

Advanced Computational Intelligence for Smart Water and Gas Grids

Scuola di Dottorato in Ingegneria dell'Informazione, XV Ciclo



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Progetto Eureka





Introduction

Short/medium-term Forecasting and Leakage Detection solutions for Smart Water and Gas Grids.

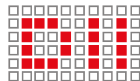
- Reduce the wide gap between energy and water and gas fields.
- Exploit the smart metering systems already present, thus low computational burden solution, and low data rates as well.
- Residential, office building, city and states scenarios.

Cross-fertilization with energy solutions: collaboration with PhD students Marco Severini and Roberto Bonfigli.



Study Activity

- Investigation and analysis of the **State of the Art**:
 - Research of suitable and available **databases**.
 - Short/medium-term **load forecasting** approaches.
 - **Leakage detection** and grid monitoring solutions.
- Publicly available databases:
 - **AMPds**: 2 year of single house consumption, power, water, and gas, at 1 minute of resolution.
 - **DFID**: water and gas consumption of the U.K. Department for International Development, 30 minute of resolution from 2011.
 - **Teheran**: monthly water consumption, about 10 years.
 - **EIA**: U.S. states monthly gas consumption, about 25 years.



Study Activity

Forecasting:

- State of the Art shortcomings:
 - Lack of short-term predictions for residential and office building solutions.
 - Few evaluations with heterogeneous data.
 - Different evaluation criteria, different databases, no objective comparison.
- Study of prediction techniques:
 - Genetic Programming and Extended Kalman Filter.
 - Support Vector Regression.
 - Extreme Learning Machine.
 - Artificial Neural Network: Feed-forward, Echo State Network, Deep Belief Network.
- Research of suitable evaluation criteria.



Study Activity

Leakage Detection:

- State of the Art shortcomings:
 - Industrial solutions: high sample rates and computational burden, invasive approaches, operator supervision.
 - Shortcomings from the experimental methodology standpoint.
 - Available databases without suitable data.
 - Different evaluation criteria, different databases, no objective comparison.
 - Novelty Detection paradigm never considered.
- Study of Novelty Detection techniques:
 - Gaussian Mixture Model.
 - Hidden Markov Model.
 - One-Class Support Vector Machine
 - Autoencoder: Feed-forward, LSTM e BLSTM.
- Study of suitable features for leakage detection.
 - Few features available, developed for industrial scenarios.
- EPANET tool models water distribution piping systems.



Research Activity

Forecasting:

- Definition of proper comparative evaluation criteria:
 - $NMSE$, R^2 , MSE , $MAPE$, $RRMSE$.
- Development and simulation of algorithms for each studied approaches:
 - GP, GP+EKF, SVR, ELM, ANN, DBN, ESN.
- Investigated approaches for load forecasting in all the operative contexts available.

Tehran	NMSE	R^2	MSE	MAPE(%)	RRMSE(%)	Parameters
ARIMA	0.360	0.630	0.0187	19.75	24.85	3 - 0 - 3
ANN	0.136	0.860	0.0086	12.64	18.54	5 - 7
DBN	0.266	0.727	0.0138	17.62	21.35	3 - 3 - 500 -100
ESN	0.209	0.785	0.0112	17.68	21.26	5 - 30 - 10 - 1 - 1e-2
SVR	0.148	0.849	0.0079	15.13	17.85	5 - 2^{13} - 2^{-3}
GP	0.240	0.753	0.0128	19.52	22.77	5 - 15
EKF-GP	0.240	0.753	0.0128	19.40	22.78	5 - 15



Research Activity

- Research and analysis of the best parameters:
 - Input lags and resolutions.
 - NN: optimal learning rate, layers and neurons number.
 - SVR: optimal C and γ .
 - GP: number of generations and individuals, levels of crossover and mutations.
- Evaluation of heterogeneous data, composed of different resource types and temperature.

