SysTol 2016

2016 3rd Conference on Control and Fault-Tolerant Systems

September 7-9, 2016
Barcelona, Spain

Conference Digest

2016 3rd Conference on Control and Fault-Tolerant Systems (SysTol)

Conference Digest

Edited by Ramon Sarrate

September 7-9, 2016

Faculty of Mathematics (UPC), Barcelona, Spain

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Welcome message

On behalf of the International Program Committee and the Organizing Committee of the 3rd International Conference on Control and Fault-Tolerant Systems, SysTol'2016, we welcome the participants of the conference to be held in Barcelona on September 7-9, 2016. The conference is sponsored by the Universitat Politècnica de Catalunya (UPC) and its Research Center for Sypervision, Safety and Automatic Control (CS2AC). It is technically cosponsored by IEEE Control System Society and IEEE Reliability Society and supported by the Spanish Committee of Automatic Control (CEA-IFAC).

Following the great success of and acceptance by the international community of control and technical diagnostics of the two previous editions (Systol'2010 and Systol'2013, both in Nice), SysTol Conferences are organized every three years between IFAC Symposia on Fault Detection, Supervision and Safety of Technical Processes (SAFEPROCESS). Previous Systol Conferences demonstrated the demand for establishing a continuous scientific forum in the general field of system monitoring, fault detection and diagnosis as well as fault-tolerant control.

The safe and reliable operation of technical systems is of great significance for the protection of human life and health as well as the environment, and of a vested economic value for supporting decision making or emergency actions and repairs. Moreover, in highly automated industrial systems where maintenance or repair cannot be carried out immediately, it is crucial to employ fault-tolerant control systems capable of ensuring acceptable performance even in the presence of faults.

The program of SysTol'2016 includes 16 regular and 8 invited sessions in 3 parallel tracks. Furthermore, the program contains 2 plenary and 4 semi-plenary talks prepared by outstanding academic and industrial experts. We hope that those talks will give the participants the opportunity to share in the knowledge and experience of world-renowned scientists and experts in many exciting topics such as distributed fault diagnosis, integration of diagnosis and fault tolerant control, model-based fault diagnosis of wind turbines, model-free approaches to fault-tolerant control, robust fault detection using set-membership approaches and fault diagnosis needs and challenges in civil aircrafts.

We hope that you will find your participation in SysTol'2016 very stimulating and rewarding. Moreover, we believe that a few days stay in Barcelona and other parts of Catalonia will give you an opportunity to enjoy and to learn more about the city and the region.

We would like to thank all members of the International Program Committee for their excellent work in ensuring a high quality of the conference program. Special thanks go to members of the Organizing Committee for their hard work that made it possible to organize this international scientific event.

Finally, we wish all participants to enjoy the 3rd International Conference on Control and Fault-Tolerant Systems, SysTol'2016 and a pleasant stay in Barcelona.

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Past SysTol Conferences

2nd International Conference on Control and Fault-Tolerant Systems
October 9-10, 2013, Nice, France

1st Conference on Control and Fault-Tolerant Systems (SysTol'10)
October 6-8, 2010, Nice Acropolis Exhibition and Convention Centre, France

Topics of Interest

Research areas	Industrial applications – Case studies
Statistical and signal processing	Transportation systems
Fault detection and isolation	Automobile
Fault tolerant control / fault recovery	Autonomous vehicles
Networked control system	Road infrastructure
Health monitoring	Power plants / energy transport
Quality monitoring	Chemical processes
Decision making	Aeronautics / aerospace
Discrete event and hybrid systems	Civil engineering
Supervisory control	Building supervision
Fault-forecasting methods	Mining and mineral
Design for reliability and safety	Metal processing
Model-based methods	Water treatment
Data driven methods	Communication networks
Soft computing	Mechatronic and robotics
Maintenance policies	Manufacturing systems
Risk analysis	Medical device

Practical Information

Barcelona: the city

In a privileged position on the north-eastern coast of the Iberian Peninsula and the shores of the Mediterranean, Barcelona is the second largest city in Spain in both size and population. It is also the capital of Catalonia, 1 of the 17 Autonomous Communities that make up Spain.

There are two official languages spoken in Barcelona: Catalan, generally spoken in all of Catalonia, and Castilian Spanish. The city of Barcelona has a population of 1,628,090, but this number spirals to more than 4,500,000 if the outlying areas are also included.

The capital of Catalonia is unequivocally a Mediterranean city, not only because of its geographic location but also and above all because of its history, tradition and cultural influences. The documented history of the city dates back to the founding of a Roman colony on its soil in the second century B.C. The foundation of Barcelona is the subject of two different legends. The first attributes the founding of the city to Hercules 400 years before the building of Rome, and that it was rebuilt by the Carthaginian Hamilcar Barca, father of Hannibal, who named the city Barcino after his family, in the 3rd century BC. The second legend attributes the foundation directly to Hamilcar Barca.

Modern Barcelona experienced spectacular growth and economic revival at the onset of industrialization during the second half of the 19th century. The 1888 World's Fair became a symbol of the capacity for hard work and the international outlook projected by the city. Culture and the arts flourished in Barcelona and in all of Catalonia; the splendour achieved by Catalonian modernism is one of the most patent displays.

Besieged several times during its history, Barcelona is today an important cultural centre and a major tourist destination and has a rich cultural heritage. Particularly renowned are architectural works of Antoni Gaudí and Lluís Domènech i Montaner that have been designated UNESCO World Heritage Sites.

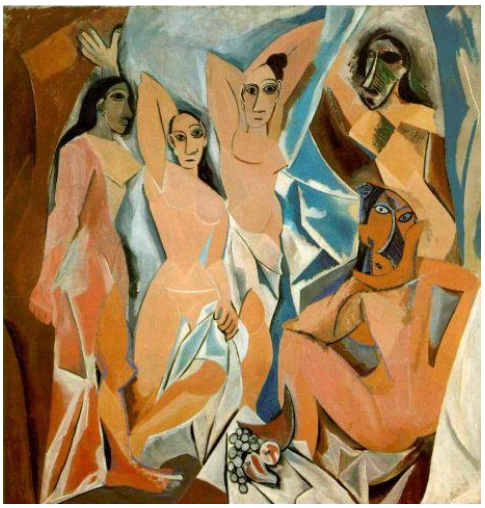
Gaudi's admirers will find Barcelona the perfect place to study his works and they can start with Sagrada Familia his unfinished masterpiece, an attraction that impress both connoisseurs' and those who don't know much about art. The church's construction

began in 1882 and it is thought to continue for some good years on as it is still not finished. It is a grand design that had as the main architect Antoni Gaudí who started working on it since he was 31. When he died only a part of it was finished and it was difficult for the followers to continue with his ideas. Now construction is advancing bit by bit and when it will be finished it will be one of the most impressive churches in Europe. Gaudi is buried here and watches over the construction of his beloved church. There is a museum where you can find out about the artist's life and about his creation.

But Sagrada Familia is not Gaudi's only masterpiece. There is Casa Milà also known as La Pedrera, a building he worked on before Sagrada Familia. Another very interesting and unique attraction is the The Guëll Park. You would be surprised by what you will see here as it has a design like no other parks. Antonio Gaudi had something to do with the design as he designed the main staircase, so you must expect the extraordinary and the surrealistic.

Barcelona, more than just a single city, is really a collection of multi-faceted and diverse cities. The visitor unfamiliar with its history might be surprised that such a modern and enterprising city preserves its historic Gothic centre almost intact, or by the curious contrast between the maze of narrow streets and the grid-like layout of the Eixample, the urban planning "Enlargement" project of the end of the 19th century.

The Plaça de Catalunya is Barcelona's busiest square, a place of gathering and spending time with friends while admiring the beautiful buildings around. You can start your journey through Barcelona on one of the most famous street called La Rambla that goes from Plaça de Catalunya to Monument a Colom. It is a pleasure to walk along it.



Barcelona has dozens of museums including one dedicated to Picasso, another to Miró and yet another to Barcelona's world famous football club, Barça!

Barcelona is almost as lively at night as it is during the day and it has a unique, exciting atmosphere, which provides the visitor with a truly unforgettable experience.

Conference Site

The conference will take place in Barcelona, at Faculty of Mathematics, in the UPC South Campus (5 Pau Gargallo Street), located in the Barcelona University Zone.

How to get to the Conference Site

Guests can enjoy excellent connections with every means of public transport:

Underground Line 3 (from city centre) or Line 9 (from airport): Zona Universitària and Palau Reial stations.

Airport Bus Plaça Espanya bus stop for bus lines A1 (connecting to Terminal T1) and A2 (connecting to Terminal T2). Then take Line 3 underground to Zona Universitària or Palau Reial stations.

Taxi €30 approx. from/to the Airport, €8 from/to the city centre.

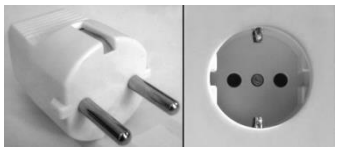
Reception & Registration Desk

The reception desk will be located at room S05 on Floor -1 (see Site Map below). The opening hours will be the following:

Tuesday September 6th	from 18:00 to 19:30
Wednesday September 7th	from 08:00 to 18:00
Thursday September 8th	from 09:00 to 18:00
Friday September 9th	from 09:00 to 16:00

Oral Session Room Facilities

Every room will be provided with a multi-media LCD projector and a desktop computer with Windows, Office Power Point and a PDF reader. Electricity will be supplied at 220 V, 50 Hz AC through standard European sockets.



Internet Facilities

Free wireless connection will be available for participants during the days of the Conference through EDUROAM network, and XSF-UPC network as guest user.

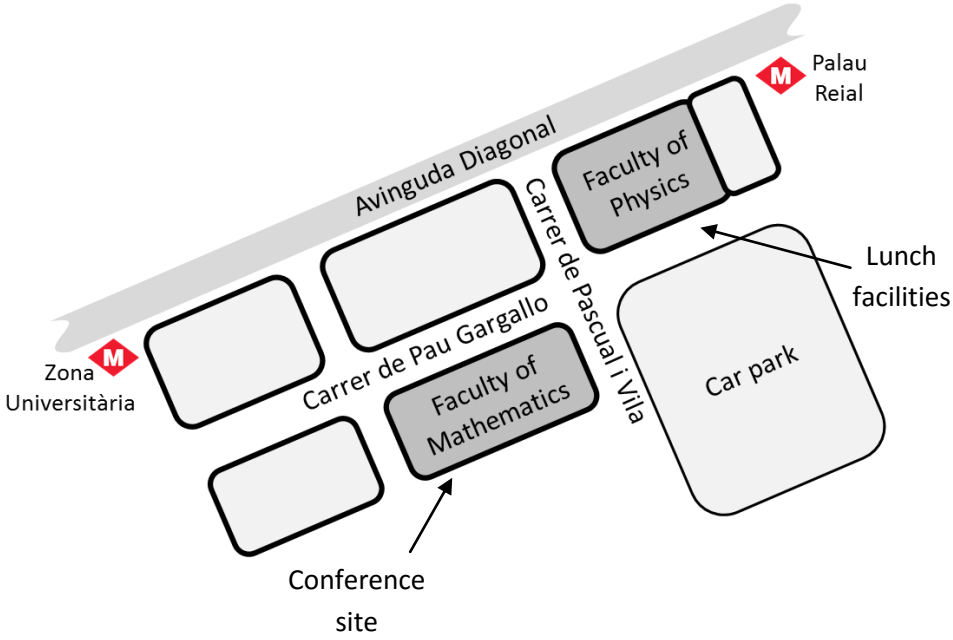
Lunch Facilities

A full registration fee includes lunch tickets for the three days of the Conference. Lunch will be served every day at 12:45, at the restaurant of the Faculty of Physics (see Site Map below).

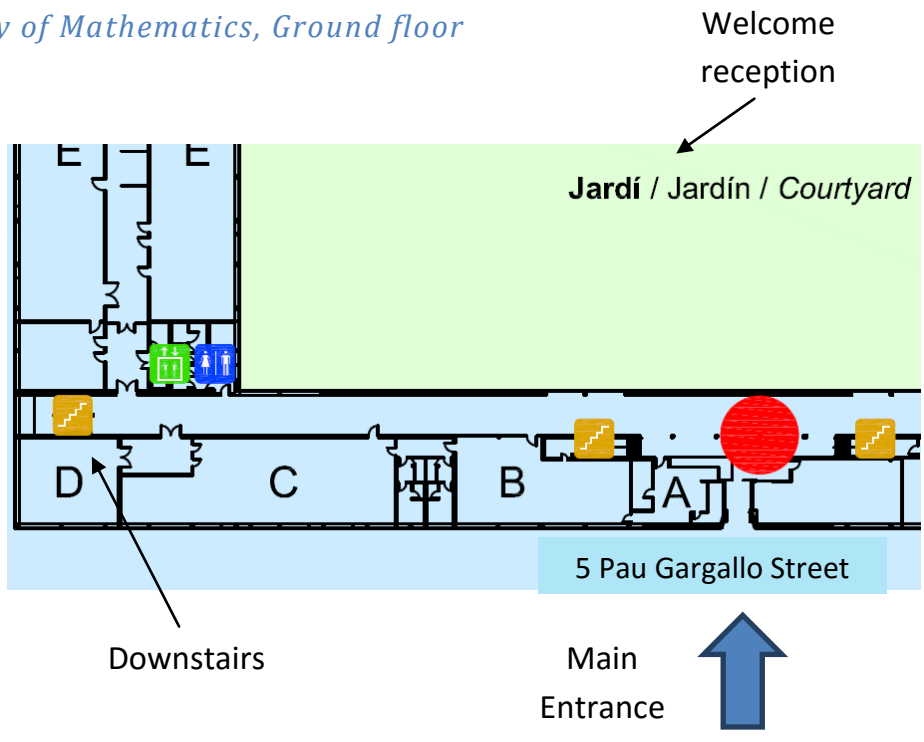
Extra lunch tickets will be available on sale in the registration desk (12€/person).

Site Map

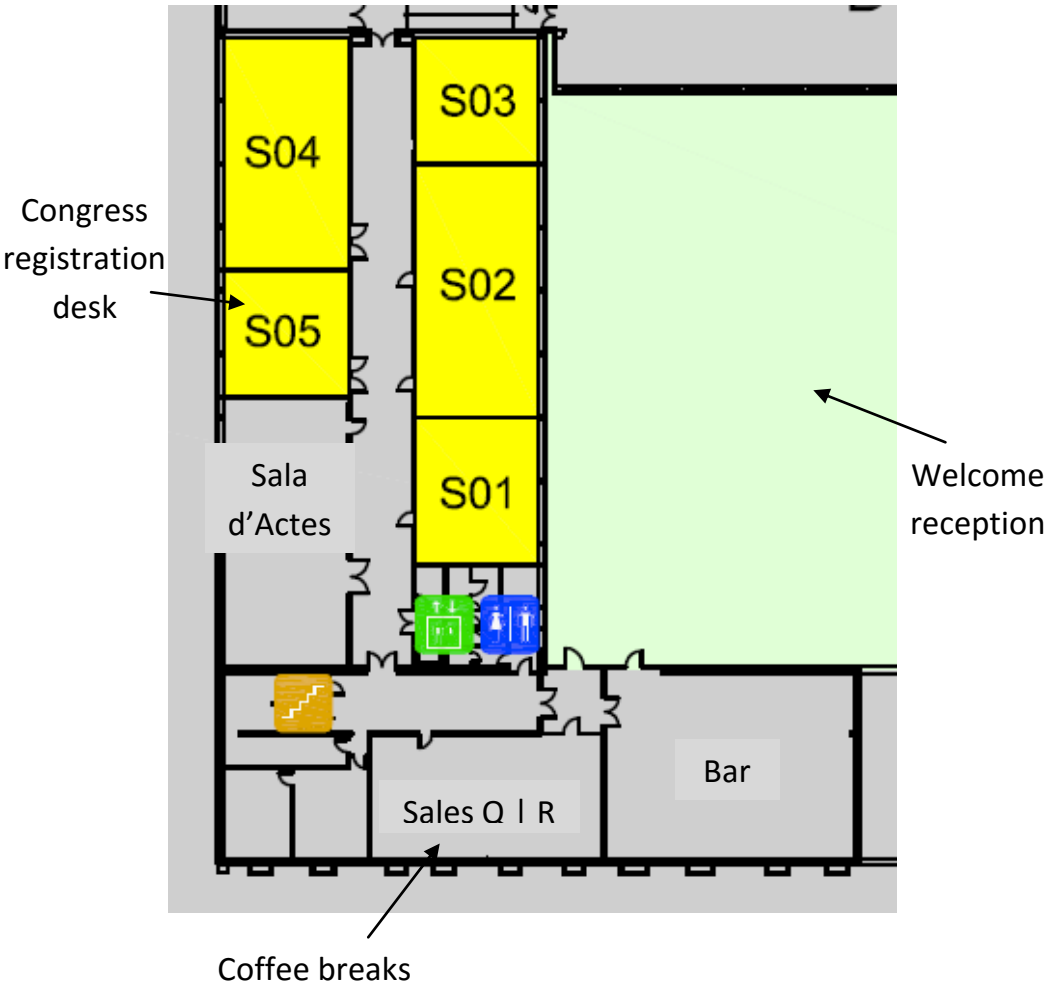
General view



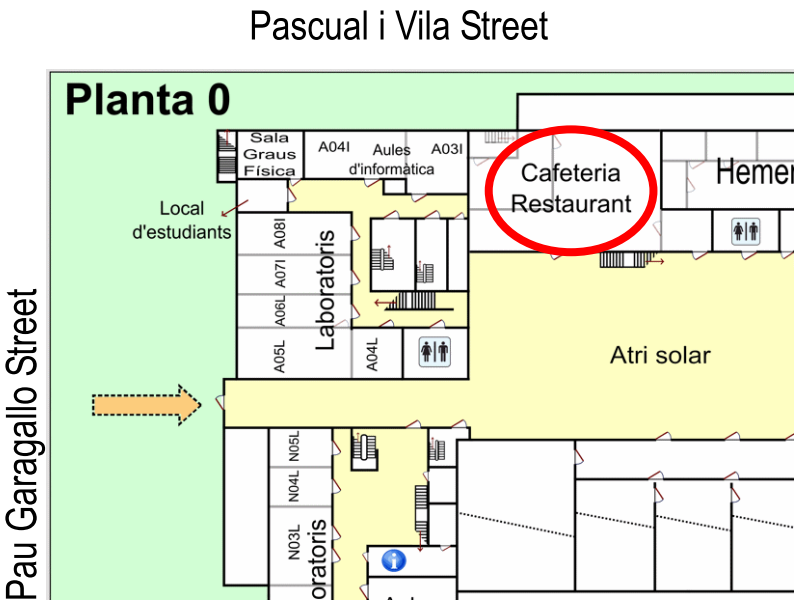
Faculty of Mathematics, Ground floor



Faculty of Mathematics, Floor -1



Faculty of Physics, Ground floor



Welcome Reception: Courtyard.

Lunches: Faculty of Physics.

Opening Ceremony and Plenary Sessions: Sala d'Actes.

Semi-plenary Sessions: Sala d'Actes and S02.

Regular and Invited Sessions: S01, S02 and S04.

Registration Desk: S05

Coffee breaks: Sales Q | R

Social Programme

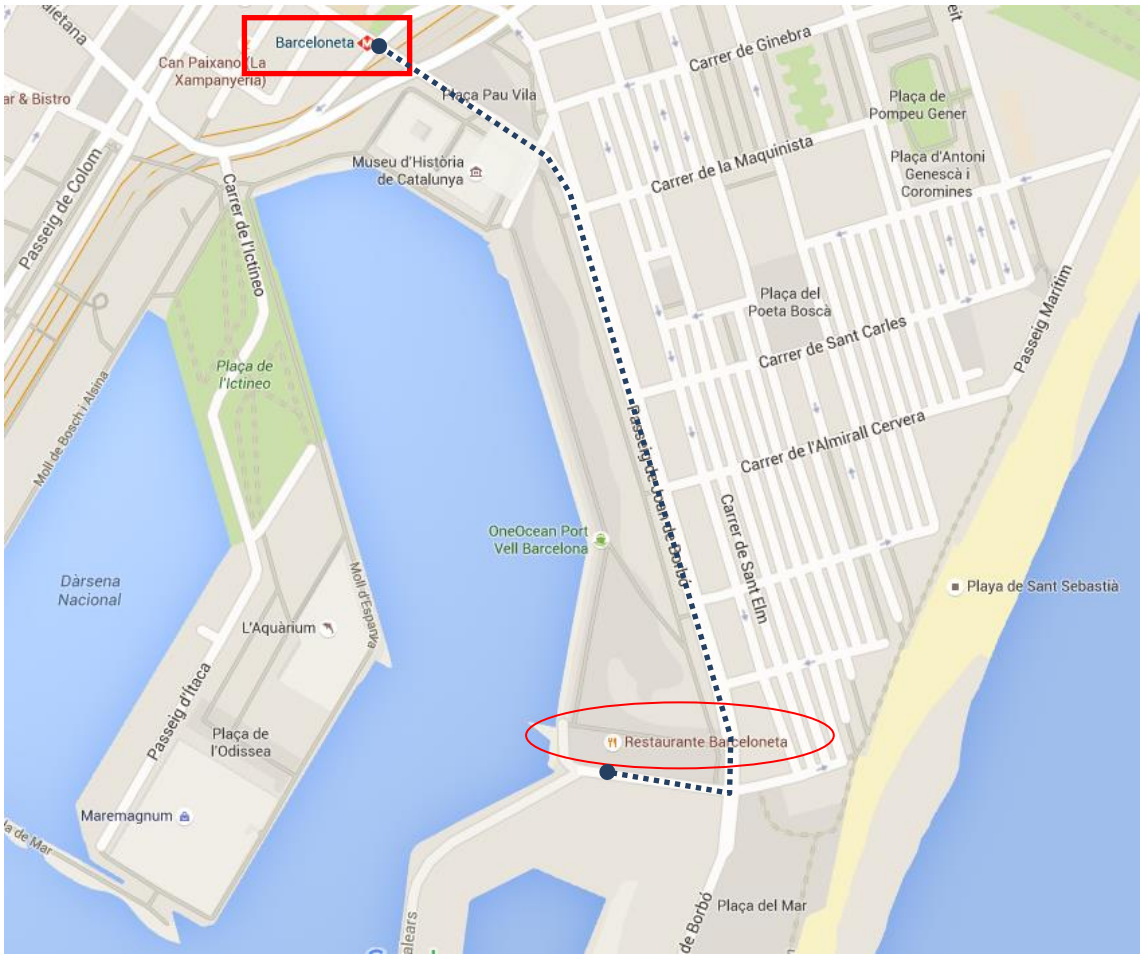
Welcome Reception

There will be a welcome cocktail for all SysTol attendees and accompanying persons at the Bar of the Faculty of Mathematics (see Site Map) on Tuesday September 6th at 19:30.

