FIG Working Week 2012
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Knowing to: Manage the territory, Protect the environment, Evaluate the cultural heritage

Cts

The GRNN and the RBF Neural Networks for 2D Displacement Field Modelling. Case study: GPS Auscultation Network of LNG reservoir (GL4/Z industrial complex – Arzew, Algeria)

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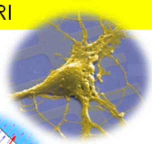

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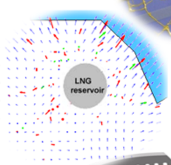

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Presentation Plan

1. Motivation & objective
2. Displacement and deformation modelling
3. Neural networks approaches
4. Case study : GPS Auscultation Network of LNG reservoir Ground (GL4/Z– Arzew, Algeria)
5. Results
6. Conclusions & perspectives

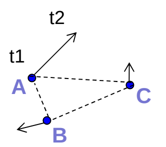
1. Motivation & objective

- Algeria is one of the most productive countries of Oil and Gas in the world, big and complex infrastructures were built for hydrocarbon industries (**Arzew is the Most famous industrial zone in Algeria**). To ensure the longevity of these industrial installations and to prevent of industrial hazards, monitoring (**auscultation**) is a necessary process.
- Topographic auscultation : **Dis**placements and **Def**ormations fields (**DisDef**) evaluation.
  - Classical methods for DisDef modelling.
  - **Objective** : Approaches based on Neural Networks (*more robust, more accurate*) for Dis/Def modelling.

2. Displacement and deformation modelling

Displacement

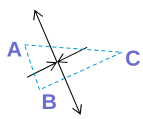
$$U(x,y)=\begin{pmatrix}u(x,y)\\ v(x,y)\end{pmatrix}$$



Under conditions of infinitesimal deformations and elasticity hypothesis ...

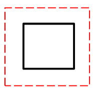
Strain Tensor

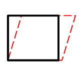
$$E(x,y)=\frac{\partial U(x,y)}{\partial X}=\begin{pmatrix}\frac{\partial u}{\partial x}(x,y) & \frac{\partial u}{\partial y}(x,y)\\ \frac{\partial v}{\partial x}(x,y) & \frac{\partial v}{\partial y}(x,y)\end{pmatrix}=\begin{pmatrix}e_{ux} & e_{uy}\\ e_{vx} & e_{vy}\end{pmatrix}$$

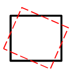


Deformation Primitives

- Total dilatation : $\lambda=\frac{1}{2}(e_{ux}+e_{vy})$;
- Total shear : $\gamma=\gamma_{xy}=\gamma_{yx}=\frac{1}{2}\sqrt{(e_{ux}-e_{vy})^2+(e_{uy}+e_{vx})^2}$.
- Differential rotation or twist: $\delta\omega=\frac{1}{2}(e_{uy}-e_{vx})-\Omega=\omega-\Omega$.







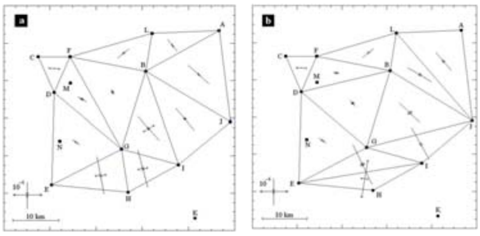
dilatation shear twist

2. Displacement and deformation modelling

Representation Modes

a. Triangulation of the geodetic network

➢ Dependence of chosen figures configuration.

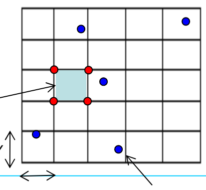


b. Delaunay triangulation

➢ Geodetic Points, non homogenate in case of non dense networks, change of configuration (addition or suppression of points).

c. Regular Grid

➢ Use of an optimal interpolation/approximation Function for displacement field.



