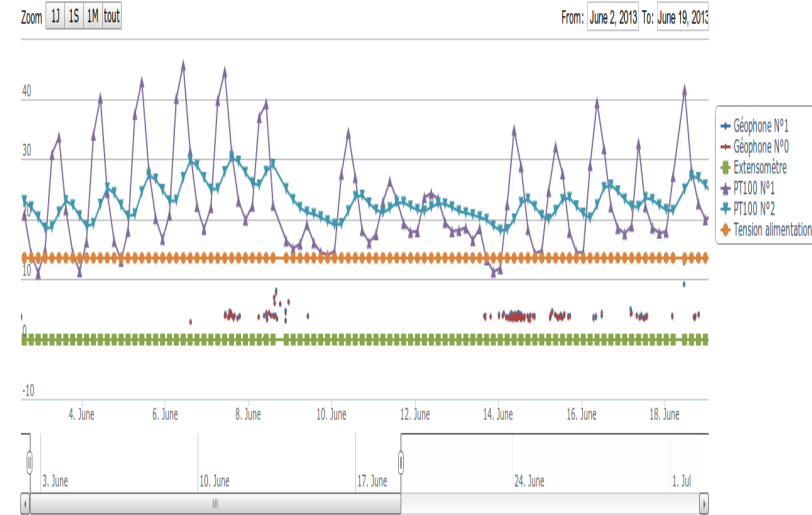
+



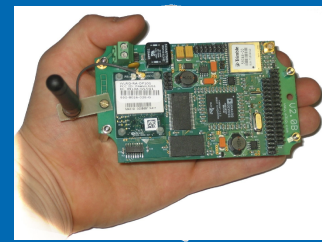
+



Internet

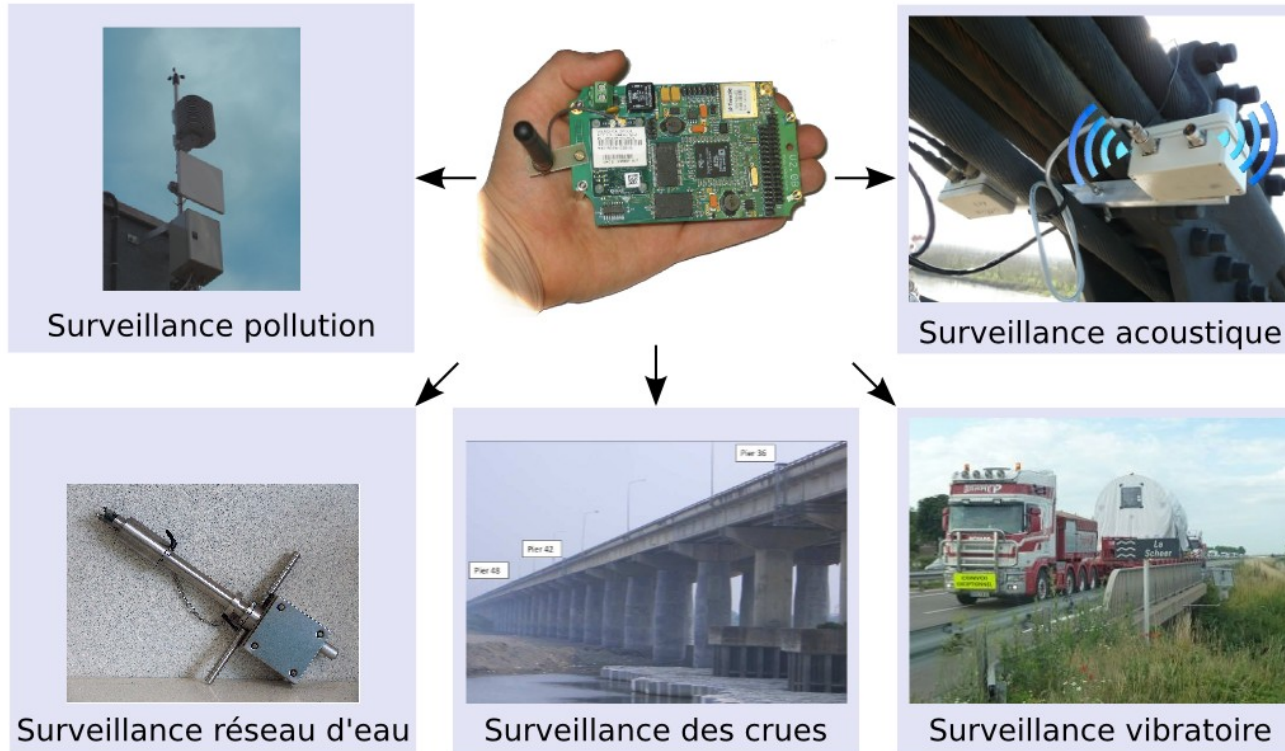


4 – IFSTTAR : PEGASE platform

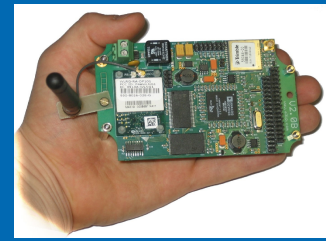


PEGASE Applications :

