Project Newsletter

Issue 1 - December 2011

Project Coordinator's Greetings

Welcome to the first issue of the i-Sense project newsletter, covering relevant news, upcoming events, and highlighting significant project outcomes. The first issue of the i-Sense newsletter comes on the first anniversary of the project's start in January 2011.

The i-Sense project is an exciting collaboration between the University of Cyprus, the University of Birmingham, the Politecnico di Milano, the Universitat Politècnica de Catalunya (UPC) and a world leading company, ST Microelectronics. The aim of the project is to develop intelligent data processing methods for handling faulty scenarios in complex monitoring and control applications.

During this first year, an essential activity aiming to develop a rigorous formulation for cognitive fault diagnosis and fault tolerant control was fulfilled, putting together a complementary effort among the different partners involved in the project.

The i-Sense Newsletter provides an outline of some of these activities. Specifically, you can read about the project objectives, some preliminary results associated with the various work packages of the project, and relevant call for papers to a special issue of a prestigious journal and a special session for the upcoming World Congress on Computational Intelligence (WCCI). These special issue/session activities are co-organized by members of the i-Sense consortium, aiming to further promote and disseminate research related to cognitive fault diagnosis.

We will be forthcoming in providing information about the project as it progresses, through upcoming newsletters and via the project website: www.i-sense.org. I hope you enjoy reading the Newsletter. If you have any questions or suggestions, please feel free to contact me at: mpolycar@ucy.ac.cy

In this issue:

- Project objectives
- Some preliminary results
- Publications
- Relevant call for papers
- News and contacts

The mission of the i-Sense project is to develop intelligent data processing methods for analyzing and interpreting the data such that faults are detected (and whereas possible anticipated), isolated and identified as soon as possible, and accommodated for in future decisions or actuator actions.

Project Objectives

The main objective of this project is to ***make sense of nonsense*** by developing - cognitive - intelligent data processing methods for analyzing and interpreting the data such that faults are detected (and where possible anticipated), isolated and identified as soon as possible, and accommodated for in future decisions or actuator actions. The problem becomes more challenging when these sensing/actuation systems are deployed in a wide range of open-ended environments which are not known a priori and, as a result, it is unrealistic to assume the existence of an accurate model for the behaviour of various components in the monitored environment. Therefore, this project will focus on cognitive system approaches that can learn characteristics or system dynamics of the monitored environment, adapt their behaviour and predict missing or inconsistent data to achieve fault tolerant monitoring and control.

This project is developing the ***i-Sense Platform***, which consists of a set of intelligent agents, integrated with the sensors, actuators and feedback control system for making the overall monitoring and control system more robust, adaptive and fault-tolerant to sensor/actuator faults and system faults or abnormalities in the environment.

The developed prototype of the i-Sense Platform will be validated for the intelligent building application domain, however, the formulation, tools and methodology developed will be transferable to other application domains such as water distribution networks, environmental monitoring, power transmission and distributions grids and more.

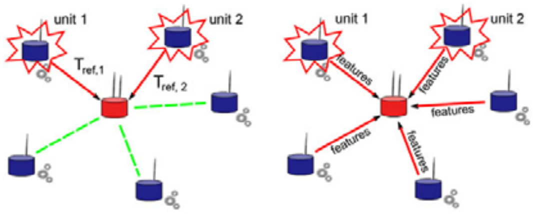
i-Sense Results

Design of a novel distributed and hierarchical test to detect changes and faults in networked systems

Promptly detecting faults and, more in general, changes in stationarity in networked systems such as sensor/actuator networks is a key issue to guarantee **robustness and adaptability in applications working in real-life environments**.

The research activity of Politecnico di Milano team is concerned with the design of a novel distributed and hierarchical test to detect changes and faults in networked systems. This solution allows prompt detection of changes while guaranteeing a reduced false positive rate. In the proposed approach, each sensing unit independently runs a test on acquired measurements, and communicates with a data-aggregation center only when a change is detected.

The data-aggregation center gathers specific information extracted from the latest measurements from all the units for validating the change.



