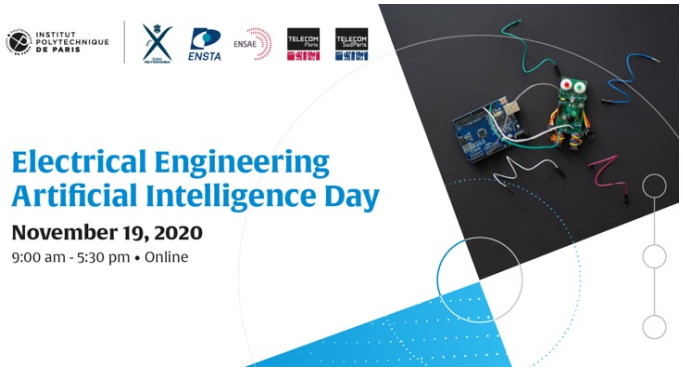
RF Exposure Mapping using EMF Sensors and Artificial Intelligence



J Wiart and S. Wang

Télécom Paris - IP Paris,
LTCI, COMELEC, C2M Chair

Outline

- Why RF exposure mapping.
- What has been done
- Artificial Neural Network and Time Series Analysis applied to EMF exposure mapping

5G raised public concern

The deployment of 5G technology reinforces these fears and questions

Demo am Staatsministerium in Stuttgart: Ä... gegen 5G-Mobilfunk

La ville de Paris va lancer une consultation concernant la 5G

Assez silencieuse sur le sujet de la 5G, Anne Hidalgo, la maire de Paris, a finalement choisi d'organiser une « conférence citoyenne métropolitaine » concernant la norme de téléphonie mobile de nouvelle génération.

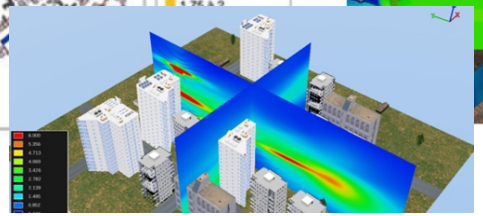
Avec le début des enchères concernant la 5G, celle-ci devrait bientôt être réelle. Les opérateurs pensent en effet la lancer à la fin de cette année,

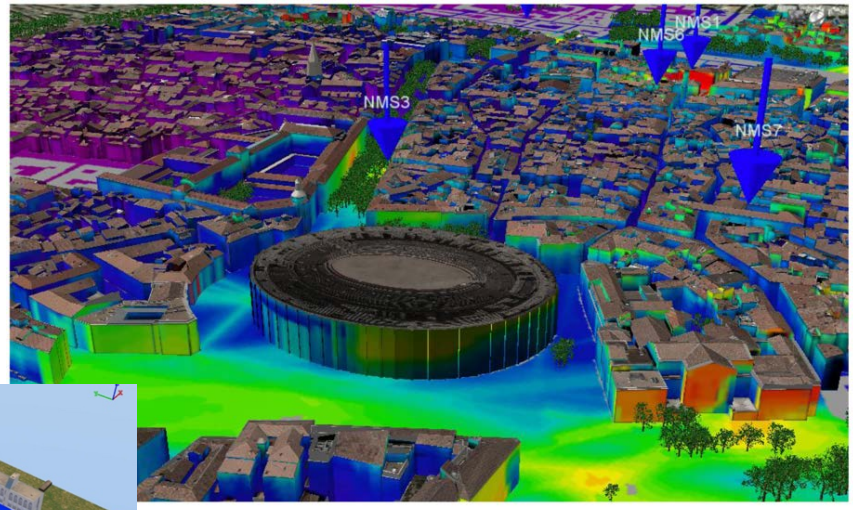
Lors d'une manifestation anti-5G en Suisse. - Association Frequencia

Protests against 5G, like this one in the northern city of Turin in Janaury, are just one of the worries operators are facing as they introduce the technology in Italy. Photo: AFP

RF exposure mapping is requested

Simulation and RF exposure mapping today





HPC that has reduced compute time, but simulations are still a burden despite

Simulations are needed when antennas have not been installed But when these antennas have been installed et are in use

Limitation of simulations : exposure map are delivered but at a given power and time.

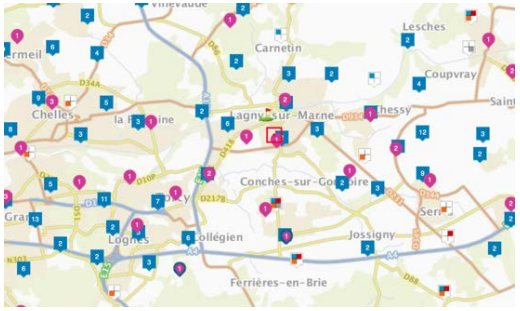
Measurement and RF exposure mapping today

Using in situ measurements

Etude de l'exposition du public aux ondes radioélectriques

Analyse des résultats de mesures d'exposition du public aux ondes radiofréquences réalisées en 2019 dans le cadre du dispositif national de surveillance.