PEGASE - **C**ontrôle **N**on **D**estructif



4 – IFSTTAR : PEGASE platform



Application 1 : Acoustic Monitoring of suspended bridge cables

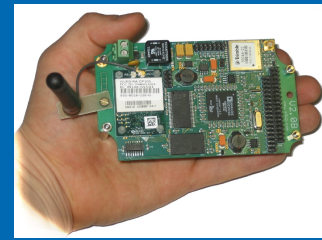


Ancenis brudge



Sully Sur Loire bridge collapse on January 1985

4 – IFSTTAR : PEGASE platform



Application 1 : Acoustic Monitoring of suspended bridge cables

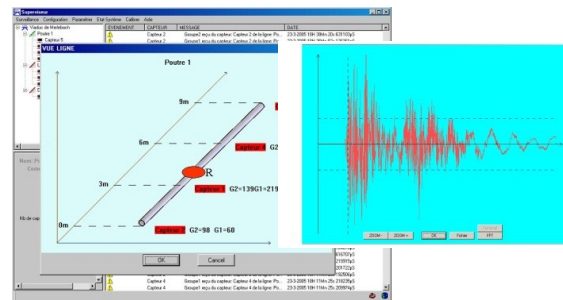
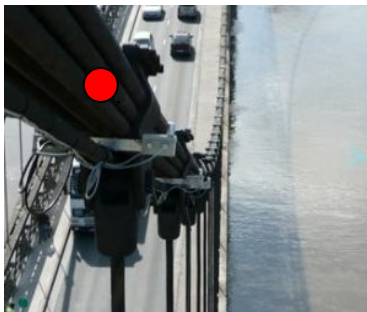


Objective : Acoustic detection and localization of wire-breaks in cable

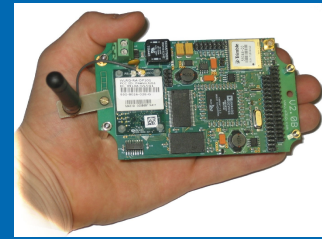
Description :

Each acoustic Pegase sensor records and analyse acoustic wave (5000 m.s-1) time-stamped at $1 \mu\text{S}$

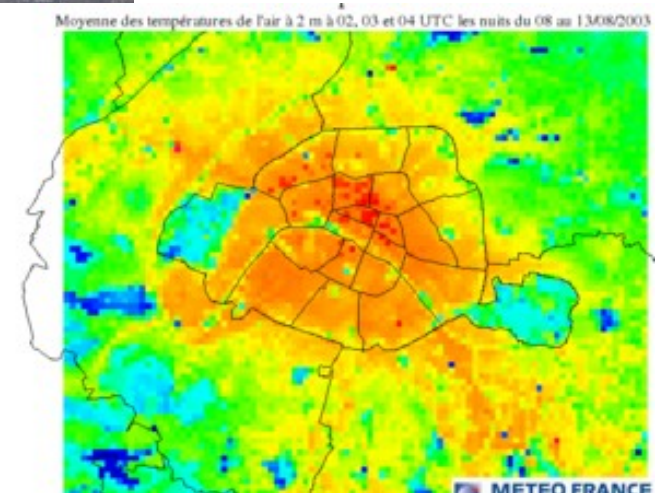
Sent to a Supervisor, events allows to localize wire breaks at $\sim 15 \text{ cms}$ and send alarms to bridge manager



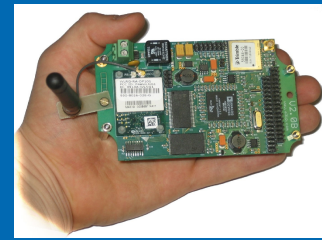
4 – IFSTTAR : PEGASE platform



Application 2 : Urban Pollution Monitoring



4- Illustration : la plateforme PEGASE d'Ifsttar



Application 2 : Urban Pollution Monitoring

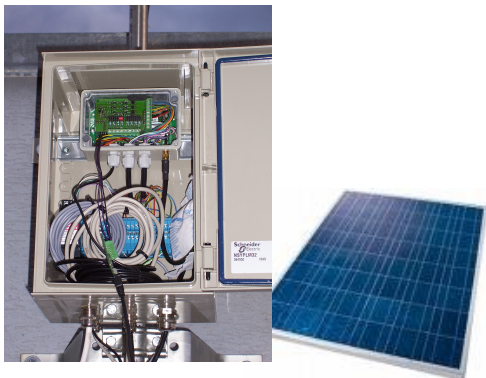


Objective : A solution to detect / to prevent and geotag Urban Pollution based on physical propagation patterns

