ICAST 2024

The 33rd International Conference on Adaptive Structures and Technologies

May 20-22, 2024

Atlanta, Georgia, USA

Welcome!

It is my pleasure to welcome you to the 33rd International Conference on Adaptive Structures and Technologies (ICAST 2024), held in person from May 20-22, 2024, in Atlanta.

ICAST is a series of international conferences dating back to its launch in 1990 as a joint USA-Japan conference held in Maui in its first year. For more than three decades, ICAST has been held at various locations in North America, Asia, and Europe. ICAST 2024 is the 33rd of these successful conferences aiming to bring together researchers exploring a broad range of topics in smart/adaptive structures.

Organized by the Smart Structures & Dynamical Systems Lab (SSDSL), ICAST 2024 is hosted at the Georgia Institute of Technology (Georgia Tech) as a single-track vibrant conference featuring leading researchers from all around the world, including four distinguished keynote speakers as well as three distinguished panelists.

ICAST 2024 is partially sponsored by SSDSL and by the journal Smart Materials and Structures (IOP).

I hope you have a great conference and a wonderful time in Atlanta!

Best regards,

Alper Erturk
- ICAST 2024 Conference Chair

ICAST@me.gatech.edu
https://sites.gatech.edu/icast

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- W. J. Staszewski, AGH University of Science & Technology, Poland
- H. Tanaka, National Defense Academy of Japan, Japan
- M. Trindade, University of São Paulo, Brazil
- H. S. Tzou, Nanjing University of Aeronautics and Astronautics, China
- H. Wang, Chongqing University, China
- K.-W. Wang, University of Michigan, USA
- N. M. Wereley, University of Maryland, USA
- A. Wickenheiser, George Washington University, USA
- B. K. S. Woods, Bristol University, UK
- W.-J. Wu, National Taiwan University, Taiwan

KEYNOTE by Prof. Paolo Ermanni – *ETH Zurich*

(May 20, Monday, 9:00)

Structural approaches for adaptive biomedical and aerospace systems

Abstract: High performance fiber reinforced polymers (FRP) are layered anisotropic materials. The fiber architecture can be tuned to tailor material properties and deformation behavior, thus allowing the realization of structural systems with amazing structural features, including extreme deformability, shape deformation and reconfigurability. The talk is presenting and discussing various design approaches, mechanisms, and applications for adaptive composite-based load-carrying systems. The presented concepts consider selective inner compliance, as well as passive and semi-active variable stiffness solutions. Controlled elastic instability and integration of multi-stable elements provide additional mechanisms to induce nonlinear variable stiffness response and therefore achieving selective deformability in load-carrying lightweight structures. The integration of FRPs elements into mechanical metamaterials is further expanding the potential of composite materials for multi-functional lightweight applications, by adding additional geometrical parameters and tunability of the repeating unit cell. A promising concept is relying on FRP shell metastructures consisting of a thin FRP-frame and a pre-stretched soft polymer membrane. The instability of the initially flat component is inducing a rich multi-stable behavior, being a first step towards the realization of programmable structures, which can morph to multiple 3D shapes from an initial flat configuration upon an external stimulus. Finally, we are currently exploring the mechanical behavior and the potential of very thin composite shells made from continuously fiber reinforced Polyether ether ketone (PEEK). Those composite materials are capable of withstanding large bending curvatures without failure and are therefore pre-destined for applications, which require a high degree of deformability for shape adaptation and deployment purposes. Applicability of thin fiber reinforced PEEK shells in selected biomedical and space systems will be discussed.

Bio: Paolo Ermanni has been Professor and Director of the Laboratory of Composite Materials and Adaptive Structures (CMASLab) in the Department of Mechanical and Process Engineering of ETH Zurich since 1998 (Associate Professor until March 2003 and Full Professor thereafter). Ermanni holds a master's degree in mechanical engineering and a Doctoral degree from ETH Zurich. He spent more than five years at Airbus in Hamburg (D) as a senior engineer and later on, as a project manager, mainly dealing with structural and technological challenges related to the realisation of a second generation of civil supersonic aircraft. In 1997, he took on a new position as a strategic consultant-manager at Kearney in Milan (Italy). Ermanni's research is inspired by real-world engineering problems and is concerned with the exploration of innovative designs, material architectures and advanced manufacturing processes. Ultimate goal is to improve the efficiency and reliability of high-performance composite materials and lightweight structural systems. Current research interests include shape adaptation for morphing and reconfigurable systems, composite metamaterials and advanced processing routes for high performance thermoplastic composites.

KEYNOTE by Prof. Diann Brei – *University of Michigan*

(May 21, Tuesday, 9:00)

Adaptive inflatable structures for avant garde automotive and medical applications

Abstract: We are on the advent of the next technological revolution. All around us our world is undergoing rapid transformative change, from mobility to medical breakthroughs. The field of adaptive structures is well positioned to play a pivotal role by providing crucial capabilities in morphing, energy absorption, active deployment, and many more. While the structures and machines from the industrial revolution were inherently hard and inflexible in nature, emerging inflatable adaptive structures can radically change their properties, shapes and behavior in a "softer" controlled manner. Combining soft inflatable structures with rigid and tensile constraint elements provides more and unique functionality with higher structural performance. One example of this is tendon-constrained inflatable interior walls within autonomous vehicles that can actively deploy to softly capture occupants and cargo while absorbing harmful energy. Similarly, an active inflatable cowling can gently cover windshield wipers from leaves and snow, yet as needed can open rigidly against aerodynamic loads using an advanced tile-based layered-bladder approach. Adaptive inflatable structures can also be used to enhance the quality of life in medical applications. A good example of where adaptive inflatable structural properties can be tailored is tendon-constrained headrest for wheelchairs that can support neck flexion stabilizing the head, while enabling rotation or other directional motions with only light resistance enabling users to move in directions that they have muscular strength. Through highlighting several avant garde applications within the automotive and medical sector, this talk will explore inflatable adaptive structures and their underlying behavioral science to understand the highly tailorable functionality gained through advanced internal architectural arrangements such as tendon-constrained and novel tile and constrained-layer techniques.

Bio: Dr. Diann Brei Professor of Mechanical Engineering and former Chair of the Integrative Systems + Design Division at the University of Michigan. She received her PhD (1993) in Mechanical Engineering and her BSE (1988) in Computer Systems Engineering (1988). Her research is focused on the underling design science for device innovation using smart materials. Her smart material architectural models along with her multi-domain, multi-stage design methods have set the foundation for a successful translational research and development paradigm adopted by industries in the automotive, medical and aerospace sectors. Dr. Brei who is an ASME Fellow and AIAA Associate Fellow, has been an active leader in the smart materials and structures community recognized by the ASME Machine Design Award, ASME Adaptive Structures and Material Systems Award, SPIE Lifetime Achievement Award SSM and the ASME Distinguished Service Award.

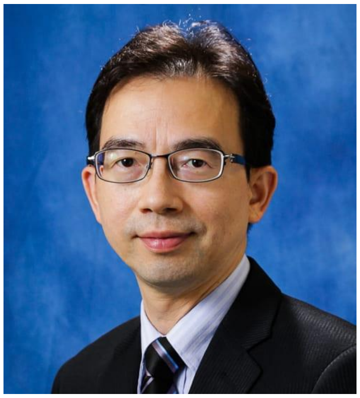
KEYNOTE by Prof. Norman M. Wereley – *University of Maryland*
(May 21, Tuesday, 14:00)

Energy absorption strategies for occupant protection

Abstract: The ability to dissipate energy in vehicle systems, especially with the goal of protecting occupants from potentially injurious vibration, repetitive shock, crash and blast loads, is becoming a critical issue as the cumulative impact of these load spectra on chronic health and acute injury are becoming better understood. The objective of this talk is to discuss what properties are optimal for energy absorption (EA) applications such impact or shock load mitigation. Two primary strategies will be discussed in this talk: passive vs. semi-active energy absorbers. The first focus is the use of crushable materials to absorb energy. Two classes of passive materials will be discussed for EA applications including sintered and composite hollow glass foam materials, as well as elastomeric or plastic cellular materials. The second focus is the use of magnetorheological fluids (MRFs) in EA applications. The properties of the MRF can be optimized for a particular application. A number of key nondimensional parameters can be used to gain insight into how to define optimality for various applications including: Bingham number, Hedstrom number, Reynolds number, Mason number, dynamic range. Also, the trade-offs associated in designing an optimal MRF for a particular application are discussed. The advantages of passive versus semi-active EA strategies will be discussed.

Bio: Dr. Wereley is the Minta Martin Professor in the Department of Aerospace Engineering at University of Maryland. His current research interests are focused on active and passive vibration and shock mitigation (especially occupant protection systems) using primarily magnetorheological materials, and soft actuators and soft robotic systems. Dr. Wereley has published over 260 journal articles, 20 book chapters, over 275 conference articles, and over 20 patents. Dr. Wereley is the Editor-in-Chief of SAMPE Journal and Editor of the Journal of Intelligent Material Systems and Structures. He also serves as an associate editor of Smart Materials and Structures, MDPI Actuators, and others. Dr. Wereley is the recipient of the ASME Adaptive Structures and Material Systems Prize (2012) and the SPIE Smart Structures and Materials Lifetime Achievement Award (2013). Dr. Wereley is a Fellow of AIAA, RAeS, VFS, ASME, SPIE, and the Institute of Physics. He is also a Senior Member of IEEE. Dr. Wereley has a B.Eng. (1982) from McGill University and M.S. (1987) and Ph.D. (1990) from the Massachusetts Institute of Technology.

KEYNOTE by Prof. Wei-Hsin Liao – *The Chinese University of Hong Kong* (May 22, Wednesday, 9:00)



Auxetic structures for energy absorption and harvesting

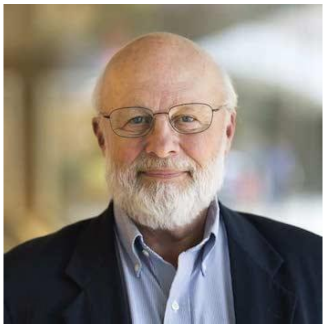
Abstract: Auxetic structures have been applied in the energy absorption field due to the unique mechanical properties. Inspired by foam filled structures, we investigate a thin-walled structure filled with double arrowed auxetic structure and investigates the energy absorption characteristics. The gradient configuration is introduced to improve the energy absorption performance. A theoretical model is also established to predict the energy absorption to quantify the energy dissipated due to thin-walled tubes, gradient auxetic structures and their interactions. On the other hand, auxetic structures are utilized to increase the power output of piezoelectric energy harvesting. We design a gradient auxetic piezoelectric energy harvester, which combines a cantilever beam and a gradient auxetic structure. Compared with the normal uniform auxetic structure, the gradient auxetic structure can contribute to a more uniform strain distribution of the piezoelectric cantilever beam; thus, the proposed gradient auxetic energy harvester can produce higher power than the uniform auxetic energy harvester without increasing the stress concentration at the same time. Our related work in auxetic structures for energy absorption and harvesting will be presented.

Bio: Wei-Hsin Liao received his Ph.D. in Mechanical Engineering from The Pennsylvania State University, University Park, USA. Since August 1997, Dr. Liao has been with The Chinese University of Hong Kong, where he is Choh-Ming Li Professor of Mechanical and Automation Engineering and the Department Chairman. His research has led to publications of about 400 technical papers and 27 patents. As the General Chair, he organized the 20th International Conference on Adaptive Structures and Technologies (ICAST 2009). He was the Conference Chair for the Active and Passive Smart Structures and Integrated Systems, SPIE Smart Structures/NDE in 2014 and 2015. He received the *T A Stewart-Dyer/F H Trevithick Prize* 2005, the ASME 2017 *Best Paper Award in Mechanics and Material Systems*, the ASME 2021 *Energy Harvesting Best Paper Award*, and the ASME 2023 *Best Paper Award in Structures and Structural Dynamics*. He is the recipient of the 2018 SPIE *Smart Structures and Materials Lifetime Achievement Award* and the 2020 ASME *Adaptive Structures and Material Systems Award*. Dr. Liao currently serves as an Associate Editor for *Journal of Intelligent Material Systems and Structures*, and on the Executive Editorial Board of *Smart Materials and Structures*. Dr. Liao is a Fellow of ASME, HKIE, and IOP.

