function apri_chiudi_div(id, tipo) { if(tipo == true) {
document.getElementById("div_"+id).style.display = "";
document.getElementById("link_"+id).innerHTML = " [no abstract] "; } else {
document.getElementById("div_"+id).style.display = "none";
document.getElementById("link_"+id).innerHTML = " [abstract] "; } }

Publications [all BibTeX]

20YY

E. Marcelli, T. Barbariol, G.A. Susto. **Active Learning-based Isolation Forest (ALIF): Enhancing Anomaly Detection in Decision Support Systems.** 20YY [url] [BibTeX]

L.C. Brito, G.A. Susto, J.N. Brito, M.A.V. Duarte. **Band Relevance Factor (BRF): a novel automatic frequency band selection method based on vibration analysis for rotating machinery.** 20YY [url] [BibTeX]

D. Dalle Pezze, E. Anello, C. Masiero, G.A. Susto. **Continual Learning Approaches for Anomaly Detection.** 20YY [url] [BibTeX]

N. Gentner, G.A. Susto. **Heterogeneous Domain Adaptation and Equipment Matching: DANN-based Alignment with Cyclic Supervision (DBACS).** 20YY [url] [BibTeX]

M. Terzi, M. Carletti, G.A. Susto. **Improving Robustness with Image Filtering.** 20YY [url] [BibTeX]

M. Carletti, M. Terzi, G.A. Susto. **On the Properties of Adversarially-Trained CNNs.** 20YY
Abstract:

Adversarial Training has proved to be an effective training paradigm to enforce robustness against adversarial examples in modern neural network architectures. Despite many efforts, explanations of the foundational principles underpinning the effectiveness of Adversarial Training are limited and far from being widely accepted by the Deep Learning community. In this paper, we describe surprising properties of adversarially-trained models, shedding light on mechanisms through which robustness against adversarial attacks is implemented. Moreover, we highlight limitations and failure modes affecting these models that were not discussed by prior works. We conduct extensive analyses on a wide range of architectures and datasets, performing a deep comparison between robust and natural models.

[abstract] [url] [BibTeX]

2023

D. Dalle Pezze, D. Deronjic, C. Masiero, D. Tosato, A. Beghi, G.A. Susto. **A Multi-label Continual Learning Framework to Scale Deep Learning Approaches for Packaging Equipment Monitoring.** *Engineering Applications of Artificial Intelligence*, vol. 1242023 [BibTeX]

A. Fabris, F. Giachelle, A. Piva, G. Silvello, G.A. Susto. **A Search Engine for Algorithmic Fairness Datasets.** *2nd European Workshop on Algorithmic Fairness*, 2023 [BibTeX]

D. Dandolo, C. Masiero, M. Carletti, D. Dalle Pezze, G.A. Susto. **AcME - Accelerated Model-agnostic Explanations: Fast Whitening of the Machine-Learning Black Box.** *Expert Systems with Applications*, vol. 2142023 [url] [BibTeX]

M. Fanan, C. Baron, R. Carli, M. Divernois, J. Marongiu, G.A. Susto. **Anomaly Detection for Hydroelectric Power Plants: a Machine Learning-based Approach.** *IEEE International Conference on Industrial Informatics (INDIN)*, 2023 [BibTeX]

Q. Wang, T. Barbariol, G.A. Susto, B. Bonato, S. Guerra, U. Castiello. **Classifying Circumnutation in Pea Plants via Supervised Machine Learning.** *Plants*, vol. 4(12), 2023 [url] [BibTeX]

F. Dalla Zuanna, N. Gentner, G.A. Susto. **Deep Learning-based Sequence Modeling for Advanced Process Control in Semiconductor Manufacturing.** *IFAC World Congress*, 2023 [BibTeX]

D. Marcato, L. Bellan, D. Bortolato, M. Comunian, F. Gelain, V. Martinelli, G. Savarese, G.A. Susto. **Demonstration of Beam Emittance Optimization using Reinforcement Learning.** *14th International Particle Accelerator Conference*, 2023 [BibTeX]

A. Fabris, G. Silvello, G.A. Susto, A. Biega. **Dissatisfaction Induced by Pairwise Swaps.** *Italian Information Retrieval Workshop*, 2023 [BibTeX]

L.C. Brito, G.A. Susto, J.N. Brito, M.A.V. Duarte. **Fault Diagnosis using eXplainable AI: a Transfer Learning-based Approach for Rotating Machinery exploiting Augmented Synthetic Data.** *Expert Systems with Applications*, 2023 [BibTeX]

M. Carletti, M. Terzi, G.A. Susto. **Interpretable Anomaly Detection with DIFFI: Depth-based Feature Importance for the Isolation Forest.** *Engineering Applications of Artificial Intelligence*, vol. 1192023

Abstract:

Anomaly Detection is an unsupervised learning task aimed at detecting anomalous behaviors with respect to historical data. In particular, multivariate Anomaly Detection has an important role in many applications thanks to the capability of summarizing the status of a complex system or observed phenomenon with a single indicator (typically called ‘anomaly score’) and thanks to the unsupervised nature of the task that does not require human tagging. The Isolation Forest is one of the most commonly adopted algorithms in the field of Anomaly Detection due to its proven effectiveness and low computational complexity. A major problem affecting Isolation Forest is represented by the lack of interpretability, an effect of the inherent randomness governing the splits performed by the Isolation Trees, the building blocks of the Isolation Forest. In this paper, we propose effective yet computationally inexpensive methods to define feature importance scores at both global and local levels for the Isolation Forest. Moreover, we define a procedure to perform unsupervised feature selection for Anomaly Detection problems based on our interpretability method. Such a procedure also serves the purpose of tackling the challenging task of feature importance evaluation in unsupervised anomaly detection. We assess the performance on several synthetic and real-world datasets, including comparisons against state-of-the-art interpretability techniques, and make the code publicly available to enhance reproducibility and foster research in the field.

[abstract] [url] [BibTeX]

S. McLoone, K. Guelton, T. Guerra, G.A. Susto, J. Kocijan, D. Romeres. **Introduction to the special issue on Intelligent Control and Optimisation.** *Engineering Applications of Artificial Intelligence*, vol. 1232023 [url] [BibTeX]

F. Zocco, M. Maggipinto, G.A. Susto, S. McLoone. **Lazy FSCA for Unsupervised Variable Selection.** *Engineering Applications of Artificial Intelligence*, vol. 1242023
Abstract:

Dimensionality reduction is a important step in the development of scalable and interpretable data-driven models, especially when there are a large number of candidate variables. This paper focuses on unsupervised variable selection based dimensionality reduction, and in particular on unsupervised greedy selection methods, which have been proposed by various researchers as computationally tractable approximations to optimal subset selection. These methods are largely distinguished from each other by the selection criterion adopted, which include squared correlation, variance explained, mutual information and frame potential. Motivated by the absence in the literature of a systematic comparison of these different methods, we present a critical evaluation of seven unsupervised greedy variable selection algorithms considering both simulated and real world case studies. We also review the theoretical results that provide performance guarantees and enable efficient implementations for certain classes of greedy selection function, related to the concept of submodularity. Furthermore, we introduce and evaluate for the first time, a lazy implementation of the variance explained based forward selection component analysis (FSCA) algorithm. Our experimental results show that: (1) variance explained and mutual information based selection methods yield smaller approximation errors than frame potential; (2) the lazy FSCA implementation has similar performance to FSCA, while being an order of magnitude faster to compute, making it the algorithm of choice for unsupervised variable selection.

[abstract] [url] [BibTeX]

A. Fabris, G. Silvello, G.A. Susto, A. Biega. **Pairwise Fairness in Ranking as a Dissatisfaction Measure.** *ACM International Conference on Web Search and Data Mining*, 2023 [BibTeX]

L. Lorenti, D. Dalle Pezze, J. Andreoli, C. Masiero, N. Gentner, Y. Yang, G.A. Susto. **Predictive Maintenance in the Industry: A Comparative Study on Deep Learning-based Remaining Useful Life Estimation.** *IEEE International Conference on Industrial Informatics (INDIN)*, 2023 [BibTeX]

L. Cristaldi, P. Esmaili, G. Gruosso, A. La Bella, M. Mecella, R. Scattolini, A. Arman, G.A. Susto, L. Tanca. **The MICS Project. A Data Science Pipeline for Industry 4.0 Applications.** *2023 IEEE International Conference on Metrology for eXtended Reality, Artificial Intelligence, and Neural Engineering (IEEE MetroXRAINE 2023)*, 2023 [BibTeX]

D. Marcato, D. Bortolato, V. Martinelli, G. Savarese, G.A. Susto. **Time-Series Deep Learning Anomaly Detection for Particle Accelerators.** *IFAC World Congress*, 2023 [BibTeX]

A. Beghi, N. Dall'Ora, D. Dalle Pezze, F. Fummi, C. Masiero, S. Spellini, G.A. Susto, F. Tosoni. **VIR2EM: VIrtualization and Remotization for Resilient and Efficient Manufacturing.** *26th Forum on specification and Design Languages*, 2023 [BibTeX]

2022

M. Maggipinto, A. Beghi, G.A. Susto. **A Deep Convolutional Autoencoder-based Approach for Anomaly Detection with Industrial, Non-images, 2-Dimensional data: a Semiconductor Manufacturing case study.** *IEEE Transactions on Automation Science and Engineering*, vol. 19(3), pp. 1477-1490, 2022 [url] [BibTeX]

D. Dalle Pezze, D. Deronjic, C. Masiero, D. Tosato, A. Beghi, G.A. Susto. **A Multi-label Continual Learning Framework to Scale Deep Learning Approaches for Packaging Equipment Monitoring.** *European Conference on Machine Learning and Principles and Practice of Knowledge Discovery (ECML-PKDD)*, 2022 [url] [BibTeX]

T. Barbariol, F. Dalla Chiara, D. Marcato, G.A. Susto. **A review of Tree-based approaches for Anomaly Detection.** *Control Charts and Machine Learning for Anomaly Detection in Manufacturing*, 2022
Abstract:

Data-driven Anomaly Detection approaches have received increasing attention in many other application areas in the past fewyears as a tool for monitoring of complex systems in addition to classical univariatecontrol charts. Tree-based approaches have proven to be particularly effective when dealing with high-dimensional Anomaly Detection problems and with underlying non-gaussian data distributions. The most popular approach in this family is the Isolation Forest, which is currently one of the mostpopular choices for scientists and practitioners when dealing with Anomaly Detection tasks. The Isolation Forest represents a seminal algorithm upon which many extended approaches have been presented in the past years aiming at improving the original method or at dealing with peculiar applicationscenarios. In this work, we revise some of the most popular and powerful Tree-based approaches to Anomaly Detection (extensions of the Isolation Forest and other approaches), considering both batch and streaming datascenarios. This work will review several relevant aspects of the methods, like computational costs and interpretability traits. To help practitioners, we also report available relevant libraries and open implementations and we review real-world industrial applications of the considered approaches.

[abstract] [BibTeX]

E. Marcelli, T. Barbariol, V. Savarino, A. Beghi, G.A. Susto. **A Revised Isolation Forest procedure for Anomaly Detection with High Number of Data Points.** *23rd IEEE Latin-American Test Symposium (LATS2022)*, 2022 [BibTeX]

F. Simmini, M. Rampazzo, F. Peterle, G.A. Susto, A. Beghi. **A Self-Tuning KPCA-based Approach to Fault Detection in Chiller Systems.** *IEEE Transactions on Control Systems Technology*, vol. 30(4), 2022 [BibTeX]

A. Fabris, A. Mishler, S. Gottardi, M. Carletti, M. Daicampi, G.A. Susto, G. Silvello. **Algorithmic Audit of Italian Car Insurance: Evidence of Unfairness in Access and Pricing.** *ACM Conference on Equity*

and Access in Algorithms, Mechanisms, and Optimization, 2022 [BibTeX]

A. Fabris, S. Messina, G. Silvello, G.A. Susto. **Algorithmic Fairness Datasets: the Story so Far.** *Data Mining and Knowledge Discovery*, 2022 [url] [BibTeX]

H.T. Jebril, M. Pleschberger, G.A. Susto. **An Autoencoder-based Approach for Fault Detection in Multi-stage Manufacturing: a Sputter Deposition and Rapid Thermal Processing case study.** *IEEE Transactions on Semiconductor Manufacturing*, 2022 [BibTeX]

L.C. Brito, G.A. Susto, J.N. Brito, M.A.V. Duarte. **An Explainable Artificial Intelligence Approach for Unsupervised Fault Detection and Diagnosis in Rotating Machinery.** *Mechanical Systems and Signal Processing*, vol. 1632022

Abstract:

The monitoring of rotating machinery is an essential task in today's production processes. Currently, several machine learning and deep learning-based modules have achieved excellent results in fault detection and diagnosis. Nevertheless, to further increase user adoption and diffusion of such technologies, users and human experts must be provided with explanations and insights by the modules. Another issue is related, in most cases, with the unavailability of labeled historical data that makes the use of supervised models unfeasible. Therefore, a new approach for fault detection and diagnosis in rotating machinery is here proposed. The methodology consists of three parts: feature extraction, fault detection and fault diagnosis. In the first part, the vibration features in the time and frequency domains are extracted. Secondly, in the fault detection, the presence of fault is verified in an unsupervised manner based on anomaly detection algorithms. The modularity of the methodology allows different algorithms to be implemented. Finally, in fault diagnosis, Shapley Additive Explanations (SHAP), a technique to interpret black-box models, is used. Through the feature importance ranking obtained by the model explainability, the fault diagnosis is performed. Two tools for diagnosis are proposed, namely: unsupervised classification and root cause analysis. The effectiveness of the proposed approach is shown on three datasets containing different mechanical faults in rotating machinery. The study also presents a comparison between models used in machine learning explainability: SHAP and Local Depth-based Feature Importance for the Isolation Forest (Local- DIFFI). Lastly, an analysis of several state-of-art anomaly detection algorithms in rotating machinery is included.