Conference Banquet

The Conference Banquet will be held at Restaurant Barceloneta on Thursday September 8th at 21:00. The restaurant can be reached by Underground (Metro): Line 4 (Barceloneta station).

The Conference Banquet is included in the full registration fee. Extra tickets will be available on sale in the registration desk (65€/person).



Restaurant Address: C/ De l'Escar, 22, Moll dels Pescadors (Port Vell), Barcelona.

Technical Programme

Plenary Sessions

Plenary Session title: *A Distributed Approach for Plug and Play Monitoring and Fault-tolerant Control of Large-scale Systems*

by *Thomas Parisini* (Imperial College London, UK)

Date: Wednesday September 7th, 2016
Time: 9:00-10:00
Room: Sala d'Actes

This lecture deals with a class of systems that are becoming ubiquitous in the current and future "distributed world" made by countless "nodes", which can be cities, computers, people, etc., and interconnected by a dense web of transportation, communication, or social ties. The term "network", describing such a collection of nodes and links, nowadays has become commonplace thanks to our extensive reliance on "connections of interdependent systems" in our everyday life, for building complex technical systems, infrastructures and so on. In an increasingly "smarter" planet, it is expected that such interconnected systems will be safe, reliable, available 24/7, and of low-cost maintenance. Therefore, health monitoring, fault diagnosis and fault-tolerant control are of customary importance to ensure high levels of safety, performance, reliability, dependability, and availability. For example, in the case of industrial plants, faults and malfunctions can result in off-specification production, increased operating costs, production line shutdown, danger conditions for humans, detrimental environmental impact, and so on. Faults and malfunctions need to be detected promptly and their source and severity should be diagnosed so that corrective actions can be taken as soon as possible. Once a fault is detected, the faulty subsystem can be unplugged to avoid the propagation of the fault in the interconnected large-scale system. Analogously, once the issue has been solved, the disconnected subsystem can be re-plugged-in.

In the talk, an adaptive approximation-based distributed fault diagnosis approach for large-scale nonlinear systems will be dealt with, by exploiting a "divide et impera" approach in which the overall diagnosis problem is decomposed into smaller sub-problems, which can be solved within "local" computation architectures. The distributed detection, isolation and identification task is broken down and assigned to a network of "Local Diagnostic Units", each having a "local view" of the system.

Moreover, the lecture will address the integration of a distributed model predictive control scheme and a distributed fault diagnosis architecture. Specifically, in the off-line control design phase we adopt a decentralized algorithm and we assume that the design of a local controller can use information at most from parents of the corresponding subsystem, i.e., subsystems that influence its dynamics. This implies that the whole model of the large-scale system is never used in any step of the design process. This approach has several advantages in terms of scalability: i) the communication flow at the design phase has the same topology of the coupling graph - usually sparse - ii) the local design of controllers and fault detectors can be conducted independently; iii) local design complexity scales with the number of parent

subsystems only; iv) if a subsystem joins/leaves an existing network (plug-in/unplugging operation) at most children/parents subsystems have to retune their controllers and fault detectors. We refer to this kind of decentralized synthesis as plug & play design, if - in addition - the plug-in and unplugging operations can be performed through a procedure for automatically assessing whether the operation does not spoil stability and constraint satisfaction for the overall large-scale system.

Thomas Parisini received the Ph.D. degree in Electronic Engineering and Computer Science in 1993 from the University of Genoa. He holds the Chair of Industrial Control at Imperial College London. Since 2001 he is also Danieli Endowed Chair of Automation Engineering with University of Trieste. He authored or co-authored more than 250 research papers in archival journals, book chapters, and international conference proceedings. His research interests include neural-network approximations for optimal control problems, fault diagnosis for nonlinear and distributed systems, nonlinear model predictive control systems and nonlinear estimation. He is a co-recipient of the 2011-2013 IFAC Best Application Paper Prize of the Journal of Process Control, Elsevier, and of the 2004 Outstanding Paper Award of the IEEE Trans. on Neural Networks. He is also a recipient of the 2007 IEEE Distinguished Member Award. In 2012 he was awarded a prestigious ABB Research Grant dealing with energy-autonomous sensor networks for self-monitoring industrial environments. Thomas Parisini is the Editor-in-Chief of the IEEE Trans. on Control Systems Technology. He is also the Chair of the IFAC Techn. Comm. on Fault Detection, Supervision & Safety of Technical Processes. He was the Chair of the IEEE CSS Conference Editorial Board and a Distinguished Lecturer of the IEEE. He is currently serving as an Associate Editor of the Int. J. of Control and served as Associate Editor of the IEEE Trans. on Automatic Control, of the IEEE Trans. on Neural Networks, of Automatica, and of the Int. J. of Robust and Nonlinear Control. Among other activities, he was the Program Chair of the 2008 IEEE CDC and a General Co-Chair of the 2013 IEEE CDC.

Plenary Session title: From Fault Diagnosis to Reconfigurable Control: A Unified Concept

by Jan Lunze (Ruhr-Universität Bochum, Germany)

Date: Thursday September 8th, 2016
Time: 11:30-12:30
Room: Sala d'Actes

Active fault-tolerant control is generally based on two steps: First, a diagnostic unit evaluates the measured input and output signals of a system in order to detect and identify a fault. Second, the controller is reconfigured to ensure that the closed-loop system including the faulty plant satisfies again the performance requirements. In the past, most of the authors have considered either the diagnostic step or the reconfiguration step and only a few results are available concerning the complete concept of fault-tolerant control. This talk presents a unified approach to both steps and demonstrates its results for a hexacopter experiment.

Jan Lunze is professor of automatic control and head of the Institute of Automation and Computer Control at the Ruhr-Universität Bochum (Germany). His research interests include fault diagnosis and reconfigurable control of discrete-event and hybrid systems, control theory with applications in the automotive and process industries, and networked control systems, where he has been the coordinator of a priority program of the German Research Foundation. He is author of numerous research papers and of monographs and textbooks on control theory, discrete-event systems and artificial intelligence with applications to dynamical systems.

Semi-plenary Sessions

Semi-plenary Session title: Analysis of Model-free Approaches for Fault-tolerance: Application to a Quadrotor UAV

by Hassan Noura (United Arab Emirates, United Arab Emirates)

Date: Wednesday September 7th, 2016
Time: 14:10-14:55
Room: Sala d'Actes

The model-free control concept has been recently developed and tested on several SISO systems. The main advantage of this concept consists of the simplicity of the design of the controller. This is achieved by adding a control law using ultra-local models to a basic classical control technique.

This concept has been used to improve the nominal control of a quadrotor UAV. It has then been developed further to design and implement an actuator fault-tolerant control (FTC) technique. The performance and the limitations of this FTC technique are analyzed through real-time flight tests on the Qball-X4 quadrotor.

Prof. Hassan Noura's research fields of interest are mainly, control systems, fault diagnosis, prognostic, and fault tolerant control with application to a variety of industrial systems: Steel industry, Helicopters, Overhead cranes, Unmanned Aerial Vehicles, Renewable Energy systems, etc. He received his Master and PhD degrees in Automatic Control from the University Henri Poincaré, Nancy 1 (now called Lorraine University), France in 1990 and 1993 respectively. He was Associate Professor in the same University from 1994 to 2003. In September 2003, he joined University Paul Cézanne, Aix-Marseille III (now called Aix-Marseille University), France as a Professor in Control Systems. He then moved to United Arab Emirates University in 2007. He served as a Chair of the Electrical Engineering Department from September 2011 to August 2016.

He has supervised several Master students and twelve PhD students. He had participated and led research projects in collaboration with industry in the fields of fault diagnosis and fault-tolerant control. He has authored and co-authored one book, and around 160 journal and conference papers.

Semi-plenary Session title: Kalman Filtering and Zonotopic State Bounding for Robust Fault Detection (Best paper in IFAC Safeprocess'2015)

by Christophe Combastel (University of Bordeaux, France)

Date: Wednesday September 7th, 2016
Time: 14:10-14:55
Room: S02

The satisfaction of advanced monitoring and fault tolerant control requirements heavily depends on the reliable estimation of physical values in many engineering systems. However, the information that can be inferred about such values is necessarily partial since measurements are usually corrupted by noise and since the knowledge brought by physical models can never be a complete and perfectly accurate image of reality. The explicit characterization of uncertainties is thus of prior importance in the context of model-based fault detection to ensure the reliability of the computed decisions. Indeed, such characterization strongly influences the computation of consistent confidence domains and/or explicit decision thresholds.

Two usually distinct paradigms exist to model uncertainties. The stochastic one deals with random uncertainties. Strong assumptions about their probability distributions are often made, especially when online computation is required. For instance, assuming independent Gaussian distributions is common practice when using standard versions of the famous Kalman Filter. Though efficient to deal with measurement noises, the assumption of known probability distributions finds its limits to characterize epistemic uncertainties. Indeed, the lack of a precise knowledge about disturbances such as the load torque of a motor may be better characterized by interval bounds with no assumption about the values distribution. This is the usual motivation for using the set-membership paradigm to model uncertainties. Though explicitly computed sets can achieve a so-called guaranteed robustness to the worst-cases resulting from the specified uncertainty bounds, the bounded-error paradigm however usually suffers from a poor management of random measurement noises.

In this talk, a joint Zonotopic and Gaussian Kalman Filter (ZGKF) will be presented. It will be shown to provide a solution for the robust fault detection of uncertain discrete-time systems simultaneously subject to bounded disturbances and Gaussian noises. The covariation of a zonotope will be introduced as a set-membership analog to covariance, making it possible to compute a time-varying optimal observer gain jointly minimizing both kinds of uncertainties: bounded/zonotopic and Gaussian. Then, given a maximal probability of false alarms, an innovation-based detection test will be shown to merge the usually mutually exclusive benefits granted by set-membership techniques (robustness to worst-case within specified bounds, domain computations) and stochastic approaches (taking noise distribution into account, probabilistic evaluation of tests). Numerical simulations will illustrate the significantly improved tradeoff between sensitivity to faults and robustness to disturbances/noises, while the computations (prediction/update, optimal gain, confidence domains, adaptive thresholds, detection test) remain explicit and can be efficiently implemented.

Christophe Combastel received his MSc degree in Electrical Engineering (1997) and his PhD in Control Systems (2000), both from Grenoble Institute of Technology (Grenoble-INP), France. His PhD thesis dealt with the fault diagnosis of electrical drives. From 2001 to 2015, he was Associate Professor at ENSEA, an engineering school in Electronics and applications located in Cergy (near Paris), and member of ECS-Lab (Electronics and Control Systems Laboratory, EA3649).

He was principal investigator for ENSEA in several collaborative research projects involving academics and industrial partners, with application targets mainly related to car industry and aerospace. His main focus is on dynamic model-based decision-making in uncertain contexts, which lead him to co-author around 50 publications in peer-reviewed international journals and conferences. Since 2015, he is with the University of Bordeaux and the IMS research lab (laboratoire de l'Intégration du Matériau au Système, CNRS UMR5218). As a member of the ARIA team in the Control System group of IMS, his research interests include interval, set-membership and stochastic algorithms for integrity control applications ranging from on-line fault diagnosis to verified model-based design, with special emphasis on uncertainty propagation and model-based data fusion.

Semi-plenary Session title: Model-based Fault Diagnosis for Wind Turbines - Can It Work in Practice?

by Michel Kinnaert (Université Libre de Bruxelles, Belgium)

Date: Friday September 9th, 2016
Time: 11:30-12:15
Room: Sala d'Actes

A fault diagnosis system for a wind turbine typically has a modular structure, each module being dedicated to specific faults and/or components. The presentation will consist of a tour of different modules emphasizing specific issues to ensure successful application on actual test bench or wind farm SCADA data, as well as implementation in industrial supervision systems. In particular, the following point will be addressed: exploitation of simple grey box models accounting for the main physical phenomena, quasi automatic identification of such models from available data, systematic tuning methodology of the parameters of the fault diagnosis system and validation requirements. Ways to use the diagnostic information for control reconfiguration at the level of the wind turbine or the wind farm will be discussed and research perspectives will be pointed out.

Michel Kinnaert is Professor in the Department of Control Engineering and System Analysis of "Université libre de Bruxelles" (ULB). He obtained the master degree in Mechanical and Electrical Engineering from ULB, the MS degree in Electrical Engineering from Stanford University and the Ph.D. degree from ULB. His research interests cover system modelling, monitoring and control with applications in mechatronics and power systems mainly. He held visiting professor positions in "Université Claude Bernard Lyon I", Lyon, France. He has been the chairman of the IFAC Technical Committee SAFEPROCESS from 2002 to 2008 and he is an associate editor of Control Engineering Practice. He co-authored, with M. Blanke, J. Lunze and M. Staroswiecki, the book Diagnosis and Fault Tolerant Control published by Springer.

Semi-plenary Session title: FDI Future Needs and Challenges for Upcoming Civil Aircraft Generation: An Industrial Vision

by Philippe Goupil (AIRBUS, Toulouse, France)

Date: Friday September 9th, 2016
Time: 11:30-12:15
Room: S02

Air transport is a major contributor to global economic prosperity and is the corner stone of global commerce with a myriad of economic and societal benefits. This expanding sector is trying to respond to the increased passenger demand - doubling every 15 years - by offering the latest innovations that meet evolving passenger trends and environmental demands while facing emerging competition. These are the 3 main pillars (air traffic growth, environmental footprint and competition) which drive the innovation need for the upcoming civil aircraft generation.

In this context, these needs come in several technical challenges that will be detailed during the presentation:

- Sustainability: not obvious at the first sight, it can be demonstrated that detecting earlier smaller and smaller fault amplitude, as well as incipient faults, can lead to weight saving which in turn help decrease the aircraft environmental footprint. Advanced Fault Detection and Isolation (FDI) represents thus a promising technology to master and to mature for next generation aircraft.
- To decrease the pilot workload, more and more extended Guidance Navigation and Control functions are used on-board. This requires extended flight parameter availability that can be achieved thanks to virtual sensors development (model-based or data-driven).
- The use of different sensing technologies like for example vision-based technics to improve present-day FDI state of practice.
- Model-based or data-driven data fusion to mix physical measurements and virtual sensors.
- Managing the complexity: avionic systems are more and more complex leading to a growing complexity that will be crucial to manage on future aircraft.

In this presentation, these technical challenges will be illustrated by focusing on FDI in the Flight Control System (FCS). FCS is used to control the aircraft speed, trajectory and attitude and is one of the most critical systems on-board the aircraft. But to adopt a new FDI solution in such a system, and in a modern civil aircraft in general, several problems must be tackled:

- To demonstrate that FDI solutions are able to answer to the aforementioned challenges: robustness, performances and complexity compliant with real-time constraints.
- To prove that they present benefits over the existing in-service and already proven technical solutions.
- To show the genericity of the solutions, that they are compliant with existing system architecture (e.g. no additional sensors).
- To build around the existing solutions (i.e. being inspired by the industrial state of practice).
- A solution that is easy to validate (e.g. not too many input parameters to tune) and accompanied by a tuning procedure.

Philippe Goupil received the PhD degree in signal processing from the French Polytechnic National Institute, Toulouse. He currently works at the Airbus design office, where he has acquired a strong experience in Flight Control System through several aircraft program developments. He is mainly in charge of R&T activities for developing advanced fault detection and diagnosis algorithms. He has been involved in the European GARTEUR Flight Mechanics Action Group FM-AG16 (2004-2008) on Fault Tolerant Control and in the French project SIRASAS which dealt with innovative and robust strategies for spacecraft autonomy (2007-2010). He was the AIRBUS representative in the FP7 European Project ADDSAFE (2009-2012) which focuses on Advanced Fault Detection and Diagnosis towards a more Sustainable Flight Guidance and Control. Dr. Goupil is currently the AIRBUS focal point in the FP7 European Project RECONFIGURE (2013-2016) which deals with aircraft GNC technologies that facilitate the automated handling of off-nominal events. He is the author or co-author of 15 industrial international patents and of more than 50 conference or journal articles. He has been the industrial supervisor of four PhD students. Philippe Goupil is a member of three IFAC Technical Committees. He served many time as IPC member and reviewer for several IFAC conferences and journals. He co-authored, with A. Zolghadri, D. Henry, J. Cieslak and D. Efimov, the book Fault Diagnosis and Fault Tolerant Control and Guidance for Aerospace Vehicles, published by Springer.

Program at a Glance

SysTol'16 Technical Program Wednesday September 7, 2016

Track T1	Track T2	Track T3
08:30-09:00 WeP0 Sala d'Actes Opening Ceremony		
09:00-10:00 WeP1 Sala d'Actes "A Distributed Approach for Plug and Play Monitoring and Fault-Tolerant Control of Large-Scale Systems" Thomas Parisini		
10:00-10:30 Sales Q | R Coffee break		
10:30-12:30 WeA2 S01 Fault Diagnosis and Fault-Tolerant Control for Mobile Application	10:30-12:30 WeA3 S04 Robotics	10:30-12:30 WeA4 S02 Set-Invariance Approaches Applied to Fault Diagnosis and Fault-Tolerant Control
12:30-14:10 Faculty of Physics Lunch		
14:10-14:55 WeSP5 Sala d'Actes "Analysis of Model-Free Approches for Fault-Tolerance: Application to a Quadrotor UAV" Hassan Noura		14:10-14:55 WeSP6 S02 "Kalman Filtering and Zonotopic State Bounding for Robust Fault Detection" Christophe Combastel
15:00-17:00 WeB2 S01 UAV	15:00-17:00 WeB3 S04 Process Applications	15:00-17:00 WeB4 S02 Data-Driven Methods
17:00-17:30 Sales Q | R Coffee break		
17:30-19:30 WeC2 S01 Mechatronics and Manufacturing	17:30-19:30 WeC3 S04 Recent Advances in FDI/FTC Techniques	17:30-19:30 WeC4 S02 Computational Intelligence

SysTol'16 Technical Program Thursday September 8, 2016

Track T1	Track T2	Track T3
09:00-11:00 ThA1 S01 Leakage Management in Water Networks	09:00-11:00 ThA2 S04 Aerospace Applications	09:00-11:00 ThA3 S02 Fault Diagnosis 1
11:00-11:30 Sales Q | R Coffee break		
11:30-12:30 ThP5 Sala d'Actes "From Fault Diagnosis to Reconfigurable Control: A Unified Concept" Jan Lunze		
12:30-14:00 Faculty of Physics Lunch		
14:00-16:00 ThB1 S01 Monitoring, Fault Detection and Supervision for Water System Management	14:00-16:00 ThB2 S04 Set-Membership-Based Techniques for FDI & FTC	14:00-16:00 ThB3 S02 Fault Diagnosis 2
16:00-16:30 Sales Q | R Coffee break		
16:30-18:30 ThC1 S01 Energy Conversion & Distribution	16:30-18:30 ThC2 S04 Health Management	16:30-18:30 ThC3 S02 Fault Tolerant Control 1

SysTol'16 Technical Program Friday September 9, 2016

Track T1	Track T2	Track T3
09:00-11:00 FrA1 S01 Wind and Wave Turbines	09:00-11:00 FrA2 S04 Fault Diagnosis and Fault Tolerant Control for Aerospace Systems	09:00-11:00 FrA3 S02 Fault Tolerant Control 2
11:00-11:30 Sales Q | R Coffee break		
11:30-12:15 FrSP5 Sala d'Actes "Model-Based Fault Diagnosis for Wind Turbines – Can It Work in Practice?" Michel Kinnaert		11:30-12:15 FrSP6 S02 "FDI Future Needs and Challenges for Upcoming Civil Aircraft Generation: An Industrial Vision" Philippe Goupil
12:15-14:00 Faculty of Physics Lunch		
14:00-16:00 FrB1 S01 Networked Control Systems	14:00-16:00 FrB2 S04 RECONFIGURE FP7 Project for Advanced Real-Time FDD and FTC for Civil Aircraft: Contributions and Results	14:00-16:00 FrB3 S02 Fault Accommodation

Technical Program for Wednesday September 7, 2016

WeA2	S01
Fault Diagnosis and Fault-Tolerant Control for Mobile Application (Invited Session)	
Chair: Witczak, Marcin	Univ. of Zielona Gora
Co-Chair: Theilliol, Didier	Univ. of Lorraine
Organizer: Theilliol, Didier	Univ. of Lorraine
Organizer: Witczak, Marcin	Univ. of Zielona Gora

10:30-10:50 WeA2.1

Robust Flocking Control Design for a Fleet of Autonomous Agents (I), pp. 1-6

BELKADI, Adel — Univ. De Lorraine
Theilliol, Didier — Univ. of Lorraine
CIARLETTA, Laurent — Univ. De Lorraine, Loria
Ponsart, Jean-Christophe — Univ. De Lorraine

Various strategies and algorithms have been developed for control of autonomous agents in a fleet. Many of these approaches are interesting but have limited performances in environments where measurements are less accurate or faults occur. The main contribution of the paper consists in the design of a robust flocking algorithm with regards to the problem of defective agents. Our approach is based on an extension of proposed models in literature, in order to synthesis a robust and suitable model for outdoor fleet control. The method is tested in simulation on a fleet of mobile robots. Test results and comparisons between different simulation requirements are presented.