DISTINGUISHED PANELISTS to talk about "*Smart structures across decades & future perspectives*"

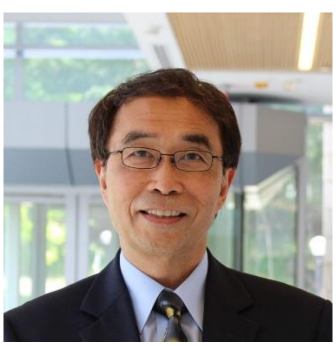
(May 20, Monday, 13:40)

Prof. Daniel J. Inman – *University of Michigan, Aerospace Engineering*



Bio: Daniel J. Inman received his Ph.D. from Michigan State University in Mechanical Engineering in 1980 and is the Harm Buning Collegiate Professor and former Chair of the Department of Aerospace Engineering at the University of Michigan. Since 1980, he has published eight books (on vibration, energy harvesting, control, statics, and dynamics), eight software manuals, 20 book chapters, over 410 journal papers and 674 proceedings papers, given 78 keynote or plenary lectures, graduated 71 Ph.D. students, and supervised more than 75 MS degrees. He works in the areas of applying smart materials and structures to solve aerospace engineering problems including energy harvesting, structural health monitoring, vibration suppression and morphing aircraft. He is a Fellow of the American Institute of Aeronautics and Astronautics, American Society of Mechanical Engineers, International Instituted for Acoustics and Vibrations, Society of Experimental Mechanics and American Academy of Mechanics. He won the ASME Adaptive Structures Award in April 2000, SPIE Smart Structures and Materials Lifetime Achievement Award in March of 2003, he received the ASME Den Hartog Award for lifetime achievement in teaching and research in vibration, the 2009 Lifetime Achievement award in Structural Health Monitoring, and the AIAA Structures, Structural Dynamics, and Materials Award, in 2014. He is currently Technical Editor of the Journal of Intelligent Material Systems and Structures (1999-present).

Prof. Kon-Well Wang – *University of Michigan, Mechanical Engineering*



Bio: Dr. Kon-Well Wang is the A. Galip Ulsoy Distinguished University Professor of Engineering and Stephen P. Timoshenko Professor of Mechanical Engineering (ME) at the University of Michigan (U-M). He has been the U-M ME Department Chair from 2008 to 2018, and has served as the Division Director of Engineering Education and Centers at the U.S. National Science Foundation for two years, 2019-20, via an Executive Intergovernmental Personnel Act appointment. Wang received his Ph.D.

degree from the University of California, Berkeley, worked at the General Motors Research Labs as a Sr. Research Engineer, and started his academic career at the Pennsylvania State University in 1988. At Penn State, Wang has served as the William E. Diefenderfer Chaired Professor, co-founder and Associate Director of the Vertical Lift Research Center of Excellence, and a Group Leader for the Center for Acoustics & Vibration. He joined the U-M in 2008. Wang's main technical interests are in structural dynamics and controls, especially in the emerging field of intelligent structural & material systems, with applications in vibration, acoustic & wave controls, energy harvesting, and sensing & monitoring. Wang is a Fellow of the American Society of Mechanical Engineers (ASME), American Association for the Advancement of Science (AAAS), and Institute of Physics (IOP). He has received numerous recognitions, including the ASME Rayleigh Lecture Award, the Pi Tau Sigma-ASME Charles Russ Richards Memorial Award, the ASME J.P. Den Hartog Award, the SPIE Smart Structures and Materials Lifetime Achievement Award, the ASME Adaptive Structures and Materials Systems Prize, the ASME N.O. Myklestad Award, the ASME Rudolf Kalman Award, and several other best paper awards. He has been the Editor in Chief for the ASME Journal of Vibration & Acoustics, and an Associate Editor or Editorial Board Member for various journals.

Prof. Shima Shahab – *Virginia Tech, Mechanical Engineering*

Bio: Shima Shahab is Mary V. Jones Faculty Fellow and an Associate Professor in the Department of Mechanical Engineering at Virginia Tech. She completed her Ph.D. and M.S. in Mechanical Engineering at Georgia Institute of Technology. Dr. Shahab is the Director of Multiphysics Intelligent and Dynamical Systems (MInDS) laboratory and an Associate Editor of Journal of Intelligent Material Systems and Structures (JIMSS). Her theoretical and experimental research program focuses on the intersection of smart materials and dynamical systems for various interdisciplinary applications such as contactless ultrasound power transfer, ultrasound responsive polymer-based systems, ultrasound atomization, and acoustic holograms. Dr. Shahab has served as principal investigator on research grants from the National Science Foundation, Alpha Foundation, Oakridge National Laboratory, and Ford Motor Company. In addition to an NSF CAREER award, Dr. Shahab is the recipient of ASME Gary Anderson Early Achievement Award. The award recognizes a young researcher on the rise who has already made significant contributions to the field of Adaptive Structures and Material Systems. She is also the recipient of 2023 Virginia Tech Dean's Award for Faculty Fellow in recognition of extraordinary performance in research.

MONDAY (May 20)

8:00		**Check in and breakfast**
8:50		**Opening/introduction**
9:00	**Session chair: Daniel J. Inman**	**Paolo Ermanni** (keynote) "Structural Approaches for Adaptive Biomedical and Aerospace Systems"
10:00		**Benjamin K. S. Woods**, Tharan Gordon, Francescogiuseppe Morabito, Rafael Heeb "BIRB: Biologically Inspired Robotic Bird Concept Overview and Wing Design Approach"
10:20		**Ralf Keimer**, Michael Schaefer, Srinivas Vasista "Experimental Results of a Fluid Actuated Morphing Winglet Trailing Edge"
10:40		**Coffee break**
11:10	**Session chair: Andrea Bergamini**	**George A. Lesieutre** "The Effects of Pre-stress on Coupling Coefficients and Damping of Flexural Piezoelectric Transducers"
11:30		Grigorios M. Chatziathanasiou, Nikolaos A. Chrysochoidis, **Dimitris A. Saravanos** "Adaptive Vibration Suppression with a Semi-Active Piezoelectric Tuned Mass Damper"
11:50		**Paolo Gardonio**, Emiliano Rustighi, Lisa Ortis, Ciro Malacarne, Matteo Perini "Online Tuning of Structured Fabric Vibration Absorber"
12:10		**Lunch**
13:40	**Moderator: Alper Erturk**	**Daniel J. Inman, Kon-Well Wang, Shima Shahab** (distinguished panel) "Smart Structures Across Decades and Future Perspectives"
15:00		**Coffee break**
15:30	**Session chair: George A. Lesieutre**	**Zhenkun Lin**, Serife Tol "Hierarchical Electromechanical Metastructures for Broadband Vibration Suppression and Asymmetric Reflection"
15:50		Luis Perez Martinez, Danilo Beli, **Carlos De Marqui Jr** "Frequency Conversion in a Tunable Piezoelectric Topological Metamaterial Beam"
16:10		Muhammad Bilal Khan, **Christopher Sugino** "Generalized Non-Reciprocal Dispersion in Non-Local Piezoelectric Metamaterials"
16:30		**Yan Borden**, Daniel Inman "Model Verification and Experimental Testing of a Hybrid Piezo-Hydraulic Actuator"
16:50		**Poster session**
18:00		**Welcome reception (at the venue)**

TUESDAY (May 21)

8:00		**Check in and breakfast**
8:50		**Opening/introduction**
9:00	**Session chair: Kon-Well Wang**	**Diann Brei** (keynote) "Adaptive Inflatable Structures for Avant Garde Automotive and Medical Applications"
10:00		**Tae-Hyun Kim**, Dae-Young Lee, Jae-Hung Han "Conceptual Design of an Origami-based Deployable Structure for Initial Space Shelter"
10:20		**Federica Conti**, Marco Eugeni, Paolo Gaudenzi "From the experience of Smart Structures to Smart Manufacturing: a general approachfor the realization of a Space Smart Factory"
10:40		**Coffee break**
11:10	**Session chair: Dimitris A. Saravanos**	Ruihai Xin, Xiongjie Che, **Nam Seo Goo** "Exploring Challenges on Mechanical Property of Additively Manufactured Composite Structures"
11:30		**Rafael Martin Heeb**, Benjamin King Sutton Woods "BIRB Feathers: Biologically inspired morphing wing covers"
11:50		**Emiliano Rustighi**, Paolo Gardonio, Mahyar Shamsikolokhi, Sofia Baldini, Davide Raffaele, Ciro Malacarne, Matteo Perini "Vibration response of tunable structured fabrics with applications"
12:10		**Lunch** **IOC meeting (12:45-13:45)**
14:00	**Session chair: S. Shahab**	**Norman M. Wereley** (keynote) "Energy Absorption Strategies for Occupant Protection"
15:00		**Coffee break**
15:30	**Session chair: Serife Tol**	**Patrick Dorin**, Kon-Well Wang "Wave-based mechanical computing in a higher-order topological metamaterial"
15:50		Andrea Esposito, Domenico Tallarico, Moustafa Sayed Ahmed, Marco Miniaci, Shima Shahab, and **Andrea Bergamini** "Impedance matching metasurface inspired by the lateral line organ of fishes"
16:10		Mohamed Mousa, Mohammadreza Moghaddaszadeh, Amjad Aref, **Mostafa Nouh** "Mechanical Intelligence via Adaptive Reconfigurable Neuromorphic Metasurfaces"
16:30		Fei Chen, Bolei Deng, Robert G. Parker, and **Pai Wang** "Adaptive Inerter-based Metamaterials with Hz and sub-Hz Band Gaps"
16:50		**Break**
17:30		**Bus transfer (from the venue)**
18:00		**GA Aquarium tour**
19:15		**Banquet at Arctic Ballroom**
21:30		**Bus transfer**

WEDNESDAY (May 22)

8:00		**Check in and breakfast**
8:50		**Opening/intro**
9:00	**Session chair: Marcias Martinez**	**Wei-Hsin Liao** (keynote) "Auxetic structures for energy absorption and harvesting"
10:00		Minghao Guo, **Bolei Deng** "Innovative Shape-Morphing Mechanisms via Mechanical Metamaterials"
10:20		**Nuhaadh Mahid**, Mark Schenk, Branislav Titurus, Benjamin Woods "Parametric Study of Flexible Fairing Design for Folding Wingtips"
10:40		**Coffee break**
11:10	**Session chair: Benjamin Woods**	**Yong Chen**, Amin Fereidooni, Rene Laliberte, Viresh Wickramasinghe "Flight Demonstration of An Active Seat Mount System for Pilot Whole-Body Vibration Mitigation on NRC Bell-412 Helicopter"
11:30		**Boris Lossouarn**, Alan Luo, Robin Darleux, Mathieu Aucejo, Kenneth A. Cunefare, Alper Erturk, Jean-François Deü "Vibration Damping Using Analogous Piezoelectric Networks: 10 Years of Research at Cnam and Georgia Tech"
11:50		Jens D. Richardt, Boris Lossouarn, **Jan Høgsberg**, Jean-François Deü “Experiment-Based Calibration of a Digital Piezoelectric Shunt for Vibration Mitigation”
12:10		**Lunch**
13:40	**Session chair: Christopher Sugino**	Salvatore Ameduri, Angela Brindisi, **Antonio Concilio** "Preliminary Applications of Acoustic Emission Detection Systems on Composite Structures"
14:00		Todd Mull, **Marcias Martinez** "Towards the Development of a Digital Twin Framework for Non-Destructive Evaluation of Adhesive Structural Joints"
14:20		**Ceren Cengiz**, Shima Shahab "Tailoring Focused Ultrasound Fields with Acoustic Lenses for Complex Heat Patterns"
14:40		**Jacob H. Brody**, Prabhakaran Manogharan, Nathan W. Moore, Alper Erturk "High-Intensity Focused Ultrasound for Adhesion Testing and Delamination of Soft Materials"
15:00		**Coffee break**
15:30	**Session chair: Boris Lossouarn**	**Moustafa Sayed Ahmed**, Shima Shahab "Flexible Frequency Tuning in Ultrasound Power Transfer Systems"
15:50		**Mario Schleyer**, Christoph Eberl "Temperature-adaptive damping through metamaterial-based control of liquid friction in a Couette flow"
16:10		**Sai Aditya Raman Kuchibhatla**, Michael Leamy "Experimental demonstration of a topological insulator-based electroacoustic transistor"
16:30		**Prabhakaran Manogharan**, Alper Erturk "Topological Interface Modes in Triply Periodic Minimal Surface and Programmable Piezoelectric Resonant Metamaterials"

LIST OF POSTERS

(May 20, Monday, 16:50)