- Usual Interpolation Functions :
  - Polynomial fitting
  - Nearest Neighbour method
  - Spline
  - Kriging
  - …
- Proposed Approximation Functions :
  - Neural Networks methods (**RBFNN** & **GRNN**)

3. Neural networks approaches

Radial Basis Function Network – Introduction

- Radial Basis Function (RBF) networks were first introduced by Broomhead & Lowe in 1988.
- Supervised Neural Networks
- Applying to problem: Classification, Regression, Time series prediction.

3. Neural networks approaches

Radial Basis Function Network – Definitions

- Approximate function with linear combination of Radial basis functions

$$Z_j = \frac{1}{M}\sum_{m=1}^{M} w_{mj}\phi_m + b_j$$

The activation of the neuron *j*

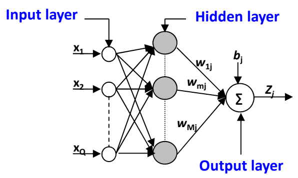
The weight between *m-th* hidden and *j-th* output neuron

The bias term of the neuron *j*

$$\phi_m = \exp\left[\frac{-\|x-\mu_m\|^2}{2\sigma_m^2}\right]$$

Smooth Factor (SF)

- Architecture



Input layer

Source nodes that connect to the network to its environment

Hidden layer

Hidden units provide a set of basis function

High dimensionality

Output layer

Linear combination of hidden functions

3. Neural networks approaches

Radial Basis Function Network – Learning strategy

- The training is performed by deciding on
  - How many hidden nodes there should be.
  - The centers and the sharpness of the Gaussians.
- The learning of a RBF network is divided into two independently stages:
  - 1^{st} stage: the input data set is used to determine the parameters of the basis functions.
  - 2^{nd} stage: functions are kept fixed while the weights and biases are determined and adjusted; this is done by minimizing mean square error between the desired outputs and calculated outputs (**Back Propagation algorithm**).

3. Neural networks approaches

GRNN– Introduction

- Generalized Regression (GR) networks were first introduced by Specht in 1991, as variant of the RBFNN.
- GRNN are probabilistic Neural Network.
- Applying to problem: Regression, Time series prediction.

Advantages :

- Can quickly learn and rapidly converge to the optimal regression surface with large number of data sets
- Strong capacity for nonlinear mapping and good robustness
- …

3. Neural networks approaches

GRNN– Definitions

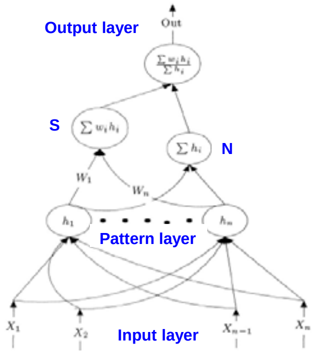
- Approximate function is given by:

Gaussian function

$$\hat{y} = \frac{\sum_{i=1}^{n} w_i h_i}{\sum_{i=1}^{n} h_i} \quad ; \quad h_i = \exp\left(\frac{-D_i^2}{2\sigma^2}\right)$$

Smooth Factor (SF)

- Architecture :



Input layer
fully connected to the pattern layer.

Pattern layer
one neuron is assigned for each training pattern. These neurons have radial basis activation functions.

Summation layer
has two units *N* and *S*. The first unit computes the weighted sum of the hidden layer outputs and the second unit has weights equal to 1.

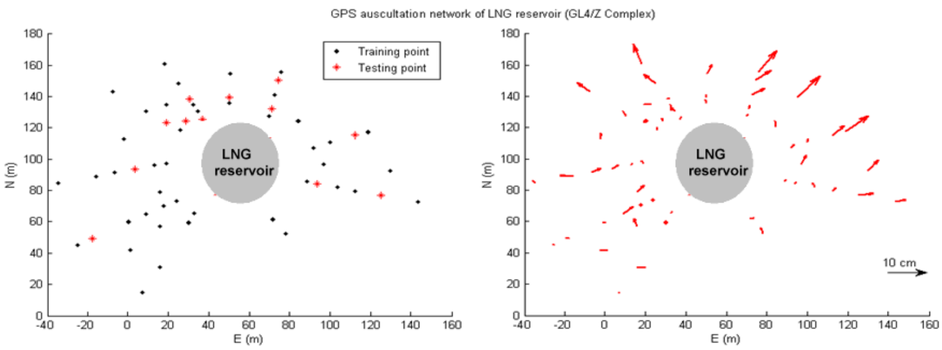
Output unit
divides *S* and *N* to provide the prediction result.