10:50-11:10 WeA2.2

A Fault Hiding Approach for the Sliding Mode Fault-Tolerant Control of a Non-Holonomic Mobile Robot (I), pp. 7-14

Stancu, Alexandru — Univ. Pol. De Catalunya (UPC)
CODRES, EDUARD ALEXANDRU — THE Univ. OF MANCHESTER
Puig, Vicenç — Univ. Pol. De Catalunya (UPC)

When mobile robots are intended to be used in hazardous environments or for long-time operations, it is needed to increase their robustness against failures. This could be achieved by means of the inclusion of Fault Tolerant Control (FTC) mechanisms. In this paper, a FTC based on fault hiding approach is proposed for a non-holonomic mobile robot. First, a Sliding Mode Controller (SMC) is designed to cope with modelling uncertainty. Later on, it is enhanced to take into account actuator faults leading to a fault hiding approach for the sliding mode fault-tolerant control of the robot. Results using simulated fault scenarios are presented to illustrate the performance of the proposed approach.

11:10-11:30 WeA2.3

Thrust Balance Estimation of an Unmanned Aerial Vehicle: Application to Fault Detection (I), pp. 15-20

Witczak, Piotr — Univ. of Zielona Gora
Pazera, Marcin — Inst. of Control and Computation Engineering
Witczak, Marcin — Univ. of Zielona Gora
Korbicz, Jozef — Univ. of Zielona Gora
Theilliol, Didier — Univ. of Lorraine

Due to uncertain flight conditions as well as faults, an outdoor performance of any unmanned aerial vehicle is a challenging task. Indeed, owing to weather conditions it is entirely different that any laboratory tests. While small and radio controlled drones are relatively common devices, they are still unruly while wind blows. Moreover, process and actuator faults may also significantly impair the overall system performance. All of these factors are reflected by the thrust balance. Thus, the main objective of this paper is to propose a scheme that can be used for simultaneous estimation the thrust balance as well as the state under uncertain environment. The estimated information allows performing decisions about the current faulty/fault-free situation of the system. The proposed approach is based on the H-infinity paradigm, which can be relatively easily implemented on the chips dedicated to popular drones, such as Arduino or Raspberry Pi based solutions that are widely available.

11:30-11:50 WeA2.4

Fault-Tolerant Cooperative Control of WMRs under Actuator Faults Based on Particle Swarm Optimization (I), pp. 21-26

Kamel, Mohamed A. — Concordia Univ
Yu, Xiang — Concordia Univ
Zhang, Youmin — Concordia Univ

This paper investigates fault-tolerant cooperative control (FTCC) of multiple wheeled mobile robots (WMRs) in the presence of severe actuator faults. Initially, a team of robots is moving in pre-defined formation configuration. When actuator faults occur in one or more robots, and the faulty robot(s) cannot complete the mission, the rest of robots start reconfiguring the formation to compensate the fault effect on the whole mission. First, the new formation reconfiguration is generated by solving an optimal assignment problem where each healthy robot should be assigned to a unique place. Then, the new formation can be reconfigured by recasting the reconfiguration problem as an optimization problem, while the objective is to minimize the time to achieve the new formation reconfiguration within the constraints of the robots' dynamics and collision avoidance. A hybrid approach of control parametrization and time discretization (CPTD) and particle swarm optimization (PSO) is proposed to solve the optimization problem. The results of the numerical simulations demonstrate the effectiveness of the proposed algorithm.

11:50-12:10 WeA2.5

FDD and FTC for Ramp-Type Actuator Fault Using Intelligent-Output-Estimator (I), pp. 27-32

Al Younes, Younes — Higher Coll. of Tech
RABHI, ABDELHAMID — MIS
NOURA, Hassan — United Arab Emirates Univ
El hajjaji, ahmed — Univ. of Picardie Jules Verne

In this paper, Fault Detection and Diagnosis (FDD) and Active Fault Tolerant Control (AFTC) algorithms are proposed to compensate for a ramp-type Loss-of-Effectiveness (LoE) actuator fault applied on the quadrotor system. Based on the Model-Free concept, an output estimator design called intelligent Output-Estimator (iOE) is presented to estimate the outputs of the system and then used to improve the estimation of the actuator faults. Then the estimation is used to detect and isolate the faulty actuator by generating fault symptoms. Finally, the estimation value is integrated into the control law to compensate for the variable actuator fault. Real-flight results validated the proposed algorithm and showed the actuator fault accommodation process.

WeA3	S04
Robotics (Regular Session)	
Chair: Reppa, Vasso	Supelec
Co-Chair: Rotondo, Damiano	Univ. Pol. De Catalunya (UPC)

10:30-10:50 WeA3.1

Multiple-Model Based Actuator Fault Compensation for Two Linked 2WD Mobile Robots, pp. 33-38

MA, Yajie — Nanjing Univ. of Aeronautics and

	Astronautics
Cocquempot, Vincent	Lille 1 Univ
Maan, El Badaoui El Najjar	Univ. Lille, CRIStAL
Jiang, Bin	NUAA

This paper develops a new compensation control scheme for two linked wheeled mobile robots with actuator failurs. First, a configuration of two linked two-wheel drive (2WD) mobile robots is described, and its kinematics and dynamics are modeled. Then, a multiple-model based control scheme is developed to compensate for actuator failures, consisting of a kinematiccontroller,multipledynamiccontrollersandacontrol switching mechanism, which can ensure system stability and asymptotic tracking properties. Simulation results verify the effectiveness of the proposed control scheme.

10:50-11:10 WeA3.2

A Kinematic Joint Fault Tolerant Control Based on Relative Jacobian Method for Dual Arm Manipulation Systems, pp. 39-44

Freddi, Alessandro	Univ. Degli Studi Ec
Longhi, Sauro	Univ. Pol. Delle Marche
Monteriù, Andrea	Univ. Pol. Delle Marche
Ortenzi, Davide	Univ. Pol. Delle Marche

The present paper presents a fault tolerant control for dual arm manipulation systems affected by joint faults. The fault is modelled like a reduction of the maximum joint velocity due to partial torque loss of a servomotor. The system is made locally fault tolerant by exploiting its redundancy degrees via two different methods. The first method permits to reduce the manipulators' manipulability loss in case of fault occurrence, by imposing an optimal fault tolerant configuration to both manipulators; this is directly obtained from the knowledge of the Jacobian null space. The second method permits to compensate the loss of the end effectors motion using the saturation null space approach. In order to handle the dual arm system as a unique equivalent manipulator, both methods are formulated according to the relative Jacobian method. The efficiency of the proposed joint fault tolerant control is shown in a case study, where joint faults occur at different time instants.

11:10-11:30 WeA3.3

Fault Tolerant Autonomous Robots Using Mission Performance Guided Resources Allocation, pp. 45-50

jaiem, lotfi	Montpellier Univ. Lab. D'informatique Robotique Et
lapierre, lionel	LIRMM
godary-dejean, karen	LIRMM
crestani, didier	LIRMM

Real long-term, complex and autonomous mission is still a challenge for robotics. This paper presents an efficient approach enhancing the robot with fault tolerance. It uses performance viewpoints to guide hardware and software resources allocation all along the mission according to faults effects and detection. Simulated and experimental results are proposed and analyzed.

11:30-11:50 WeA3.4

Modified Robust Panel Method for Mobile Robot Path Planning in Partially Unknown Static and Dynamic Environments, pp. 51-58

Ibrahimović, Belma	Faculty of Electrical Engineering, Sarajevo
Velagić, Jasmin	Univ. of Sarajevo

This paper proposes a novel panel method, called modified robust panel method (MRPM), useful to represent open polygonal chains. MRPM extends an existing panel method approach in order to account for moving obstacles. It is effective for the mobile robot path planning in both static and dynamic environments under partially unknown conditions satisfying real-time requirements. The robustness of the method lays in automatically adjusting the potential field parameters based on the obstacle shapes and sizes taking in account all field segments. These parameters need to be limited so that convergence to the goal position is guaranteed. An activation window and an algorithm to select the relevant obstacles are also presented in order to reduce the computation time. The modified Histogramic-In-Motion-Map (HIMM) algorithm is used to continuously update a grid-based map in which each cell stores the probability of the related region that is occupied by an obstacle. In order to verify the proposed methods a three-layered robot navigation system is developed. The effectiveness and robustness of the proposed methods are demonstrated through simulations.

11:50-12:10 WeA3.5

PSO-Based Method for Navigation of Mobile Robot in Unstructured Static and Time-Varying Environments, pp. 59-66

Irfan, Jabandžić	Faculty of Electrical Engineering, Sarajevo
Velagić, Jasmin	Univ. of Sarajevo

The paper considers a problem of the mobile robot navigation in unstructured environments based on an improved Particle Swarm Optimization (PSO) method. It introduces a new fitness function divided into sub-functions, where each sub-function is responsible for accomplishing given objectives and imposed constraints. The main objectives of proposed sub-functions are to maximize the distance between the robot and a previously detected nearest obstacle, minimize distance from the robot to a global best position of the particles and the local minima problem avoidance. Also, proper constraints are included to prevent the robot from penetrating into restricted (prohibited) areas around detected obstacles or to avoid that particle moves too far away from the mobile robot's current position. The proposed PSO based planner generates a smooth collision free path with a low computational cost and approaches the goal position employing an adaptive control strategy. The adjustment and selection of suitable parameters values of PSO method are based on extensive simulations performed in various environments. The effectiveness of the proposed method has been verified with a series of simulations.

WeA4 S02

Set-Invariance Approaches Applied to Fault Diagnosis and Fault-Tolerant Control (Invited Session)

Chair: Ocampo-Martinez, Carlos	Tech. Univ. of Catalonia (UPC)
Co-Chair: Martinez Molina, John Jairo	Gipsa-Lab, Grenoble-INP
Organizer: Reppa, Vasso	Supelec
Organizer: Ocampo-Martinez, Carlos	Tech. Univ. of Catalonia (UPC)
Organizer: Martinez Molina, John Jairo	Gipsa-Lab, Grenoble-INP

10:30-10:50 WeA4.1

Robust State Estimation and Fault Detection Combining Unknown Input Observer and Set-Membership Approach (I), pp. 67-72

Xu, Feng	Tsinghua Univ
Tan, Junbo	Tsinghua Univ
Wang, Xueqian	Tsinghua Univ
Puig, Vicenç	Univ. Pol. De Catalunya (UPC)
Liu, Houde	Tsinghua Univ
Liang, Bin	Tsinghua Univ
Yuan, Bo	Tsinghua Univ

This paper aims to propose a new robust state-estimation and fault-detection method by combining the unknown input observer (UIO) and the set-membership estimator (SME). It is known that both the SUIO and the SME can be used to estimate the states of a system. The former aims to obtain a particular value by actively decoupling the effect of unknown inputs, while the latter can obtain

state-estimation sets by prediction and correction based on the set theory. Instead of particular state values, the latter can obtain state-estimation sets guaranteeing to contain system states (i.e., robust state estimation). In this paper, we propose to use the framework of the UIO to actively decouple part of unknown inputs and then further employ the set-membership estimation method to estimate state sets and detect faults. The objective of the proposed method is to reduce the conservatism of robust state-estimation sets by using the UIO to remove the contribution of part of unknown inputs to the sizes of state-estimation sets. At the end of this paper, a numerical example is used to illustrate the effectiveness and advantages of the proposed approach.

10:50-11:10 WeA4.2

Recoverable Set Computation for Post-Fault/failure Quadrotors Based on Sum of Squares (SOS) (I), pp. 73-78

Qi, Xin	Shenyang Inst. of Automation(SIA)
Theilliol, Didier	Univ. of Lorraine
He, Yuqing	Shenyang Inst. of Automation, CAS, P.R.China
Han, Jianda	Shenyang Inst. of Automation

In this paper, an evaluation approach of recoverable performance for post-fault quadrotors is investigated. Both propeller faults and failures are considered, such as loss of partial propeller effectiveness and loss of one or more propellers. The main contribution is to propose a method to compute recoverable set for different faulty conditions using sum of squares (SOS). The recoverable set is an invariant set and it is the set of initial states, which can be driven to the equilibrium point while respecting propeller faults, failures and rotating speed limits. Before computing the set, feasible equilibrium points are calculated to guarantee relaxed hover solutions against different faulty cases. Simulations illustrate the effectiveness of proposed approach with nonlinear quadrotor dynamics under various fault and failure conditions.

11:10-11:30 WeA4.3

Characterization of the Minimum Detectable Fault of Interval Observers by Using Set-Invariance Theory (I), pp. 79-86

Pourasghar, Masoud	UPC
Puig, Vicenç	Univ. Pol. De Catalunya (UPC)
Ocampo-Martinez, Carlos	Tech. Univ. of Catalonia (UPC)

This paper addresses the characterization of the minimum detectable fault when using interval observers. The interval observers consider both input and uncertainty as unknown but bounded. The minimum detectable fault is characterized by means of residual sensitivity and invariant sets for interval observers. The design of such observers is performed by using zonotopic-set representations. The mathematical expression of the minimum magnitude of the fault that can be detected is derived for a given type of faults in separate formulations. Finally, a simulation example is employed to illustrate and discuss the effectiveness of the obtained results.

11:30-11:50 WeA4.4

Set-Invariance Analysis for Deterioration Prediction on a Roller-On-Tire Actuator (I), pp. 87-92

Rodriguez Obando, Diego J.	Univ. Grenoble Alpes, GIPSA-Lab, F-38000 Grenoble, France. CNRS,
Martinez Molina, John Jairo	Gipsa-Lab, Grenoble-INP
Berenguer, Christophe	Grenoble Inst. of Tech. & CNRS

The paper deals with the problem of predicting deterioration of a roller-on-tire actuator in presence of unpredictable but bounded motor torques. Set-invariance is used to characterize the nominal behavior of the actuator and the maximal admissible deterioration behavior. A novel index of deterioration is presented and allows to model the mechanical actuator as a polytopic Linear Parameter Varying model. For a given initial deterioration, the probabilistic certification approach is used to numerically predict an interval of "expected time" for reaching the total outage of the actuator. A simulated example illustrates the interest of the proposed approach and its potential integration on future predictive maintenance techniques.

11:50-12:10 WeA4.5

Switching-Stable Control Mechanism in the Presence of Guaranteed Detectable Sensor Faults (I), pp. 93-98

Kodakkadan, Abid Rahman	CentraleSupelec
Reppa, Vasso	Supelec
Olaru, Sorin	CentraleSupélec

This paper deals with the design and analysis of a switching stable control reconfiguration mechanism for compensating the effects of the abnormal functioning of sensors on the closed-loop system operation. Robust positive invariance based approach is followed aiming at detecting and isolating faults in the sensors. The main objective of the paper is to guarantee the fault detection, and isolation of the faulty sensors, which are switched off from the feedback control scheme in order to use only the healthy sensors. A parametrized controller is used to ensure the stability of the closed-loop system during switching satisfying a desired performance. Simulation results are used to illustrate the efficiency of the proposed active fault tolerant control scheme in preserving switching stability.

WeB2 S01

UAV (Regular Session)

Chair: Morcego, Bernardo	Univ. Pol. De Catalunya
Co-Chair: Nejjari, Fatiha	Univ. Pol. De Catalunya

15:00-15:20 WeB2.1

Velocity Tracking Control of AUVs in Horizontal Motion, pp. 99-104

Herman, Przemyslaw	Poznan Univ. of Tech
Kowalczyk, Wojciech	Poznan Univ. of Tech

In the paper the problem of velocity tracking control of Autonomous Underwater Vehicles (AUVs) in horizontal plane is considered. The proposed approach is based on transformed equations of motion and it allows one to apply the dynamical couplings in the control gain matrix. As a result, the dynamics of the vehicle is included into the control process what leads to fast system response. The stability of the system with the controller is done using the Lyapunov method. Effectiveness of the control algorithm is validated via simulations on a 3 DOF underwater marine vehicle model.

15:20-15:40 WeB2.2

A NLPCA Hybrid Approach for AUV Thrusters Fault Detection and Isolation, pp. 105-110

Fabiani, Filippo	Univ. of Pisa
Grechi, Simone	Univ. of Pisa
Della Tommasina, Simone	Univ. of Pisa
Caiti, Andrea	Univ. of Pisa

The objective of this paper is to address the problem of Fault Detection and Isolation (FDI) on thrusters of an over-actuated Autonomous Underwater Vehicle (AUV). The objective is pursued through Non-Linear Principal Component Analysis (NLPCA), which is the non-linear extension of the popular Principal Component Analysis (PCA). While the Fault Detection (FD) system directly exploits the model-free nature of NLPCA (data-driven approach), the Fault Isolation (FI) is achieved by properly train off-line Artificial Neural Network (ANN). The consistency and robustness of the proposed method is verified in realistic simulation.

15:40-16:00 WeB2.3

Modelling and Control of a Coaxial Helicopter UAV in an Indoor Laboratory, pp. 111-118

Rubí, Bartomeu	Univ. Pol. De Catalunya

perez, ramon UPC (Univ. Pol. De Catalunya)
Morcego, Bernardo Univ. Pol. De Catalunya

This paper describes the modelling, the control algorithm and the flight experiments performed with an Unmanned Aerial Vehicle (UAV). The vehicle is a coaxial toy helicopter and the control platform is an indoor platform with a computer vision sensor. The dynamic model of the vehicle as well as the identification process of its parameters are described. The controller consists on a cascade control structure formed by trajectory, velocity and attitude control loops implemented with PID-based controllers. The experimental results show a maximum position error of 5cm on hovering experiments and exhibit a great precision in the trajectory tracking experiments.

16:00-16:20 WeB2.4

Experimental Evaluation of an Active Fault-Tolerant Control Scheme for Multirotor UAVs, pp. 119-126

Vey, Daniel Univ. of Bochum
Lunze, Jan Univ. of Bochum

This paper presents experimental results that have been obtained by applying an active fault-tolerant control (FTC) framework to multirotor UAVs subject to actuator failures. The proposed fault-tolerant control scheme combines a bank of observers for diagnosis with the concept of the virtual actuator for control reconfiguration. Therefore, an evaluation method for fault detection and isolation is presented, which guarantees that the diagnosis result is always adequate for control reconfiguration. The experiments with a hovering multirotor UAV subject to a rotor failure validate the applicability of the proposed FTC scheme under real-time constraints and in the presence of natural uncertainties, measurement noise and process disturbances.

16:20-16:40 WeB2.5

Fault-Tolerant Cooperative Control of Multiple UAVs for Forest Fire Detection and Tracking Mission, pp. 127-132

Ghamry, Khaled A. Concordia Univ
Zhang, Youmin Concordia Univ

A fault-tolerant cooperative control (FTCC) strategy for cooperative unmanned aerial vehicles (UAVs) used in forest monitoring, fire detection and tracking is investigated in this paper. The proposed algorithm solves the problem of monitoring and detection of forest fires, even when fault occurs to one or more UAVs. During the search stage, the UAVs team moves in a certain formation shape, a distributed sliding mode formation control is designed to keep the desired formation shape during this stage. Once a fire is detected, another distributed reconfigurable controller is designed based on sliding mode control (SMC) to evenly distribute UAVs team around the elliptical fire perimeter in fault-free case. When one or more UAVs cannot continue their mission due to a fault or leaving from formation for refueling/recharging, an FTCC strategy will be deployed to decrease the effects of the changed formation condition and the faulty/absent UAV's tasks will be reassigned to the remaining healthy/operable ones. Therefore, the new formation will be reconfigured and the UAVs still be evenly distributed around the fire spot for best coverage of the fire site. Simulation results are used to demonstrate the effectiveness of the proposed algorithm using six degreeof-freedom (DOF) quadrotor dynamic models of UAVs.

16:40-17:00 WeB2.6

Velocity Tracking Controller for Planar Motion of Underwater Vehicles, pp. 133-138

Herman, Przemyslaw Poznan Univ. of Tech
Kowalczyk, Wojciech Poznan Univ. of Tech

A control algorithm for velocity tracking of autonomous underwater vehicles (AUV) is presented in this work. The controller is realized using the transformed equations of motion obtained from the inertia matrix decomposition. The control gains contain dynamics of the vehicle, which cause that the motion strictly depend on the system parameters. The stability of the system together with the controller is done based on a Lyapunov method. The proposed strategy is suitable for fully actuated vehicles moving in the planar space. However, it is shown that also if the system is underactuated it is possible to use the approach. An explanation of this idea is given for diving of a 3 DOF planar AUV model. The controller performance of the proposed is validated via simulation on a 3 DOF AUV.

WeB3 S04

Process Applications (Regular Session)

Chair: Maquin, Didier Univ. De Lorraine
Co-Chair: Rampazzo, Mirco Univ. Di Padova

15:00-15:20 WeB3.1

Transfer Function Models for Distributed Parameter Systems: Application in Pipeline Diagnosis, pp. 139-145

Bartecki, Krzysztof Opole Univ. of Tech

The occurrence of a leak in a transportation pipeline affects not only its steady-state characteristics, such as pressure and flow profiles, but also its dynamical properties, which can be represented, for instance, by a transfer function. The transfer function considered in the paper represents the hydraulic impedance of the pipeline, defined as the ratio of the complex pressure to the complex flow of the transported fluid. A result of the leak, the hydraulic impedance of the pipeline changes, which can be observed, for example, on its frequency- and time-domain pressure responses. The analysis performed in the paper shows that the patterns introduced into these responses by the leaks of different sizes and locations can be used as symptoms, allowing leak detection and classification.