Jiehao Chen, Herit Patel, Adriane G. Moura, Bohan Wang, Yuhang Hu, Alper Erturk "UV-reprogrammable hydrogel for shape morphing metamaterial with tunable bandgap"	C
Ravi Kiran Bollineni, Moustafa Sayed Ahmed, Reza Mirzaeifar, Shima Shahab "Acoustic metamaterials with nacre-like phononic band gaps and mechanical qualities"	C
Elizabeth Davidson, Trevor Irwin, Todd Mull, Marcias Martinez "Non-Destructive Evaluation and Distributed Sensing Monitoring of Double Lap Shear Joints"	C
Kevin Dix, Ihab El-Kady, Alper Erturk "Multiphysics Through-Metal Ultrasonic Data Transmission Bridging Electromagnetic and Piezoelectric Methods"	
Hrishikesh Kulkarni, Ahmed Sallam, Phoenix Lee, David Safranski, Shima Shahab "Analysis of shape recovery in 4D-printed ultrasound-responsive polymers"	C
Ananya Bhardwaj, Alper Erturk, Karim Sabra "Broadband Piezoelectric Acoustic Identification Tag Design and Optimization for Underwater Applications"	
Nuhaadh M. Mahid, Mark Schenk, Branislav Titurus, Benjamin K. S. Woods "Morphing GATOR Skin Fairings for Folding Wingtip Joints"	C
Mihir Pewekar, Moustafa Sayed Ahmed, Shima Shahab "Shear effects in holographic acoustic lenses"	C
Allen Zhou, **Kevin Dix**, Prabhakaran Manogharan, Ihab El-Kady, Alper Erturk "Design of Multi-Stage Detachable Ultrasonic Power Transfer System and the Effect of Self-Heat Generation"	
Yuning Zhang, Kon-Well Wang "Embodying Mechano-intelligence in Phononic Metastructures via Physical Computing and Learning"	C
Moustafa Sayed Ahmed, Shima Shahab "Modifiable Acoustic Lens for Changing Target Patterns Spatially"	
Tiantian Li, Jonathan Luntz, Diann Brei "Pneumatic Tile-Based Approach for Localized, Distributed, Proportional Actuation of Active Origami"	C
Christopher Sugino, **Joseph Shedleski**, Matthew Irving, Eetu Kohtanen, Ihab El-Kady, Alper Erturk "Dynamic Pressure Inversion Using a Piezoelectric Sensor Array and Faulty Sensor Detection"	
Derek J. Willis, J. Boomer Perry, Daniel J. Inman "Vibration and Stability of Morphing Wing"	
Jacob H. Brody, Prabhakaran Manogharan, Nathan W. Moore, Alper Erturk "High-Intensity Focused Ultrasound for Adhesion Testing and Delamination of Soft Materials"	
Jiaxin Xi, Ahmed Sallam, David Safranski, Reza Mirzaeifar, Shima Shahab "Focused Ultrasound-Actuated Shape Memory Polymers for Biomedical Devices"	C
Nadine Fahed, Yang Wang, Lauren Stewart "Joint Input-State Estimation for Inelastic Structural Systems Subjected to Extreme Dynamic Input"	
Fernando M. Dapino, Samir A. Emam, Daniel J. Inman "On the Dynamic Response of a Smart Bistable Plate"	

C: Student poster competition

Things to do around Technology Square

RESTAURANTS

Atwoods Pizza Cafe
817 West Peachtree St. NW, A105
404-748-9577
www.atwoodspizzacafe.com

Boho Taco
22 5th St NW, Atlanta, GA 30308
404-500-1356
www.eatboho.com

Buffalo Wild Wings 'GO'
68 5th St NW, Atlanta, GA 30308
404-905-5010
www.buffalowildwings.com

Cypress Street Pint and Plate
817 W Peachtree St. NW
404-815-9243
www.cypressatl.com

Georgia Tech John Lewis Student Center
351 Ferst Dr NW, Atlanta, GA 30332

Gyro Bros
85 5th St. NW, Suite B
404-892-5707

Insomnia Cookies
930 Spring St. NW
404-649-0167
www.insomniacookies.com

J. Christopher's
950 W Peachtree St. NW
www.jchristophers.com

Moe's Southwest Grill
85 5th St. NW, Suite C
404-541-9940
www.moes.com

Ray's New York Pizza
26 5th St. NW
404-888-9911
www.raysnewyorkpizza.com

Rowdy Tiger Whiskey Bar & Kitchen
866 W Peachtree St. NW
678-412-2402
www.rowdytigeratlanta.com

Sankranti Indian Kitchen
85 5th St. NW
404-343-6358
www.sankranti.com

Starbucks @ Georgia Tech Bookstore
48 5th St. NW
404-894-1858
www.starbucks.com

Subway
85 5th St. NW, Suite D-2
www.subway.com

Taco Bell
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20 Sankranti Indian Kitchen

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ABSTRACTS
for
oral and poster
presentations

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BIRB: Biologically Inspired Robotic Bird – Concept Overview and Wing Design Approach

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Abstract: This paper introduces a new line of research at the University of Bristol on the development of a Biologically Inspired Robotic Bird (BIRB) wing. This project aims to combine a number of novel approaches to designing and building biologically-inspired flight vehicles to create a fully integrated, multi-physics coupled, seagull-inspired morphing wing structure. The focus areas of development are structures, aerodynamics, and actuation, with biologically inspired concepts pursued in each. The structure of the BIRB wing consists of ultra-lightweight Wrapped Tow Reinforced truss "bones" with integrated hardpoints, connected together into a biomimetic, moveable skeletal structure. A tendon-based actuation system controls the desired degrees of freedom with a very low on-wing mass. The aerodynamic shape is created by a hybrid compliant/mechanical approach employing feather analogues in concert with rigid elements and compliant connections. These three core constituent concepts are to be designed and evaluated concurrently in a bespoke low-fidelity, partitioned, loosely coupled, fluid-structure-actuation interaction analysis framework, which is also under development. This talk will discuss the design concept, motivation, and approach, and overview progress made to date.

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Experimental Results of a Fluid Actuated Morphing Winglet Trailing Edge

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Abstract: Designing active control surface technology into thin regions of aircraft wings is challenging due to small available volumes. To be able to do so is potentially beneficial to enable more efficient wing designs using morphing for e.g. load alleviation. This paper details a winglet trailing edge surface composed of fluid actuated morphing unit structures (FAMoUS) that enable control surface deflections under the corresponding aerodynamic hinge moments. These FAMoUS actuators are comprised of elastomer and metallic stiffeners, which under internal pressure from a fluid exert displacement and force and thus output work. Combining these unit structures in a bimorph setup a trailing edge control surface is build. This paper outlines the design, finite element analyses and manufacturing process of a demonstrator with 1 m span-width. These finite element analyses consist of detailed tuned material parameters obtained from testing on the individual unit structure tests as well as the inclusion of hydrostatic fluid elements to determine effective stiffnesses from the pressure-volume relationship between the housing structure and internal fluid. Manufacturing of the demonstrator is conducted using composite fabrication and machining techniques to ensure that the demanding tolerances and surface qualities are to be maintained. The structural part of the demonstrator is joint with an actuating system, where in combination wíth feedback sensors position control is achieved. The setup of the actuating system is introduced, elucidating the hydraulic system and the overall control design. Experimental results of tests are presented, starting with calibration of the feedback system with an external measurement, also clarifying deflection uniformity along the span of the demonstrator. Further results of deflection performance and deflection rate are presented and compared to the predictions derived from the finite element analyses. The findings are discussed and contextualized. A summary of the results is given and an outlook on the way forward is presented.

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The Effects of Pre-stress on Coupling Coefficients and Damping of Flexural Piezoelectric Transducers

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Abstract: Membrane (or in-plane) loads (or internal pre-stresses) are often encountered in thin-walled aerospace structures. Examples of tensile loads include those associated with spinning helicopter rotor blades, bladed disks in engines, and pressurized aircraft cabins; compressive loads can be due to gravitational forces and acceleration, or to pressure loads in buoyant structures. The primary effects of such in-plane loads on the linear dynamics of flexural structures (beams, plates, shells) are generally agreed to be changes in the natural frequencies (and mode shapes) of the structures. Such behavior can be exploited in the development of, for example, tunable piezoelectric transducers.

Other effects of these membrane loads, however, are not as widely appreciated. One effect is specialized to piezoelectric structures – structures in which electrical and mechanical behavior are intimately coupled. In this case, membrane loads influence the apparent strength of system electromechanical coupling coefficients. A coupling coefficient is a measure of the effectiveness with which a piezoelectric material (or device) converts the energy in an imposed signal to useful mechanical energy. With compressive pre-loads, some device coupling coefficients can exceed those of the piezoelectric material and, in principle, even approach the ideal of perfect energy conversion. This approach provides a way to simultaneously increase both displacement and force, distinguishing it from alternatives such as motion amplification, and allows transducer designers to achieve performance gains for some actuator and sensor devices. Notably, this effect of membrane loads has been exploited in flight control actuators of micro air vehicles and has potential for application to other flexural transducers including reed valves and energy harvesters.

An additional effect of membrane loads is to change the damping observed in various modes of structural vibration. Tensile loads tend to increase the natural frequencies of vibration and decrease the modal damping. Conversely, compressive loads decrease the natural frequencies and increase the modal damping. This effect can be considerable in applications such as pressurized aircraft fuselages or spinning rotor blades.

This research considers the transverse motion of symmetric flexural piezoelectric transducers subjected to preloads that are tangent to the midplane of the structure; the effects of such membrane loads on the piezoelectric coupling coefficients and the damping of the transducer vibration modes are of particular interest. The implications for various kinds of piezoelectric transducers and their uses (*e.g.*, quasi-static positioning, resonant energy harvesting) will be described.

Adaptive Vibration Suppression with a Semi-Active Piezoelectric Tuned Mass Damper

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Abstract: Large flexible structures, such as airframe or transport structures, often operate under undesirable high amplitude vibrations, which deteriorate the comfort of passengers and reduce the residual fatigue life. In many cases, the frequency content of the exciting loads changes during operation, leading to higher vibrations. Notable examples are: (i) varying and/or multiple tonal excitations due to changes in engine/rotor RPMs, which may excite one or more structural modes; (ii) varying broadband low-frequency excitation due to unsteady aerodynamic forces on aircrafts, and (iii) variation of the dynamic characteristics of the structure, due to changes in structural parameters (e.g., mass diminution due to fuel consumption). To address the robust vibration suppression in large flexible structures with minimal low weight and structural interference, an electromechanical Semi-Active Tuned Mass Damper (SATMD) has been developed, which consists of an auxiliary mass and a combined spring-piezoelectric device connected to an external resistive-inductive (RL) circuit. The device introduces two coupled electromechanical modes, which are highly tunable through the shunt circuit inductance and act as kinetic energy sinks. The transferred kinetic energy to the SATMD can be also dissipated electrically by adding resistance to the circuit, which further enhances the vibration control.

The proposed paper builds on the potential of the SATMD to provide adaptive vibration control and presents the methodology to achieve the desired adaptive performance. The structural frequency profile is identified by using the Discrete Fourier Transform (DFT) of the measured structural acceleration in short regular time intervals. The inductance which places one SATMD electromechanical mode at the most critical frequency is structure-independent and can be directly calculated. The acceleration signal RMS can then be used to tune the resistance for higher energy dissipation and as a result high vibration control performance.

The adaptive performance of the SATMD is quantified numerically and experimentally on a down-scaled airframe structure, for various types of harmonic and broadband excitation. Preliminary simulations, so far, have shown exceptional anti-resonance manipulation with varying inductance, which effectively compensate for the frequency alterations, and achieve continuous high vibration levels.

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Online Tuning of Structured Fabric Vibration Absorber

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Abstract: This paper presents a new tunable vibration absorber, which is made by a beam-like composite structure with a post in the middle section. The low-frequency vibration response of this system is controlled by the fundamental flapping bending mode of the composite beam such that it's dynamics resembles that of a mass-spring-damper vibration absorber, which can be used to control either the time-harmonic or resonant vibrations of structures/machines. The beam is formed by a single or a double layer of structured fabric core material wrapped in a deflated plastic bag, which works as the outer skin of the composite material. The fabrics are formed by chain mails made with a) cubic, b) spherical-octahedral, c) octahedral truss-like particles. The post has been conceived in such a way as it works both as a mechanical joint and a vacuum connector, which is linked to a vacuum control platform. The platform is formed by a miniature diaphragm pump, four electro-mechanical valves and a pressure error sensor. Also, the beam-like structure is equipped with three accelerometers: one positioned in the middle section and the other two at the outer sections. In this way they can be suitably used to detect the vibration energy absorbed by the system. The pump and the electromechanical valves are commanded by a dSpace digital controller. The pressure output signal from the error sensor is also feed to the controller together with the output signals from three accelerometer error sensors. The pressure sensor is used in a single channel feedback control loop to regulate the vacuum in the bag. The output signals from the accelerometer sensors are instead employed to detect the vibration absorption of the system and thus to implement a feedback loop that sets the vacuum level in the bag in such a way as the system maximizes the vibration absorption from the hosting machine/structure. The paper presents preliminary results on the design and development of a prototype control platform and on the implementation of the pressure feedback regulator and tuning feedback approach, which is based on a model-free extremum seeking algorithm.