Description : PEGASE – pollution

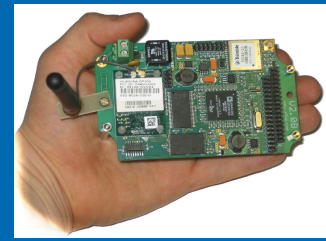
Physico-chemical records computed and directly sent to City Information System :

- Wifi / 3G communications
- Temperature
- Anemometer
- Humidity
- Sound level meter
- CO2
- Sunshine magnitude
- ...



Main benefit : **to anticipate** arriving pollution wave !

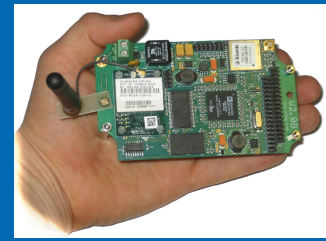
4 – IFSTTAR : PEGASE platform



Application 3 : Cracking and Extensometry monitoring



4 – IFSTTAR : PEGASE platform



Application 3 : Cracking and Extensometry monitoring



Objective : Multi channels monitoring of crack in concrete evolutions

Description : PEGASE - Cracking

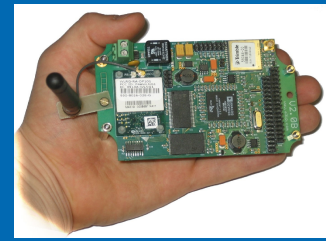
- 3G wireless communications to Cloud
- Monitoring of:
 - 5 displacement sensors
 - Temperature sensor
- Solar Cells provide full autonomy 365 d/y

SHM :

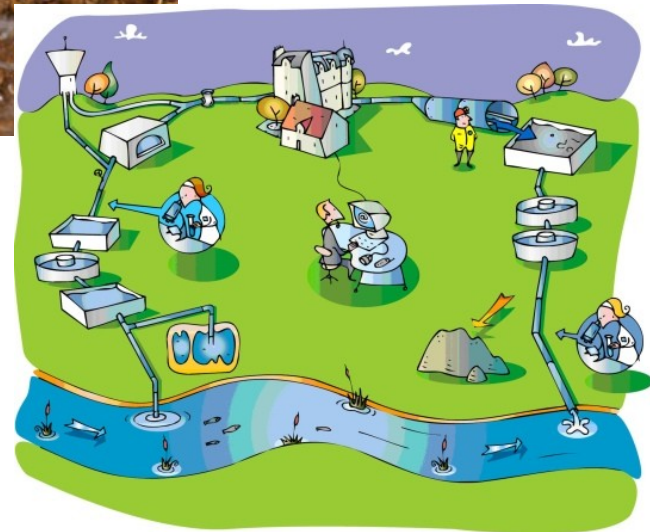
Check if Crack evolution follows a correct evolution or is entropic → alarm



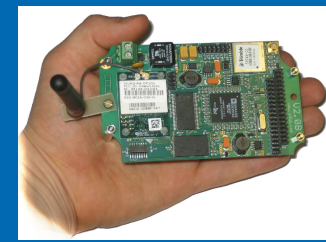
4 – IFSTTAR : PEGASE platform



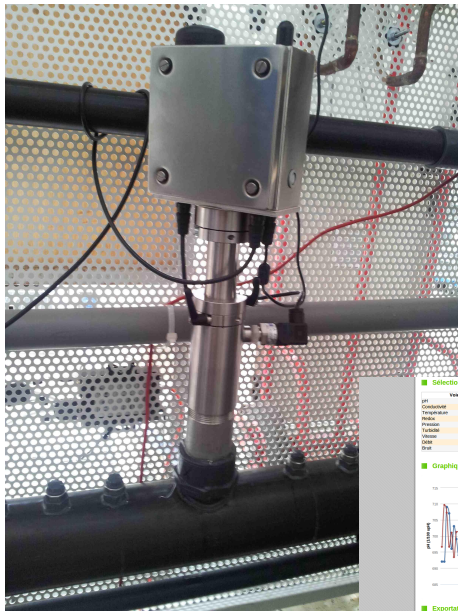
Application 4 : Smart Potable Water network