Avril 2020



CARTORADIO

ANFR
AGENCE NATIONALE DES FRÉQUENCES

In situ Measurements provide EMF exposure but at given time and location

Using Sensors measurements

Sensor Measurements *provide EMF exposure but at given location*

Experimentation : Paris 14ieme

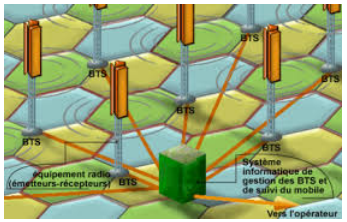
50 sensors are to be installed on streetlamps

EMF is recorded 12 times per day, each data averaged, each lasts 480ms in total for three directions)

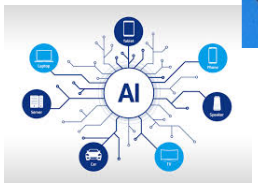
Breakthrough : Use AI toward EMF exposure mapping

- We know the physical phenomenon
- We know the infrastructure architecture
- We cannot install vey large number of sensors

Telecom Network architecture (antenna location, freq used, azimuth..)



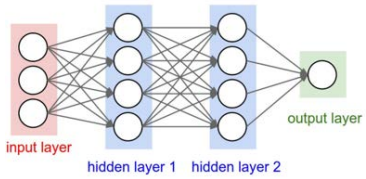
Sensors networks



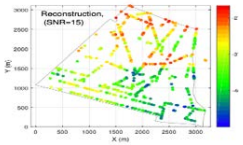
EXEM.fr

Combine

- Information on network (cartoradio)
- Measurements (sensors and drive test)
- Artificial Intelligence (Art Neural Network)



RF exposure map :

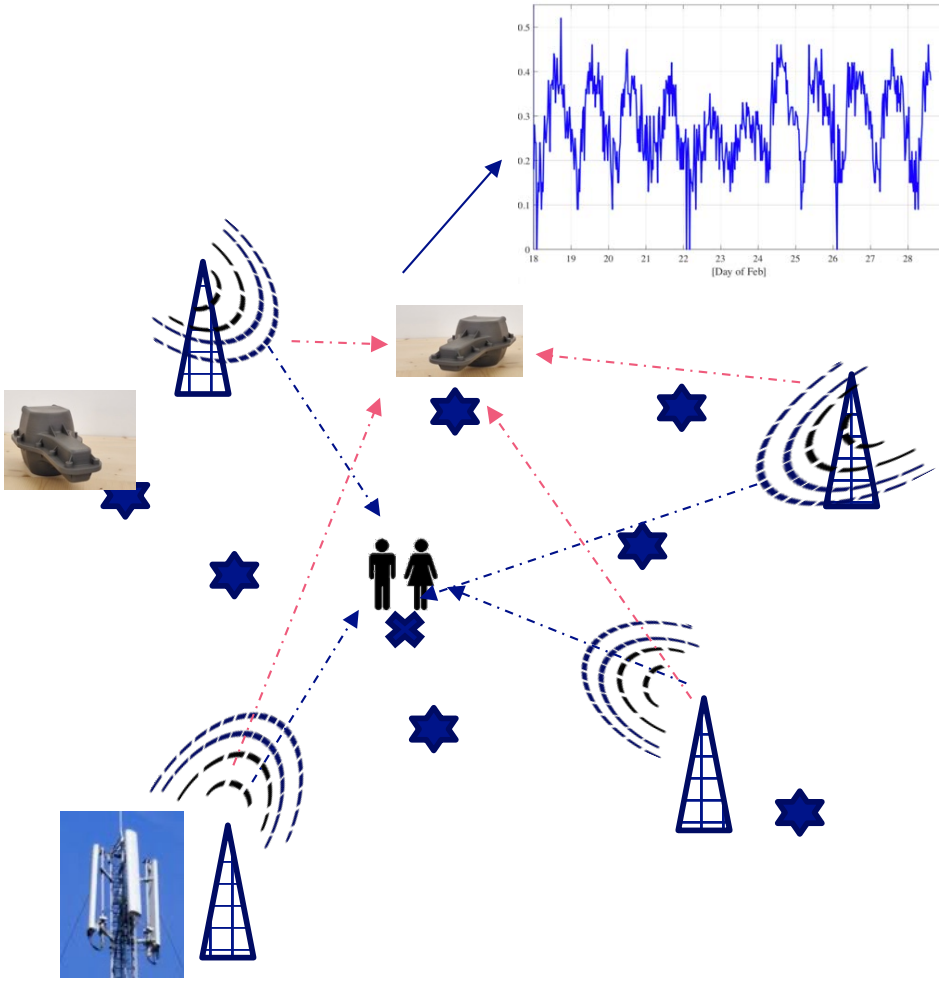


Training is feasible :