15:20-15:40 WeB3.2

Fault Tolerant MPC of a Solar Trough Field Based on Classification and Regression Trees, pp. 146-151

Sánchez, Adolfo J. Univ. of Seville
Escano, Juan Manuel Univ. De Sevilla
Gallego, Antonio J. Escuela Superior De Ingenieros
Eduardo, Camacho Escuela Superior De Ingenieros

Direct solar radiation is important in a solar trough plant because it is the perturbation that affects most the operation. Generally, it is measured locally. Production losses or dangerous situations may occur when controlling a plant with wrong measurements. A possible solution is to have several pyrheliometers though two problems arise: cost and sensor fusion (complexity). The aim of this paper is to prove that a solar estimation based on Classification and Regression Trees can be used to design a Fault Tolerant Model Predictive Control strategy capable to work with erroneous values of radiation or even none, avoiding dangerous situations or production losses.

15:40-16:00 WeB3.3

Model-Based Fault Detection and Diagnosis for Centrifugal Chillers, pp. 152-157

Beghi, Alessandro Univ. Di Padova
Cecchinato, Luca Univ. Di Padova
Peterle, Fabio Univ. of Padova
Rampazzo, Mirco Univ. Di Padova
Simmini, Francesco Univ. of Padova

Faulty operations of Heating, Ventilation and Air Conditioning (HVAC) chiller systems can lead to discomfort for the users, energy wastage, system unreliability and shorter equipment life. Faults need to be early diagnosed to prevent further deterioration of the system behaviour and energy losses. In this paper a model-based approach is used in order to detect important chiller systems faults. First, a linear dynamic black-box model is identified for each of the relevant characteristic features of the system during the normal functioning of the chiller. Then, an on-line correlogram method verifies the whiteness property of the residuals in order to distinguish anomalies from normal operations. A decision table, that matches the influence of anomalies with the characteristic features, allows to identify chiller faults. The

proposed fault detection and diagnosis approach is assessed by using real chiller data provided by the ASHRAE research project RP-1043.

16:00-16:20 WeB3.4

Nonlinear Joint State-Parameter Observer for VAV Damper Position Estimation, pp. 158-163

Srinivasarengan, Krishnan — Univ. of Lorraine
Ragot, Jose — Univ. De Lorraine
Maquin, Didier — Univ. De Lorraine
Aubrun, Christophe — Univ. of Lorraine

Variable Air Volume (VAV) based Heating Ventilation and Air Conditioning (HVAC) systems are common in large non-residential buildings. The dynamic model of a VAV system along with the Air Handling Unit (AHU) and the zones has a nonlinear characteristic. In this paper, a nonlinear model based joint state and parameter observer is proposed to estimate the VAV damper position in such systems. First, a Takagi-Sugeno (T-S) equivalent model for the AHU-VAV-Zone model is obtained using sector nonlinearity approach. The damper position estimation problem is then posed as a time varying parameter estimation problem. A procedure based on existing literature results on T-S joint state and parameter estimation is implemented. Simulation results show the effectiveness of this approach. A bank of observers based approach is then described that can help in detecting and isolating VAV damper faults in the system using the state and parameter estimates.

16:20-16:40 WeB3.5

Fault-Adaptive Control of VAV Damper Stuck in a Multizone Building, pp. 164-170

Darure, Tejaswinee — Univ. of Lorraine, Nancy, France
Yamé, Joseph-Julien — Univ. De Lorraine
Hamelin, Frederic — Univ. of Lorraine

This paper presents a potential effective approach to fault adaptive control for damper stucks in variable-air-volume (VAV) boxes in building heating, ventilation and air-conditioning systems. The fault-adaptive controller integrates a dedicated bank of unknown input residual generators for fault detection/isolation followed by suitably designed fault estimators and a model predictive controller. The adaptation of the controller to the fault is achieved by online modification of the constraints in the model predictive control to achieve reduced energy consumption and thermal comfort under faulty modes. The proposed fault-adaptive control law is demonstrated on a four-zones building benchmark.

WeB4 S02

Data-Driven Methods (Regular Session)

Chair: Graells, Moisès — UPC
Co-Chair: Blesa, Joaquim — Inst. De Robòtica I Informàtica Industrial (CSIC-UPC)

15:00-15:20 WeB4.1

A Combined Diagnosis System Design Using Model-Based and Data-Driven Methods, pp. 171-176

Jung, Daniel — Linköping Univ
Ng, Kok Yew — Monash Univ. Malaysia
Frisk, Erik — Linkoping Univ
Krysander, Mattias — Linköping Univ

A hybrid diagnosis system design is proposed that combines model-based and data-driven diagnosis methods for fault isolation. A set of residuals are used to detect if there is a fault in the system and a consistency-based fault isolation algorithm is used to compute all diagnosis candidates that can explain the triggered residuals. To improve fault isolation, diagnosis candidates are ranked by evaluating the residuals using a set of one-class support vector machines trained using data from different faults. The proposed diagnosis system design is evaluated using simulations of a model describing the air-flow in an internal combustion engine.

15:20-15:40 WeB4.2

A Framework for Unsupervised Fault Detection and Diagnosis Based on Clustering Assisted Kriging Observer, pp. 177-182

Ardakani, Mohammad Hamed — UPC
Abdelaleem Taha Zied, Ahmed Shokry — Univ. Pol. De Cataluña
Gerard, Escudero — UPC
Graells, moises — UPC
Espuña, Antonio — Tech. Univ. of Catalonia

This paper presents an unsupervised data-driven method for Fault Detection and Diagnosis (FDD) of nonlinear dynamic processes. The proposed approach is based on the combination of automatic and non-automatic clustering techniques with a data-driven observer based on Multivariate Dynamic Kriging (MDK) metamodels. The proposed framework is studied via its application to a well-known benchmark simulation case study based on the control of a three-tanks system, showing promising performance in terms of accuracy, robustness and simplicity of applications.

15:40-16:00 WeB4.3

A New Approach for Implementing Transfer Entropy Using Process Topology, pp. 183-189

Landman, Rinat — Aalto Univ
Jamsa-jounela, Sirkka-liisa — Helsinki Univ. of Tech

Causal analysis is frequently applied to identify cause and effect relationships among process variables and thereby enables to obtain the propagation path of disturbances. This paper introduces a new approach to detect causality in complex systems based on the Transfer entropy (TE) method by incorporating the information on process topology using an explicit search algorithm. Initially, the TE is calculated for the pathways which are considered as direct based on the process topology. Thereafter, the Direct Transfer Entropy (DTE) is employed to discriminate spurious and/or indirect pathways. This concept is demonstrated on industrial board machine.

16:00-16:20 WeB4.4

Self-Organzied Critical Control for the European XFEL Using Black Box Parameter Identification for the Quench Detection System, pp. 190-195

Nawaz, Ayla — DESY
Pfeiffer, Sven — DESY
Lichtenberg, Gerwald — Tech. Univ. Hamburg-Harburg
Schlarb, Holger — DESY

The European Free Electron Laser (XFEL) consists of a large and complex plant, with many cost intensive and technological high-end components. It is therefore important that the XFEL can be operated reliably and safely using exception handling and fault detection systems. A crucial part of the system are the superconducting cavities for which especially quenches, i.e. the break down of the superconductivity have to be avoided. The paper shows the interaction of the fault detection system with the Low Level RF (LLRF) control system to maximize the field gradients. This is an example for process supervision, which can neither be classified as fault-tolerant, nor is it a reconfiguration system, but uses the result of the fault detection to operate the system at its fault critical limit. This scheme simulates a system which behaves like a self-organized critical system, and drives the process at its critical performance limit. It is therefore called Self-organized Critical Control (SOCC). The paper shows the basic set-up and quench detection methods of the European XFEL and gives an example for an application of SOCC.

16:20-16:40 WeB4.5

Combined Holt-Winters and GA Trained ANN Approach for Sensor Validation and Reconstruction: Application to Water Demand Flowmeters (I), pp. 196-201

Rodriguez Rangel, Hector — Univ. Pol. De Cataluña
Puig, Vicenç — Univ. Pol. De Catalunya (UPC)
Flores, Juan J. — Univ. Michoacana De San Nicolás De Hidalgo
Lopez, Rodrigo — IMT Inst. for Advanced Studies, Lucca

This paper proposes a Double Seasonal Holt- Winters (DSHW) forecasting model with an auxiliary Artificial Neural Network (ANN) trained with a Genetic Algorithm (GA) to model the DSHW residuals. ANN complements and improves the DSHW prediction. The proposed model also includes an on- line validation and reconstruction mechanism useful to detect and correct missing and erroneous data. This mechanism also impacts improving the DSHW prediction accuracy and precision. The proposed model and validation mechanism are applied to predict the time series generated by two moni- tored flowmeters of two sectors of Barcelona's drinking water network (DWN). The accuracy and precision improvement of the proposed method with respected to standards DSHW and ARIMA approaches is provided.

WeC2 — S01

Mechatronics and Manufacturing (Regular Session)

Chair: Sename, Olivier — Grenoble INP / GIPSA-Lab
Co-Chair: Reppa, Vasso — Supelec

17:30-17:50 — WeC2.1

Optimal Integrated Maintenance Strategy for Parallel Leased Machines with Warranty Periods, pp. 202-207

Askri, Tarek — LGIPM
Hajej, Zied — LGIPM Univ. Paul Verlaine Metz
rezg, nidhal — Univ. Paul Verlaine Metz

This paper deals with an integrated production/maintenance problem of manufacturing system with considering a warranty and leasing constraints. The lessor may provide warranty periods to encourage the lessee to sign a lease contract with a longer lease period. The problem consists on a several parallel machines that have to satisfy a random demand over a finite time horizon under given service level and taking into account the warranty periods. First of all, to obtain an economical production planning, we minimize the total production and inventory cost. Secondly, we determine the optimal maintenance strategy for different machines according to obtained production plan. The key of this study is to show the impact of the length of warranty periods on the optimal maintenance strategy. An analytical study and a numerical example are presented in order to prove the developed approach.

17:50-18:10 — WeC2.2

Performances Evaluation and Optimization of Production System with Free Shipping Option, pp. 208-213

Turki, Sadok — LGIPM / Univ. De Lorraine, Ile Du Saulcy, 57045 Metz
Prokopishyna, Anastasiia — International Univ. of Logistics and Transport

Today many production companies are proposing free shipping as a marketing strategy to attract customers in e-commerce. In this paper we empirically examine the impacts of free shipping on the performance of a production system. Two cases of the transport services are considered: the first is a classic case in which the delivery charges are paid by the customer and the second is the case of the free shipping in which the delivery charges are paid by the company. Discrete flow model is used to describe the production system and to take into account delivery activities. The objective of this work is to provide a performance evaluation study that allows choosing the suitable case according to the indicators of interest such as delivery cost or the demand increase. Numerical results are presented to discuss the choice of the suitable case. Also an optimization study of the production system with free shipping option is presented.

18:10-18:30 — WeC2.3

Feature Extraction for Fault Diagnosis in Series Elastic Actuators, pp. 214-220

Perner, Gernot — Tech. Univ. Darmstadt
Yousif, Leonard — Tech. Univ. Darmstadt
Rinderknecht, Stephan — Tech. Univ. Darmstadt
Beckerle, Philipp — Inst. for Mechatronic Systems in Mech. Eng

Series elastic actuators provide beneficial characteristics for safe human-robot interaction and energy efficient robotic motions. Yet, such actuators might have an increased probability of faults due to their higher complexity and operation in critical states, e.g., antiresonance. This contribution investigates feature extraction methods for fault diagnosis in such actuators. Stiffness and motion sensor faults are focused since those are assessed to have high occurrence probabilities with potentially severe consequences. To detect stiffness deviations, a recursive least squares estimator is implemented while Kalman-Bucy filters are applied to generate residuals that indicate encoder faults. The methods are examined using models of system and fault dynamics of a variable torsion stiffness actuator. The simulation results show that very distinct features for fault diagnosis can be extracted. The investigated feature extraction methods are very promising for interpretation by classification methods. Recommendations on how to implement those methods for diagnosis purposes are given.

18:30-18:50 — WeC2.4

Comparison of Observer Approaches for Actuator Fault Estimation in Semi-Active Suspension Systems, pp. 221-226

Nguyen, Manh Quan — Grenoble INP/Gipsa-Lab
Sename, Olivier — Grenoble INP / GIPSA-Lab
Dugard, Luc — CNRS-INPG

In this paper, the actuator fault estimation problem of semi-active suspension systems is considered. For instance, an oil leakage in the damper could cause a reduction of the damping force. The fault estimation requires a modeling of the damper fault (both multiplicative and additive fault models can be used). Three observer-based approaches are compared for fault estimation: an observer using fast adaptive fault estimation (FAFE) approach (used for estimation of additive faults), a parametric adaptive observer (AO) and a switched LPV observer (LPVO) (both intended to estimate mulplicative faults). Since the damper fault estimation is strongly affected by the unknown road disturbances, an H¥ performance objective is used to reduce the effect of disturbances on the estimation error for performance assessment. Some simulations are performed on a quarter car model to validate these methodologies and a comparison is then given to show the interest of each method.

18:50-19:10 — WeC2.5

Model-Based Analysis of Timing Errors for Reliable Design of Mechatronic Medical Devices, pp. 227-232

Mutzke, Thomas — Siemens Healthcare GmbH
Ding, Kai — TU Dresden
Morozov, Andrey — TU Dresden
Janschek, Klaus — TU Dresden
Braun, Joel — Siemens Healthcare GmbH, Tech. Innovation Mechatronics And

Concurrent processes of distributed systems might be not perfectly synchronized because of various design limitations. This is a potential cause of timing errors, e.g. a data package from a providing interface of one component reaches a required interface of another component too early or too late. A timing error may result in a data error that can propagate further and become a reason of a system failure. This paper introduces a comprehensive method for stochastic, model-based analysis of timing errors. Application of the method is demonstrated at a reference mechatronic system, a medical patient table, which is modeled with a baseline UML activity diagram. The paper introduces a method for automatic transformation of an annotated activity

diagram into a formal generalized stochastic Petri net model. The reachability graph of the Petri net, weighted with transition probabilities, forms a discrete time Markov chain model, which is used for estimation of several reliability metrics related to timing errors.

19:10-19:30 WeC2.6

Robust Diagnosis Based on BG Modelling Online Implementation in the Rear Suspension Motorcycle, pp. 233-238

ZANZOURI, Nadia — Univ. De Tunis El Manar, Ec. Nationale D'ingenieurs De Tu

In this paper, a Bond Graph of the rear suspension motorcycle is proposed. The model is used to study the robust diagnosis of the considered process. The Analytical Redundancy Relations (ARRs) are generated for monitoring system. The bond graph and LFT form (linear fractional transformation) were exploited to the graphical representation of parametric uncertainties. The simulation and experimental results on rear suspension of BMW R1200GS motorcycle validate the studied approach. Keywords—Rear Suspension Motorcycle, Bond Graph Modelling, Robust Diagnosis, ARRs.

WeC3 S04

Recent Advances in FDI/FTC Techniques (Invited Session)

Chair: Simani, Silvio — Univ. of Ferrara

Co-Chair: Franze', Giuseppe' — Univ. Degli Studi Della Calabria

Organizer: Simani, Silvio — Univ. of Ferrara

17:30-17:50 WeC3.1

Multiple Fault Diagnosis by Signature Recognition of Time-Varying Residuals (I), pp. 239-244

Fadda, Gianluca — Univ. of Cagliari

Pilloni, Alessandro — DIEE-Univ. of Cagliari

Pisano, Alessandro — Univ. Di Cagliari

Usai, Elio — Univ. Degli Studi Di Cagliari

Marjanovic, Aleksandra — Univ. of Belgrade, School of Electrical Engineering

Vujnovic, Sanja — School of Electrical Engineering, Univ. of Belgrade

A Fault Detection and Diagnosis scheme able to deal with concurrent, incipient, sensor and actuator faults is presented. The architecture allows the diagnosis whenever the system's outputs are less than the number of faults. Residual generation is achieved by taking advantage from observer-based design, whereas the classification is performed by extending the concept of directional residual towards a time-varying setting. The scheme is designed to leverage the power from both model-based and data-driven approaches while mitigating their inherent drawbacks. The performances of the proposed strategy are evaluated by employing real data coming from the TEKOB1 Thermal Plant of Kostolac, Serbia.

17:50-18:10 WeC3.2

Fault Tolerant Model Predictive Control Applied to a Simulated Hydroelectric System (I), pp. 245-250

Simani, Silvio — Univ. of Ferrara

Alvisi, Stefano — Univ. of Ferrara, Department of Engineering

Venturini, Mauro — Univ. Degli Studi Di Ferrara

This paper proposes a joint data–driven and model–based approach oriented to the design of a fault tolerant controller for regulating the speed of a Francis turbine included in a hydroelectric system developed in the Matlab and Simulink environments. The nonlinear characteristics of hydraulic turbine and the inelastic water hammer effects were considered to simulate the comprehensive behaviour of this dynamic process. The data–driven strategy has been suggested for deriving in a straightforward way a prediction filter able to reconstruct the fault affecting the hydroelectric system. The fault tolerant controller development requires the knowledge of the dynamic model of the monitored system, which is achieved by means of a model predictive control scheme that compensates the fault. These features of the work represent an important point when plug–and–play implementations are considered for a viable application of an effective fault tolerant methodology. In particular, by means of this methodology, the fault tolerance properties are achieved by using an active approach. It is assumed that the fault considered in this work affects the electric servomotor used as a governor. The performances obtained are compared to those of a passive solution already implemented by the authors for the same hydroelectric system.

18:10-18:30 WeC3.3

A Fault Tolerant Control Architecture for Constrained Systems Subject to Sensor Stuck Faults (I), pp. 251-256

Famularo, Domenico — Univ. Degli Studi Della Calabria

Fedele, Giuseppe — Univ. of Calabria

Franze', Giuseppe' — Univ. Degli Studi Della Calabria

Manna, Cristina — Univ. of Calabria

In this paper, a sensor stuck fault tolerant control framework for linear time invariant plan models subject to input/state constraints and bounded disturbances is proposed. By taking advantage of a recent contribution on actuator stuck scenarios of the same authors, a receding horizon control reconfigurable scheme is proposed to contrast undesired effects due to sensors malfunctioning. The main merit of the proposed strategy relies on its intrinsic capability to quickly identify fault occurrences and to take a decision on the adequate control action. This is formally obtained by jointly exploiting set-theoretic polyhedral ideas and the certainly equivalence concept. Two numerical examples are provided and the control performance contrasted with a well-reputed competitor fault tolerant control scheme.

18:30-18:50 WeC3.4

Integrated Fault Estimation and Fault-Tolerant Control Design for Large-Scale Interconnected Systems (I), pp. 257-262

Lan, Jianglin — Univ. of Hull

Patton, Ron J. — Univ. of Hull

An integrated fault estimation and fault-tolerant control (FTC) design is proposed in this paper for interconnected linear systems with uncertain nonlinear interactions subject to unknown bounded sensor faults. A decentralized FTC strategy, using the state/fault estimates obtained simultaneously by a decentralized unknown input observer, is employed to maintain the robust stability of the overall interconnected system and compensate the sensor fault effects. The observer and controller gains are solved together using a single-step linear matrix inequality (LMI) formulation. The performance effectiveness of the presented design is illustrated through an example of a 3-machine power system.

18:50-19:10 WeC3.5

Model-Free Active Fault-Tolerant Cooperative Control in an Offshore Wind Farm (I), pp. 263-268

Badihi, Hamed — Concordia Univ

Zhang, Youmin — Concordia Univ

Hong, Henry — Concordia Univ

With respect to the important issue of reliability and availability in wind farms, this paper deals with the development of an integrated fault diagnosis and fault-tolerant control scheme in a cooperative framework at wind farm level. The paper presents a novel integrated fault detection and diagnosis (FDD) and fault-tolerant control (FTC) approach oriented to the design and development of an active fault-tolerant cooperative control (FTCC) scheme for an offshore wind farm against the decreased power generation caused by turbine blade erosion and debris build-up on the blades over time. The scheme employs a model-free FDD system to provide accurate and timely diagnosis information to be used in an appropriate automatic signal correction algorithm for

accommodation of faults in the farm. Different simulations on a high-fidelity offshore wind farm benchmark model demonstrate the effectiveness and performance of the proposed scheme in the presence of wind turbulences, measurement noises and realistic fault scenarios.

19:10-19:30 WeC3.6

Two-Layer Observer-Based FDI with Application to NREL 5 MW Wind Turbine Model (I), pp. 269-274

Schulte, Horst — HTW-Berlin, Univ. of Applied Sciences

Gauterin, Eckhard — Univ. of Applied Sciences Berlin (HTW)

In this paper, a two-layer fault detection and isolation (FDI) scheme with application in wind turbines is presented. Commonly, model-based FDI concepts use a suitable mathematical model of the plant as a redundancy for on-line available data such as measurements and control outputs. In addition, the proposed two-layer concept exploits the redundancy between component and structure models at their common physical interfaces. It is shown by a illustrated example how the FDI problem can be formalized to a two-layer scheme. First, the models of both layers are proposed, a observer is derived for the component-layer and combined with the structure-layer. Applicability is shown by means of the NREL 5 MW reference wind turbine with objective of detection and isolation of parameter faults in the blade slewing bearings and blade structure.

WeC4 S02

Computational Intelligence (Regular Session)

Chair: Korbicz, Jozef — Univ. of Zielona Gora

Co-Chair: Tornil-Sin, Sebastian — IRI-CSIC

17:30-17:50 WeC4.1

Nonlinear Predictive Control of Temperature in Long Duct Using Specially Designed Neural Model, pp. 275-280

Lawrynczuk, Maciej — Warsaw Univ. of Tech

This paper describes a nonlinear Model Predictive Control (MPC) algorithm for a distributed parameter thermal system (a long duct). For prediction a specially designed neural model of the process is used. The model consists of a set of local neural sub-models, which calculate temperatures for a number of predefined locations of sensors, and a neural interpolator, which calculates the temperature for any sensor location. In order to obtain a computationally simple MPC scheme, the predicted output trajectory of the process is linearised on-line which leads to a quadratic optimisation MPC problem. It is shown that due to nonlinearity of the process, the classical MPC algorithm based on linear models is unable to give satisfactory control quality whereas the described nonlinear MPC algorithm leads to good control performance. The paper also studies the effect of model pruning (removing some of the sub-models) on the performance of MPC.