4 – IFSTTAR : PEGASE platform



Application 4 : Smart Potable Water network – Smart cities



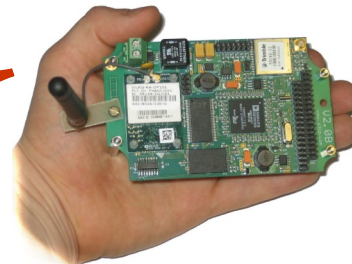
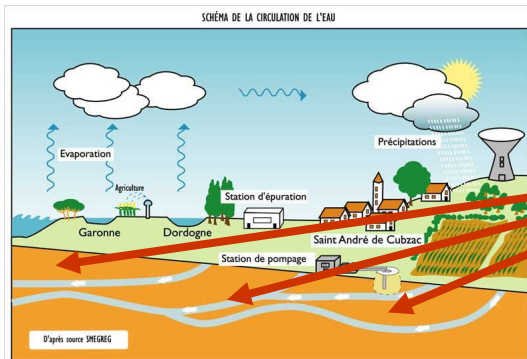
Objective : Monitoring Health of potable water pipes

Context : national project « Smart Water Network »

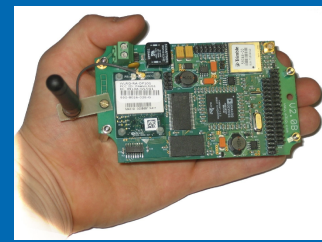
Partners : [Suez Environnement](#), Ifsttar, EFS, Advitam, A3IP, ESIEE

Description : PEGASE – Probe that sample various embeded chemical / physical parameters :

- Acoustic
- Redox
- Conductivity
- Turbidity
- Total chlorine
- Temperature
- Debit
- PH
- Pressure
- Free chlorine



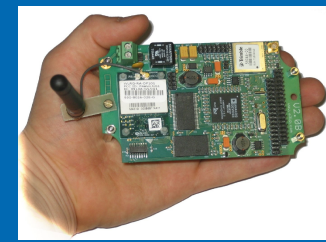
4 – IFSTTAR : PEGASE platform



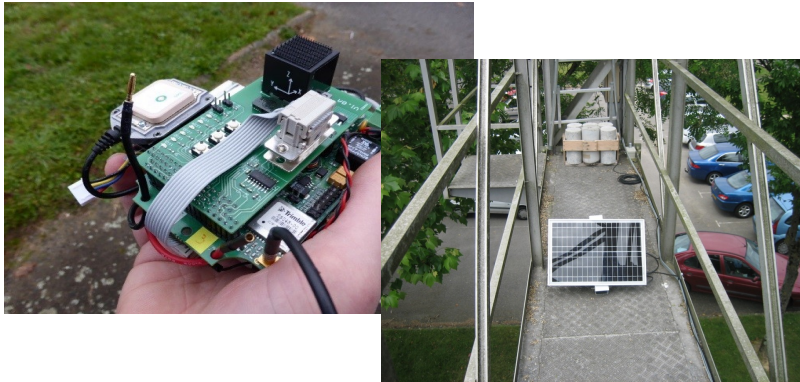
Application 5 : Road Gantry Monitoring



4 – IFSTTAR : PEGASE platform



Application 5 : Road Gantry Monitoring



Objective : Anticipate Road Gantry degradation



IFSTTAR

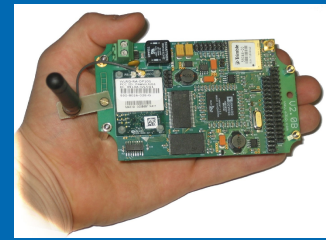
Inria

Description :

- Difficult to detect by traditional monitoring or inspection (or too late)
- Choice of **vibration / Modal Analysis**
- Modal frequencies evolution give intrinsic informations on gantry health
- A very complex and heavy SSI (Subspace Stochastic Identification) algorithm is embedded in PEGASE



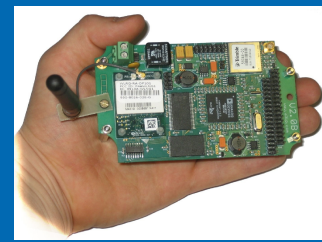
4 – IFSTTAR : PEGASE platform



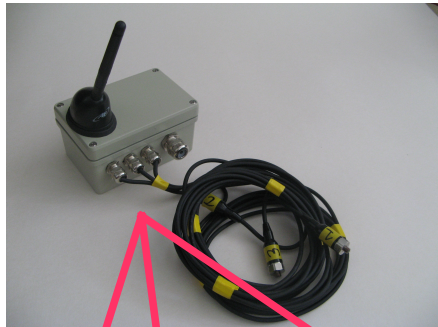
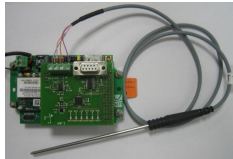
Application 5 : Scour Monitoring