[abstract] [url] [BibTeX]

E. Anello, M. Chiara, F. Ferro, F. Ferrari, B. Mukaj, A. Beghi, G.A. Susto. **Anomaly Detection for the Industrial Internet of Things: an Unsupervised Approach for Fast Root Cause Analysis.** *IEEE Conference on Control Technology and Applications (CCTA)*, 2022 [BibTeX]

L. Lorenti, G. De Rossi, A. Annoni, S. Rigutto, G.A. Susto. **CUAD-Mo: Continuos Unsupervised Anomaly Detection on Machining Operations.** *IEEE Conference on Control Technology and Applications (CCTA)*, 2022 [BibTeX]

D. Dalle Pezze, C. Masiero, D. Tosato, A. Beghi, G.A. Susto. **FORMULA: A Deep Learning Approach for Rare Alarms Predictions in Industrial Equipment.** *IEEE Transactions on Automation Science and Engineering*, vol. 19(3), pp. 1491--1502, 2022 [url] [BibTeX]

G.A. Susto, A. Diebold, A. Kyek, C. Lee, N. Patel. **Guest Editorial: Process-Level Machine Learning Applications in Semiconductor Manufacturing.** *IEEE Transactions on Semiconductor Manufacturing*, 2022 [BibTeX]

A. Purpura, G. Sartori, G. Orrù, G.A. Susto. **Identifying Faked Responses in Questionnaires with Self-Attention Based Autoencoders.** *Informatics*, 2022 [BibTeX]

M. Maggipinto, M. Terzi, G.A. Susto. **IntroVAC: Introspective Variational Classifiers for Learning Interpretable Latent Subspaces.** *Engineering Applications of Artificial Intelligence*, vol. 1092022
Abstract:

Learning useful representations of complex data has been the subject of extensive research for many years. With the diffusion of Deep Neural Networks, Variational Autoencoders have gained lots of attention since they provide an explicit model of the data distribution based on an encoder/decoder architecture which is able to both generate images and encode them in a low-dimensional subspace. However, the latent space is not easily interpretable and the generation capabilities show some limitations since images typically look blurry and lack details. In this paper, we propose the Introspective Variational Classifier (IntroVAC), a model that learns interpretable latent subspaces by exploiting information from an additional label and provides improved image quality thanks to an adversarial training strategy.We show that IntroVAC is able to learn meaningful directions in the latent space enabling fine-grained manipulation of image attributes. We validate our approach on the CelebA dataset.

[abstract] [url] [BibTeX]

A. Beghi, G.A. Susto, G. Zambonin, F. Altinier, T. Girotto, M. Rampazzo. **LAUNDRY DRYING MACHINE AND CONTROL METHOD THEREOF.** *Patent*, 2022 [BibTeX]

A. Purpura, G. Silvello, G.A. Susto. **Learning to Rank from Relevance Judgments Distributions.** *Journal of the Association for Information Science and Technology*, 2022
Abstract:

LEarning TO Rank (LETOR) algorithms are usually trained on annotated corpora where a single relevance label is assigned to each available document-topic pair. Within the Cranfield framework, relevance labels result from merging either multiple expertly curated or crowdsourced human assessments. In this paper, we explore how to train LETOR models with relevance judgments distributions (either real or synthetically generated) assigned to document-topic pairs instead of single-valued relevance labels. We propose five new probabilistic loss functions to deal with the higher expressive power provided by relevance judgments distributions and show how they can be applied both to neural and gradient boosting machine (GBM) architectures. Moreover, we show how training a LETOR model on a sampled version of the relevance judgments from certain probability distributions can improve its performance when relying either on traditional or probabilistic loss functions. Finally, we validate our hypothesis on real-world crowdsourced relevance judgments distributions. Overall, we observe that relying on relevance judgments distributions to train different LETOR models can boost their performance and even outperform strong baselines such as LambdaMART on several test collections.

[abstract] [BibTeX]

A. Purpura, G. Silvello, G.A. Susto. **Learning to rank from relevance judgments distributions.** *Italian Information Retrieval Workshop*, 2022 [BibTeX]

L.C. Brito, G.A. Susto, J.N. Brito, M.A.V. Duarte. **Mechanical faults in rotating machinery dataset (normal, unbalance, misalignment, looseness).** *Mendeley Data*, 2022 [url] [BibTeX]

D. Tosato, E. Convento, C. Masiero, G.A. Susto, A. Beghi. **Packaging Industry Anomaly DEtection**

(PIADE). 2022 [url] [BibTeX]

K.S.S. Alamin, Y. Chen, S. Gaiardelli, S. Spellini, A. Calimera, A. Beghi, G.A. Susto, F. Fummi, S. Vinco. **SMARTIC: Smart Monitoring and Production Optimization for Zero-waste Semiconductor Manufacturing.** *23rd IEEE Latin-American Test Symposium (LATS2022)*, 2022 [BibTeX]

A. Fabris, S. Messina, G. Silvello, G.A. Susto. **Tackling Documentation Debt: A Survey on Algorithmic Fairness Datasets.** *ACM Conference on Equity and Access in Algorithms, Mechanisms, and Optimization*, 2022 [BibTeX]

T. Barbariol, G.A. Susto. **TiWS-iForest: Isolation Forest in Weakly Supervised and Tiny ML scenarios.** *Information Sciences*, vol. 610pp. 126-143, 2022 [url] [BibTeX]

2021

A. Purpura, G.A. Susto. **A Bayesian Neural Model for Documents' Relevance Estimation.** *Design of Experimental Search & Information Retrieval Systems*, 2021 [BibTeX]

M. Berno, M. Canil, N. Chiarello, L. Piazzon, F. Berti, F. Ferrari, A. Zaupa, N. Ferro, M. Rossi, G.A. Susto. **A Data Management and Anomaly Detection Solution for the Entertainment Industry.** *Italian Symposium on Database Systems (SEBD)*, 2021 [BibTeX]

M. Berno, M. Canil, N. Chiarello, L. Piazzon, F. Berti, F. Ferrari, A. Zaupa, N. Ferro, M. Rossi, G.A. Susto. **A Machine Learning-based Approach for Advanced Monitoring of Automated Equipment for the Entertainment Industry.** *International Workshop on Metrology for Industry 4.0 & IoT*, 2021 [BibTeX]

S. Tedesco, G.A. Susto, N. Gentner, A. Kyek, Y. Yang. **A Scalable Deep Learning-based Approach for Anomaly Detection in Semiconductor Manufacturing.** *Winter Simulation Conference*, 2021
Abstract:

The diffusion of the Industry 4.0 paradigm lead to the creation and collection of huge manufacturing datasets; such datasets contain for example measurements coming from physical sensors located in different equipment or even in different productive manufacturing organizations. Such large and heterogeneous datasets represent a challenge when aiming for developing data-driven approaches like Anomaly Detection or Predictive Maintenance. In this work we present a new approach for performing Anomaly Detection that is able to handle heterogeneous data coming from different equipment, work centers or production sites.

[abstract] [BibTeX]

M. Terzi, A. Achille, M. Maggipinto, G.A. Susto. **Adversarial Training Reduces Information and Improves Transferability.** *35th AAAI Conference on Artificial Intelligence*, (arXiv:2007.11259), 2021
Abstract:

Recent results show that features of adversarially trained networks for classification, in addition to being robust, enable desirable properties such as invertibility. The latter property may seem counter-intuitive as it is widely accepted by the community that classification models should only capture the minimal information (features) required for the task. Motivated by this discrepancy, we investigate the dual relationship between Adversarial Training and Information Theory. We show that the Adversarial Training can improve linear transferability to new tasks, from which arises a new trade-off between

transferability of representations and accuracy on the source task. We validate our results employing robust networks trained on CIFAR-10, CIFAR-100 and ImageNet on several datasets. Moreover, we show that Adversarial Training reduces Fisher information of representations about the input and of the weights about the task, and we provide a theoretical argument which explains the invertibility of deterministic networks without violating the principle of minimality. Finally, we leverage our theoretical insights to remarkably improve the quality of reconstructed images through inversion.

[abstract] [url] [BibTeX]

A. Fabris, A. Mishler, S. Gottardi, M. Carletti, M. Daicampi, G.A. Susto, G. Silvello. **Algorithmic Audit of Italian Car Insurance: Evidence of Unfairness in Access and Pricing.** *Fourth AAAI/ACM Conference on Artificial Intelligence, Ethics, and Society (AIES)*, 2021 [BibTeX]

N. Bargellesi, A. Beghi, M. Rampazzo, G.A. Susto. **AutoSS: A Deep Learning-Based Soft Sensor for Handling Time-Series Input Data.** *IEEE Robotics and Automation Letters*, vol. 6(3), pp. 6100--6107, 2021
Abstract:

Soft Sensors are data-driven technologies that allow to have estimations of quantities that are impossible or costly to be measured. Unfortunately, the design of effective soft sensors is heavily impacted by time-consuming feature engineering steps that may lead to sub-optimal information, especially when dealing with time-series input data. While domain knowledge may come into help when handling feature extraction in soft sensing applications, the feature extraction typically limits the adoption of such technologies: in this work, we propose AutoSS, a Deep-Learning based approach that allows to overcome such issue. By exploiting autoencoders, dilated convolutions and an ad-hoc defined architecture, AutoSS allows to develop effective soft sensing modules even with time-series input data. The effectiveness of AutoSS is demonstrated on a real-world case study related to Internet of Things equipment.

[abstract] [url] [BibTeX]

N. Gentner, M. Carletti, A. Kyek, G.A. Susto, Y. Yang. **DBAM: Making Virtual Metrology/Soft Sensing with Time Series Data Scalable Through Deep Learning.** *Control Engineering Practice*, vol. 1162021
Abstract:

Machine Learning (ML) based technologies, like Virtual Metrology (VM)/Soft Sensing, Predictive Maintenance and Fault Detection, have been successfully applied in the past recent years in data intensive manufacturing industries, like semiconductor manufacturing, to improve process monitoring and related operations. Standardization and alignment over multiple equipment is a key element to ensure

industry-wide adoption and scalability for ML-based technologies in complex production environment. In this work we address the topic of VM/Soft Sensing – a particular ML-based technology for process control – in the context of equipment matching and scalability. We present a Deep Learning-based domain adaptation approach, called DANN-Based Model Alignment (DBAM), that provides a common VM model for two identical-in-design systems whose data are following different distributions. The proposed approach has the merit of (i) exploiting directly raw sensor data (that typically present themselves in the form of time series) and (ii) offering interpretability of the features. The proposed approach is compared against other approaches in the literature for VM/Soft Sensing on a real-world case study from semiconductor manufacturing.

[abstract] [BibTeX]

S. Arena, Y. Budrov, M. Carletti, N. Gentner, M. Maggipinto, Y. Yang, A. Beghi, A. Kyek, G.A. Susto. **Exploiting 2D Coordinates as Bayesian Priors for Deep Learning Defect Classification of SEM Images.** *IEEE Transactions on Semiconductor Manufacturing*, 2021
Abstract:

Deep Learning approaches have revolutionized in the past decade the field of Computer Vision and, as a consequence, they are having a major impact in Industry 4.0 applications like automatic defect classification. Nevertheless, additional data, beside the image/video itself, is typically never exploited in a defect classification module: this aspect, given the abundance of data in data-intensive manufacturing environments (like semiconductor manufacturing) represents a missed opportunity. In this work we present a use case related to Scanning Electron Microscope (SEM) images where we exploit a Bayesian approach to improve defect classification. We validate our approach on a real-world case study and by employing modern Deep Learning architectures for classification.

[abstract] [BibTeX]

L.C. Brito, G.A. Susto, J.N. Brito, M.A.V. Duarte. **Fault Detection of Bearing: an Unsupervised Machine Learning Approach Exploiting Feature Extraction and Dimensionality Reduction.** *Informatics*, 2021 [BibTeX]

D. Biasion, A. Fabris, G. Silvello, G.A. Susto. **Gender Bias in Italian Word Embeddings.** *CLIC-IT 2020 Seventh Italian Conference on Computational Linguistics*, 2021 [BibTeX]

G.M. Di Nunzio, A. Fabris, G. Silvello, G.A. Susto. **Incentives for Item Duplication under Fair Ranking Policies.** *European Conference on Information Retrieval (ECIR) 2021*, 2021 [BibTeX]

M. Viola, L. Brunelli, G.A. Susto. **Instagram Images and Videos Popularity Prediction: a Deep Learning-Based Approach.** *Italian Workshop on Artificial Intelligence and Applications for Business and Industries*, 2021 [BibTeX]

D. Marcato, G. Arena, D. Bortolato, F. Gelain, V. Martinelli, E. Munaron, M. Roetta, G. Savarese, G.A. Susto. **Machine Learning-based Anomaly Detection for Particle Accelerators.** *5th IEEE Conference on Control Technology and Applications (CCTA)*, 2021
Abstract:

Particle accelerators are complex systems composed of multiple subsystems that must work together to produce high quality beams employed for physics experiments. A fault or an anomalous behaviour in one of such subsystems can lead to expensive downtime for the whole facility. Thus, it is of paramount importance to be able to promptly detect anomalies.Given the vast amount of streaming data generated by accelerator field sensors, Machine Learning (ML)-based tools are promising candidates for efficient monitoring of such systems: an approach based on unsupervised ML techniques exploiting the data from a Radio Frequency tuning system is here proposed. Feature importance is exploited to guide the definition of the optimal windowing for feature extraction. The proposed approach is here validated on real-world data related to the ALPI accelerator at Legnaro National Laboratories in Italy.

[abstract] [BibTeX]

A. Fabris, A. Purpura, G. Silvello, G.A. Susto. **Measuring Gender Stereotype Reinforcement in Information Retrieval Systems.** *Proceedings of the 2021 Italian Information Retrieval Workshop*, 2021 [BibTeX]

A. Purpura, K. Buchner, G. Silvello, G.A. Susto. **Neural Feature Selection for Learning to Rank.** *Proceedings of the European Conference on Information Retrieval*, 2021 [BibTeX]

L. Mancin, I. Rollo, J.F. Mota, F. Piccini, M. Carletti, G.A. Susto, G. Valle, A. Paoli. **Optimizing Microbiota Profiles for Athletes: Dream or Reality?.** *Exercise and sport sciences reviews*, vol. 49(1), pp. 42--49, 2021
Abstract:

Gut microbiome influences athletes' physiology but, due to the complexity of sport performance and the great inter-variability of microbiome features, it is not reasonable to define a single healthy microbiota profile for athletes. We suggest the use of specific meta-omics analysis coupled with innovative computational systems to uncover the hidden relationship between microbes and athlete's physiology and predicting personalized recommendation.

[abstract] [url] [BibTeX]

L. Frau, G.A. Susto, T. Barbariol, E. Feltresi. **Uncertainty estimation for Machine Learning models in Multiphase flow Applications.** *Informatics*, vol. 8(3), 2021
Abstract:

In oil and gas production, it is essential to monitor some performance indicators that are related to the composition of the extracted mixture, such as the liquid and gas content of the flow. These indicators cannot be directly measured and must be inferred with other measurements by using soft sensor approaches that model the target quantity. For the purpose of production monitoring, point estimation alone is not enough, and a confidence interval is required in order to assess the uncertainty in the provided measure. Decisions based on these estimations can have a large impact on production costs; therefore, providing a quantification of uncertainty can help operators make the most correct choices. This paper focuses on the estimation of the performance indicator called the water-in-liquid ratio by using data-driven tools: firstly, anomaly detection techniques are employed to find data that can alter the

performance of the subsequent model; then, different machine learning models, such as Gaussian processes, random forests, linear local forests, and neural networks, are tested and employed to perform uncertainty-aware predictions on data coming from an industrial tool, the multiphase flow meter, which collects multiple signals from the flow mixture. The reported results show the differences between the discussed approaches and the advantages of the uncertainty estimation; in particular, they show that methods such as the Gaussian process and linear local forest are capable of reaching competitive performance in terms of both RMSE (1.9–2.1) and estimated uncertainty (1.6–2.6).

