CSNDD 2023

5th International Conference on Structural Nonlinear Dynamics and DiagnosisJ

May 15-17, Marrakech 2023, Morocco

Edited by:
M. Belhaq, M. Houssni & I. Kirrou

Group of Nonlinear Dynamics
Department of Physics
Faculty of Sciences Aïn chock

University Hassan II – Casablanca

CSNDD 2023

Conference on Structural Nonlinear Dynamics and Diagnosis

May 15–17, 2023, Marrakech

Booklet of Abstracts

Eds.: M. Belhaq, M. Houssni & I. Kirrou

Imprimé au Maroc.

The abstracts of the paper in this Booklet were set individually by the authors. Only minor typographical changes have been made by the local organizing committee.

Booklet of Abstracts

Preface

The last four versions of the International Conference on Structural Nonlinear Dynamics and Diagnosis (CSNDD 2012, CSNDD 2014, CSNDD 2016 and CSNDD 2018) organized by the nonlinear dynamic group of the University Hassan II in Casablanca were held in Marrakech (2012, 2016), Agadir (2014) and Tangier (2018). The meetings have attracted a representative international scientific community in nonlinear dynamics and control. More than 500 scientists from 30 countries attended the meetings. Several mini-symposia were organized in each conference by leading experts in nonlinear dynamics.

Following the success of the last versions of the conference, the nonlinear dynamic group of the University Hassan II in Casablanca is pleased to organize the 5^{th} version of the conference in Marrakech during the period of May 15-17, 2023.

The 4^{th} CSNDD 2018 was organized in memoriam of Ali H. Nayfeh, University Distinguished Professor Emeritus of nonlinear dynamics (1933-2017). Professor Nayfeh has been the honorary chairman of the CSNDD series and he greatly contributed to its success. He helped launch the first conference and he gave the first opening keynote.

The meeting aims to provide a forum for scientists in different branches of applied mathematics, physics and mechanics to present and discuss recent advances in theoretical, numerical and experimental techniques in nonlinear dynamics. Focuses are directed toward diverse topics, ranging from dynamical systems theory to different physical and engineering applications. The CSNDD 2023 covers a large field of nonlinear dynamics, including:

Applications of the method of multiple scales in engineering
Dynamics and multiphysics problems of micro- and nano-electro-mechanical systems
Analytical and semi-analytical methods in nonlinear dynamics
Deterministic, stochastic dynamics, control of vibrating systems
Vibration energy harvesters
Nonlinear dampers and vibration absorbers
Time series analysis methods for fault diagnosis and prognosis
Time delay in nonlinear systems
Linear and nonlinear vibrations of periodic and near-periodic lattices
Nonlinear phenomena of electrical power and energy circuits and systems
Nonlinear dynamics in rotating machinery
Structural health monitoring
Nonlinear vibrations of cables, beams, plates, shells, and innovative structures
Nonlinear dynamics of aeroelastic and hydroelastic systems
Nonlinear PDEs and their dynamics

It is a great privilege for the nonlinear dynamic group in Casablanca to host this 5^{th} version of the conference and to sustain such a high-level meeting in Morocco.

I am happy to report that the 5^{th} CSNDD 2023 has attracted more than 100 participants from more than 20 countries. Ten keynote lectures are invited.

On the behalf of the organizing committee, I would like to thank the Keynote lecturers, the mini-symposia organizers as well as reviewers for their precious help in maintaining a high-quality scientific program of the conference.

At the same time, I would like to thank all participants, PhD students, colleagues and friends who meaningfully helped with the organization.

On behalf of the CSNDD 2023 committees, welcome to Marrakech.

Enjoy a scientific stimulating and socially nice conference!

Mohamed Belhaq
CSNDD 2023 Chair

Contents

Preface v

Committees ix

Scientific Program xi

Conference Synthetic Timetable xiii

Technical Program xv

Abstracts 1

Plenary Lectures Abstracts 3

Orale presentations 9

MS1 Dynamics of Micro/Nano Electromechanical Systems and Energy Harvesting 11

MS2 Dynamics and Control of Oscillating Systems in Engineering Sciences 25

MS3 Dynamics of PDEs 39

MS4 Dynamics of Mechanical Structures and Structural Health Monitoring 45

MS5 Modeling, Control and Analysis of Switching Systems 53

MS6 Recent Advances in Nonlinear Dynamics 65

MS7 Time Delayed Systems 71

Index of Authors 77

Committees

Honorary Chairmen

Raouf A. Ibrahim	Wayne State University, USA
Sami F. Masri	University of Southern California, USA
Giuseppe Rega	University La Sapienza, Italy
Manuel G. Velarde	Universidad Complutense Madrid, Spain

Chairman

Mohamed Belhaq	Hassan II University, Casablanca, Morocco

Co-Chairmen

A. Azouani	University Sultan Moulay Sliman, Morocco
M. Hajj	Stevens Institute of Technology, USA
F. Lakrad	University Hassan II, Morocco
M. Younis	KAUST, Saudi Arabia

International Organizing Committee

N. Bouhaddi	University Bourgogne Franche-Comté, France
A. El Aroudi	Universitat Rovira i Virgili, Spain
M.N. Ichchou	École Centrale Lyon, France
J. Mahfoud	INSA Lyon, France

Local Organizing Committee

M. Aouadi	University Hassan II, Casablanca
A. Bichri	FST, University Moulay Ismail, Errachidia
A. Chtouki	FST, Hassan First University Settat
M. El Gadari	ENSAM, Moulay Ismail University, Meknes
Z. Ghouli	University Ibnou Zohr, Agadir
M. Hamdi	FST, Mohamed I University, Al Houceima
I. Kirrou	ESEFB, Hassan First University Settat

Advisory Board

Eihab Abdel-Rahman	University of Waterloo, Canada
Abdessattar Abdelkefi	New Mexico State University, USA
Balakumar Balachandran	University of Maryland, USA
Jose Balthazar	UNESP, Sao Paulo, Brazil
Olivier Bareille	Ecole Centrale de Lyon, France
Rhali Benamar	University Mohamed V, Morocco
Noureddine Bouhaddi	University of Franche-Comté, France
Kwok Chung	City University of Hong Kong, Hong Kong
Americo Cunha Jr.	Rio de Janeiro State University, Brazil
Mohammed Daqaq	New York University, Abu Dhabi, Dubai
Sergey Dmitriev	Russian Academy of Sciences, Ufa, Russia
Abdelkhalek El Hami	INSA, Rouen, France
Bernold Fiedler	Free University of Berlin, Germany
Emilio Freire	Universidad de Sevilla, Spain
Peter Hagedorn	Technische Universität Darmstadt, Germany
Muhammad Hajj	Stevens Institute of Technology, USA
Michael Hanss	University of Stuttgart, Germany
Jianliang Huang	Sun Yat-sen University, China
Mohamed Ichchou	Ecole Centrale de Lyon, France
Elzbieta Jarzebowska	Warsaw University of Technology, Poland
Najib Kacem	University of Franche-Comté, France
Ivana Kovacic	University of Novi Sad, Serbia
Cedrick Kwuimy	University of Cincinnati, USA
Alain Le Bot	Ecole Centrale de Lyon, France
Stefano Lenci	Polytechnic University of Marche, Italy
Jarir Mahfoud	INSA de Lyon, France
Fehmi Najar	Tunisia Polytechnic School, Tunisia
Chandrashekar Nataraj	Villanova University, USA
Hassen Ouakad	Sultan Qaboos University, Oman
Joel Perret-Liaudet	Ecole Centrale de Lyon, France
Richard Rand	Cornell University, USA
Mikhail Semenov	Voronezh State University, Russia
Ferdinand Verhulst	University of Utrecht, The Netherlands
Jerzy Warminski	Lublin University of Technology, Poland
Mohammad Younis	KAUST, Saudi Arabia
Weidong Zhu	University of Maryland, USA
Daniele Zulli	University of l'Aquila, Italy

Scientific Program

The scientific program includes:

- Plenary Lectures
- Minisymposia Sessions on pre-defined topics

The minisymposia are organized through parallel lecture sessions. As a rule, the available time slot per lecture presentation is 20 min, including discussion.

Plenary Lectures

- Muhammad R. Hajj, Stevens Institute of Technology, USA
  Physics-informed neural networks for system identification of fluid-structure interactions
- Jürgen Kurths, Potsdam Institute for Climate Impact Research, Germany
  Exploring predictability of extreme climate events via a complex network approach
- Eihab Abdel-Rahman, University of Waterloo, Canada
  Noise-driven sensors
- Mohammed F. Daqaq, Clemson University, USA/NYU Abu Dhabi, UAE
  Origami inspired design of nonlinear springs with tunable characteristics
- Ivana Kovacic, University of Novi Sad, Serbia
  Bending and unbending a backbone curve of nonlinear oscillators
- Bernold Fiedler, Free University Berlin, Germany
  Simultaneous noninvasive stabilization of infinitely many, large and rapid Duffng oscillations, by delayed feedback control
- Hatem Zaag, CNRS & University Sorbonne Paris Nord, France
  On degenerate blow-up profiles for nonlinear parabolic equations
- Ferdinand Verhulst, University of Utrecht, The Netherlands
  Emergence and approximation of tori
- Grzegorz Litak, Lublin University of Technology, Poland
  Identification of failures in the dynamical response of machines

Minisymposia and chairs

- **MS1. Dynamics of Micro/Nano Electromechanical Systems and Energy Harvesting**
  M.F. Daqaq (UAE), F. Najar (Tunisia), N. Bouhaddi (France), L. Kloda (Poland)
- **MS2. Dynamics and Control of Oscillating Systems in Engineering Sciences**
  M. Semenov (Russia), I. Kovacic (Serbia), A. Nabarrete (Brazil)
- **MS3. Dynamics of PDEs**
  H. Zaag (France), N. Nouaili (France), C. Collot (France), F. Hamel (France)

- **MS4. Dynamics of Mechanical Structures and Structural Health Monitoring**
  J. Latalski (Poland), D. Gaska (Poland)
- **MS5. Modeling, Control and Analysis of Switching Systems**
  A. El Aroudi (Spain), K. Mandal (Spain)
- **MS6. Recent Advances in Nonlinear Dynamics**
  E. Ponce (Spain), F. Torres (Spain)
- **MS7. Time Delayed Systems**
  G. Litak (Poland)

Conference Synthetic Timetable

Registration (Adam Park Hotel, Marrakech)

– Sunday, May 14, 16:00–20:00

Monday, May 15, 2023

08:00–09:00	***Registration***
09:00–09:15	Opening Ceremony
09:15–09:45	Opening Plenary Lecture 1: Muhammad Hajj
09:45–10:15	Plenary Lecture 2: Jürgen Kurths
10:15–10:50	***Conference Photo and Coffe Break***
10:50–11:20	Plenary Lecture 3: Eihab Abdel-Rahman
11:20–11:50	Plenary Lecture 4: Mohammed F. Daqaq
11:50–12:20	Plenary Lecture 5: Ivana Kovacic
12:30–14:00	***Lunch***
14:00–15:45	Minisymposia (Parallel Sessions: S1, S2, S3)
15:45–16:15	***Coffee Break***
16:15–18:00	Minisymposia (Parallel Sessions: S1, S2, S3)

Tuesday, May 16, 2023

09:00–09:30	Plenary Lecture 6: Bernold Fiedler
09:30–10:00	Plenary Lecture 7: Hatem Zaag
10:00–10:30	***Coffee Break***
10:30–12:15	Minisymposia (Parallel Sessions: S1, S2, S3)
12:30–14:00	***Lunch***
14:00–15:40	Minisymposia (Parallel Sessions: S3, S4, S5)
15:40–16:10	***Coffee Break***
16:10–18:00	Minisymposia (Parallel Sessions: S4, S5)
20:00	***Conference Dinner***

Wednesday, June 17, 2023

08:30–10:15	Minisymposia (Parallel Sessions: S6, S7)
10:15–10:45	***Coffee Break***
10:45–11:15	Plenary Lecture 8: Ferdinand Verhulst
11:15–11:45	Plenary Lecture 9: Grzegorz Litak
11:50	***Closing***
12:30–14:00	***Lunch***

Technical Program

Sunday, May 14

16:00-20:00 Registration at Adam Park Hotel

Monday, May 15

08:00-09:00 Registration at Adam Park Hotel

09:00-09:15 Opening Ceremony **Room:** Louka

09:15-10:15 Opening Plenary Lectures **Room:** Louka

Chairman: F. Verhulst

09:15-09:45 Muhammad Hajj, *Stevens Institute of Technology, USA*: ***Physics-informed neural networks for system identification of fluid-structure interactions***

09:45-10:15 Jürgen Kurths, *Potsdam Institute for Climate Impact Research, Germany*: ***Exploring predictability of extreme climate events via a complex network approach***

10:15-10:50 Coffee Break & Conference Photo

10:50-12:20 Plenary Lectures **Room:** Louka

Chairman: M. R. Hajj

10:50-11:20 Eihab Abdel-Rahman, *University of waterloo, Canada*: ***Noise-driven sensors***

11:20-11:50 Mohammed F. Daqaq, *Clemson University, USA/NYU Abu Dhabi, UAE*: ***Origami inspired design of nonlinear springs with tunable characteristics***

11:50-12:20 Ivana Kovacic, *University of Novi Sad, Serbia*: ***Bending and unbending a backbone curve of nonlinear oscillators***

12:30-14:00 Lunch at Adam Park Hotel

14:00-15:45 Parallel Sessions

- **S1:** Dynamics of Micro / Nano Electromechanical Systems and Energy Harvesting
- **S2:** Dynamics and Control of Oscillating Systems in Engineering Sciences
- **S3:** Dynamics of PDEs

15:45-16:15 Coffee Break

16:15-18:00 Parallel Sessions

- **S1:** Dynamics of Micro / Nano Electromechanical Systems and Energy Harvesting
- **S2:** Dynamics and Control of Oscillating Systems in Engineering Sciences
- **S3:** Dynamics of PDEs

Tuesday, May 16

09:00-10:00 Plenary Lectures **Room:** Louka

Chairmen: H. Zaag & B. Fiedler

09:00-09:30 Bernold Fiedler, *Free University of Berlin, Germany:* ***Simultaneous non-invasive stabilization of infinitely many, large and rapid Duffing oscillations, by delayed feedback control***

09:30-10:00 Hatem Zaag, *CNRS & University Sorbonne Paris Nord, France:* ***On degenerate blow-up profiles for nonlinear parabolic equations***

10:00-10:30 Coffee Break

10:30-12:00 Parallel Sessions

- **S1:** Dynamics of Micro / Nano Electromechanical Systems and Energy Harvesting (Cont.)
- **S2:** Dynamics and Control of Oscillating Systems in Engineering Sciences (Cont.)
- **S3:** Dynamics of PDEs (Cont.)

12:30-14:00 Lunch at Adam Park Hotel

14:00-15:40 Parallel Sessions

- **S4:** Dynamics of Mechanical Structures and Structural Health Monitoring
- **S5:** Modeling, Control and Analysis of Switching Systems
- **S3:** Dynamics of PDEs (Cont.)

15:40-16:10 Coffee Break

16:10-18:00 Parallel sessions

- **S4:** Dynamics of Mechanical Structures and Structural Health Monitoring
- **S5:** Modeling, Control and Analysis of Switching Systems

Wednesday, May 17

08:30-10:15 Parallel Sessions

- **S6:** Recent Advances in Nonlinear Dynamics
- **S7:** Time Delayed Systems and Quasiperiodic Systems

10:15-10:45 Coffee Break

10:45-11:45 Plenary Lectures **Room:** **Louka**

Chairman: **J. Kurths & E. Jarzebowska**

10:45-11:15 Ferdinand Verhulst, *University of Utrecht, The Netherlands:* ***Emergence and approximation of tori***

11:15-11:45 Grzegorz Litak, *Lublin University of Technology, Poland:* ***Identification of failures in the dynamical response of machines***

11:45 Closing **Room: Louka**

12:00 Lunch at Adam Park Hotel

Oral presentations

Monday program

Physics-informed neural networks for system identification of fluid-structure interactions

Presented by **M. Hajj** • **Room:** Louka 3

Exploring predictability of extreme climate events via a complex network approach

Presented by **J. Kurths** • **Room:** Louka 3

Noise-driven sensors

Presented by **E. Abdel-Rahman** • **Room:** Louka 4

Origami inspired design of nonlinear springs with tunable characteristics

Presented by **M.F. Daqaq** • **Room:** Louka 5

Bending and unbending a backbone curve of nonlinear oscillators

Presented by **I. Kovacic** • **Room:** Louka 5

Dynamics of the energy harvesting system for a fixed, tuned and cyclically variable potential barrier

Presented by **D. Gaska** • **Room:** Tichka 11

Nonlinear analysis of a rotating double pendulum energy harvester for tire pressure monitoring systems

Presented by **E. Zaouali** • **Room:** Tichka 12

Harvesting energy with two coupled horizontal beams

Presented by **P. Wolszczak** • **Room:** Tichka 12

Dynamic mode decomposition for vortex-induced vibration energy harvesting

Presented by **L.S. Araújo** • **Room:** Tichka 12

Nonlinear vibration energy harvesting based on weakly coupled biperiodic oscillators

Presented by S. Dowlati • Room: Tichka 13

Methodological description of obtaining and stabilizing solitons in macromechanical damped resonators subjected to a base acceleration

Presented by A. Barbosa • Room: Tichka 14

An origami inspired cellular cushion material

Presented by S. Khazaaleh • Room: Tichka 15

A reduced-order modeling approach for nonlinear vibration analysis of piezoelectric micro-electro-mechanical systems

Presented by J.F. Deü • Room: Tichka 15

A comparative study of resonant drive techniques

Presented by E.M. Abdel-Rahman • Room: Tichka 16

Performance analysis of a bi-stable point wave energy absorber under random waves

Presented by M. Khasawneh • Room: Tichka 18

A study of mathematical model of AFM with casimir force by means of averaging method

Presented by G.A. Kurina • Room: Tichka 18

On dynamical behavior and control of microscopy atomic force: a review

Presented by I. Kirrou • Room: Tichka 19

Metamodeling and sensitivity analysis of a piezoelectric energy harvester based on polynomial chaos expansions

Presented by W. Larbi • Room: Tinmel 25

Nonlinear modelling and control of satellite with propellant sloshing dynamics

Presented by E. Jarzebowska • Room: Tinmel 26

A hybrid, low-level behavior-based steering as an alternative for computationally demanding approaches

Presented by A. Chelchowski • Room: Tinmel 27

Nonlinear model fitting for sloshing using an equivalent pendulum mechanical model

Presented by K. Cichorek • Room: Tinmel 28

Bifurcation analysis of a parametrically excited nonlinear micro-ring gyroscope

Presented by A.A. Barakat • Room: Tinmel 29

Galloping vibration energy harvesting using a van der Pol circuit

Presented by M. Hamdi • Room: Tinmel 30

Widening of anti-resonances by increasing amplitude of parametric excitation

Presented by Z. Kraus • Room: Tinmel 30

Dynamics modeling of an underwater glider based on the Boltzmann-Hamel equations approach with the relaxed symmetry constraint

Presented by Z. Kostka • Room: Tinmel 31

A novel pseudorandom number generator based on a simple oscillatory system

Presented by M.E. Semenov • Room: Tinmel 32

Nonlinear piezoelectric vibration energy harvesting of a cantilever beam using homotopy analysis method

Presented by A. Nabarrete • Room: Tinmel 33

Nonlinear model of disturbances acting on spacecraft attitude during a tubular boom deployment process

Presented by M. Kukuryka • Room: Tinmel 34

Soliton resolution for the radial quadratic wave equation in six space dimensions

Presented by C. Collot • Room: Louka 39

Logarithmic corrections in kinetic reaction transport waves

Presented by E. Bouin • Room: Louka 40

Large-time dynamics of solutions of reaction-diffusion equations in $\mathbb{R}^N$ with general initial support

Presented by F. Hamel • Room: Louka 40

Near-resonance approximation of rotating Navier-Stokes equations

Presented by B. Cheng • Room: Louka 40

Scattering of solutions of the inhomogeneous nonlinear Schrödinger equation
Presented by S. Tayachi • Room: Louka 40

On a data assimilation algorithm for tumor growth
Presented by S. Trabelsi • Room: Louka 41

Tuesday program

Simultaneous noninvasive stabilization of infinitely many, large and rapid Duffing oscillations, by delayed feedback control
Presented by B. Fiedler • Room: Louka 6

On degenerate blow-up profiles for nonlinear parabolic equations
Presented by H. Zaag • Room: Louka 6

Energy harvesting in a system whose energy potential was mapped by the hyperbolic Fibonacci function
Presented by J. Margielewicz • Room: Tichka 20

Modal interaction of MEMS shallow arch under out-of-plane fringing-fields
Presented by F. Najar • Room: Tichka 21

MEMS electrostatic kinetic energy harvester with double capacitor bennet doubler conditioning circuit and autonomous buck DC/DC converter
Presented by H. Samaali • Room: Tichka 22

Electromechanical modeling and parametric analysis of L-shaped-based bending-torsion piezoelectric energy harvester
Presented by S. Baroudi • Room: Tichka 23

Optimizing power output in combined galloping and vortex-induced vibrations-based electromagnetic energy harvesting
Presented by Y. El Moussati • Room: Tichka 23

Sampled-based methods used in an analysis of a multistable dynamical systems
Presented by P. Perlikowski • Room: Tinmel 35

Dynamic modelling and diagnosis of a high contact ratio gear
Presented by O.D. Mohammed • Room: Tinmel 35

Distributed hysteresis properties in the Euler-Bernoulli beam
Presented by M.E. Semenov • Room: Tinmel 36

Remaining useful life estimation framework for maintenance improvement of rotor dynamic systems with crack propagation
Presented by A. Nabarrete • Room: Tinmel 37

Effect of periodic vibrations with frequency modulation on convective instability in porous media
Presented by K. Allali • Room: Tinmel 38

Mathematical study of the spread and blockage of an inflammatory disease
Presented by S. Latrach • Room: Louka 42

Singularities in the complex Ginzburg Landau equation
Presented by N. Nouaili • Room: Louka 43

Parameter recovery for the KdV equations via continuous data assimilation
Presented by M. Azoua • Room: Louka 43

Oscillatory dynamics for evolution equations using Favard's theory in uniformly convex Banach spaces
Presented by K. Ezzinbi • Room: Louka 43

Blow up of p-Laplacian type heat equation with nonlinear source term
Presented by Y. Abouelhanoune • Room: Louka 44

Optimizing the bandgap region of a meta-beam with bistable resonators
Presented by J.P. Norenberg • Room: Tichka 45

Time integration of constrained multi-catenary systems
Presented by D. Sedlar • Room: Tichka 46

Reliability analysis of mechanical structure with surrogate model
Presented by L. Shao • Room: Tichka 47

Multi-scale dynamics and nonlinear eigenvalue problem of heterogeneous metastructures using a wave finite element scheme and modal strain energy method
Presented by D. Cui • Room: Tichka 47

Nonlinear vibration of thin imperfect plate by an asymptotic numerical method
Presented by L. Benchouaf • Room: Tichka 48

Parametric resonances and stability of the rotating blade subjected to base excitation
Presented by J. Latalski • Room: Tichka 49

Enhanced group analysis and analytical solutions for the mode shapes of non-uniform rods
Presented by A.W. Nunes • Room: Tichka 49

Nonlinear dynamics and energy harvesting of multi-stable cantilever shells with embedded piezoelectric patch
Presented by L. Kloda • Room: Tichka 50

Piecewise integrable neural network: an interpretable chaos identification framework
Presented by N. Novelli • Room: Tichka 51

Linear and nonlinear vibration biodynamic models of hand-arm systems
Presented by F. Lakrad • Room: Tichka 52

Stadium roof structure analysis in dynamics
Presented by P. Rosko • Room: Tichka 52

Backstepping control of interleaved double dual boost converter for renewable energy system
Presented by F. Ait bellah • Room: Tinmel 53

A cascaded controller design for grid connected PV system through a double stage based on SIDO converter
Presented by O. Arich • Room: Tinmel 54

Global dynamical analysis of a boost converter with a constant power load and actively damped by a series loss free resistor
Presented by L. Benadero • Room: Tinmel 55

Stabilization of a photovoltaic power source interfacing a current-mode-controlled SEPIC converter with MPPT using piecewise quadratic slope compensation
Presented by K. Mandal • Room: Tinmel 55

Nonlinear control of grid connected PV systems using modular multilevel converter
Presented by A. El Boudali • Room: Tinmel 57

Backstepping based control and stability analysis for single stage grid connected photovoltaic system through half bridge power inverter
Presented by N. Hourri • Room: Tinmel 58

Interaction of multiple timescale dynamics of interconnected subsystems in electric vehicle
Presented by K. Mandal • Room: Tinmel 58

Exact numerical method for predicting instabilities of switching converters with constant power load
Presented by A. El Aroudi • Room: Tinmel 60

Shunt active power filter based on the NPC structure : harmonics neutralization and reactive power injection
Presented by O. Mikram • Room: Tinmel 61

Backstepping based control and stability analysis for three-phase four-wire shunt active power filter
Presented by K. Naftahi • Room: Tinmel 61

The impact of high-frequency excitation on a bistable energy harvesting system
Presented by Z. Ghouli • Room: Tinmel 63

Wednesday program

The emergence and approximation of tori
Presented by F. Verhulst • Room: Louka 8

Identification of failures in the dynamical response of machines
Presented by G. Litak • Room: Louka 8

Real chaos, and complex time
Presented by B. Fiedler • Room: Louka 65

Dynamics and bifurcation of the Rattleback, a nonholonomic system
Presented by J. Galán-Vioque • Room: Louka 65

Normal form around a double invisible tangency point
Presented by F. Torres • Room: Louka 66

Some bifurcations from periodic orbits at infinity in 3D piecewise linear systems
Presented by E. Ponce • Room: Louka 67

Saddle-node bifurcation curve and hidden attractors in 4D memristor oscillator
Presented by J. Ros • Room: Louka 68

Torsion-bending coupling in non-linear model order reduction
Presented by L. Silveira • Room: Louka 69

Design of a full-scale wave energy converter: challenges and technological solutions
Presented by M. Hajj • Room: Tinmel 71

A novel algorithm for dynamical integrity estimation in time delayed systems
Presented by B. Szaksz • Room: Tinmel 71

Kalman filtering of stochastic laser dynamics: parameter and state space estimation from time-delayed measurements
Presented by L. Mertenskötter • Room: Tinmel 72

Quasiperiodic birhythmicity in a multicycle van der Pol oscillator with modulated time delay
Presented by M. Hamdi • Room: Tinmel 73

Incremental harmonic balance with two time scales for a nonlinear quasi-periodic Mathieu equation
Presented by B.X. Zhang • Room: Tinmel 74

Quasiperiodic energy harvesting in a delayed Rayleigh-Duffing harvester device near primary and secondary resonances
Presented by I. Kirrou • Room: Tinmel 74

Abstracts

Plenary Lectures Abstracts

Scheduled:				
	Monday	*9:50–12:20*	Adam Park Hotel	**Room Louka**

Physics-informed neural networks for system identification of fluid-structure interactions

Mon.
09:15–09:45
R Louka

M. Hajj , M. Ayyad , A. Ahmed

Department of Civil, Environmental and Ocean Engineering Stevens Institute of Technology, Hoboken, NJ

Fluid-structure interaction (FSI) problems are characterized by the interdependence of the fluid motion and structural response. Advances in computing speed and storage capacity have enabled the development and implementation of high-fidelity algorithms and simulations that capture significant physical features of complex FSI problems. Still, such simulations may not discern underlying phenomena that are usually interrelated in a complex manner, which makes it difficult to characterize the relevant causal mechanisms. Besides, extensive computational resources and time associated with the implementation of high-fidelity simulations usually limit the number of configurations for design and optimization purposes or effective control strategies.