The data-aggregation center thus exploits temporal and spatial correlation among the observations at group-level. When the change is confirmed, the data-aggregation center signals a change in stationarity; otherwise, the local detections are considered false positives and the units providing the detections are retrained to continue the monitoring activity. The distributed aspect of the test guarantees prompt detections, while the hierarchical one aims at reducing the occurrence of false positives.

The test, combined with proper pre-processing phases at the units, has been applied both to i.i.d. data sequences and to the residual of dynamic systems. We are currently investigating its use for detecting changes in dynamic systems and in correlation patterns among the units.

Results can be immediately integrated in the iSense framework, where adaptive solutions are envisaged to address changes in stationarity of the considered application.

Designing techniques for sensor and process fault detection and isolation in distributed uncertain systems

Amongst the research goals of the iSense project is the **development of intelligent methods for analyzing data for the detection, isolation and identification of faults in distributed systems**. Towards this goal, the research work of the University of Cyprus (UCY) team has focused on designing techniques for sensor and process fault detection and isolation (FDI) in distributed uncertain systems with inherent nonlinearities. Recognizing the usefulness of the FDI in safety-critical systems, the UCY team has proposed the FDI application for monitoring the contaminant dispersion in an indoor building environment. In this context, the contaminant sources are treated as process faults, whose prompt detection and accurate isolation should be guaranteed and the proper actions should be taken to ensure the safety of the people. In such safety-critical applications, the decision making relies on the information provided by the sensors. Motivated by this fact, the UCY team has designed techniques in order to cope with the erroneous information provided by a large set of distributed sensors.

The UCY team has developed a filtering technique for diminishing the effect of high frequency noise on sensors' measurements, based on which a distributed fault detection method has been designed for capturing process faults in a class of interconnected, uncertain nonlinear systems. Considering that usually a large number of distributed sensors is used for the monitoring and control of distributed nonlinear systems, the UCY team has developed a multi-level architecture based on clusters of sensor FDI modules, tailored to monitor the healthy operation of a set of sensors, capture the presence of faults in this set and isolate the faulty sensors.

Adaptation and learning for fault diagnosis

The Birmingham team has been working on the **adaptation and learning for fault diagnosis**. To accommodate the real-time requirement of fault diagnosis, we have proposed an efficient probabilistic classification vector machine (EPCVM) algorithm and have verified the algorithm using data from the Barcelona water system.

In EPCVM, a truncated Gaussian prior is employed for robust performance with respect to parameter settings and sparse solutions. EPCVM operates as a growing model by sequentially adding basis functions, therefore achieving an effective advantage for real-time applications, such as fault diagnosis. The probabilistic output is another benefit of EPCVM as the probabilistic output is good for decision making and fault detection.

In this project, we also study "**learning on models**", which change the signal space to model/parameter space that are used to fit the signal. The benefits to use "learning on models" include robust to unequal-length signal and effective dimensionality reduction. Based on these techniques, we have worked on simulated fault detection data from Barcelona water system. The EPCVM with "learning on models" have achieved 93.59% detection accuracy and the result has confirmed their effectiveness on real-time fault diagnosis applications.

Fault Tolerant Control

The Universitat Politècnica de Catalunya team has addressed different activities in the framework of the i-Sense project, related with optimal sensor placement and data validation/reconstruction for fault detection in water distribution networks, and Fault Tolerant Control (FTC). The problem of leakage detection and isolation in water distribution networks is addressed using optimal sensor placement methodology (which is based on structural models and thus is suitable to handle non-linear and large scale systems) and successfully applied to a District Metered Area (DMA) in the Barcelona network. In the same network, data validation, reconstruction and fault detection have been applied. The proposed **Fault Detection and Isolation (FDI) strategy** is based on the definition of a set of tests for a given sensor data, taking into account empirical information of the system and several models of the data behaviour. The raw data of the telemetry system is validated or invalidated using these tests and invalidated data is reconstructed with its estimation using these models. The proposed FDI system is applied to several real scenarios providing promising results in order to be applied in real-time operation. Regarding the FTC problem, the use of virtual sensor/actuator approaches is proposed. The methodology suggested is based on input/output form reformulation of FTC schemes, previously stated in state space form. The FTC module uses information from the FDI module previously designed using set-membership techniques. A fault estimation scheme is also proposed based on batch least squares approach. The performance of the proposed FTC schemes will be tested in the i-Sense project application benchmarks in the future.