4. Case study : GPS Auscultation Network of LNG reservoir Ground (GL4/Z– Arzew, Algeria)

- LNG underground reservoir (GL4/Z – Arzew), built in 1965, represented more than 50% of storage capacity of the complex.
- The prevention of industrial hazards on the complex infrastructures and on the population of Arzew's town, has required a **GPS monitoring network** to perform a **topographic auscultation** of this important industrial site.

4. Case study : GPS Auscultation Network of LNG reservoir Ground (GL4/Z– Arzew, Algeria)

Geodetic network and displacements

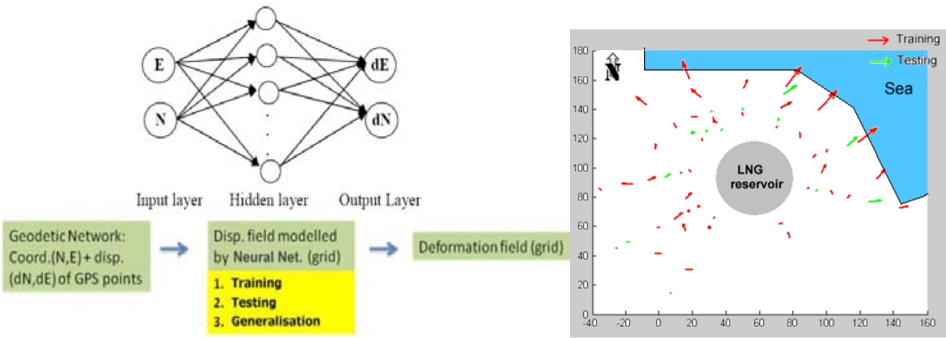


56 GPS points
σ : few mm
Obs. Period: **2000 - 2006**

Max. *dN* = **126** mm
Max. *dE* = **119** mm
Max. *dep* = **178** mm

4. Case study : GPS Auscultation Network of LNG reservoir Ground (GL4/Z– Arzew, Algeria)

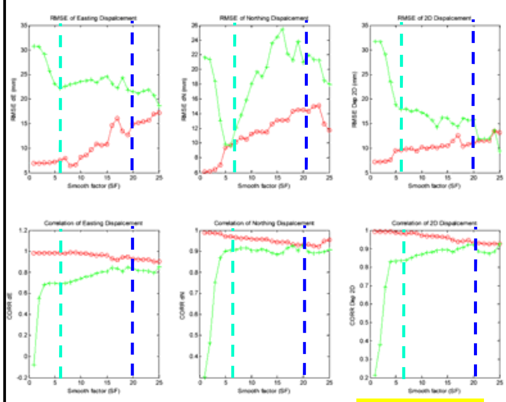
Scheme of Neural Network based Deformation process



Training points set : **44** pts (79%)
Testing points set : **12** pts (21%)
Generalisation points set : **340** pts → grid of **304** meshes (10x10 m²)