Physics governing fluid structure interactions are usually represented by nonlinear partial differential equations that can yield complex responses. Additional complexities include memory or future effects. For example, the lift on flapping wing depends on the history of the flapping motion and generated wake. As another example, wave excitation and radiation damping forces on floating or submerged structures are represented by convolution integrals that respectively account for future wave conditions and the motion's history. Such integrals require storage and updating of the history of the motions at every time step, which presents a significant computational burden, especially in problems involving different degrees of freedom or motions. To address these issues, simplifying assumptions are usually made to develop reduced-order models that are capable of characterizing relevant physical phenomena while yielding important response characteristics.

In contrast to computationally expensive brute-force high-fidelity simulations, physics informed neural networks (PINN) can leverage deep neural networks capabilities to infer hidden/latent information of interest from scattered data in time and space. In the presentation, we implement a data-driven system identification (discovery) of different examples of fluid structure interactions. Specifically, data training is performed to identify the coefficients in physics or phenomena-based governing equations of these examples, which include integro-differential equations, as required for specific applications.

Exploring predictability of extreme climate events via a complex network approach

Mon.
09:45–10:15
R Louka

J. Kurths

Potsdam Institute for Climate Impact Research & Humboldt University, Berlin

The Earth system is a very complex and dynamical one basing on various feedbacks. This makes predictions and risk analysis even of very strong (sometime extreme) events as floods, landslides, heatwaves, earthquakes etc. a challenging task. Here I will introduce a recently developed approach via complex networks mainly to analyze strong climate events. It is shown how this new method can reveal new insights into the underlying mechanisms which enables us to construct substantially better predictions, in particular of strong rainfall in Bolivia, of the onset of the Indian Summer Monsoon and El Nino strength.

Bibliography

[1] Boers, N., B. Bookhagen, N. Marwan, J. Kurths, and J. Marengo, Geophys. Res. Lett. 40, 4386 (2013)
[2] N. Boers, B. Bookhagen, H.M.J. Barbosa, N. Marwan, J. Kurths, and J.A. Marengo, Nature Communications 5, 5199 (2014)
[3] N. Boers, R. Donner, B. Bookhagen, and J. Kurths, Climate Dynamics 45, 619 (2015) J. Runge et al., Nature Communications 6, 8502 (2015)
[4] V. Stolbova, E. Surovyatkina, B. Bookhagen, and J. Kurths, Geophys. Res. Lett. (2016)
[5] D. Eroglu, F. McRobies, I. Ozken, T. Stemler, K. Wyrwoll, S. Breitenbach, N. Marwan, J. Kurths, Nature Communications 7, 12929 (2016)
[6] B. Goswami, N. Boers, A. Rheinwalt, N. Marwan, J. Heitzig, S. Breitenbach, J. Kurths, Nature Communications 9, 48(2018) N. Boers,
[7] B. Goswami, A. Rheinwalt, B. Bookhagen, B. Hoskins, J. Kurths, Nature 566, 373 (2019).

Noise-driven sensors

Mon.
10:50–11:20
R Louka

A. Elhady[1], Y. Qiao[2], M. Arabi[3], W. Zhang[2], E.M. Abdel-Rahman[1]

[1] *Department of Systems Design Engineering, University of Waterloo, Waterloo, ON, Canada*
[2] *School of Mechanical Engineering, Shanghai Jiao Tong University, Shanghai, China*
[3] *Applied Science University, Kingdom of Bahrain*

Intrinsic noise processes impose fundamental limitations upon the signal-to-noise ratio (SNR) of MEMS & NEMS sensors. Typically, noise suppression measures or higher actuation levels have been deployed to increase the SNR. The former approach imposes stringent operating conditions, such as working in vacuum and at ultra-low temperatures. The latter is limited by the power handling capacity of the sensor.
We propose a paradigm shift that turns the intrinsic thermal noise from an impediment to a constituent of the sensor by adopting it as the driving force. A resonant sensor is deployed to 'color' the white thermal bath energy, thereby creating features that can be

used for sensing. The fundamental challenge to this approach is the fact that the driving force is phase incoherent which precludes the use of traditional phase-locked detection mechanisms.
As a proof-of-concept, we present noise-driven sensors that operate without external actuation and embody detection mechanisms immune to phase incoherence. The first measures the area under the power spectral density to estimate a stimulus that impacts the level of excitation (thermal noise). The second observes quantitative changes in the magnitude of the resonant peak in response to a stimulus that affects the sensor damping or excitation levels, such as temperature or pressure. The third observes shifts in the resonant frequency in response to a stimulus that affects the structural stiffness or mass of the sensor.
We demonstrate noise-driven pressure and temperature sensors. Our design paradigm offers an opportunity to deliver practical NEMS sensors that function at room temperature and under ambient pressure.

Origami inspired design of nonlinear springs with tunable characteristics

Mon.
11:20–11:50
R Louka

M.F. Daqaq

Engineering Division New York University, Abu Dhabi

Origami-inspired design has recently emerged as a major thrust area of research in the fields of science and engineering. One such design utilizes Kresling pattern origami to construct nonlinear springs that can act as mechanical bit memory switches, wave guides, fluidic muscles, and vibration isolators. In this presentation, we report on the design of such springs and the characterization of their static equilibria and bifurcations as the geometric parameters of the Kresling pattern are varied. To this end, we develop a nonlinear model of the spring which assumes that the different panels can be represented by truss elements which undergo axial deformation and buckling. The model accounts for the rotary stiffness of the creases, and self-avoidance of the panels due to panel contact at small angles. Results of the modeling effort are validated against experimental data obtained using paper-based springs demonstrating the ability of the model to predict the qualitative and quantitative trends of the experiments. Based on these findings, a rubber-based springs is designed and, for the first time, successfully 3-D printed. This new concept can open new avenues for the design of nonlinear tunable springs.

Bending and unbending a backbone curve of nonlinear oscillators

Mon.
11:50–12:30
R Louka

I. Kovacic

Centre for Vibro-Acoustics Systems and Signal Processing CEVAS, Faculty of Technical Sciences, University of Novi Sad, Serbia

A backbone curve is a graphical presentation of the relationship between the natural frequency of an oscillator and its amplitude. A linear oscillator has a straight-line backbone curve as its natural frequency is amplitude-independent. Nonlinear oscillators, in general, have the frequency that changes with their amplitude, which implies that their backbone curve is not straight, but bent. When these oscillators are externally excited, the primary resonance response around the backbone curve is associated with certain nonlinear phenomena, such as multiple coexisting response outcomes and sudden discontinuous changes of the amplitude, which can be unwanted in practical applications. The overview of the possible shapes of backbone curves is presented, including the case when multiple banding of the backbone curve is created. The insight into the corresponding dynamics is provided. It is also shown how one can use nonlinearity to unbend a backbone curve of nonlinear oscillators to make it be straight as in the linear oscillator.

Scheduled:

Tuesday *09:00–10:00* Adam Park Hotel **Room Louka**

Simultaneous noninvasive stabilization of infinitely many, large and rapid Duffing oscillations, by delayed feedback control

Tue.
09:00–09:30
R Louka

B. Fiedler

Institute of Mathematics Free University of Berlin, Germany

For many decades it has been know that stable periodic solutions in scalar first order delay equations with monotone feedback are neces-sarily slowly oscillating. Occasionally, and in contrast to the first order case, it has been remarked how scalar second order delay equations may well exhibit stable rapid oscillations.

At the previous Tangier CSNDD2018, Richard Rand suggested how the delayed Duffing oscillator might exhibit an infinity of stable rapidly oscillating solutions, with amplitudes tending to infinity and periods tending to zero. We pursue the mathematical basis for this remarkable phenomenon, which also arises in the desirable context of linear delayed noninvasive feedback control of the standard Duffing oscillator.

Results are based on joint work with Lopez-Nieto, Rand, Sah, Schneider, Shayak, and de Wolff.

On degenerate blow-up profiles for nonlinear parabolic equations

Tue.
09:30–10:00
R Louka

H. Zaag

CNRS & University Sorbonne Paris Nord, France

Since the pioneering work of Fujita in 1966, Nonlinear Parabolic equations are known to have finite time blowing up solutions. Given such a solution, the blow-up behavior has attracted a lot of attention since the 1980’, with the introduction of the notion of "blow-up profile". In particular, Herrero and Velázquez showed in the early 1990’ that the blow-up profile should obey some well specified set of possible forms, based on Hermite polynomials.

In one space dimension, examples of blow-up solutions for all the possible forms were constructed. In higher space dimensions, apart from some trivial cases coming from the 1-d case, the question remained open so far.
In this talk, we positively answer this question, for a large class of possible forms of blow-up profiles, among them many degenerate cases, which are much harder to handle. In particular, in the Sobolev subcritical range, we construct a solution which blows up in finite time only at the origin, with a completely new blow-up profile, which is cross-shaped. This is a joint work with Frank Merle.

Scheduled:

Wednesday *10:15–10:45* Adam Park Hotel **Room Louka**

The emergence and approximation of tori

Wed.
10:45–11:15
R Louka

F. Verhulst

Mathematical Institute University of Utrecht The Netherlands

A remarkable aspect of the system Sprott A and families of invariant tori, known earlier inconservative systems. We can link the tori bifurcation phenomenon to time-reversal and canards.
For more general isolated tori in dissipative systems we can develop an integral iteration scheme based on contraction quasi priodic secularity conditions. The technique leads to condition for the presence of tori and possibly other invariant manifolds. The general idea can be illustrated by instance coupled Van der Pol-equations.

Identification of failures in the dynamical response of machines

Wed.
11:15–11:45
R Louka

G. Litak

Department of Applied Mechanics Lublin University of Technology, Poland

Various methods would be introduced and applied to the simulated experimental data. For periodical responses, I would suggest the application of mathematical filters, especially, using nonlinear dynamics. A tested signal (measured or simulated) would be the input to the filter model while its dynamical response would give more clear information on investigated system state. Additionally, some model disturbances (noise or harmonic) will be considered and controlled. Finally, recurrence statistics will be applied.

Orale presentations

MS 1

Dynamics of Micro/Nano Electromechanical Systems and Energy Harvesting

Chairmen: *M. Daqaq* UAE, *F. Najar* Tunisia, *N. Bouhaddi* France, *L. Kloda* Poland

Scheduled:

Monday	*14:00–15:45*	Adam park Hotel	**Room Tichka**
Monday	*16:15–18:00*	Adam park Hotel	**Room Tichka**
Tuesday	*10:30–12:15*	Adam park Hotel	**Room Tichka**

Dynamics of the energy harvesting system for a fixed, tuned and cyclically variable potential barrier

Mon.
14:00–14:20
R Tichka

D. Gaska[1], J. Margielewicz[1], S. Bucki [1], G. Litak[2], P. Wolszczak[2]

[1] *Silesian University of Technology, Faculty of Transport and Aviation Engineering, Katowice Poland*
[2] *Lublin University of Technology, Faculty of Mechanical Engineering, Lublin, Poland*

For over 20 years, we have been dealing with interest in recovering energy from various sources previously considered ineffective. Such a source may be, for example, vibrations of various machine elements. The amount of harvested energy is small, but it is sufficient to power simple measurement and data transmission systems. The significant development of systems for energy recovery from vibrations took place thanks to the introduction of non-linear characteristics that allow for effective energy harvesting in a wider frequency range, and not only in resonance. Typical energy harvesters are based on a cantilever beam on which a piezoelectric transducer is glued, while non-linearities are introduced by a system of permanent magnets [1], spring elements, beam construction, etc.

In paper we compare the dynamics of kinetic energy harvester with the additional possibility of a cyclically variable potential barrier in the nonlinear resonator and typical energy harvester with fixed positions of permanent magnets. In order to improve the efficiency of the energy harvester, we numerically test the possibility of using cyclical or abrupt changes in the potential characteristics parameters. We analyse the voltage output efficiency for various frequencies of both the harmonic excitations and the potential barrier change. The research was motivated by various publications on the modification of the potential function during the operation of the energy harvester [2]. However, none of them assumed a sudden and cyclical change. Particular attention was paid to the identification of zones in which chaotic movement takes place and the assessment of co-existing solutions. The results of numerical calculations will be depicted in the form of multi-coloured distribution maps of the largest Lyapunov exponent and a diagram showing the number of coexisting solutions.

Acknowledgement: This research was funded by National Science Centre, Poland under the project SHENG-2, No. 2021/40/Q/ST8/00362.

Bibliography

[1] S. Zhou, M. Lallart, and A. Erturk, Multistable vibration energy harvesters: Principle, progress, and perspectives, J. Sound Vib., p. 116886, Mar. 2022, doi: 10.1016/J.JSV.2022.116-886.

[2] P. Sosna, O. Rubes, and Z. Hadas, Verification and analysis of advanced tuneable nonlinear vibration energy harvester, Mech. Syst. Signal Process., vol. 189, p. 110096, Apr. 2023, doi: 10.1016/J.YMSSP.2023.110096.

Nonlinear analysis of a rotating double pendulum energy harvester for tire pressure monitoring systems

Mon.
14:20–14:40
R Tichka

E. Zaouali[1], F. Najar [2], N. Kacem [3], E. Foltete[3]

[1] *Applied Mechanics and Systems Research Laboratory, Ecole Polytechnique de Tunisie, University of Carthage, Tunisia*

[2] *Department of Mechanical Engineering, College of Engineering at Al Kharj, Prince Sattam bin Abdulaziz University, Al Kharj, Saudi Arabia*

[3] *Department of Applied Mechanics, FEMTO-ST Institute, University of Franche-Comté, UMR 6174, CNRS/UFC/ENSMM/UTBM, Besançon, France*

Tire pressure monitoring system (TPMS) are mandatory in all new commercial vehicles. They allow a constant measure of the pressure inside the tires for security reasons. Adding an energy harvesting system to this device allow the reduction of costly and complicated maintenance operation necessary to because of energy shortage. It turns out that double pendulum based energy harvester coupled to an electromagnetic generator could be a convenient solution to power TPMS and avoid repetitive maintenance intervention. The double pendulum is subjected in this case to a base rotation corresponding to the tire motion. The nonlinear analysis of the device will help to understand how it can be optimized to this kind of complicated motion under internal and parametric resonances. The method of multiple scales will be used to examine the nonlinear dynamics of the system, including the electromagnetic transduction mechanism. Frequency and force response curves will help understand the dynamic response of the device under different excitation conditions.

Harvesting energy with two coupled horizontal beams

Mon.
14:40–15:00
R Tichka

P. Wolszczak

Faculty of Mechanical Engineering, Lublin University of Technology, Lublin, Poland

We present the study of a system of two flexible mechanically or magnetically coupled beams. Piezoelements are placed on the beams, which convert the kinetic energy of vibrations into electrical energy. The system is tested in order to develop an energy harvester. Beam coupling causes a nonlinearity phenomenon that extends the effective frequency range. Various beam coupling systems were investigated, and the records were statistically analyzed in the time and frequency domains.

Dynamic mode decomposition for vortex-induced vibration energy harvesting

Mon.
15:00–15:15
R Tichka

L.S. Araújo[1], A. Cunha Jr[2]

[1] *São Paulo State University, Brazil*
[2] *Rio de Janeiro State University, Brazil*

The motion induced by the vortex shedding along a structure is usually considered a possible damage factor. Nevertheless, this energy can be helpful as a renewable energy source. Therefore, this work studies the dynamical behavior of an energy harvesting system focused on converting the energy from the Vortex-Induced Vibration (VIV) phenomenon to an electric power supply using a piezoelectric conversion mechanism. Moreover, in order to describe the coupling between the cross-flow, mechanical, and electrical equations, the Wake Oscillator Model is used [1]. The nonlinearities inherent to this system could represent a point of complexity to the modeling, so it demands special treatment. This work proposes simplifying the representation of the dynamics using the Koopman formalism, which main advantage is the capability to represent a finite-dimensional nonlinear dynamical system as an infinite-dimensional linear system. For this purpose, Dynamic Mode Decomposition (DMD) [2] is used to obtain a simplified model for the system based on a data-driven problem [3]. This approach provides an easier way to control the system, aiming to improve the efficiency of the energy harvester. Through the system responses obtained, a comparison between different values of the physical parameters provides a sensitivity analysis.

Bibliography

[1] L.S. Madi, C.P. Pesce, G.R. Franzini, DINAME 2019 - XVIII International Symposium on Dynamic Problems of Mechanics, March 10th to 15th, Buzios, RJ, Brazil, 2019..
[2] H. Zhang et.al, Physics of Fluids, 34, 093610, 2022.
[3] J.N. Kutz et. al, Dynamic Mode Decomposition: Data-Driven Modeling of Complex Systems, 1st edition, 2016.

Nonlinear vibration energy harvesting based on weakly coupled biperiodic oscillators

Mon.
15:15–15:30
R Tichka

S. Dowlati, N. Kacem , E. Joseph N. Bouhaddi

University of Franche-Comté, FEMTO-ST Institute, Department of Applied Mechanics, Besançon, France

Electromagnetic Vibration Energy Harvesting (VEH) is a viable solution for the energy supply of self-powered sensors and systems. However, despite many research studies, narrowband harvesting and maximal power limits are still the main challenges in the implementation of vibratory energy harvesters. In this work, we propose an electromagnetic energy harvester based on weakly coupled biperiodic oscillators where the combined effects of nonlinear dynamic and energy localization phenomena are employed. This design allows to maximize the harvested energy in a large frequency bandwidth. It consists of two coupled periodic subsystems which target two different but close frequency bands. Therefore, a biperiodic multimodal VEH prototype is designed, and fabricated with steel spiral-shaped springs (Area=2cm x 2cm, mass=0.35g) and coupled magnets as proof mass (0.45g). Spiral-shaped springs are designed with a smaller size to lower the operating frequency range [50-60]Hz. Mass mistuning is introduced in each subsystem to generate the mode localization and increase the harvested energy with two conversion circuits. The experimental and numerical results are in good agreement, proving that the device highlights the beneficial features of the nonlinear dynamics and the energy localization phenomenon.

Bibliography

[1] P.W. Anderson, Physical review 109(5), 1492, 1958.
[2] K. Aouali, N. Kacem, N. Bouhaddi, E. Mrabet and M. Haddar, Smart Mater. Struct. 29, 10LT02, 2020.

Methodological description of obtaining and stabilizing solitons in macromechanical damped resonators subjected to a base acceleration

Mon.
15:30–15:45
R Tichka

A. Barbosa, N. Kacem N. Bouhaddi

University of Franche-Comté, FEMTO-ST Institute, Department of Applied Mechanics, Besançon, France

The study of localized vibration in nonlinear systems has received considerable attention in the last decade. Contrary to linear systems, these studies suggest that nonlinear systems can exhibit Intrinsic Localized Modes (ILMs, often called solitons) even when the periodicity hypothesis is rigorously considered. In mechanical systems, this phenomenon can be mathematically described by the Nonlinear Schrödinger equation (NLS), in which a solitonic solution is generally provided for an array of weakly coupled nonlinear oscillators [1]. There have been a significant number of investigations reporting the conditions of existence and stability of solitons in a wide variety of fields. Some examples of applications include micro/nanoelectromechanical systems, optical waveguides, photonic crystals, fluid surfaces, and, more recently, metamaterials. Moreover, experimental replication of nonlinear waves in macromechanical systems remains a promising application area [2]. In this context, the purpose of this study is to present a general methodology that describes the conditions for finding and stabilizing solitonic solutions in macromechanical damped resonators subjected to a base acceleration. As the objective of this work is not restricted to a specific oscillator model, such as pendulums or bladed disks, the mathematical treatment is presented for an equivalent discrete model. The solution of the nonlinear equations is achieved by using the method of multiple scales and the consequent cancellation of the secular term imposes the emergence of the NLS. Once the solution is obtained, physical parameters (stiffness, mass and damping) are then analyzed in order to assess the stability of the nonlinear wave. The analytical results reported in this study are in agreement with the conclusions of papers with similar objectives, as reported in [3]. To the best of our knowledge, further research is required to provide more detailed descriptions of solitons experimental replications in damped macromechanical systems. Based on the results obtained, an experimental validation appears promising and is the main focus of ongoing work.

Bibliography

[1] Jallouli, Aymen, Najib Kacem, and Noureddine Bouhaddi, Stabilization of solitons in coupled nonlinear pendulums with simultaneous external and parametric excitations, Communications in Nonlinear Science and Numerical Simulation 42, 1-11, 2017.

[2] Talebi Bidhendi, M. Reza, and Ahmad Mohammadpanah, olitary Waves in an Array of Nonlinear Oscillators With Time-Periodic Damping and Stiffness Coefficients, ASME International Mechanical Engineering Congress and Exposition. Vol. 85628., November, Online event, 2021.

[3] Grolet, Aurelien, et al., Travelling and standing envelope solitons in discrete nonlinear cyclic structures, Mechanical systems and signal processing 81, 75-87, 2016.

An origami inspired cellular cushion material

Mon.
16:15–16:35
R Tichka

A. Dalaq[1], S. Khazaaleh [2], M.F. Daqaq [3]

[1] *Research Scientist, Engineering Division, New York University Abu Dhabi*
[2] *Ph.D. Candidate, Tandon School of Engineering, New York University, NY*
[3] *Global Network Professor of Mechanical Engineering, Engineering Division, New York University Abu Dhabi and Tandon School of Engineering, NY*

Nature continues to inspire the design of many manmade systems. For instance, current engineered cushion materials, which are mostly polymeric foams, mimic to some extent those optimized by nature through a lengthy process of natural selection and evolution. They are disordered cellular viscoelastic structures with open or closed cells that have high crushability and energy absorption capacity. Porosity serves to absorb kinetic energy through compaction, while viscosity serves to dissipate a part of the absorbed energy as heat. This is very similar to the design seen in the parts of animals that are constantly subjected to high impact forces. For instance, the feet of the African elephants have a subcutaneous cushion consisting of layers of fatty viscoelastic fibrous connective tissue to dissipate large stresses induced by the elephant's weight during locomotion.
Inspired by nature, we propose in this paper to combine advanced manufacturing technologies with Origami principles to create a new class of architectured cellular viscoelastic cushion material which combines low weight and high energy absorption efficiency with damage resistance and full behavior customization. Each unit cell in the proposed material is inspired by the Kresling Origami topology, which absorbs impact energy by gracefully folding the different interfaces forming the cell to create axial and rotational motions. A large part of the absorbed energy is then dissipated through viscoelasticity and friction between the interfaces. The result is a nearly ideal cushion material exhibiting high energy absorbing efficiency ($\sim 70\%$) combined with high energy dissipation (94% of the absorbed energy). The material is also tunable for optimal performance, reliable despite successive impact events, and achieves full shape recovery.