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Hierarchical Electromechanical Metastructures for Broadband Vibration Suppression and Asymmetric Reflection

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Abstract: Hierarchical structures featuring multiple-length scales are common in natural materials such as glass sponges and bones. Inspired by these structures, researchers have proposed different hierarchical engineered material systems to achieve unconventional mechanical properties and dynamic behaviors. For example, structural hierarchy has been employed to improve mechanical properties, such as thermal resistance, stiffness, and strength. Recent explorations into hierarchical metastructures have also shown potential in dynamic vibration control, demonstrating the capability for multiple and broadband gaps (i.e., forbidden waves) by harnessing their multi-scale periodicity. While promising, a key challenge in hierarchical engineered structures is achieving real-time performance tunability without the need for structural modifications. To this end, we explored a hierarchical electromechanical metastructure (HEM) with tunable transmission and reflection capability stemming from its hierarchical periodicity and electromechanical coupling effects. In our design, shunt circuits with negative capacitance and resistance are utilized for controlling flexural wave propagation. We developed fully coupled electromechanical models in a transfer matrix form to analyze the dispersion relations and wave propagation in various hierarchical systems. Our analytical and numerical results show that arranging electromechanical metastructures in a hierarchical manner can enlarge the band gap and increase the maximum wave attenuation constant by more than three times as compared to the non-hierarchical system. Additionally, employing a graded NC-R shunt allows the HEM to achieve adjustable asymmetric reflection while maintaining wave attenuation performance. The use of hierarchical arrangement in the electromechanical metastructure can improve wave attenuation performance in a lightweight and controllable manner, requiring fewer piezoelectric materials and providing tunable wave propagation control without the need for structural modification. The proposed HEM concept has potential applications in mechanical and aerospace systems, enabling tunable elastic wave control for different environments.

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Frequency conversion in a tunable piezoelectric topological metamaterial beam

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Abstract: In this work, we numerically investigate a tunable piezoelectric metamaterial beam that enables frequency conversion of topological modes. The coupled metamaterial is a bimorph piezoelectric beam with electrically interconnected unit cells. The unit cell is defined as two consecutive pairs of segmented electrode sections that are connected to inductive shunt circuits. A secondary chain of capacitors interconnects the resonant shunt circuits of the main chain. Manipulating the coupling capacitances of the secondary chain while the main resonant chain is tuned to a target frequency leads to the nucleation of trivial and non-trivial band gaps, in which a shared interface supports topological modes. Through a supercell dispersion analysis and frequency response of a finite beam, we demonstrate the presence of interface states in a beam composed of two sub-structures with distinct topological properties. Furthermore, we use time integration to illustrate the potential of robust frequency up- and down-conversion by changing the frequency of the topological interface states due to time-varying inductances.

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Generalized Non-Reciprocal Dispersion in Non-Local Piezoelectric Metamaterials

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Abstract: This talk will present the theoretical and experimental investigation of vibration and wave propagation in a class of piezoelectric metamaterials with non-local electrical interactions. Conventional piezoelectric metamaterials have effective properties that depend on a shunt circuit that acts locally at each unit cell: each shunt circuit supplies current to a unit cell in response to that same unit cell's voltage. These local interactions add frequency-dependence to the dispersion of the metamaterial via mechanisms such as inductive-capacitive (LC) local resonance and resistive damping. In this work, we show that non-local shunt circuit connections between unit cells modify the wavenumber-dependence of the metamaterial's dispersion curves, greatly expanding the possibilities for wave manipulation and enabling behaviors that are otherwise unachievable, such as roton-like dispersion. Furthermore, the use of non-local interaction enables symmetry-breaking via unbalanced, directional electrical connections, such that non-reciprocal behavior can be created without nonlinearity or time-varying material properties. To explore the full design space of non-local piezoelectric metamaterials, we present a general analytical model and inverse design methods to calculate the required shunt circuitry for a given set of non-reciprocal dispersion curves. An array of voltage-controlled current sources provides the non-local connections between unit cells, creating an electrical lattice whose dispersion can be made non-Hermitian, non-reciprocal, and drawn to specification via a Fourier series expansion. The piezoelectric dispersion curves form from the hybridization of elastic and electrical dispersion curves, similar to the case of local resonance, which informs the design of the electrical lattice. One- and two-dimensional analytical and numerical (finite-element) case studies are given for non-local resistive, inductive, and capacitive shunt circuits, which provide insight into the uses of each of these circuits in non-local metamaterial systems. We then experimentally demonstrate this approach using a piezoelectric bimorph beam with local and non-local circuit interactions, highlighting non-reciprocity and the tunability of the dispersion relation of the system.

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Model Verification and Experimental Testing of a Hybrid Piezo-Hydraulic Actuator

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Abstract: Piezoelectric stacks have excellent force and response characteristics, but their applications are limited by their relatively small stroke. Various mechanical methods of amplification, such as levers and Scott-Russel mechanisms, have been discussed in literature. In a previous paper, it was proposed to amplify the stroke of piezoelectric stacks using a direct hydraulic stage. In the presented actuator, piezoelectric stacks move a hydraulic fluid through an area contraction which, in theory, amplifies the stroke by the area ratio. This idea is extended into this paper where a working prototype for this mechanism is presented. Three piezoelectric stacks are used in combination with a hydraulic stage consisting of three parts: input and output pistons with an area ratio of approximately 100, and the stage casing. Issues with assembly and setup of the prototype such as static friction due to the hydraulic seals, as well as hydraulic fluid leakage and delivery are discussed as well. The analytical model of this system which includes a frequency-dependent non-symmetrical Bouc-Wen hysteresis model for the piezoelectric stacks is shown and verified with experimental testing of the prototype. Different approaches to modelling the fluid in the system such as a simple model based on Pascal's Law are also presented. Possible return mechanisms using linear/torsional springs for the device are presented. The prototype is controlled by adjusting the voltage across the piezoelectric stacks. The current maximum stroke of the actuator is 8 millimeters, while the maximum stroke of the piezoelectric stacks is 100 micrometers, which gives an actual amplification ratio of 80. This is less than the theoretical maximum of approximately 10 millimeters with the area ratio of the channels in the hydraulic stage. Response characteristics for the prototype are discussed with a focus on the speed of the response. The effects of the stiffness of the load applied to the actuator are also experimentally studied and compared to previous analytical results.

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Conceptual Design of an Origami-based Deployable Structure for Initial Space Shelter

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Abstract: With recent advancements in space launch technologies, the feasibility of various advanced space missions such as deep space exploration and manned missions are increasing. However, the space environment poses risks including excessive heat, micro-meteoroids, radiation, and so on. To protect equipment and astronauts from these hazards for sustainable long-duration missions, a space protection system, such as Lunar base or Mars habitat, is essential. However, previously proposed concepts may not be practical for initial space habitation systems, as they require considerable time and resources for installation and construction. In this research, we propose a novel deployable structure suitable for space habitation hardware in initial space exploration missions. The proposed design incorporates a new origami pattern, Recessed Pyramid Origami (RPO), as a fundamental element to create an enclosing shape. The proposed design has a dome-like configuration in the operational state and a flat shape in the folded state. Therefore, it is possible to efficiently transport multiple units at once by a launch vehicle. Additionally, the base pattern can be folded without deforming the surface during the folding process, making it possible to employ thick materials. Moreover, the proposed deployable structure allows for simple deployment using cable-driven actuation and a stable final configuration. To validate the feasibility of the proposed concept, we construct a proof-of-concept model using thick panels and conduct a deployment test. Consequently, we expect that the proposed deployable space shelter is suitable for an initial space habitation for future exploration missions.

From the experience of Smart Structures to Smart Manufacturing: a general approach for the realization of a Space Smart Factory

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Abstract: Smart structures represent an innovative evolution in the very concept of structural systems. While maintaining the classic functions of a structure, smart structures go beyond by possessing additional engineering capabilities [1]. Wada, Fanson, and Crawley [2] provided a comprehensive framework for defining intelligent structures. They initially categorized sensory structures as those equipped with sensors for determining or monitoring system states or characteristics, and adaptive structures as those featuring actuators enabling controlled alterations of system states or characteristics. Intelligent structures integrate sensors and actuators within a feedback architecture, closely interwoven with control logic and electronics. The parallels between the concept of intelligent structures in [2] and the modern Industry 4.0 paradigm are evident, where the factory itself functions as an intelligent system, capable of self-awareness through sensing capabilities and real-time adaptability to emerging demands and commercial scenarios [3,4]. This alignment becomes particularly pertinent in the space industry, experiencing a shifting commercial landscape marked by the entry of private companies and a growing interest in mega-constellations of small satellites for telecommunications or Earth observation purposes [4]. In response to this dynamic environment, the space manufacturing industry must swiftly adapt, exploring new approaches to optimize both satellite and launcher production processes. In this study, drawing on insights gained from years of work in the field of Smart Structures within their research group, the authors present a general framework for applying Industry 4.0 concepts to the space industry. In this context, the notion of a Cyber-Physical System is crucial, and the concept of an "Intelligent Structure" can be considered an archetype [4].

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Exploring Challenges on Mechanical Property of Additively Manufactured Composite Structures

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Abstract: This study investigates the challenges on mechanical property use of additively manufactured continuous carbon fiber reinforced polymer composites measured by ASTM standards and proposes strategies for their real-world applications. Tensile, transverse tensile and in-plane shear tests were conducted on specimens produced with a Markforged X7 printer, providing material properties of Onyx and carbon fiber filaments which was applied for further numerical analysis. A cylindrical shell structure, relevant to urban air mobility application, was additively manufactured using the same printer and a compression test was performed, followed by a finite element analysis. However, a large discrepancy between numerical and experimental results were observed. To address this, we performed microstructural analysis of the cylindrical shell structure and identified significant fiber volume fraction reduction compared to ASTM standard specimens. Fiber volume fraction compensation produces good agreement between numerical and experimental results in terms of compression stiffness. However, the well established analysis method cannot predict buckling load adequately. We believe the sliding effect of composite layer interface is one of the possible reasons. For the real world application of additive manufacturing for composite structures, the their characteristics needs to considered significantly.

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BIRB_Feathers: Biologically inspired morphing wing covers

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Abstract: This paper discusses initial development work into aeroelastically tailored and structurally optimised 3D printed feather analogues for use in bird-inspired unmanned aerial vehicle wings. The intent of this work is to attempt to replicate some of the incredible design features that have existed within feather for many millions of years in order to create aeroelastically stable and incredibly lightweight wing covers capable of large changes in wing shape and area. These feather analogues are being explored in concert with the development of a Biologically Inspired Robotic Bird (BIRB) at the University of Bristol, which will use them as covers over an actuated skeletomuscular system constructed from ultra-lightweight Wrapped Tow Reinforced Bone structures (WrapToR_Bones) and actuated via elastic tendon systems. Bird wings have evolved to adapt their geometry for diverse flight conditions in order to maintain optimal performance across a range of aerodynamic and structural metrics, enabled by the incredible aerostructural performance of feathers. The presented BIRB_Feather is a rough initial approximation of a bird feather that emphasizes mimicking key functional aspects of their structural and aerodynamic performance over a direct copying of their incredibly complex microstructure. This concept is presented in the context of previous work in the area of morphing skins, and the relative merits of compliance-based and mechanism-based approaches are discussed, with natural feathers displaying aspects of both. Limitations in both the manufacturability and scalability of feather analogues motivate a hybrid approach in producing practical BIRB covers employing feather analogues, rigid elements, and compliant connections. This paper delves into the design concept, motivation, and approach and presents initial functional prototypes of primary flight feathers.

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Vibration response of tunable structured fabrics with applications

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Abstract: Structured fabrics are fabrics realized by rigid mechanical truss structures interwoven to obtain flexible garments such as chain mail armors. Although fabrics' properties are usually fixed, recent publications have demonstrated the tuneability of structured fabrics. It has been shown that vacuum pressure applied between two layers of 3D printed chain mails causes jamming of the chain mails and an increase in the bending modulus up to twenty-five times. The increase in the effective bending modulus is due partly to the compressive frictional forces and partly to the geometrical interlocking of the complex shapes. In this paper we investigate the vibration response of tunable structured fabrics when subject to variables vacuum pressures. The investigation is focused on the variation of the vibration characteristic and of the dynamical properties with the vacuum pressure, and the geometry and dimension of the truss-structure elements. The chain mails are fabricated with different geometries (spheres, tetrahedra and cubes) using 3D-printing technology. The material is then wrapped in a bag whose vacuum pressure is tuned with a vacuum pump such that the stiffness and damping properties of the resultant smart structure can be suitably tuned. To start with, the paper presents static and dynamic 3-point bending tests which show that the bending stiffness and fundamental resonance frequency of the specimens can be increased significantly by augmenting the void in the bags. The damping effect does not depend substantially on the vacuum level but varies significantly with respect to the geometry of the constitutive elements of the fabrics. Possible applications include the realization of lightweight adaptive and semiactive vibration mitigation devices. Hence, the paper shows that this smart structure can be conveniently used to develop a tunable vibration absorber, which can be used to control the time-harmonic response of a mechanical system subject to variable tonal excitation.