Glossary

Fault Detection: recognize that the malfunctioning of the (controlled) system is due to the occurrence of a fault (or not proper behavior) affecting some physical or functional component of the system

Fault Isolation: locate a fault and discriminate which particular fault has occurred out of a (large) class of potential ones, by distinguishing it from any other and from effects due to disturbances possibly acting on the system

Fault Identification: provide and estimate of the magnitude or severity of the fault

Fault Accommodation: modify the control law so as to compensate for the effects of the detected and isolated fault (possibly also identified)

i-Sense Journal Publications

Adaptation and Learning

► Alippi, C., Boracchi, G., Roveri, M (2011) "*A just-in-time adaptive classification system based on the intersection of confidence intervals rule*", Neural Networks, Elsevier vol. 24 (2011), pp. 791-800.

Abstract: Classification systems meant to operate in non-stationary environments are requested to adapt when the process generating the observed data changes. A straightforward form of adaptation implementing the instance selection approach suggests releasing the obsolete data onto which the classifier is configured by replacing it with novel samples before retraining. In this direction, we propose an adaptive classifier based on the intersection of confidence intervals rule for detecting a possible change in the process generating the data as well as identifying the new data to be used to configure the classifier. A key point of the research is that no assumptions are made about the distribution of the process generating the data. Experimental results show that the proposed adaptive classification system is particularly effective in situations where the process is subject to abrupt changes.

Fault-tolerant control

► Ocampo-Martinez, C.; Bovo, S.; Puig, V. (2011) "*Partitioning approach oriented to the decentralised predictive control of large-scale systems*". Journal of Process Control, vol. 21, pp. 775-786.

Abstract: In this paper, a partitioning approach for large-scale systems based on graph-theory is presented. The algorithmstarts with the translation of the system model into a graph representation. Once the system graph is obtained, the problem of graph partitioning is then solved. The resultant partition consists in a set of non-overlapping subgraphs whose number of vertices is as similar as possible and the number of interconnecting edges between them is minimal. To achieve this goal, the proposed algorithm applies a set of procedures based on identifying the highly-connected subgraphs with balanced number of internal and external connections. In order to illustrate the use and application of the proposed partitioning approach, it is used to decompose a dynamical model of the Barcelona drinking water network (DWN). Moreover, a hierarchical-like DMPC strategy is designed and applied over the resultant set of partitions in order to assess the closed-loop performance. Results obtained when used several simulation scenarios show the effectiveness of both the partitioning approach and the DMPC strategy in terms of the reduced computational burden and, at the same time, of the admissible loss of performance in contrast to a centralised MPC strategy.

Fault Diagnosis

► Rosich, A., Frisk, E., Aslund, J., Sarrate, S. and Nejjari, F. (2011) "*Fault Diagnosis Based On Causal Computations*". IEEE Transactions on Systems, Man and Cybernetics Part A: Systems and Humans. vol. 99, (2011), pp. 1 - 11 .

Abstract: This work focuses on residual generation for modelbased fault diagnosis. Specifically, a methodology to derive residual generators when non-linear equations are present in the model is developed. A main result is the characterization of computational sequences that are particularly easy to implement as residual generators and that take causal information into account. An efficient algorithm, based on the model structure only, that finds all such computational sequences, is derived. Further, fault detectability and fault isolability performance depend on the sensor configuration. Therefore, another contribution is an algorithm, also based on model structure, that places sensors with respect to the class of residual generators that take causal information into account. The algorithms are evaluated on a complex, highly non-linear, model of a fuel cell stack system. A number of residual generators are computed that are, by construction, easy to implement and provide full diagnosability performance predicted by the model.

► Blesa, J., Puig, V., Saludes, J. (2011) "*Robust Fault Diagnosis based on Uncertain LPV MIMO Parity Equations and Zonotopes*". Journal of Process Control. To appear.