5. Results

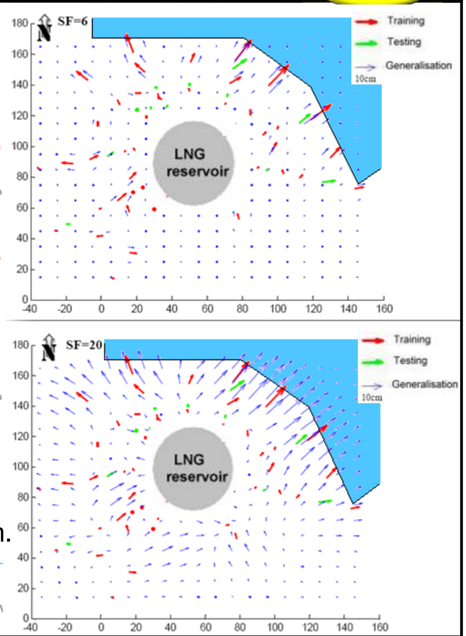
Neural Methods RBFNN



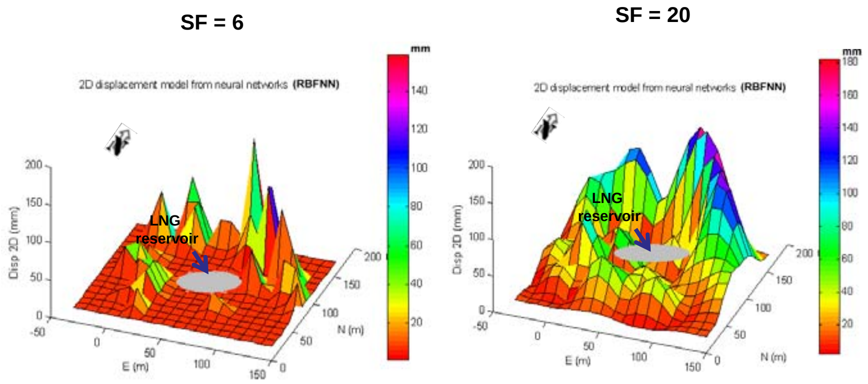
SF = 6 SF = 20 23 neurons

• SF=6, good statistics, local approxim. around the learning pts.

• SF=20, faintly statistics, global approxim.



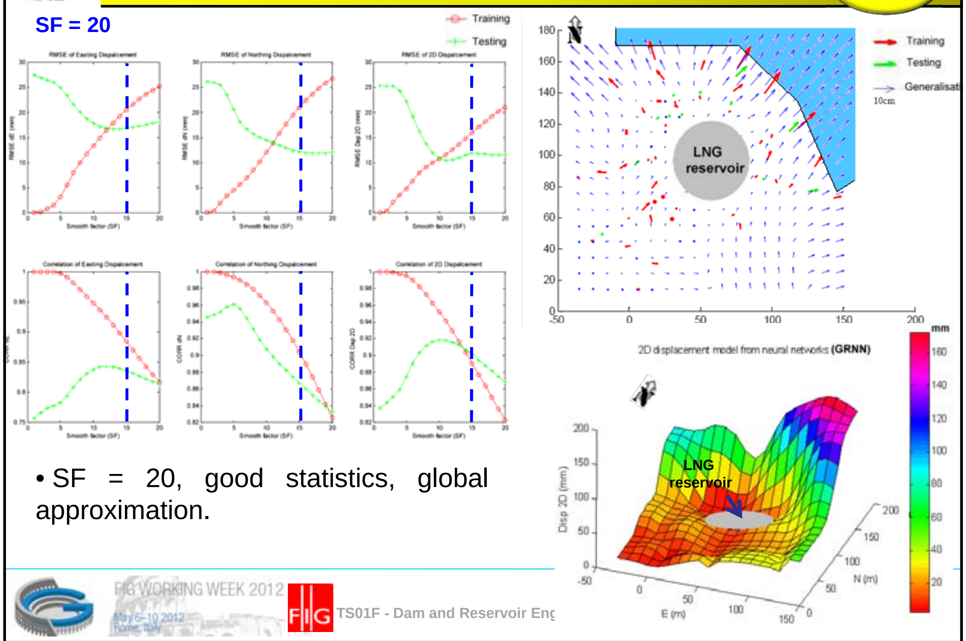
5. Results — Neural Methods — RBFNN



3D visualisation of the displacement field model according to the previous results : SF = 6 *vs* SF = 20

5. Results — Neural Methods — GRNN

SF = 20



• SF = 20, good statistics, global approximation.