Supervised learning process can be used

Challenge 1 Forecast exposure at unsampled location

Forecast exposure at unsampled location, taking into account the EMF recorded at sensor location



Feasibility

	Sensor numb	Latitude	Longitude	Adresse
2	02	48.829879	2.316120	20 rue Bardinet; 75014 Paris
3	03	48.831853	2.319400	13 Cité Bauer; 75014 Paris
4	07	48.830317	2.313545	15 Rue des Suisses; 75014 Paris
5	10	48.835233	2.322588	4 rue Asseline; 75014 Paris
6	18	48.827923	2.315330	113 Rue Didot; 75014 Paris
7	19	48.827653	2.328748	39 rue d'Alésia; 75014 Paris
8	25	48.831926	2.330941	15B Avenue du Général Leclerc; 75014 Paris
9	30	48.824828	2.325640	122 Avenue du Général Leclerc; 75014 Paris
10	31	48.827701	2.328748	73 rue d'Alésia; 75014 Paris
11	35	48.830841	2.321073	42 Rue Hippolyte Maindron; 75014 Paris
12	37	48.833720	2.335539	50 boulevard saint jacques; 75014 Paris (opposé)
13	38	48.829638	2.326387	199 Avenue du Maine; 75014 Paris
14	47	0.000000	0.000000	Télécom Paris; 19 place Marguerite Perey F-91120 Palaiseau
15	50	48.824695	2.319918	55 avenue Jean Moulin; 75014 Paris
16	51	48.829858	2.332369	16 rue Rémy Dumoncel; 75014 Paris
17	52	48.830250	2.335865	37-39 rue Dareau (opposé); 75014 Paris
18	42	48.8341373	2.3186248	71 rue Raymond Losserand, 75014 Paris

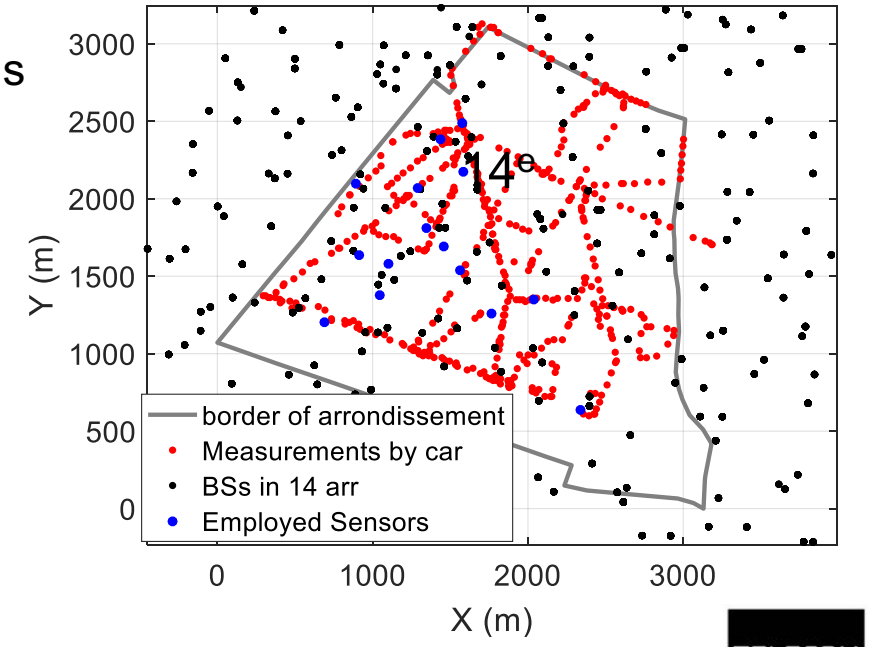
Sensors installation is still on going (18 are installed in Paris 14e)

Test the idea has therefore been based on simulations

INPUTS

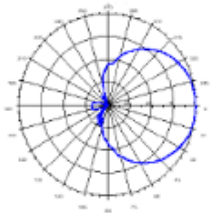
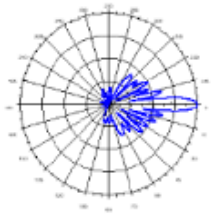
Paris GIS open database

Base station location and azimuth: Cartoradio



Simulations for training and testing

- Directional Antennas

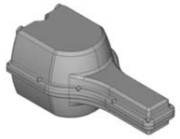




- Simplistic propagation model with non constant Path loss exponent

$$Path\ Loss = \beta * d^{-\alpha}$$

- Background Noise. Adding 10% noise to the received power (SNR = 10dB).