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Wave-based mechanical computing in a higher-order topological metamaterial

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Abstract: Mechanical metamaterials unlock the capability to manipulate the flow of elastic waves in structural systems through the formation of waveguides. Recent advances have uncovered the potential of exploiting this useful functionality to achieve wave-based mechanical computing. For instance, a growing body of research has focused on the exploration of mechanical metamaterials that can emulate Boolean logic by treating elastic waves propagating through engineered structures as carriers of information. The outcomes from these initial studies are very promising, illustrating how elastic waves can be utilized to conduct many of the fundamental Boolean logic operations. However, more research is required to create mechanical computing systems with robust operational performance, even in the presence of undesired structural defects. Furthermore, an unexplored opportunity exists to study mechanical computing in mechanical metamaterials with more complex physics, such as topological metamaterials that are inspired by topological phase theory from condensed matter physics. To address these research gaps and advance the state of the art, this research proposes a 2D topological metamaterial that harnesses higher-order topological phases and multimodal resonances to achieve robust and multifunctional wave-based mechanical computing. The proposed metamaterial is constructed as a 2D thin plate with periodically attached resonators that are designed to attain multimodal resonances. The resonators are arranged in a configuration that facilities higher-order topological phases according to the Su-Schrieffer-Heeger model. Calculation of the band structure for the metamaterial reveals four topological bandgaps that align with the multimodal resonant modes. A supercell study illuminates gapped 1D topological edge states that emerge within each topological bandgap. An eigenfrequency analysis shows 0D topological corner states that appear in each of the topological bandgaps and contain distinct displacement field attributes. Further investigation illustrates how these corner states can be utilized to construct fundamental Boolean logic elements. Multifunctional and defect-immune computing operations that are dependent on the frequency and phase properties of the input are achieved by taking advantage of the diverse characteristics of the topological corner states. The promising outcomes from this investigation open the door to future research of higher-order topological metamaterials for wave-based mechanical computing.

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Impedance matching metasurface inspired by the lateral line organ of fishes

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Abstract: When designing an acoustic device, the study of the impedance mismatch between the device itself and its surroundings is of critical importance to achieve good performances. In fact, a high impedance mismatch would prevent the transmission of the energy across the interface, thus limiting the amount of energy that the device itself could treat. Generally, this is overcome by applying acoustic impedance matching layers, for instance in form of gradients, similar to what done in optical coatings. The minimal form of such a gradient can be seen as an intermediate layer with specific properties laying between the ones of the two media to impedance match, and, in any case, requiring a minimum thickness of the order of at least one quarter wavelength of the lowest frequency under consideration. The selection of materials is traditionally dictated by the required combination(s) of the (limited) available elastic properties and densities. Nature, also constrained by the use of a limited number of materials in the design of the biological structures, shows the way to a different approach, where the design space is swept by varying specific geometrical and/or material parameters. The middle ear of mammals and the lateral line of fishes are examples of such an approach, the latter already embodying an architecture of distributed impedance matched underwater layers. Inspired by this organ, here we describe a resonant mechanism, whose properties can be tuned to provide impedance matching at different frequencies by choosing appropriate values for a small set of geometrical parameters. Similar to the lateral line organ, the mechanism at hand is intended as the base unit for the construction of an impedance matching meta-surface. A numerical investigation and a parameter optimization demonstrate its ability to match the impedance of water and air in a deeply sub-wavelength regime.

Mechanical Intelligence via Adaptive Reconfigurable Neuromorphic Metasurfaces

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Abstract: Mechanical intelligence, the ability of mechanical systems to perform basic logic and computational operations, has gained traction over the past few years, providing an unconventional low-power alternative to digital electronic computing. However, much of the work in mechanical computing has focused on correlating mechanical deformations in soft matter, bistable lattices, and origami-inspired structures to intended functions. The notion of utilizing wave-based elastic scatterers as differential operators to conduct complex mathematical functions remains a work in progress, largely because of the limited capabilities and low computational speeds offered by such systems. Among such limitations is the inability to concurrently perform multiple tasks, which represents a major hindrance. In pursuit of more complex tasks such as perception and recognition, wave-based analog computing (which exploit and manipulate wave scattering in a physical medium) and neuromorphic devices (which implement models of neural networks) have shown success in the optical and acoustic domains. Recent advances in elastic waveguides, smart materials, and fabrication technologies present an opportunity to significantly advance mechanical computing, enabling conceptual devices with broader computational capabilities. In the first thrust of this talk, we present a first attempt to describe the fundamental framework of an elastic neuromorphic metasurface that performs distinct classification tasks, providing a new set of challenges given the complex nature of elastic waves with respect to scattering and manipulation. In the second thrust, we discuss the feasibility of parallel processing in elastic wave-based computing platforms. By exploiting a time-modulated metasurface which enables simultaneous multi-wave beaming in distinct frequency channels, we attempt to unlock parallel mechanical computing within a prescribed mechanical domain. The realization of neuromorphic computing as well as parallel processing in elastic structures lays the foundation for substantial advancements and unlocks several features which this far have been elusive in physical and reservoir computing.

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Adaptive Inerter-based Metamaterials with Hz and sub-Hz Band Gaps

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Abstract: We reveal the unique and fundamental advantage of inerter-based elastic metamaterials by a comparative study among different configurations. When the embedded inerter is connected to the matrix material on both ends, the metamaterial shows definite superiority in forming a band gap in the ultralow frequency - equivalently the ultra-long wavelength - regime, where the unit cell size can be four or more orders of magnitude smaller than the operating wavelength. In addition, our parametric studies in both one and two dimensions pave the way towards designing next-generation metamaterials for structural vibration mitigation. A defining feature of our system will be its dynamic adaptability: The reconfigurability and tunability by integrating bi-stable and multi-stable metamaterials, enabling seamless transitions between energy harvesting and vibration control modes. It responds in real-time to environmental stimuli and seismic changes, maintaining operational integrity through proactive adaptation. These capabilities allow the system to efficiently alternate between converting kinetic energy and mitigating vibrations during seismic disturbances. Designed to strengthen civil infrastructure resilience and safety, especially in seismically prone areas, this Invention synthesizes cutting-edge material science with intricate control mechanisms. It tackles the persistent challenge of dampening low-frequency vibrations and establishes a novel precedent in metamaterial for infrastructural technologies, where the reconfigurable and tunable nature of the metamaterials plays a pivotal role in system adaptability and performance optimization.

Innovative Shape-Morphing Mechanisms via Mechanical Metamaterials

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Abstract: In the vast expanse of nature, myriad creatures exhibit a fascinating array of morphing techniques as a survival mechanism in unpredictable environments. The agility of a jellyfish changing shape to propel through water, the ability of certain organisms to compress their bodies to maneuver through narrow spaces, and the transformative capabilities seen in chameleons and cuttlefish. These natural phenomena have long inspired human innovation, particularly in the realm of robotics, leading to the development of morphable robots designed to emulate such adaptive characteristics. However, existing approaches in this field often encounter significant challenges. Traditional morphable robots typically depend on numerous actuators operating in unison, orchestrated by a complex central processing unit (CPU). This design not only increases the complexity and cost of construction but also makes the system vulnerable to malfunction; the failure of even a single component can render the robot inoperative.

Addressing these challenges, our work introduces a novel approach to shape-morphing in robotics, leveraging the potential of mechanical metamaterials. We specifically explore the use of rotating polygons in metamaterials, where interconnected polygonal shapes pivot at their vertices, allowing for intricate and flexible deformation patterns. We developed an algorithm optimizing the placement and angular connections of these polygons, enabling precise control over the local strain and curvature of the metamaterial. Through computational design, these structures can seamlessly transition between multiple geometries, effectively morphing from one form to another. Unlike conventional morphable robots that require a multitude of actuators, our design necessitates only a single actuator. This significantly reduces the complexity and potential points of failure in the system. Moreover, by inverse design the dynamic behavior of these structures, we can realize non-reciprocal morphing dynamics, enabling locomotion and other complex movements. Essentially, the intelligence of the robot is embedded within its physical structure, a concept that was recently termed *physical intelligence*. This breakthrough not only simplifies the control mechanisms but also opens new avenues in the design and application of adaptive, morphable robotic systems.

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Parametric Study of Flexible Fairing Design for Folding Wingtips

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Abstract: Folding wingtips enable longer wingspan in flight while shortening the wing to fit within the airport gate size. A wingtip that is hinged to the inboard wing at an outward angle to the line of flight and free to flap in response to gust provides structural weight saving due to reduced peak loads. A flexible fairing is required around the hinged joint to provide a smooth aerodynamic surface as the wingtip is movable in flight. This fairing must be flexible in the direction across the hinge to allow folding of the wingtip but stiff in the out-of-plane direction to carry pressure loads. This paper investigates a morphing fairing concept incorporating three key design features to achieve these objectives for the fairing. Firstly, a central rib pivoted and co-located with the folding hinge is used to support the fairing. This architecture reduces the torsional stiffness compared to a rigid rib and avoids contact between the hinge and the fairing as the wingtip folds. Secondly, floating ribs supporting the fairing are used to minimise the localised warping of the fairing, but this comes at the cost of increased torsional stiffness. However, this penalty on the torsional stiffness can be reduced by increasing the flexibility of the fairing in the morphing direction. Thirdly, a sandwich panel with a cellular core and flexible facesheets is used as the fairing. The cellular core consists of parallel ribs with chevrons in between them. This configuration provides high flexibility in the direction across the ribs as the chevrons predominantly deform in bending instead of axial stretching. The ribs provide high stiffness in the direction along the rib, thereby achieving near zero Poisson's ratio. The panels are oriented with the ribs of the panel parallel to the hinge. These three design features together provide a flexible fairing for the folding wingtip joint. The design variables can be further tuned to reduce torsional stiffness and panel warping as the wingtip folds. This paper discusses the design features of the fairing and presents a parametric study of the design space. The results show the solution space of torsional stiffness and panel warping, achievable within the constraints of the design variables. These results help assess the benefits and drawbacks of flexible fairing for a commercial aircraft with hinged wingtips.

Flight Demonstration of An Active Seat Mount System for Pilot Whole-Body Vibration Mitigation on NRC Bell-412 Helicopter

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Abstract: Helicopter aircrew are exposed to high levels of whole-body vibrations (WBV) during fight missions, which may adversely affect their ride comfort and performance. Long term exposure to excessive WBV has been identified as a contributing factor to several adverse health issues such as the lower back pain and neck strain in the military helicopter aircrew community. National Research Council (NRC) Canada has developed a patented active seat mount technology to reduce the whole-body vibration levels for the helicopter pilot at the seat and occupant cushion interfaces in accordance with ISO2631-1 and MIL-STD-1472 standards. The active seat mount system is designed for installation between the helicopter cabin floor and the pilot seat frame and acts as an active interface to suppress the major N/rev harmonic vibration peaks of the main rotor speed. The prototype active seat design has demonstrated significant WBV reduction to the mannequin occupants on the mechanical shaker table using helicopter floor vibration profiles. Full-scale flight demonstration of the active seat mount technology on the helicopter is required to evaluate the potential of this technology using human subjects in flight conditions.

This paper presents the recent progresses of the NRC flight demonstration program. Topics will include the required structural re-designs and modifications for integration of the active seat mount system with the rear cabin floor of the NRC Bell-412 helicopter, as well as design considerations for FAA airworthiness compliance. Extensive test results of mannequin and human subjects on a human rated shaker platform confirmed the proper functionality and adequate performance of the re-designed active seat mount system. A total of three flights on the NRC Bell-412 helicopter have been completed in March 2023. Flight test conditions included rotor ground run at 100% Nr, hover within ground effect, and level flights at 100 and 120 kts. In each condition, the active seat mount actuators were activated to reduce the aircrew WBV levels at the bottom seat cushion interface. Two male aircrew, one 50th and the other 85th percentile, were tested as the occupants. The aircrew vibration levels at the seat cushion interface and head/helmet locations were measured. Flight test results successfully demonstrated that the performance of the NRC-patented Active Seat Mount technology. Through adaptive suppression of the dominant multiple N/rev vibration peaks at the bottom seat cushion interface, it achieved significant and simultaneous reductions to the occupant WBV and the head vibrations, and also demonstrated consistent performance in the tested flight conditions. The ISO weighted WBV levels indicated that the occupant ride comfort was improved from "Fairly Uncomfortable" to "not Uncomfortable", and the aircrew daily exposure time was effectively extended from 2.8 hrs to "Unlimited", a significant improvement over the current Bell-412 pilot seat system. Details will be presented in the full-length paper.