5. Results

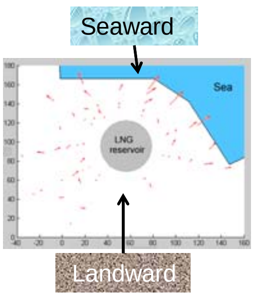
Comparison of methods results (Performance)

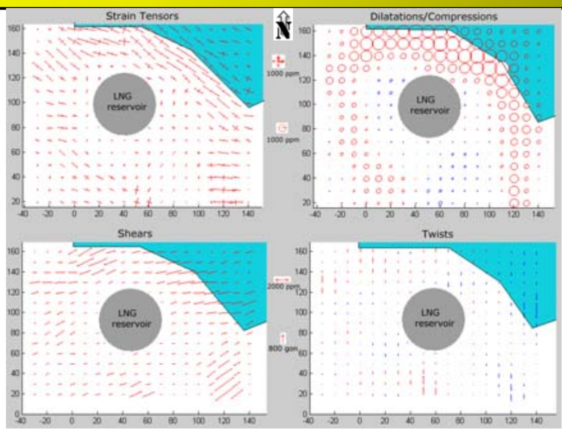
Method	Correlation ρ(dE) %	Correlation ρ(dN) %	RMSE σ(dE) mm	RMSE σ(dN) mm	Representation	Prediction
GRNN (SF=15)	83.6	86.7	16.9	12.2	Continuous	Good
RBFNN (SF=6) 23 hidden neurons	69.2	90.5	22.2	9.7	Discontinuous	Bad
Polynomial (PD=4)	85.7	84.1	15.9	17.8	Continuous	Bad
RBFNN (SF=20) 23 hidden neurons	83.6	92.8	21.4	21.0	Continuous	Faintly good
Polynomial (PD=2)	59.0	73.3	25.7	14.9	Continuous	Faintly good
Nearest Neighbour (NNP=4)	85.4	92.9	17.4	16.7	Continuous	Faintly good

5. Results

Deformation components

GRNN, SF=15





- Dominant dilatation phenomenon (3000 – 4700ppm) in N&E, Weak dilatation & Compression at neighbourhood of reservoir (NW & SE)
- Proximity to the sea: The sea acts as a warmer with a limitation of freezing
- Soil: Supposition of the presence of a rocky area which opposes to the progression of the freezing front.
- Shear (change in configuration) (1000 – 2000ppm) in N&E, Weak shear in S&W sides of reservoir (200ppm)
- Disproportionate tensions on the landward and seaward sides
- Twist (differential rotation) (790" max.)

6. Conclusions & perspectives

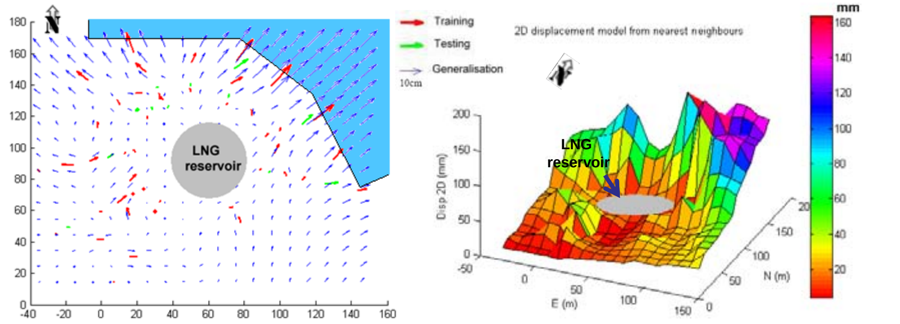
- ✓ The **GRNN** and the **RBF** Neural Networks were successfully applied for horizontal displacement field modelling of GPS Auscultation Network of LNG reservoir.
- ✓ The preliminary experimental results demonstrate the potentials and the efficiency of the **GRNN** method compared to **RBFNN** and classical interpolations.
- **Future research :**
  - Use of the Least Vector Quantization (**LVQ**) method in order to optimize the **RBFNN** structure (Hidden Nodes).
  - Comparative study of **GRNN** with Kriging and Spline methods.
  - Performing a statistical analysis of Strain tensors (Monte Carlo Method).
  - Extension of study for **3D** displacement field modelling.