[abstract] [BibTeX]

2020

T. Barbariol, E. Feltresi, G.A. Susto. **A Machine Learning-based System for Self-diagnosis Multiphase Flow Meters.** *International Petroleum Technology Conference*, 2020 [BibTeX]

J.A. Mat Jizat, I.M. Khairuddin, A. Razman, A.F. Nasir, M.S.A. Karim, A.A. Jaafar, L. Wei Hong, A. Abdul Majeed, H. Myung, H. Choi, G.A. Susto. **Advances in Robotics, Automation and Data Analytics. Selected Papers from iCITES 2020.** 2020
Abstract:

This book presents essentially a collection of proceedings that deliberate on the key challenges and recent trends on robotics, automation and data analytics which are the pillars of Industry 4.0. Solutions that are employed in the multitude spectra of innovative robotics & automation and data analytics are discussed. The readers are expected to gain an insightful view on the current trends, issues, mitigating factors as well as solutions from the book. This book consists of selected papers presented at the 2nd International Conference on Innovative Technology, Engineering and Sciences 2020 (iCITES) hosted virtually by Universiti Malaysia Pahang on 22nd December 2020. iCITES is a biennial conference, aimed at building a platform that allows relevant stakeholders to share and discuss their latest researches, ideas and survey reports from theoretical to a practical standpoint especially in the Innovative Robotics & Automation and Data Analytics tracks which was published in this book.

[abstract] [url] [BibTeX]

D. Tosato, D. Dalle Pezze, C. Masiero, G.A. Susto, A. Beghi. **Alarm Logs in Packaging Industry (ALPI).** *IEEEDataPort*, 2020
Abstract:

The advent of the Industrial Internet of Things (IIoT) has led to the availability of huge amounts of data, that can be used to train advanced Machine Learning algorithms to perform tasks such as Anomaly Detection, Fault Classification and Predictive Maintenance. Even though not all pieces of equipment are

equipped with sensors yet, usually most of them are already capable of logging warnings and alarms occurring during operation. Turning this data, which is easy to collect, into meaningful information about the health state of machinery can have a disruptive impact on the improvement of efficiency and up-time. The provided dataset consists of a sequence of alarms logged by packaging equipment in an industrial environment. The collection includes data logged by 20 machines, deployed in different plants around the world, from 2019-02-21 to 2020-06-17. There are 154 distinct alarm codes, whose distribution is highly unbalanced. This data can be used to address the following tasks:

1. Next alarm forecasting: this problem can be framed as a supervised multi-class classification task, or a binary classification task when a specific alarm code is considered.
2. Predicting alarms occurring in a future time frame: here the goal is to forecast the occurrence of certain alarm types in a future time window. Since many alarms can occur, this is a supervised multi-label classification.
3. Future alarm sequence prediction: here the goal is predicting an ordered sequence of future alarms, in a sequence-to-sequence forecasting scenario.
4. Anomaly Detection: the task is to detect abnormal equipment conditions, based on the pattern of alarms sequence. This task can be either unsupervised, if only the input sequence is considered, or supervised if future alarms are taken into account to assess whether or not there is an anomaly.

All of the above tasks can also be studied from a continual learning perspective. Indeed, information about the serial code of the specific piece of equipment can be used to train the model; however, a scalable model should also be easy to apply to new machines, without the need of a new training from scratch. The collection and release of this dataset has been supported by the Regione Veneto project PreMANI (MANIFATTURA PREDITTIVA: progettazione, sviluppo e implementazione di soluzioni di Digital Manufacturing per la previsione della Qualita e la Manutenzione Intelligente - PREDICTIVE MAINTENANCE: design, development and implementation of Digital Manufacturing solutions for the intelligent quality and maintenance systems).

[abstract] [url] [BibTeX]

M. Maggipinto, M. Terzi, G.A. Susto. **Beta-Variational Classifiers Under Attack.** *IFAC World Congress*, 2020 [BibTeX]

L. Meneghetti, M. Terzi, S. Del Favero, G.A. Susto, C. Cobelli. **Data-Driven Anomaly Recognition for Unsupervised Model-Free Fault Detection in Artificial Pancreas.** *IEEE Transactions on Control Systems Technology*, vol. 28(1), pp. 33-47, 2020
Abstract:

The last decade has seen tremendous improvements in technologies for Type 1 Diabetes (T1D) management, in particular the so-called artificial pancreas (AP), a wearable closed-loop device modulating insulin injection based on glucose sensor readings. Unluckily, the AP actuator, an insulin pump, is subject to failures, with potentially serious consequences for subject safety. This calls for the development of advanced monitoring systems, leveraging the unprecedented data availability. This paper tackles for the first time the problem of automatically detecting pump faults with multidimensional data-driven anomaly detection (AD) methodologies. The approach allows to avoid the subtask of identifying a physiological model, typical of model-based approaches. Furthermore, we employ unsupervised methods, removing the need of labeled data for training, hardly available in practice. The adopted data-driven AD methods are local outlier factor, connectivity-based outlier factor, and isolation forest. Moreover, we propose a modification of these methods to cope with the dynamic nature of the underlying problem. The algorithms were tuned and tested on: 1) two-synthetic 100-patients' data set, of one-month data each, generated using the ``UVA/Padova T1D Simulator," a large-scale nonlinear

computer simulator of T1D subject physiology, largely adopted in AP research and accepted by the American Food and Drug Administration as a replacement of preclinical animal trials for AP and 2) a real 7-patients' data set consisting of one month in free-living conditions. The satisfactory accuracy of the proposed approach paves the way to the embedding of these methodologies in AP systems or their deployment in remote monitoring systems.

[abstract] [url] [BibTeX]

M. Terzi, G.A. Susto, P. Chaudhari. **Directional Adversarial Training for Cost Sensitive Deep Learning Classification Applications.** *Engineering Applications of Artificial Intelligence*, vol. 912020
Abstract:

In many real-world applications of Machine Learning it is of paramount importance not only to provide accurate predictions, but also to ensure certain levels of robustness. Adversarial Training is a training procedure aiming at providing models that are robust to worst-case perturbations around predefined points. Unfortunately, one of the main issues in adversarial training is that robustness w.r.t. gradient-based attackers is always achieved at the cost of prediction accuracy. In this paper, a new algorithm, called Wasserstein Projected Gradient Descent (WPGD), for adversarial training is proposed. WPGD provides a simple way to obtain cost-sensitive robustness, resulting in a finer control of the robustness-accuracy trade-off. Moreover, WPGD solves an optimal transport problem on the output space of the network and it can efficiently discover directions where robustness is required, allowing to control the directional trade-off between accuracy and robustness. The proposed WPGD is validated in this work on image recognition tasks with different benchmark datasets and architectures. Moreover, real world-like datasets are often unbalanced: this paper shows that when dealing with such type of datasets, the performance of adversarial training are mainly affected in term of standard accuracy.

[abstract] [url] [BibTeX]

N. Gentner, M. Carletti, G.A. Susto, A. Kyek, Y. Yang. **Enhancing Scalability of Virtual Metrology: a Deep Learning-based Approach for Domain Adaptation.** *Winter Simulation Conference*, 2020
Abstract:

One of the main challenges in developing Machine Learning-based solutions for Semiconductor Manu-facturing is the high number of machines in the production and their differences, even when consideringchambers of the same machine; this poses a challenge in the scalability of Machine Learning-based so-lutions in this context, since the development of chamber-specific models for all equipment in the fab isunsustainable. In this work, we present a domain adaptation approach for Virtual Metrology (VM), one ofthe most successful Machine Learning-based technology in this context. The approach provides a commonVM model for two identical-in-design chambers whose data follow different distributions. The approach isbased on Domain-Adversarial Neural Networks and it has the merit of exploiting raw trace data, avoidingthe loss of information that typically affects VM modules based on features. The effectiveness of theapproach is demonstrated on real-world Etching.

[abstract] [BibTeX]

A. Fabris, A. Purpura, G. Silvello, G.A. Susto. **Gender Stereotype Reinforcement: Measuring the Gender Bias Conveyed by Ranking Algorithms.** *Information Processing & Management*, vol. 57(6), 2020
Abstract:

Search Engines (SE) have been shown to perpetuate well-known gender stereotypes identified in psychology literature and to influence users accordingly. Similar biases were found encoded in Word Embeddings (WEs) learned from large online corpora. In this context, we propose the *Gender Stereotype Reinforcement* (GSR) measure, which quantifies the tendency of a SE to support gender stereotypes, leveraging gender-related information encoded in WEs.

Through the critical lens of construct validity, we validate the proposed measure on synthetic and real collections. Subsequently, we use GSR to compare widely-used Information Retrieval ranking algorithms, including lexical, semantic, and neural models. We check if and how ranking algorithms based on WEs inherit the biases of the underlying embeddings. We also consider the most common debiasing approaches for WEs proposed in the literature and test their impact in terms of GSR and common performance measures. To the best of our knowledge, GSR is the first specifically tailored measure for IR, capable of quantifying representational harms.

[abstract] [BibTeX]

T. Barbariol, E. Feltresi, S. Galvanin, D. Tescaro, G.A. Susto. **How to improve Water Cut measurements in MPFM using a Sensor Fusion and Machine Learning-based Approach.** *North Sea Flow Measurement Workshop*, 2020 [BibTeX]

A. Razman, A. Majeed, R.M. Musa, Z. Taha, G.A. Susto, Y. Mukai. **Hyperparameter Tuning of the Model for Hunger State Classification.** *SpringerBriefs in Applied Sciences and Technology*, pp. 49-57, 2020
Abstract:

To increase the classification, the rate of prediction based on existing models requires additional technique or in this case optimizing the model. Hyperparameter tuning is an optimization technique that evaluates and adjusts the free parameters that define the behaviour of classifiers. Data sets were classified practical with classifiers like SVM, *k*-NN, ANN and DA. To further improve the design efficiency, the secondary optimization level called hyperparameter tuning will be further investigated. DA, SVM, *k*-NN, decision tree (Tree), logistic regression (LR), random forest tree (RF) and neural network (NN) are evaluated. The *k*-NN provided 96.47% of the test sets with the best reliability in classifications. Bayesian optimization has been used to refine the hyperparameter; hence, standardize Euclidean distance metric with a *k* value of one is the ideal hyperparameters which could achieve classification performance of 97.16%.

[abstract] [url] [BibTeX]

A. Razman, A. Majeed, R.M. Musa, Z. Taha, G.A. Susto, Y. Mukai. **Image Processing Features Extraction on Fish Behaviour.** *SpringerBriefs in Applied Sciences and Technology*, pp. 25-36, 2020
Abstract:

This chapter demonstrates the pipeline from data collection until classifier models that achieve the best possible model in identifying the disparity between hunger states. The pre-processing segment describes the features of the data sets obtained by means of image processing. The method includes the simple moving average (SMA), downsizing factors, dynamic time warping (DTW) and clustering by the *k*-means method. This is to rationally assign the necessary significant information from the data collected and processed the images captured for demand feeder and fish motion as a synthesis for anticipating the state of fish starvation. The selection of features in this study takes place via the boxplot analysis and the principal component analysis (PCA) on dimensionality reduction. Finally, the validation of the hunger

state will be addressed by comparing machine learning (ML) classifiers, namely the discriminant analysis (DA), support vector machine (SVM) and *k*-nearest neighbour (*k*-NN). The outcome in this chapter will validate the features from image processing as a tool for identifying the behavioural changes of the fish in school size.

[abstract] [url] [BibTeX]

G.A. Susto, M. Maggipinto, F. Zocco, S. McLoone. **Induced Start Dynamic Sampling for Wafer Metrology Optimization.** *IEEE Transactions on Automation Science and Engineering*, vol. 17(1), pp. 418-432, 2020 [url] [BibTeX]

M. Carletti, N. Gentner, Y. Yang, A. Kyek, M. Maggipinto, A. Beghi, G.A. Susto. **Interpretable Anomaly Detection for Knowledge Discovery in Semiconductor Manufacturing.** *Winter Simulation Conference*, 2020
Abstract:

Machine Learning-based Anomaly Detection (AD) approaches are efficient tools to monitor complexprocesses. One of the advantages of such approaches is that they provide a unique anomaly indicator,a quantitative index that captures the degree of 'outlierness' of the process at hand considering possiblyhundreds or more variables at the same time, the typical scenario in semiconductor manufacturing. Oneof the drawback of such approaches is that Root Cause Analysis is not guided by the system itself. Inthis work, we show the effectiveness of a method, called DIFFI, to equip Isolation Forest, one of themost popular AD algorithms, with interpretability traits that can help corrective actions and knowledgeunderstanding. Such approach is validated on real world semiconductor manufacturing data related to aChemical Vapor Deposition process.

[abstract] [BibTeX]

A. Razman, A. Majeed, R.M. Musa, Z. Taha, G.A. Susto, Y. Mukai. **Machine Learning in Aquaculture Hunger Classification of Lates calcarifer.** 2020
Abstract:

This book highlights the fundamental association between aquaculture and engineering in classifying fish hunger behaviour by means of machine learning techniques. Understanding the underlying factors that affect fish growth is essential, since they have implications for higher productivity in fish farms. Computer vision and machine learning techniques make it possible to quantify the subjective perception of hunger behaviour and so allow food to be provided as necessary. The book analyses the conceptual framework of motion tracking, feeding schedule and prediction classifiers in order to classify the hunger state, and proposes a system comprising an automated feeder system, image-processing module, as well as machine learning classifiers. Furthermore, the system substitutes conventional, complex modelling techniques with a robust, artificial intelligence approach. The findings presented are of interest to researchers, fish farmers, and aquaculture technologist wanting to gain insights into the productivity of fish and fish behaviour.

[abstract] [url] [BibTeX]

A. Razman, A. Majeed, R.M. Musa, Z. Taha, G.A. Susto, Y. Mukai. **Monitoring and Feeding Integration of Demand Feeder Systems.** *SpringerBriefs in Applied Sciences and Technology*, pp. 11-24, 2020

Abstract:

This chapter highlights the findings of the developmental monitoring systems for swimming pattern or motion analysis with regard to feeding behaviour. A benchmark for examining the framework on how scientists control fish in animal variable function factors was gathered and referred to gauge the adequate design in constructing a viable device. The validation of image processing and automated demand feeder to determine the results will also be considered, as a validation aspect between the system of tracking and the behaviour of the *Lates calcarifer* where the pixel intensity will be extracted as the features. The results of this chapter will enable the reader on the development of an integrated feeder scheme that consolidates surveillance scheme to identify the feeding behaviour and relation towards the specific growth rate (SGR).