17:50-18:10 WeC4.2

Temporal-Difference Q-Learning in Active Fault Diagnosis, pp. 281-286

Skach, Jan — Univ. of West Bohemia

Puncochar, Ivo — Univ. of West Bohemia

Lewis, Frank L. — Univ. of Texas at Arlington

The paper deals with a novel design of an approximate active fault detector for discrete-time stochastic linear Markovian switching systems on the infinite-time horizon. The problem is formulated as an optimization problem with the aim to minimize a general discounted detection cost criterion. The proposed solution is inspired by approximate dynamic programming and reinforcement learning. The active fault detector is trained by a temporal-difference Q-learning algorithm with a linear parametric Q-function approximation adjusted to fit the true Q-function. The main advantage is that this approach is computationally less expensive than a temporal-difference learning with a value function.

18:10-18:30 WeC4.3

Design of Iterative Learning Control by the Means of State Space Neural Networks, pp. 287-292

Czajkowski, Andrzej — Univ. of Zielona Góra

Patan, Maciej — Univ. of Zielona Gora

Patan, Krzysztof — Univ. of Zielona Gora

This paper deals with the application of state space neural model to Iterative Learning Control (ILC) design. Described work addresses the issue when analytical model of the nonlinear system is not available or is hard to identify. The state space neural network can be easily trained with the use of historical data. Further it is linearised to obtain linear model possible to use with ILC technique. All experimental data are obtained from the real-life laboratory stand of Modular Servo under RealTime Workshop in Matlab/Simulink environment.

18:30-18:50 WeC4.4

A Neural Network-Based Simultaneous State and Actuator Fault Estimation under Unknown Input Decoupling, pp. 293-298

Witczak, Piotr — Univ. of Zielona Gora

Patan, Krzysztof — Univ. of Zielona Gora

Witczak, Marcin — Univ. of Zielona Gora

Pazera, Marcin — Inst. of Control and Computation Engineering

The paper presents the problem of a neural network-based robust state and actuator fault estimator design for non-linear discrete-time systems. At the beginning a review of recent developments in the area of robust estimators and observers for non-linear discrete-time systems is portrayed and a less restrictive procedure for designing a neural network-based H1 observer is proposed. The developed approach guaranties a predefined disturbance attenuation level and convergence of the observer, as well as unknown input decoupling, and state and actuator fault estimation. The main advantage of the design procedure is its simplicity. The paper describes an observer design procedure which comes to solving a set of linear matrix inequalities. The final part of the paper shows an illustrative example concerning an application of the proposed approach to a multi-tank system benchmark.

18:50-19:10 WeC4.5

On-The-Fly Diagnosability Analysis of LPN Using Verifier Nets, pp. 299-306

LI, BEN — Ec. Centrale De Lille

Khlif Bouassida, Manel — Ec. Centrale De Lille

Toguyeni, Armand — Ec. Centrale De Lille

In this paper, the on-the-fly diagnosability analysis using Verifier Nets (VN) is developed. The objective is to improve the VN approach by using on-the-fly diagnosability analysis technique. The diagnosability is analyzed in the framework of bounded and unbounded labeled Petri nets (LPN) with no deadlock after firing any fault transition. The VN and its reachability graph (for bounded LPN)/ coverability graph (for unbounded LPN) are built on-the-fly and in parallel for diagnosability analysis. Stop conditions are proposed to stop the construction as soon as a diagnosability decision is established. This approach achieves a compromise between computation efficiency and combinatorial explosion limitation.

ThA1 S01

Leakage Management in Water Networks (Invited Session)

Chair: perez, ramon	UPC (Univ. Pol. De Catalunya)
Co-Chair: Sanz, Gerard	UPC
Organizer: perez, ramon	UPC (Univ. Pol. De Catalunya)
Organizer: Sanz, Gerard	UPC

09:00-09:20 ThA1.1

Leaks' Detection in Water Distribution Networks with Demand Patterns (I), pp. 307-312

Quiñones-Grueiro, Marcos	CUJAE
Verde, Cristina	Inst. De Ingenieria, UNAM
Prieto Moreno, Alberto	Inst. Superior Pol. José Antonio Ec. Cujae

A novel approach for the continuous detection of leaks in water distribution networks (WDNs) assuming uncertain demand patterns is presented. The proposal is based on a demand pattern construction with repetitive multiple statistic models which allow detection through residual generation for each corresponding model. The key of the method is the time division of the pattern such that the demand satisfies the stationarity condition during each time interval. Thus, the sequential set of demand models allows the use of traditional multivariate statistical tool such as principal component analysis (PCA) for the monitoring of each interval in a sequential manner. Simulations with an academic network are used to test the performance of the proposal, and the results show a lower false alarm rate than the standard PCA.

09:20-09:40 ThA1.2

Uncertainty Effect on Leak Localisation in a DMA (I), pp. 313-318

perez, ramon	UPC (Univ. Pol. De Catalunya)
Blesa, Joaquim	Inst. De Robòtica I Informàtica Industrial (CSIC-UPC)
Cugueró Escofet, Pep	Univ. Pol. De Catalunya
Cugueró, Miquel À.	Univ. Pol. De Catalunya
Sanz, Gerard	UPC

The leak localisation methodologies based on data and models are affected by both uncertainties in the model and in the measurements. This uncertainty should be quantified so that its effect on the localisation methods performance can be estimated. In this paper, a model-based leak localisation methodology is applied to a real District Metered Area using synthetic data. In the generation process of the data, uncertainty in demands is taken into account. This uncertainty was estimated so that it can justify the uncertainty observed in the real measurements. The leak localisation methodology consists, first, in generating the set of possible measurements, obtained by Monte Carlo Simulation under a certain leak assumption and considering uncertainty, and second, in falsifying sets of nodes using the correlation with a leak residual model in order to signal a set of possible leaky nodes. The assessment is done by means of generating the confusion matrix with a Monte Carlo approach.

09:40-10:00 ThA1.3

Optimal Sensor Placement for Classifier-Based Leak Localization in Drinking Water Networks (I), pp. 319-324

Soldevila, Adrià	Univ. Pol. De Catalunya
Tornil-Sin, Sebastian	IRI-CSIC
Fernandez-Canti, Rosa M.	UPC
Blesa, Joaquim	Inst. De Robòtica I Informàtica Industrial (CSIC-UPC)
Puig, Vicenç	Univ. Pol. De Catalunya (UPC)

This paper presents a sensor placement method for classifier-based leak localization in Water Distribution Networks. The proposed approach consists in applying a Genetic Algorithm to decide the sensors to be used by a classifier (based on the k-Nearest Neighbor approach). The sensors are placed in an optimal way maximizing the accuracy of the leak localization. The results are illustrated by means of the application to the Hanoi District Metered Area and they are compared to the ones obtained by the Exhaustive Search Algorithm. A comparison with the results of a previous optimal sensor placement method is provided as well.

10:00-10:20 ThA1.4

A Methodology of Leakage Detection and Location in Water Distribution Networks - the Case Study (I), pp. 325-330

Moczulski, Wojciech	Silesian Univ. of Tech
Wyczółkowski, Ryszard	Silesian Univ. of Tech
Ciupke, Krzysztof	Silesian Univ. of Tech
Przystalka, Piotr	Silesian Univ. of Tech
Tomasik, Piotr	Silesian Univ. of Tech
Wachla, Dominik	Silesian Univ. of Tech

The paper deals with a methodology of detecting and localizing leakages in water distribution networks. Two approaches are presented: based on a hydraulic model of the network, and based on approximate models and fuzzy classifiers. Moreover, a case study concerning applications of the methodology to a real network in Rybnik, Poland is presented. A pilot version of the system has been running since 2013 and shows quite satisfactory efficiency.

10:20-10:40 ThA1.5

Fault Detection Data Creation Using an Experimental Water Distribution System (I), pp. 331-336

Guenther, Markus	Graz Univ. of Tech
Steffelbauer, David Bernhard	Graz Univ. of Tech
Fuchs-Hanusch, Daniela	Graz Univ. of Tech

Model based event detection and localization states one method to deal with leakage occurrence in water distribution systems (WDS). Since access to hydraulic models and measurement data of real world systems is limited for researchers the opportunities for testing new model approaches on one and the same WDS are scarce. In this article we present an experimental water distribution system (EWDS-TUG) that allows for simulating scaled real world water demand and leakage scenarios. We show example experiments and the related measurement data along with metadata that are supposed to be provided to the scientific community for model testing.

10:40-11:00 ThA1.6

Fitness Landscapes and Distance Metrics for Model-Based Leakage Localization (I), pp. 337-342

Steffelbauer, David Bernhard	Graz Univ. of Tech
Fuchs-Hanusch, Daniela	Graz Univ. of Tech

This paper aims to investigate the effect of distance metrics on the fitness landscape for model-based leakage localization and its impact on the performance of the differential evolution optimization algorithm applied to a theoretical water distribution network from literature.

ThA2 S04

Aerospace Applications (Regular Session)

Chair: Morcego, Bernardo	Univ. Pol. De Catalunya
Co-Chair: perez, ramon	UPC (Univ. Pol. De Catalunya)

09:00-09:20 ThA2.1

A Self-Healing Control Method for Satellite Attitude Tracking Based on Simultaneous Fault Estimation and Control Design, pp. 343-348

Zhou, Meng	Harbin Inst. of Tech
Wang, Zhenhua	Harbin Inst. of Tech
Theilliol, Didier	Univ. of Lorraine
shen, yi	Harbin Inst. of Tech

Rodrigues, Mickael — Univ. CLAUDE BERNARD LYON 1

This paper proposes a novel self-healing control method for satellite attitude tracking based on simultaneous fault estimation and control design. The proposed method integrates the fault estimation and fault-tolerant control units in a dynamic system, which is less complex and more reliable than the separately designed self-healing architectures. In this paper, the model reference approach is used to obtain a tracking error dynamic equation. Following this, an augmented error system is constructed by taking the fault as an auxiliary vector. Based on the augmented error system, a fault estimator/controller is designed to achieve robust fault-tolerant control and robust fault estimation simultaneously. The design conditions for the proposed fault estimator/controller are transformed as a set of linear matrix inequalities, which can be easily solved. Finally, numerical simulation results are given to demonstrate the effectiveness of proposed method.

09:20-09:40 ThA2.2

Maturation and In-Flight Testing of H∞ Fault Detection and Accommodation for a Model-Scale Autonomous Aircraft, pp. 349-354

Vasconcelos, José Maria Fernandes — Deimos Engenharia
Rosa, Paulo Andre Nobre — Inst. for Systems and Robotics - Inst. Superior
Kerr, Murray Lawrence — DEIMOS Space SLU
Latorre, Antonio — Elecnor Deimos
Recupero, Cristina — Elecnor Deimos Space
Hernández-Hernández, Lucía — Elecnor Deimos

This paper describes the maturation and in-flight testing of a recently developed fault detection (FD) system for a model scale unmanned aerial vehicle (UAV). The FD system design methodology is based on H∞ techniques and exploits an LFT description of the aircraft (A/C) longitudinal dynamics. The maturation of the FD system, presented in the paper, introduces a fault isolation logic to distinguish between bias and stuck-in-place faults in the elevator, and a fault accommodation strategy to recover the nominal operation of the controller, thus attaining fault detection and isolation (FDI) and fault tolerant control (FTC). An overview of the experimental setup of the FDI/FTC system is described, presenting the high-fidelity Functional Engineering Simulator (FES) development environment, the UAV platform, and the flight test plan definition. Results are presented for the FDI/FTC system tested in real-time and onboard the UAV, for typical maneuvers of climbing/descent, turning, cruising and waypoint following, covering the expected flight envelope. Extension of the system for a planetary exploration glider is also briefly discussed.

09:40-10:00 ThA2.3

Passive Fault-Tolerant Control of an Octorotor Using Super-Twisting Algorithm: Theory and Experiments, pp. 355-360

Saied, Majd — Univ. of Tech. of Compiègne - Lebanese Univ
Lussier, Benjamin — Univ. of Tech. of Compiègne
Fantoni, Isabelle — Univ. De Tech. De Compiegne
shraim, hassan — Consulting Company
Francis, Clovis — Lebanese Univ

This paper presents the design and implementation of a Passive Fault-Tolerant Control (PFTC) strategy for a coaxial counter-rotating octorotor based on the Super-Twisting algorithm. This second-order sliding mode technique ensures robustness with respect to uncertainties and disturbances and is also able to deal directly with faults and failures by compensating the actuators loss in the system without prior knowledge on the fault, its location and its severity. The effectiveness of this PFTC is illustrated through real experimental application to a coaxial octorotor, where two motors failures are considered.

10:00-10:20 ThA2.4

Zonotopic Extended Kalman Filter and Fault Detection of Discrete-Time Nonlinear Systems Applied to a Quadrotor Helicopter, pp. 361-366

Wang, Ye — Univ. Pol. De Catalonia
Puig, Vicenç — Univ. Pol. De Catalunya (UPC)

This paper presents the extension of the zonotopic Kalman filter of linear systems to nonlinear systems subject to unknown-but-bounded system disturbances and Gaussian white noises known as zonotopic extended Kalman filter (ZEKF). Due to the computational simplicity of zonotopes, the uncertain system states are bounded into a zonotopic set. The consistency test with the system measurements is completed without using the intersection between two sets but following the extended Kalman filtering procedure that requires to find the optimal observer gain. A fault detection method based on the ZEKF algorithm is also introduced. Finally, the proposed ZEKF algorithm is applied to the quadrotor helicopter under an online closed-loop simulation scheme and the simulation results illustrate the effectiveness of the proposed algorithm and fault detection method.

10:20-10:40 ThA2.5

Hexacopter Outdoor Flight Test Results Using Adaptive Control Allocation Subject to an Unknown Complete Loss of One Propeller, pp. 367-374

Falconí, Guillermo P. — Tech. Univ. München
Angelov, Jorg — Tech. Univ. München
Holzapfel, Florian — Tech. Univ. München

This paper presents hexacopter outdoor flight test results using an adaptive control allocation subject to an unknown complete loss of one propeller. The proposed approach is composed of two main elements: The adaptive estimation of the control effectiveness of the propellers and the optimization based control allocation. The adaptive estimation is based on concurrent learning and the optimization is gradient based. The adaptive control allocation is able to deal with faults or failures in the propulsion system without reconfiguration of the controller. Simultaneously it is able to implement a degraded control strategy which prioritizes some control directions in case of extreme degradation.

ThA3 S02

Fault Diagnosis 1 (Regular Session)

Chair: Nejjari, Fatiha — Univ. Pol. De Catalunya
Co-Chair: Pulido, Belarmino — Univ. De Valladolid

09:00-09:20 ThA3.1

State and Fault Estimation of Singular Delayed LPV Systems Via Proportional-Integral Observer, pp. 375-380

Hassanabadi, Amir Hossein — Amirkabir Univ. of Tech
Shafiee, Masoud — Amirkabir Univ. of Tech
Puig, Vicenç — Univ. Pol. De Catalunya (UPC)

In this paper, a singular LPV system with multiple time delays in state is considered. The system is subject to input disturbances and actuator faults. First, the considered system is transformed to polytopic representation and then a polytopic proportional-integral unknown input observer (PI-UIO) is designed for it. This observer can estimate both the system states and the actuator faults in the system. The conditions for disturbance decoupling, existence and convergence of the PI-UIO are obtained in a set of LMIs in the polytope vertices. Actuator fault diagnosis is achieved via the fault estimates provided by the observer. The applicability of the proposed scheme is illustrated via a numerical example.

09:20-09:40 ThA3.2

Observer-Based Causal Ordering Graph Models for Fault Detection, pp. 381-386

atitallah, manel — ENIG
rafika, elharabi — MACS-ENIG
Abdelkrim, Mohamed Naceur — ENIG

This paper deals with the problem of modeling and fault detection design using a unified energy-based frame-work. Motivated by benefits of the Causal Ordering Graph as a useful tool for large scale systems and which is characterized by structural and causal properties, the new proposed approach is therein able to obtain an accurate model. An observer-based fault detection is later carried out so as to derive systematically energy-based indicators in terms of faults. The efficiency and the relevance of the developed scheme are proved through simulation results on a DC. Motor together with and without fault scenarios.

09:40-10:00 ThA3.3

Precomputable Kalman-Based Filter for Markov Jump Linear Systems, pp. 387-392

de Saporta, Benoite — Univ. Montpellier
Costa, Eduardo F. — Univ. De São Paulo

This paper presents a new efficient numerical method for state estimation of Markov Jump Linear Systems (MJLSs). It is based on the selection of a finite set of typical trajectories of an underlying piecewise deterministic Markov process (PDMP) related to the gain matrices of the optimal Kalman-Bucy filter and allows for pre-computations. The trajectories are optimally selected using quantization of the post jump locations of the PDMP. The performance of this approach is evaluated both theoretically and on a numerical example of a magnetic suspension system subject to failures.

10:00-10:20 ThA3.4

Structural Analysis for Robust Diagnosis Via Kalman Filters, pp. 393-400

Jarmolowitz, Fabian — Robert Bosch GmbH
Fischer, Alexander — Robert Bosch GmbH

Structural analysis provides methods to find all possible residual generators in an over-constrained model structure. The number of residual candidates though growths exponentially with the degree of over-constrainedness. Since on the one hand not all candidates are necessary for fault detection and isolation and on the other hand not all candidates provide sufficient information to distinguish between fault effects and model uncertainties robustly, it is an open problem how to find an optimal subset of residuals. This subset should be optimal in the sense that it provides a robust diagnosis in the presence of uncertainties with maximal fault isolation. In this paper linear stochastic models are structurally analysed for most informative over-constrained subsystems. These subsystems are treated as separate state-space models for which Kalman filters are designed. The resulting bank of Kalman filters provides a method for robust fault isolation in the presence of uncertainties and unknown fault dynamics.

10:20-10:40 ThA3.5

Performance-Based Design of PI Observers for Fault Diagnosis in LTI Systems under Gaussian Noises, pp. 401-406

Sales-Setién, Ester — Univ. Jaume I De Castelló
Peñarrocha, Ignacio — Univ. Jaume I
Dolz, Daniel — Univ. Jaume I, Castelló
Sanchis, Roberto — Univ. Jaume I

This work addresses the fault diagnosis problem for LTI systems under the presence of Gaussian noises through model-based proportional-integral observers with predefined gains. We propose an integrated design of residual generators and evaluators which takes into account the trade-off between physically meaningful parameters such as the false alarm rate, the minimum isolable faults and the integral squared error of the residuals under step faults. Dynamical fault isolation is also taken into account. In order to solve this design problem, we present two different approaches: one based on the steadystate Kalman filter and another based on convex optimization techniques.

Monitoring, Fault Detection and Supervision for Water System Management (Invited Session)

Chair: Blesa, Joaquim — Inst. De Robòtica I Informàtica Industrial (CSIC-UPC)
Co-Chair: Verde, Cristina — Inst. De Ingenieria, UNAM
Organizer: Blesa, Joaquim — Inst. De Robòtica I Informàtica Industrial (CSIC-UPC)
Organizer: Duviella, Eric — Ec. Des Mines De Douai

14:00-14:20 ThB1.1

Locating Leaks by Using the Step Response of a Pipeline (I), pp. 407-412

Verde, Cristina — Inst. De Ingenieria, UNAM
Torres, Lizeth — UNAM
Rentería, Flor Denisse — Univ. Nacional Autónoma De México

This paper presents a formal analysis of the pressure wave propagation along a pipeline to locate possible leaks. More specifically, this paper studies the step response of a pipeline when a downstream valve is closed to associate leaks' parameters (magnitude and position) with their effects on the pressure wave, such as the diversion and dissipation of the wave energy. The analysis starts with a matrix formulation (in the Laplace domain) to represent the behavior of a pipeline with a leak.Subsequently, boundary and initial conditions are imposed on the formulation in order to obtain the downstream pressure when a downstream valve is closed. Before converting the pressure response expression from the Laplace to the time domain, it is expanded into a series of exponential terms with negative exponents. The resulting transient expression is a sum of step functions with arguments that depend on time, the length of the pipeline, the wave speed and the leak position. From these arguments and the amplitude of the steps, the position and the magnitude of the leak can be determined.

14:20-14:40 ThB1.2

Application of a Novel Leakage Detection Framework for Municipal Water Supply on AAU Water Supply Lab (I), pp. 413-418

Jensen, Tom Nørgaard — Section for Automation & Control, Aalborg Univ
Kallesøe, Carsten Skovmose — Grundfos

Water scarcity is an increasing problem worldwide and at the same time, a huge amount of water is lost through leakages in the distribution networks. Detecting and isolating leakages fast is very important not only to save water but also to avoid destruction of roads and houses. This paper deals with isolation of leakages using a reduced network model. We propose a heuristic leakage detection/isolation algorithm which uses the reduced network model to estimate nominal behaviour. The model is adaptive and thus adapts slowly to changes in the network. However, some leakages change the behaviour instantly, and the deviation between pressures estimated by the reduced network model and the actual measured pressure indicates the location of the leakage. The proposed algorithm is tested on a specially designed laboratory setup that emulates a water distribution network. The test shows that the algorithm is in fact able to indicate in which area of the network a leakage has appeared.