A reduced-order modeling approach for nonlinear vibration analysis of piezoelectric micro-electro-mechanical systems

Mon.
16:35–16:55
R Tichka

J.F. Deü[1], A. Givois [1,2], O.Thomas[2]

[1] *Laboratoire de Mécanique des Structures et des Systèmes Couplés (LMSSC) Conservatoire national des arts et métiers, Paris, France*
[2] *Laboratoire d'Ingénierie des Systèmes Physiques et Numériques (LISPEN), Arts et Métiers Paris-Tech, Lille, France*

This work deals with the modeling of nonlinear vibrations of thin structures with piezoelectric transducers. The targeted applications concern the design of microelectromechanical systems (MEMS). The objective is to propose a numerical strategy to efficiently compute the dynamics of electromechanical problems with geometric nonlinearities that takes into account both the piezoelectric coupling and the large displacements of the structure. The methodology is based on the computation of reduced order models (ROM) obtained from full order finite element solutions using a modal projection technique and a non-intrusive STEP (STiffness Evaluation Procedure) approach. Special attention is given to the computation of the unknown nonlinear coefficients of the ROM and the chosen projection basis. The reduced order model is then solved with an original purely harmonic continuation method. Our numerical tool is finally used to calculate the nonlinear vibrations of laminated beams and circular plates equipped with piezoelectric patches. Interesting vibrational phenomena, such as internal resonances and parametric amplifications, are thus highlighted and can be used for the design of such micro-devices.

Bibliography

[1] A. Lazarus, O. Thomas, J.-F. Deü. Finite element reduced order models for nonlinear vibrations of piezoelectric layered beams with applications to NEMS. Finite Elements in Analysis and Design, 49(1), 35-51, 2012.
[2] A. Givois, A. Grolet, O. Thomas, J.-F. Deü. On the frequency response computation of geometrically nonlinear flat structures using reduced-order finite element models. Nonliner Dynamics, 97(2), 1747-1781, 2019.
[3] A. Givois, J.-F. Deü, O. Thomas. Dynamics of piezoelectric structures with geometric nonlinearities: A non-intrusive reduced order modelling strategy, Computers and Structures, 253, 106575, 2021

A comparative study of resonant drive techniques

Mon.
16:55–17:15
R Tichka

R. Abdelrahman[1], A. Elhady [1], M. Yavuz[2], E.M. Abdel-Rahman[1]

[1] *Systems Design Engineering, University of Waterloo, Canada*
[2] *Mechanical and Mechatronics Engineering, University of Waterloo, Canada*

Electrostatic actuation is a popular actuation mechanism in microelectromechanical systems (MEMS) because of its many advantages. However, it requires high voltage typically provided by a power supply and a high voltage amplifier which is limited in gain at high

frequencies. As research interest has shifted to explore higher frequency MEMS, various methods have been proposed to amplify the voltage signal fed into the system by coupling it to a series LC tank circuit. These methods are based on utilizing the electrical quality factor Q_e of an RLC circuit driven at its natural frequency f_e to amplify the actuation voltage of a MEMS. Our work analyzes and compares three resonant drive excitation techniques. In the first, electrical and mechanical resonances are matched and simultaneously activated $f_e \approx f_m$ by tuning an external inductor L. In the second method, the MEMS is excited with a signal consisting of two frequencies f_1 and f_2. The electric resonance is adjusted to set $f_1 \approx f_e$ and f_2 is set so that [1-3]. In the third method, the microbeam is driven using an amplitude-modulated (AM) signal that contains both an RF carrier frequency and a baseband frequency. The LC circuit is tuned to match the RF carrier frequency $f_c \approx f_e$, and the baseband frequency is set equal to the mechanical natural frequency $f_b \approx f_m$. Since the mechanical resonance is much lower than the carrier frequency, the MEMS follows the envelope of the modulated signal [4,5].
In this study, we found that resonant circuits were more effective at amplifying MEMS response than a voltage amplifier. This is due to amplifiers' limitations at high frequencies. Furthermore, we show that mixed frequency and amplitude modulation techniques are more flexible and easier to tune than resonance matching. However, we found that resonance matching is more effective for AC excitation since it results in higher voltage amplification than the other two technique.

Bibliography

[1] M.H. Hasan, F.M. Alsaleem, N. Jaber, M.A.A. Hafiz and M.I. Younis, "Simultaneous electrical and mechanical resonance drive for large signal amplification of micro resonators," AIP Advances, vol. 8, no. 1, p. 015312, 2018.
[2] N. Jaber, M.A.A. Hafiz, S.N.R. Kazmi, M.H. Hasan, F. Alsaleem, S. Ilyas and M.I. Younis, "Efficient Excitation of Micro/Nano Resonators and Their Higher Order Modes," Sci Rep, vol. 9, no. 1, 2019.
[3] H.M. Ouakad, M.H. Hasan, N.R. Jaber, M.A.A. Hafiz, F. Alsaleem and M. Younis, "On the double resonance activation of electrostatically actuated microbeam based resonators," Int. J. Non-Linear Mech., vol. 121, p. 103437, 2020.
[4] S. Park and E. Abdel-Rahman, "Low Voltage Electrostatic Actuation and Displacement Measurement Through Resonant Drive Circuit," in Proc. ASME IDETCCIEC, 2012, pp. 119-126.
[5] S.R. Chung, S. Park, E. M. Abdel-Rahman, J. T. Yeow and M. Khater, "Architecture for MEMS-based analogue demodulation," J. Micromech. Microeng., vol. 23, p. 045013, 2013.

Performance analysis of a bi-stable point wave energy absorber under random waves

Mon.
17:15–17:30
R Tichka

M. Khasawneh[1], M.F. Daqaq[2]

[1] *Ph.D. Candidate, Tandon School of Engineering, New York University, NY*
[2] *Global Network Professor of Mechanical Engineering, Engineering Division, New York University Abu Dhabi and Tandon School of Engineering, NY*

Due to their high energy density, ocean waves are considered to be a promising source of renewable energy. As a result, many smart solutions have been proposed over the years to harness their energy efficiently at different scales. In the current work, we are interested in point wave energy absorbers (PWAs) because of their design simplicity and large penetration in the wave energy market. In its most primitive form, a PWA consists of a partially submerged buoy connected through a rigid cable to a linear electromagnetic generator fixed to the seabed. Waves set the buoy into motion, which in turn, pulls the cable and creates relative motions between a magnet and a coil. This has the effect of creating a current in the coil as per Faraday's law of induction. Because of their wide resonant frequency bandwidth which extends to the lower range of wave frequencies, the research community has recently paid significant attention to the design and performance analysis of bi-stable point wave energy absorbers (PWAs). In this study, we study the behavior of bi-stable PWAs under random wave inputs. Using Monte Carlo simulations, we delineate the effect of the wave spectral content on the average output power and the average capture width ratio (CWR), for different shapes of the absorber's potential energy function. We show that there is a direct correlation between the stochastic response of the absorber and its steady-state behavior under harmonic wave excitations. We also develop design maps to demonstrate how the CWR of the bi-stable PWA varies with the peak frequency and significant height of the waves.

A study of mathematical model of AFM with casimir force by means of averaging method

Mon.
17:30–17:45
R Tichka

G.A. Kurina[1], J.M. Balthazar[2], M.A. Ribeiro [3], A.M. Tusset[4]

[1] *Voronezh State University and Federal Research Center "Computer Science and Control" of Russian Academy of Sciences*
[2] *University of Technology-Parana and Faculty of Mechanical Engineering of Bauru, São Paulo State University*
[3] *Federal University of Technology-Parana*
[4] *Federal University of Technology-Parana*

Atomic force microscopy (AFM) is a powerful approach in modern science and engineering. An essential component of atomic force microscope is a microcantilever with a tip attached to its free end. Interaction forces, existing between the tip and the surface to be measured, cause deflection of the microcantilever. The first paper was done by G. Binning, C.F. Quate, Ch.Gerber (1986) and after a large number of researchers worked over this theme. In this paper, a dimensionless mathematical model of atomic force microscopy with Casimir force from [1] is considered. Here, the averaging method, which is one of the effective methods in the perturbation theory, is used. The first order ap-

proximation of this method gives often a good proximity to an exact solution. Sometimes, higher order approximations of this method are necessary. See, for instance, [2] and [3], where high order approximations of the averaging method have been applied in a nonlinear theory of a cyclotron-resonance maser with a Fabry-Perot resonator and in a theory of atomic force microscopy without Casimir force. The studied model is reduced to a standard form, and relations for the first, second, third and fourth approximations of averaging method are obtained. An illustrative example is given, showing the efficiency of averaging method for some values of parameters, which were taken from [1], then one parameter was changed.

Bibliography

[1] M.A. Ribeiro, J.M. Balthazar, W.B. Lenz, R.T. Rocha, A.M. Tusset, Shock and Vibration, 2020, Article ID 4048307, 2020.

[2] A.F. Kurin, G.A. Kurina, V.V. Novikov, Radophysics and Quantum Electronics, 19, 742-747, 1976.

[3] M.A. Ribeiro, G.A. Kurina , A.M. Tusset, J.M. Balthazar, Archive of Applied Mechanics, 92, 3817-3827, 2022.

On dynamical behavior and control of microscopy atomic force: a review

Mon.
17:45–18:00
R Tichka

M.A. Ribeiro[1], J.M. Balthazar[2,7], I. Kirrou[3], A.M. Tusset[4], A.M. Bueno[5], H.H. Daum[6]

[1] *Universidade Tecnológica Federal do Paraná-Campus Ponta Grossa, Ponta Grossa, PR, Brasil*
[2] *Universidade Tecnológica Federal do Paraná-Campus Ponta Grossa, Ponta Grossa, PR, Brasil*
[3] *MISI Laboratory, FSTE, Hassan First University Settat, Morocco*
[4] *Universidade Tecnológica Federal do Paraná- Campus Ponta Grossa, Ponta Grossa, PR, Brasil*
[5] *Polytechnic School of the University of São Paulo, Brazil*
[6] *Universidade Tecnológica Federal do Paraná-Campus Guarapuava, Ponta Grossa, PR, Brasil*
[7] *Faculdade de Engenharia de Bauru - FEB/UNESP, Bauru, São Paulo. Brazil*

The Atomic force microscopy (AFM) is the technique used for topological surface analysis of synthetic and biological samples. It is one kind of observation method that takes advantage of the atomic force between the probe and the sample surface. There are different modes of AFM analysis. Examples of these modes are: Contact and non-contact, Trolling and the intermittent mode. In these cases, several authors have been exploring the nonlinear dynamics behavior and thus determining the conditions in which such mathematical models have a chaotic and periodic behavior. Such results corroborate to propose control techniques that will suppress the chaos presented in the models. Another important aspect is the application of fractional calculus, along with the viscoelasticity term, to obtain approximations of the nonlinear dynamics of the biological environment. In this paper, we will approach some recent mathematical models applied in the AFM to explore its nonlinear dynamic aspects and its control.

Bibliography

[1] M.A. Ribeiro, J.M. Balthazar, W.B. Lenz, R.T. Rocha, A.M. Tusset. Shock and Vibration, 2020, 1-18,2020.
[2] M.A. Ribeiro, A.M. Tusset, J.M. Balthazar. Brazilian Journal of Physics, 6, 1-7, 2020.
[3] M.A. Ribeiro, A.M., Tusset, W.B. Lenz, I. Kirrou, J.M. Balthazar, Eur. Phys. J. Spec. Top. 230, 3655-3661, 2021.
[4] M.A. Ribeiro, J.M. Balthazar, A.M. Tusset, A.M. Bueno, H.H. MEMS-Based Atomic Force Microscope: Nonlinear Dynamics Analysis and Its Control. In MEMS - Applications to Engineering and Science. 1th Edition, 2022.
[5] M.A. Ribeiro, G.A. Kurina, A.M. Tusset, J.M. Balthazar, J.M. Arch Appl Mech 92, 3817-3827, 2022.

Energy harvesting in a system whose energy potential was mapped by the hyperbolic Fibonacci function

Tue.
10:30–10:50
R Tichka

J. Margielewicz [1], D. Gaska[1], S. Bucki[1], G. Litak[2], P. Wolszczak[2]

[1] *Silesian University of Technology, Faculty of Transport and Aviation Engineering, Katowice, Poland*
[2] *Lublin University of Technology, Faculty of Mechanical Engineering, Lublin, Poland*

Model and laboratory research on the energy harvesting from vibrating mechanical devices are increasingly becoming an important subject of interest. A bibliography query indicates the existence of many design solutions for devices enabling the energy harvesting from vibrating mechanical systems [1]. Their characteristic distinguishing feature is the presence of permanent magnets, whose number and arrangement determine the shape of the energy potential function [2]. Systems for obtaining energy with permanent magnets, however, have some limitations, which mainly due to the required level of energy of external dynamic excitation. Achieving the appropriate level of vibration, which allows overcoming local potential barriers, has a significant impact on the efficiency of energy harvesting, because trajectories recorded on the phase plane achieve the largest possible displacement amplitudes. According to the authors, these restrictions are devoid of design solutions in which the energy potential is described by a flat bottom energy well characteristic. In this paper, the main goal was to study the dynamic properties of a non-linear energy harvesting system, in which the energy potential was mapped by Fibonacci hyperbolic function. Particular attention was paid to the identification of zones in which chaotic movement takes place and the assessment of coexisting solutions. The results of numerical calculations will be depicted in the form of multi-coloured distribution maps of the largest Lyapunov exponent and a diagram showing the number of coexisting solutions.
Acknowledgement: This research was funded by National Science Centre, Poland under the project SHENG-2, No. 2021/40/Q/ST8/00362.

Bibliography

[1] S. Zhou, M. Lallart, and A. Erturk, Multistable vibration energy harvesters: Principle, progress, and perspectives, J. Sound Vib., p. 116886, Mar. 2022, doi: 10.1016/J.JSV.2022.116886.
[2] Z. Zhou, W. Qin, Y. Yang, and P. Zhu, Improving efficiency of energy harvesting by a novel penta-stable configuration, Sensors Actuators A Phys., vol. 265, pp. 297-305, Oct. 2017, doi: 10.1016/J.SNA.2017.08.039.

Modal interaction of MEMS shallow arch under out-of-plane fringing-fields

Tue.
10:50–11:10
R Tichka

H.M. Ouakad[1], F. Najar [2], N. Kacem[3]

[1] *Mechanical and Industrial Engineering Department, College of Engineering, Sultan Qaboos University, Al-Khoudh, Muscat, Oman*
[2] *Department of Mechanical Engineering, College of Engineering, Prince Sattam bin Abdulaziz University, Al-Kharj, 11942, Kingdom of Saudi Arabia*
[3] *Department of Applied Mechanics, FEMTO-ST Institute, University of Bourgogne Franche-Comté, UMR 6174, Besançon, France*

In this research, we examine the lower order modes' interactions of a clamped-clamped shallow arch flexible microbeam. The flexible electrode is electrically actuated out-of-plane electrostatic fringing-fields. A nonlinear beam model is introduced consisting of a nonlinear partial deferential equation governing the flexible shallow arch in-plane deflection. Then, a resultant reduced-order model (ROM) is derived assuming a Galerkin modal decomposition with mode-shapes of a clamped-clamped beam as basis functions. The ROM coupled modal equations are simultaneously numerically solved and the variation of the first three lower natural frequencies when the microbeam is electrostatically actuated are obtained. Results show that controlling the microbeam stroke with a proper DC voltage on the gate electrodes, enables to tune the system frequency, resulting in a possibility of a tunable MEMS device without a pull-in scenario and plenty of modal interaction such as mode veering and mode crossings.

The Micro Electromechanical Systems (MEMS) industry has been acknowledged as one of the most auspicious technologies during the past Century, primarily in developing both industrial and domestic products through combining silicon-based microstructures with the micromachining technology [1]. The electrostatic actuation is known to be the most prevalent transduction mechanisms for actuating microbeams because of simplicity of use and fabrication, and most importantly low power consumption capabilities. This electrostatic transduction technique can have several arrangement ranging from the parallel-plates configuration represented, in the past, the most reputable and common actuation method because of its easiness and high efficacy [2]. However, this nonlinear actuation method is limited by a common structural instability, well known as pull-in stiction instability, which occurs when the actuating voltage exceeds a certain limit value, leading to a collapse of the parallel-plates capacitor [3]. Therefore, numerous research works have been communicated to possibly suggest ways to suppress the effect of this pull-in instability and among these ideas, we can cite the so-called fringing-fields actuator base micro-device. This research work, and in contrast to one of our previous work [4], a detailed analysis of the device's modal interaction is presented. We show the mapping of the design and operational parameters, and a numerical demonstration of both mode veering and mode crossings for better sensitivity.

Bibliography

[1] Senturia S.D., Microsystem Design, Chapter 6, Dordrecht: Kluwer Academic Publishers, (2001).
[2] Marquès. A. F., Castelló. R.C., Shkel. A.M., "Modelling the Electrostatic Actuation of MEMS: State Of The Art 2005", Technical Report, IOC-DT, Vol 18, pp 1-24, (2005).
[3] Newell. W., "Miniaturization of Tuning Forks". Smithsonian/NASA Physics Query Form Science, Vol 161(3848), pp 1320-1326, (1968).
[4] Ouakad. Hassen M. "Static response and natural frequencies of microbeams actuated by out-of-plane electrostatic fringing-fields." International Journal of Non-Linear Mechanics 63, 39-48, (2014).

MEMS electrostatic kinetic energy harvester with double capacitor bennet doubler conditioning circuit and autonomous buck DC/DC converter

Tue.
11:10–11:30
R Tichka

H. Samaali[1], F. Najar [2]

[1] *Applied Mechanics and Systems Research Laboratory, Ecole Polytechnique de Tunisie, BP 743, University of Carthage, Tunisia*
[2] *Department of Mechanical Engineering, College of Engineering at Al Kharj, Prince Sattam bin Abdulaziz University, Al Kharj, Saudi Arabia*

The work aims to design and analyze the performance of a MEMS-based kinetic energy harvester. The system is composed of three parts, a double capacitor transducer that harvest the kinetic energy, a conditioning circuit implemented as a Bennet doubler circuit, and a buck DC-DC converter activated by a self activated mechanical microswitch. The design uses only simple and classical MEMS fabrication techniques such as the SOI technology. The transducer is based on two out of phase variable capacitors. The microswitch is activated by the harvested voltage when it exceeds its activation voltage and turns OFF below it. A coupled analytical model is derived for the transducer, the microswitch and the Bennet Doubler circuit. The dynamic response of the system is investigated by solving numerically the coupled model and analyze its response in terms of output voltage, current and displacements of the mechanical elements. Electrical analysis concerning the Q-V cycle of the transducer is also considered in this work where the self activation command of the microswitch and the power load of the sensor electronics are taken into consideration

Electromechanical modeling and parametric analysis of L-shaped-based bending-torsion piezoelectric energy harvester

Tue.
11:30–11:45
R Tichka

A. Magdich[1], S. Baroudi [1], A. Abdelkefi [2], F. Najar[3,1]

[1] *Applied Mechanics and Systems Research Laboratory, Ecole Polytechnique de Tunisie, University of Carthage, Tunisia,*
[2] *Rio de Janeiro State University, Brazil*
[3] *Department of Mechanical Engineering, College of Engineering at Al Kharj, Prince Sattam bin Abdulaziz University, Al Kharj, Saudi Arabia*

Improving the performance of cantilevered piezoelectric energy harvesters is the aim of lot of research work scientists. It was proved, namely, that developing a broadband and highly efficient bending-torsion L-shaped harvester through exploiting the d36 mode may increase the amount of the harvested energy and the frequency bandwidth of those devices. In this work, we propose to model and study an energy harvesting system made up of bimorph L-shaped beam-mass structures. The L-shaped bimorph piezoelectric harvester consists of two composite flexible beams with perfectly bonded piezoelectric layers and one punctual mass located at the free end. The system is subjected to a single base excitation which is sufficient to cause the coupled bending and torsion motions. The intention of this work is to exploit the d36 mode and to compare the performance of the studied harvester based on harvested energy and frequency bandwidth. Using the Euler-Bernoulli theory and Hamilton's principle, we develop a distributed-parameter model of the harvester and deduce the governing equations of motion and the corresponding boundary conditions. Then, we apply the Galerkin procedure to obtain a reduced order using closed-form mode shapes of the beam. The results, represented by the displacement, twisting angle, output voltage, and harvested electrical power, reveal that the exploiting the d36 mode enhances the performance of the energy harvester. The average harvested power improves by 67.95% in comparison with the case of the classical treated structures.

Optimizing power output in combined galloping and vortex-induced vibrations-based electromagnetic energy harvesting

Tue.
11:45–12:00
R Tichka

Y. El Moussati[1], M. Hamdi[1], M. Belhaq[2]

[1] *Faculty of Sciences and Technologies, Al Hoceima, Abdelmalek Essaâdi University, Tetouan, Morocco*
[2] *Faculty of Sciences Ain Chock, Hassan II University, Casablanca, Morocco*

This work investigates combined galloping and vortex-induced vibrations based on electromagnetic energy harvesting (EEH) in a linear two-degree-of-freedom (2-DOF) mechanical system coupled to an electrical circuit through an electromagnetic mechanism. For the current investigation, a 2-DOF galloping and vortex-induced vibrations-based EEH consists of mounting a primary system on a secondary structure with a bluff body at the tip of every beam, leading to undergoing galloping and vortex-induced oscillations. The harmonic balance method is applied to obtain approximate solutions. The analytically obtained responses are numerically validated. Our findings show that combining

galloping and vortex-induced vibrations enables the system to harvest higher power output than the conventional 2-DOF vortex-induced vibrations-based EEH system under a single hydrodynamic force from vortex-induced oscillations. Also, it was demonstrated that the energy harvester system might have low critical wind speeds.

MS 2

Dynamics and Control of Oscillating Systems in Engineering Sciences

Chairmen: *M. Semenov* Russia, *I. Kovacic* Serbia, *A. Nabarrete* Brazil

Scheduled:

Tuesday	*14:00–15:45*	Adam park Hotel	**Room Tinmel**
Tuesday	*16:15–18:00*	Adam park Hotel	**Room Tinmel**
Tuesday	*10:30–12:15*	Adam park Hotel	**Room Tinmel**

Metamodeling and sensitivity analysis of a piezoelectric energy harvester based on polynomial chaos expansions

Mon.
14:00–14:20
R Tinmel

R. Aloui[1,2], W. Larbi [3], M. Chouchane[1]

[1] *University of Monastir, National Engineering School of Monastir, Mechanical Engineering Laboratory (LGM), Monastir, Tunisia*
[2] *Design Office, Research and Technology Pole, Safran Seats, Safran Group*
[3] *Structural Mechanics and Coupled Systems Laboratory (LMSSC), Conservatoire National des Arts et Metiers (CNAM), Paris, France*

Over the last decade, energy harvesting from ambient vibration sources has received substantial attention. Piezoelectric materials are widely used to convert ambient vibrations into electrical energy due to the efficiency of their electromechanical transduction. The finite element method is classically used for model this kind of system. Among its advantages, it makes it possible to capture the influence and effects of the different geometrical, mechanical and electronic parameters of the problem on its electromechanical behavior and to study in particular the dependence between the eigenmodes of the system and its frequency response. The amount of electrical energy recovered by the system is influenced by the uncertainty of its geometric and physical parameters (electrical and mechanical properties of the piezoelectric layers). The Monte Carlo method is widely used to assess this influence. Nevertheless, its prohibitive calculation time in the case of dynamic modeling by finite element method, limits its use. Metamodels are proposed in the literature allowing a robust modeling of these systems and a considerable reduction of calculation time for analyzes of uncertainty and sensitivity.

In this context, this work focuses on the metamodeling of a piezoelectric energy harvester based on polynomial chaos expansions (PCE) to predict electrical outputs with low computational cost. The metamodel is built using a database created from finite element simulations previously fixed by the plan of experiments. It considers a regression technique with a polynomial of degree six. The surrogate is then used for a sensitivity analysis which consists of calculating Sobol indices. The main objective is to put the uncertain parameters in a hierarchical order of influence on the harvester's responses. Results using the polynomial chaos expansion method show that that the proposed method is more efficient than the Monte Carlo approach with lower computational cost. Furthermore, it has been found that the elastic modulus and density of the piezoelectric layers are the parameters which lead to the largest output variability.