Abstract: In this paper, a robust fault diagnosis method for uncertain Multiple Input Multiple Output (MIMO) Linear Parameters Varying (LPV) models is presented. The fault detection methodology is based on checking if measurements are inside the prediction bounds provided by a MIMO LPV model identified using real data and the parity equations approach. The proposed approach takes into account existing coupling between the different measured outputs. Modeling and prediction uncertainty bounds are handled using zonotopes. An identification algorithm that provides model parameters and their uncertainty such that all measured data free of faults will be inside the predicted bounds is also proposed. The fault isolation and estimation algorithm is based on the use of residual fault sensitivity. Finally, two case studies (one based on a water distribution network and the other on a four tank system) are used to illustrate the effectiveness of the proposed approach.

Abrupt faults are modeled as instantaneous changes in system parameter values at a point in time.
Degradations are typically modeled as **incipient faults**, which are slow drifts in system dynamics over time.
An **intermittent fault** is a malfunction of a system that occurs at intervals, usually irregular, in a device or system that functions normally at other times.

i-Sense Conference Papers

Fault Diagnosis

- Alippi, C., Boracchi, G., Roveri, M. (2011)"*A distributed Self-adaptive Nonparametric Change-Detection Test for Sensor/Actuator Networks*", In Proceedings of the 21th International Conference on Artificial Neural Networks (ICANN), June 14-17th, 2011, Espoo, Finland. Lecture Notes in Computer Science, 2011, Vol. 6792/2011.

Abstract: The prompt detection of faults and, more in general, changes in stationarity in networked systems such as sensor/actuator networks is a key issue to guarantee robustness and adaptability in applications working in real-life environments. Traditional change-detection methods aiming at assessing the stationary of a data generating process would require a centralized availability of all observations, solution clearly unacceptable when large scale networks are considered and data have local interest. Differently, distributed solutions based on decentralized change-detection tests exploiting information at the unit and cluster level would be a solution. This work suggests a novel distributed change-detection test which operates at two-levels: the first, running on the unit, is particularly reactive in detecting small changes in the process generating the data, whereas the second exploits distributed information at the cluster-level to reduce false positives. Results can be immediately integrated in the machine learning community where adaptive solutions are envisaged to address changes in stationarity of the considered application. A large experimental campaign shows the effectiveness of the approach both on synthetic and real data applications.

- Alippi, C., Boracchi, G., Roveri, M. (2011) "*A Hierarchical, Nonparametric Sequential Change-Detection Test*", In Proceedings of IJCNN (International Joint Conference on Neural Networks), San Jose, California July 31 - August 5, 2011.

Abstract: Design of applications working in non-stationarity environments requires the ability to detect and anticipate possible behavioral changes affecting the system under investigation. In this direction, the literature provides several tests aiming at assessing the stationary of a data generating process; of particular interest are nonparametric sequential change-point detection tests that do not require any a-priori information regarding both process and change. Moreover, such tests can be made automatic through an on-line inspection of sequences of data, hence making them particularly interesting to address real applications. Following this approach, we suggest a novel two-level hierarchical change detection system designed to detect possible occurrences of changes by observing incoming measurements. This hierarchical solution significantly reduces the number of false positives at the expenses of a negligible increase of false negatives and detection delays. Experiments show the effectiveness of the proposed approach both on synthetic and real applications.

- Keliris, C., Polycarpou, M. (2011) "*A Distributed Fault Detection Filtering Approach for a Class of Interconnected Continuous-Time Nonlinear Systems*", In Proceedings of 50th IEEE Conference on Decision and Control and European Control Conference, December 12-15, 2011, Orlando, Florida.

Abstract: This paper develops a filtering approach for distributed fault detection of a class of interconnected continuous time nonlinear systems with modeling and measurement uncertainties. A distributed fault detection scheme and corresponding thresholds are designed based on filtering certain signals so that the effect of high frequency measurement uncertainty is diminished. The analysis of the proposed distributed fault detection scheme shows that the derived thresholds guarantee that there are no false alarms and characterizes quantitatively the class of detectable faults.