4 – IFSTTAR : PEGASE platform



Application 5 : Scour Monitoring



Objective : Monitoring Scour Monitoring effect on bridge piers

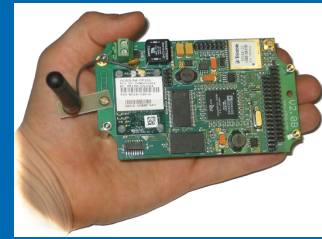
Partners: Ifsttar, Taiwan university, Advitam

Description :

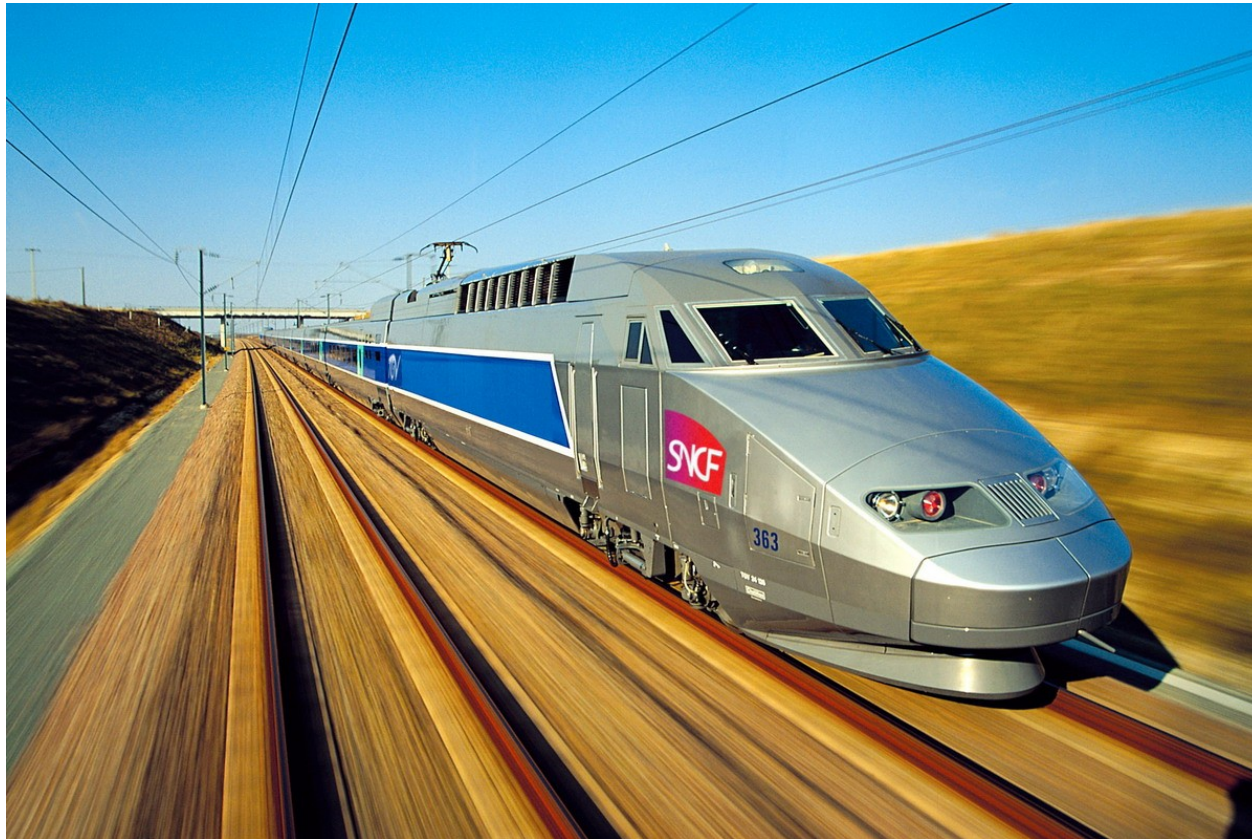
Real Time Sampling and computing :

- 3D Acceleration for Modal Analysis **SHM**
- Pier tilt
- Water Level
- Data and alert sent by WiFi/3G from Taiwan Bridge to a French Company

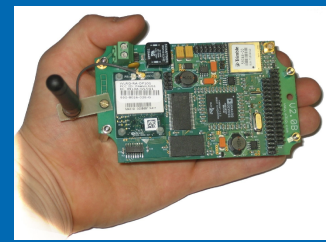
4 – IFSTTAR : PEGASE platform



Application 6 : Railways Monitoring



4 – IFSTTAR : PEGASE platform



Application 6 : Railways Monitoring

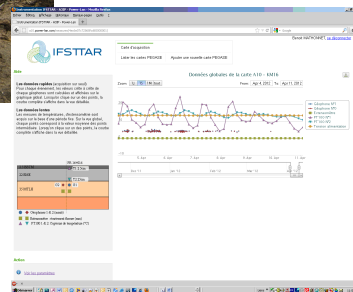


Objectives :