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Vibration Damping Using Analogous Piezoelectric Networks: 10 Years of Research at Cnam and Georgia Tech

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Abstract: Structural vibrations can be reduced by employing piezoelectric material as passive electromechanical transducers. Piezoelectric shunt damping consists in connecting a one-port electrical circuit to a piezoelectric transducer for impedance matching and thus optimized energy transfers. Using passive components such as resistors, inductors or capacitors leads to autonomous and inherently stable control solutions. When using an inductance in parallel with the piezoelectric capacitance, impedance matching is reached when tuning the resonance of the shunt to a natural frequency of the mechanical structure. The equivalent of a tuned mass damper is thus implemented with a vibration absorber that is designed as the electrical counterpart of the mechanical resonance to be controlled. This classical uni-modal case introduces the interest of electrical analogues for piezoelectric damping. Indeed, analogous coupling can be extended to broadband vibration mitigation. A multi-resonant electrical network is then required to approximate the modal properties of the mechanical structure. On one hand, the electrical network should exhibit similar modal distributions. Such a spatial coherence condition is met by discretizing the constitutive equations of the continuous mechanical medium, applying an electromechanical analogy, and deriving the electrical connections which are analogous to the considered mechanical boundary conditions. On the other hand, the structure and the electrical network should have similar wave propagation properties to meet a frequency coherence condition. Hence, a passive broadband damping can be achieved by coupling a structure to its analogous electrical network. After a first experimental validation on a rod in 2014, this method was then applied to vibration mitigation of other structures such as straight beams (2015), plates (2015 & 2018), curved beams (2019), thin rings (2022), thick beams and plates (2023) and thick rings (2023). This 10-year line of research has created opportunities for fruitful collaborations between the Conservatoire national des arts et métiers (France) and the Georgia Institute of Technology (USA). Such investigations on passive analogous networks may now extend to digital implementation and hybrid active-passive electrical networks.

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Experiment-Based Calibration of a Digital Piezoelectric Shunt for Vibration Mitigation

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Abstract: Piezoelectric shunts can be used efficiently for vibration mitigation of flexible structures when the electrical impedance is designed correctly and precisely tuned to enhance the overall damping performance. The electrical impedance can be composed of physical electrical components such as resistances, inductors, and capacitors. Alternatively, the electrical impedance can be synthesized using a digital control unit, often referred to as a digital piezoelectric shunt. In the present study, such a digital piezoelectric shunt is attached and calibrated to damp vibrations of a single mode of a composite blade. The calibration of the impedance requires knowledge of structural parameters in terms of the natural frequency, modal capacitance, and electromechanical coupling factor. When a detailed numerical model is not available, these parameters need to be determined experimentally. In this study, it is demonstrated that the required structural parameters can be obtained experimentally from measurements of the dynamic capacitance of the piezoelectric transducer. Furthermore, it is shown that the measurement of the dynamic capacitance can be done directly with the digital shunt by applying a current and measuring the voltage across the piezoelectric patch. Thereby, the use of additional sensors is not required for the calibration of the shunt. Removing this requirement can reduce the cost of implementation of digital shunts and allows for re-tuning to account for changes in structural parameters in operation, e.g. due to temperature changes or changes in the structural parameters during the lifespan of the structure. Yet, in contrast to a passive shunt with physical components, a digital shunt requires external power and is not inherently stable. A more robust shunt with the same benefits as the digital shunt can potentially be obtained by combining the digital control unit with physical components. Such a hybrid shunt with adaptive capability can reduce the power demand and secure a minimum functionality in case of loss of power.

Preliminary Applications of Acoustic Emission Detection Systems on Composite Structures

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Abstract: Acoustic Emission (AE) is finding new attention from the scientific and technological community for a number of applications that needs a prompt identification of the health status of a certain structure. For instance, they allow getting info on the released energy after a crack event, making it possible to extrapolate indications on its residual life, and support other SHM systems to easily identify maps of the existing, current damage. Such potentialities are particularly interesting for critical structures, like the hydrogen tanks, recently identified as a novel component on-board of commercial aircraft, following the Greening wave that is investing all the means of transport, and even the all-day life. In this perspective, the widely used piezoelectric ceramics, excellent for their very large bandwidth, are hard to be used for the possibility of spark insurgence after being exposed to strain fields. In this view, optical sensors could be a viable mean for overcoming those limitations. Within the H2ELIOS*, a EU Clean Aviation Project, CIRA is starting to develop its own expertise, with the support of all the Consortium, to deploy a suitable AE sensor network for SHM monitoring purposes. In this activity, preliminary results are shown, mainly dealing with the characterization of typical crack signals by a common PZT sensor networks for individuating its main features, in view of replacing it with an optical acoustic system. Different coupons have been tested on a standard mechanical rig. At first, a simple growing damage was imposed and the strain history was recorded and post processed in details, highlighting some peculiar properties of the acquired signal. In a second case, the signals were detected at the event insurgence, irrespectively of the magnitude and variability of the quasi-static load therein applied, in the perspective of a full real-time application. A correlation analysis was then performed among the successive acquisitions, and some preliminary conclusions were drafted.

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Towards the Development of a Digital Twin Framework for Non-Destructive Evaluation of Adhesive Structural Joints

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Abstract: Marine and aerospace structures require the assessment of critical structural components to ensure safe operational performance. Ultrasonic non-destructive evaluation (NDE) techniques are typically used to assess discontinuities within these critical structures, ensuring parts operate within their specified damage tolerances. To predict the useful remaining component life of critical assets, researchers have been working towards the development of a digital twin framework to assess their structural integrity and remaining component life in a virtual environment; thus, predicting metrics like component strength and time to failure. While informative, NDE of digital twins has been found to be lacking within the open literature. To investigate the formation of discontinuities and the similarities between digital and physical results, the authors are studying the incorporation of ultrasonic inspections in the digital twin framework applied to single and double lap shear joints. In this study, aluminum adherend single and double lap shear joints have been manufactured, tested, instrumented, and inspected. Finite element models, capable of producing realistic failure modes, have been developed for structural life assessment of the lap joints. Ultrasonic NDE models have been developed based on 2D cross sections of the ABAQUS CAE/Explicit™ lap joint models at a healthy, semi-damaged and fully fractured state. Modifications to the structural models were made using Blender®, to fix erroneous mesh components, and then SolidWorks® for the conversion to a file format suitable for plugin to ABAQUS CAE/Explicit™, used for ultrasonic simulations. The ultrasonic NDE in both experimental and computational cases were performed using water immersion pulse-echo techniques, simplifying the interpretation of the inspection by introducing a delay between the initial and subsequent wave packets. Future work will be focused on running simulations across the entire 3D lap joint domains, and generating a pseudo-3D volume from the computational results that can be compared to experimental findings. In addition, the authors plan to overlay and compare the ultrasonic data to the lap joint geometric models to further improve the interpretation of discontinuities; therefore, creating a more complete digital twin framework.

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Tailoring Focused Ultrasound Fields with Acoustic Lenses for Complex Heat Patterns

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Abstract: The accumulation of heat caused by concentrated ultrasonic energy pushes the evolution of controlled drug delivery systems and therapeutic uses in medicine. Ultrasound sensitive materials, such as polymers and biological matter, absorb and attenuate the acoustic field, allowing energy to be converted into useful thermal gain for practical use. However, present techniques for producing focused ultrasound (FUS) fields employing curved single-element and phased array transducers fall short of the required flexibility, ease of control, and affordability for these applications. Recent advances in sound manipulation with acoustic holographic lenses (AHLs) show promise as a potential option for concentrating ultrasonic energy. AHLs develop complicated focused ultrasound beams by dynamically modifying the acoustic wavefront generated by a single source element to reconstruct acoustic pressure fields in the desired shape. Although AHLs show promise in a variety of applications, their potential benefits in precise temperature manipulation, particularly in terms of heat transport and control, have yet to be completely examined. In this presentation, we will describe an efficient and exact way for designing AHLs using a machine-learning-assisted single inverse problem approach for creating particular and controllable acousto-thermal fields. Layer-by-layer assessments of various complicated patterns are carried out for both thin and thick case studies, improving our grasp of AHLs' versatility in building personalized thermal maps. Heat transmission within the tissue-mimicking sample is simulated using three-dimensional linear, k-space pseudospectral acoustic simulations combined with Pennes' Bioheat equation. Furthermore, pressure and thermal measurements are used to experimentally validate the theoretical framework. The results show that our suggested method not only allows for exact temperature control within heterogeneous acousto-thermal sample materials, but also provides a solid foundation for predicting thermal changes within materials using only outer surface data. Finally, the findings of this study are expected to add vital knowledge to the field of acousto-thermal research, paving the way for breakthroughs in controlled thermal manipulation for a variety of applications.

High-Intensity Focused Ultrasound for Adhesion Testing and Delamination of Soft Materials

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Abstract: High-Intensity Focused Ultrasound (HIFU) research today primarily focuses on biomedical therapy applications, such as tissue ablation, histotripsy, and lithotripsy. In this study, we investigate the potential of using HIFU as a low-impact test for laminated materials. Specifically, we explore the delamination of adhesively bonded thin-film laminates with varying HIFU excitation conditions. HIFU is attractive in nature due to its ability to generate high-strain-rate pulses in a non-contact, localized manner. More specifically, we used these features to study the damage on the thin films by gradually exploring various levels of power intensity and duration of the pulse. Our thin film laminates are made of Kapton polyimide layers bonded using epoxy. By varying the excitation intensity of HIFU, we create shock waves of different pressure levels to interact with our test specimen. Our experimental results show that the regions of HIFU excitation on the thin films display different ring/circular pattern-like damages and visible color changes based on the location, power intensity, and bond conditions. The morphological details of HIFU-induced areas on the thin film laminates are studied using optical profilometry and micro-computed tomography. These tools, when assisted with image processing algorithms, can allow us to establish a correlation between the HIFU transducer's power intensity, duration, and position with the size and shape of the damage. In addition, we extend this relationship to the laminate's bond condition as a measurement of adhesion strength. The developed procedure is then compared with traditional materials science techniques, such as the peel testing, for characterizing adhesion strength of the adhesively bonded thin-film laminates. Numerical simulations (using finite-element software) are conducted to corroborate our findings and further understand the potential effects of the temperature distribution generated by the HIFU transducer. This study further expands our understanding of HIFU-induced effects on the strength, failure, and damage mechanisms of adhesively bonded thin films.

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Flexible Frequency Tuning in Ultrasound Power Transfer Systems

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Abstract: Ultrasound Power Transfer (UPT) systems have attracted attention in numerous engineering applications due to their exceptional efficiency and wireless connectivity. These systems are preferred for transmitting through a metal wall, due to the absence of Faraday shielding commonly associated with electromagnetic power transfer techniques in conductive media. Through-wall UPT (TWUPT) systems consist of a metal barrier sandwiched between two piezoelectric elements using coupling layers. In the past few decades, researchers mainly focused on analyzing TWUPT systems operating at the 1st thickness extensional mode utilizing piezoelectric elements with high diameter-to-thickness ratios. In contrast, radial-mode UPT systems, featuring various aspect ratios, undergo the occurrence of different vibration modes in close proximity to each other, leading to the phenomenon of mode couplings. The occurrence of mode coupling and/or operating at higher order modes is attributed to low efficiency and active power levels. In this presentation, we accurately predict the occurrence of mode couplings between symmetric and asymmetric vibration modes for assessing the overall efficiency and performance of these systems. In addition, we propose the use of non-uniform electrode configurations attached to the face of the piezoelectric transducer and receiver for selective mode excitations. The electrodes employed in this study are designed to prevent electrical charge cancellation on the receiver's side and enhance the mechanical quality factor on the emitter's side. We demonstrated through numerical simulations and experiments that electrode patterning along with avoiding mode couplings results in a substantial improvement in both overall efficiency and active power.