Adaptation and Learning

- Alippi, C., Boracchi, G., Roveri, M. (2011) "*An Effective Just-in-Time Adaptive Classifier for Gradual Concept Drifts*", In Proceedings of IJCNN (International Joint Conference on Neural Networks), San Jose, California July 31 - August 5, 2011.

Abstract: Classification systems designed to work in non-stationary conditions rely on the ability to track the monitored process by detecting possible changes and adapting their knowledge-base accordingly. Adaptive classifiers present in the literature are effective in handling abrupt concept drifts (i.e., sudden variations), but, unfortunately, they are not able to adapt to gradual concept drifts (i.e., smooth variations) as these are, in the best case, detected as a sequence of abrupt concept drifts. To address this issue we introduce a novel adaptive classifier that is able to track and adapt its knowledge base to gradual concept drifts (modeled as polynomial trends in the expectations of the conditional probability density functions of input samples), while maintaining its effectiveness in dealing with abrupt ones. Experimental results show that the proposed classifier provides high classification accuracy both on synthetically generated datasets and measurements from real sensors.

- Chen, H., Yao, X., and Tino P., **Tutorial** on "*Ensemble Learning through Diversity Management: Theory, Algorithms, and Applications*" at 2011 International Joint Conference on Neural Networks (IJCNN'11), San Jose, California on 31 July, 2011.

i-Sense Dissemination: Special Issue

IEEE TRANSACTIONS ON
NEURAL NETWORKS AND LEARNING SYSTEMS
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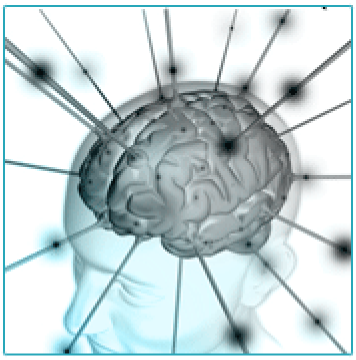
www.ieee-cis.org/pubs/tnnls

IEEE TRANSACTIONS ON NEURAL NETWORKS AND LEARNING SYSTEMS
SPECIAL ISSUE ON LEARNING IN NONSTATIONARY AND EVOLVING ENVIRONMENTS

Using a computational model to learn under various environments has been a well-researched field that produced relevant results; unfortunately, the majority of these efforts rely on three fundamental assumptions: i) there is a sufficient and representative data set to configure and assess the model performance; ii) data are drawn from a fixed – albeit unknown – distribution; and iii) samples are mostly supposed to be independent. Alas, all these assumptions often do not hold in many real-world applications, such as in the analysis of climate or financial data, network intrusion, spam and fraud detection, electricity demand and industrial quality inspection among many others.
Recent efforts towards incremental and online learning allow us to relax the “sufficiency” requirement by continuously updating a model to learn from small batches or online data, yet, the data that become available are still assumed to be drawn from a fixed distribution. More recently, approaches commonly called concept drift – and to some extend domain adaptation– algorithms, possibly in collaboration with change detection tests, have attempted to remove this assumption, by accommodating a stream or batches of data whose underlying distribution changes over time. However, early efforts have made other assumptions, such as restricting the type of faults or changes affecting the system or the distribution and are primarily heuristic in nature with several free parameters to be fine-tuned.

Against this background, the need for a general framework to learn from – and adapt to – a changing environment can be hardly overstated. A special issue that discusses the state-of-the-art and latest results on detecting and adapting to changes in underlying data distributions is very timely. We invite original and unpublished contributions in all areas relevant to learning in a changing environment. Papers must present original work or review the state-of-the-art in the following non-exhaustive list of topics:

- Learning in non-stationary, drifting or dynamic environments
- Adaptive learning in a missing, faulty, limited or unbalanced data context
- Incremental, lifelong and cumulative learning from nonstationary data
- Faults, changes or anomaly detection in data streams
- Domain adaptation
- Data mining from streams of data
- Architectures, techniques and algorithms for learning in such environments
- Applications requiring learning in dynamic and nonstationary environments