Bibliography

[1] R. Aloui, W. Larbi, et M. Chouchane, Global sensitivity analysis of piezoelectric energy harvesters, Compos. Struct., vol. 228, p. 111317, nov. 2019, doi: 10.1016/j.compstruct.2019.111317.
[2] R. Aloui, W. Larbi, et M. Chouchane, Uncertainty quantification and global sensitivity analysis of piezoelectric energy harvesting using macro fiber composites, Smart Mater. Struct., vol. 29, no 9, p. 095014, août 2020, doi: 10.1088/1361-665X/ab9f12.
[3] L. L. Gratiet, S. Marelli, et B. Sudret, Metamodel-Based Sensitivity Analysis: Polynomial Chaos Expansions and Gaussian Processes, in Handbook of Uncertainty Quantification, R. Ghanem, D. Higdon, et H. Owhadi, Éd. Cham: Springer International Publishing, 2015, p. 1-37. doi: 10.1007/978-3-319-11259-6-38-1.
[4] A. Baklouti, K. Dammak, et A. El Hami, Uncertainty Analysis Based on Kriging Meta-Model for Acoustic-Structural Problems, Appl. Sci., vol. 12, no 3, p. 1503, janv. 2022, doi: 10.3390/app12031503.
[5] E. García-Macías, R. Castro-Triguero, M. I. Friswell, S. Adhikari, et A. Sáez, Metamodel-based approach for stochastic free vibration analysis of functionally graded carbon nanotube reinforced plates, Compos. Struct., vol. 152, p. 183-198, sept. 2016, doi: 10.1016/j.compstruct.2016.05.019.

Nonlinear modelling and control of satellite with propellant sloshing dynamics

Mon.
14:20–14:40
R Tinmel

M.A. Gonçalves[1], J.M. Balthazar[2,3], E. Jarzebowska [4], M.A. Ribeiro [5], A.M. Tusset[6], H.H. Daum[7]

[1] *Faculdade de Engenharia de Bauru - FEB/UNESP, Bauru, São Paulo*
[2] *Universidade Tecnológica Federal do Paraná-Campus Ponta Grossa, Ponta Grossa, PR, Brasil*
[3] *Faculdade de Engenharia de Bauru-FEB/UNESP, Bauru, São Paulo*
[4] *Warsaw University of Technology-WUT, Warsaw, Poland*
[5] *Universidade Tecnológica Federal do Paraná- Campus Ponta Grossa, Ponta Grossa, PR, Brasil*
[6] *Universidade Tecnológica Federal do Paraná- Campus Ponta Grossa, Ponta Grossa, PR, Brasil*
[7] *Universidade Tecnológica Federal do Paraná-Campus Guarapuava, Ponta Grossa, PR, Brasil*

Historically, slosh dynamics is a problem for spacecrafts projects and that is the reason that the first studies concerning this theme are related to space vehicles and satellites. Even a minimum amount of liquid can induce to big accidents such a loss of an entire spacecraft, for example. The majority of recent researchers use computational fluid dynamics (CFD) based on the pendulum equivalent mechanical model to simulate liquid sloshing inside partially filled fuel tanks on spacecrafts. Although there is a great number of studies of liquid sloshing on spacecrafts using CFD models, this method still is not the ideal. Therefore, we investigate the dynamics and attitude control of a satellite which is modeled in such way as to obtain a nonlinear differential equation system. This model represents the satellite as a rigid body whose motion is coupled with the liquid sloshing forces in its interior. The dynamical analysis determine the conditions to chaotic and periodic behavior of the system. Based in such results we propose control techniques to suppress the sloshing forces inside the spacecraft.

Bibliography

[1] M. Reyhanoglu, J. R. Hervas. Modeling and Control of Space Vehicles with Fuel Slosh Dynamics. Advances in Spacecraft Technologies,. p.549-562, 2011. Embry-Riddle Aeronautical University.

[2] V. S. Rodrigues, A. Fenili. Attitude Control Of Satellite With Propellant Sloshing Dynam- Ics. XL Ibero-Latin-American Congress on Computational Methods in Engineering, ABMEC. Anais... , 2019.

[3] M. Rafikov and J. M. Balthazar. Optimal Linear and Nonlinear Control Design for Chaotic Systems, in ASME 2005 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference. Volume 6: 5th International Conference on Multibody Systems, Nonlinear Dynamics, and Control, Parts A, B, and C, Sep. 2005, vol. 6, no. 11, pp. 867-873.

[4] M.A. Gonçalves, J.M. Balthazar; E. Jarzebowska.; et al. On a Nonlinear and Non-Ideally Excited Tank. In: J. Awrejcewicz; M. Kazmierczak; J. Mrozowski; P. Olejnik (Orgs.); 11th Conference On Dynamical Systems Theory And Applications. Anais... . p.802, 2021.

A hybrid, low-level behavior-based steering as an alternative for computationally demanding approaches

Mon.
14:40–15:00
R Tinmel

A. Chelchowski[1], E. Jarzebowska[1], A. Debowski [2]

[1] *Warsaw University of Technology, Poland*
[2] *The Military University of Technology, Poland*

Nowadays, complicated missions to be performed require more than one agent to be involved, which implies formation of groups of Unmanned Aerial Vehicles (UAVs). This however, induces an undeniable need for even more reliable steering algorithms, yet the amount of streamed data, especially in the real - time computing (RTC) applications connected with state of the art optimization techniques expands greatly. All of this results in highly computationally demanding algorithms.
We propose a modified, hybrid, redefined low - level behavior - based steering approach, which aims to resemble the steering properties of animals reactions seen in wildlife. The main idea behind the suggested approach uses reinforcement learning. The concept of such an algorithm is initially extraordinarily complex. The algorithm' s architectural concept bases on a definition of the R3 space of the various desired positions of the agent. Firstly, the numerical simulation is applied to get the matrix of solutions in an undisturbed environment, which will be thoroughly discussed in this conference paper. All of the solutions to get the UAV to the corresponding points in space are calculated a priori and optimized simultaneously. Having obtained the numerous solutions of steering in an unobstructed area, the reinforcement learning algorithm is then applied to perform

a similar task but in a real - life experiment in the open area, which, most importantly, should be similar to the one in which the swarm of drones is going to operate. Moreover, the data gathered from the aeronautical systems, e.g. IMU, out of many realizations, would form numerous time series, which may then be used by time series classification algorithms to adapt steering inputs more accurately. Finally, for this purpose, the simulated solutions shall be used again. The idea behind the above mentioned approach is to gather knowledge of how to steer in foul atmospheric conditions, e.g. strong wind. Such data spaciousness concerning propellers' disturbances in the form of turbulence or wind velocity gradients is quantitatively difficult to obtain and probably not necessarily indispensable/essential. The authors state, that there is no need to solve each equation of motion independently according to situation, but the solution may be interpolated from the already precalculated, optimized and prelearned data, from which the agent can simply choose the proper behavior. Not only should it improve the time of completion of a given task, but it would also, presumably, allow for easier, and more intuitive, space-reorientation of the whole swarm of moving objects.

The paper focuses on one of the core/initial aspects of the suggested modification. The fundamental matrix of behaviors will be derived and analyzed according to the accuracy, speed of action taking and cooperation of multiple drones.

Nonlinear model fitting for sloshing using an equivalent pendulum mechanical model

Mon.
15:00–15:15
R Tinmel

K. Cichorek[1], E. Jarzebowska[2], S. Gepner [3]

[1] *Doctoral School, Warsaw University of Technology*
[2] *Institute of Aeronautics and Applied Mechanics, Warsaw University of Technology*
[3] *Institute of Aeronautics and Applied Mechanics, Warsaw University of Technology*

Sloshing is the phenomena of liquid free surface motion in a container. Sloshing can affect motion stability and cause accidents of vehicles, for example road vehicles as well as satellites or rockets. The first recorded failure of a spacecraft due to fuelsloshing was in April 1957, when a Jupiter Intermediate Range Ballistic Missile was terminated $93s$ after its launch. More recently, sloshing caused the failure of Falcon One rocket in 2006 [1]. Sloshing can be modelled using, e.g. analytical methods and the Lagrange equations approach [2] or CFD software, see e.g. [3] and references there. The mechanical equivalent models of sloshing, such as mass-spring or pendulum models can be used in areas where CFD methods are computationally too demanding. Another computationally cheap way of sloshing modelling is by adopting the Duffing equation. Experimental evidence shows that low-excitation sloshing can be modelled by the Duffing equation [3]. Equivalent sloshing models are particularly popular in aerospace engineering. However, the most common assumptions that are adopted in these models, e.g. the small pendulum swing angle and the height of non-disturbed water level, are rather rarely verified experimentally. In this paper, we investigate a pendulum sloshing model of a spacecraft. First, we derive, using the Lagrange formalism, a nonlinear sloshing model enabling an arbitrary swing angle of the pendulum. We also build a CFD model in Open FOAM software. Then, we compare the displacements of the center of gravity of the sloshing fluid from the CFD simulations with experimental results presented in [3]. Based on this, we make fitting of the CFD model parameters. Using the assessed and verified CFD model we conduct parametrical identification of the pendulum - sloshing water model. The experimental data, the CFD model and the fitted pendulum model simulation results can be then compared. Based upon this comparison, we can demonstrate ranges of applications of the proposed pendulum model and discuss possible ways of its development.

Bibliography

[1] B. Sivasubramanian, L.P. Rosario, S. Krishnappa et al., 56th AIAA/ASCE/AHS/ASC Structural Dynamics and Materials Conference, 5-9 January 2015, AIAA SciTech Forum, 2015.

[2] V. S. Rodrigues, A. Fenili, XL Ibero-Latin American Congress on Computational Methods in Engineering, 11-14 November 2019, Pralamar Natal Hotel & Convention, 2019.

[3] B. Bäuerlein, K. Avila, Phase lag predicts nonlinear response maxima in liquid-sloshing experiments, Journal Fluid Mechanics vol. 925, A22-1 - A22-29, 2021.

Bifurcation analysis of a parametrically excited nonlinear micro-ring gyroscope

Mon.
15:15–15:30
R Tinmel

A.A. Barakat[1,2], P. Hagedorn[2]

[1] *Chair of Nano and Quantum Sensors, Technical University of Munich, Germany*
[2] *Dynamics and Vibrations Group, Institute of Numerical Methods in Mechanical Engineering, Technical University of Darmstadt, Germany*

Microelectromechanical (MEM) vibratory gyroscopes were introduced nearly three decades ago. The low-cost manufacturing of these devices motivated their development to achieve a comparable performance with other types of gyroscopes. The operation of vibratory gyroscopes is based on the transfer of energy between a drive mode to a sense mode only under rotation through Coriolis effect. However, the conventional excitation of the drive mode is accompanied by secondary noise sources which limits the targeted performance [1]. Different solutions were proposed before to overcome such limitation, one thereof is using a parametric excitation.

MEM gyroscopes are found in various designs, one of which is based on a micro elastic ring which offers a better sensitivity. However, micro-ring gyroscopes were often modeled linearly, which restricts its operation in relatively limited vibration amplitudes. Only recently, few studies considered a nonlinear model for these devices, however, without intentional parametric excitation [2]. Nevertheless, based on recently discussed phenomena in coupled nonlinear time-periodic systems, a bimodal parametric excitation of micro-gyroscopes can offer amplification in a wide range of frequencies, thus providing higher robustness and better performance [3].

In the current contribution, the effects of bimodal parametric excitation on a micro-ring gyroscope are studied. Considering the nonlinear elasticity and the coupling with the electrostatic field, a nonlinear model for the gyroscope is presented and the stability of its trivial and nontrivial stationary solutions is investigated showing a pitch-fork bifurcation point. The micro-gyroscope is amplified through a bimodal asynchronic parametric excitation scheme which provides a destabilization of the trivial stationary solution in a broad band of frequencies leading to a broadband parametric amplification. Moreover, the limit cycles under parametric excitation were studied revealing a softening behavior and isolated branches of the non-trivial stationary solutions. In addition, the mathematical model could be validated experimentally using an analogous microelectromechanical system.

Bibliography

[1] B J Gallacher, J S Burdess and K M Harish, Journal of Micromechanics and Microengineering 16, 320-331, 2006.
[2] P M Polunin, S W Shaw, International Journal of Non-Linear Mechanics 94, 300-308, 2017.
[3] A. Barakat, P. Hagedorn, Sensors and Actuators A: Physical, 332, 113130, 2021.

Galloping vibration energy harvesting using a van der Pol circuit

Mon.
15:30–15:45
R Tinmel

M. Hamdi[1], M. Belhaq[2]

[1] *Faculty of Sciences and Technologies, Al Hoceima, Abdelmalek Essaâdi University, Tetouan, Morocco*
[2] *Faculty of Sciences Ain Chock, Hassan II University, Casablanca, Morocco*

This paper investigates galloping vibration-based electromagnetic energy harvesting (EH) in a Duffung-Rayleigh oscillator coupled to a van der Pol circuit. The self-excited vibration is caused by aeroelastic instability. The electromagnetic coupling mechanism between the circuit and mechanical structure is obtained by permanent interaction magnet-coil. The analytical approximations of the vibration response and output power are derived using the averaging method. The analytical solution is compared with the numerical simulation. Results show that introducing by coupling a van der Pol circuit [1] to the Duffing-Rayleigh oscillator can further enhance the EH and broaden the bandwidth of energy scavenging compared to the case in which the system is coupled to a classical storage RLC circuit. It is also shown that for appropriate values of the parameters, the presence of van der Pol circuit can eliminate bistability behavior in the system.

Bibliography

[1] A. Slavin, V. Tiberkevich: Nonlinear Auto-Oscillator Theory of Microwave Generation by Spin- Polarized Current. IEEE TRANSACTIONS ON MAGNETICS, 45(4), (2009).

Widening of anti-resonances by increasing amplitude of parametric excitation

Mon.
16:15–16:35
R Tinmel

Z. Kraus[1], P. Hagedorn [2]

Dynamics and Vibrations Group, FNB, Technical University of Darmstadt, DolivostraSSe 15, 64293 Darmstadt

Anti-resonance is a stabilizing phenomenon, observable in multidimensional linear systems. It can only occur in systems that may be represented by equations of motion with time-dependent coefficients, also called parametrically excited systems. Additionally, a coupling between degrees of freedom (DoFs) is needed. In contrast to fundamental resonances, which appear at certain rational fractions of the eigenfrequencies, anti-resonance may emerge at the sum or difference of the coupled DoFs' eigenfrequencies. To be applicable in real systems, anti-resonance must be designed robustly against parameter variation. One way to increase robustness is to widen the frequency range in which the anti-resonance can be utilized for vibration mitigation. In this contribution, a two-dimensional, parametrically excited system is investigated, which is sufficient for showing all relevant effects. In accordance with previous work [1,2], Lyapunov characteristic exponents (LCEs) serve as an indicator for damping behavior of the system. For an optimal insight into each parameter's influence, a semi-analytical approach is indispensable. Using the method of normal forms, a semi-equivalent, autonomous system is derived. The eigenvalues of the system are then used to calculate an approximate solution of the LCEs in vicinity of the anti-resonance. Analyzing the LCEs, it is found that an increase in amplitude of the parametric excitation leads to widening of the anti-resonance in respect to excitation frequency.

Bibliography

[1] Z. Kraus, A. Karev, P. Hagedorn, F. Dohnal, Enhancing vibration mitigation in a Jeffcott rotor with active magnetic bearings through parametric excitation, Journal of Nonlinear Dynamics, 109, 393- 400, 2022.

[2] A. Karev, Asynchronous parametric excitation in dynamical systems, PhD thesis, Technical University of Darmstadt, Darmstadt, 2020.

Dynamics modeling of an underwater glider based on the Boltzmann-Hamel equations approach with the relaxed symmetry constraint

Mon.
16:35–16:55
R Tinmel

Z. Kostka[1], E. Jarzebowska [2]

[1] *Warsaw University of Technology, Power and Aeronautical Engineering Dept., Warsaw, Poland*
[2] *Warsaw University of Technology, Power and Aeronautical Engineering Dept., Warsaw, Poland*

An underwater glider is a robot that utilizes variable-buoyancy propulsion instead of standard propulsion systems employed in most of the conventional autonomous underwater vehicles(AUV). The vehicle usually moves at very low speed, but it can operate for months and traverse thousands of kilometers, what makes it a very energy efficient method of collecting information on ocean conditions. This class of AUV is underactuated, what leads to their limited maneuverability. To fully understand its dynamics and enable designing effective and better performing control methods, we need to create a more accurate and versatile dynamic model of the vehicle. In the presented paper, the Boltzmann-Hamel modeling method is used to build an AUV dynamics model that would be more efficient than widely used methods based upon Newton-Euler, see e.g. [1] and more general than the previous attempts which also utilized the Boltzmann-Hamel approach [2]. The constraint assuming that the centers of mass and buoyancy of the AUV, and the centers of masses of both of its ballast containers are coaxial is relaxed. Only the symmetry along z-axis is kept. Due to these changes, the centers of mass of the underwater glider can be placed below the center of buoyancy, so the AUV is much more stable and consistent with the real life design cases. Furthermore, the centers of masses of both ballast containers can be displaced due to the change of the fluid level, what is often omitted in dynamics analyses presented in the literature. The more general dynamics model of the AUV indicate that it can approximate the properties of real AUV's more accurately than previous attempts and can match the characteristics of a wider range of the underwater vehicles. It can be applied to design more sophisticated control patterns, which could achieve better performance then already existing solutions. The paper demonstrates the general dynamics of the AUV and its linearization.

Bibliography

[1] J. G. Graver, Underwater Gliders: Dynamics, Control and Design, Ph.D. Thesis, Princeton University (2005).
[2] E. Jarzebowska, M. Cichowski, Dynamics modeling and performance analysis of underwater vehicls based on the Boltzmann-Hamel equations approach, MATEC Web Conf., 148 (2018) 03005 DOI: https://doi.org/10.1051/matecconf/201814803005.

A novel pseudorandom number generator based on a simple oscillatory system

Mon.
16:55–17:15
R Tinmel

P.A. Meleshenko[1], M.E. Semenov[1,2,3]

[1] *Voronezh State University*
[2] *Geophysical Survey of Russia Academy of Science*
[3] *Voronezh State Technical University*

Conservative chaos plays a special role in the modern field of engineering sciences including digital communications and cryptography. At the same time, an important area in the field of the modern communication systems is focused to development of high efficient and fast operating pseudorandom number generators (PRNGs). However, many of the known classical PRNGs do not provide sufficient randomness or have some features that reduce the security. In the presented work we propose a novel PRNG which is based on a relatively simple oscillatory system consisting non-smooth nonlinearities and exhibiting conservative chaotic dynamics. The main features such as no dissipation, no attractors, time-reversal symmetry, symmetry of non-zero Lyapunov characteristic exponents with respect to zero, and integer dimension make systems with conservative chaos as promising sources of chaotic signals in various engineering tasks. The main properties of the proposed PRNG are discussed and analyzed. Numerical results show that the proposed generator has a well performance and successfully passes the standard NIST test for randomness (within the NIST Statistical Test Suite). A comparison of the proposed PRNG to various chaotic-based PRNGs is also presented. The obtained results for the security claim and speed characteristics make it possible to consider this PRNG as a promising source of pseudorandom numbers in the field of chaotic-based digital communications and cryptography.

Bibliography

[1] P.A. Meleshenko, M.E. Semenov, A.F. Klinskikh Nonlinear Dyn. 101, 2523-2540, 2020.
[2] P.A. Meleshenko J. Vib. Eng. Technol. 10, 2203-2215, 2022.
[3] J. C. Sprott Physical Review E 50, R647-R650, 1994

Nonlinear piezoelectric vibration energy harvesting of a cantilever beam using homotopy analysis method

Mon.
17:15–17:30
R Tinmel

A. Nabarrete[1], J. Luis[1], J.M. Balthazar [2]

[1] *ITA-Aeronautics Institute of Technology, São Jose dos Campos, Brazil*
[2] *Federal University of Technology-Paraná, UTFPR, Ponta Grossa, Brazil*

The vibration energy collectors based on piezoelectric resonators are promising elements for energizing remotely located systems. However, differences between the resonant frequency of these traditional harvesters and the vibration frequency can drastically decrease the collected energy and make them ineffective. Appropriate mathematical models, different analysis and optimization techniques to tune the resonant frequency of piezoelectric collectors have been researched. In this study, the model of an inverted vertical cantilever beam with piezoelectric patch and a tip mass is used for energy harvesting. The beam is subjected to base excitations that can induce large lateral displacements of the tip, and consequently large deformation for the piezoelectric patch. Applying the homotopy analysis method (HAM) to the coupled electromechanical governing equations of motion, novel analytical solutions of the transverse displacement of the cantilever beam, of its amplitude and phase as well as the output voltage obtained from the piezoelectric patch are derived. The analytical solutions are derived for the transversal displacements of the beam, even if it presents a varying cross-sectional area. The analytical solution considers the nonlinear behavior characteristics emphasizing the capabilities of a first-order approximation of HAM to present highly accurate closed-form solutions. Accuracy of this approximation of HAM is confirmed by comparison to numerical integration methods.

Bibliography

[1] Esmailzadeh, E. and Nakhaie-Jazar, G. Periodic behaviour of a cantilever beam with end mass subjected to harmonic base excitation. International Journal of Non-Linear Mechanics 33(4): (1998) 567-577.
[2] Friswell, M.I., Ali, S.F., Bilgen, O., Adhikari, S., Lees, A.W., Litak, G. Non-linear piezoelectric vibration energy harvesting from a vertical cantilever beam with a tip mass. Journal of Intelligent Material Systems and Structures 23(13):(2012) 1505-1521.
[3] Shahlaei-Far, S., Nabarrete, A., Balthazar, J.M. Nonlinear vibrations of cantilever Timoshenko beams: A homotopy analysis. Latin American Journal of Solids and Structures 13(10): (2016) 1866-1877.
[4] Liang, J., Liao, W.-H. Impedance Modeling and Analysis for Piezoelectric Energy Harvesting Systems. IEEE/ASME Transactions on Mechatronic 17(6): (2012) 1145-1157.

Nonlinear model of disturbances acting on spacecraft attitude during a tubular boom deployment process

Mon.
17:30–17:45
R Tinmel

M. Kukuryka[1], T. Barcinski[2], E. Jarzebowska [3]

[1] *Warsaw University of Technology*
[2] *Space Research Centre of the Polish Academy of Sciences*
[3] *Warsaw University of Technology*

Deployable booms based on tape springs are widely used in spacecraft. The most common use cases involve support structures for antennas, solar arrays or other deployable structures[1][2] . One of the most lightweight and storable solutions relies on the self-actuated deployment of the booms, since it greatly simplifies the deployment mechanism. Still, the use of these booms utilizing self-actuated deployment is less common. It is caused by design challenges due to difficult control of deployment process, which raises a need to use expensive simulation models combined with physical testing. Also, to the best of authors knowledge, there are no dynamical models of tubular deployable booms of this kind.
The aim of this paper is to present the results of experiments dedicated to study of the process of deployment of tubular booms. The experiments are focused on the reaction forces and torques impacting both the mounting assembly of the boom as well as the attitude of spacecraft. The experiments utilized tape spring booms with an open circular cross-section, made of beryllium bronze tape. The booms are self-deployed due to the relaxation of the elastic energy stored in the deformed tape. Multiple deployments were executed using booms of varying physical parameters. For all of the deployments, reaction forces at the fixed end were recorded. Additionally, visual recordings using a high speed camera were captured. Using the registered data a stochastic evaluation of reaction forces was possible. Finally the boom's deployment process and reaction forces acting on the spacecraft are simulated using a novel dynamic model developed for it. The simulation results are then compared with the deployment study results obtained experimentally.

Bibliography

[1] D. Auslander, J. Cermenska, G. Dalton, M. Pena, C.K.H. Dharan, W. Donokowski, R. Duck, J. Kim, D. Pankow, A. Plauche, M. Rahmani, S. Sulack, T.F. Tan, P. Turin, T. Williams, Instrument Boom Mechanisms on the THEMIS Satellites; Magnetometer, Radial Wire, and Axial Booms, Space Sci Rev 141, 185-211, 2008.

[2] B. Hoang, S. White, B. Spence, S. Kiefer, Commercialization of Deployable Space Systems' Roll-Out Solar Array (ROSA) Technology for Space Systems Loral (SSL) Solar Arrays, IEEE Aerospace Conference, 05-12 March, Big Sky, MT, USA, 2016.

Sampled-based methods used in an analysis of a multistable dynamical systems

Tue.
10:30–10:50
R Tinmel

P. Perlikowski[1], P. Brzeski[2]

Division of Dynamics, Lodz University of Technology, Lodz, Poland

We present how sample-based analysis can complement classical methods for analysing dynamical systems. The sampled-based methods are especially important in analysing complex, multistable systems. Relying on the simple direct numerical integration, we are able to detect all possible solutions, including hidden and rare attractors; investigate the ranges of stability in multiple parameters space; analyse the influence of parameters mismatch or model imperfections; assess the risk of dangerous or unwanted behaviour and reveal the structure of multidimensional phase space. We introduce basin stability, extended basin stability, basin entropy and survivability methods. The basin stability approach is based on calculating multiple numerical trials with random initial conditions. The result of each trial is monitored and classified concerning the final attractor. It gives an overview of the structure of the phase space of the multiple degrees of freedom system. Later, the basin stability method was extended to include the influence of varying parameter values of the system. This modification helps us to investigate the robustness of solutions in systems where parameter values vary or it is impossible to determine their exact values. The following measure is a survivability measure where additionally to the final attractor, the transient time is monitored. The last discussed sample-based method is the basin entropy measure. It quantifies the structure of basins of attraction and provides information about the unpredictability of the dynamical system. To present the methods, we use several real-life examples of mechanical systems. We show the phase space structure and the properties that are hard to determine with classical analysis.