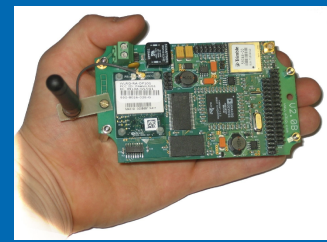
- with **SNCF** (Franch National Railway Company) contract to make progress in Smart Monitoring of structures
- Gauge contributions of WSN in old/traditionnal SnCF jobs

Many sub-projects to Monitor and Compute SHM algos :

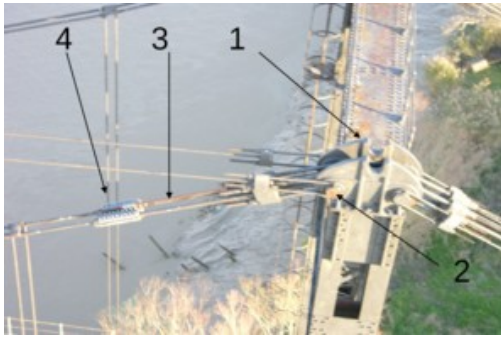
- Vibration at high speed train
- New concrete ballast evolution
- New rail's switch
- Railroad crossing motors...
- ...



4 – IFSTTAR : PEGASE platform



And many other applications ...



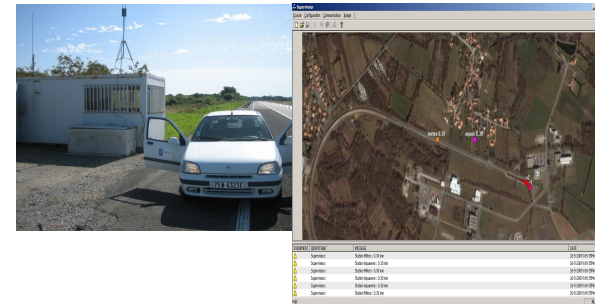
Concrete beam



UAV
Monitoring



Wind and
acoustic noise



Traffic Monitoring

5) Conclusions –new trends



5) Conclusions –new trends



Are technological ruptures really possible in our « old » jobs ?



Questions:

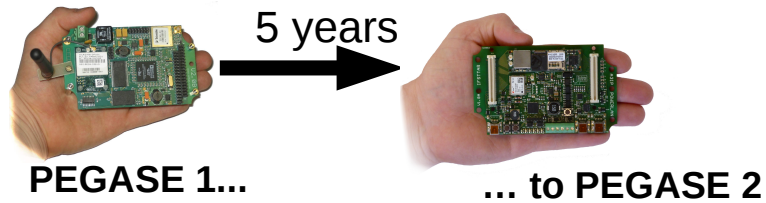
- Are technological ruptures really possible in our « old » jobs ?
- If a sensors says nothing during 10 years, does this mean that everything is ok ? Or sensor is inoperative since 10 years ?
- Which confidence in provided data after 5 years ? 10 years ? 50 years ?
- **Do we need to develop native instrumented structures ? Reduce separation between Structure's design and Structure's instrumentation**



5) Conclusions –new trends



How to face electronic lifetime vs structure's lifetime ???



2000 years

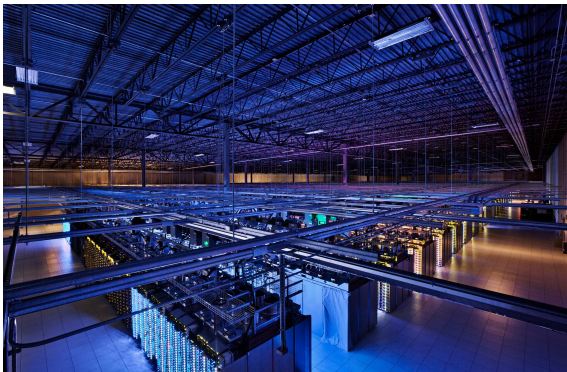


5) Conclusions –new trends



Is « Big Data » only a positive trend ?

- What to do with so much of data ?
- **Big Data :**
 - **1 zeta bytes each day** (1 exp 21 bytes)
 - 7700 DVD
 - First Google internal cost (after personal wages)
- Real cost (electricity) didn't reach yet end user...but it should arrive !