14:40-15:00 ThB1.3

Sensor Placement for Leak Monitoring in Drinking Water Networks Combining Clustering Techniques and a Semi-Exhaustive Search (I), pp. 419-424

Sarrate, Ramon — Univ. Pol. De Catalunya
Blesa, Joaquim — Inst. De Robòtica I Informàtica Industrial (CSIC-UPC)
Nejjari, Fatiha — Univ. Pol. De Catalunya

This paper presents an optimal sensor placement strategy based on pressure sensitivity matrix analysis and a semi-exhaustive search strategy that maximizes some diagnosis specifications for water distribution networks. A mean average worst leak expansion

distance has been proposed as a new leak location performance measure. The approach is combined with a clustering technique in order to reduce the size and the complexity of the sensor placement problem. The strategy is successfully applied to determine the location of a set of pressure sensors in a district metered area (DMA) in the Barcelona water distribution network (WDN).

15:00-15:20 ThB1.4

Boundary PDE-Based Observer for Leakage Detection in Pressurized Pipes (I), pp. 425-430

Idellette Judith, HERMINE SOM	Univ. Lille 1
Cocquempot, Vincent	Lille 1 Univ
Aitouche, Abdel	CRISTAL/HEI

In this paper, an observer is designed with the objective to detect leakages in pressurized water pipes. Three known time-varying measures at boundary (namely inlet and outlet pressures and inlet flow rate) are used to estimate the fourth boundary variable (namely outlet flow rate). A general nonlinear PDE model of the pipe is used to design the boundary observer and the exponential stability of the state estimation error is proven. The residual signal is computed as the difference between the estimated outlet flow rate and the delayed inlet flow rate where the delay is the time condition for water flow pipe observability. Due to the continuity equation, the residual equals zero if there is no leakage and differs from zero in the contrary case. The performance of the leakage detection algorithm is demonstrated on a water pipe simulated example.

15:20-15:40 ThB1.5

Prognosis of Quality Sensors in the Barcelona Drinking Water Network (I), pp. 431-436

García Valverde, Diego	UPC
Creus, Ramon	AGBAR
Minoves, Meritxell	AGBAR
Pardo, Xavier	AGBAR
Quevedo, Joseba	Tech. Univ. of Catalonia
Puig, Vicenç	Univ. Pol. De Catalunya (UPC)

One of the most important areas of the water utilities is the water quality management. This area is responsible of guaranteeing safety in the water supply to the citizens. The strategy to guarantee the safety is based on two principal elements: disinfection and monitoring. Disinfection techniques, such as chlorination, allow to prevent the growing of microorganisms present in the water. Moreover, in order to guarantee this safety in the whole water network and avoid any unexpected event, on-line sensors are required to monitor a set of quality parameters. The whole process is based on the assumption that the information retrieved from quality sensors is totally reliable. But due to the complexity of the calibration and maintenance of these chemical sensors, several factors affect the accuracy of the raw data collected. Consequently, any decision based on this raw data might be based on a non solid base. Therefore, this work presents a data analytics approach consisting in two modules: fault diagnosis and prognosis. The fault diagnosis module first discerns if a sensor is detecting a real change on water quality parameters or actually is providing inconsistent information due to some malfunction. The prognosis module aims to predict the fault instant due to a slow degradation, which is very common in chlorine sensors. This approach allows to apply a predictive maintenance strategy reducing corrective actions. The proposed methodology has been satisfactorily tested on the Barcelona Drinking Water Network.

15:40-16:00 ThB1.6

Optimal Sensor Location for Overland Flow Network Monitoring (I), pp. 437-442

NGUYEN, Van Tri	Grenoble Inst. of Tech. (Grenoble INP) , Gipsa-Lab
Georges, Didier	Grenoble Inst. of Tech
Besancon, Gildas	Ense3 - Grenoble INP

The problem of optimal sensor location for monitoring of an overland flow network is addressed in this paper. The flow dynamics in each branch is described by the continuity equation of Saint-Venant model and Green-Ampt infiltration formula, while the initial states are assumed to be unknown. A methodology is then proposed to optimize the placement of sensors, with the purpose of estimating those states by a least square error minimization between measured and estimated water heights. Considering the method of variational calculus to solve for this minimization, a criterion based on the computed adjoint state is used to maximize the output sensitivity by appropriate sensor locations. A case-study of three small surface runoffs connected together at a point where two upper flows stream down into the third one is considered as an application example, and numerical simulations are provided with different measurement scenarios to validate the proposed optimal sensor location technique as well as the estimation method.

ThB2 S04

Set-Membership-Based Techniques for FDI & FTC (Invited Session)

Chair: Combastel, Christophe	Ec. ENSEA
Co-Chair: Travé-Massuyès, Louise	CNRS
Organizer: Raïssi, Tarek	Conservatoire National Des Arts Et Métiers
Organizer: Combastel, Christophe	Ec. ENSEA

14:00-14:20 ThB2.1

Model-Based Prognosis Algorithms with Uncertainty Propagation: Application to Fatigue Crack Growth (I), pp. 443-450

Robinson, Elinirina Iréna	ONERA - the French Aerospace Lab
Marzat, Julien	ONERA - the French Aerospace Lab
Raïssi, Tarek	Conservatoire National Des Arts Et Métiers

In this paper, deterministic and stochastic nonlinear prognosis methods that take uncertainty propagation into account are evaluated. More specifically, a deterministic method using interval techniques and two stochastic methods based on Bayesian filtering, namely extended Kalman filter and particle filter, are considered. The three algorithms are compared with reference to a classical benchmark which is a crack growth analysis, however they can be extended to other applications as well. The advantages and drawbacks of each approach are studied through different prognosis metrics such as accuracy, precision and timeliness. Based on these numerical simulations, the results show that deterministic methods for prognosis are suitable to manage bounded uncertainty.

14:20-14:40 ThB2.2

Interval Methods for Variable-Structure Control of Dynamic Systems with State Constraints (I), pp. 451-456

Rauh, Andreas	Univ. of Rostock
Senkel, Luise	Univ. of Rostock, Chair of Mechatronics
Aschemann, Harald	Univ. of Rostock

The control of nonlinear dynamic systems is often a challenging task for practical applications if the process model under consideration is significantly influenced by uncertain parameters and bounded (additive) uncertainty and if it has to be guaranteed simultaneously that specific state constraints are not violated. According to previous work, the handling of bounded uncertainty becomes possible by using techniques from interval analysis in real time. This paper deals with the description of interval-based variable-structure control approaches which are extended in such a way that the violation of state constraints can be ruled out with

certainty. For that purpose, possibilities are investigated that allow a combination of barrier Lyapunov function techniques with interval-based variable-structure control routines. Simulation results for an academic benchmark application as well as for the stabilization of an inverted pendulum conclude this paper.

14:40-15:00 ThB2.3

Set-Membership Functional Diagnosability: Definitions and Analysis (I), pp. 457-462

Jauberthie, Carine LAAS-CNRS
Verdière, Nathalie IUT Du Havre - Caucriauville-Place Robert Schuman
Travé-Massuyès, Louise CNRS

This paper introduces the concept of functional diagnosability for nonlinear dynamical uncertain models. Set-membership functional diagnosability is based on the notion of functional signature introduced in (Verdiere et al., 2015) extended to the set-membership framework. The link between functional diagnosability and set-membership functional diagnosability is established. Contrary to classical definitions, the study of functional diagnosability highlights some of the residual properties related to the fault acting on the system in time. Set-membership functional diagnosability extends this concept to bounded faults, i.e. faults whose magnitude is unknown but belongs to a bounded set. Numerical simulations for a system based on water tanks illustrate the potential of set-membership functional diagnosability.

15:00-15:20 ThB2.4

Guaranteed State Estimation and Fault Detection Based on Zonotopes for Differential-Algebraic-Equation Systems (I), pp. 463-469

Wang, Ye Univ. Pol. De Catalonia
Puig, Vicenç Univ. Pol. De Catalunya (UPC)
Cembrano, Gabriela UPC
Alamo, Teodoro Univ. De Sevilla

This paper presents a new set-membership approach based on zonotopes for differential-algebraic-equation (DAE) systems with unknown-but-bounded disturbances and noise, which can be subsequently used for guaranteed state estimation and fault detection. Complex systems are usually modeled by differential and algebraic equations, where differential equations describe system dynamics and additionally, algebraic equations represent the static relations. The proposed algorithm provides a way to propagate a zonotopic set that contains the system states not only consistent with the measurement outputs but also constrained with their static relations. Finally, a real application has been presented to verify the proposed approach.

15:20-15:40 ThB2.5

Multiobjective Interval Observer Via LMI Techniques for Fault Detection (I), pp. 470-475

Ellero, Nicolas Univ. De Bordeaux, Lab. IMS
Gucik-Derigny, David Univ. De Bordeaux, Lab. IMS
Henry, David Univ. Bordeaux I

This paper proposes a robust fault detection method based on interval observer design. This method offers the advantage of being robust against disturbances, measurement noises, uncertain parameters and unknown inputs. The H_∞ optimization framework is used to reduce the conservatism of the interval-based approach. The design of the observer parameters is formulated using the Linear Matrix Inequality technique and it is shown how some extra LMI specifications can be judiciously formulated to ensure a minimum sensitivity level to the fault. Finally, the actuator fault detection of an atmospheric re-entry vehicle provides a test to demonstrate the efficiency of the proposed method.

ThB3 S02

Fault Diagnosis 2 (Regular Session)

Chair: Pulido, Belarmino Univ. De Valladolid
Co-Chair: Jung, Daniel Linköping Univ

14:00-14:20 ThB3.1

From Structural Analysis to Observer-Based Residual Generation for Fault Detection, pp. 476-483

Lunze, Jan Ruhr-Univ. Bochum
Pröll, Sebastian Robert Bosch GmbH
Jarmolowitz, Fabian Robert Bosch GmbH

Structural analysis methods use bipartite graphs to find over-determined subsets of equations within a system model which allow to compute residuals. In observer-based diagnosis by contrast, observable subsystems are used to build residuals by state estimation. The observability of a system can be verified by structural techniques using directed graphs. This paper reveals a fundamental relationship between the two graph-theoretic approaches to system analysis and shows that for linear systems the structurally over-determined set of model equations equals the output connected part of the system. Moreover, a condition is provided which allows to verify structural observability of a system by means of the corresponding bipartite graph. The important consequence of this result is a comprehensive way to fault detection systems. It starts with finding the over-determined part of a given system by means of a bipartite structure graph and continues with designing an observer-based residual generator for the fault-detectable subsystem found in the first step.

14:20-14:40 ThB3.2

Faster and More Accurate FDI for Hybrid Systems Using Hybrid Possible Conflicts, pp. 484-489

Bregon, Anibal Univ. of Valladolid
Alonso, Carlos Univ. De Valladolid
Pulido, Belarmino Univ. De Valladolid

Model-based fault isolation and identification in hybrid systems is computationally expensive or even unfeasible for complex systems due to the presence of uncertainty concerning the actual state, and also due to the presence of both discrete and parametric faults coupled with changing modes in the system. In this work we improve fault isolation and identification performance for hybrid systems diagnosis using Hybrid Possible Conflicts. Fault detection with Hybrid Possible Conflicts relied upon a statistical test to decide when a significant deviation in the residual occurs. Fault detection time is later used to trigger the fault isolation and identification stages. In this work we propose to analyze the evolution of the residual signal using CUSUM to find a more accurate estimation of the time of fault occurrence, which allows to improve both the potential new modes tracking and the parametric fault identification. Moreover, we extend our previous proposal for fault identification in continuous systems allowing mode changes while performing parameter identification.

14:40-15:00 ThB3.3

Integration of Techniques and Alarm Sequences for Fault Detection and Diagnosis, pp. 490-495

Agudelo, Carlos Ec. Inst. Colombiano Del Petroleo
Morant, Francisco UPV
Quiles, Eduardo UPV
Garcia, Emilio UPV

This work has been developed around the integration of techniques for the early fault detection and diagnosis in industrial processes. It has been considered the sequence of the alarms of a fluidized catalytic Cracking Unit and its use in early fault detection and diagnosis. The specific objectives are process safety, operational reliability and alarm management. The aim of this work and previous research work is to increase process safety and operational reliability and to decrease the number of alarms that are presented to the operators of industrial plants, contributing to the appropriate fault detection and troubleshooting. First we make a review of the state of the art techniques for the fault detection and diagnosis and their integration, as well as the search of algorithms to analyze sequences of alarms. Its application is subsequently displayed in a set of data associated with a real fault of a fluidized catalytic cracking plant, to find the sequence of

alarms associated with the faults in question. Then we discuss the techniques proposed for integration and the issue of the development of an intelligent software tool for the early fault detection and diagnosis, which is already in operation at one of the crude oil refineries in Colombia. A clear methodology is shown to be able to find sequences of alarms. At the end we reach some valuable conclusions and detailed contributions to the state of the art in the field of fault detection and diagnosis.

15:00-15:20 ThB3.4

Active Fault Detection Based on a Statistical Test, pp. 496-503

Sekunda, André — Tech. Univ. of Denmark
Niemann, Henrik — Tech. Univ. of Denmark
Poulsen, Niels Kjølstad — Tech. Univ. of Denmark

In this paper active fault detection of closed loop systems using dual Youla-Jabr-Bongiorno-Kucera(YJBK) parameters is presented. Until now all detector design for active fault detection using the dual YJBK parameters has been based on CUSUM detectors. Here a method for design of a matched filter detector is proposed instead, based upon the Neyman-Pearson criterion for optimal detector design. Furthermore alternative ways to design the excitation signal which relates to indirect identification methods are presented. Examples are given on detection of actuator faults using a simulated gas bearing for both one and multiple possible parametric faults.

15:20-15:40 ThB3.5

A Generalized Fault Isolability Matrix for Improved Fault Diagnosability Analysis, pp. 504-509

Jung, Daniel — Linköping Univ

A generalized fault isolability matrix is proposed for quantitative analysis of fault isolability properties. The original fault isolability matrix gives information about which faults that are isolable from each other. However, other relavant isolability properties are not visible which can be important, for example, information regarding alternative fault hypotheses and multiple-fault isolability. The result of the analysis can be presented in the same compact form as the existing fault isolability matrix which makes it simple to visualize. As a case study, a model of an internal combustion engine is analyzed and two different solutions to the test selection problem are compared.

15:40-16:00 ThB3.6

Accounting for Modelling Errors in Model-Based Diagnosis by Using Gaussian Process Models, pp. 510-515

Dolenc, Bostjan — Jozef Stefan Inst
Stepancic, Martin — Jozef Stefan Inst
Juričić, Đani — Jožef Stefan Inst
Kocijan, Jus — Jozef Stefan Inst
Pianese, Cesare — Univ. of Salerno
Marra, Dario — Dept of Industrial Engineering, Univ. of Salerno

Imperfections in process models, if ignored, may affect reliability of the diagnostic system, for example through excessive false alarm rates. The problem tackled in this paper is how to handle unmodelled effects, caused by imperfect nominal models. We propose a covariance model, which builds on the idea that bias in nominal model can be described by a stochastic process. The Gaussian process model is used to capture the discrepancy between reality and nominal model, hence resulting in a refined model of the plant. With unmodelled dynamics as a second-order stochastic process, fault detection problem reduces to the problem of statistical decision making. The onset of a fault is inferred by comparing the statistical pattern of the residuals, collected under current operating mode with the pattern in the nominal (fault-free) condition. Major novelty of the approach resides in employing Jensen-Renyi divergence as a means to express the "distance" between the two corresponding ensembles of distributions. The ideas of the approach and their potentials are demonstrated on a simulated solid oxide fuel cell system.

ThC1 S01

Energy Conversion & Distribution (Regular Session)

Chair: Aitouche, Abdel — CRISTAL/HEI
Co-Chair: HOBLOS, Ghaleb — IRSEEM/ESIGELEC

16:30-16:50 ThC1.1

Data Fusion for Fault Diagnosis in Smart Grid Power Systems, pp. 516-521

Kordestani, Mojtaba — Univ. of Windsor
Saif, Mehrdad — Univ. of Windsor

In smart grid power systems, fast and accurate fault detection and diagnosis (FDD) is vital for isolating faulty components and avoiding further complications. This paper introduces a new data fusion method based on ordered weighted averaging (OWA) operator for power smart grids. For this purpose, the discrete time data from circuit breakers (CB) is combined with continuous time data of recorders to enhance the reliability of the fault diagnosis approach. Radial basis functions (RBF) artificial neural network and wavelet transform (WT) are individually employed to identify the location of the fault from the continuous voltage of the buses. Then, a combination of these two methods along with the information from CBs are utilized into a unique framework by OWA operator to diagnose the faults at an early stage. IEEE standard 14 bus system is used to illustrate and validate the proposed method. Several phase to ground faults are injected into the simulation model to validate the diagnostic capability of the FDD system. Simulation results show a better performance of the fusion FDD system in comparison with three other methods.

16:50-17:10 ThC1.2

Model-Based Broken Rotor Bars Fault Detection and Diagnosis in Squirrel-Cage Induction Motors, pp. 522-524

Duvvuri, SSSR Sarathbabu — IIT Hyderabad
Detroja, Ketan — Indian Inst. of Tech. Hyderabad

In this paper, a new model-based fault detection and diagnosis method for broken rotor bars in squirrel-cage induction motor is proposed. The proposed method rely on innovation sequence generated by the conventional extended Kalman filter. The innovations would follow a Gaussian distribution under normal operation, however a fault, i.e. broken rotor bar, would change this underlying distribution. It has been shown that this change in the distribution is indicative of a fault. The proposed method use only readily available current measurements and no additional sensors are required. Further, the proposed method is robust to unbalanced supply voltage and load changes. Computer simulations are carried out for a 4-hp squirrel-cage induction motor using MATLAB software. The results demonstrate the advantage of the proposed technique as it provides accurate estimates for broken rotor bar fault detection.

17:10-17:30 ThC1.3

Fault Diagnosis of Active Magnetic Bearings Based on Gaussian GLRT Detector, pp. 525-532

Nagel, Leon — Tech. Univ. of Denmark
Galeazzi, Roberto — Tech. Univ. of Denmark
Voigt, Andreas — Loyd Register Consulting
Santos, Ilmar — Tech. Univ. of Denmark

Active magnetic bearings are progressively replacing conventional bearings in many industrial applications, particularly in the energy sector. Magnetic bearings have many advantages such as contactless support and clean operation; however their use poses also some challenges connected to their inherent open loop instability. Occurrence of faults in one or more components of an active magnetic bearing may lead to loss of control of the rotor. Timely detection and isolation of faults in an active magnetic bearing could prevent hazardous system's behaviours by enabling proper reconfiguration of the control system. A structural model of the bearing-rotor system is presented and used to perform a diagnosability and isolability analysis of faults in the magnetic actuator. Structural diagnosability and group-wise isolability is concluded for single and multiple faults in the actuator.

A Gaussian GLRT detector is proposed for detecting faults striking the electromagnet. The detector is capable to diagnose and isolate the occurrence of faults in e.g. the windings of bearing by tracking changes in the mean value of a Gaussian distribution. The statistical distribution of the residuals in non faulty condition is characterized by experimental data of a full-scale bearing-rotor system. Verification of the detection performance is done through simulated data of a nonlinear model of the magnetic bearing calibrated against the real system.

17:30-17:50 ThC1.4

Fault Detection and Isolation Methodology Using Interval Predictors with Application to DC-DC Buck Converters, pp. 533-538

THABET, RIHAB EL HOUDA — Univ. OF BORDEAUX 1
Chafouk, Houcine — Irseem / Esigelec

In this paper, the problem of Fault Detection and Isolation (FDI) in DC-DC Buck converter is addressed. In a bounded error context and taking into account the parameters uncertainties of a basic Buck converter model, a set-membership FDI methodology is proposed. A Linear Parameter Varying (LPV) form of the basic DC-DC Buck converter is firstly given. Under noisy environment and based on the proposed LPV model, an interval predictor developed in recent work for LPV systems is applied in this paper in order to detect and isolate multiple faults. An original signal is proposed to ensure the purpose with no need to a bank of residuals in multi-fault cases. The efficiency of the proposed methodology is illustrated through simulation results.

17:50-18:10 ThC1.5

Modeling Approach and Fault Index Analysis of a Voltage-Source Brushless DC Motor, pp. 539-544

Alameh, kawthar — Inst. De Recherche En Systèmes électroniques Embarqués
Ginzarly, Riham — Univ. De Rouen
HOBLOS, Ghaleb — IRSEEM/ESIGELEC
BARAKAT, Georges — Univ. Le Havre, Normandie Univ

This paper presents a modeling approach and a fault index analysis of a voltage-source brushless DC motor. First, an analytical multi-physical model of the inverter-fed Permanent Magnet DC motor is developed and simulated using Matlab/Simulink. This model enables the generation of electrical, magnetic and vibration signals under healthy and faulty motor behaviors, with several fault categories and severities. Before simulating faulty conditions in the different parts of the analytical model, they are compared to Finite Element models, developed using Matlab for air-gap flux density and ANSYS software for stator natural frequency calculation. Simulation results of the motor during normal functioning and under faulty conditions are presented. In particular, rotor eccentricity and single pole demagnetization faults are studied in this paper. Then, different features, including time-, space-, frequency- and harmonic-domain characteristics, are extracted from vibration signals for different cases. Finally, these indicators are analyzed with respect to the fault severity to select the most discriminative one(s) allowing an efficient fault detection and isolation.

18:10-18:30 ThC1.6

Harmonic Fault Diagnosis in Power Quality System Using Harmonic Wavelet, pp. 545-550

Kordestani, Mojtaba — Univ. of Windsor
Safavi, Ali Akbar — Shiraz Univ
Saif, Mehrdad — Univ. of Windsor

The increasing use of non-linear loads such as power electronics, converters, arc furnaces, transformers, fluorescent and high intensity discharge lights have caused harmonics distortion in power quality (PQ) systems. On the other hand, harmonics have numerous effects on electrical systems. For examples, they can be troublesome to communication systems, they increase heating in the transformers and motors, and consequently decrease their life cycle. The first step to address these issues is to diagnose harmonic faults in power distribution systems. This paper introduces a new method for detecting harmonic faults using harmonic wavelets. For this purpose, harmonic wavelet transform (HWT) is used to decompose the faulty signal at different levels. Then, the energies of the decomposition levels based on parseval's theorem are computed. Finally, the faulty signal is reconstructed with harmonics wavelets. Simulation results show that the suggested fault detection and diagnosis (FDD) system can successfully identify the maximum harmonic in the faulty signal and the amount of harmonics in the faulty signal compared to fundamental signal.