Bibliography

[1] M. Leszczynski, P. Perlikowski, T. Burzynski, T. Kowalski, P. Brzeski, Chaos, 32, 082101, 2022
[2] P. Brzeski and P. Perlikowski, Archives of Computational Methods in Engineering 26, 1515-1545 2019.
[3] P. Brzeski, J. Kurths and P. Perlikowski, Chaos 28, 093104, 2018.

Dynamic modelling and diagnosis of a high contact ratio gear

Tue.
10:50–11:10
R Tinmel

O.D. Mohammed

Mechanical Engineering Department, Prince Mohammad Bin Fahd University PMU, Saudi Arabia

High contact ratio HCR gears are needed in different cases for having lower generated stresses and smoother operation as compared to the standard low contact ratio LCR gears. For the purpose of gear tooth diagnosis and to avoid possible failure consequences due to tooth cracks, it is important to study the possibility of fault detection with crack propagation. A reduction in the gear mesh stiffness due to the existence of a

crack can be used to detect and assess tooth damage. Time-varying gear mesh stiffness has an impact on the system's dynamic response, and then the gear diagnosis indicators applied to the response signal will be affected. The current paper studies the influence of increasing the tooth addendum for having a high contact ratio on the gear diagnosis indicators, namely the RMS, kurtosis, peak value and crest factor. Twenty different crack cases are modelled by using both the LCR and HCR designs. For every crack case, the mesh stiffness is evaluated and input to a gear dynamic model that is built for obtaining the system dynamic response. The results of the applied gear diagnosis indicators show that in the HCR design case the indicators change with the crack size will have less increase than in the LCR one. Therefore, the LCR design case can be detected earlier than the HCR case.

Distributed hysteresis properties in the Euler-Bernoulli beam

Tue.
11:10–11:30
R Tinmel

M.E. Semenov[1,2,3], P.A. Meleshenko[1], E.A. Karpov [1]

[1] *Voronezh State University, Voronezh, Russia*
[2] *Voronezh State Technical University, Voronezh, Russia*
[3] *Geophysical Survey of Russian Academy of Science, Obninsk, Russia*

To this date, the problem of stability of various structures has an important meaning in the field of the modern engineering applications, particularly, in the field of construction. One of the most important characteristics is the response of the structure to external loads of various types. The properties of structures under load are partly determined by the properties of the materials from which it is made. One of the most elementary and at the same time important part of any constructions is a beam. During loads, it deforms, generating stresses in the internal structure of the material, tending to return it to its original shape. If, after removing the load, it takes a shape different from the original, then we are talking about elastic-plastic hysteresis. In this paper, we derive the equations of beam oscillations (within the Euler-Bernoulli theory) with distributed elastic-plastic hysteresis properties, based on the variational principle of Hamilton:

$$u_{tt} + \Gamma[u_{xx}]_{xx} = g(x,t)\, 0, x \in [0, L] \tag{2.1}$$

where $u = u(x,t)$ is the deviation of the beam from the equilibrium, the lower indices denote partial derivatives, $g(x,t)$ is the vertical load or control, $S(t)$ is the external load, applied to the fixed ends of the beam (seismological excitation), $t > 0$ is the simulation time, L is the beam length, $\Gamma[...]$ is the hysteresis operator. Note, that the distributed hysteresis properties have been considered in a limited range of works. This work shows the results of numerical simulations related to vibrations of classical and "hysteresis" beams (depending on external loads: seismic, shock and periodic). Two approaches were used to describe the hysteresis properties: phenomenological (the Bouc-Wen model) and design (the Prandtl-Ishlinskii operator). A comparative and qualitative analysis of the dynamics of beams has been executed. Based on the numerical results, we show that a beam with distributed hysteresis properties has better (compared to the classical one) resistance to external loads.

Bibliography

[1] M. Krasnoselskii, A. Pokrovskii, Systems with hysteresis, Springer, 2011.
[2] S. Timoshenko, History of strength of materials, McGraw-Hill, 1953.
[3] P. Kreich, Reliable solutions to the problem of periodic oscillations of an elastoplastic beam Author links open overlay panel, International Journal of Non-Linear Mechanics 37, 1337-1349, 2002.
[4] N. Firouzi, Mechanics of nonlinear visco-hyperelastic-hysteresis membranes, International Journal of Non-Linear Mechanics 147, 104231, 2022.

Remaining useful life estimation framework for maintenance improvement of rotor dynamic systems with crack propagation

Tue.
11:30–11:45
R Tinmel

Z. Samuel Franciscus[1,2], A. Nabarrete[1], A. Martinetti[2], M.A. Arbelo[1]

[1] *ITA-Aeronautics Institute of Technology, São José dos Campos, Brazil*
[2] *University of Twente, Enschede, Netherlands*

This research aims to make the next step from diagnostics towards prognostics, using the Health and Usage Monitoring System (HUMS) in combination with fracture mechanics to determine the Remaining Useful Life (RUL) of the EC225 helicopter main rotor shaft. This main rotor shaft transfers the power delivered by the engine and the main gear box to the main rotors. At the moment, maintenance to this shaft is carried out after a fixed amount of time, resulting in unused potential. The RUL predictions are used to improve this maintenance strategy and are based on the crack propagation of the main rotor shaft. It is created using a combination of stochastic, deterministic and statistical calculations. Three main loading types are used as input for the crack propagation calculations: axial, bending and moment loading. Probability density functions (PDF) of these loads are created and used as stochastic load input. A relation is found between the load, crack geometry and stress intensity factor (SIF) [1]. This SIF is obtained by modeling the cracked main rotor shaft in the finite element program Abaqus. The relation between the load, crack geometry and SIF is then used to calculate the crack growth rate deterministically using the Walker modification on the Paris' law and Irwin's model [2]. The crack growth rate is calculated for different stress levels during flights. Each flight consists of different stress levels, based on the Felix/28 standard in combination with the PDF stochastic load input. Using this crack growth rate, the crack propagation during flights is determined and so-called degradation paths are constructed [3]. Using the Monte Carlo method, multiple degradation paths are simulated and the RUL is estimated statistically. At last, this RUL estimation is used for maintenance purposes, like determining the inspection interval and plan and anticipate maintenance scenarios.

Bibliography

[1] Zhao, F., Tian, Z., Bechhoefer, E., Zeng, Y. An integrated prognostics method under time-varying operating conditions. IEEE Transactions on Reliability, 2, (2015) 637-686.

[2] Sajith, S., Murthy, K.S., & Robi, P.S. Fatigue life prediction under mixed-mode loading using equivalent stress intensity factor models. MATEC Web of Conferences, 172 (2018).
[3] Hines, J. W., & Usynin, A. Current Computational Trends in Equipment Prognostics. International Journal of Computational Intelligence Systems, 1(1), (2008) 94- 102.

Effect of periodic vibrations with frequency modulation on convective instability in porous media

Tue.
11:45–12:00
R Tinmel

K. Allali[1], M. Belhaq [2]

[1] *Faculty of Sciences and Technologies, Hassan II University Casablanca, Morocco*
[2] *Faculty of Sciences Ain Chock, Hassan II University Casablanca, Morocco*

This work deals with the influence of periodic vibrations with frequency modulation on convective instability in porous media. The model considers the coupling between the heat equation, the concentration equation and the hydrodynamics equations. Two approximations are assumed; the first represents the incompressibility and formulated by Boussinesq approach while the second represents the effect of the porous matrix on the flow and formulated by the Darcy law. Linear stability analysis of the problem is fulfilled and the convective instability boundary is determined using numerical simulations. Results show that the modulation of the frequency of vibrations has a significant influence on the convective instability boundary in porous media.

MS 3

Dynamics of PDEs

Chairmen: *H. Zaag* France, *N. Nouaili* France, *C. Callot* France, *F. Hamel* France

Scheduled:

Monday	*14:00-15:40*	Adam Park Hotel	**Room Louka**
Monday	*16:10-18:10*	Adam Park Hotel	**Room Louka**
Tuesday	*10:45-12:25*	Adam Park Hotel	**Room Louka**
Tuesday	*14:00-15:30*	Adam Park Hotel	**Room Louka**

Soliton resolution for the radial quadratic wave equation in six space dimensions

Mon.
14:00–14:30
R Louka

C. Collot[1], T. Duyckaerts [2], C. Kenig[3], F. Merle[4]

[1] *CY Cergy Paris Universite*
[2] *Universite Sorbonne Paris Nord*
[3] *The University of Chicago*
[4] *CY Cergy Paris Universite et Institut des Hautes Etudes Scientifiques*

This talk will be about the quadratic semilinear wave equation in six dimensions. This energy critical problem admits a ground state solution, which is the unique (up to scaling) positive stationary solution. We prove that any spherically symmetric solution, that remains bounded in the energy norm, evolves asymptotically to a sum of decoupled modulated ground states, plus a radiation term. We will discuss related results we obtained that are used the proof. The first are new dispersive estimates called channels of energy, which are of a weakened form due to a degeneracy in even dimensions. The second is the classification of non-radiative solutions outside an exterior cone, with as a by-product their asymptotic behaviour at spatial infinity.

Bibliography

[1] C. Collot, T. Duyckaerts, C. Kenig, F. Merle, Soliton resolution for the radial quadratic wave equation in six space dimensions, 2022, arXiv:2201.01848.
[2] C. Collot, T. Duyckaerts, C. Kenig, F. Merle, On channels of energy for the radial linearised energy critical wave equation in the degenerate case, 2022, Int. Math. Res. Not.
[3] C. Collot, T. Duyckaerts, C. Kenig, F. Merle, On classification of non-radiative solutions for various energy-critical wave equations, 2022, arXiv:2211.16085.

Logarithmic corrections in kinetic reaction transport waves

Mon.
14:35–15:05
R Louka

E. Bouin

CEREMADE-Université Paris-Dauphine PSL

In this talk, we will present propagation results in a kinetic reaction-transport equation of monostable type. Earlier result shows the existence of traveling wave solutions and their stability. The aim here is to show the occurrence of a logarithmic Bramson correction in the Cauchy problem. This requires hypocoercive estimates on linearized BGK operators in half bounded domains, interesting for themselves. It is noteworthy to observe a reaction diffusion type pattern in a model that describes purely hyperbolic motions.

Large-time dynamics of solutions of reaction-diffusion equations in $\mathbb{R}^N$ with general initial support

Mon.
15:10–15:40
R Louka

F. Hamel

Aix Marseille Univ, CNRS, I2M, Marseille, France

The talk will focus on the large-time dynamics of bounded solutions of reaction-diffusion equations in $\mathbb{R}^N$ with general bounded or unbounded initial support. I will discuss the existence of spreading speeds and spreading sets of the solutions in any direction, in connection with the existence of planar traveling fronts. I will also explain some results on the asymptotic one dimensional symmetry of the elements of the $\Omega - limit$ sets of the solutions. Lastly, I will discuss the influence of the fragmentation of the initial support on the large-time dynamics. The talk is based on joint works with Luca Rossi and with Matthieu Alfaro and Lionel Roques.

Near-resonance approximation of rotating Navier-Stokes equations

Mon.
16:10–16:40
R Louka

B. Cheng

University of Surrey, UK

We formalise the concept of near resonance for the rotating Navier-Stokes equations, based on which we propose a novel way to approximate the original PDE. The spatial domain is a three-dimensional flat torus of arbitrary aspect ratios. We prove that the family of proposed PDEs are globally well-posed for any rotation rate and initial datum of any size in any H^s space with $s \geq 0$. Such approximations retain many more 3-mode interactions, and are thus more accurate, than the conventional exact-resonance approach. Our approach is free from any limiting argument that requires physical parameters to tend to zero or infinity, and is free from any use of small divisors (so that all estimates depend smoothly on the torusŠs aspect ratios). The key estimate hinges on the counting of integer solutions of Diophantine inequalities rather than Diophantine equations. Using a range of novel ideas, we handle rigorously and optimally challenges arising from the non-trivial irrational functions in these inequalities. The main results and ingredients of the proofs can form part of the mathematical foundation of a non-asymptotic approach to nonlinear, oscillatory dynamics in real-world applications.

Scattering of solutions of the inhomogeneous nonlinear Schrödinger equation

Mon.
16:40–17:10
R Louka

S. Tayachi

Universite de Tunis El Manar, Faculte des Sciences de Tunis, Laboratoire Equations aux Derivees Partielles, Tunis, Tunisia

In this talk, we will present some results obtained in [1, 2] for the in homogeneous nonlinear Schrodinger equation $i\partial_t + \triangle u = K(x)|u|^\alpha u, u(0) = u_0 \epsilon H^s(\mathbb{R})^N, s = 0, 1, N \geq 1, |\ K(x)\ | + |x|^s \nabla^s K(x) \leq |x|^{-b}, 0 < b < min(2, N - 2s), 0 < \alpha \leq (4 - 2b)/(N - 2s)$.
We will discuss a local well-posedness theory which enables us to reach the critical case $\alpha = (4-2b)/(N-2s)$) and to unify results for $b = 0$ and $b > 0$ We shall also discuss some results of global existence for oscillating initial data and scattering theory in a weighted L^2-space for a new range $\alpha_0(b) < \alpha < (4 - 2b)/N$. The value $\alpha_0(b)$ is the positive root of $N\alpha^2 + (N - 2 + 2b)\alpha - 4 + 2b = 0$ which extends the Strauss exponent known for $b = 0$ ([3, 4]).
In the defocusing case, we prove decay estimates provided that the potential satisfies some rigidity type condition which leads to a scattering result. We give also a new scattering criterion taking into account the potential K.
Our results improve the known ones for $K(x) = \mu|x|^{-b}, \mu \in \mathbb{C}$. For general potentials, we highlight the impact of the behavior at the origin and infinity on the allowed range of α.
In particular if the potential is regular, we show that more it decreases, more the range of allowed α giving scattering is wider. For instance, if the decay of K at infinity exceeds $|x|^{-2}$, then the scattering for small data in $H^1(\mathbb{R}^N)$ or in the weighted L^2-space occurs for the whole range $0 < \alpha < 4/(N - 2)$.
These are joint works with Lassaad Aloui (University of Tunis El Manar).

Bibliography

[1] L. Aloui and S. Tayachi, Local well-posedness for the inhomogeneous nonlinear Schrodinger equation, Discrete Contin. Dyn. Syst., 41 (2021), 5409-5437.
[2] L. Aloui and S. Tayachi, Global existence and scattering for the inhomogeneous nonlinear Schrĺodinger equation, arXiv:2108.02583 (2021).
[3] T. Cazenave and F. B. Weissler, Rapidly decaying solutions of the nonlinear Schrĺodinger equation, Comm. Math. Phys., 147(1992), 75-100.
[4] Y. Tsutsumi, Scattering problem for nonlinear Schrĺodinger equations, Ann. Inst. H. Poincare Phys. Theor., 43 (1985), 321-347.

On a data assimilation algorithm for tumor growth

Mon.
17:10–17:40
R Louka

S. Trabelsi

Division of Mathematical and Computer Science and Engineering, King Abdullah University of Science and Technology, Thuwal, Saudi Arabia

In this talk, I will present a data assimilation algorithm, initially introduced by Azouani and Titi, and inspired by ideas developed for designing finite-parameters feedback control for

dissipative systems. Specifically, we present an application of this algorithm forecasting the evolution of a brain tumor based on a Cahn-Hilliard type model. Additionally, the algorithm is combined with arguments arising from optimal control theory aiming at personalizing tumor growth models based on patient's data.
This work is in collaboration with Mostafa Kadiri (TAMUQ), Mohammed Louaked (Univ. Caen) and Edriss Titi (Cambridge and TAMU).

Mathematical study of the spread and blockage of an inflammatory disease

Tue.
10:45–11:15
R Louka

S. Latrach, N. Vauchelet , H. Zaag

Sorbonne Paris Nord University, Sorbonne Paris Nord University

Ulcerative colitis (UC) and Crohn's disease (CD) are chronic inflammatory diseases that affect the digestive tract, causing daily discomfort. Although symptoms are similar, the modes of disease propagation are different. CD spreads discontinuously and excavating along the digestive tract, while UC spreads continuously and superficially, affecting a uniform area from the rectum to different parts of the colon (see [2] and [1]). In our research work, we are interested in studying a mathematical model of inflammation caused by Inflammatory Bowel Disease that has been developed in [3] with modifications. It is a reaction-diffusion system governing the dynamics of a pathogen in interaction with immune cells. The first study focuses on the existence of propagation waves for such a system in a homogeneous medium, the second study focuses on blocking these waves in a heterogeneous medium. We will use numerical simulations to highlight these theoretical results.

Bibliography

[1] Yong-Ping Ding, Yannick Ladeiro, Ian Morilla, Yoram Bouhnik, Assiya Marah, Hatem Zaag, Dominique Cazals-Hatem, Philippe Seksik, Fanny Daniel, Jean-Pierre Hugot, et al. Integrative network-based analysis of colonic detoxification gene expression in ulcerative colitis according to smoking status. Journal of Crohn's and Colitis, 11(4):474-484, 2017.
[2] Wing-Cheong Lo, Razvan I Arsenescu, and Avner Friedman. Mathematical model of the roles of t cells in inflammatory bowel disease. Bulletin of mathematical biology, 75(9):1417-1433, 2013.
[3] Gregoire Nadin, Eric Ogier-Denis, Ana I Toledo, and Hatem Zaag. A turing mechanism in order to explain the patchy nature of crohn's disease. Journal of Mathematical Biology, 83(2):1-17, 2021.

Singularities in the complex Ginzburg Landau equation

Tue.
11:20–11:50
R Louka

N. Nouaili[1], G.K. Duong [2], H. Zaag[3]

[1] *CEREMADE, Université Paris Dauphine, Paris Sciences et Lettres, Paris, France*
[2] *Université Paris 13, Sorbonne Paris Cité, LAGA, CNRS, Villetaneuse, France*
[3] *Institute of Applied Mathematcis, University of Economics Ho Chi Minh City, Vietnam*

The equation of complex Ginzburg Landau (CGL) have a long history in physics. The CGL-equation describes a lot of phenomena including nonlinear waves, second-order phase transitions, and superconductivity. The study of collapse, chaotic or blow-up solutions of equation appears in many works; in the description of an unstable plane Poiseuille flow or in the context of binary mixtures. The talk will present constructive examples of finite-time blow-up solution to the CGL equation.

Parameter recovery for the KdV equations via continuous data assimilation

Tue.
11:55–12:25
R Louka

M. Azoua[1], A. Azouani [2,3], I. Hafidi[4]

[1] *Sultan Moulay Slimane University, National School of Applied Sciences, Khouribga, Morocco*
[2] *Freie University Berlin, Institut fur Mathematik, Berlin, Germany*
[3] *Sultan Moulay Slimane University, National School of Applied Sciences, Khouribga, Morocco*
[4] *Sultan Moulay Slimane University, National School of Applied Sciences, Khouribga, Morocco*

We study the numerical performance of a continuous data assimilation algorithm proposed by Azouani, Olson, and Titi (AOT), based on ideas from feedback control theory of dynamical systems, in the context of the KdV equation. The motivation of this work is the estimation of some parameters of this equation. We determine the large-scale error between the real solution of the KdV equation and the assimilated solution in the context of two different values were assigned to the same parameter. Finally, we execute through Matlab some numerical simulations to approve and verify our theoretical results.

Bibliography

[1] A. Azouani, E. Olson, and E. S. Titi, Continuous data assimilation using general interpolant observables, J. Nonlinear Sci., 24, 277-304, 2014.
[2] D. A. Albanez, H. J. Nussenzveig Lopes, and E. S. Titi, Continuous data assimilation for the three-dimensional Navier-Stokes-a model, Asymptot. Anal., 97, 139-164, 2016.

Oscillatory dynamics for evolution equations using Favard's theory in uniformly convex Banach spaces

Tue.
14:00–14:30
R Louka

K. Ezzinbi

Faculty of Sciences Semlalia Department of Mathematics, Marrakech, Morocco

In this work, we use an approach due to Favard (Acta Math 51:31-81, 1928) to study the existence of weakly almost periodic and almost automorphic solutions for some evolution equation whose linear part generates a C_0 -group satisfying the Favard condition in uniformly convex Banach spaces. When this C_0 -group is bounded, which is a condition stronger than Favard's condition, we prove the equivalence between almost automorphy and weak almost automorphy of solutions

Blow up of p-Laplacian type heat equation with nonlinear source term

Tue.
14:30–15:00
R Louka

Y. Abouelhanoune, A. Azouani

[1] *UAE, National School of Applied Sciences Al-Hoceima*
[2] *USMS, National School of Applied Sciences Khouribga*

In some classes of nonlinear heat equations, solutions may not exist globally for t>0 but maydevelop singularities in finite time. The blow-up has been asubject of intensive mathematical studies inconnection with various fields of science such asplasma physics, combustion theory and population dynamics.
The purpose of this work is to study the blow-up behavior of the nonlinear heat propagation in a reactive medium with nonlinear source term

$$u_t=\Delta_p u+|u|^{q-1}u;x\in\mathbf{R}^N$$

where $pq>2$ and $\Delta_p u= \mathrm{div}?\left(|\nabla u|^{p-2}\nabla u\right)$ is the well-known nonlinear p-Laplacian operator. Our contribution is an extension of the work of Georgi [1] who considered the problem of the existence of solutions which approach the steady state solution in the strong stable manifold with some exponential rate. We apply the index theory techniques after reducing the problem to finite dimensional one to show the shape of the profiles exhibiting blow-up solutions for compatible boundary condition.

Bibliography

[1] M. Georgi, The shape of profiles exhibiting blow up in forward and backward time, Preprint, FU Berlin (2007).
[2] Giga, Y., and Kohn, R., Nondegeneracy of blow-up for semi linear heat equations, Comm. Pure Appl. Math. 42, 1989, pp. 845-884.
[3] Giga, Y., and Kohn, R., Characterizing blowup using similarity variables, Indiana Univ. Math. J. 36, 1987, pp. 1-40.
[4] Weissler, F., Single-point blowup for a semi linear initial value problem, J. Di. Equations 55, 1984, pp. 204-224.
[5] F. Merle and H. Zaag. Optimal estimates for blowup rate and behavior for non-linear heat equations. Comm. Pure Appl. Math., 51(2):139n?196, 1998. 6. Herrero, M.A, and Velazquez, J.J.L., Flat blow-up in one-dimensional semi linear heat equations, Differentialand Integral eqns. 5, 1992, pp. 973-997.

MS 4

Dynamics of Mechanical Structures and Structural Health Monitoring

Chairmen: *J. Latalski* Poland, *D. Gaska* Poland

Scheduled:			
Tuesday	*14:00–15:40*	Adam park Hotel	**Room Tichka**
Tuesday	*16:10–17:50*	Adam park Hotel	**Room Tichka**

Optimizing the bandgap region of a meta-beam with bistable resonators

Tue.
14:00–14:20
R Tichka

J.P. Norenberg[1], A. Cunha Jr[2]

[1] *São Paulo State University, Ilha Solteira, Brazil*
[2] *Rio de Janeiro State University, Rio de Janeiro, Brazil*

Mechanical vibrations can damage the structure's health, typically leading to failure. Several researchers have been dedicated to developing mechanisms to avoid undesired structure vibrations. Recently, metamaterials applications showed efficiency at forbidding elastic wave propagations in a frequency band in the whole body of interest. This specific frequency domain is known as the bandgap region. A low-frequency bandgap can be obtained by tuning the resonance of resonators because of the local resonance mechanism [1]. In this context, this work studies the suppression of flexural wave propagation in a meta-beam. The system consists of a cantilever beam with nonlinear resonators uniformly spread across its body. The cantilever beam is modeled by the Euler-Bernoulli equation, and the resonators are attached using discrete mass with a bistable potential as proposed by [2]. Bandgap region is defined using the modal analysis by sweeping sine from transmissibility concerning the fixed and end node of the beam. This work aims to optimize the resonators' nonlinear stiffness to widen the bandgap region. For this purpose, the cross-entropy (CE) method, a metaheuristic for non-convex optimization, is employed. The CE method transforms the optimization problem into an equivalent rare event estimation problem, being a global search algorithm, robust and simple [3]. The stochastic model response is approximated by a polynomial chaos expansion (PCE) surrogate model to reduce the computational cost. We identified a pattern of different stiffness values that can broaden the length of the bandgap. The presence of a nonlinearity feature can decrease the resonance peaks close to the bandgap. However, the bistability did not carry any advantage inside the bandgap region for the range values studied.