Google

April. 2015





5) Conclusions –new trends



BIG DATA at Airbus Group

We are sitting on a huge amount of data we do not fully leverage

Example: Aircraft Operation Data

	Flight Test	A/C In-Service Data		Take-Off / Year	Total Fleet / year	
		Std ACMS	Potentially Recordable		Std ACMS	Potentially Recordable
 A350	#Parameters 670 000 Data Recorded/flight 500 GB <small>450 TB produced for the certification process in 2014</small>	4000	400 000	N/A	N/A	N/A
 A380	#Parameters 320 000 Data Recorded/flight 250 GB	4 000	400 000	5.800	2,6 TB	1,1 PB
 Long Range	#Parameters 14 000 Data Recorded/flight 10 GB	1 500	40 000	84.000	17 TB	2,5 PB
 Single Aisle	#Parameters 12 000 Data Recorded/flight 10 GB	1 500	13 000	744.000	37 TB	9 PB

Stored & used

Stored & limited use

Not stored & not used

x 50 in ~30 years (Flight tests)

5) Conclusions –new trends



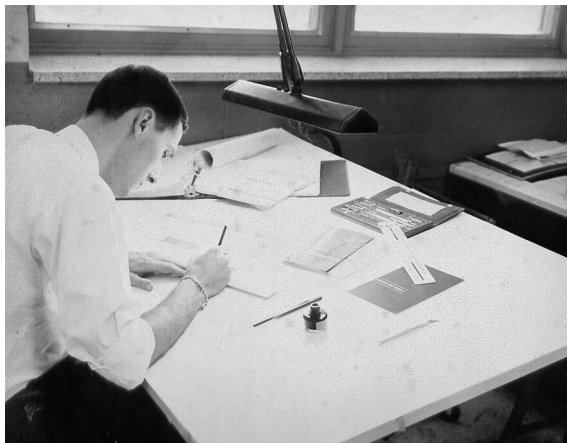
SHM and NDT Monitoring means technologies and means evolutions



Middles ages



Renaissance



5) Conclusions –new trends



But not making clear cut choices...is a (bad) choice

Who would have think 20 years before, they would disappear ?

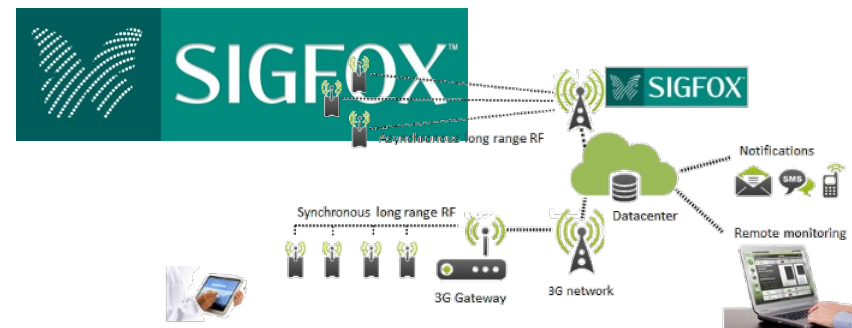


5) Conclusions –new trends



In wireless jungle.... Revolution is on the way !

- LORA, Sigfox protocoles...
- will offer a structured wireless protocol for Wireless Sensors (as GSM for mobile phone) !
- answer the LAN / WAN question !



5) Conclusions –new trends



New way of energy harvesting

Example - coming soon (Nantes University) :

- A simple Matrix of PZT arranged like a small « grass square » harvest breath of the air energy !



solar



breath of air

5) Conclusions –new trends



And some personal visions :

- Advocacy for **VERY Smart sensors** :
 - Not only able to compute SHM algorithms
 - But also to make self control, self diagnostic. Able to output a trust level in data computed
- Internet Of Things (IOT) + Big Data + Emerging wireless technos make everybody think that Billions of WSN will be installed... **where is the business model** ? Who would pay 100 dollars + 10 dollars/month to get temperature of his kitchen ? Gain should be proven.
- Civil Engineering Instrumentation could make progress if imposed by standard (EUROCODE for example)
- **Missing end-user tools** : a lot of WSN do exist...last step is often forgiven. Missing tools :
 - how to be sure of available wireless network ?
 - How to be sure of enough energy (solar) ? ... Let think to the guy who will install !



5) Conclusions –new trends



Future won't wait for WSN evolution...