Shanshan Wang and Joe Wiart. "Sensor-Aided EMF Exposure Assessments in an Urban Environment Using Artificial Neural Networks." International Journal of Environmental Research and Public Health 17.9 (2020)



Sensors and drive tests acquisitions will come from simulation

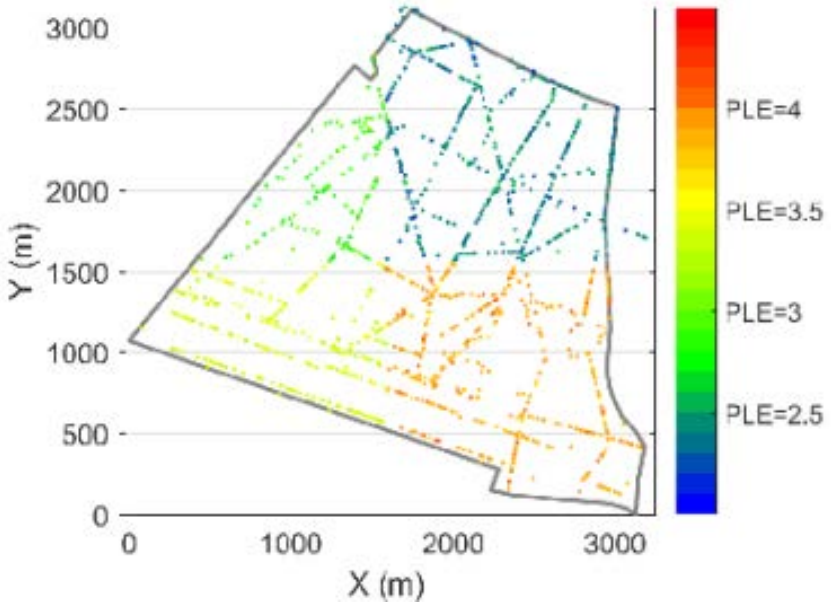
Block-based path loss model

For receivers located in the same block, PLE (path loss exponent) α_x follows Normal distribution, here μ is determined by α of the block.

$$\alpha_x \sim \mathcal{N}(\mu, \sigma^2)$$

Propagation model

$$E = \beta * d^{-\alpha}$$

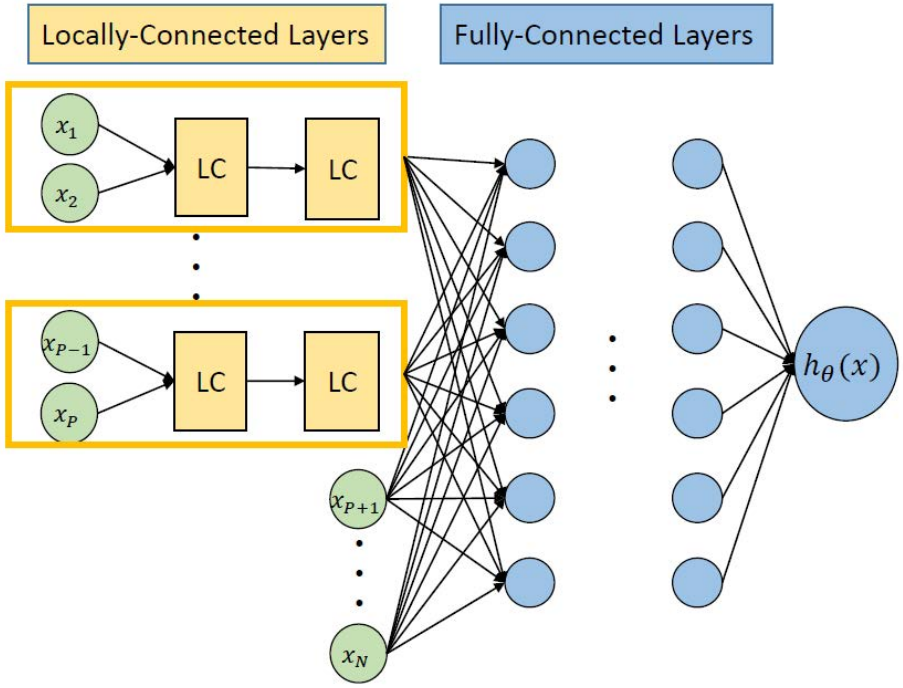


What is the suitable ANN architecture

ANN are already used in Speech, Vision ..
Different architecture can be used

Exposure : we can take advantage that the closest (to user) base stations antenna have a predominant impact on the user 's exposure