[abstract] [url] [BibTeX]

M. Maggipinto, G.A. Susto, P. Chaudhari. **Proximal Deterministic Policy Gradient.** *IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, 2020 [BibTeX]

T. Barbariol, E. Feltresi, G.A. Susto. **Self-Diagnosis of Multiphase Flow Meters through Machine Learning-based Anomaly Detection.** *Energies*, vol. 12(13), pp. 1 -- 24, 2020
Abstract:

Measuring systems are becoming increasingly sophisticated in order to tackle the challenges of modern industrial problems. In particular, the Multiphase Flow Meter (MPFM) combines different sensors and data fusion techniques to estimate quantities that are difficult to be measured like the water or gas content of a multiphase flow, coming from an oil well. The evaluation of the flow composition is essential for the well productivity prediction and management, and for this reason, the quantification of the meter measurement quality is crucial. While instrument complexity is increasing, demands for confidence levels in the provided measures are becoming increasingly more common. In this work, we propose an Anomaly Detection approach, based on unsupervised Machine Learning algorithms, that enables the metrology system to detect outliers and to provide a statistical level of confidence in the measures. The proposed approach, called AD4MPFM (Anomaly Detection for Multiphase Flow Meters), is designed for embedded implementation and for multivariate time-series data streams. The approach is validated both on real and synthetic data.

[abstract] [url] [BibTeX]

T. Barbariol, E. Feltresi, G.A. Susto, D. Tescaro, S. Galvanin. **Sensor Fusion And Machine LearningTechniques To Improve Water Cut Measurements Accuracy In Multiphase Application.** *2020 SPE Annual Technical Conference and Exhibition*, 2020 [BibTeX]

M. Zanon, G. Zambonin, G.A. Susto, S. McLoone. **Sparse Logistic Regression: Comparison of Regularization and Bayesian implementations.** *Algorithms*, vol. 13(6), pp. 1 -- 24, 2020
Abstract:

In knowledge-based systems, besides obtaining good output prediction accuracy, it is crucial to understand the subset of input variables that have most influence on the output, with the goal of gaining deeper insight into the underlying process. These requirements call for logistic model estimation techniques that provide a sparse solution, i.e., where coefficients associated with non-important variables are set to zero. In this work we compare the performance of two methods: the first one is based on the well known Least Absolute Shrinkage and Selection Operator (LASSO) which involves regularization

with an ?1 norm; the second one is the Relevance Vector Machine (RVM) which is based on a Bayesian implementation of the linear logistic model. The two methods are extensively compared in this paper, on real and simulated datasets. Results show that, in general, the two approaches are comparable in terms of prediction performance. RVM outperforms the LASSO both in term of structure recovery (estimation of the correct non-zero model coefficients) and prediction accuracy when the dimensionality of the data tends to increase. However, LASSO shows comparable performance to RVM when the dimensionality of the data is much higher than number of samples that is p>>n

[abstract] [url] [BibTeX]

T. Barbariol, D. Masiero, E. Feltresi, G.A. Susto. **Time series Forecasting to detect anomalous behaviours in Multiphase Flow Meter.** *North Sea Flow Measurement Workshop*, 2020 [BibTeX]

A. Razman, A. Majeed, R.M. Musa, Z. Taha, G.A. Susto, Y. Mukai. **Time-Series Identification on Fish Feeding Behaviour.** *SpringerBriefs in Applied Sciences and Technology*, pp. 37-47, 2020
Abstract:

The identification of relevant parameters that could describe the state of fish hunger is vital for ensuring the appropriate allocation of food to the fish. The establishment of these relevant parameters is non-trivial, particularly when developing an automated demand feeder system. The present inquiry is being undertaken to determine the hunger state of *Lates calcarifer*. For data collection, a video analysis system is used, and the video was taken all day, where the fish was fed by an automatic feeding system. Sixteen characteristics of the raw data set have been extracted through feature engineering for 0.5 min, 1.0 min, 1.5 min and 2.0 min, respectively, in accordance with the mean, peak, minimum and variability of each of the different time window scales. Furthermore, the features extracted have been evaluated through principal component analysis (PCA) both for dimension reduction and PCA with varimax rotation. The details were then categorized using support vector machine (SVM), K-NN and random forest tree (RF) classifiers. The best identification accuracy was shown with eight described features in the varimax-based PCA. The forecast results based on the K-NN model built on selected data characteristics showed a level of 96.5% indicating that the characteristics analysed were crucial to classifying the actions of hunger among fisheries.

[abstract] [url] [BibTeX]

2019

M. Carletti, C. Masiero, A. Beghi, G.A. Susto. **A deep learning approach for anomaly detection with industrial time series data: a refrigerators manufacturing case study.** *Procedia Manufacturing*, vol. 38pp. 233-240, 2019
Abstract:

We propose a Deep Learning (DL)-based approach for production performance forecasting in fresh products packaging. On the one hand, this is a very demanding scenario where high throughput is mandatory; on the other, due to strict hygiene requirements, unexpected downtime caused by packaging machines can lead to huge product waste. Thus, our aim is predicting future values of key performance indexes such as Machine Mechanical Efficiency (MME) and Overall Equipment Effectiveness (OEE). We address this problem by leveraging DL-based approaches and historical production performance data related to measurements, warnings and alarms. Different architectures and prediction horizons are analyzed and compared to identify the most robust and effective solutions. We provide experimental results on a real industrial case, showing advantages with respect to current policies implemented by the

industrial partner both in terms of forecasting accuracy and maintenance costs. The proposed architecture is shown to be effective on a real case study and it enables the development of predictive services in the area of Predictive Maintenance and Quality Monitoring for packaging equipment providers.

[abstract] [url] [BibTeX]

M. Maggipinto, A. Beghi, G.A. Susto. **A Deep Learning-based Approach to Anomaly Detection with 2-Dimensional Data in Manufacturing.** *International Conference on Industrial Informatics (INDIN)*, pp. 187 -- 191, 2019
Abstract:

In modern manufacturing scenarios, detecting anomalies in production systems is pivotal to keep high-quality standards and reduce costs. Even in the Industry 4.0 context, realworld monitoring systems are often simple and based on the use of multiple univariate control charts. Data-driven technologies offer a whole range of tools to perform multivariate data analysis that allow to implement more effective monitoring procedures. However, when dealing with complex data, common data-driven methods cannot be directly used, and a feature extraction phase must be employed. Feature extraction is a particularly critical operation, especially in anomaly detection tasks, and it is generally associated with information loss and low scalability. In this paper we consider the task of Anomaly Detection with twodimensional, image-like input data, by adopting a Deep Learningbased monitoring procedure, that makes use of convolutional autoencoders. The procedure is tested on real Optical Emission Spectroscopy data, typical of semiconductor manufacturing. The results show that the proposed approach outperforms classical feature extraction procedures.

[abstract] [BibTeX]

G.A. Susto, L. Vettore, G. Zambonin, F. Altinier, D. Beninato, T. Girotto, M. Rampazzo, A. Beghi. **A Machine Learning-based Soft Sensor for Laundry Load Fabric Typology Estimation in Household Washer-Dryers.** *5th IFAC International Conference on Intelligent Control and Automation Sciences*, 2019 [BibTeX]

N. Bargellesi, M. Carletti, A. Cenedese, G.A. Susto, M. Terzi. **A Random Forest-based Approach for Hand Gesture Recognition with Wireless Wearable Motion Capture Sensors.** *5th IFAC International Conference on Intelligent Control and Automation Sciences*, 2019
Abstract:

Gesture Recognition has a prominent importance in smart environment and home automation. Thanks to the availability of Machine Learning approaches it is possible for users to define gestures that can be associated with commands for the smart environment. In this paper we propose a Random Forest-based approach for Gesture Recognition of hand movements starting from wireless wearable motion capture data. In the presented approach, we evaluate different feature extraction procedures to handle gestures and data with different duration. To enhance reproducibility of our results and to foster research in the Gesture Recognition area, we share the dataset that we have collected and exploited for the present work.

[abstract] [url] [BibTeX]

G. Zambonin, F. Altinier, A. Beghi, L.D.S. Coelho, T. Girotto, M. Rampazzo, G. Reynoso-Meza, G.A. Susto. **Data-Driven Models for the Determination of Laundry Moisture Content in a Household Laundry Treatment Dryer Appliance.** *Lecture Notes in Control and Information Sciences –*

Proceedings, 2019
Abstract:

Two methods based on Regression are presented to determine the moisture content of items, e.g. clothes and the like, which are introduced in a household laundry dryer appliance. The aim of this work is to develop Soft Sensors (SS) for a household Heat Pump Washer-Dryer (WD-HP) to provide an estimation of the desired signal (the laundry moisture during drying) avoiding the use of additional physical sensors with the goal of improving the current performance in terms of precision and energy consumption of the automatic drying cycle end and using the machine equipment already available. On an algorithmic point of view, the SS developed in this work exploits regularization methods and Genetic Programming for Symbolic Regression in order to find suitable models for the purpose at hand. Proposed approaches have been tested on real data provided by an industrial partner.

[abstract] [pdf] [BibTeX]

L. Brunelli, C. Masiero, D. Tosato, A. Beghi, G.A. Susto. **Deep Learning-based Production Forecasting in Manufacturing: a Packaging Equipment Case Study.** *Procedia Manufacturing*, vol. 38pp. 248-255, 2019
Abstract:

We propose a Deep Learning (DL)-based approach for production performance forecasting in fresh products packaging. On the one hand, this is a very demanding scenario where high throughput is mandatory; on the other, due to strict hygiene requirements, unexpected downtime caused by packaging machines can lead to huge product waste. Thus, our aim is predicting future values of key performance indexes such as Machine Mechanical Efficiency (MME) and Overall Equipment Effectiveness (OEE). We address this problem by leveraging DL-based approaches and historical production performance data related to measurements, warnings and alarms. Different architectures and prediction horizons are analyzed and compared to identify the most robust and effective solutions. We provide experimental results on a real industrial case, showing advantages with respect to current policies implemented by the industrial partner both in terms of forecasting accuracy and maintenance costs. The proposed architecture is shown to be effective on a real case study and it enables the development of predictive services in the area of Predictive Maintenance and Quality Monitoring for packaging equipment providers.

[abstract] [BibTeX]

M. Maggipinto, A. Beghi, S. McLoone, G.A. Susto. **DeepVM: A Deep Learning-based Approach with Automatic Feature Extraction for 2D Input Data Virtual Metrology.** *Journal of Process Control*, vol. 84pp. 24-34, 2019

Abstract:

Industry 4.0 encapsulates methods, technologies, and procedures that transform data into informed decisions and added value inan industrial context. In this regard, technologies such as Virtual Metrology or Soft Sensing have gained much interest in thelast two decades due to their ability to provide valuable knowledge for production purposes at limited added expense. However,these technologies have struggled to achieve wide-scale industrial adoption, largely due to the challenges associated with handlingcomplex data structures and the feature extraction phase of model building. This phase is generally hand-engineered and basedon specific domain knowledge, making it time consuming, difficult to automate, and prone to loss of information, thus ultimatelylimiting portability. Moreover, in the presence of complex data structures, such as 2-dimensional input data, there are no establishedprocedures for feature extraction. In this paper, we present a Deep Learning approach for Virtual Metrology, called DeepVM,that exploits semi-supervised feature extraction based on Convolutional Autoencoders. The proposed approach is demonstratedusing a real world semiconductor manufacturing dataset where the Virtual Metrology input data is 2-dimensional Optical EmissionSpectrometry data. The feature extraction method is tested with different types of state-of-the-art autoencoder.

[abstract] [url] [BibTeX]

L. Meneghetti, G.A. Susto, S. Del Favero. **Detection of insulin pump malfunctioning to improve safety in artificial pancreas using unsupervised algorithms.** *Journal of Diabetes Science and Technology*, 2019

Abstract:

Background:

Recent development of automated closed-loop (CL) insulin delivery systems, the so-called artificial pancreas (AP), improved the quality of type 1 diabetes (T1D) therapy. As new technologies emerge, patients put increasing trust in their therapeutic devices; therefore, it becomes increasingly important to detect malfunctioning affecting such devices. In this work, we explore a new paradigm to detect insulin pump faults (IPFs) that use unsupervised anomaly detection.

Methods:

We generated CL data corrupted with IPFs using the latest version of the T1D Padova/UVA simulator. From the data, we extracted several features capable to describe the patient dynamics and making more apparent suspicious data portions. Then, a feature selection is performed to determine the optimal feature set. Finally, the performance of several popular unsupervised anomaly detection algorithms is analyzed and compared on the identified optimal feature set.

Results:

Using the identified optimal configuration, the best performance is obtained by the Histogram-Based Outlier Score (HBOS) algorithm, which detected 87% of the IPF with only 0.08 false positives per day on average. Isolation forest is the best algorithm that offers more conservative performances, detection of 85% of the faults but only 0.06 false positives per day on average.

Conclusion:

Unsupervised anomaly detection algorithms can be used effectively to detect IPFs and improve the safety of the AP. Future studies will be dedicated to test the presented method inside dedicated clinical trials.

M. Carletti, C. Masiero, A. Beghi, G.A. Susto. **Explainable Machine Learning in Industry 4.0: Evaluating Feature Importance in Anomaly Detection to Enable Root Cause Analysis.** *2019 IEEE International Conference on Systems, Man, and Cybernetics*, 2019

Abstract:

In the past recent years, Machine Learning methodologies have been applied in countless application areas. In particular, they play a key role in enabling Industry4.0. However, one of the main obstacles to the diffusion of Machine Learning-based applications is related to the lack of interpretability of most of these methods. In this work, we propose an approach for defining a ‘feature importance’ in Anomaly Detection problems. Anomaly Detection is an important Machine Learning task that has an enormous

applicability in industrial scenarios. Indeed, it is extremely relevant for the purpose of quality monitoring. Moreover, it is often the first step towards the design of a Machine Learning based smart monitoring solutions because Anomaly Detection can be implemented without the need of labelled data. The proposed feature importance evaluation approach is designed for Isolation Forest, one of the most commonly used algorithm for Anomaly Detection. The efficacy of the proposed method is tested on synthetic and real industrial datasets.

[abstract] [url] [BibTeX]

A. Purpura, C. Masiero, G. Silvello, G.A. Susto. **Feature Selection for Emotion Classification.** *10th Italian Information Retrieval Workshop (IIR)*, 2019 [BibTeX]

A. Razman, A.S.A. Ghani, A. Cenedese, F.A. Adnan, G.A. Susto, K.M. Ismail, R.M. Musa, Y. Mukai, Z. Taha, A. Majeed. **Hunger Classification of Lates Calcarifer by means of an automated feeder and image processing.** *Computers and Electronics in Agriculture*, vol. 1632019
Abstract:

In an automated demand feeder system, underlining the parameters that contribute to fish hunger is crucial in order to facilitate an optimised food allocation to the fish. The present investigation is carried out to classify the hunger state of *Lates calcarifer*. A video surveillance technique is employed for data collection. The video was taken throughout the daytime, and the fish were fed through an automated feeding system. It was demonstrated through this investigation that the use of such automated system does contribute towards a higher specific growth rate percentage of body weight as well as the total length by approximately 26.00% and 15.00%, respectively against the conventional time-based method. Sixteen features were feature engineered from the raw dataset into window sizes ranging from 0.5?min, 1.0?min, 1.5?min and 2.0?min, respectively coupled with the mean, maximum, minimum and variance for each of the distinctive temporal window sizes. In addition, the extracted features were analysed through Principal Component Analysis (PCA) for dimensionality reduction as well as PCA with varimax rotation. The data were then classified using a Support Vector Machine (SVM), *k*-Nearest Neighbor (*k*-NN) and Random Forest Tree models. It was demonstrated that the varimax based PCA yielded the highest classification accuracy with eight identified features. The prediction results based of the developed *k*-NN model on the selected features on the test data exhibited a classification rate of 96.5% was achieved suggesting that the features examined are non-trivial in classifying the fish hunger behaviour.