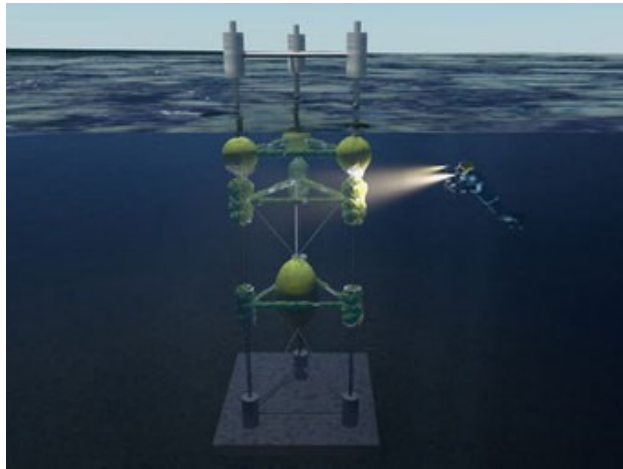
...new structures...



5) Conclusions –new trends



...ask for new jobs, new sensors,...



5) Conclusions –new trends



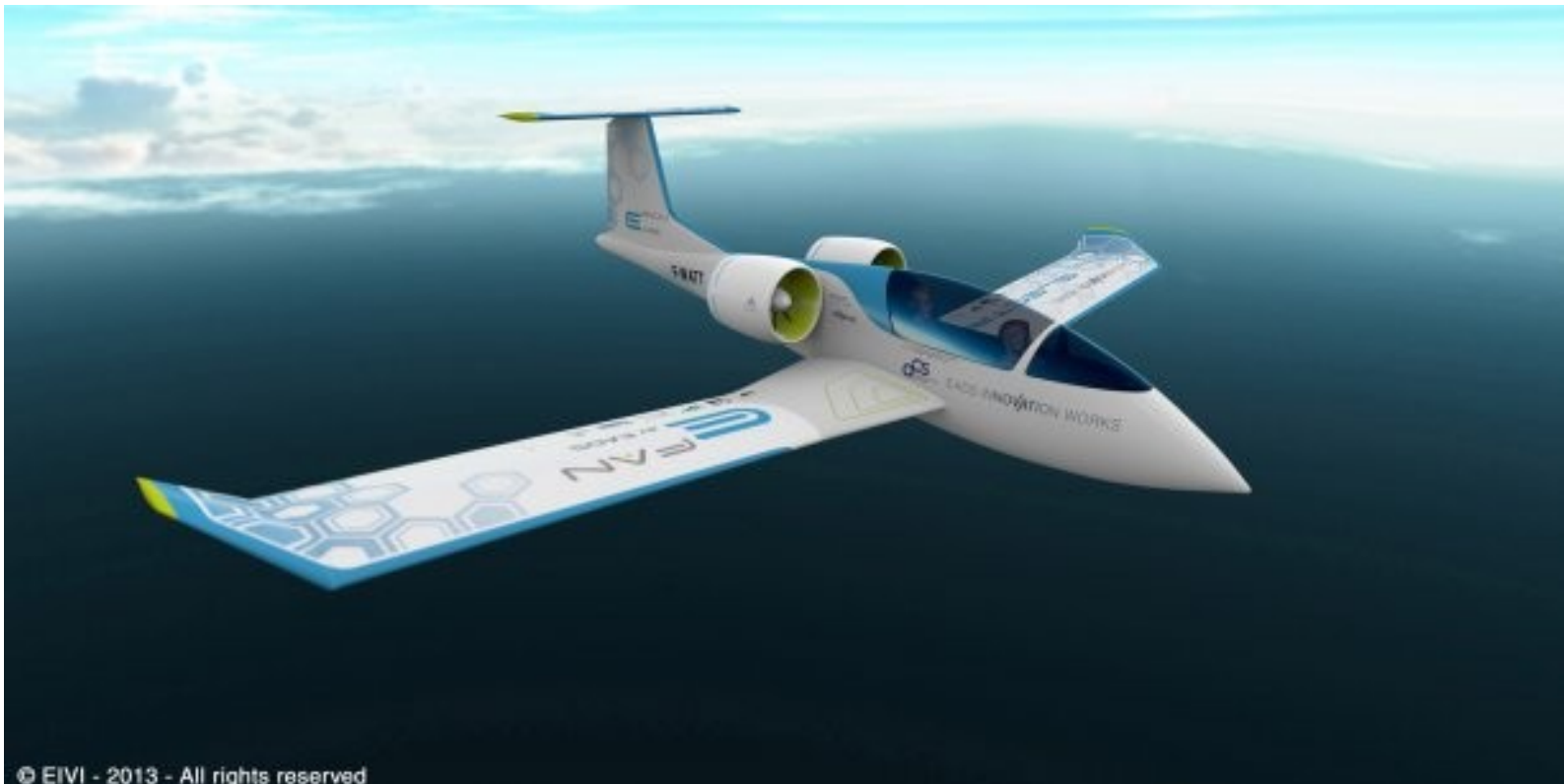
Positive energy bridge



5) Conclusions –new trends



Electric plane



5) Conclusions –new trends



MERCI !!!