hybrid ANN architecture has been investigated



We used existing libraries working with GPUs

python
ANACONDA
Keras
TensorFlow

Hybrid ANN in a nutshell

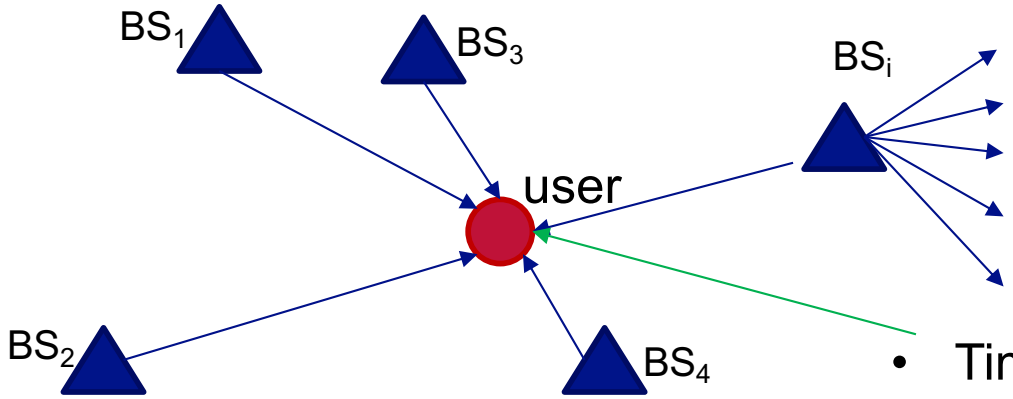
Fully-Connected Layers

All features from all BS are fed to NN, which might cause redundant inputs into ANN.

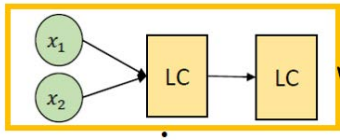
Locally-Connected Layers + Fully-Connected Layers

Features from each BS are processed locally, then fed to fully-connected layers.

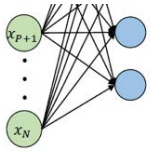
Unnecessary interactions between neurons reduced in hybrid ANN



Features of one BS_i:
Distance d_{BS_i-user}
Azimuth of antenna
• …

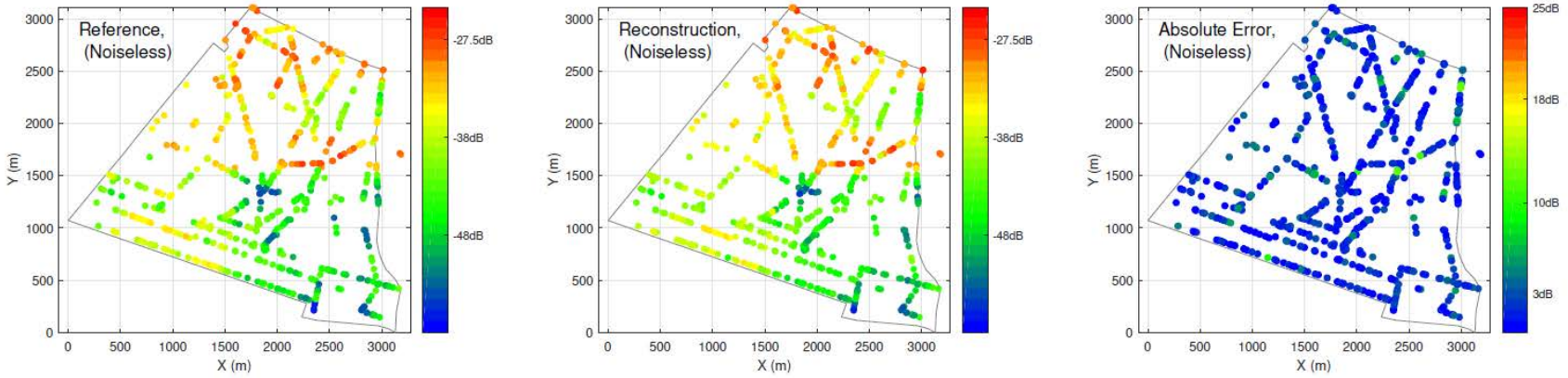


- Time information
- location of the user



Results

Scenarios	Num. of Para.	MSE (±STD)	R^2 (±STD)
Conventional ANN without considering sensors	8851	11.2 (±0.91)	0.81 (±0.02)
Conventional ANN considering sensors	8951	9.2 (±0.73)	0.85 (±0.01)
Hybrid ANN with considering sensors	5431	7.9 (±1.06)	0.87 (±0.02)
Conventional ANN without considering sensors with noise	8851	16.3(±0.85)	0.72 (±0.01)
Conventional ANN considering sensors with noise	8951	14.6 (±0.76)	0.75 (±0.01)
Hybrid ANN without considering sensors with noise	5431	12.8 (±0.96)	0.78 (±0.02)



Wang, Shanshan, and Joe Wiart. "Sensor-Aided EMF Exposure Assessments in an Urban Environment Using Artificial Neural Networks." International Journal of Environmental Research and Public Health 17.9 (2020)

Challenge 2 : Forecast the Temporal Variations of Exposure

Forecast exposure at unsampled location, taking into account the temporal variations of exposure at sensors locations