[abstract] [url] [BibTeX]

M. Maggipinto, E. Pesavento, F. Altinier, G. Zambonin, A. Beghi, G.A. Susto. **Laundry Fabric Classification in Vertical AxisWashing Machines using Data-driven Soft Sensors.** *Energies*, vol. 12(21), 2019
Abstract:

Embedding household appliances with smart capabilities is becoming common practice among major fabric-care producers that seek competitiveness on the market by providing more efficient and easy-to-use products. In Vertical Axis Washing Machines (VA-WM), knowing the laundry composition is fundamental to setting the washing cycle properly with positive impact both on energy/water consumption and on washing performance. An indication of the load typology composition (cotton, silk, etc.) is typically provided by the user through a physical selector that, unfortunately, is often placed by the user on the most general setting due to the discomfort of manually changing configurations. An automated mechanism to determine such key information would thus provide increased user experience, better washing performance, and reduced consumption; for this reason, we present here a data-driven soft

sensor that exploits physical measurements already available on board a commercial VA-WM to provide an estimate of the load typology through a machine-learning-based statistical model of the process. The proposed method is able to work in a resource-constrained environment such as the firmware of a VA-WM.

[abstract] [url] [BibTeX]

T. Barbariol, E. Feltresi, G.A. Susto. **Machine Learning approaches for Anomaly Detection in Multiphase Flow Meters.** *5th IFAC International Conference on Intelligent Control and Automation Sciences*, 2019 [BibTeX]

G. Zambonin, F. Altinier, A. Beghi, L.D.S. Coelho, N. Fiorella, T. Girotto, M. Rampazzo, G. Reynoso-Meza, G.A. Susto. **Machine Learning-based Soft Sensors for the Estimation of Laundry Moisture Content in Household Dryer Appliances.** *Energies*, vol. 20(12), pp. 1 -- 24, 2019
Abstract:

The aim is to develop soft sensors (SSs) to provide an estimation of the laundry moisture of clothes introduced in a household Heat Pump Washer–Dryer (WD-HP) appliance. The developed SS represents a cost-effective alternative to physical sensors, and it aims at improving the WD-HP performance in terms of drying process efficiency of the automatic drying cycle. To this end, we make use of appropriate Machine Learning models, which are derived by means of Regularization and Symbolic Regression methods. These methods connect easy-to-measure variables with the laundry moisture content, which is a difficult and costly to measure variable. Thanks to the use of SSs, the laundry moisture estimation during the drying process is effectively available. The proposed models have been tested by exploiting real data through an experimental test campaign on household drying machines.

[abstract] [url] [BibTeX]

A. Purpura, M. Maggipinto, G. Silvello, G.A. Susto. **Probabilistic Word Embeddings in Neural IR: A Promising Model That Does Not Work as Expected (For Now).** *5th ACM SIGIR International Conference on the Theory of Information Retrieval (ICTIR)*, 2019 [BibTeX]

A. Dalla Libera, M. Terzi, A. Rossi, G.A. Susto, R. Carli. **Robot kinematic structure classification from time series of visual data.** *2019 European Control Conference*, 2019
Abstract:

In this paper we present a novel algorithm to solve the robot kinematic structure identification problem. Given a time series of data, typically obtained processing a set of visual observations, the proposed approach identifies the ordered sequence of links associated to the kinematic chain, the joint type interconnecting each couple of consecutive links, and the input signal influencing the relative motion. Compared to the state of the art, the proposed algorithm has reduced computational costs, and is able to identify also the joints' type sequence.

[abstract] [BibTeX]

A. Purpura, C. Masiero, G. Silvello, G.A. Susto. **Supervised Lexicon Extraction for Emotion Classification.** *Proceedings of the 28th International Conference on World Wide Web Companion*, pp. 1071 - 1078, 2019
Abstract:

Emotion Classification (EC) aims at assigning an emotion label to a textual document with two inputs – a set of emotion labels (e.g. anger, joy, sadness) and a document collection. The best performing approaches for EC are dictionary-based and suffer from two main limitations: (i) the out-of-vocabulary (OOV) keywords problem and (ii) they cannot be used across heterogeneous domains. In this work, we propose a way to overcome these limitations with a supervised approach based on TF-IDF indexing and Multinomial Linear Regression with Elastic-Net regularization to extract an emotion lexicon and classify short documents from diversified domains. We compare the proposed approach to state-of-the-art methods for document representation and classification by running an extensive experimental study on two shared and heterogeneous data sets.

[abstract] [url] [BibTeX]

T. Barbariol, E. Feltresi, G.A. Susto. **Validity and consistency of MPFM data through a Machine learning-based system.** *37th International North Sea Flow Measurement Workshop*, 2019 [BibTeX]

M. Maggipinto, G.A. Susto, F. Zocco, S. McLoone. **What are the Most Informative Data for Virtual Metrology? A use case on Multi-Stage Processes Fault Prediction.** *IEEE Conference on Automation Science and Engineering*, 2019 [BibTeX]

2018

M. Maggipinto, M. Terzi, C. Masiero, A. Beghi, G.A. Susto. **A Computer Vision-inspired Deep Learning Architecture for Virtual Metrology modeling with 2-Dimensional Data.** *IEEE Transactions on Semiconductor Manufacturing*, vol. 31(3), pp. 376 - 384, 2018
Abstract:

The rise of Industry 4.0 and data-intensive manufacturing makes Advanced Process Control (APC) applications more relevant than ever for process/production optimization, related costs reduction, and increased efficiency. One of the most important APC technologies is Virtual Metrology (VM). VM aims at exploiting information already available in the process/system under exam, to estimate quantities that are costly or impossible to measure. Machine Learning approaches are the foremost choice to design VM solutions. A serious drawback of traditional Machine Learning methodologies is that they require a features extraction phase that generally limits the scalability and performance of VM solutions. Particularly, in presence of multi-dimensional data, the feature extraction process is based on heuristic approaches that may capture features with poor predictive power. In this work, we exploit modern Deep Learning-based technologies that are able to automatically extract highly informative features from the data, providing more accurate and scalable VM solutions. In particular, we exploit Deep Learning architectures developed in the realm of Computer Vision to model data that have both spatial and time evolution. The proposed methodology is tested on a real industrial dataset related to Etching, one of the most important Semiconductor Manufacturing processes. The dataset at hand contains Optical Emission Spectroscopy data and it is paradigmatic of the feature extraction problem in VM under examination.

[abstract] [url] [BibTeX]

M. Maggipinto, C. Masiero, A. Beghi, G.A. Susto. **A Convolutional Autoencoder Approach for Feature Extraction in Virtual Metrology.** *Procedia Manufacturing, 28th International Conference on Flexible Automation and Intelligent Manufacturing*, vol. 17pp. 126-133, 2018
Abstract:

Exploiting the huge amount of data collected by industries is definitely one of the main challenges of the so-called Big Data era. In this sense, Machine Learning has gained growing attention in the scientific community, as it allows to extract valuable information by means of statistical predictive models trained on historical process data. In Semiconductor Manufacturing, one of the most extensively employed data-driven applications is Virtual Metrology, where a costly or unmeasurable variable is estimated by means of cheap and easy to obtain measures that are already available in the system. Often, these measures are multi-dimensional, so traditional Machine Learning algorithms cannot handle them directly. Instead, they require feature extraction, that is a preliminary step where relevant information is extracted from raw data and converted into a design matrix. Features are often hand-engineered and based on specific domain knowledge. Moreover, they may be difficult to scale and prone to information loss, affecting the effectiveness and maintainability of machine learning procedures. In this paper, we present a Deep Learning method for semi-supervised feature extraction based on Convolutional Autoencoders that is able to overcome the aforementioned problems. The proposed method is tested on a real dataset for Etch rate estimation. Optical Emission Spectrometry data, that exhibit a complex bi-dimensional time and wavelength evolution, are used as input.

[abstract] [url] [BibTeX]

G.A. Susto, M. Maggipinto, F. Zocco, S. McLoone. **A Dynamic Sampling Approach for Cost Reduction in Semiconductor Manufacturing.** *Procedia Manufacturing, 28th International Conference on Flexible Automation and Intelligent Manufacturing*, vol. 17pp. 1031-1038, 2018
Abstract:

In semiconductor manufacturing, metrology is generally a high cost, non-value added operation that impacts significantly on cycle time. As such, reducing wafer metrology continues to be a major target in semiconductor manufacturing efficiency initiatives. Data-driven spatial dynamic sampling methodologies are here compared. Such strategies aim at minimizing the number of sites that need to be measured across a wafer surface while maintaining an acceptable level of wafer profile reconstruction accuracy. The Spatial Dynamic Sampling approaches are based on analyzing historical metrology data to determine, from a set of candidate wafer sites, the minimum set of sites that need to be monitored in order to reconstruct the full wafer profile using statistical regression techniques. Spatial Dynamic sampling is then implemented in various strategies that guarantee coverage of all the possible sites in a given set of process iteration. In this way, the risk of not detecting previously unseen process behavior is mitigated. In this work, we demonstrate the efficacy of spatial dynamic sampling methodologies using both simulation studies and metrology data from a semiconductor manufacturing process.

[abstract] [url] [BibTeX]

G.A. Susto, M. Terzi, C. Masiero, S. Pampuri, A. Schirru. **A Fraud Detection Decision Support System via Human On-line Behavior Characterization and Machine Learning.** *1st International Conference on Artificial Intelligence for Industries (AI4I)*, pp. 9-14, 2018
Abstract:

On-line and phone banking frauds are responsible for millions of dollars loss every year. In this work, we propose a Machine Learning-based Decision Support System to automatically associate a risk factor to each transaction performed through an on-line/mobile banking system. The proposed approach has a hierarchical architecture: First, an unsupervised Machine Learning module is used to detect abnormal patterns or wrongly labeled transactions; then, a supervised module provides a risk factor for the transactions that were not marked as anomalies in the previous step. Our solution exploits personal and historical information about the user, statistics that describe online traffic generated on the online/mobile

banking system, and features extracted from motives of the transactions. The proposed approach deals with dataset unbalancing effectively. Moreover, it has been validated on a large database of transactions and on-line traffic provided by an industrial partner.

[abstract] [url] [BibTeX]

G.A. Susto, A. Schirru, S. Pampuri, A. Beghi, G. De nicolao. **A Hidden-Gamma Model-Based Filtering and Prediction Approach for Monotonic Health Factors in Manufacturing.** *Control Engineering Practice*, vol. 74pp. 84-94, 2018
Abstract:

In the context of Smart Monitoring and Fault Detection and Isolation in industrial systems, the aim of Predictive Maintenance technologies is to predict the happening of process or equipment faults. In order for a Predictive Maintenance technology to be effective, its predictions have to be both accurate and timely for taking strategic decisions on maintenance scheduling, in a cost-minimization perspective. A number of Predictive Maintenance technologies are based on the use of “health factors” quantitative indicators associated with the equipment wear that exhibit a monotone evolution. In real industrial environment, such indicators are usually affected by measurement noise and non-uniform sampling time. In this work we present a methodology, formulated as a stochastic filtering problem, to optimally predict the evolution of the aforementioned health factors based on noisy and irregularly sampled observations. In particular, a hidden Gamma process model is proposed to capture the nonnegativity and nonnegativity of the derivative of the health factor. As such filtering problem is not amenable to a closed form solution, a numerical Monte Carlo approach based on particle filtering is here employed. An adaptive parameter identification procedure is proposed to achieve the best trade-off between promptness and low noise sensitivity. Furthermore, a methodology to identify the risk function associated to the observed equipment based on previous maintenance data is proposed. The present study is motivated and tested on a real industrial Predictive Maintenance problem in semiconductor manufacturing, with reference to a dry etching equipment.

[abstract] [url] [pdf] [BibTeX]

N. Normani, A. Urru, L. Abraham, M. Walsh, S. Tedesco, A. Cenedese, G.A. Susto, B. O'Flynn. **A Machine Learning Approach for Gesture Recognition with a Lensless Smart Sensor System.** *15th International Conference on Wearable and Implantable Body Sensor Networks*, pp. 136--139, 2018
Abstract:

Hand motion tracking traditionally re- quires highly complex and expensive systems in terms of energy and computational demands. A low-power, low-cost system could lead to a revolution in this field as it would not require complex hardware or additional equipment. The present paper exploits the Multiple Point Tracking algorithm developed at the Tyndall National Institute as the basic algorithm to perform a series of gesture recognition tasks. The hardware relies upon the combination of a stereoscopic vision of two novel Lensless Smart Sensors (LSS) combined with IR filters and five hand-held LEDs to track. Track- ing common gestures generates a six-gestures dataset, which is then employed to train three Machine Learning models: k-Nearest Neighbors, Support Vector Machine and Random Forest. An offline analysis highlights how different LEDs’ positions on the hand affect the clas- sification accuracy. The comparison shows how the Random Forest outperforms the other two models with a classification accuracy of 90-91%.

[abstract] [url] [BibTeX]

S. McLoone, A.B. Johnston, G.A. Susto. **A Methodology for Efficient Dynamic Spatial Sampling and Reconstruction of Wafer Profiles.** *IEEE Transactions on Automation Science and Engineering*, vol. 15(4), pp. 1692-1703, 2018
Abstract:

In semiconductor manufacturing, metrology is generally a high cost nonvalue-added operation that significantly impacts on cycle time. As such, reducing wafer metrology continues to be a major target in semiconductor manufacturing efficiency initiatives. A novel data-driven spatial dynamic sampling methodology is presented that minimizes the number of sites that need to be measured across a wafer surface while maintaining an acceptable level of wafer profile reconstruction accuracy. The methodology is based on analyzing historical metrology data using forward selection component analysis (FSCA) to determine, from a set of candidate wafer sites, the minimum set of sites that need to be monitored in order to reconstruct the full wafer profile using statistical regression techniques. Dynamic sampling is then implemented by clustering unmeasured sites in accordance with their similarity to the FSCA selected sites and temporally selecting a different sample from each cluster. In this way, the risk of not detecting previously unseen process behavior is mitigated. We demonstrate the efficacy of the proposed methodology using both simulation studies and metrology data from a semiconductor manufacturing process.