ThC2 S04

Health Management (Regular Session)

Chair: Provan, Gregory — Univ. Coll. Cork
Co-Chair: Sarrate, Ramon — Univ. Pol. De Catalunya

16:30-16:50 ThC2.1

A Graphical Framework for Stochastic Model-Based Diagnosis, pp. 551-556

Provan, Gregory — Univ. Coll. Cork

Diagnosing systems with uncertainty has significant practical importance. Many different methods for performing diagnostics inference on stochastic systems have been developed in fields such as FDI and AI. We provide a factor graph framework that integrates several of these approaches for diagnosing stochastic systems. This integration provides several advantages, e.g., showing inter-relationships among the inference algorithms, a computational toolbox for solving diagnostics problems, and an a priori means for predicting inference complexity based solely on the graph structure.

16:50-17:10 ThC2.2

Reliability Importance Measures for Availability Enhancement in Drinking Water Networks, pp. 557-563

Salazar, Jean C. — Univ. Pol. De Catalunya
Nejjari, Fatiha — Univ. Pol. De Catalunya
Sarrate, Ramon — Univ. Pol. De Catalunya
Weber, Philippe — Univ. De Lorraine
Theilliol, Didier — Univ. of Lorraine

This work focuses on a health-aware Model Predictive Control (MPC) scheme, which aims at enhancing the availability of the system. The objective is to extend the uptime of the system by delaying, as much as possible the system reliability decay. The weights of the MPC cost function are set according to some reliability importance measures. This work describes the main reliability importance measures and studies which of them are best suited for a health-aware MPC strategy applied to a Drinking Water Network. The overall system reliability as well as the reliability importance measures are computed online through a Dynamic Bayesian Network.

17:10-17:30 ThC2.3

Fault Detection on Bearings Coupled to Permanent Magnet DC Motors by Using a Generalized Takagi-Sugeno PI Observer, pp. 564-569

Martínez García, Citlaly — Cenidet
Osorio-Gordillo, Gloria-Lilia — Centro Nacional De Investigación Y Desarrollo Tecnológico
Astorga-Zaragoza, Carlos — TecnolÓgico Nacional De MÉxico - Cenidet
Puig, Vicenç — Univ. Pol. De Catalunya (UPC)

This paper presents a fault detection system for rotative machinery. A permanent-magnet DC motor is used as case of study. The main idea is to estimate on-line the non-load torque (To) in order to monitor the bearing health condition. The fault detection system is based on the design of a generalized Takagi-Sugeno PI (proportional-integral) observer. The main advantage of this approach is that it can be easily implemented because the

observer gains are obtained by solving a set of LMIs (linear matrix inequalities). Moreover the method can be extended to more complicated nonlinear systems by using the Takagi-Sugeno approach. A simulation is performed to show that this fault detection scheme can be applied to detect abrupt faults on rotative machinery which can lead the system to undesirable performance caused by vibrations or breakdown.

17:30-17:50 ThC2.4

Photovoltaic Module Health Monitoring and Degradation Assessment, pp. 570-577

laayouj, nabil — National School of Applied Sciences Industrial Department, Ibn Z
Jamouli, Hicham — Ibn Zohr Univ
El Hail, M.Amine — Univ. Ibn Zohr, ENSA

All industrial systems or machines are subjected to degradation processes which can be related to the operating conditions. This degradation can cause unwanted stops and the need of urgent maintenance at any time. Prognostic activity is now recognized as a key feature in maintenance strategies and conditional based maintenance, it gives to operators a potent tool in decision making by quantifying how much time is left until functionality is lost. The reason is to plan the heavy interventions and to manage the stock of spare parts. In addition, it can be used for degradation assessment and Remaining useful life (RUL) estimation. In this paper, we will develop a new smart prognostic method for photovoltaic module health degradation, which is based on on-line diagnosis and data-driven prognosis to achieve more accurate predictions. This framework of forecasting integrates the strengths of real time monitoring in the first approach and Relevant Vector Machine in the second. The results show that the proposed method is plausible due to the good prediction of RUL, and can be effectively applied to many systems for monitoring and prognosis.

17:50-18:10 ThC2.5

Supporting the Shift towards Continuous Pharmaceutical Manufacturing by Condition Monitoring, pp. 578-583

Schenkendorf, René — TU Braunschweig

Over the last decade there has been an increased interest in the pharmaceutical industry to shift the manufacturing process of drugs from batch to continuous operation. The continuous manufacturing of pharmaceuticals provides significant benefits, i.e. savings in cost, time and materials - to name but a few. The implementation of a continuous manufacturing strategy, however, is challenging. To gain profit from a continuous process one has to ensure its proper operation, i.e. a long time-span until the next prospective unscheduled downtime. Thus, the installed operation units have to be: 1) robust against disturbances by engineering design and by advanced fault tolerant control schemes, respectively; and 2) the condition of the operation units has to be monitored reliably to trigger, in case of need, appropriate intervention strategies in a timely manner. In this paper, the focus is on the monitoring aspect. Here, a model-based fault detection and identification framework is implemented, which selects the most data-supported model candidate from a set of predefined model candidates including the reference model (normal behaviour) and failure models. In addition, to enable an improved diagnosis the system under study can be steered deliberately based on the proposed concept resulting into an active fault diagnosis framework. Preliminary results of the proposed concept are demonstrated by an academic three-tank system.

18:10-18:30 ThC2.6

Model-Based Prognostic Algorithm for Online RUL Estimation of PEMFCs, pp. 584-589

Polverino, Pierpaolo — Univ. of Salerno
Pianese, Cesare — Univ. of Salerno

The proposed work deals with the development of a simple but effective prognostic algorithm, able to predict to a certain extent the Remaining Useful Life (RUL) of a Polymer Electrolyte Membrane Fuel Cell (PEMFC). The algorithm is based on mathematical equations derived from physical analysis of the key degradation mechanisms, mainly focusing on those involving the electrochemical surface area (ECSA). Through the understanding of ECSA reduction rate, a proper formulation for voltage decay is given. This formulation allows performing quick online RUL estimation at given operating conditions, representing a useful guideline for suitable mitigation strategies choice.

ThC3 S02

Fault Tolerant Control 1 (Regular Session)

Chair: Blanke, Mogens — DTU
Co-Chair: Ponsart, Jean-Christophe — Univ. De Lorraine

16:30-16:50 ThC3.1

LMI-Based Design of Cascade Reconfiguration Control Structures, pp. 590-595

Krokavec, Dusan — Tech. Univ. of Kosice
Filasova, Anna — Tech. Univ. of Kosice
Liščinský, Pavol — Tech. Univ. of Košice

The paper considers the problem of control reconfiguration to retain fault tolerance in control of linear continuous-time systems with plant dynamics faults. Following the concept of reference model control, the main idea is to keep untouched the nominal control parameters, where in addition the nominal controller remains a part of the reconfigured control loop. The full state control tenet is applied for nominal control strategy and the static output control principle for the compensation control law specification in the so called cascade reconfiguration structure. Analyzing as a mixed control problem, new conditions for control structure parameter design are introduced and proven. The obtained results, offering the sufficient and necessary design conditions, are illustrated with a numerical example to note the effectiveness of the proposed approach.

16:50-17:10 ThC3.2

A Receding Horizon Control of Markov Jump Linear Systems with Imperfect State Information and Probabilistic State Constraints, pp. 596-602

Chitraganti, Shaikshavali — Amrita Vishwa Vidyapeetham
Aberkane, Samir — Uhp, Nancy 1
Aubrun, Christophe — Univ. of Lorraine

A receding horizon control of discrete-time Markov jump linear systems with additive Gaussian measurement and process noise, and stochastic constraints is addressed. Given the availability of the underlying jump parameter, recursive equations for optimal state estimation that resemble Kalman filter equations are provided. The receding horizon control law is considered in state-feedback form. Under some detectability conditions, the overall system is pre-stabilized off-line with state-feedback gains by ensuring mean square boundedness of system states. Using a Gaussian assumption, the stochastic constraints are reposed and approximated the original problem as a tractable deterministic receding horizon control problem in terms of conditional means and covariances of the state variable, and solved it on-line with control offset terms. The overall approach is applied on a vertical take-off and landing vehicle dynamical system example.

17:10-17:30 ThC3.3

Effectiveness of PID and DMC Control Algorithms Automatic Code Generation for Microcontrollers: Application to a Thermal Process, pp. 603-608

Chaber, Patryk — Warsaw Univ. of Tech
Lawrynczuk, Maciej — Warsaw Univ. of Tech

An effective approach to implement control algorithms using code auto-generation is presented. Using MATLAB and C languages as input, an optimised pure C code is generated using a custom transcompiler. The considered solution is focused on microcontrollers from the STM32 family but any other can be used due to flexibility of the presented system. Controller development for a laboratory thermal process is thoroughly described, PID and

DMC algorithms are used. Electronic connection between microcontroller and the process is discussed. Results of the experiments are reported.

17:30-17:50 ThC3.4

From Safety Analysis of Reconfigurable Systems to Design of Fault-Tolerant Control Strategies, pp. 609-614

Piriou, Pierre-Yves EDF

Faure, Jean-Marc ENS Cachan

Lesage, Jean-Jacques ENS-Cachan

The design of fault-tolerant control strategies requires a perfect knowledge of both the possible reconfigurations of the system and of the behavior of this system when failures occur. In this paper it is shown that the use of a model-based safety analysis (MBSA) framework, able to cope with repairable and reconfigurable phased-mission systems, is helpful for the choice of the best reconfiguration strategies to be implemented in the control system. The core of this approach is based on the integration of a model of the system structure (Fault Tree), a model of the dysfunctional behaviors of the components of the system (Switched Markov Processes) and a model of the reconfiguration mechanisms (Moore Machines). The syntax and semantics of the different models and their integration is first defined. The benefits of this approach for performance evaluation of fault-tolerant control strategies are afterwards illustrated through an application example.

17:50-18:10 ThC3.5

Model-Free Control for Unknown Delayed Systems, pp. 615-620

Doublet, Maxime Univ. De Lorraine

Join, Cédric Nancy Univ

Hamelin, Frederic Univ. of Lorraine

The use of model-free control (MFC) spreads now more and more in industry. Nevertheless, control unknown delayed systems with this method remains an open problem. In this contribution, we present the use of model-free control in this context and we propose a solution to improve the effectiveness of this approach using a parameter estimation.

FrA1 S01

Wind and Wave Turbines (Regular Session)

Chair: Patton, Ron J. Univ. of Hull

Co-Chair: Vidal, Yolanda Univ. Pol. De Catalunya

09:00-09:20 FrA1.1

Passive Fault Tolerant Control Strategy in Controlled Wind Turbines, pp. 621-626

Acho, Leonardo Univ. Pol. De Catalunya-EUETIB

Rodellar, Jose Tech. Univ. of Catalonia

Tutivén, Christian Univ. Pol. De Catalunya

Vidal, Yolanda Univ. Pol. De Catalunya

In wind turbines (WTs), some faults can induce saturation of the control signal, and these saturation nonlinearities might lead to instability. Therefore, a robust system against saturation can better deal with faults. In this work, an avoid saturation strategy is proposed for the torque control of WTs. The key idea is that the reference power and generator speed set-points are hysterically manipulated. Simulation results from a 5MW benchmark model show that the proposed strategy has a clear added value with respect to the baseline controller not only in healthy condition but also in presence of a realistic fault.

09:20-09:40 FrA1.2

Adaptive Nonlinear Filters for Joint Fault Estimation and Accommodation of a Wind Farm Benchmark, pp. 627-632

Simani, Silvio Univ. of Ferrara

Castaldi, Paolo Univ. of Bologna

Bonfe, Marcello Univ. Di Ferrara

In order to improve the availability of offshore wind farms, thus avoiding unplanned operation and maintenance costs, which can be high for offshore installations, the accommodation of faults in their earlier occurrence is fundamental. Therefore, this paper addresses the design of an active fault tolerant control scheme that is applied to a small wind park benchmark of nine wind turbines, based on their nonlinear models, as well as the wind and interactions between the wind turbines in the wind farm. The controller accommodation scheme provides the on–line estimate of the fault signals generated by nonlinear filters exploiting the nonlinear geometric approach to obtain estimates decoupled from both model uncertainty and the interactions among the turbines. This paper proposes also a data–driven approach to provide these disturbance terms in analytical forms, which are subsequently used for designing the nonlinear filters for fault estimation. In general, purely analytic approaches, where the system nonlinearity and disturbance decoupling properties are explicitly considered, could require complex design strategies. This feature of the work, followed by the simpler solution relying on a data–driven approach, can represent the key point when on–line implementations are considered for a viable application of the proposed scheme. The wind farm benchmark is considered to validate the performances of the suggested scheme in the presence of different fault conditions, modelling and measurement errors.

09:40-10:00 FrA1.3

Condition Monitoring of Permanent Magnet Synchronous Generator for Wind Turbine Applications, pp. 633-638

Ibrahim, Raed Loughborough Univ

Watson, Simon Loughborough Univ

Wind energy has gained a considerable attention from industries and academia to increase the reliability and availability of wind turbines (WTs) and, consequently, to reduce wind energy cost. With this attention has come investments and new technologies from WT manufacturers as industrial solutions. Among these technologies the new arrivals, the variable speed generation systems based on permanent magnet synchronous generators (PMSGs) with full-scale power converters are an emerging and promising technology. Better designs of the WT components is of course one answer to the solution of this problem; the other is condition monitoring of the WT systems. This allows to reduce maintenance cost, hardware damaging and unscheduled downtime. In this context, this paper investigates the possibility to detect mechanical faults by analysing the electrical signals with the aim of improving the reliability of WTs based on PMSGs. Rotor eccentricity is used as an illustrative example to describe how the fault signature frequencies may occur in PMSG current signals, and potentially how they may deviate from a healthy state, firstly under steady state, constant speed test operation and secondly under transient, variable speed conditions. Simulation results yield valuable information for condition monitoring and effective algorithm development for fault detection.

10:00-10:20 FrA1.4

Estimation of Wave Excitation Force for Wave Energy Converters, pp. 639-644

Abdelrahman, Mustafa Univ. of Hull

Patton, Ron J. Univ. of Hull

Guo, Bingyong Univ. of Hull

Lan, Jianglin Univ. of Hull

This paper presents a novel technique to estimate the wave excitation force which is an essential signal in the control of a Point Absorber Wave Energy Converter (PAWEC). The work uses a nonlinear PAWEC simulation together with a modified form of the well-known fast adaptive actuator fault estimation (FAFE) technique for nonlinear Lipschitz system, the fast adaptive unknown input estimation (FAUIE). The estimated wave excitation force is an important reference input for optimum power control and is considered as an unknown input. The results show accurate wave excitation force estimation based on irregular wave generation as well as the performance of the power tuning controller.

10:20-10:40 FrA1.5

Control of a DC-AC Inverter in a Wind Energy Generation System Using T-S Fuzzy Modeling, pp. 645-650

Harrabi, Naziha Lab-STA/ENIS

Souissi, Mansour Engineering School of Sfax, Tunisia

Aitouche, Abdel CRISTAL/HEI

Chaabane, Mohamed National Engineering School of Sfax, Tunisia

The wind generation system treated in this paper is composed of a fixed pitch angle wind turbine followed by a Permanent Magnet Synchronous Generator (PMSG) and power electronic converters AC-DC-AC which are coupled to a DC link. This work deals with the control of the inverter in order to ensure a constant DC link voltage. The control design is based on Takagi Sugeno fuzzy model. Stability analysis of the problem is realized using Lyapunov theorem and H-infinity performance. In order to calculate the controller gains, the problem is treated by means of Linear Matrix Inequality (LMI). Simulation results are carried out using MATLAB/SIMULINK to test the effectiveness of the proposed control algorithm.

FrA2 S04

Fault Diagnosis and Fault Tolerant Control for Aerospace Systems (Invited Session)

Chair: Simani, Silvio Univ. of Ferrara

Co-Chair: NOURA, Hassan United Arab Emirates Univ

Organizer: Simani, Silvio Univ. of Ferrara

09:00-09:20 FrA2.1

Hierarchical Fault-Tolerant Control of a Quadrotor Based on Fault Severity (I), pp. 651-656

MERHEB, Abdel-Razzak LIU

Bateman, François Lab Des Sci. Des Systèmes D'info

NOURA, Hassan United Arab Emirates Univ

Al Younes, Younes — Higher Coll. of Tech

In this paper, a hierarchical Fault Tolerant Controller (FTC) for quadrotor hovercrafts is developed. The proposed controller switches between suitable controllers according to the actuator fault severity. Low amplitude faults are tolerated using the inherent robustness of a regular Sliding Mode Controller (SMC). When fault magnitude increases, an Active FTC is activated. This controller uses the fault estimates provided by an Extended Kalman Filter (EKF) to recover the control loss. When a fault magnitude rises to dangerous values, an emergency controller is activated and the quadrotor continues its mission as a trirotor. Simulation results emphasize the robustness of the proposed controller in real environments where measurement noise and actuator faults affect severely the quadrotor.

09:20-09:40 FrA2.2

Adaptive FTC Based on Control Allocation and Fault Accommodation for Satellite Reaction Wheels (I), pp. 657-662

Baldi, Pietro — Univ. of Bologna
Blanke, Mogens — DTU
Castaldi, Paolo — Univ. of Bologna
Mimmo, Nicola — Univ. of Bologna
Simani, Silvio — Univ. of Ferrara

This paper proposes an active fault tolerant control scheme to cope with faults or failures affecting the flywheel spin rate sensors or satellite reaction wheel motors. The active fault tolerant control system consists of a fault detection and diagnosis module along with a control allocation and fault accommodation module directly exploiting the on-line fault estimates. The use of the nonlinear geometric approach and radial basis function neural networks allows to obtain a precise fault isolation, independently from the knowledge of aerodynamic disturbance parameters, and to design generalised estimation filters, which do not need a priori information about the internal model of the signal to be estimated. The adaptive control allocation and sensor fault accommodation can handle both temporal faults and failures. Simulation results illustrate the convincing fault correction and attitude control performances of the proposed system.

09:40-10:00 FrA2.3

A Set Based Approach for SFDI on Small Commercial Aircraft (I), pp. 663-668

Mattei, Massimiliano — Seconda Univ. Di Napoli
Ollio, Luciano — DIIES - Univ. Degli Studi Di Reggio Calabria
Scordamaglia, Valerio — Univ. of Reggio Calabria

The problem of detecting and isolating faults on duplex sensor architecture in a small commercial aircraft is considered. The use of a Set-Based approach involving a bank of consistency signal generators is proposed. In particular, by exploiting the knowledge of dynamic relations between command inputs and sensed variables in discrete time, sensor measurements accuracy has been estimated also in the presence of bounded disturbances and model uncertainties. Then, a Health Measurement Voting Supervisor detects and isolates faulty sensor. Numerical simulations involving a nonlinear aircraft mathematical model subject to atmospheric disturbance and sensor noise are performed in order to show the practical applicability of the proposed technique.

10:00-10:20 FrA2.4

Fault Diagnosis and Fault Tolerant Control Strategies for Aerospace Systems (I), pp. 669-674

Simani, Silvio — Univ. of Ferrara
Castaldi, Paolo — Univ. of Bologna
Mimmo, Nicola — Univ. of Bologna

This work presents two active fault tolerant control systems for aerospace applications. The former case study regards an aircraft longitudinal autopilot and the latter one a satellite attitude control system, both in case of faults affecting the actuators. The main features of the presented active fault tolerant control schemes are the fault detection and diagnosis module and its design technique, the nonlinear geometric approach. Such an approach allows, using adaptive filters in the fault detection and diagnosis module, fault detection, isolation and estimation. The fault estimates, obtained by different methods including recursive least squares and neural network, are exploited by a controller reconfiguration mechanism. In particular, by means of a nonlinear geometric approach, relying on nonlinear differential algebra, it is possible to obtain fault estimates decoupled from wind components in case of aircraft and aerodynamic disturbances in case of spacecraft, thus giving to the overall control system very good robustness properties and performances. The effectiveness of the designed solutions is shown by means of high fidelity simulators, in different flight conditions and in the presence of faults on actuators, turbulence, measurement noise, and modelling errors.

10:20-10:40 FrA2.5

Detection of Icing and Actuators Faults in the Longitudinal Dynamics of Small UAVs Using an LPV Proportional Integral Unknown Input Observer (I), pp. 675-682

Rotondo, Damiano — Univ. Pol. De Catalunya (UPC)
Cristofaro, Andrea — Norwegian Univ. of Science and Tech
Johansen, Tor Arne — Norweigian Univ. of Sci. & Tech
Nejjari, Fatiha — Univ. Pol. De Catalunya
Puig, Vicenç — Univ. Pol. De Catalunya (UPC)

This paper proposes a linear parameter varying proportional integral unknown input observer (PI-UIO) for the diagnosis of actuator faults and icing in unmanned aerial vehicles. It is shown that in presence of sensor noise, the proposed PI-UIO has the advantage of being affected by the noise, but not by its derivative. Another contribution of the paper is the introduction of an icing to wind/noise ratio, which allows performing an optimal tuning of some PI-UIO design parameters. Results obtained with a Zagi Flying Wing simulator are used to validate the effectiveness of the proposed approach.