Bibliography

[1] Z. Liu, X. Zhang, Y. Mao, Y. Y. Zhu, Z. Yang, C. T. Chan, P. Sheng, Science 289, 1734-1736, 2000.
[2] Y. Xia, M. Ruzzene, A. Erturk, Nonlinear Dynamics 102, 1285-1296, 2020.
[3] A. Cunha Jr, Nonlinear Dynamics 103, 137-155, 2021.

Time integration of constrained multi-catenary systems

Tue.
14:20–14:40
R Tichka

D. Sedlar[1], Z. Lozina [2]

[1] *University of Split, FESB*
[2] *University of Split, FESB*

The multi-catenary systems offer interesting possibilities for miscellaneous tension structures and shaping different three-dimensional forms such as cable-stayed bridges, roofs, power lines, zip-lines, pantograph-catenary interaction. This wide variety of application was achieved thanks to catenary flexibility. Because of catenary flexibility this structures are expose to the large displacements which lead to the geometric nonlinearities which is main difficulty encountered in dynamic analysis of multi-catenary systems. In this work the concept of isogeometric analysis (IGA) is applied [1]. IGA is recently introduced method of computational analysis with goal of merging design and analysis into one model by employing Non-Uniform Rational B-Splines (NURBS). Since its good results, the research in the field of IGA is in increasing path and has been applied to the various problems. Due to its complexity the constrained multi-catenary systems is insufficiently researched. The multi-catenary system is modeled and analyzed by employing IGA approach. The obtained equations of motion for a constrained multi-catenary system present the form of a mixed set of second order differential and algebraic equations (DAE) [2]. In this work different aspect of the implementation of Newmark family algorithms for integration of DAE is analyzed. The augmented Lagrangian method is used to solve holonomic constrained problem which consists of slider joint [3]. To confirm the derived and proposed procedure, it is applied to the several numerical examples. The catenaries in numerical examples are modeled with different number of elements and polynomial degrees. The obtained results showed that dynamics of constrained multi-catenary system is successfully solved using IGA approach and augmented Lagrangian method. The important role in solving such complex system has time step and numerical damping which need to be carefully selected depending on chosen Newmark algorithm.

Bibliography

[1] T.J.R. Hughes, J.A. Cottrell, Y. Bazilevs, Isogeometric analysis: CAD, finite elements, NURBS, exact geometry and mesh refinement, Computer methods in applied mechanics and engineering 194, 4135-4195, 2005.
[2] M. Geradin, A. Cardona, Flexible Multibody Dynamics-A finite Element Approach, Wiley, 2001.

[3] D. Sedlar, I. Tomac, P. Latinac, Dynamic analysis of elastic pendulum with slider, 3 rd International Conference on Smart and Sustainable Technologies, 26-29 June, Split, Croatia, 2018.

Reliability analysis of mechanical structure with surrogate model

Tue.
14:40–15:00
R Tichka

L. Shao[1], A. Saidi [2], A. Zine[2], M. Ichchou [2]

[1] *Laboratory of Tribology and Dynamics of Systems, Ecole Centrale Lyon, Ecully, France*
[2] *Computer Science Laboratory for Image Processing and Information Systems, Ecole Centrale Lyon, Ecully, France*
[3] *Institut Camille Jordan, Ecole Centrale Lyon, Ecully, France*

Structural Reliability Analysis (SRA) is a big challenge in civil and mechanical engineering. One of the reasons is that uncertainty quantification of complex physic systems is an essential component to be evaluated. Over the past few decades, a wide variety of SRA methods have been investigated. However, the classical techniques require information about Limit State Function (LSF), which can be computationally expensive. As a solution, machine learning models such as ensemble learning models are recently attracting more and more attention. In this research, the reliability analysis is performed in a surrogate-based ensemble learning model that models structural parameter uncertainties and maps them into failure probabilities. The basic idea is to find a surrogate model equivalent to the performance function. This research uses the Machine Learning-based surrogate model to evaluate TMD structural uncertainties propagation. Seen as a regression procedure, the prediction task is realized by machine learning models such as Random Forest, Gradient Boosting, XGBoost, and Neural network. Different structures with TMD are investigated. The longitudinal vibration and the transversal shear effect in a beam-like structure are also considered. Besides, a beam-like model is created and dynamic response simulations are carried out under seismic excitations. The analytical analysis and numerical examples are carried out to evaluate the benchmarking performance of different ML methods. Simulation results verify that the proposed surrogate mechanics are efficient.

Multi-scale dynamics and nonlinear eigenvalue problem of heterogeneous metastructures using a wave finite element scheme and modal strain energy method

Tue.
15:00–15:20
R Tichka

D. Cui[1,2], M. Ichchou [1], A. Zine[3], N. Atalla[2]

[1] *Vibroacoustics & Complex Media Research Group, LTDS- CNRS UMR, Ecole Centrale de Lyon, Ecully, France*
[2] *Groupe d'Acoustique de l'Université de Sherbrooke, Université de Sherbrooke, Québec, Canada.*
[3] *Institute Camille Jordan-CNRS UMR, Ecole Centrale de Lyon, Ecully, France*

In this article, the Modal Strain Energy Method is used within the Wave Finite Element (WFE) scheme to reveal the multi-scale dynamics and damping characteristics of heterogeneous metastructures. Firstly, an in-depth clarification of high contrast and high dissipation in metastructures is addressed, especially on the multi-scale dynamics of Highly

Contrasted Structure (HCS) and the relative rheological damping of PVB in Highly Dissipative Structures (HDS). The High Order Homogenization Method (HOHM) is introduced to calculate the wave numbers which reflect the Bending-Shear Coupling effect in the HCS through the two limit behaviors of HCS, the monolithic limit and bi-layer limit. The numerical method, Wave Finite Element (WFE) scheme and the Nonlinear Eigenvalue Problem (NEP) when considering the wavevector propagation in different heading angle is detailed and tackled by the Contour Integral method, the veering effect of the wavenumbers induced by the high contrast is surmounted by Weighted Wave Assurance Criteria (WWAC) accounting for the energetic distribution for pairing the numerically derived wavemodes obtained from WFE, the WFE scheme is further developed to handle the wave identification and calculate the Damping Loss Factor (DLF) in metastructures using the Modal Strain Energy Method (MSEM). For validation purposes, the tricky problem of multi-scale behavior in the Finite Element (FE) modelling of heterogeneous metastructures are investigated, the bending-shear coupling of Laminated Glass (LG) is overcome by sharing the nodes at the interfaces, for its counterpart, the sandwich structures, the Classical Lamination Plate Theory and Small Deformation Theory are combined to constrain the motion of the SHELL and SOLID elements, the wavenumbers of WFE scheme show good agreement with results from HOHM and numerical outcomes via General Laminate Model (GLM) and classical model RKU. The agreement of wavenumbers and DLF shows the general feasibility of WFE scheme for HDS, the multi-scale behavior is correctly captured in the heterogeneous metastructures by analyzing the wavenumber, and some useful conclusions are discussed.

Nonlinear vibration of thin imperfect plate by an asymptotic numerical method

Tue.
15:20–15:40
R Tichka

L. Benchouaf[1], E.H. Boutyour [2]

[1] *National School of Applied Sciences, Ibn Zohr University, Agadir, Morocco*
[2] *Faculty of Sciences and Technologies, Hassan First University, Settat, Morocco (boutyour.elhassan@gmail.com).*

Nonlinear free vibrations of thin rectangular plates taking into account the initial geometric imperfections are investigated by an asymptotic numerical method. The von Kármán nonlinear strain-displacement relationships are adopted to describe the geometric nonlinearity. The harmonic balance approach and Hamilton's principle has been introduced to convert the equation of motion into an operational formulation. The principle of the asymptotic numerical method is to represent the unknowns (displacements, frequency,) by a power series expansion with respect to a control parameter. By introducing the expansion into the governing equation, the nonlinear problem is transformed into a sequence of simple linear problems having the same stiffness matrix, which can be solved by the finite element method using a specific triangular shell element having three nodes and ten degrees of freedom per node, not considered previously. At each stage of the proposed procedure, Padé approximants are incorporated to improve the validity range of the power series and to reduce the computational cost. The continuation technique is also used to obtain the complete solution. Numerical results are discussed and compared to those available in the literature and convergence of the solution is shown for

various amplitudes of initial imperfection of square and rectangular plates. Two types of boundary conditions will be presented in the present study: (i) simply supported plates with immovable edges and (ii) fully clamped plates.

Parametric resonances and stability of the rotating blade subjected to base excitation

Tue.
16:10–16:30
R Tichka

J. Latalski, J. Warminski

Department of Applied Mechanics Faculty of Mechanical Engineering Lublin University of Technology, Poland

The presentation discusses the dynamics of a rotating laminated cantilever beam when subjected to harmonic to-and-fro base excitation. In the adopted mathematical model of the structure the complex bending-shear-twisting deformations of the blade resulting from the layout of the composite material are considered. In the proposed formulation both compact and thin-walled cross sections of the blade are considered to capture modern light-weight designs. Moreover, to enhance the generality of the analysis, an arbitrary orientation and stacking sequence of the laminate is considered. To account for shear-prone properties of composite materials and their inherent complex deformations the mathematical model of the beam complies the classical Timoshenko beam theory but has been extended with the elastic torsional component.

The governing equations and corresponding boundary conditions have been derived following the Hamilton's principle. The written equations provide a system of cross-coupled partial differential equations with some time dependent coefficients contributing to the possibility of the parametric resonances. Next, the formulated partial differential equations are reduced to the ordinary differential ones following the Galerkin's approach . To study the dynamic performance of the system the method of multiple time scales up-to the second approximation order (ε^2) is used and the transition lines separating stability regions on the Ince-Strut diagrams are determined. In numerical simulations different laminate stacking sequences entailing different ratios of bending-shear-twisting deformations within an individual natural mode are investigated. Moreover, the influence of beam rotating speed and base excitation frequency on the dynamic stability of the structure is examined. The validity of the analytical results is confirmed by numerical simulations in Mathlab/Simulink software.

Bibliography

[1] T.J.R. Hughes, J.A. Cottrell, Y. Bazilevs, Isogeometric analysis: CAD, finite elements, NURBS, exact geometry and mesh refinement, Computer methods in applied mechanics and engineering 194, 4135-4195, 2005.
[2] J. Latalski, J. Warminski, Journal of Sound and Vibrations 523, 116680, 2022.
[3] J. Latalski, J. Warminski, Mathematics and Mechanics of Solids 22(6), 1303-1325, 2017.

Enhanced group analysis and analytical solutions for the mode shapes of non-uniform rods

Tue.
16:30–16:50
R Tichka

A.W. Nunes[1], A.Ruiz [2], S. da Silva [1], S. Dimas[3]

[1] *Departamento de Engenharia Mecânica, Faculdade de Engenharia de Ilha Solteira, UNESP Ű Universidade Estadual Paulista, SP, Brazil*
[2] *Departamento de Matemáticas, Facultad de Ciencias, Universidad de Cádiz, Puerto Real, Spain*
[3] *Departamento de Matemática, Divisão de Ciências Fundamentais, ITA-Instituto Tecnológico da Aeronáutica, São José dos Campos, SP, Brazil*

Structural modeling of non-uniform cross-sections plays a crucial role in the vibration analysis of non-conventional elastic bodies and usually involves complicated differential equations (DEs). The difficulty in computing analytical solutions for such equations directs their resolution toward numerical approaches, which do not work for arbitrary material and geometric cross-section variations. Scarce analytical solutions are available in the literature for these problems, even considering particularly simple non-uniformities. Whereas numerical methods provide fruitful results for assessing the motion behavior of particular non-uniform-like structures with high sophistication, analytical solutions also offer notable benefits, e.g., avoiding convergence studies and approximation errors, reducing computational time, and inspecting problems with arbitrary elements such as undefined non-uniform cross-sections. Within the framework of finding analytical solutions, symmetry methods encompass changing coordinate procedures via group transformations for classifying, simplifying, and solving DEs. Among these methods, enhanced group analysis gives equivalence transformations for classifying and determining families of DEs that may be free of arbitrary parameters and constants or at least have fewer of them. It brings the benefit of dealing with simpler but mathematically equivalent equations, thus likely accomplishing their analytical solutions. This work deals with the computation of such equivalent equations and their solution via symmetry methods and power series for vibration models of rods with both material and geometric non-uniformities. These models follow the associated mode shape equations, which provide displacement patterns for the given vibrating systems. From that, an elegant way of deriving analytical solutions arises for non-uniform rod configurations.

Nonlinear dynamics and energy harvesting of multi-stable cantilever shells with embedded piezoelectric patch

Tue.
16:50–17:10
R Tichka

L. Kloda[1], M. Brunetti[2], A. Mitura[1], F. Romeo[3], J. Warminski[1], D. Melnyk[1]

[1] *Department of Applied Mechanics, Lublin University of Technology, Poland*
[2] *Polytecnic department of Engineering and Architecture, University of Udine, Italy*
[3] *Department of Structural and Geotechnical Engineering, Sapienza University of Rome, Italy*

Experimental studies on bi-stable structures available in the wide literature focus on stacking the composite plate on a flat table, and the morphing effect comes from the shrinkage of the asymmetric material in the curing process. In this work, pseudo-conical shells with clamped boundary conditions on one side are investigated. In our case the morphing effect arises from a practical clamping of the specimen which induces an initial pre-stress and, therefore, an accumulation of elastic potential energy in the fundamental

configuration called I-shape. In the quasi-static approach, various types of external loads are tested for potential energy profiles depending on the geometrical parameters of the conical surface e.g., length-to-width ratio or radii of curvature. Based on potential energy profiles having more than one well multi-stability maps are elaborated. Two geometric configurations, namely **A** with the co-directional and **B** with opposite curvatures, have been shown to possess two and four steady stable equilibrium states, respectively [1]. In [2], static analyses of bi-stable shell **A** were extended to tackle its peculiar nonlinear dynamic regimes. Under kinematic excitation with frequency in the vicinity of two stable configurations-I-shape and C-shape-corresponding to two separate potential wells, initial experimental tests were carried out. However, due to experimental setup limitations snap-through effects were not reached.

The experience gained from previous works allowed to revise the geometry and material properties of the prototype **A**. The new structure exhibits a rather rich nonlinear dynamics: weak softening of C-shape and strong softening of I-shape together with $1:1$, $2:1$ and $3:1$ modal interaction. Moreover, the two-way snap-through effect between stable configurations is achieved. The observed nonlinear dynamic regimes lend the newly designed shell to be exploited for energy harvesting purposes. By embedding MFC patches on the shell an extensive series of experimental tests was carried out. The derived experimental maps enable to assess the interplay between energy harvesting performance and different dynamic regimes. Vibration and energy harvesting testing on the shell **B** are scheduled for future work.

The work is financially supported by grant 2021/41/B/ST8/03190 from the National Science Centre, Poland.

Bibliography

[1] M. Brunetti, L. Kloda, F. Romeo, J. Warminski, Composites Science and Technology 165, 397-410.

[2] M. Brunetti, A. Mitura, F. Romeo, J. Warminski, Journal of Sound and Vibration 526, 116779

Piecewise integrable neural network: an interpretable chaos identification framework

Tue.
17:10–17:30
R Tichka

N. Novelli, P. Belardinelli, S. Lenci

Civil Engineering and Architecture-Polytechnic University of Marche, Ancona, Italy-Electronic

Artificial Neural Networks (ANNs) are effective data-driven tools to model chaotic dynamics. They allow for incorporating mathematical structure, physical information and constraints. This work develops an interpretable neural network framework that describes chaotic dynamics via piecewise models. Among all the possible descriptions of the chaotic data, the suggested ANN architecture recovers an integrable representation of the equations of motion. The integrability permits us to find a formula for all time describing the system's future state. The piecewise nature gives insights on the fixed points, and it helps to simplify the mathematical structure of the sub-models in which the dynamics is reconstructed. We benchmark the minimal mathematical-biased artificial neural network on two archetypal systems exhibiting chaotic behaviour, namely, the Lorenz system (ODE) and the one-dimensional KuramotoŰSivashinsky equation (PDE). The minimal mathematical-biased artificial neural network succeeds in extracting analytically tractable piecewise-smooth models that directly account for the integrability condition. It is foreseen to augment the algorithm in order to account for stochastic effects and to introduce parametrization during the learning process. The tool has the potential to serve for applications as weather and emergency events forecasting.

Bibliography

[1] G.F.V. Amaral, C. Letellier, and L.A. Aguirre, Piecewise affine models of chaotic attractors: The rössler and lorenz systems, Chaos: An Interdisciplinary Journal of Nonlinear Science 16, 013-115, 2006.

[2] A. Kratsios and B. Zamanlooy, Learning sub-patterns in piecewise continuous functions, Neurocomputing 480, 192-211, 2022.

Linear and nonlinear vibration biodynamic models of hand-arm systems

Tue.
17:30–17:45
R Tichka

N. Hida, M.A. Aouadi, F. Lakrad

Laboratory of Renewable Energy and Dynamics of Systems, Faculty of Sciences Ain Chock, University Hassan II-Casablanca, Morocco

The commonly used vibration models of the hand-arm system (HAS) are mainly linear with passive restoring and dissipative parameters. In this study, we explore both linear and a nonlinear biodynamic HAS models that incorporate active restoring and dissipative parameters. This latter depend mainly on the hand forces and the excitation parameters. The outputs are computed through the calculation of the driving- point mechanical impedance and the vibration transmissibility.

Stadium roof structure analysis in dynamics

Tue.
17:45–18:00
R Tichka

P. Rosko

Slovak University of Technology & Vienna University of Technology

The contribution deals with dynamics and nonlinear stability of the largest stadium roof in Austria. The shape of the roof is defined between outer elliptical ring and inner ring. The height of the roof is variable because only the outer ring is vertically supported. The static idea of the stadium roof structure without inner supports is based on stress in outer ring and tension in inner ring. The bearing structure of the roof is constructed from the steel beams connected with steel-concrete composite joins. The numerical structural model was identified on the base of dynamic measurement. The response spectrum analysis and time history analysis for selected strong motion data were executed. Although the stresses and deformations did not exceed the limits given in Eurocode, the ultimate bearing capacity of the stadium roof was calculated. The arc-length method as an iteration procedure for stability analysis was applied until the snap-through was achieved.

MS 5

Modeling, Control and Analysis of Switching Systems

Chairmen: *A. El Aroudi* Spain, *K. Mandal* Spain

Scheduled:

Tuesday	*14:00–15:40*	Adam park Hotel	**Room Tinmel**
Tuesday	*16:10–17:50*	Adam park Hotel	**Room Tinmel**

Backstepping control of interleaved double dual boost converter for renewable energy system

Tue.
14:00–14:20
R Tinmel

F. Ait bellah[1], A. Abouloifa[1], A. El Aroudi [2], C. Aouadi [1], S. Echalih [1]

[1] *ENSEM of Casablanca, Hassan II University of Casablanca, Casablanca, Morocco*
[2] *Department of Electronics, Electrical Engineering and Automatic Control, Universitat Rovira i Virgili, Tarragona, Spain*

Structural the interleaved double dual boost converter (IDDBC) is considered as promising and reliable approach to interface the low-voltage renewable energy sources (RESs), such as battery packs, fuel cells, and photovoltaic (PV) panels. In fact, it could give a higher voltage step-up ratio and reduce voltage and current stresses on the power devices. The present paper investigates the problem of controlling an interleaved double dual boost converter associated with a PV panel. The main control objectives of this work are threefold: i) regulating the voltage across the PV panel in order to extract the available maximum power; ii) regulating the output voltage; iii) regulating the inductor current. The achievement of these objectives is done thanks to a controller based on a multi-loop structure. Indeed, the PV generator is controlled to track the maximum power point. On the other hand, two cascaded loops are developed, using backstepping approach with Lyapunov theory. The outer loop is constructed to control the energy, which is an image of the output voltage, stored in the output capacitor. Whereas, the inner loop is designed for controlling the inductor current in each sub-converter separately, which their references are generated from the outer loop controller. The performance of the studied system is tested via MATLAB/SimPowerSystems environment. The obtained results demonstrate that the suggested controller successfully meets its objectives and shows the strong dynamic response and resilience against parameter fluctuations and disturbances.

Bibliography

[1] B. Venkata Siva Kumar, B. Guru Raju, "Modeling and Control Design of the Interleaved Double Dual Boost Converter" International Journal of Advanced Technology and Innovative Research Volume.07, IssueNo.21, December-2015.

[2] M. Phattanasak, W. Kaewmanee, Martin, S. Pierfederici, B. Davat, "Interleaved Double Dual Boost Converter for Renewable Energy System" Advanced Materials Research Vols. 931-932.

A cascaded controller design for grid connected PV system through a double stage based on SIDO converter

Tue.
14:20–14:40
R Tinmel

O. Arich, A. Abouloifa, S. Echalih

ENSEM of Casablanca, Hassan II University of Casablanca, Casablanca, Morocco

The DC-DC multilevel boost converter (MBC) derives from a conventional boost converter just by adding (2N-1) number of capacitors and diodes in order to obtain N levels of output voltage. This converter is proposed to be used as DC link in applications where several controlled voltage levels are needed with self-balancing and unidirectional current flow, this feature makes it a suitable candidate for renewable applications such as photovoltaic (PV) or fuel cell generation systems. This paper introduces the problem of controlling the double stage grid connected PV system. The proposed power plants consist of a PV panel, a single input dual output (SIDO) boost converter, two DC link capacitors, and a half bridge inverter. This study aims at reaching simultaneously three control objectives: Extracting the available maximum power by regulating the voltages across the PV panel, ii) regulating the SIDO output voltages (DC link) to track their desired reference values; iii) performing power factor correction (PFC) by forcing the grid current to be sinusoidal and in phase with the electric grid voltage. To achieve these objectives, a cascaded nonlinear controller based on multi-loop structure is developed using backstepping technique for PFC and maximum power point Tracking (MPPT) objectives with a well-known Perturbation and Observation (P&O) algorithm based on the averaged nonlinear model. A proportional-integral PI regulator is used to achieve DC voltages regulation. In this application, its model is based on the equivalent circuits that depend on the commutation states. In addition, the energy produced by PV systems depends mainly on atmospheric conditions such as temperature and solar irradiation. The performance of the studied system is tested via MATLAB/Simulink environment. The obtained results confirm that the proposed controllers meet their objectives under varying environmental conditions without failures [1-3].

Bibliography

[1] Hekss, Z. et al. Nonlinear adaptive control design with average performance analysis for photovoltaic system based on half bridge shunt active power filter. Int. J. Electr. Power Energy Syst. 125, 106-478 (2021).

[2] Echalih, S. et al. A Cascaded Controller for a Grid-Tied Photovoltaic System With Three-Phase Half Bridge Interleaved Buck Shunt Active Power Filter: Hybrid Control Strategy and Fuzzy Logic Approach. IEEE J. Emerg. Sel. Top. Circuits Syst. 12, 320-330 (2022).

[3] Mahajan, S. B., Sanjeevikumar, P., Ojo, O., Rivera, M. & Kulkarni, R. M. Non-isolated and inverting Nx multilevel boost converter for photovoltaic DC link applications. in 2016 IEEE International Conference on Automatica (ICA-ACCA) 1-8 (IEEE, 2016).

Global dynamical analysis of a boost converter with a constant power load and actively damped by a series loss free resistor

Tue.
14:40–15:00
R Tinmel

L. Benadero, A. El Aroudi, M. Sebastiá-Rullo, H. Valderrama-Blavi, A. Cid-Pastor, L. Martínez-Salamero

[1] *Universitat Politècnica de Catalunya, Barcelona, Spain*
[2] *Universitat Rovira I Virgili, Tarragona, Spain*

Cascaded DC-DC power converters appear in many engineering applications of power electronics such as electric vehicles and ships, microgrids, more electric power aircrafts and more electric ships among others. In cascaded DC-DC converters, the first stage is called the source or the upstream converter and the second stage is the load or the downstream converter. When the latter is controlled to maintain a tightly regulated output voltage on the load, it behaves as a constant power load (CPL) for the source converter. For instance, in a microgrid with different voltage buses, if the downstream power electronics interface, which could be a grid-connected DC-AC inverter or a DC-DC converter, is tightly regulated, it will absorb constant power from the upstream DC-DC converter. An electrical machine in an electric vehicle (EV) with tight velocity control and under constant torque operation will also absorb constant power from the three phase DC-AC inverter hence resulting in a CPL to the upstream DC-DC boost converter.

Since the overall dynamics of the converter with CPL tends to be unstable, it can be stabilized by means of a suitable feedback, so requiring sensing the state variables of the converter, either voltage, current or both. Instead, to make stable the converter with CPL in open loop operation, an additional resistor could be added. Because this strategy would imply a reduction in the efficiency of the converter, a convenient alternative solution would be the use of a loss free resistor (LFR). The LFR consists of an additional converter that can feed dissipative loads, for example, lighting or other elements in an electric car.