[abstract] [url] [pdf] [BibTeX]

G.A. Susto, G. Zambonin, F. Altinier, E. Pesavento, A. Beghi. **A Soft Sensing approach for Clothes Load Estimation in Consumer Washing Machines.** *2nd IEEE Conference on Control Technology and Applications (CCTA)*, 2018
Abstract:

Fabric care home appliances are pervasive inhouses worldwide and manufactures are constantly working for improving product performance, efficiency, and usability. From a manufacturing perspective, increase of performancehas to be attained while minimizing the increase of production costs. In this context, a Soft Sensor for estimating the clothes load weight in a horizontal axis household washing machines ishere presented. The proposed Soft Sensor is based on Machine Learning approaches. Several methodologies, both time-seriesand feature-based, are employed and compared. The approach has been tested on real world data on commercial household washing machines.

[abstract] [url] [BibTeX]

L. Meneghetti, M. Terzi, G.A. Susto, S. Del Favero, C. Cobelli. **Fault Detection in Artificial Pancreas: A Model-Free approach.** *Conference on Decision and Control (CDC)*, pp. 303-308, 2018
Abstract:

Subjects affected by Type I Diabetes (T1D) are constantly confronted with the complicated problem of administering themselves an adequate amount of insulin, so as to keep their blood-glucose concentration in a nearly physiological range. Recently, powerful technological tools have been developed to better face this challenge, in particular the so-called Artificial Pancreas (AP). Unluckily, the AP actuator, an insulin

pump, is subject to faults, with potential serious consequences for subjects' safety. This calls for the development of advanced fault detection (FD) methods, leveraging the unprecedented data availability in this application. In this paper we tackle the problem of detecting insulin pump malfunctioning using a model-free approach, so that the complex sub-task of identifying a model of patients physiology is avoided. Moreover, we employed unsupervised methods since labeled data are hardly available in practice. The adopted data-driven Anomaly Detection (AD) methods are Local Outlier Factor and Connectivity-based Outlier Factor. The methods are applied on a feature set able to account for the physiological dynamics of T1D patients. The proposed algorithms are tested on a synthetic dataset, generated using the “UVA/Padova Type 1 Diabetic Simulator”, an accurate nonlinear computer simulator of the T1D subject physiology. Both methods show precision ~75% and recall ~60%• The described approach is suitable both for embedding in medical devices, such as the AP, and implementation in cloud-based remote monitoring systems.

[abstract] [url] [BibTeX]

G.A. Susto, M. Maggipinto, G. Zannon, F. Altinier, E. Pesavento, A. Beghi. **Machine Learning-based Laundry Weight Estimation for Vertical Axis Washing Machines.** *European Control Conference (ECC2018)*, pp. 3179 - 3184, 2018
Abstract:

In laundry treatment appliances, the weight ofthe laundry loaded by the user inside the drum dramaticallyaffects the operating behavior. Therefore, it is important toobtain a good estimate of the said quantity in order tocorrectly configure the machine before the washing/dryingstarts. In Vertical Axis Washing Machinesthe laundry weightis computed by exploiting the quantity of water absorbed bythe clothes. However, such approach does not grant accurateresults because the water absorption depends on the clothesfabric. For this reason, we propose a Soft Sensing approachfor weight estimation that exploits the information obtainedfrom physical sensors available on board without added costs.Data-driven Soft Sensors are developed, where, using MachineLearning techniques, a statistical model of the phenomenon ofinterest is created from a set of sample data.

[abstract] [url] [BibTeX]

S. McLoone, F. Zocco, M. Maggipinto, G.A. Susto. **On Optimising Spatial Sampling Plans for Wafer Profile Reconstruction.** *3rd IFAC Conference on Embedded Systems, Computational Intelligence and Telematics in Control*, 2018
Abstract:

Wafer metrology is an expensive and time consuming activity in semiconductor manufacturing, but is essential to support advanced process control, predictive maintenance and other quality assurance functions. Keeping metrology to a minimum is therefore desirable. In the context of spatial sampling of wafers this has motivated the development of a number of data driven methodologies for optimizing wafer sampling plans. Two such methodologies are considered in this paper. The first combines Principal Component Analysis and Minimum Variance Estimation (PCA-MVE) to determine an optimum subset of sites from historical metrology data from a larger candidate set, while the second employs Forward Selection Component Analysis (FSCA), an unsupervised variable selection technique, to achieve the same result. We investigate the relationship between these two approaches and show that under specific conditions a regularized extension of FSCA, denoted FSCA-R, and PCA-MVE are equivalent. Numerical studies using simulated data verify the equivalence conditions. Results for simulated and industrial case studies show that the improvement in wafer profile reconstruction accuracy with regularization is not statistically significant for the case studies considered, and that when PCA-MVE is implemented with a

denoising step as originally proposed, it is outperformed by FSCA. Therefore, FSCA is the preferred methodology.

[abstract] [url] [BibTeX]

G. Zambonin, F. Altinier, L. Corso, A. Beghi, G.A. Susto. **Soft Sensors for Estimating Laundry Weight in Household Heat Pump Tumble Dryers.** *Conference on Automation Science and Engineering (CASE)*, 2018
Abstract:

The laundry weight of the loaded in the drum of a laundry treatment machine is an important piece of information; laundry weight can be used to set various washing/drying cycle parameters and to optimize performances and efficiency. Unfortunately, dedicated weight sensors cannot be included in consumer laundry equipment given the related costs. For this reason, we present in this work a soft sensor approach for estimating laundry weight based on sensors already in place in a laundry treatment equipment; in particular, we consider here a heat pump tumble dryer as case study. The proposed soft sensor is based on regularization, a popular approach in Machine Learning to provide models without overfitting the training data. Different studies are provided in this work, by considering different constrains on timing and complexity of the Soft Sensor solution. The developed Soft Sensors have been tested on laboratory data provided by an industrial partner.

[abstract] [url] [BibTeX]

A. Purpura, C. Masiero, G.A. Susto. **WS4ABSA: an NMF-based Weakly-Supervised Approach for Aspect-Based Sentiment Analysis with Application to Online Reviews.** *Lecture Notes in Computer Science*, pp. 386--401, 2018
Abstract:

The goal of Aspect-Based Sentiment Analysis is to identify opinions regarding specific targets and the corresponding sentiment polarity in a document. The proposed approach is designed for real-world scenarios, where the amount of available information and annotated data is often too limited to train supervised models. We focus on the two core tasks of Aspect-Based Sentiment Analysis: aspect and sentiment polarity classification. The first task – which consists in the identification of the opinion targets in a document – is tackled by means of a weakly-supervised technique based on Non-negative Matrix Factorization. This strategy allows users to easily embed some a priori domain knowledge by means of short seed terms lists. Experimental results on publicly available data sets related to online reviews suggest that the proposed approach is very flexible and can be easily adapted to different languages and domains.

[abstract] [url] [BibTeX]

2017

G.A. Susto. **A Dynamic Sampling Strategy based on Confidence Level of Virtual Metrology Predictions.** *IEEE/SEMI Advanced Semiconductor Manufacturing Conference*, pp. 78-83, 2017
Abstract:

Metrology is a costly and time consuming activity in semiconductor fabrication; for this reason, Dynamic Sampling strategies and Virtual Metrology approaches have proliferated in the past recent years. Both Dynamic Sampling strategies and Virtual Metrology techniques aim at minimizing the amount of performed measures while keeping acceptable levels of production quality. In this work we study a Dynamic Sampling scheme recently proposed in literature that takes into account the availability of a Virtual Metrology module in the advanced process control architecture. The idea supporting the investigated strategy is based on the availability of a confidence level in the Virtual Metrology predictions; in our implementation of this scheme, this is achieved by exploiting a popular Machine Learning approach for supervised learning tasks, called Random Forests. The aforementioned scheme is tested on a real industrial dataset related to Plasma Etching and it is compared with classical metrology strategies.

[abstract] [url] [BibTeX]

M. Terzi, A. Cenedese, G.A. Susto. **A multivariate symbolic approach to activity recognition for wearable applications.** *IFAC World Congress 2017*, pp. 16435-16440, 2017
Abstract:

With the aim of monitoring human activities (in critical tasks as well as in leisure and sport activities), wearable devices provide enhanced usability and seamless human experience with respect to other portable devices (e.g. smartphones). At the same time, though, wearable devices are more resource-constrained in terms of computational capability and memory, which calls for the design of algorithmic solutions that explicitly take into account these issues. In this paper, a symbolic approach for activity recognition with wearable devices is presented: the Symbolic Aggregate approXimation technique is here extended to multi-dimensional time series, in order to capture the mutual information of different dimensions. Moreover, a novel approach to identify gestures within activities is here presented. The performance of the proposed methodology is tested on the two heterogeneous datasets related to cross-country skiing and daily activities.

[abstract] [pdf] [BibTeX]

G.A. Susto, M. Terzi, A. Beghi. **Anomaly Detection Approaches for Semiconductor Manufacturing.** *Procedia Manufacturing*, *27th International Conference on Flexible Automation and Intelligent Manufacturing*, vol. 11pp. 2018-2024, 2017
Abstract:

Smart production monitoring is a crucial activity in advanced manufacturing for quality, control and maintenance purposes. Advanced Monitoring Systems aim to detect anomalies and trends; anomalies are

data patterns that have different data characteristics from normal instances, while trends are tendencies of production to move in a particular direction over time. In this work, we compare state-of-the-art ML approaches (ABOD, LOF, onlinePCA and osPCA) to detect outliers and events in high-dimensional monitoring problems. The compared anomaly detection strategies have been tested on a real industrial dataset related to a Semiconductor Manufacturing Etching process

[abstract] [url] [BibTeX]

G.A. Susto, A. Beghi, S. McLoone. **Anomaly Detection through on-line Isolation Forest: an Application to Plasma Etching.** *IEEE/SEMI Advanced Semiconductor Manufacturing Conference*, 2017
Abstract:

Advanced Monitoring Systems are fundamental in advanced manufacturing for control, quality and maintenance purposes. Nowadays, with the increasing availability of data in production and equipment, the need for high-dimensional Anomaly Detection techniques is thriving; anomalies are data patterns that have different data characteristics from normal production instances and that may be associated with faults or drifts in production. Tools for dealing with high-dimensional monitoring problems are provided by Machine Learning: in this paper, we test the performance of a state-of-the-art anomaly detection technique, called Isolation Forest, on a real industrial dataset related to Etching, one of the most important semiconductor manufacturing process. The monitoring has been performed exploiting Optical Spectroscopy Data.

[abstract] [url] [BibTeX]

M. Terzi, C. Masiero, A. Beghi, M. Maggipinto, G.A. Susto. **Deep Learning for Virtual Metrology: Modeling with Optical Emission Spectroscopy Data.** *IEEE 3rd International Forum on Research and Technologies for Society and Industry (RTSI)*, 2017
Abstract:

Virtual Metrology is one of the most prominentAdvanced Process Control applications in SemiconductorManufacturing. The goal of Virtual Metrology is to provideestimations of quantities that are important for production andto assess process quality, but are costly or impossible to bemeasured. Virtual Metrology solutions are based on MachineLearning approaches. The bottleneck of developing VirtualMetrology solutions is generally the feature extraction phase thatcan be time-consuming, and can deeply affect the estimationperformance. In particular, in presence of data with additionaldimensions, such as time, feature extraction is typicallyperformed by means of heuristic approaches that may pickfeatures with poor predictive capabilities. In this work, wepropose the usage of modern Deep Learning approaches tobypass manual feature extraction and to provide highperformanceautomatic Virtual Metrology modules. Theproposed methodology is tested on a real industrial datasetrelated to Etching. The dataset at hand contains OpticalEmission Spectroscopy data and it is paradigmatic of the featureextraction problem under examination.

[abstract] [url] [BibTeX]

F. Altinier, E. Pesavento, A. Beghi, G.A. Susto, G. Zambonin, G. Zannon. **Method for the Determination of a Laundry Weight in a Laundry Treatment Appliance.** (Pub. No.: WO/2017/144085 International Application No.: PCT/EP2016/053788), 2017
Abstract:

The invention relates to a method for the determination of a laundry weight in a laundry treatment appliance comprising: Selecting a laundry program in the laundry treatment appliance; Starting the selected laundry program; Sensing a plurality of parameters indicating operating conditions of the laundry treatment appliance during the laundry program; and Predicting a weight of the laundry present within the laundry treatment appliance based on said plurality of parameters by means of a data-driven soft sensor.

[abstract] [url] [BibTeX]

G.A. Susto, A. Cenedese, M. Terzi. **Big Data Application in Power Systems - Ch. 2.5.** *Time Series Classi cation Methods: Review and Applications to Power Systems Data.* 2017
Abstract:

The diffusion in Power Systems of distributed renewable energy resources, electric vehicles and controllable loads has made advanced monitoring systems fundamental to cope with the consequent disturbances in power flows; advanced monitoring systems can be employed for Anomaly Detection, Root Cause Analysis and Control purposes.

Several Machine Learning-based approaches have been developed in the past recent years to detect if a power system is running under anomalous conditions and, eventually, to classify such situation with respect to known problems.

One of the aspects that makes Power Systems challenging to be tackled, is that the monitoring has to be performed on streams of data that have a time series evolution; this issue is generally tackled by performing a features extraction procedure before the classi cation phase. The features extraction phase consists of translating the informative content of time series data into scalar quantities: such procedure may be a time-consuming step that requires the involvement of process experts to avoid loss of information in the making; moreover, extracted features designed to capture certain behaviors of the system, may not be informative under unseen conditions leading to poor monitoring performances.

A different type of data-driven approaches, that will be reviewed in this chapter, allow to perform classi cation directly on the raw time series data, avoiding the features extraction phase: among these approaches, Dynamic Time Warping and Symbolic-based methodologies have been widely applied in many application areas.

In the following, pros and cons of each approach will be discussed and practical implementation guidelines will be provided.

[abstract] [url] [BibTeX]

2016

A. Cenedese, G.A. Susto, M. Terzi. **A Parsimonious Approach for Activity Recognition with Wearable Devices: an Application to Cross-country Skiing.** *European Control Conference 2016 (ECC'16)*, pp. 2541-2546, 2016
Abstract:

With the aim of monitoring the human activity, wearable devices provide an enhanced usability and a seamless human experience with

respect to other portable devices (e.g. smartphones) in critical tasks as well as in leisure and sport activities. At the same time, though, wearable devices are more resource-constrained in terms of computational capability and memory, which calls for the design of algorithmic solutions that explicitly take into account these issues. In this paper, a parsimonious approach for activity recognition with wearable devices is presented. The methodology is based on Relevant Vector Machines (RVMs), a sparse machine learning framework for classification, and allows to tackle the activity recognition problem by identifying the two phases of Event Identification and Gesture Recognition. The performance of the presented methodology is tested on the interesting case study of cross- country skiing (classic style): such a dataset presents three different classes of gestures in addition to non-gesture activities and has been obtained by recording the training sessions of a heterogeneous set of executors in different environment conditions.