AMPds	1 h			6 h			12 h			24 h		
	NMSE	R ²	Comb.	NMSE	R ²	Comb.	NMSE	R ²	Comb.	NMSE	R ²	Comb.
ANN	0.619	0.381	WGT	0.182	0.818	GET	0.170	0.830	GET	0.153	0.847	GT
DBN	0.723	0.277	WGET	0.238	0.762	WGET	0.185	0.815	GET	0.188	0.812	GET
ESN	0.695	0.305	WGET	0.247	0.753	GET	0.176	0.823	GET	0.188	0.811	GT
SVR	0.644	0.356	WGET	0.182	0.818	WGET	0.145	0.854	WGT	0.178	0.821	GT
ELM	0.620	0.380	WGET	0.180	0.820	WGET	0.147	0.853	WGT	0.176	0.823	GT
GP	0.753	0.247	WGET	0.273	0.728	GET	0.186	0.813	GT	0.204	0.795	WGT



Research Activity

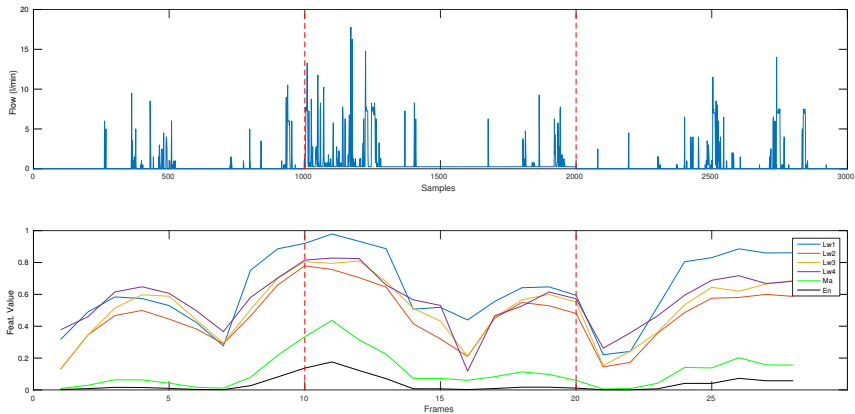
Leakage Detection:

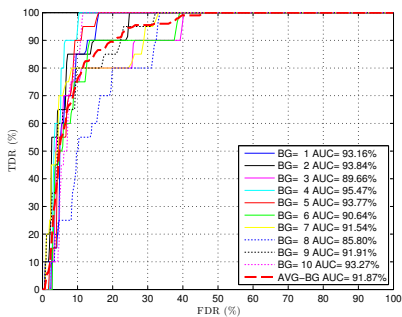
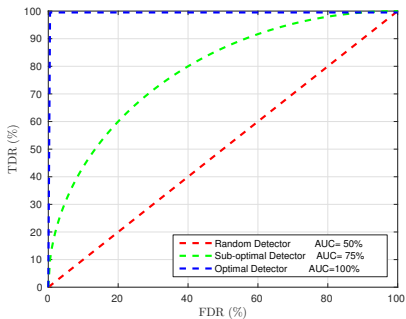
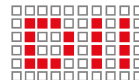
- Research and development of new features.
 - A standard set of features is actually missing in the related literature.
- Development of an ad hoc Sequential Feature Selection, to identify the best features combination.
- Simulations adopting normality models, representing the normal condition:
 - GMM, HMM, One-Class SVM, Autoencoder.
- Residential and office building scenarios.

Flow Data					
Res.	Features comb.	AUC (%)	SD	Model	Param.
1	MA+ENE	81.03	10.51	GMM	128
1	MA+ENE+WPEC	85.89	11.39	HMM	4-64
1	MA+WDE	60.43	19.02	OC-SVM	2^{-7}
10	DATA+dWPEC	66.99	12.45	GMM	256
10	DATA+WPEC+dWPEC	78.55	15.01	HMM	4-256
10	DATA+MA	65.55	27.76	OC-SVM	2^{-9}
30	WPEC+MA	63.80	13.18	GMM	256
30	MA+WPEC	73.69	17.89	HMM	4-256
30	DATA+dWDE	68.39	20.86	OC-SVM	2^3



Research Activity







Research Activity

- Sensitivity analysis: leakage dimension, position, and duration.
- Evaluations assuming temporal cluster: i.e., low and high consumption.
- Development and simulations with ad hoc temporal features.
- Adoption of the EPANET tool to extract pressure data and simulate more realistic leakages.