This work deals with the analysis of the dynamics of an open loop DC-DC boost converter with a stabilizing resistor in series with the inductor and a constant power load. To simplify the analysis and to provide algebraic explicit mathematical results, an averaged model of the circuit is used with a reduced three dimensional parameter space. This model has two possible equilibrium points, a node and a saddle, whose existence and stability are linked to codimension-one smooth fold and Hopf bifurcations, both emerging from a codimension-two fold-Hopf bifurcation. Actually, the node equilibrium, which can be a focus or not, is the approximation of the desired limit cycle of the real switched system. Then, we get parameter restrictions for a correct operation from this analysis. Moreover, an appropriate design requires not only a stable limit cycle with small amplitude, but also that its attractor basin being big enough to include normal starting initial conditions. Then, we make an extended analysis taking into account the global dynamics of the system, mainly related to the stable saddle manifold or to an unstable limit cycle whenever it exists. The boundaries for existence in the parameter space of this unstable big cycle are the hopf bifurcation itself and a global homoclinic bifurcation, which also emerges from the fold-hopf one.

Stabilization of a photovoltaic power source interfacing a current-mode-controlled SEPIC converter with MPPT using piecewise quadratic slope compensation

Tue.
15:00–15:20
R Tinmel

K. Mandal, A. El Aroudi

Department of Electronics, Electrical Engineering and Automatic Control, Universitat Rovira i Virgili, Tarragona, Spain

Current mode control is a predominant strategy in controlling DC-DC switched mode power electronic converters for different applications due to many advantages such as fast system response and better system performances and inherent over current protection, easy parallel operation but it is rarely used in photovoltaic (PV) applications. A PV system consisting of a PV generator interlinked to a DC-DC converter under current mode control may exhibit a rich variety of nonlinear phenomena such as period doubling bifurcation causing subharmonic oscillation and chaotic behavior. The use of an appropriate model allows mathematically predicting the onset of period doubling bifurcation and offers useful physical insights into the behavior of the system without the need for excessive numerical simulations. In this paper we propose to use a single loop control scheme for DC-DC converters when used in a PV system. We propose to use the inductor current both for controlling the converter to a reference provided by a Perturb-and-Observe (P&O) MPPT algorithm as well as to estimate the average value of the PV source power which is used by the same algorithm. It is shown that period doubling bifurcation arises from the instability of the inner current loop of the DC-DC converter and is not significantly related to the nonlinearity of the PV generator. Therefore, linearizing appropriately the PV generator model does not affect the accuracy of the model in predicting the period doubling bifurcation of the system. This is especially beneficial for modeling PV systems and analytically predicting their period doubling bifurcation behavior. A piecewise quadratic slope compensation technique is used for stabilizing the converter with maximum power point. The technique is capable of eliminating subharmonic oscillations in the complete system. With this technique, a self-generated signal is used in the compensation scheme resulting in a naturally full duty cycle stability domain. The expression of the piecewise quadratic compensating signal within a switching cycle is derived. It is obtained that the steady-state value of the amplitude of this signal is the same as in the conventional linear slope compensation scheme that guarantees stability for all values of the duty cycle. However, in the piecewise quadratic scheme this is achieved without exact knowledge of the inductance value nor sensing the input and the output voltages. A SEPIC converter under peak current mode control is used to validate the theoretical results both by numerical simulations and by experiments. Simulation results are obtained from a circuit-level switched model of the converter. The results are analyzed and compared to the performances of the state-of-art techniques.

Bibliography

[1] R. W. Erickson and D. Maksimovic, Fundamentals of Power Electronics. Kluwer, Springer, 2001.

[2] A. El Aroudi, K. Mandal, M. S. Al-Numay, D. Giaouris and S. Banerjee, "Piecewise Quadratic Slope Compensation Technique for DC-DC Switching Converters," in IEEE

Transactions on Circuits and Systems I: Regular Papers, vol. 67, no. 12, pp. 5574-5585, Dec. 2020.

Nonlinear control of grid connected PV systems using modular multilevel converter

Tue.
15:20–15:40
R Tinmel

A. El Boudali[1], A. Abouloifa[1], M. Aourir [1], C. Aouadi [1], A. El Aroudi [2]

[1] *ENSEM of Casablanca, Hassan II University of Casablanca, Casablanca, Morocco*
[2] *Department of Electronics, Electrical Engineering and Automatic Control, Universitat Rovira i Virgili, Tarragona, Spain*

This paper presents the modelling and Control of grid-connected Photovoltaic Panel (PV) systems using a Modular Multilevel Converter (MMC) as an interfaced power system. MMCs are more used in high voltage/medium power applications such as wind/solar system, different motors, energy distribution and transmission system because of modular design, high efficiency and low distortion of the output voltage. In other hand MMCs are considered a suitable topology for PV systems applications as they offer significant benefits, including the generation of a multilevel output waveform which reduces the harmonic content and leads to the use of smaller size filters, besides reducing the voltage stress on the power switches. In this work, we seek the achievement of the following objectives: i) Extract the maximum power from the PV generators despite the climatic conditions of temperature and irradiance; ii) ensure the regulation of the DC link voltage; iii) ensure the power factor correction by injecting a sinusoidal current synchronized with the grid voltage. To realize the objectives mentioned above, a cascaded controller is designed. First, an outer loop has been made using a filtered Proportional Integrator (PI) regulator to regulate DC link voltage to a fixed value, and then an inner loop has been designed using the Lyapunov approach to ensure the power factor correction. The performance of the suggested system and its designed control unit have been tested through simulation using MATLAB environment and Simulink/SimpowerSystems toolboxes. The obtained results of various simulation profiles prove the excellent performance of the controlled system.

Bibliography

[1] Solas, E., Abad, G., Barrena, J. A., Cárcar, A. & Aurtenetxea, S. Modelling, Simulation and Control of Modular Multilevel Converter. 14th International Power Electronics and Motion Control Conference (EPE-PEMC), 6-8 September, Ohrid (Republic of Macedonia), 2010.
[2] Swetha SP & Sumangala, B. V. Solar photovoltaic power conversion using modular multilevel inverter, International Conference on Emerging Research in Electronics, Computer Science and Technology (ICERECT), 17-19 December, Mandya India, 2015.
[3] Ishfaq, M. et al. Output Current Control of Modular MultiLevel Converter Using Back-Stepping Controller. 15th International Conference on Emerging Technologies (ICET), 2-3 December, Peshawar Pakistan, 2019.

Backstepping based control and stability analysis for single stage grid connected photovoltaic system through half bridge power inverter

Tue.
16:10–16:30
R Tinmel

N. Hourri [1], A. Abouloifa [1], A. El Aroudi [2], Z. Hekss [1], M. Aourir [1], S. Echalih [1], O. Arich[1]

[1] *ENSEM of Casablanca, Hassan II University of Casablanca, Casablanca, Morocco*
[2] *Department of Electronics, Electrical Engineering and Automatic Control, Universitat Rovira i Virgili, Tarragona, Spain*

In this work, a new approach based on Backstepping technique for three-phase single stage grid connected photovoltaic system is developed. The aim of this work is to solve the problem of controlling a single stage half-bridge inverter applying two DC link capacitors, and a grid side LCL filter by providing the three following objectives: (i) the PV panels should give their maximum power by applying a MPPT algorithm, (ii) a balance power exchange by controlling the DC link voltage, and (iii) a unit power factor by forcing the grid currents to be in phase with the grid voltages. To meet these purposes, a multi-loop nonlinear controller is established by using the Backstepping technique with Lyapunov approaches. To this end, an internal loop is designed in three steps using the backstepping technique and Lyapunov's stability tools for ensuring the unit power factor. Consequently, the subsystem will be stabilized by forcing the grid currents to follow their references with a simple technique to estimate current reference signal. An outer loop is designed with a filtered proportional integral regulator to ensure a tight voltage regulation by controlling the capacitors voltage to follow their references given by MPPT algorithm. The maximum power point tracking (MPPT) block is established utilizing the incremental conductance algorithm for achieving perfect tracking accuracy at steady state and under rapidly varying weather conditions. The performance of this approach is formally analyzed using both steady state analysis and closed loop stability analysis by applying an indirect Lyaponuv stability, averaging theory and Routh criteria. Finally, the simulation results, obtained using the MATLAB/SimPowerSystems environment, demonstrate that the developed controller satisfies its objectives under different operating conditions.

Bibliography

[1] Abouloifa A, Aouadi C, Lachkar I, Boussairi Y, Aourir M, Hamdoun A. Output-feedback nonlinear adaptive control strategy of the single-phase grid-connected photovoltaic system. J Sol Energy 2018;2018:1-14.
[2] Hekss, Z., Abouloifa, A., Echalih, S., and Lachkar, I. (2019). Cascade Nonlinear Control of Photovoltaic System Connected to Single Phase Half Bridge Shunt Active Power Filter, In 2019 4th World Conference on Complex Systems (WCCS) (pp. 1-6). Ouarzazate, Morocco. IEEE.
[3] Z. Hekss, A. Abouloifa, J. M. Janik, I. Lachkar, S. Echalih, F. Z. Chaoui, F. Giri, IFAC PapersOnLine 53- 2 (2020) 12847-1285, period of the conference, venue, 2017.
[4] Aouadi, C., Abouloifa, A., Hamdoun, A., Boussairi, Y., 2014. Backstepping Based Control of PV system Connected to the Grid. Int. J. Comput. Inf. Technol.

Tue.
16:30–16:50
R Tinmel

Interaction of multiple timescale dynamics of interconnected subsystems in electric vehicle

K. Mandal , A. El Aroudi

Department of Electronics, Electrical Engineering and Automatic Control, Universitat Rovira i Virgili, Tarragona, Spain

A general electric vehicle (EV) consists of many interconnected subsystems such as battery, bi-directional boost/buck converter, three phase voltage source inverter (VSI), motor, and vehicle body. Depending on the applications and cost requirement, the type of battery (Lead-acid, Li-ion), motor (Permanent Magnet Brushless DC Motor (PMBLDC), Induction Motor (IM), Permanent Magnet Synchronous Motor (PMSM), Switched Reluctance Motor (SRM)), and vehicle body (two-wheeler (2W), three-wheeler (3W), four-wheeler (4W), bus or truck) are selected. The power has been fed to the three-phase inverter-motor combination from the battery through bidirectional dc-dc converter (boost mode). The bidirectional converter is placed for the flexibility of the choice of rated battery voltage and rated input voltage of three phase VSI. The motor is connected to the vehicle body through the transmission system consists of fixed gear. During regenerative braking the power flows in reverse direction through bidirectional converter (buck mode) to charge the battery. It is a process of recovering the kinetic energy of the EV at the time of braking which in turn increases the efficiency and range per charge of the overall system. A two loop control is selected for bidirectional boost/buck dc-dc converter. The outer loop and inner loop are implemented to regulate the dc-link voltage and to limit the battery discharge current by average current mode control respectively. For different motors, different control methods can be used e.g., two loop control, direct torque control (DTC), Field-oriented control (FOC), V/f scalar control etc.

In this paper, a switched nonlinear model of complete EV is presented using state-space modelling which can be used to identify different instabilities related to nonlinear switching dynamics. As the time constants of the different subsystems varies from s to seconds, the study of the dynamical interaction of the subsystems is very important considering high switching frequency dynamics. To the best of the authors' knowledge, this is the first attempt in this system. Later it can be extended to other complex interconnected switching systems. Such analysis provides useful guidelines for the design and control of the interconnected subsystems under parameter variation.

Bibliography

[1] M. Amrhein and P. Krein, "Dynamic Simulation for Analysis of Hybrid Electric Vehicle System and Subsystem Interactions, Including Power Electronics," IEEE Transactions on Vehicular Technology, vol. 54, no. 3, May 2005.

[2] Y. Cao, R. Kroeze, and P. Krein, "Multi-timescale Parametric Electrical Battery Modelfor Use in Dynamic Electric Vehicle Simulations," IEEE Transactions on Transportation Electrification, vol. 2, no. 4, December 2016.

[3] F. Adegbohun, A. Jouanne, B. Phillips, E. Agamloh, and A. Yokochi, "High performance electric vehicle powertrain modeling, simulation and validation," Energies, vol. 14, no. 5, p. 1493, 2021.

Exact numerical method for predicting instabilities of switching converters with constant power load

Tue.
16:50–17:10
R Tinmel

K. Mandal , A. El Aroudi

Department of Electronics, Electrical Engineering and Automatic Control, Universitat Rovira i Virgili, Tarragona, Spain

Instabilities in switching dc-dc converter loaded by constant power load (CPL) is a major topic of research in different industrial applications such as microgrids and electrified transportation. The advanced modelling technique and stability analysis could unfold the exact onset of the slow- and fast-timescale instabilities under different operating conditions of the system compare to the averaged or approximate design-oriented models. Therefore, finding the stability boundaries in the parameter space helps the designer to select the parameters for reliable and efficient operation of the system.
Though switching converters with resistive load is a nonlinear system, it can be mathematically described as piecewise linear time invariant (LTI) subsystems in switch ON-state and OFF-state. The switching condition is decided by control methods. The stability analysis of the periodic orbit can be done by calculating the fundamental solution matrix using exponential matrices for evolution within the subsystems, and the saltation matrices for transition across subsystems through switching conditions. However, with CPL, the subsystems are nonlinear and the state matrices are not constant. Therefore, state transition matrices in each subsystem have to be calculated numerically by solving the system equations and variational equations simultaneously. In this paper, an algorithm has been developed to calculate fundamental solution matrix for switching systems with nonlinear subsystems. The effectiveness of the algorithm has been tested on different systems with CPL.
The available methods in the literature have limitation on the problem size. As the number of subsystems in a periodic orbit increases, the size of the matrices increases, therefore not suitable for application in really complex systems. The presented algorithm is applicable to different operating condition with no limitation in problem size i.e., dimensions and number of subsystems. Higher number of subsystems in a period only increases the number of matrices to be multiplied, and not the dimension of the matrices. This method can be used in general for any hybrid systems including impact system, robotic system, power system.

Bibliography

[1] H. Wu, V. Pickert, M. Ma, B. Ji, and C. Zhang, "Stability study and nonlinear analysis of DC-DC power converters with constant power loads at the fast timescale," IEEE Journal on Emerging and Selected Topics in Power Electronics, vol. 8, no. 4, pp. 3225-3236, December 2020.

[2] A. El Aroudi, M. S. Al-Numay, R. Haroun, and G. Zhang, "Analytical Determination of Fast-Scale Instability Boundaries for Current Mode Controlled DC-DC Converters With CPL and Closed Voltage Loop," IEEE Journal on Emerging and Selected Topics in Circuits and Systems, vol. 11, no. 1, pp. 39-48, March 2021.

[3] K. Mandal, SBSDS - Stability and Bifurcation of Switched Dynamical System, DSWeb 2019 Tutorials on DS Software Contest, November 2019.

Shunt active power filter based on the NPC structure : harmonics neutralization and reactive power injection

Tue.
17:10–17:30
R Tinmel

O. Mikram, A. Abouloifa , I.Lachkar, M. Aourir C. Aouadi

ENSEM, Hassan II University of Casablanca, Casablanca, Morocco

The presence of harmonics in the electrical grid also called harmonic pollution, is one of the important phenomena leading to the degradation of power quality, especially the distortion of the voltage wave. The harmonic pollution of the electrical power distribution grid is currently a major problem, especially in industry. The presence of this phenomenon is mainly due to non-linear loads. The harmonic depollution in an electrical grid can be possible with the development of shunt active filters. In this work, a nonlinear control law of a three-phase shunt active power filter based on a five-level NPC inverter using to compensate for reactive and harmonic power absorbed by the nonlinear load and the injection of additional reactive power into the electrical grid. The control objectives are twofold, the first one consists on compensating the reactive and harmonic power absorbed by the nonlinear load, and the second one concerns the regulation of the inverter DC capacitor voltage. To achieve these objectives, two cascaded loops are designed, An inner loop using a nonlinear control law for compensating the harmonic and reactive power with excellent steady-state performance. The outer loop is developed with a PI controller for the regulation of the output voltage to track the desired reference. the proposed model has been simulated in Matlab/Simulink environment. From simulation results, the proposed controller has successfully demonstrated better performance of compensation at the same time the harmonic and the reactive currents with a lower THD value which complies with the limit set by alternative standard and the regulation of the voltage with its designed reference finally.

Bibliography

[1] A. Abouloifa, F. Giri, I. Lachkar, F. Z. Chaoui, M. Kissaoui, et Y. Abouelmahjoub, Cascade nonlinear control of shunt active power filters with average performance analysis, Control Eng. Pract., vol. 26, p. 211-221, 2014.

[2] O. Mikram, A. Abouloifa, I. Lachkar, H. Katir, et C. Aouadi, Flatness-SVPWM Control for Three-Phase Shunt Active Power Filter Based on Five-Level NPC Inverter, IFAC-PapersOnLine, vol. 55, no 12, p. 671-676, 2022.

[3] Z. Hekss, I. Lachkar, A. Abouloifa, S. Echalih, M. Aourir, et F. Giri, Nonlinear Control Strategy of Single Phase Half Bridge Shunt Active Power Filter Interfacing Renewable Energy Source and Grid, in 2019 American Control Conference (ACC), p. 1972-1977, 2019.

[4] M. Aourir, A. Abouloifa, C. Aouadi, A. Hamdoun, et I. Lachkar, Flatness based control of single phase multicellular shunt active power filter for power quality improvement, in 2018 Renewable Energies, Power Systems & Green Inclusive Economy (REPS-GIE), p. 1-6, 2018.

Backstepping based control and stability analysis for three-phase four-wire shunt active power filter

Tue.
17:30–17:45
R Tinmel

K. Naftahi[1], A. Abouloifa [1], Z. Hekss [1], S. Echalih [1] F. Ait bellah[1], A. El Aroudi [2]

[1] *ENSEM of Casablanca, Hassan II University of Casablanca, Casablanca, Morocco*
[2] *Department of Electronics, Electrical Engineering and Automatic Control, Universitat Rovira i Virgili, Tarragona, Spain*

This paper addresses the problem of controlling the three-phase four-wire shunt active power filter (SAPF). The structure used by studied system employs a three-leg split capacitor voltage source inverter (VSI). We seek the achievement of the two control objectives: i) compensation of the current harmonics and the reactive power absorbed by the nonlinear load by forcing the grid currents to be in phase with the grid voltages in order to achieve power factor correction (PFC) and ii) regulation of the voltage of the DC link capacitor. To achieve the above control objectives, a two-loop cascaded nonlinear controller is developed using the backstepping design technique based on the averaged nonlinear model and Lyapunov's stability tools with a simple technique to estimate of harmonics reference signal in the inner-loop for ensuring the unit power factor. A proportional-integral PI regulator and fuzzy logic regulator are developed in the outer-loop to ensure a strict regulation by controlling the capacitors voltage to follow their references. This approach is examined using both steady state analysis and closed loop stability analysis by applying an indirect Lyaponuv stability, averaging theory and Routh criteria. Finally, the results are confirmed by simulations in Matlab Simulink environment, which show that the proposed controller meets its objective under different operating conditions.

Bibliography

[1] Abouloifa A, Aouadi C, Lachkar I, Boussairi Y, Aourir M, Hamdoun A. Output-feedback nonlinear adaptive control strategy of the single-phase grid-connected photovoltaic system. J Sol Energy 2018;2018:1-14.
[2] Hekss, Z., Abouloifa, A., Echalih, S., and Lachkar, I. (2019). Cascade Nonlinear Control of Photovoltaic System Connected to Single Phase Half Bridge Shunt Active Power Filter, In 2019 4th World Conference on Complex Systems (WCCS) (pp. 1-6). Ouarzazate, Morocco. IEEE.
[3] Z. Hekss, A. Abouloifa, J. M. Janik, I. Lachkar, S. Echalih, F. Z. Chaoui, F. Giri, IFAC PapersOnLine 53-2 (2020). Hybrid Automaton Control of Three Phase Reduced Switch Shunt Active Power Filter Connected Photovoltaic System

The impact of high-frequency excitation on a bistable energy harvesting system

Tue.
17:45–18:00
R Tinmel

Z. Ghouli[1], G. Litak [2]

[1] *Polydisciplinary Faculty of Taroudant, University Ibn Zohr, Taroudant, Morocco*
[2] *Faculty of Mechanical Engineering, Lublin University of Technology,Lublin, Poland*

This study investigates the impact of moderate amplitude high-frequency (HF) excitation on energy harvesting in a bistable Duffing-type harvester with nonlinear damping that is excited inertially. The dynamics of the electromechanical system are separated into slow and fast time scales, and an effective hardening mono-stable potential is obtained. Analytical analysis reveals that higher power output can be achieved in the main resonance area of the slow dynamics effective system. Numerical simulations are also conducted to support the analytical predictions. The high-frequency excitation modifies the properties of the dynamic solution, converting it from a double-well to a single-well in the original system. This provides an opportunity to explore vibrational resonance as a useful energy mechanism.

MS 6

Recent Advances in Nonlinear Dynamics

Chairmen: *E. Ponce* Spain, *F. Torres* Spain

Scheduled:

Wednesday *08:30–10:15* Adam Park Hotel **Room Louka**

Real chaos, and complex time

Wed.
08:30–08:50
R Louka

B. Fiedler

Institute of Mathematics Freie Universität Berlin

The homoclinic orbit $z(t) = 1 - 3/\cosh^2(t/\sqrt{2})$ of the pendulum $\ddot{z} = z^2 - 1$ possesses double poles at complex times $t/\sqrt{2} = \mathrm{i}(k + \frac{1}{2})\pi$, for integer k. Esoteric and imaginary as that may sound, one real consequence are exponentially small upper bounds

$$C(\eta)\exp(-\eta/\varepsilon)$$

on homoclinic splittings under standard discretizations of step size $\varepsilon > 0$, or under rapid forcings of that period. Here $\eta > 0$ should be less than the distance of any complex poles of the homoclinic orbit $z(t)$ from the real axis. However, what if $z(t)$ itself is globally complex analytic in t, and hence η can be chosen arbitrarily large?
We consider connecting orbits $z(t)$ between limiting hyperbolic equilibria $v_\pm$, for real $t \to \pm\infty$. We assume separately nonresonant real unstable eigenvalues, at v_-, and stable eigenvalues, at v_+. We conclude the existence of singularities of $z(t)$ in complex time t.
In deep respect for your explicit expertise, we also beg for *any* analytic examples of connecting orbits without complex poles.

Dynamics and bifurcation of the Rattleback, a nonholonomic system

Wed.
08:50–09:10
R Louka

J. Galán-Vioque, J. Valverde, E. Briales

[1] *Departamento de Matemática Aplicada II, Universidad de Sevilla, Spain*
[2] *Virtualmechanics S.L. , Spain*
[3] *Instituto de Matemáticas de la Universidad de Sevilla (IMUS), Spain*

We explore the full dynamical behavior of the Rattleback, a mechanical system based on an unsymmetrical top rotating over a flat surface which constraint depends explicitly on the velocity in a nonholonomic manner [1,3]. The equations of motion of the system are derived following two different approaches. On the one hand [1], the classical Newton law equations are used to arrive to a set of minimum unknown variables by explicitly obtaining the velocity of the top from the nonholonomic constraint equation. The nonholonomic constraint is therefore not solved as an independent equation. On the other hand, the approach proposed in [2] is adopted, making use of the d'Alambert principle

and a Hamiltonian description of the system, with the Langrange multipliers expressed in terms of the Poisson bracket, $\{H, \mathbf{C}\}$, of the Hamiltonian, $H(\mathbf{q}, \mathbf{p})$, and the nonholonomic constraint, $\mathbf{C}(\mathbf{q}, \dot{\mathbf{q}}) = \mathbf{B}(\mathbf{q})\dot{\mathbf{q}} = \mathbf{0}$, where $\mathbf{q} = (q_1, ..., q_n)$ are the generalized coordinates, $\dot{\mathbf{q}} = (\dot{q}_1, ..., \dot{q}_n)$the corresponding velocities and $\mathbf{p} = (p_1, ..., p_n)$ the generalized momentum.
Both sets of equations are used to solve the time evolution of the system for a given set of parameters describing the geometry, initial spin velocity and initial position. The characteristic reversal dynamics [1,3] are simulated in both cases and the expected behavior in the system's generalized coordinates and velocities is obtained along their time-evolution. Note that one drawback of the former case (Newton law-based EQ's) is that the system is solved for velocities and accelerations, therefore positions remain unknown and must be integrated afterwards from the velocities. For both approaches, on the other hand, the time integration of the constraint equations is avoided, resulting in an automatic fulfillment of those constraints at all levels, that is, positions $\mathbf{C}(\mathbf{q}, \dot{\mathbf{q}}) = \mathbf{0}$, velocities $\dot{\mathbf{C}}(\mathbf{q}, \dot{\mathbf{q}}) = \mathbf{0}$ and accelerations $\ddot{\mathbf{C}}(\mathbf{q}, \dot{\mathbf{q}}) = \mathbf{0}$. Eventually bifurcation analysis is applied to the later system of equations to fully characterize the dynamics of such a rich system.