[abstract] [url] [BibTeX]

A. Cenedese, L. Minetto, G.A. Susto, M. Terzi. **A Symbolic Approach to Human Activity Recognition.** *5th International Workshop on Symbiotic Interaction*, 2016
Abstract:

In the context of activity recognition, wearable devices arenowadays the preferable hardware thanks to their usability, user expe-rience and performances; at the same time, these devices present limi-tations in terms of computational capability and memory, which forcethe algorithm design to be at the same time e□cient and simple. Inthis work, we adopt Symbolic Aggregate Approximation (SAX), a sym-bolic approach for information retrieval in time series data that allowsdimensionality and numerosity reduction; SAX is employed here, in com-bination with 1-Nearest Neighbor classi er, to identify activity phases incontinuous repetitive activities from inertial time-series data. The pro-posed approach is validated on a public activity recognition dataset.

[abstract] [BibTeX]

G.A. Susto, A. Beghi. **Dealing with Time-Series Data in Predictive Maintenance Problems.** *Emerging Technologies and Factory Automation*, 2016
Abstract:

In this paper an approach to deal with Predictive Maintenance (PdM) problems with time-series data is discussed. PdM is a important approach to tackle maintenance and it is gaining an increasing attention in advanced manufacturing to minimize scrap materials, downtime, and associated costs. PdM approaches are generally based on Machine Learning tools that require the availability of historical process and maintenance data. Given the exponential growth in data logging in modern equipment, time series dataset are increasingly available in PdM applications. To exploit time series data for PdM, a functional learning methodology, namely Supervised Aggregative Feature Extraction (SAFE), is here employed on a semiconductor manufacturing maintenance problem.

[abstract] [url] [BibTeX]

A. Cenedese, L. Minetto, G.A. Susto, M. Terzi. **Human Activity Recognition with Wearable Devices: A Symbolic Approach.** *PsychNology*, vol. 14(2-3), pp. 99-115, 2016
Abstract:

In the context of activity recognition, wearable devices are nowadays the preferable hardware thanks to their usability, user experience and performances; at the same time, these devices present limitations in terms of computational capability and memory, which force the algorithm design to be at the same time efficient and simple. In this work, we adopt Symbolic Aggregate Approximation (SAX), a symbolic approach for information retrieval in time series data that allows dimensionality and numerosity reduction; SAX is employed here, in combination with 1-Nearest Neighbor classifier, to identify activity phases in continuous repetitive activities from inertial time-series data. The proposed approach is validated on a cross-country skiing dataset and on a daily living activities dataset.

[abstract] [url] [BibTeX]

G.A. Susto, A. Schirru, S. Pampuri, S. McLoone. **Supervised Aggregative Feature Extraction for Big Data Time Series Regression.** *IEEE Transactions on Industrial Informatics*, vol. 12pp. 1243 - 1252, 2016
Abstract:

In many applications, and especially thosewhere batch processes are involved, a target scalar outputof interest is often dependent on one or more time seriesof data. With the exponential growth in data logging inmodern industries such time series are increasingly availablefor statistical modeling in soft sensing applications. In orderto exploit time series data for predictive modelling, it isnecessary to summarise the information they contain as aset of features to use as model regressors. Typically thisis done in an unsupervised fashion using simple techniquessuch as computing statistical moments, principalcomponents or wavelet decompositions, often leading tosignificant information loss and hence suboptimal predictivemodels. In this paper, a functional learning paradigm isexploited in a supervised fashion to derive continuous,smooth estimates of time series data (yielding aggregatedlocal information), while simultaneously estimating a continuousshape function yielding optimal predictions. Theproposed Supervised Aggregative Feature Extraction (SAFE)methodology can be extended to support nonlinear predictivemodels by embedding the functional learning framework ina Reproducing Kernel Hilbert Spaces setting. SAFE has anumber of attractive features including closed form solutionand the ability to explicitly incorporate first and secondorder derivative information. Using simulation studies and apractical semiconductor manufacturing case study we highlightthe strengths of the new methodology with respect tostandard unsupervised feature extraction approaches.

[abstract] [url] [BibTeX]

2015

A. Cenedese, G.A. Susto, G. Belgioioso, G.I. Cirillo, F. Fraccaroli. **Home Automation Oriented Gesture Classification From Inertial Measurements.** *IEEE Transactions on Automation Science and Engineering*, vol. 12(4), pp. 1200--1210, 2015
Abstract:

In this paper, a Machine Learning (ML) approach is presented that exploits accelerometers data to deal with gesture recognition (GR) problems. The proposed methodology aims at providing high accuracy

classi?cation for Home Automation systems, which are generally user independent, device independentand device orientation independent, an heterogeneous scenario that was not fully investigated in previous GR literature. The approach illustrated in this work is composed of three main steps: event identi?cation, feature extraction and ML-based classi?cation; elements of novelty of the proposed approach are:

1. a pre-processing phase based on Principal Component Analysis to increase the performance in real-world scenario conditions;

2.the development of parsimonious novel classi?cation techniques based on Sparse Bayesian Learning.

This methodology is tested on two datasets of 4 gesture classes (horizontal, vertical, circles and eight-shaped movements) and on a further dataset with 8 classes. In order to authentically describe a real-world Home Automation environment, the gesture movements are collected from more than 30 people who freely perform any gesture. It results a dictionary of 12 and 20 different movements respectivelyin the case of the 4-class and the 8-class databases.

[abstract] [url] [BibTeX]

G.A. Susto, A. Schirru, S. Pampuri, S. McLoone, A. Beghi. **Machine Learning for Predictive Maintenance: a Multiple Classifiers Approach.** *IEEE Transactions on Industrial Informatics*, vol. 11(3), pp. 812 - 820, 2015
Abstract:

In this paper a multiple classifier machine learning methodology for Predictive Maintenance (PdM) is presented. PdM is a prominent strategy for dealing with maintenance issues given the increasing need to minimize downtime and associated costs. One of the challenges with PdM is generating so called 'health factors' or quantitative indicators of the status of a system associated with a given maintenance issue, and determining their relationship to operating costs and failure risk. The proposed PdM methodology allows dynamical decision rules to be adopted for maintenance management and can be used with high-dimensionaland censored data problems. This is achieved by training multiple classification modules with different prediction horizons to provide different performance trade-offs in terms of frequency of unexpected breaks and unexploited lifetime and then employing this information in an operating cost based maintenance decision system to minimise expected costs. The effectiveness of the methodology is demonstrated using a simulated example and a benchmark semiconductor manufacturing maintenance problem.

[abstract] [url] [BibTeX]

G.A. Susto, S. Pampuri, A. Schirru, A. Beghi, G. De nicolao. **Multi-Step Virtual Metrology for Semiconductor Manufacturing: a Multilevel and Regularization Methods-based Approach.** *Computers & Operations Research*, vol. 53pp. 328–337, 2015
Abstract:

In semiconductor manufacturing, wafer quality control strongly relies on product monitoring and physical metrology. However, the involved metrology operations, generally performed by means of scanning electron microscopes, are particularly cost-intensive and time-consuming. For this reason, in

common practice a small subset of only a productive lot is measured at the metrology stations and it is devoted to represent the entire lot. Virtual Metrology (VM) methodologies are able to obtain reliable predictions of metrology results at process time, without actually performing physical measurements; this goal is usually achieved by means of statistical models and by linking process data and context information to target measurements. Since semiconductor manufacturing processes involve a high number of sequential operations, it is reasonable to assume that the quality features of a given wafer (such as layer thickness and critical dimensions) depend on the whole processing and not on the last step before measurement only. In this paper, we investigate the possibilities to enhance VM prediction accuracy by exploiting the knowledge collected from previous process steps. We present two different schemes of multi-step VM, along with dataset preparation indications; special consideration will be reserved to regression techniques capable of handling high-dimensional input spaces. The proposed multi-step approaches are tested on production data provided by a partner semiconductor manufacturing industry.

[abstract] [url] [BibTeX]

G.A. Susto, S. McLoone. **Slow Release Drug Dissolution Profile Prediction in Pharmaceutical Manufacturing: a Multivariate and Machine Learning Approach.** *11th IEEE Conference on Automation Science and Engineering*, pp. 1218-1223, 2015
Abstract:

Slow release drugs must be manufactured to meettarget speci?cations with respect to dissolution curve pro?les.In this paper we consider the problem of identifying thedrivers of dissolution curve variability of a drug from historicalmanufacturing data. Several data sources are considered: rawmaterial parameters, coating data, loss on drying and pellet sizestatistics. The methodology employed is to develop predictivemodels using LASSO, a powerful machine learning algorithmfor regression with high-dimensional datasets. LASSO providessparse solutions facilitating the identi?cation of the most importantcauses of variability in the drug fabrication process.The proposed methodology is illustrated using manufacturingdata for a slow release drug.

[abstract] [url] [BibTeX]

2014

G. Belgioioso, A. Cenedese, G.I. Cirillo, F. Fraccaroli, G.A. Susto. **A Machine Learning based Approach for Gesture Recognition from Inertial Measurements.** *IEEE 53rd Conference on Decision and Control*, pp. 4899--4904, 2014
Abstract:

The interaction based on gestures has become a prominent approach to interact with electronic devices. In this paper a Machine Learning (ML) based approach to gesture recognition (GR) is illustrated; the proposed tool is freestanding from user, device and device orientation. The tool has been tested on a heterogeneous dataset representative of a typical application of gesture recognition. In the present work two novel ML algorithms based on Sparse Bayesian Learning are tested versus other classification approaches already employed in literature (Support Vector Machine, Relevance Vector Machine, k-Nearest Neighbor, Discriminant Analysis). A second element of novelty is represented by a Principal Component Analysis- based approach, called *Pre-PCA*, that is shown to enhance gesture recognition with heterogeneous working conditions. Feature extraction techniques are also investigated: a Principal Component Analysis based approach is compared to Frame- Based Description methods.

[abstract] [url] [pdf] [BibTeX]

A. Beghi, L. Cecchinato, C. Corazzol, M. Rampazzo, F. Simmini, G.A. Susto. **A One-Class SVM Based Tool for Machine Learning Novelty Detection in HVAC Chiller Systems.** *19th World Congress of the International Federation of Automatic Control*, pp. 1953-1958, 2014
Abstract:

Faulty operations of Heating, Ventilation and Air Conditioning (HVAC) chiller systems can lead to discomfort for the occupants, energy wastage, unreliability and shorter equipment life. Such faults need to be detected early to prevent further escalation and energy losses. Commonly, data regarding unforeseen phenomena and abnormalities are rare or are not available at the moment of HVAC systems installation: for this reason in this paper an unsupervised One-Class SVM classifier employed as a novelty detection system to identify unknown status and possible faults is presented. The approach, that exploits Principal Component Analysis to accent novelties w.r.t. normal operations variability, has been tested on a HVAC literature dataset.

[abstract] [url] [BibTeX]

G.A. Susto, S. Pampuri, M. Zanon, A.B. Johnston, P.G. O'Hara, S. McLoone. **An Adaptive Machine Learning Decision System for Flexible Predictive Maintenance.** *Conference on Automation Science and Engineering*, pp. 806-811, 2014
Abstract:

Process monitoring and Predictive Maintenance (PdM) are gaining increasing attention in most manufacturing environments as a means of reducing maintenance related costs and downtime. This is especially true in industries that are data intensive such as semiconductor manufacturing. In this paper an adaptive PdM based flexible maintenance scheduling decision support system, which pays particular attention to associated opportunity and risk costs, is presented. The proposed system, which employs Machine Learning and regularized regression methods, exploits new information as it becomes available from newly processed components to refine remaining useful life estimates and associated costs and risks. The system has been validated on a real industrial dataset related to an Ion Beam Etching process for semiconductor manufacturing.

[abstract] [url] [BibTeX]

S. Pampuri, G.A. Susto, J. Wan, A.B. Johnston, P.G. O'Hara, S. McLoone. **Insight Extraction for Semiconductor Manufacturing Processes.** *Conference on Automation Science and Engineering*, pp. 786 - 791, 2014
Abstract:

In the semiconductor manufacturing environment it is very important to understand which factors have the most impact on process outcomes and to control them accordingly. This is usually achieved through design of experiments at process start-up and long term observation of production. As such it relies heavily on the expertise of the process engineer. In this work, we present an automatic approach to extracting useful insights about production processes and equipment based on state-of-the-art Machine Learning techniques. The main goal of this activity is to provide tools to process engineers to accelerate the learning-by-observation phase of process analysis. Using a Metal Deposition process as an example,

we highlight various ways in which the extracted information can be employed.

[abstract] [url] [BibTeX]

M. Zanon, G.A. Susto, S. McLoone. **Root Cause Analysis by a Combined Sparse Classification and Monte Carlo Approach.** *19th World Congress of the International Federation of Automatic Control*, pp. 1947-1952, 2014
Abstract:

Classification methods with embedded feature selection capability are very appealing for the analysis of complex processes since they allow the analysis of root causes even when the number of input variables is high. In this work, we investigate the performance of three techniques for classification within a Monte Carlo strategy with the aim of root cause analysis. We consider the naive Bayes classifier and the logistic regression model with two different implementations for controlling model complexity, namely, a LASSO-like implementation with a l1 norm regularization and a fully Bayesian implementation of the logistic model, the so called relevance vector machine. Several challenges can arise when estimating such models mainly linked to the characteristics of the data: a large number of input variables, high correlation among subsets of variables, the situation where the number of variables is higher than the number of available data points and the case of unbalanced datasets. Using an ecological and a semiconductor manufacturing dataset, we show advantages and drawbacks of each method, highlighting the superior performance in term of classification accuracy for the relevance vector machine with respect to the other classifiers. Moreover, we show how the combination of the proposed techniques and the Monte Carlo approach can be used to get more robust insights into the problem under analysis when faced with challenging modelling conditions.

[abstract] [url] [BibTeX]

2013

G.A. Susto, A. Schirru, S. Pampuri, D. Pagano, S. McLoone, A. Beghi. **A Predictive Maintenance System for Integral Type Faults based on Support Vector Machines: an Application to Ion Implantation.** *Automation Science and Engineering (CASE), 2013 IEEE International Conference on*, 2013
Abstract:

In semiconductor fabrication processes, effectivemanagement of maintenance operations is fundamental todecrease costs associated with failures and downtime. PredictiveMaintenance (PdM) approaches, based on statistical methodsand historical data, are becoming popular for their predictivecapabilities and low (potentially zero) added costs. We presenthere a PdM module based on Support Vector Machines forprediction of integral type faults, that is, the kind of failuresthat happen due to machine usage and stress of equipmentparts. The proposed module may also be employed as a healthfactor indicator. The module has been applied to a frequentmaintenance problem in semiconductor manufacturing industry,namely the breaking of the filament in the ion-source ofion-implantation tools. The PdM has been tested on a realproduction dataset.