Res.	Features comb.	AUC (%)	SD	Model	Param.
Flow&Pressure Data					
1	MAf+ENEp+MAp	86.03	8.40	GMM	32
1	MAf+ENEf+ENEp	87.87	9.35	HMM	3-256
1	MAf+WDEf	60.43	19.02	OC-SVM	2 ⁻⁷
10	MAf+MAp+ENEp+dMAp	86.12	8.40	GMM	32
10	MAf+ENEp+MAp	87.47	8.81	HMM	3-64
10	DATAf+MAf	65.55	27.26	OC-SVM	2 ⁻⁹
30	MAf+ENEp+MAp+dENEp	86.34	9.14	GMM	32
30	MAf+ENEp+MAp	88.51	9.20	HMM	3-64
30	DATAf+dWDEf	68.39	20.86	OC-SVM	2 ³



Other Activities

- Collaborations:
 - Techniques for the optimal resources and energy management in micro-grids.
 - Techniques for NILM and disaggregation simulations with Neural Networks (CNN autoencoder).
- Research and experimentation of a ultrasound sensor (non-invasive) for residential gas smart-metering.
- Development of IoT software using FIWARE enablers.
- Support to documenting and EMS software development within the SHELL project.



Activities and Stays Abroad

International Conference:

- IEEE World Congress on Computational Intelligence, IEEE WCCI2016, Vancouver (Canada), 24-29 July 2016. *[2 oral presentation, 1 poster]*
- The International Joint Conference on Neural Networks, IJCNN 2015, Killarney (Ireland), 12-17 July 2015. *[1 oral presentation]*
- 15th IEEE International Conference on Environment and Electrical Engineering, EEEIC2015, Rome, 10-13 June 2015. *[1 oral presentation]*



Training Activity (1)

Courses:

- *"Progettare la ricerca: i progetti europei"*, Prof. Nicola Paone.
- *"Metodi e strumenti di rappresentazione e gestione di processi"*, Prof. Ferruccio Mandorli.

Seminars:

- *"Il 'Metodo Scientifico' per la conoscenza delle leggi della Natura (secondo un fisico sperimentale)"*, Prof. Gaetano Cannelli.
- Ciclo di *"Seminari di Epistemologia"*, Prof. Giancarlo Galeazzi.
- *"Software Defined Networking with Applications in 5G Networks"*, Dr. Chirag Warty.
- *"LINUX Embedded & RealTime"*, Ing. Ginaluigi Biancucci.
- *"Creative applications of airborne ultrasound"*, Dr. Miha Ciglar.
- *"Tecniche di Elaborazione Numerica dei Segnali Applicata alla Sintesi della Canna d'Organo"*, Ing. Carlo Zinato.



Training Activity (2)

- "*Situational Intelligence for Utility Power System and Micro-Grid Operations*", Prof. Kumar Venayagamoorthy.

Other:

- Ciclo di incontri "4EUREKA".
- Reviewer for international journals (*Special Issue of Neurocomputing and Hindawi*), and international conferences (*IJCNN 2015, WIRN2015, IEEE-EEEIC2016 and IEEE WCCI2016*).
- *ISCRA: Class C Project Proposal*, granted 9-months access with 120.000CoreHours available at CINECA-HPC GALILEO.
- *NVIDIA Grant Proposal*, granted video card GTX TITAN X (3072 Cuda Cores, 12GB GDDR5)



Tutoring Activity

- Exam supervision and integrative teaching for Circuit Theory (Elettrotecnica).
- Exam supervision and integrative teaching for CAES - Circuiti e Algoritmi per l'Elaborazione dei Segnali.
- Tutoring activity for CAES 2 - Circuiti e Algoritmi per l'Elaborazione dei Segnali 2.
- Exam supervision and integrative teaching for MRE - Macchine e Reti Elettriche.