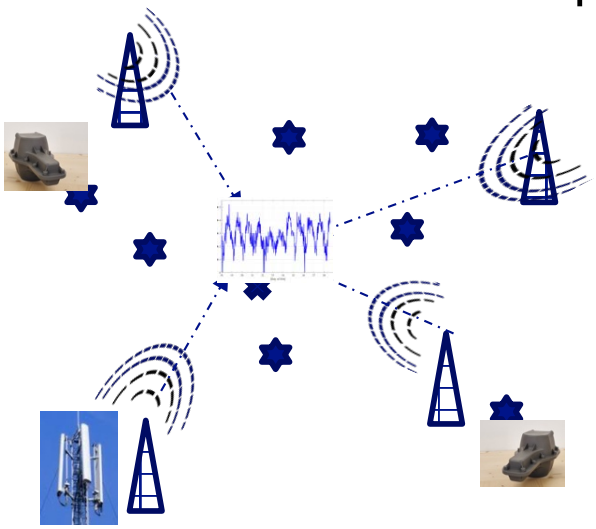
Time variations of power emitted is specific to each base station
What is the behavior of the sum

Trafic

Power emitted

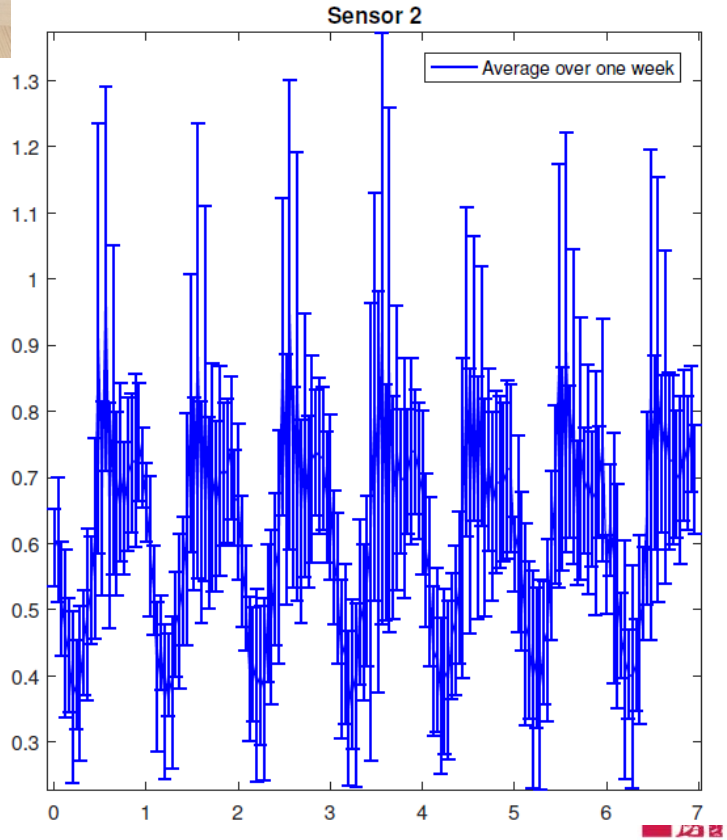
$$P = \sum PL_i(x - x_i, y - y_i, z - z_i) P_i(x_i y_i z_i) F_i(t)$$

propagation



Sensor EMF Exposure Measurements

Installed sensors record 12 or 24 times per day, each data averaged for all x, y, z directions averaged over 6 mins.



Time Series Analysis: ARIMA or RNN

Autoregressive Integrated Moving Average (ARIMA)

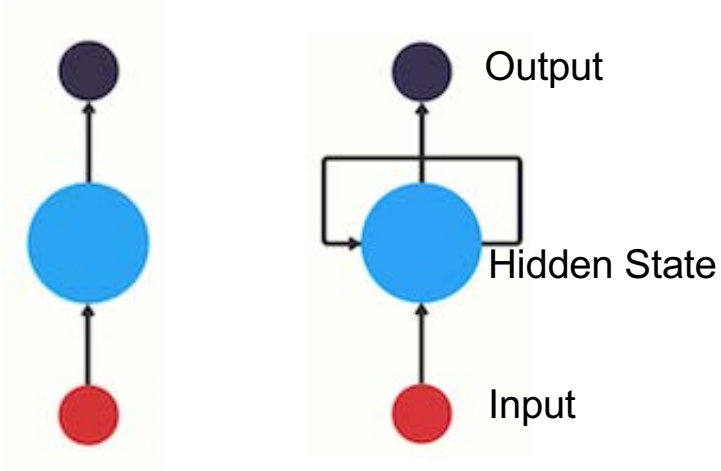
- Simple to implement
- Pre-assume linear form of the mode (even if most of real time series are not pure linear)
- Perform better when applied to stationarity data
- Become expensive to train when the number of lag observations included in the model).