Thank you for your attention

5. Results — Classical Methods — NNM

Nearest Neighbour Method

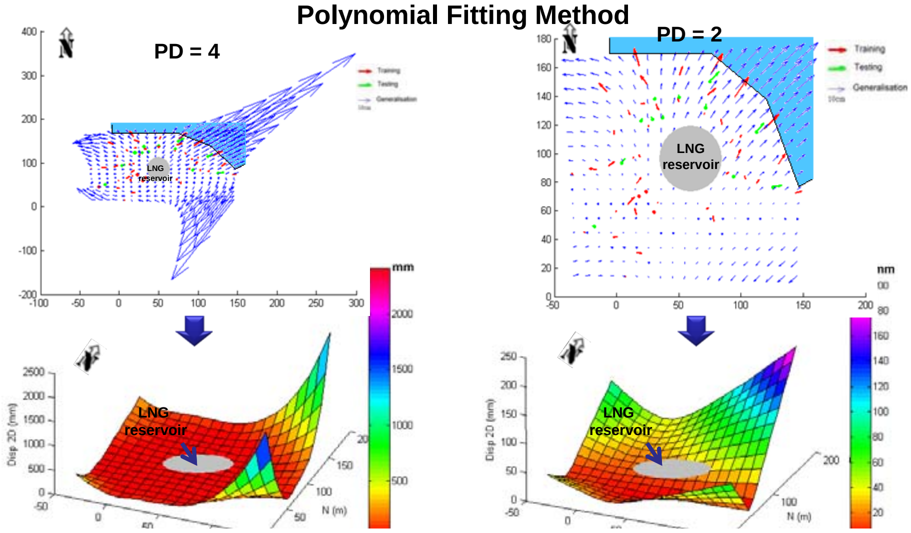
NNP = 4



Several tests (NNP = 1, 2, 3, 4, 5, etc.) Good results obtained with NNP = 4

5. Results — Classical Methods — PFM

Polynomial Fitting Method

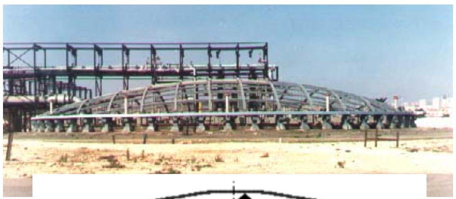


Several tests (PD = 1, 2, 3, 4, 5, etc.) Good result obtained with PD = 4, bad extrapolation outside the network zone than PD = 2.

4. Case study : GPS Auscultation Network of LNG reservoir Ground (GL4/Z– Arzew, Algeria)

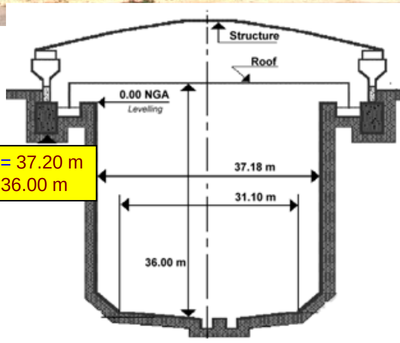
External structure:

- Roof in alloy of aluminum
- Metallic framework
- Crown in steel carbon
- **60** posts in reinforced concretes



Resistance and sealing:

Contact of the progressive freezing of the ground with the LNG (-161°C)



Diameter = 37.20 m
Depth = 36.00 m

Main Characteristic:

Absence of isolation and barrier of sealing on the vertical walls. Only freezing of water contained in the soil which ensures its impermeability