Temperatur-adaptive damping through metamaterial-based control of liquid friction in a Couette flow

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Abstract: In many technical applications mechanical damping should be temperature-independent (e.g., motor vehicles, air and spacecraft). Active damping systems are commonly controlled by complex sensor-actuator systems which vary valve openings or even trigger magnetorheological effects to actively tune flow resistance to continuously adapt the level of energy dissipation. Temperature control is particularly necessary when using oil, as the viscosity decreases exponentially with increasing temperature. Here, temperature-sensitive metamaterials can offer a material- and energy-saving alternative. Metamaterials exhibit atypical effective structural and physical material properties and consist of only a few or even one single structured base material. The metamaterial consists of repeating unit cells in which properties e.g., stiffness, and shape are implemented as functions of deformation, temperature, stiffness, etc. This contribution demonstrates how the comprehension of the Couette flow is utilized to design suitable metamaterial unit cells. The Couette flow considers the flow of mediums between two walls moving relative to each other. The fluid viscosity and applied shear rate cause fluid friction, leading to the dissipation of kinetic energy. The shear rate usually depends on the width of the flow gap. The force for the wall displacement increases with wall area. Therefore, two geometric parameters are accessible to regulate fluid friction adaptively. Vertical fluid friction tests were carried out to identify suitable geometries for the fixed wall (frame) and moving wall (piston) made of TiAl6V4 and polycarbonate using additive manufacturing. To determine the influence of relevant parameters, the position of the piston and frame in relation to each other, the oscillation speed, and the viscosity of the surrounding liquid (water, soap, oil) were varied. An analytical fluid friction model was then developed and fitted to the experimental results to determine the contribution of fluid friction to the total flow resistance. The interaction of fluid with a temperature-dependent flow gap controlled by a metamaterial shows the potential for novel adaptive and temperature-independent damping solutions.

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Experimental demonstration of a topological insulator-based electroacoustic transistor

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Abstract: We experimentally demonstrate an electroacoustic transistor using topologically-protected valley-Hall interface states. We construct a monolithic reconfigurable phononic analog of the quantum valley-Hall insulator composed of piezoelectric (PZT) disks bonded to a patterned aluminum plate. The unit cell of the transistor structure contains two PZT disks each of which is either shunted or open circuited. The device allows for dynamic reconfiguration to host one or more topological interface states which are established through inversion symmetry breaking achieved by selectively powering the shunt circuits. The shunt circuits employed here offer an impedance resembling a negative capacitance effectively reducing the elastic modulus of the PZT disks. Differently shunting PZT disks of the unit cell in two neighboring domains in the phononic structure results in topological states with localized energy at the interface between the domains. First, we demonstrate a single topological interface. Next, we set up a control region within the phononic structure consisting of two groups of shunted PZT disks. Based on the amplitude of wave energy at a chosen location in the first topological interface, we dynamically switch the power between the two groups of shunts in the control region to turn on a second interface. This enables the flow of wave energy between two locations in the reconfigured interface analogous to the voltage-controlled electron flow in a field effect transistor. The amplitude of wave energy in the second interface is used for bit abstraction to implement acoustic logic. The device can be readily used as a NOT gate by switching the power supply to the two groups of shunts in the control region. Further, using finite element simulations, we illustrate various combinations of the demonstrated transistor to obtain other fundamental gates (AND and OR). The proposed electroacoustic transistor is envisioned to find applications in wave-based devices and edge computing in extreme environments, and inspire novel technologies leveraging acoustic logic.

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Topological Interface Modes in Triply Periodic Minimal Surface and Programmable Piezoelectric Resonant Metamaterials

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Abstract: With growing interest in topological insulators, and emulation of topological properties such as quantum hall, quantum spin hall, quantum valley-hall and Weyl physics in acoustic and elastic systems have led to new ways to manipulate mechanical waves in unconventional manners. Of particular interest are topological interface modes due to their immunity to structural defects and backscattering. In this study, we show the existence of topological interface modes in two different smart structures: (1) Bio-inspired – triply periodic minimal surface (TPMS) I-WP structure, and (2) Programmable piezoelectric resonant metamaterial. Due to the zero mean curvature property at each point on the surface of TPMS structures they have high load bearing and energy absorption capabilities. On the other hand, piezoelectric resonant metamaterials are also of interest due to their ability to tune band gaps and guide waves at will. In this regard, we use both these structures to explore topological properties for wave localization effect. In both these structures, we use the band folding mechanism, where by doubling the unit cells, the bands in the high symmetric points are closed. In order to realize the topological interface mode, the space inversion symmetry (SIS) degeneracies are broken by changing the stiffness of the unit cells, either by manipulating the geometry or shunting the unit cells with a synthetic impedance circuit. Specifically, we stretch or compress one of the I-WP unit cell to break the SIS, further we show that hybridization of different shell thicknesses of I-WP unit cells also breaks the SIS, avoiding the need to manipulating or changing the structural geometry. In piezoelectric resonant metamaterial, we change the shunt inductor frequency to break the SIS. We then propose a 1D Su–Schrieffer–Heeger (SSH) type beam using I-WP and piezoelectric resonant structure to realize the topological interface modes. Experimental studies are carried out to validate the numerical simulation and support the existence of interface modes in these structures. The reported topological interface modes in TPMS and resonant piezoelectric metamaterial can lead to building multifunctional acoustic and elastic devices for wave guiding, filter, vibration control and energy harvesting applications.

UV-reprogrammable hydrogel for shape morphing metamaterial with tunable bandgap

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Abstract: Nature creatures constantly evolving shapes and properties to realize various functions and become adaptive to the changing environment. In the past several decades, intensive efforts have been made to develop materials with tunable properties. Among those, hydrogels because of their good biocompatibility, large deformation, versatile stimuli-responsiveness, have attracted significant attention among researchers in many engineering fields. Furthermore, hydrogels exhibit less internal damping compared to commonly used soft materials and have close-to-water impedance. It is considered a good candidate for shape morphable metamaterials which offers potential for structural dynamics and wave propagation applications.

Traditional shape morphing hydrogels rely on structural implementation of inhomogeneity inside the material during fabrication to realize predetermined complex shape changes upon stimuli activation. Although intriguing, most of these strategies can only realize one predetermined configurational change, which is pre-set during fabrication and not reprogrammable. Recent advancements have introduced systems with rewritable shape-morphing capabilities, including electrothermal, photothermal, and reversible ion-printing gels. Photochemical hydrogels offer superior spatial and temporal control, yet their photoactivation is often coupled with deformation, complicating complex 3D morphing. To address this, a novel approach utilizing photo-ionizable molecules in hydrogels is proposed. By incorporating two photocleavable molecules that react upon light activation, a reactive ion couple is formed within the gel. This reaction not only locks the molecules in their activated states but also drives the reversible photochemical reaction, decoupling the photopatterning process from morphing.

This research then explores bandgap formation in such hydrogel-based programmable periodic structures and also studies the effects of parameters such as photo-sensitive group concentration and unit length ratio onto the width and center frequency of the bandgaps. For cantilevered hydrogel-based periodic structures, experimental results are validated using finite element and diatomic chain model (represents the simplest type of periodic systems). Both experiments and models conclude that increase in the concentration of the photo-sensitive group increases bandgap width and attenuation while reducing its center frequency whereas, an increase in unit cell length ratio reduces both the bandgap width and center frequency.

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Acoustic metamaterials with nacre-like phononic band gaps and mechanical qualities

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Abstract: The remarkable mechanical characteristics of nacre-like metamaterials, such as their strength, stiffness, and toughness, are explained by the periodic arrangement of their microstructures with organic and mineral phases forming a "brick and mortar" structure. Moreover, it is hypothesized that the hierarchical periodicity seen in nacre structures leads to wider band gaps at different frequencies. In order to take advantage of the wide range of design options that these systems offer, we have developed a framework that blends Bayesian optimization and deep learning. This framework makes it easier to explore nacre structures for multi-objective design in both forward and inverse directions. We employ optimization techniques to identify optimal geometry constants aligned with predefined fitness functions. Despite the largely unexplored role of hierarchy in the dynamic behavior of metamaterials, our simulations demonstrate the existence of complete band gaps, attributed to the coupling effects of local resonances and Bragg scattering. This research significantly contributes to the advancement of mechanically robust acoustic metamaterials capable of controlling acoustic and elastic waves.

Non-Destructive Evaluation and Distributed Sensing Monitoring of Double Lap Shear Joints

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Abstract: The continuous drive to reduce weight in the aerospace and maritime industry has required engineers to use adhesive systems to potentially eliminate commonly used mechanical fasteners and rivets. Unfortunately, adhesively bonded Double Lap Shear Joints (DLSJ) can lead to catastrophic failures with little to no warning. In this study, the use of fiber optic distributed sensing systems is investigated to measure the mechanical behavior of these joints during manufacturing and testing. A distributed fiber optic sensor is embedded within the adhesive layer to measure the residual strain formation during manufacturing. This same sensor is further used to monitor changes in strain in the adhesive layer during a tensile pull test to failure following ASTM D3528-96. To evaluate the damage mechanisms many coupons will be taken to failure, while others will be pulled to a non-failure load and inspected for damage. Additionally, the DLSJ adherends were manufactured using aluminum alloy 5083, and ProSet ADV176/276 was used for the adhesive. The primary objective of this research is to link the strain data from the distributed fiber optic sensor to the A, B, and C-Scans of an ultrasonic water immersion Non-Destructive Evaluation (NDE) technique. A secondary goal is to characterize the induced strain due to curing and determine how this may affect the load to failure of the joint. Preliminary experimental evidence suggests that the failure mechanism of these types of joints is asymmetric, where one side of the joint fails before the other. Thus, the research group hypothesize that Structural Health Monitoring (SHM) using fiber optic sensors can be directly linked to standard NDE techniques widely accepted by the aerospace and maritime community. The research team envisions that a direct link between SHM and NDE would provide a greater confidence level for the use of SHM in these critical structural applications.

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Multiphysics Through-Metal Ultrasonic Data Transmission Bridging Electromagnetic and Piezoelectric Methods

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Abstract: For systems requiring a complete metallic enclosure for isolation from electromagnetic interference, it has been shown in literature that pairs of piezoelectric transducers can be utilized to form an ultrasonic channel through such a barrier capable of transmitting data. Prior work has utilized direct electrical stimulus of the piezoelectric transducers. In many applications, however, wireless communication to such a system is desirable. Coupling a traditional antenna to such an ultrasonic channel presents several challenges. Material damping within the ultrasonic channel limits the operating frequency to below about 50MHz. Efficient antennae must be near a quarter wavelength which are impractically large in this efficiency regime. Instead, subwavelength antenna must be used. These kinds of antenna have fundamental efficiency limits based on their size and have port impedances that are difficult to match to receiver impedances. Recently, there has been much interest in the literature regarding mechanically actuated antenna. These antennae utilize mechanical resonances rather than electrical ones to accelerate charges to produce electromagnetic radiation. The current literature suggests that for small antenna these mechanically actuated antenna perform orders of magnitude better than their traditional counterparts. This work presents an optimization study of traditional antenna and piezo-barrier parameters to ascertain a baseline for expected system performance to be used as a point of comparison for future work. This study utilizes analytical models for the performance of a small magnetic loop antenna and the transfer matrix parameters for piezo-barrier of PZT-4 and aluminum. Antenna and piezo-barrier models are validated experimentally using vector network analyzer measurements. Good agreement is found between the theory and experiment for both the measured impedance and network properties as well as expected system performance. Demonstration of the fully constructed system is also presented showcasing both line of sight range measurements and the ability to receive commercial AM radio broadcasts.

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Analysis of shape recovery in 4D-printed ultrasound-responsive polymers

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Abstract: 4D printing is a cutting-edge development of 3D printing in the field of additive manufacturing that incorporates time as a crucial component. Shape memory polymers (SMPs), are responsive materials that can dynamically change in shape, characteristics, and function when triggered by an external stimuli like heat, moisture, light, or mechanical force. SMPs are used to create complex structures. The need for precise, targeted manipulation of SMP structures over predetermined time frames has increased for biomedical applications. Although heat activation has been well investigated, there is a significant knowledge gap regarding an emerging non-invasive triggering mechanism, ultrasound actuation. Focused ultrasound (FU) is used in this work as a trigger to activate SMP-based devices. Because of its enhanced capacity to localize heating, the shape recovery process can be initiated only in certain areas of the polymer. This work examines FU's potential for actuating 4D manufactured SMPs in detail and examines how 3D printing parameters affect recovery. The experimental investigation's iterative approach methodically verifies the effects of variables on the shape recovery of thermoplastic polyurethane filaments under thermo-acoustic actuation, including printing temperature, speed, infill density, and infill structures. When paired with FU activation, this is critical for developing the spatial-temporal control of the shape memory effect, particularly in the advanced area of 4D printing techniques. In addition, the study shows a systematic relationship between additive manufacturing parameters and SMP viscoelastic deformation properties. This correlation is accomplished by the combination of acoustical principles, thermo-mechanical experimental data, and polymer surface morphological data, paving the way for a better understanding and use of acoustic actuation in 4D printing in real-world applications.