IMPORTANT DATES

15 April 2012 – Deadline for manuscript submission
15 August 2012 – Notification of authors
15 September 2012 – Deadline for submission of revised manuscripts
30 September 2012 – Final decision
January/February 2013 – Special issue publication in the IEEE TNNLS

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SUBMISSION INSTRUCTIONS

1. Read the information for Authors at http://ieee-cis.org/pubs/tnn/papers/
2. Submit the manuscript at the IEEE-TNNLS webpage http://mc.manuscriptcentral.com/tnn and follow the submission procedure. Please, clearly indicate on the first page of the manuscript and the Author's Cover Letter that the manuscript has been submitted to the Special Issue on Learning in Nonstationary and Evolving Environments. Send also an email to the guest editors to notify about your submission.

i-Sense Dissemination: Special Session

2012 IEEE World Congress on Computational Intelligence (WCCI 2012)
Special Session on Data Regularisation, Fault and Anomaly Detection, Isolation and Mitigation

Modern societies rely on smooth operation of complex systems often operating in uncertain challenging environments producing data of diverse character - e.g. multidimensional, multi-scale and spatially distributed - often corrupted with significant noise or with observational gaps. In addition, the environment may be subject to non-stationary phenomena and the measurement devices prone to permanent or transient faults, ageing effects or thermal drifts. This poses significant challenges to intelligent systems operating on such data where it is no longer possible to rely on stable re-emerging patterns to take advantage of. Examples include data coming from distributed monitoring and actuating systems such as water distribution networks, manufacturing processes, transportation systems, robotic systems, intelligent buildings, etc.

The aim of this special session is to foster research on robust learning/control/monitoring in such challenging scenarios. It will be a platform to exchange ideas on novel approaches to fault tolerant modeling, monitoring and/or control that can learn characteristics of the monitored environment and adapt their behaviour as well as successfully deal with missing or perturbed data.

Topics of this special session at **IEEE World Congress on Computational Intelligence 2012** (WCCI 2012) include, but not limited to:

- Data regularization and validation
- Unsupervised, semi-supervised and supervised machine learning techniques for signal compensation and missing data reconstruction
- Online learning and imbalanced learning
- Clustering techniques
- Cognitive Fault Diagnosis
- Fault Tolerant Control: Passive Fault Tolerant Control, Active Fault Tolerant Control and Fault Tolerant Model Predictive Control
- Fault Modelling
- Centralized, hierarchical and distributed architectures for fault detection, isolation and identification
- Exploiting spatial and temporal dependencies and redundancies in developing robust monitoring and/or control systems
- Accommodation and mitigation of new "never seen before" faults

***Submissions** should follow the guidance given on the IEEE IJCNN 2012 conference website.*
When submitting, please select:
1. Submission to IEEE-IJCNN 2012
2. Main research topic: Special Session on "Data Regularisation, Fault and Anomaly Detection, Isolation and Mitigation".

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PAPER SUBMISSION

News and Contacts

Project website

You can find the i-Sense project website at the link **http://www.i-sense.org**
In the website you can find the full description of the project activities and the main results that are progressively reached. Papers related to Adaptation and Learning, Fault Diagnosis and Fault-tolerant control fields published by the project team in international journals and conferences are already available in the publications area.

Relevant events

1. IEEE International Symposium on Circuits and Systems, May 20-23, Seoul, Korea (ISCAS 2012)
2. IEEE World Congress on Computational Intelligence, June 10-15, Brisbane, Australia (WCCI 2012)
3. International Conference on Machine Learning, June 26 - July 1, Edinburgh, Scotland (ICML 2012)
4. IEEE Mediterranean Control and Automation, July 3-6, Barcelona, Spain (MED 2012)
5. IFAC Symposium on Fault detection, supervision and safety for technical processes, August 29-31, Mexico City, Mexico (SAFEPROCESS 2012)
6. IEEE International Conference on Artificial Neural Networks, September 11-14, Lauzanne, Switzerland (ICANN 2012)
7. IEEE Multi-Conference on Systems and Control , October 3-5 2012, Dubrovnik, Croatia (MCS)
8. IEEE Conference on Decision and Control, December 10-13, Maui, Hawaii (CDC 2012)

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