Bibliography

[1] A. García, M. Hubbard, Proc. R. Soc. Lond. A 418, 165-197, 1988.

[2] M. Molina-Becerra, J. Galán-Vioque, E. Freire, Int. J. Bifurc. Chaos. 22(2),1250040-1250054, 2012.

[3] A.V. Borisov, I.S. Mamaev, Physics-Uspekhi (Russian Academy of Sciences) 46(4), 393-403, 2003.

Normal form around a double invisible tangency point

Wed.
09:10–09:30
R Louka

F. Torres, M. Esteban , E. Freire, E. Ponce

Departamento de Matemática Aplicada II, E.T.S. Ingeniería & Instituto de Matemáticas de la Universidad de Sevilla (IMUS), Sevilla, Spain

In order to analyze the qualitative behavior of a vector field near a non-hyperbolic equilibrium point, a very useful technique is to find successive coordinate transformations which simplify the expression of the vector field. The resulting simplified vector field is called normal form. In the case of analytical vector fields is very well known. Thus, by means of iterative homogeneous changes of variables we can remove the non-essentials terms.
Discontinuous piecewise smooth vector fields can exhibit the so-called pseudo-equilibrium points which are not present in smooth vector fields. Although neither of the involved vector fields vanish at a pseudo-equilibrium point, these points act as equilibria of the whole vector field. A particular instance of pseudo-equilibrium points is the fused focus, where both vector fields have an invisible tangency point, where the vector field rotates around it.
In this talk, we extend the classical normal form theory around a equilibrium point for analytical vector fields to the case of fused focus in discontinuous vector fields. Since we have different vector fields discontinuously glueing along a common boundary, the iterative changes of variables must be selected depending on the region where the vec-

tor fields are defined. Furthermore, to guarantee the topological equivalence between the initial and the transformed vector fields, the points of the discontinuity line must be invariant under the different changes of variables. A new methodology to obtain normal forms for planar discontinuous piecewise smooth vector fields in a neighborhood of a fused focus, by resorting to successive quasi-homogeneous changes of variables (see [1]) is proposed.
Once obtained the normal form, we can compute the Poincaré map, getting the so-called focal values, that is, the coefficients of the series expansion of such a map; the first non-vanishing focal value will be called Lyapunov constant. We can give focal values of higher order with simpler expressions than the previously obtained, see [2]. Thus, the stability and possible bifurcations of a fused focus are easily studied.

Bibliography

[1] A. Algaba, E. Freire, E. Gamero, C. Garcia, Quasi-homogeneous normal forms, Journal of Computational and Applied Applied Mathematics, 150 (2003), 193-216.

[2] B. Coll, A. Gasull, R. Prohens, Degenerate Hopf Bifurcations in Discontinuous Planar Systems, Journal of Mathematical Analysis and Applications,253 (2001), 671-690.

[3] M. Esteban, E. Freire, E. Ponce, F.Torres, On normal forms and return maps for pseudofocus points Journal of Mathematical Analysis and Applications 507 (2022) 125774

[4] M. Esteban, E. Freire, E. Ponce, F.Torres, Piecewise smooth systems with a pseudo-focus: A normal form approach, Applied Mathematical Modelling, 115 (2023) 886-897.

Some bifurcations from periodic orbits at infinity in 3D piecewise linear systems

Wed.
09:30–09:45
R Louka

E. Ponce, E. Freire , M. Ordóñez, J. Ros , E. Vela

Departamento de Matemática Aplicada II, E.T.S. Ingeniería & Instituto de Matemáticas de la Universidad de Sevilla (IMUS)

We consider three-dimensional piecewise linear systems and the possible bifurcation of limit cycles from non-hyperbolic periodic orbits at infinity. For the analysis, it turns out necessary to develop specific ad hoc techniques in order to deal in a convenient way with periodic orbits of great amplitude, see Ref. 1.
In these three-dimensional systems, there can appear isolated and non-isolated periodic orbits at infinity. For the symmetric case of isolated periodic orbit at infinity in systems with three zones, we will briefly review a Hopf-like bifurcation result that turns out to be of interest in the analysis of certain electronic oscillators, obtaining estimates for amplitude and period of the bifurcating limit cycle as well as its stability character, as shown in Ref. 2.
A more involved problem regarding the bifurcation from a center at infinity in non-symmetric systems with two zones leads, in the semi-homogeneous case, to the bifurcation of invariant semi-cones. In the non-homogeneous case, a limit cycle bifurcation from the center at infinity can be characterized, see Ref. 3.

Recently, symmetric relay systems have been analyzed in Ref. 4, where a complete analysis of the bifurcation from infinity and its possible degeneration is presented.

Bibliography

[1] E. Freire, E. Ponce, J. Ros, A new methodology for limit cycle bifurcation from infinity in n-dimensional symmetric piecewise linear control systems, Chaos'06, 1st IFAC Conference on Analysis and Control of Chaotic Systems Notes 39 (8).doi:10.3182/20060628-3-fr-3903.00039.

[2] E. Freire, E. Ponce, J. Ros, E. Vela and A. Amador, Hopf bifurcation at infinity in 3D symmetric piecewise linear systems. Application to a Bonhoeffer-Van der Pol oscillator, Nonlinear Analysis Real World Applications 54 (2020) 103112.

[3] E. Freire, M. Ordóñez and E. Ponce, Bifurcations from a center at infinity in 3D piecewise linear systems with two zones, Physica D 402 (2020) 132280.

[4] E. Freire, E. Ponce, J. Ros, E. Vela, Hopf bifurcation at infinity in 3D relay systems, Physica D 444 (2023) 133-586.

Saddle-node bifurcation curve and hidden attractors in 4D memristor oscillator

Wed.
09:45–10:00
R Louka

J. Ros[1], E. Ponce[2], A. Amador[3]

[1] *Departamento de Matemática Aplicada II, Escuela Técnica Superior de Ingeniería, Universidad de Sevilla, Spain*
[2] *Departamento de Matemática Aplicada II, Escuela Técnica Superior de Ingeniería, Sevilla, Spain*
[3] *Facultad de Ingeniería y Ciencias, Departamento de Ciencias Naturales y Matemáticas, Pontificia Universidad Javeriana-Cali, Santiago de Cali, Colombia*

In the frame of memristor oscillators, see [1], the so-called multiple focus center bifurcation (MFCC) that leads to the appearance of a topological sphere foliated by periodic orbits was recently investigated in a 4D discontinuous memristor oscillator, see [2]. Extending the quoted work, in this work we study the points where the MFCC bifurcation point is degenerate. Starting from previous analytical results, see [3] and [4], we show the existence of a saddle-node bifurcation curve of periodic orbits that emanate from such points of degeneration and apply numerical continuation techniques to the closing equations of the piecewise linear system, to follow such a curve. We prove the existence of a parameter region where stable limit cycles coexist with stable equilibrium points, an instance of what is known as a hidden attractor, see [5].

Bibliography

[1] M. Itoh, L.O. Chua. Memristor oscillators. International Journal of Bifurcation and Chaos, 18(11):3183-3206, 2008.

[2] E. Ponce, A. Amador, J. Ros. A multiple focus-center-cycle bifurcation in 4D discontinuous piecewise linear memristor oscillators. Nonlinear Dynamics, 94(4):3011-3028, 2018.

[3] E. Freire, E. Ponce, J. Ros. Bistability and hysteresis in symmetric 3d piecewise linear oscillators with three zones. International Journal of Bifurcation and Chaos, 18(12):3633-3645, 2008.
[4] E. Freire, E. Ponce, J. Ros. A biparametric bifurcation in 3D continuous piecewise linear systems with two zones: Application to chua's CIRCUIT. International Journal of Bifurcation and Chaos, 17(02):445-457, 2007.
[5] N.V. Kuznetsov, G.A. Leonov, and S.M. Seledzhi. Hidden oscillations in nonlinear control systems. IFAC Proceedings Volumes, 44(1):2506-2510, 2011 2022.

Torsion-bending coupling in non-linear model order reduction

Wed.
10:00–10:15
R Louka

L. Silveira

Department of Mechanical and Electrical Engineering, University of South Denmark

In some structures, torsion-bending coupling is used to minimize external loads like aerodynamic forces. A reduced-order model must therefore accurately capture the twist angle of the deformed structure, such as a wind turbine blade. A linear modal truncation does not capture the variation of the modal basis and quadratic manifolds are unable to capture non-linear variations of the modal basis like veered mode shapes. In this work, it is shown that a linear modal basis augmented with modal derivatives accurately predicts the twist angle even when the variation of the modal basis is non-linear since the contribution of linear modes and modal derivatives are modelled as independent variables.

The variation of the first six natural frequencies of an L-shaped cantilever beam with respect to a displacement in the first modal coordinate are analysed. The fourth and fifth natural frequencies, corresponding to the first torsional and fourth bending modes respectively, approach each other and veer apart without crossing. This veering is accompanied by hybridizations in the correspondent mode shapes.

The angular displacement of the right end surface of the cantilever beam when subjected to a vertical load applied on the right end surface is computed using the aforementioned model order reduction methods. The linear modal truncation fails in predicting the angular displacement. Despite the non-linear variations of the modal basis, model order reductions based on a linear modal basis augmented with modal derivatives still accurately predict the angular displacements.

The introduction of modal derivatives "quickly increases the size of the basis" [1]. In this work, it is investigated how a sequential backward selection of the modal derivatives provides a computationally cheap method of reducing the basis size. Minimizing the static deflection error, with the precaution of not significantly changing the deflected natural frequencies, is a cheap criterion to select which modal derivatives to include in the reduced model.

Bibliography

[1] Shobhit Jain, Paolo Tiso, Johannes Rutzmoser, and Daniel Rixen. A quadratic manifold for model order reduction of nonlinear structural dynamics. Computers and Structures, 188, 04 2017.

MS 7

Time Delayed Systems

Chairmen: *G. Litak* Poland

Scheduled:

Wednesday *08:30–10:15* Adam Park Hotel **Room Tinmel**

Design of a full-scale wave energy converter: challenges and technological solutions

Wed.
08:30–08:50
R Tinmel

M. Hajj [1], A. Ahmed[1], A. Shalaby [1], R. Datla[2], J. Mi[2], J. Huang[2], L. Yang [2], L. Zuo [2]

[1] *Civil, Environmental and Ocean Engineering, Stevens Institute of Technology, Hoboken, NJ Naval*
[2] *Marine Engineering, University of Michigan at Ann Arbor*

Wave energy is a critical source of clean renewable energy. Yet, from a readiness perspective and for many reasons, there has not been a prevailing design for wave energy converters. Developing the technology requires system design of components including the prime mover, foundation or mooring, power take-off, and control systems. In this talk, challenges-faced and advances made towards realizing electric power from wave energy will be discussed. The discussion is mostly based on an effort supported by the US Department of Energy and led by researchers at Stevens Institute of Technology and in collaboration with researchers from the University of Michigan and Resolute Marine Energy to design a 100-kW floating oscillating wave energy converter for potential testing at the PacWave south site. Particularly, we will discuss (1) the utility and limitations of multi-fidelity numerical simulations and model testing for the design of a full-scale converter, (2) the need for system level co-design when setting the design parameters including the natural frequency vs. wave torque, flap shape, flap buoyancy, flap moment of inertia, mooring platform, and PTO control, and (3) the metrics for performance evaluation and validation including the hydrodynamics, PTO, operation in extreme conditions, parametric cost breakdown, and levelized cost of energy.

A novel algorithm for dynamical integrity estimation in time delayed systems

Wed.
08:50–09:10
R Tinmel

B. Szaksz, G. Habib

Department of Applied Mechanics, Budapest University of Technology and Economics, Budapest, Hungary and MTA-BME Lendület "Momentum" Global Dynamics Research Group, Budapest, Hungary

In engineering, it is common practice to linearize dynamical systems around the desired equilibrium and neglect their nonlinear properties. Although this is often a useful simplification, a system may still diverge from a stable equilibrium if subject to sufficiently large perturbations. The robustness of a stable solution against external perturbation is referred to as dynamical integrity. Thisstudy introduces a novel algorithm for the rapid estimation of the dynamical integrity of an equilibrium in the case of delayed nonlinear systems.

The algorithm is designed to find the local integrity measure (LIM) of the desired fixed point, which is the radius of the largest hypersphere centered at the fixed point that is entirely contained within its basin of attraction (BoA). The authors generalize the results of the paper [1] for delay differential equations with distinct time delay. This generalization poses the challenge that a solution is not determined by an initial value but by an initial function, resulting in an infinite dimensional phase space. This requires a redefinition of the BoA, which was determined by the headpoints of a restricted set of initial functions that uniquely associate each headpoint with a specific initial function. The algorithm uses an iterative procedure to gradually improve the estimation of the LIM for subsequent trajectories of the system in the phase space. Trajectories are obtained exploiting the semi-discretization method [2], which significantly speed up the computation, and they are characterized as either converging or diverging through a cell-subdivision of the phase space, similarly to the cell-mapping method [3].

The algorithm was tested on various mathematical models, including a time-delayed Duffing oscillator, an inverted pendulum, and a model of turning machining. In all cases, the algorithm provided results that were consistent with the topology and amplitude of the coexisting steady-state solutions, suggesting that the estimated LIM values are meaningful from an engineering perspective. In addition, the results showed that the algorithm is rapid compared to alternative methods and does not have memory issues, making it a potentially interesting tool for engineering design

Bibliography

[1] Habib G. Dynamical integrity assessment of stable equilibria: a new rapid iterative procedure. Nonlinear Dynamics 106(3): 2073-2096, 2021.

[2] Insperger T., Stepan G Semi-discretization for time-delay systems: stability and engineering applications 178 Springer, 2011

[3] Hsu, C. A probabilistic theory of nonlinear dynamical systems based on the cell state space concept. Journal of Applied Mechanics, 49(4), 895-902, 1982.

Kalman filtering of stochastic laser dynamics: parameter and state space estimation from time-delayed measurements

Wed.
09:10–09:30
R Tinmel

L. Mertenskötter[1], M. Kantner[2]

[1] *Weierstrass Institut (WIAS), Berlin, Germany*
[2] *Weierstrass Institut (WIAS), Berlin, Germany*

State space models are a tried and tested method to estimate a Markovian dynamical system's parameters from data, simultaneously describing the system's dynamics and its measurement. The tool of choice to infer on the model's parameters given a measured time series are Markov chain Monte Carlo methods. The optimal estimate of the distribution of state space variables needed in the evaluation of the likelihood function is given by the Kalman filter. In the case of nonlinear systems whose state space variables are approximately Gaussian the extended Kalman filter can be employed instead.

When dealing with measurements that incorporate time delayed state space variables a modification of these Kalman filter methods is required. The established methods, however all suffer from their computational cost scaling with the length of the delay [1], which can make them unfeasible for large delays. For a measurement consisting of a simple addition of an instantaneous and time-delayed state space variable, as it occurs in interferometric measurements [2], we develop a state space reconstruction and parameter estimation technique that is independent of the delay time in its computational cost.

We apply this method to time series data from delayed self-heterodyne beat note measurements of a semiconductor laser, where the light is superimposed with a delayed version of itself. In this case the delay is on the order of a thousand time steps, which brings previous methods such as state augmentation to their limits. We model the laser via three-dimensional nonlinear stochastic differential equations including 1/f-type colored noise [3]. The latter can be approximated by a 10 to 20-dimensional Markovian embedding that aims to reproduce the system's non-Markovian correlation characteristics in a Markovian framework. In this case computational cost is of even stronger concern as the methods already scale unfavorably in the dimensionality of the system.

Bibliography

[1] A. Gopalakrishnan et al., Journal of Process Control 21, 119-129, 2011.
[2] M. Schiemangk et al., Appl. Opt. 53, 7138-7143, 2014.
[3] M. Kantner, L. Mertenskötter, WIAS preprint 2983, 2022.

Quasiperiodic birhythmicity in a multicycle van der Pol oscillator with modulated time delay

Wed.
09:30–09:45
R Tinmel

M. Hamdi[1], M. Belhaq [2]

[1] *University Abdelmalek Essaâdi, Faculty of Sciences and Technology-Al Hoceima, Morocco*
[2] *University Hassan II of Casablanca, Faculty of Sciences Ain Chock, Morocco*

In this work, the dynamics of a time-delayed multicycle van der Pol oscillator is investigated in the case where the delay amplitude is harmonically modulated around a mean value with certain amplitude and frequency. Using perturbation methods, approximate analytical solutions of QP oscillations and their bifurcation equations are obtained and regions of existence of different solutions are determined. It is revealed that, apart from monorhythmic and birhythmic oscillations commonly present in the undelayed or delay-unmodulated multicycle van der Pol oscillator, the delay-modulated oscillator exhibits QP-monorhythmicity or QP-birhythmicity. Based on the bifurcation diagrams, transitions between different rhythmicities are derived. The results show that for appropriate values of delay parameters, large-amplitude monostable (monorhythmic and QP-monorhythmic) oscillations can take place over a broadband of the modulation frequency near the delay-induced parametric resonance. Bistability generated by birhythmicity or QP-birhythmicity can also occur for different values of delay parameters.

Incremental harmonic balance with two time scales for a nonlinear quasi-periodic Mathieu equation

Wed.
09:45–10:00
R Tinmel

B.X. Zhang[1,2], J.L. Huang [1,2], W.D. Zhu[2]

[1] *Department of Applied Mechanics and Engineering, Sun Yat-sen University, Guangzhou, China*
[2] *Department of Mechanical Engineering, University of Maryland, Baltimore County, Baltimore*

Quasi-periodic (QP) solutions of a damped nonlinear QP Mathieu equation with cubic nonlinearity

$$\ddot{x} + cx + (\tilde{\omega}_0^2 + \alpha\cos(2\omega t) + \beta\cos(2\omega_d t))x \tag{7.1}$$

are investigated by using the incremental harmonic balance (IHB) method with two time scales. The damped nonlinear QP Mathieu equation contains two incommensurate harmonic excitation frequencies, one is a small frequency while the other nearly equals twice the linear natural frequency. It is found that Fourier spectra of QP solutions of the equation consist of uniformly spaced sidebands due to cubic nonlinearity. The IHB method with two time scales, which relates to the two excitation frequencies, is adopted to trace solution curves of the equation in an automatical way and find all frequencies of solutions and their corresponding amplitudes. Effects of parametric excitation are studied in detail. Based on approximation of QP solutions by periodic solutions with a large period (the corresponding frequency

$$\tilde{\omega} = min\{|m\omega + n\omega_d|m, n\epsilon Z\} \tag{7.2}$$

can achieve computer accuracy), Floquet theory is used to study the stability of QP solutions. Three types of QP solutions can be obtained from the IHB method, which agree very well with results from numerical integration. However, the perturbation method using the double-step method of multiple scales (MMS) obtains only one type of QP solutions since MMS will fail if the ratio of the small frequency to the linear natural frequency of the first reduced-modulation equation is nearly 1 in the second perturbation procedure, while there is no such restriction in the IHB method. Furthermore, the results from the double-step MMS are different from those numerical integration and the IHB method with two-time scales.

Quasiperiodic energy harvesting in a delayed Rayleigh-Duffing harvester device near primary and secondary resonances

Wed.
10:10–10:15
R Tinmel

I. Kirrou[1], A. Bichri [2], M. Belhaq[3]

[1] *MISI Laboratory, FST Settat, University Hassan I, Morocco*
[2] *Department of physics, MMESA Laboratory, FSTE, University Moulay Ismail, Morocco*
[3] *University Hassan II Casablanca, Morocco*

The paper studies quasiperiodic vibration-based energy harvesting in a forced and delayed Rayleigh-Duffing oscillator coupled to a piezoelectric circuit. The study focuses on the effect of the time delay on the output power performance near primary and the subharmonic resonance of order 3. Using the multiple scales method, quasiperiodic solutions and the corresponding output powers are obtained near the subharmonic resonance. The effect of the delay parameters on the energy extraction performance is analyzed in the case where the delay is introduced either in the position, in the velocity or in both. The analytical results supported by numerical simulations showed the potential of the time delay to achieve high quasiperiodic output power over a large bandwidth around the 3-subharmonic resonance region.

Index of Authors

A

Abdel-Rahman E.M. 4, 16
Abdelkefi A. 23
Abdelrahman R. 16
Abouelhanoune Y. 44
Abouloifa A. 53, 54, 57, 58, 61, 62
Ahmed A 3, 71
Ait bellah F. 53, 62
Allali K. 38
Aloui R. 25
Amador A. 68
Aouadi C. 53, 57, 61
Aouadi M.A. 52
Aourir M. 57, 58, 61
Araújo L.S. 13
Arabi M. 4
Arbelo M.A. 37
Arich O. 54, 58
Atalla N. 47
Ayyad M. 3
Azoua M. 43
Azouani A. 43, 44

B

Balthazar J.M. 18, 19, 26, 33
Barakat A.A. 29
Barbosa A. 14
Barcinski T. 34
Baroudi S. 23
Belardinelli P. 51
Belhaq M. 23, 30, 38, 73, 74
Benadero L. 55
Benchouaf L. 48
Bichri A. 74
Bouhaddi N. 13, 14
Bouin E. 40
Boutyour E.H. 48
Briales E. 65
Brunetti M. 50
Brzeski P. 35
Bucki S. 11, 20
Bueno A.M. 19

C

Callot C. 39
Chelchowski A. 27
Cheng B. 40
Chouchane M. 25
Cichorek K. 28
Cid-Pastor A. 55
Collot C. 39
Cui D. 47
Cunha Jr A. 13, 45

D

da Silva S. 50
Dalaq A. 15
Daqaq M.F. 5, 11, 15, 18
Datla R. 71
Daum H.H. 19, 26
Deü J.F. 16
Debowski A. 27
Dimas S. 50
Dowlati S. 13
Duong G.K. 43
Duyckaerts T. 39

E

Echalih S. 53, 54, 58, 62
El Aroudi A. 53, 55–60, 62
El Boudali A. 57

Elhady A. 4, 16
El Moussati Y. 23
Esteban M. 66
Ezzinbi K. 43

F

Fiedler B. 6, 65
Foltete E. 12
Freire E. 66, 67

G

Galán-Vioque J. 65
Gaska D. 11, 20, 45
Gepner S. 28
Ghouli Z. 63
Givois A. 16
Gonçalves M.A. 26

H

Habib G. 71
Hafidi I. 43
Hagedorn P. 29, 30
Hajj M. 3, 71
Hamdi M. 23, 30, 73
Hamel F. 39, 40
Hekss Z. 58, 62
Hida N. 52
Hourri N. 58
Huang J. 71
Huang J.L. 74

I

Ichchou M. 47

J

Jarzebowska E. 26–28, 31, 34
Joseph E. 13

K

Kacem N. 12–14, 21
Kantner M. 72
Karpov E.A. 36
Kenig C. 39
Khasawneh M. 18
Khazaaleh S. 15
Kirrou I. 19, 74
Kloda L. 11, 50
Kostka Z. 31
Kovacic I. 5, 25
Kraus Z. 30
Kukuryka M. 34
Kurina G.A. 18
Kurths J. 4

L

Lachkar I. 61
Lakrad F. 52
Larbi W. 25
Latalski J. 45, 49
Latrach S. 42
Lenci S. 51
Litak G. 8, 11, 20, 63, 71
Lozina Z. 46
Luis J. 33

M

Magdich A. 23
Mandal K. 53, 56, 59, 60
Margielewicz J. 11, 20
Martínez-Salamero L. 55
Martinetti A. 37
Meleshenko P.A. 32, 36
Melnyk D. 50
Merle F. 39
Mertenskötter L. 72
Mi J. 71
Mikram O. 61
Mitura A. 50
Mohammed O.D. 35

N

Nabarrete A. 25, 33, 37
Naftahi K. 62
Najar F. 11, 12, 21–23
Norenberg J.P. 45
Nouaili N. 39, 43
Novelli N. 51
Nunes A.W. 50

O

Ordóñez M. 67
Ouakad H.M. 21

P

Perlikowski P. 35
Ponce E. 65–68

Q

Qiao Y. 4

R

Ribeiro M.A. 18, 19, 26
Romeo F. 50
Ros J. 67, 68
Rosko P. 52
Ruiz A. 50

S

Saidi A. 47
Samaali H. 22
Samuel Franciscus Z. 37
Sebastiá-Rullo M. 55
Sedlar D. 46
Semenov M. 25
Semenov M.E. 32, 36
Shalaby A. 71
Shao L. 47
Silveira L. 69
Szaksz B. 71

T

Tayachi S. 41
Thomas O. 16
Torres F. 65, 66
Trabelsi S. 41
Tusset A.M. 18, 19, 26

V

Valderrama-Blavi H. 55
Valverde J. 65
Vauchelet N. 42
Vela E. 67
Verhulst F. 8

W

Warminski J. 49, 50
Wolszczak P. 11, 12, 20

Y

Yang L. 71
Yavuz M. 16

Z

Zaag H. 6, 39, 42, 43
Zaouali E. 12
Zhang B.X. 74
Zhang W. 4
Zhu W.D. 74
Zine A. 47
Zuo L. 71