Recurrent Neural Networks (RNN):

- Works with both stationarity and non-stationarity data
- No need to analyze and extract trend and seasonality of the series before training the model
- Fine-tuning of hyper parameters required to obtain a good performance
- Retain the past information; Track the state of the world and update the state of the world as the network moves forward.

Time Series Analysis: RNN

Recurrent neural networks (RNNs) are used in speech recognition, language translation, stock predictions, time series analysis.



a. Traditional feed forward neural network

b. Recurrent neural network

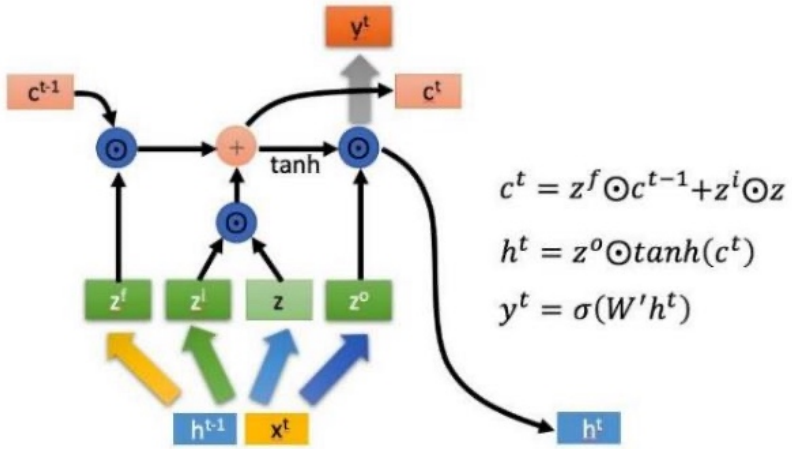
Time Series Analysis with RNN

No vanishing gradient problem

- **Long Short Term Memory (LSTM) network.**
- **Gate Recurrent Unit (GRU) network is similar to LSTM, but requires less training parameters.**

Inside hidden state:

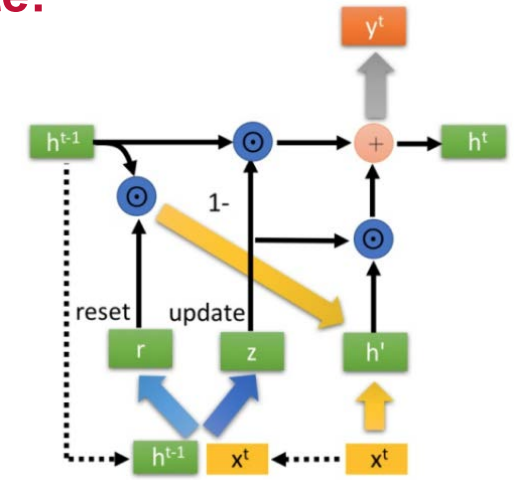
LSTM



$$c^t = z^f \odot c^{t-1} + z^i \odot z$$

$$h^t = z^o \odot tanh(c^t)$$

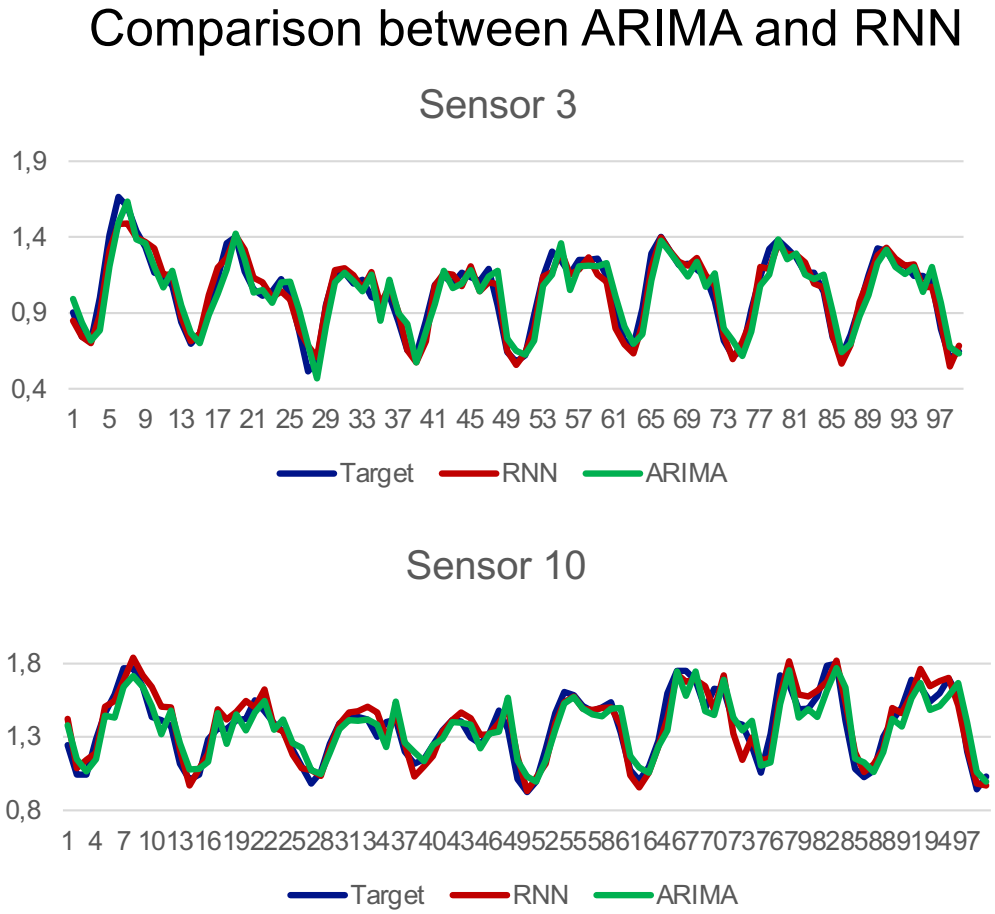
$$y^t = \sigma(W' h^t)$$



GRU

The gradient contains the forget gate's vector of activations, which allows the network to better control the gradients values, at each time step, using suitable parameter updates of the forget gate. **The presence of the forget gate's activations allows the LSTM to decide, at each time step, that certain information should not be forgotten** and to update the model's parameters accordingly.

Time Series Analysis of measurement



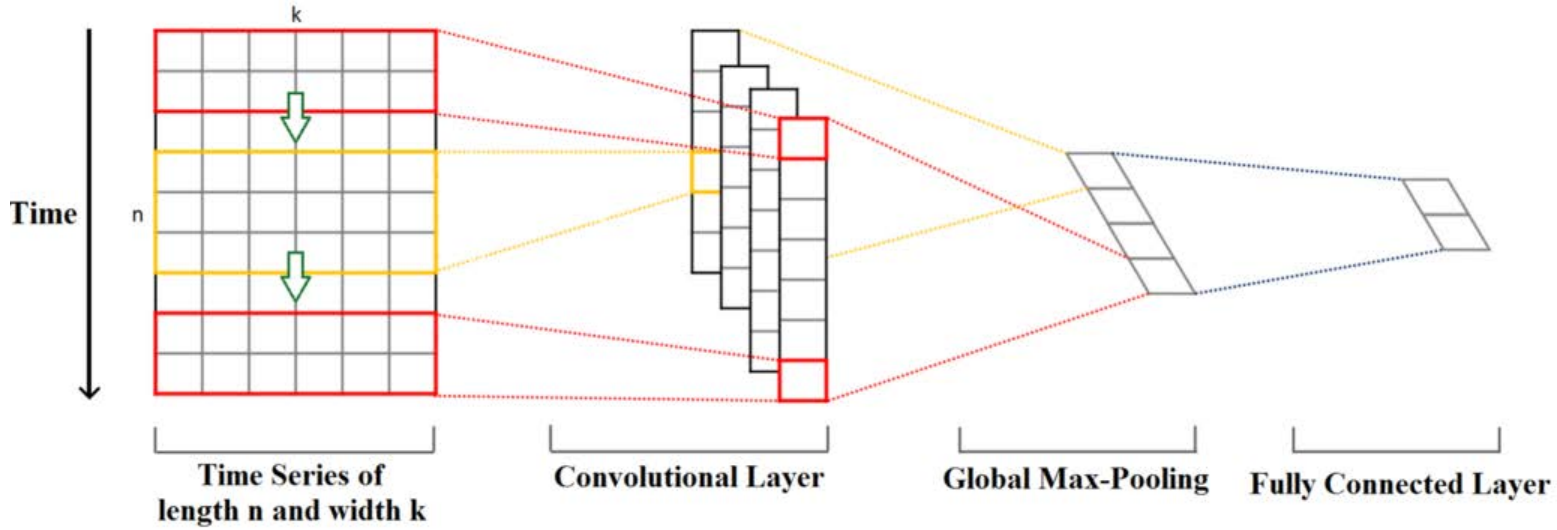
The time variation patterns of EMF exposure from different sensors are correlated,

What about multivariate time series analysis?

A **Multivariate time series** has more than one **time**-dependent variable. Each variable depends not only on its past values but also has some dependency on other variables. This dependency is used for forecasting future values.

Next step : Multivariate time series

Convolutional Neural Networks



Due to its ability to operate convolutionally, CNN is considered to be suitable for sequence processing and multivariate time series analysis.
Suitability to emf exposure is on going

C2M

THANKS

Dans la confusion trouver la simplicité
De la discorde faire jaillir l'harmonie
Au milieu de la difficulté se trouve l'opportunité

Albert Einstein,
Trois règles de travail

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