FrA3 S02

Fault Tolerant Control 2 (Regular Session)

Chair: Aubrun, Christophe — Univ. of Lorraine
Co-Chair: Rotondo, Damiano — Univ. Pol. De Catalunya (UPC)

09:00-09:20 FrA3.1

State-Feedback H Infinity Stabilization of State-Dependent Jump Linear Systems, pp. 683-688

Chitraganti, Shaikshavali — Amrita Vishwa Vidyapeetham
Aberkane, Samir — Uhp, Nancy 1
Aubrun, Christophe — Univ. of Lorraine

A state-dependent jump linear system (SDJLS) is a particular type of stochastic switching system, where the transition rates or probabilities of the underlying random jump process depend on the state variable. In this paper, a continuous-time SDJLS subject to external disturbances with finite energy is considered. Regarding the underlying random jump process, the transition rates are assumed to have different values across different sets where the state of the system evolves. By evaluating the infinitesimal generator for the stochastic Lyapunov function of SDJLS, a state-feedback H infinity controller is synthesized that guarantees disturbance rejection while ensuring stochastic stability via solving a set of sufficient linear matrix inequalities. The overall approach is illustrated with a numerical example.

09:20-09:40 FrA3.2

Fault-Tolerant Periodic Economic Model Predictive Control of Differential-Algebraic-Equation Systems, pp. 689-695

Wang, Ye — Univ. Pol. De Catalonia
Puig, Vicenç — Univ. Pol. De Catalunya (UPC)
Cembrano, Gabriela — UPC

This paper addresses a fault-tolerant periodic economic model predictive control (MPC) strategy for differentialalgebraic- equation (DAE) systems. Fault tolerance evaluation of the proposed economic MPC strategy uses set computations and a performance degradation analysis. By means of the set computations, the feasible solution set (including states and inputs) can be determined as well as the admissible performance set can be obtained when system reconfiguration or fault accommodation strategies are used. The proposed control strategy allows to carry out an analysis of performance degradation by using the feasible and admissible performance set. As a result, if the performance degradation is accepted, the economic MPC controller can be applied with system reconfiguration or fault accommodation. Finally, the proposed fault-tolerant MPC strategy is verified through an illustrative example.

09:40-10:00 FrA3.3

Sensor Fault Tolerance in Output Feedback Nonlinear Model Predictive Control, pp. 696-701

Knudsen, Brage Rugstad	Norwegian Univ. of Science and Tech
Alessandretti, Andrea	Inst. Superior Técnico - École Pol. Fédérale De Lau
Jones, Colin N	EPFL, Lausanne

This paper presents an active output feedback fault-tolerant model predictive control (MPC) scheme for systems with sensor faults. The proposed control scheme actively steers the system in order to prevent loss of observability caused by a sensor fault. To this end, the standard tracking objective of the MPC controller is augmented with an observability cost term which strongly penalizes unobservable state and input trajectories. A numerical example illustrates the use of the proposed approach on a target estimation and tracking control problem with faulty sensors.

10:00-10:20 FrA3.4

Fault Tolerance Evaluation of Nonlinear Systems Using Viability Theory, pp. 702-708

Ghaniee Zarch, Majid	Iran Univ. of Science and Tech
Puig, Vicenç	Univ. Pol. De Catalunya (UPC)
Poshtan, Javad	Iran Univ. of Science and Tech

This paper presents a computational procedure based on viability theory to evaluate the fault tolerance ad- missibility of a given fault configuration of a nonlinear system controlled by means of a predictive control law. The admissible solution set for control problem, including the effect of faults, is determined using viability kernel and capture basin. Finally, water heater part of pasteurization process is provided as benchmark in order to show the usefulness of viability theory for fault tolerance evaluation.

10:20-10:40 FrA3.5

Fault Tolerant Control System Based on Subspace Predictive Control and Multiple Model Predictive Control, pp. 709-714

QU, Zukun	LAAS-CNRS
Dahhou, Boutaieb	LAAS-CNRS
Roux, Gilles	LAAS-CNRS

A fault tolerant control system is proposed using recursive subspace predictive control and multiple model predictive control method, which combines off-line projection-based method and on-line redesign method. For anticipated situations, including normal state and occurrences of different faults, stable controller corresponding to each situation is designed off-line using model predictive control method with fixed parameters, and adaptive subspace model predictive control method plays a key role in on-line controller redesign. A switching mechanism is proposed for the global fault tolerant control system. In this paper actuator faults are considered. A simulation example is used to illustrate the efficacy of the proposed approach.

FrB1 S01

Networked Control Systems (Regular Session)

Chair: Sauter, Dominique	Lorraine Univ
Co-Chair: Boem, Francesca	Imperial Coll. London

14:00-14:20 FrB1.1

Plug-And-Play Diagnosis of Locally Interconnected Systems with Limited Model Information, pp. 715-722

Bodenburg, Sven	Ruhr-Univ. Bochum
Lunze, Jan	Ruhr-Univ. Bochum

This paper proposes a novel method to organise the design of a diagnostic unit that should detect faults in a decentralised controlled interconnected system. A fault at a subsystem should be detected by a local model-based diagnostic unit that only evaluates the local signals of the faulty subsystem. The focus of this paper is on the organisation of the design process of the diagnostic unit without a central coordinator. Design agents exist for each of the subsystems which store the subsystem model. A local algorithm is presented to gather models from neighbouring design agents with the aim to set-up a model which describes the behaviour of the faulty subsystem used by the diagnostic unit. Based on a proposed detectability condition the amount of model information is determined in order to guarantee the detection of the fault. As a onsequence, with the plug-in of the diagnostic unit into the control hardware, the detection of the fault is ensured. The proposed plug-and-play diagnosis is applied to a multizone furnace.

14:20-14:40 FrB1.2

Fault-Tolerant Control of Networked Systems with Re-Distribution of Control Tasks in Case of Faults, pp. 723-729

Schenk, Kai	Ruhr-Univ. Bochum
Lunze, Jan	Ruhr-Univ. Bochum

The paper proposes a new method for fault-tolerant control of networked systems. The main idea is to re-distribute the common control task among the subsystems if the ability of a single subsystem to satisfy its specifications is limited by a fault. Two methods are proposed to find new set-points for the non-faulty subsystems such that the overall control goal is reached again. The main problem to be solved results from the fact that networked system do not have a coordinating unit and the subsystems have to agree about the re-distributed set-points by local information exchange. The ideas are llustrated by using a distillation process.

14:40-15:00 FrB1.3

Coding Control Signals and Switching LQG Controller for Secure Fault-Tolerant Control against Stealthy False Data Injection, pp. 730-735

Rhouma, Taouba	Univ. of Gabes, ENIG, MACS
Keller, Jean-Yves	Univ. Henri Poincaré, CRAN
Chabir, Karim	ENIG
Sauter, Dominique	Lorraine Univ
Abdelkrim, Mohamed Naceur	National Engineering School of Gabes, Tunisia. Res. Unit Of

Security of Cyber-Physical Systems (CPS) against Cyber attacks has become an important challenging research field. If false data injections on control and/or measurement signals of a Fault-Tolerant Control System (FTCS) can be treated as detectable virtual actuator or sensor faults, the FTCS can automatically accommodate false data injections by triggering the controller reconfiguration mechanism at detection time given by the mode-based Fault Detection and Isolation (FDI) algorithm. After having shown that an intelligent adversary can destabilize the non minimum phase plant of the FTCS by designing a false data injection attack on the control signal while remaining undetectable from any passive FDI algorithm, this paper proposes to transform stealthy false data injections into detectable attacks from an active FTCS based on a switching Linear Quadratic Gaussian (LQG) controller and a confining coding method able to block the attack signal on a minimum number of encoded control signals.

15:00-15:20 FrB1.4

Fault-Tolerant Coupling of Real-Time Systems: A Case Study, pp. 736-742

Tranninger, Markus	Graz Univ. of Tech
Haid, Timo	TU Graz / Posche AG
Stettinger, Georg	VIRTUAL VEHICLE Res. Center
Benedikt, Martin	Virtual Vehicle Res. Center
Horn, Martin	Graz Univ. of Tech

This paper demonstrates the application of a model-based coupling approach to cope with non negligible coupling imperfections and faults of interconnected real-time systems. Performance degradation of the coupled overall system is prevented via model-based prediction schemes, which compensate for effects caused by e.g. deadline violations of the coupled real-time systems or data losses and transmission time delays due to the communication network. As an example, the real-time co-simulation setup of a modular driving simulator demonstrates the practical applicability and effectiveness of the proposed coupling approach.

15:20-15:40 FrB1.5

Sensor Placement Algorithm for Distributed Fault Diagnosis, pp. 743-750

Gupta, Vikas	UPC
Puig, Vicenç	Univ. Pol. De Catalunya (UPC)

In this paper, an algorithm for sensor placement for distributed fault diagnosis is proposed. The main objective of this algorithm is to place the sensorsin a system in such a manner the partition of a system into various subsystems become more easy facilitating the implementation of a distributed fault diagnosis system. This algorithm also reduces or minimized the number of sensors to be used or install thus reducing overall cost. Binary integer linear programming is used for optimization in this algorithm. A four water tank system has been used to demonstrate and validate the proposed algorithm.

15:40-16:00 FrB1.6

Decentralized Fault Diagnosis for Heterogeneous Multi-Agent Systems, pp. 751-756

Boem, Francesca	Imperial Coll. London
Sabattini, Lorenzo	Univ. of Modena and Reggio Emilia
Secchi, Cristian	Univ. of Modena

The paper proposes a decentralized method for fault detection and isolation in heterogeneous multi-agents systems. The agents are partitioned into independent nodes, providing the control inputs and monitoring the system, and dependent nodes, controlled by local interaction laws and subject to faults. The approach uses a decentralized state estimation algorithm allowing the independent nodes to estimate both the state of the dependent nodes and the control input components computed by the other independent nodes, in a completely decentralized way, without requiring communication among the independent nodes. Suitable detection and isolation residuals and thresholds are derived. Detectability and isolability sufficient conditions are provided. Simulation results show the effectiveness of the proposed approach.

FrB2 S04

RECONFIGURE FP7 Project for Advanced Real-Time FDD and FTC for Civil Aircraft: Contributions and Results (Invited Session)

Chair: Kerr, Murray Lawrence	DEIMOS Space SLU
Co-Chair: GOUPIL, Philippe	AIRBUS Operations S.A.S
Organizer: Kerr, Murray Lawrence	DEIMOS Space SLU
Organizer: GOUPIL, Philippe	AIRBUS Operations S.A.S

14:00-14:20 FrB2.1

RECONFIGURE FP7 Project Preliminary Results and Contributions (I), pp. 757-762

Kerr, Murray Lawrence	DEIMOS Space SLU
GOUPIL, Philippe	AIRBUS Operations S.A.S
BOADA BAUXELL, JOSEP	AIRBUS
Rosa, Paulo Andre Nobre	Inst. for Systems and Robotics - Inst. Superior
Recupero, Cristina	Elecnor Deimos Space

This paper presents an overview of the preliminary results and contributions of the European Union 7th Framework Program (FP7) project RECONFIGURE (REconfiguration of CONtrol in Flight for Integral Global Upset REcovery). The RECONFIGURE project ran from January 2013 to June 2016, with the aim to investigate and develop advanced aircraft Guidance, Navigation and Control (GNC) technologies, for onboard Fault Detection and Diagnosis (FDD) and Fault Tolerant Control (FTC), that facilitate the automated handling of off-nominal events and optimize the aircraft status and flight. These technology developments will extend the operation of the current GNC functionalities that assist the pilot and optimize the aircraft performance in off-nominal events. The paper presents the employed design, development and validation approach of the project for the industrial and academic partners, describes the industrial benchmark (fault scenarios and models) and the Verification and Validation (V&V) facilities and processes employed in the project, provides an overview of the test results in the different facilities, and presents a preliminary assessment of achievements of the project.

14:20-14:40 FrB2.2

Enhancing Flight Control in Case of Total Angle of Attack Sensor Loss (I), pp. 763-769

Joos, Hans-Dieter	German Aerospace Center (DLR)
Ossmann, Daniel	Aerospace Engineering and Mechanics

To maintain nominal flight control system functionalities during fault scenarios, enhancements of the state of- practice angle of attack fault accommodation strategies are presented. The enhancements rely on combining modern fault detection and diagnosis (FDD) techniques with a robust envelope protection algorithm. The FDD system is able to detect and isolate partial or total losses of angle of attack sensors. The angle of attack is not a directly controlled variable in the flight control system, but is used to protect the aircraft from exceeding the flight envelope. To avoid the state-of-practice degradation towards an unprotected control law in case of a total angle of attack sensor loss, longitudinal protection law functionalities independent of the lost measurements are proposed. They provide satisfactory prevention of reaching difficult flight conditions and can be operated together with the nominal command and stability augmentation system. This paper discusses the protection law design in conjunction with the sensor monitoring scheme and the nominal inner loop control law. The latest results of an extensive industrial validation and verification campaign are reported.

14:40-15:00 FrB2.3

A Recursive Estimation Algorithm to Track Aircraft Model Parameters (I), pp. 770-777

Hardier, Georges	ONERA the French Aerospace Lab
Ferreres, Gilles	Onera / Dcsd
Seren, Cedric	ONERA - the French Aerospace Lab

On-line parameter tracking is often an attractive option for advanced FDD/FTC systems that require a global monitoring in contrast with a local (component) one. This is the case for impaired aircraft, but also for under-equipped vehicles (UAVs, small airplanes), since an updated model is a prerequisite for many indirect adaptive or reconfigurable control algorithms. Many schemes have been proposed since the 80s to deal with the tricky problem of on-line estimation. However for aircraft, their computational burden is often incompatible with the constraints resulting from onboard implementation and certification issues. As

a result, this paper relies on the well-known pros of frequency domain techniques, but proposes a fully recursive algorithm simple enough to comply with those requirements. The approach is applied to the parameter tracking of a civil aircraft on view of designing an adaptive gain-scheduled flight control law. Results are displayed, achieved in realistic flight conditions using the industrial nonlinear simulator of the RECONFIGURE European project.

15:00-15:20 FrB2.4

Adaptive Control of a Civil Aircraft through On-Line Parameter Estimation (I), pp. 778-784

Ferreres, Gilles	Onera / Dcsd
Hardier, Georges	ONERA the French Aerospace Lab
Seren, Cedric	ONERA - the French Aerospace Lab

An adaptive gain-scheduled flight control law is designed for a transport aircraft, within the context of the European project RECONFIGURE. A primary concern being on-line implementation, a recursive frequency domain estimator of the linearized aerodynamic model is developed, with a low on-line computational burden and the capability to track time-varying parameters. Next, an LFT flight controller is synthesized using a state-space modal technique, which depends on the model parameters to be estimated. Since the LFT controller on-line depends on the parameter estimates instead of the true values, its robustness to estimation errors needs to be assessed using mu and IQC analysis techniques. Full nonlinear simulations along a trajectory validate the good performance properties of the combined estimator and gain-scheduled flight controller. These results are achieved in realistic flight conditions using the industrial simulator of the RECONFIGURE European project.

15:20-15:40 FrB2.5

Development and Evaluation of Sliding Mode Schemes for the RECONFIGURE Benchmark Problem (I), pp. 785-790

Bharani Chandra, Kumar Pakki	Univ. of Leicester
Chen, Lejun	Univ. of Exeter
Alwi, Halim	Univ. of Exeter
Edwards, Christopher	Univ. of Exeter

This paper describes the development and evaluation of sliding mode schemes to handle actuator and sensor faults for the RECONFIGURE benchmark problem. For the actuator fault problem, a linear parameter varying (LPV) sliding mode control allocation scheme has been developed. The scheme is retro-fitted to the existing baseline controller. When faults/failures are present in an elevator, the LPV sliding mode activates and re-allocates the control signal to the remaining healthy elevators. For the sensor fault problem, an LPV sliding mode observer (SMO) has been developed in such a way that the effect of uncertainty on the fault reconstruction as well as the effect of the observer-plant mismatch due to uncertain scheduling parameters are minimised. Both schemes have been coded using the AIRBUS graphical library so that they can be directly implemented on an industrial flight control computer. Both schemes are validated using Monte-Carlo simulations for various load factor manoeuvres.

FrB3 S02

Fault Accommodation (Regular Session)

Chair: Witczak, Marcin	Univ. of Zielona Gora
Co-Chair: Ponsart, Jean-Christophe	Univ. De Lorraine

14:00-14:20 FrB3.1

Distributed Fault Diagnosis Using Minimal Structurally Over-Determined Sets: Application to a Water Distribution Network, pp. 791-798

Gupta, Vikas	UPC
Puig, Vicenç	Univ. Pol. De Catalunya (UPC)

In this paper, a distributed fault diagnosis algorithm for large scale systems has been proposed. This fault diagnosis approach starts from obtaining the minimal structurally over-determined (MSO) sets using the system model and the set of available sensors. These MSO sets are converted into a graph. This graph is further divided into various subgraphs using a partition algorithm. Each subgraph corresponds to a subsystem. From various subgraphs, different local fault signature matrices for various subsystems are obtained. Finally, using various local fault signature matrices, a set of diagnoser agents are created that allow the global diagnosis in a large scale system. The entire proposed distributed fault diagnosis approach is divided into five different blocks. In order to illustrate the application of the proposed approach, a case study based on the Barcelona drinking water network(DWN) is used.

14:20-14:40 FrB3.2

Sensor Location for Fault Accommodation Problem, pp. 799-804

Zhirabok, Alexey	Far Eastern Federal Univ
Shumsky, Alexey	Far Eastern Federal Univ
Zuev, Alexander	Inst. of Automationa and Control Processes FEB RAS
Bobko, Evgeniy	Far Eastern Federal Univ

The problem of sensor location for fault accommodation problem in nonlinear dynamic systems is considered. Solution of the problem is related to constructing the control law which provides full decoupling with respect to fault effects. The logic-dynamic approach is used to solve the problem. The main features of this approach are: it involves known linear methods that results in possibility to solve the fault accommodation problem by existing programming systems without using the symbolic software and it can be applied both to discrete-time and continuous-time systems. Existing conditions are formulated and calculating relations are given for the control law. Theoretical results are illustrated by example.

14:40-15:00 FrB3.3

Fault-Tolerant Control and Diagnosis for LPV System with H-Infinity Virtual Sensor, pp. 805-810

Luzar, Marcel	Univ. of Zielona Góra
Witczak, Marcin	Univ. of Zielona Gora

A robust H-infinity virtual sensor design is the aim of this paper. Such a sensor is used in a fault-tolerant control scheme which can be applied to wide class of non-linear systems. To deal with system non-linearity, a linear parameter-varying systems are considered. A robust virtual sensor is developed in such a way that the level of disturbances attenuation can be reached in relation to the fault estimation error. Using similar approach in the control scheme, the level of disturbances attenuation can be reached in relation to the tracking error. Finally, the design scheme ends with solving a number of linear matrix inequalities, which can be efficiently realised using i.e. numerical solvers implemented in Matlab. The empirical verification which demonstrates the performance of the presented approach is given in the final section of this paper.

15:00-15:20 FrB3.4

Virtual Actuator-Based FTC for LPV Systems with Saturating Actuators and FDI Delays, pp. 811-817

Rotondo, Damiano	Univ. Pol. De Catalunya (UPC)
Ponsart, Jean-Christophe	Univ. De Lorraine
Nejjari, Fatiha	Univ. Pol. De Catalunya
Theilliol, Didier	Univ. of Lorraine
Puig, Vicenç	Univ. Pol. De Catalunya (UPC)

The main contribution of this paper consists in solving the problem of fault tolerant control (FTC) for linear parameter varying (LPV) systems subject to actuator saturation and fault detection and isolation (FDI) delays. The FTC is based on virtual actuators that reconfigure the faulty plant to maintain the stability and to avoid the saturation of the actuators. On the other hand, a design methodology that provides the nominal output-feedback controller,

which maximizes the tolerated delay between the fault occurrence and its isolation, is developed. The design process consists in finding the optimal feasible solution to a finite set of linear matrix inequalities (LMIs). Finally, an example is used to illustrate the theoretical results.

15:20-15:40 FrB3.5

Stochastic Stabilization of a Discrete-Time Inhomogeneous Markov Jump Linear System with Interval Transition Probability Matrix, pp. 818-822

Chitraganti, Shaikshavali	Amrita Vishwa Vidyapeetham
Aberkane, Samir	Uhp, Nancy 1
Aubrun, Christophe	Univ. of Lorraine

Stochastic stabilization of discrete-time inhomogeneous Markov jump linear system is addressed for the case of transition probability matrix considered as an interval matrix. The approach involves representing the interval transition probability matrix as a convex combination of stochastic matrices, where stochastic stabilization can be addressed using stochastic version of Lyapunov's second method. The current approach is superior to the existing result for the same system, because of the ability to synthesize a state-feedback stabilizing controller. A vertical take-off and landing vehicle dynamics are utilized to illustrate the effectiveness of the results.

15:40-16:00 FrB3.6

Robust Adaptive Simultaneous State and Fault Estimation for Nonlinear Systems: Application to an Aerodynamical System (I), pp. 823-828

Buciakowski, Mariusz	Univ. of Zielona Góra
Witczak, Marcin	Univ. of Zielona Gora
Puig, Vicenç	Univ. Pol. De Catalunya (UPC)
Rotondo, Damiano	Univ. Pol. De Catalunya (UPC)
Nejjari, Fatiha	Univ. Pol. De Catalunya

The paper is concerned with the task of robust adaptive fault estimation and an unknown input decoupling for nonlinear systems using a quadratic boundedness approach. In particular, the fault estimation strategy and decoupling of the unknown input is based on an unknown input observer. The above methods are used to describe a robust fault and state observer problem by a set of linear matrix inequalities, which are efficiently handled by freely available solvers. The proposed approach allows obtaining a feasible set of joint state and fault estimation errors. Based on this knowledge, the confidence intervals of the system state and actuator fault, which supports diagnostic decisions, are proposed. The final part of the paper presents an illustrative example concerning an aerodynamical twin-rotor system, which exhibits the performance of the proposed approach.

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