Lista Pubblicazioni (1)

International Journal:

[3 articles, 3 first author]

1. **M. Fagiani**, S. Squartini, L. Gabrielli, M. Severini, and F. Piazza, "A statistical framework for automatic leakage detection in smart water and gas grids," *Energies*, vol. 9, no. 9, p. 665, 2016.
2. **M. Fagiani**, S. Squartini, L. Gabrielli, S. Spinsante, and F. Piazza, "A review of datasets and load forecasting techniques for smart natural gas and water grids: Analysis and experiments," *Neurocomputing*, vol. 170, pp. 448 – 465, 2015.
3. **M. Fagiani**, E. Principi, S. Squartini, and F. Piazza, "Signer independent isolated italian sign recognition based on hidden markov models," *Pattern Analysis and Applications*, vol. 18, no. 2, pp. 385–402, 2015.

International Conference:

[11 articles, 6 first author]

4. R. Bonfigli, E. Principi, S. Squartini, **M. Fagiani**, M. Severini, and F. Piazza, "User-aided Footprint Extraction for Appliance Modelling in Non-Intrusive Load Monitoring," in *2016 IEEE Symposium Series on Computational Intelligence (SSCI)*, December 2016. *Accepted*.
5. **M. Fagiani**, S. Squartini, R. Bonfigli, M. Severini, and F. Piazza, "Exploiting Temporal Features and Pressure Data for Automatic Leakage Detection in Smart Water Grids," in *2016 IEEE World Congress on Computational Intelligence (WCCI)*, July 2016. *To appear*.
6. R. Bonfigli, M. Severini, S. Squartini, **M. Fagiani**, and F. Piazza, "Improving the performance of the AFAMAP algorithm for Non-Intrusive Load Monitoring," in *2016 IEEE World Congress on Computational Intelligence (WCCI)*, July 2016. *To appear*.



Lista Pubblicazioni (2)

7. M. Severini, A. Scorrano, S. Squartini, **M. Fagiani**, and F. Piazza, "SW Framework for simulation and evaluation of partial shading effects in configurable PV systems," in *Environment and Electrical Engineering (EEEIC), 2016 IEEE 16th International Conference on*, June 2016. *To appear.*
8. **M. Fagiani**, S. Squartini, M. Severini, and F. Piazza, "A novelty detection approach to identify the occurrence of leakage in smart gas and water grids," in *2015 International Joint Conference on Neural Networks (IJCNN)*, pp. 1–8, July 2015.
9. M. Severini, S. Squartini, **M. Fagiani**, and F. Piazza, "Energy management with the support of dynamic pricing strategies in real micro-grid scenarios," in *2015 International Joint Conference on Neural Networks (IJCNN)*, pp. 1–8, July 2015.
10. R. Bonfigli, S. Squartini, **M. Fagiani**, and F. Piazza, "Unsupervised algorithms for non-intrusive load monitoring: An up-to-date overview," in *Environment and Electrical Engineering (EEEIC), 2015 IEEE 15th International Conference on*, pp. 1175–1180, June 2015.
11. **M. Fagiani**, S. Squartini, R. Bonfigli, and F. Piazza, "Short-term load forecasting for smart water and gas grids: A comparative evaluation," in *Environment and Electrical Engineering (EEEIC), 2015 IEEE 15th International Conference on*, pp. 1198–1203, June 2015.
12. **M. Fagiani**, S. Squartini, L. Gabrielli, S. Spinsante, and F. Piazza, "Domestic water and natural gas demand forecasting by using heterogeneous data: A preliminary study," *Smart Innovation, Systems and Technologies*, vol. 37, pp. 185–194, 2015.



Lista Pubblicazioni (3)

13. **M. Fagiani**, S. Squartini, L. Gabrielli, M. Pizzichini, and S. Spinsante, "Computational intelligence in smart water and gas grids: An up-to-date overview," in *Neural Networks (IJCNN), 2014 International Joint Conference on*, pp. 921–926, July 2014.
14. **M. Fagiani**, E. Principi, S. Squartini, and F. Piazza, "A new system for automatic recognition of italian sign language," in *Neural Nets and Surroundings* (B. Apolloni, S. Bassis, A. Esposito, and F. C. Morabito, eds.), vol. 19 of *Smart Innovation, Systems and Technologies*, pp. 69–79, Springer Berlin Heidelberg, 2013.