[abstract] [url] [BibTeX]

G.A. Susto, A. Beghi. **A virtual metrology system based on least angle regression and statistical clustering.** *Applied Stochastic Models in Business and Industry*, vol. 29(4), pp. 362-376, 2013

Abstract:

In semiconductor manufacturing plants, monitoring physical properties of all wafers is crucial to maintain good yield and high quality standards. However, such an approach is too costly, and in practice, only few wafers in a lot are actually monitored. Virtual metrology (VM) systems allow to partly overcome the lack of physical metrology. In a VM scheme, tool data are used to predict, for every wafer, metrology measurements. In this paper, we present a VM system for a chemical vapor deposition (CVD) process. On the basis of the available metrology results and of the knowledge, for every wafer, of equipment variables, it is possible to predict CVD thickness. In this work, we propose a VM module based on least angle regression to overcome the problem of high dimensionality and model interpretability. We also present a statistical distance-based clustering approach for the modeling of the whole tool production. The proposed VM models have been tested on industrial production data sets.

[abstract] [url] [BibTeX]

G.A. Susto, S. McLoone, A. Schirru, S. Pampuri, D. Pagano, A. Beghi. **Prediction of Integral Type Failures in Semiconductor Manufacturing through Classification Methods.** *18-th IEEE Conference on Emerging Technologies and Factory Automation*, 2013

Abstract:

Smart management of maintenances has become fundamental in manufacturing environments in order to decrease downtime and costs associated with failures. Predictive Maintenance (PdM) systems based on Machine Learning (ML) techniques have the possibility with low added costs of drastically decrease failures-related expenses; given the increase of availability of data and capabilities of ML tools, PdM systems are becoming really popular, especially in semiconductor manufacturing. A PdM module based on Classification methods is presented here for the prediction of integral type faults that are related to machine usage and stress of equipment parts. The module has been applied to an important class of semiconductor processes, ion-implantation, for the predictionof ion-source tungsten filament breaks. The PdM has been tested on a real production dataset.

[abstract] [url] [BibTeX]

G.A. Susto, A.B. Johnston, P.G. O'Hara, S. McLoone. **Virtual Metrology Enabled Early Stage Prediction for Enhanced Control of Multi-stage Fabrication Processes.** *Automation Science and Engineering (CASE), 2013 IEEE International Conference on*, 2013

Abstract:

Semiconductor fabrication involves several sequentialprocessing steps with the result that critical productionvariables are often affected by a superposition of affects overmultiple steps. In this paper a Virtual Metrology (VM) systemfor early stage measurement of such variables is presented;the VM system seeks to express the contribution to theoutput variability that is due to a defined observable partof the production line. The outputs of the processed systemmay be used for process monitoring and control purposes. Asecond contribution of this work is the introduction of ElasticNets, a regularization and variable selection technique for themodelling of highly-correlated datasets, as a technique for thedevelopment of VM models. Elastic Nets and the proposed VMsystem are illustrated using real data from a multi-stage etchprocess used in the fabrication of disk drive read/write heads.

[abstract] [url] [BibTeX]

2012

G.A. Susto, A. Schirru, S. Pampuri, A. Beghi. **A Predictive Maintenance System based on Regularization Methods for Ion-Implantation.** *23rd IEEE/SEMI Advanced Semiconductor Manufacturing Conference*, pp. 175-180, 2012
Abstract:

Ion Implantation is one of the most sensitiveprocesses in Semiconductor Manufacturing. It consists inimpacting accelerated ions with a material substrate and isperformed by an Implanter tool. The major maintenanceissue of such tool concerns the breaking of the tungstenfilament contained within the ion source of the tool. Thiskind of fault can happen on a weekly basis, and theassociated maintenance operations can last up to 3 hours.It is important to optimize the maintenance activities bysynchronizing the Filament change operations with otherminor maintenance interventions. In this paper, a PredictiveMaintenance (PdM) system is proposed to tackle such issue;the filament lifetime is estimated on a statistical basisexploiting the knowledge of physical variables acting onthe process. Given the high-dimensionality of the data,the statistical modeling has been based on RegularizationMethods: Lasso, Ridge Regression and Elastic Nets. Thepredictive performances of the aforementioned regularizationmethods and of the proposed PdM module have beentested on actual productive semiconductor data.

[abstract] [url] [BibTeX]

G.A. Susto, A. Beghi, C. De luca. **A Predictive Maintenance System for Epitaxy Processes based on Filtering and Prediction Techniques.** *IEEE Transactions on Semiconductor Manufacturing*, vol. 25pp. 638 - 649, 2012
Abstract:

Silicon Epitaxial Deposition is a process strongly influenced by wafer temperature behaviour, that has to be constantly monitored to avoid the production of defective wafers. However, temperature measurements are not reliable and the sensors have to be appropriately calibrated with some dedicated procedure. A Predictive Maintenance (PdM) System is proposed here with the aim of predicting process behaviour and scheduling control actions on the sensors in advance. Two different prediction techniques have been employed and compared: the Kalman predictor and the Particle Filter with Gaussian Kernel Density Estimator. The accuracy of the PdM module has been tested on real industrial production datasets.

[abstract] [url] [BibTeX]

G.A. Susto, A. Beghi. **An Information Theory-based Approach to Data Clustering for Virtual Metrology and Soft Sensors.** *3rd International conference on CIRCUITS, SYSTEMS, CONTROL, SIGNALS*, pp. 198--203, 2012
Abstract:

Soft Sensors (SSs) are on-line estimators of “hardly to be measured” quantities of a process. The difficultyin measuring can be related to economic or temporal costs that cannot be afforded in a high-intensivemanufacturing production. In semiconductor manufacturing this technology goes with the name of Virtual Metrology(VM) systems. While a lot of efforts in research have been produced in the past years to identify the bestregression algorithms for these statistical modules, small amount of work has been done to develop algorithms fordata clustering of the entire production. This paper contains a new Information Theory-based approach to dataclustering for Virtual Metrology and Soft Sensors; the

proposed algorithm allows to automatically split the datasetinto groups to be equally modeled. The proposed approach has been tested on real industrial dataset.

[abstract] [url] [BibTeX]

G.A. Susto, A. Schirru, S. Pampuri, G. De nicolao, A. Beghi. **An Information-Theory and Virtual Metrology-based approach to Run-to-Run Semiconductor Manufacturing Control.** *Automation Science and Engineering (CASE), 2012 IEEE International Conference on*, pp. 358 -363, 2012
Abstract:

Virtual Metrology (VM) module have become popular in the past years and they are now widely adopted in the semiconductor plants. However, nowadays, still few works have been presented to deal with the interaction between VM and Run-to-Run (R2R), the most common control approach in the fabs. We present in this paper a new strategy to integrate VM with R2R based on Information Theory measure. The proposed control method penalizes statistical measure based on their statistical distance from the physical measure. This new approach also cope with the virtual loop control, where the R2R runs for several process iterations without in-situ measures, but based only on VM predictions. The results are compared with the actual state-of-the-art.

[abstract] [url] [BibTeX]

G.A. Susto, S. Pampuri, A. Schirru, G. De nicolao, S. McLoone, A. Beghi. **Automatic Control and Machine Learning for Semiconductor Manufacturing: Review and Challenges.** *10th European Workshop on Advanced Control and Diagnosis*, 2012
Abstract:

Semiconductor manufacturing is one of the most technologically advanced industrial sectors. Process quality and control are critical for decreasing costs and increasing yield. The contribution of automatic control and statistical modeling in this area can drastically impact production performance. For this reason in the past decade major collaborative research projects have been undertaken between fab industries and academia in the areas of Virtual Metrology, Predictive Maintenance, Fault Detection, Run-to-Run control and modeling. In this paper we review some this research, discuss its impact on production and highlight current challenges.

[abstract] [BibTeX]

G.A. Susto, A. Schirru, S. Pampuri, S. McLoone. **Enhanced Virtual Metrology with Time Series Data.** *Intel Ireland Research Conference (ERIC 2012)*, 2012 [BibTeX]

A. Schirru, G.A. Susto, S. Pampuri, S. McLoone. **Learning from Time Series: Supervised Aggregative Feature Extraction.** *51st IEEE Conference on Decision and Control*, pp. 5254--5259, 2012
Abstract:

Many modeling problems require to estimate ascalar output from one or more time series. Such problemsare usually tackled by extracting a fixed number of featuresfrom the time series (like their statistical moments), with aconsequent loss in information that leads to suboptimal predictivemodels. Moreover, feature extraction techniques usuallymake assumptions that are not met by real world settings (e.g.uniformly sampled time series of constant length), and failto deliver a thorough methodology to deal with noisy data.In this paper a methodology based on functional learningis proposed to overcome the

aforementioned problems; theproposed Supervised Aggregative Feature Extraction (SAFE)approach allows to derive continuous, smooth estimates oftime series data (yielding aggregate local information), whilesimultaneously estimating a continuous shape function yieldingoptimal predictions. The SAFE paradigm enjoys severalproperties like closed form solution, incorporation of first andsecond order derivative information into the regressor matrix,interpretability of the generated functional predictor and thepossibility to exploit Reproducing Kernel Hilbert Spaces settingto yield nonlinear predictive models. Simulation studies areprovided to highlight the strengths of the new methodology withrespect to standard unsupervised feature selection approaches.

[abstract] [url] [BibTeX]

G.A. Susto, A. Beghi. **Least Angle Regression for Semiconductor Manufacturing Modeling.** *Control Applications (CCA), 2012 IEEE International Conference on*, pp. 658--663, 2012
Abstract:

In semiconductor manufacturing plants, monitoringphysical properties of all wafers is fundamental in order tomaintain good yield and high quality standards. However, suchan approach is too costly and in practice only few wafers in a lotare actually monitored. Virtual Metrology (VM) systems allowto partly overcome the lack of physical metrology. In a VMscheme, tool data are used to predict, for every wafer, metrologymeasurements. In this paper, we present a VM system for aChemical Vapor Deposition (CVD) process. On the basis ofthe available metrology results and of the knowledge, for everywafer, of equipment variables, it is possible to predict CVDthickness. In this work we propose a VM module based onLARS to overcome the problem of high dimensionality andmodel interpretability. The proposed VM models have beentested on industrial production data sets.

[abstract] [url] [BibTeX]

S. Pampuri, A. Schirru, G.A. Susto, G. De nicolao, A. Beghi, C. De luca. **Multistep Virtual Metrology Approaches for Semiconductor Manufacturing Processes.** *Automation Science and Engineering (CASE), 2012 IEEE International Conference on*, pp. 91 -- 96, 2012
Abstract:

In semiconductor manufacturing, state of the art for wafer quality control relies on product monitoring and feedback control loops; the involved metrology operations, performed by means of scanning electron microscopes, are particularly cost-intensive and time-consuming. For this reason, it is not possible to evaluate every wafer: in common practice, a small subset of a productive lot is measured at the metrology station and devoted to represent the whole lot. Virtual Metrology (VM) methodologies are able to obtain reliable predictions of metrology results at process time, without actually performing physical measurements; this goal is usually achieved by means of statistical models, linking process data and context information to target measurements. Since semiconductor manufacturing processes involve a high number of sequential operations, it is reasonable to assume that the quality features of a certain wafer (such as layer thickness, critical dimensions, electrical test results) depend on the whole processing and not only on the last step before measurement. In this paper, we investigate the possibilities to improve the Virtual Metrology quality relying on knowledge collected from previous process steps. We will present two different scheme of multistep VM, along with dataset preparation indications; special consideration will be reserved to regression techniques capable of handling high dimensional input spaces. The proposed multistep approaches will be tested against actual data from semiconductor manufacturing industry.

[abstract] [url] [BibTeX]

G.A. Susto, S. Pampuri, A. Schirru, A. Beghi. **Optimal Tuning of Epitaxy Pyrometers.** *23rd IEEE/SEMI Advanced Semiconductor Manufacturing Conference*, pp. 294-299, 2012
Abstract:

Epitaxy is a process strongly dependent onwafer temperature. Unfortunately, the performance ofthe pyrometers in charge of sensing wafer temperaturedeteriorate with the usage. This represents the majormaintenance issue for epitaxy process engineers who haveto frequently calibrate pyrometers emissivity coefficient. Atthe present state the change of the emissivity coefficient isheuristically based on fab tradition and process engineersexperience. We present a statistical tool to map therelationship between change in the temperature readingsand emissivity adjustments. The module has been testedon real industrial dataset.

[abstract] [url] [BibTeX]

2011

G.A. Susto, A. Beghi, C. De luca. **A Predictive Maintenance System for Silicon Epitaxial Deposition.** *Proceeding of 7th IEEE International Conference on Automation Science and Engineering*, pp. 262-267, 2011
Abstract:

Silicon Epitaxial Deposition is a process strongly influenced by wafer temperature behavior, that has to be constantly monitored to avoid the production of defective wafers. A Predictive Maintenance (PdM) System is here proposed with the aim of predicting process behavior and scheduling control actions in advance. Two different prediction techniques have been employed and compared: the Kalman predictor and the Particle Filter with Gaussian Kernel Density Estimator. The accuracy of the PdM module has been tested on real fab data. The proposed approach is flexible and can handle the presence of different recipes on the same equipment.

[abstract] [url] [BibTeX]

G.A. Susto, A. Beghi, C. De luca. **A Virtual Metrology System for Predicting CVD Thickness with Equipment Variables and Qualitative Clustering.** *Proceeding of 16th IEEE International Conference on Emerging Technologies and Factory Automation*, pp. 1-4, 2011
Abstract:

In semiconductor manufacturing plants, monitoring of all wafers is fundamental in order to maintain good yield and high quality standards. However, this is a costly approach and in practice only few wafers in a lot are actually monitored. With a Virtual Metrology (VM) system it is possible to partly overcome the lack of physical metrology. In a VM scheme, tool data are used to predict, for every wafer, metrology measurements. In this paper, we present a VM system for a Chemical Vapor Deposition (CVD) process. Various data mining techniques are proposed. Due to the huge fragmentation of data derived from CVD's mixed production, several kind of data clustering have been adopted. The proposed models have been tested on real productive industrial data sets.

[abstract] [url] [BibTeX]

2010

G.A. Susto, M. Krstic. **Control of PDE-ODE cascades with Neumann interconnections.** *Journal of the Franklin Institute*, vol. 347 Dynamics and Control(1), pp. 284 - 314, 2010

Abstract:

We extend several recent results on full-state feedback stabilization and state estimation of PDE–ODE cascades, where the PDEs are either of heat type or of wave type, from the previously considered cases where the interconnections are of Dirichlet type, to interconnections of Neumann type. The Neumann type interconnections constrain the PDE state to be subject to a Dirichlet boundary condition at the PDE–ODE interface, and employ the boundary value of the first spatial derivative of the PDE state to be the input to the ODE. In addition to considering heat-ODE and wave-ODE cascades, we also consider a cascade of a diffusion–convection PDE with an ODE, where the convection direction is “away” from the ODE. We refer to this case as a PDE–ODE cascade with “counter-convection.” This case is not only interesting because the PDE subsystem is unstable, but because the control signal is subject to competing effects of diffusion, which is in both directions in the one-dimensional domain, and counter-convection, which is in the direction that is opposite from the propagation direction of the standard delay (transport PDE) process. We rely on the diffusion process to propagate the control signal through the PDE towards the ODE, to stabilize the ODE.

[abstract] [url] [BibTeX]