Broadband Piezoelectric Acoustic Identification Tag Design and Optimization for Underwater Applications

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Abstract: Across domains such as biomedical ultrasound, through-wall communications, and underwater navigation, piezoelectric based acoustic backscatter offers a low-power data transfer solution. Additionally, leveraging piezoelectric energy harvesting enables these devices to be self-powered. In certain applications such as communication with Autonomous Underwater Vehicles (AUVs) for localization, these devices need to achieve fast data-rates, high energy efficiency and robust communication schemes for optimal performance. In this work we detail the development of broadband Acoustic Identification (AID) tags which achieve concomitant, frequency multiplexed power harvesting and high data-rate communication using broadband acoustic-electric impedance tuned transducers and electric circuit design. Using a two-port network modeling approach for the piezoelectric element, we implement broadband impedance matching to develop the piezoelectric transducer for the AID tag. With the same multi-port network approach, the optimal electrical circuit including the impedance matching and frequency splitting filters separating the energy harvesting and backscatter communication circuit paths are designed. A scaled AID tag prototype, including the transducer, energy harvesting and communication circuits is developed and experimentally validated. The high-frequency (1 MHz center frequency) prototype achieves backscatter communication rates of up-to 200 kbps and an end-to-end electrical energy efficiency of up-to 50% in water tank experiments. Extending the scaled tag design methodology, a full-scale AID tag, targeting operation for short-range underwater applications (~10m) is designed, with an operational center frequency of 350 kHz. The full scale AID tag is designed for efficient operation utilizing a low power microcontroller, and minimizing electrical losses to alternate circuit paths. The tag is tested experimentally in a large acoustic water tank, and demonstrates an operational range of up to 5m (range limited by the tank geometry) for power transfer, high data-rate backscatter communication at long range, as well as simultaneous power transfer and backscatter communication. Additionally, the advantages of wide communication bandwidth is demonstrated through broadband communication schemes such as Frequency Shift Keying (FSK) and Linear Frequency Modulated (LFM) carriers which improve robustness of communication underwater to narrowband interferers, Doppler effects and frequency selective fading in channels.

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Shear effects in holographic acoustic lenses

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Abstract:

Engineering applications are particularly interested in controlling and steering elastic waves across isotropic material slabs. Holographic acoustic lenses (HALs) can be used to accomplish this. Elastic wave manipulation through solid objects remains a barrier for sensors or devices that are charged locally. Wave propagation via solid structures, as opposed to fluid mediums, entails the propagation of longitudinal and shear waves, which must be considered when building HALs. This work hypothesizes that shear in the hologram is introduced into the hologram stack via two sources: internal shear stresses in the elastic material and the interface between the PZT disc and the elastic material (metals). Numerical simulations and experiments are carried out to validate our approach and demonstrate HALs' ability to pattern elastic waves.

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Design of Multi-Stage Detachable Ultrasonic Power Transfer System and the Effect of Self-Heat Generation

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Abstract: Ultrasonic power transmission (UPT) has gained growing attention due to its ability to wirelessly transfer power and data across a variety of low-powered electronic devices such as biomedical implants, sensors, and electrical components inside a nuclear waste container or pressure vessel. Conventional wireless techniques such as electromagnetic waves are not suitable for sealed metallic enclosures since they act as Faraday cages, shielding electromagnetic waves. In addition, practical design constraints limit perforating the metal barriers to feed-through wires, otherwise compromising the structural integrity of barriers. Ultrasonic power transfer is thus an important alternative for powering and communicating with such systems. A typical UPT system consists of two piezoelectric transducers bonded on either side of a metallic barrier, where the transducers transmit and receive elastic waves and convert the mechanical energy into electrical energy. Such single-barrier systems have been widely studied, though the effects of self-generated heat during Watt-level power transmission have not been studied in detail. Different sources of loss exist within piezoelectric transducers, which lead to self-generated heat that may affect the efficiency of the UPT system. Initially, the self-heat generation and effects of temperature on UPT efficiency are studied using both numerical and experimental methods. While UPT systems with piezoelectric transducers permanently bonded to either side of a metallic barrier typically present the best performance, it is important to also consider applications that require multiple sealed metallic enclosures that are coupled in a detachable way for power and data transmission between enclosures. In this regard, two different detachable wand systems - a semi-detachable UPT stage, and a completely detachable wand UPT stage are proposed with electro-permanent magnet and 3D printed attachment methods to find the most efficient and practical design for both power and data transmission. Furthermore, due to the non-bonded nature of these multi-stage systems, a couplant (gasket) material is key for ensuring good transmission. To this end, the transmission efficiency of various couplant materials is also investigated. Our reported results are useful in designing an optimal multi-stage UPT system and understanding the self-heat generation characteristics of through-metal piezoelectric systems.

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Embodying Mechano-intelligence in Phononic Metastructures via Physical Computing and Learning

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Abstract: The rapid advances in technologies have demanded the next generation of adaptive structural and material systems to perceive and learn from their working conditions, decide the appropriate actions, and execute real-time commands autonomously and efficiently. Such a need for highly integrated intelligence requires us to dramatically advance from conventional add-on electronics-based computing, sensing, control, and actuating platforms, by exploring the emerging mechano-intelligence. Although studies have attempted to embed intelligence directly in the design of mechanical systems, there is still a lack of a systematic foundation for constructing and integrating the different aspects of intelligence, namely perception, learning, decision making, and execution. In this study, we lay down this broad foundation by utilizing the promising physical computation and learning concept. Especially to advance from mere physical computing to multifunctional mechano-intelligence by achieving and integrating the essential functions in the mechanical domain, forming the basis for multi-faceted functional-relevant intelligence embedded in future adaptive structural systems. As an exemplar platform, we construct a mechanically intelligent phononic metastructure to achieve intelligent wave functionality adaptation by harnessing a physical reservoir computing framework. That is, by employing the computing power hidden in the wave dynamics of a phononic metastructure as a physical-body-based analog neural network, we embed and integrate the various key elements of intelligence in the mechanical domain of the metastructure such as learning from sensory processing, perceiving input features, making decisions, and commanding actions to actuator. Through analyses and experimental investigations, we uncover multiple adaptive structural functions by training our system to intelligently tune itself according to different working conditions ranging from self-tuning wave propagation controls to wave-based logic gates. Overall, this research will provide the basis for creating future new structures that would greatly surpass the state of the art — such as lower power consumption, more direct interactions, and much better survivability in harsh environment or under cyberattacks. Moreover, it will enable the addition of new functions and autonomy to systems without overburdening the onboard computers.

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Modifiable Acoustic Lens for Changing Target Patterns Spatially

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Abstract: Acoustic wave front shaping techniques have gained interest due to their importance in enhancing the performance of medical imaging and various other applications. Acoustic holographic lenses generate complex acoustic patterns by modulating the phase and/or amplitude of an acoustic wave front. The pressure amplitude is reconstructed by interference at a predefined fixed target plane located at a certain distance from the modulation plane. The static nature of such acoustic lenses hinders the ability of such holograms to target different spots at different time steps. In this presentation, a modified acoustic lens is utilized where continuously adjustable acoustic targets can be generated spatially. This lens allows fine-tuning of the pattern at different spatial locations which is useful in many applications including cell/tissue engineering and medical ultrasound. Numerical simulations are carried out for homogenous and heterogeneous mediums and their accuracy is confirmed through experimental validation.

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Pneumatic Tile-Based Approach for Localized, Distributed, Proportional Actuation of Active Origami

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Abstract: Origami structures provide sophisticated reconfigurable shapes and tunable mechanical properties such as stiffness and multi-stability. However, automating these functionalities with self-folding requires effective actuation methods. Controllably folding origami structures requires *localized* actuation to fold individual creases, *distributed* actuation to coordinate motion across the patterns, and *proportional* actuation to reach continuous ranges of shapes and properties. Distributed actuation is difficult to implement on the compact hinge-and-plate structure with traditional actuators, yet localized and proportional actuation can be challenging for distributed smart materials approaches without complicated design. This paper explores a simple, compact pneumatic tile-based approach to provide localized, distributed, and proportional actuation to achieve controllable active origami folding and structural property tuning such as stiffness and bistability. Thin-layered inflation bladders are layered beneath rigid origami plates (tiles) spanning the folding creases. When inflated, the inextensible bladders pull the origami plates together providing folding torques at the mountain creases and unfolding torques at the valley creases. Selectively placing and interconnecting the bladders over subsets of creases enables distributed and localized actuation of multi-degree-of-freedom, structurally coupled origami tessellations tailorable for a diverse range of shape changes and controllable functionalities. To enable analysis of the origami actuation, the ability of an inflation bladder to produce folding torque along a single crease is modeled based on first principles and phenomenological bladder effects. Incorporating the experimentally validated local crease actuation model, a structural kinematic model predicts origami pattern folding, validated by a single-degree-of-freedom four-crease Miura-Ori unit prototype. This prototype can predictably fold itself into multiple patterns (Miura, straight hinge, and reversed Miura) controllably and reversibly with bistable behaviors that can be enabled and disabled when different creases are pressurized. Further, the intrinsic synergetic and antagonistic coupling between the actuated creases predictably enables additional active tunability of the stiffness and multi-stability. The pneumatic tile-based surface approach provides distributed, localized, and proportional actuation to enable controllable active origami self-folding and property tuning in a simple, compact, and predictable way.

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Dynamic Pressure Inversion Using a Piezoelectric Sensor Array and Faulty Sensor Detection

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Abstract: Conventional pressure sensors require direct access to the pressure environment being measured, and so they require through-holes to be drilled into the underlying structure. For applications where such structural modification is impossible, an alternative solution is to invert the dynamic response of the structure to estimate the applied pressure load. This is a challenging load identification problem, as the applied load (i.e., the external pressure) can vary smoothly across the entire external surface of the structure. To solve this problem, we present an approach to estimate the dynamic pressure applied to the external surface of a structure using an internally mounted array of piezoelectric sensors. First, we experimentally establish a model that relates point forces on the external surface of the structure to the piezoelectric sensor output. Then, during operation, we regularize and invert the model to estimate the applied pressure based on measured piezoelectric data. We demonstrate the concept through numerical and experimental studies on a flat plate and cylindrical shell. In each case, aluminum structures were instrumented with arrays of piezoelectric patches, and impact hammer/shaker tests were performed to construct the system model. Distributed forces were applied using an impact hammer and loudspeaker, and comparisons were made between the measured and estimated (i.e., inverted) distributed loads. Overall, these results show that piezoelectric sensors can be used to reproduce an applied distributed load accurately; however, due to the nature of the inverse problem, it is necessary to use a large array of sensors to resolve the pressure field with high spatial resolution. We then extend this method to more complex structures by leveraging modal superposition, rather than point forces, to reproduce the applied pressure on a conical shell. In this approach, the unknown pressure is expanded using structure mode shapes, rather than point forces, and finite-element models are used to relate each mode shape as pressure input to the sensor output. Finally, a method of monitoring the health of individual piezoelectric sensors through comparison with baseline frequency response functions is explored. Due to the complexities of matrix inversion, a single faulty piezoelectric sensor will negatively impact the accuracy of the resolved pressure. Thus, it is important to be able to detect faulty sensors during operation and remove them from the matrix inversion when estimating a pressure field.

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Vibration and Stability of Morphing Wing

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Abstract: Using a simple pitch plunge model of a typical section for aeroelastic analysis we examine the vibration properties of a two-dimensional wing model for various morphing shapes. The morphing condition discussed is wing sweep for small uninhabited air vehicles (UAVs). Asymmetric wing sweep can be used to effect advantageous roll maneuvers for highly agile flight. Essential with one wing swept, the mass moment of inertial decreases causing a large roll velocity, desirable to initiate a fast turn. The issue addressed here is how does such a drastic change effect wing vibration, and does it cause flutter and/or divergent instability? Using the typical section model and expanding it slightly by modeling the torsional spring effect as that due to a beam model of the wing in torsion the characteristic equation describing the wing vibration is studied. Adding flexibility to the basic pitch-plunge model but modeling the torsional and bending stiffness as that of a simple beam further extends the model. The model then allows the eigenvalue solution corresponding to the first modes of vibration to be computed. This is done for each wing shape in order to determine and characterize the effect of wing morphing on the wing's vibration. In particular, the shapes at which the wing will experience instability due to flutter or divergence are examined. Previous work on the vibration of morphing wings examined symmetric morphing consisting of wing folding and sweep. While they focused on the effect of the folding and sweep mechanisms, they did determine that the flutter speed changes with changing wing fold angle, motivating the present study into the effect of morphing on wing vibrations for small UAVs experiencing asymmetric morphing for increased roll performance.

Avian studies have shown that birds change their stability characteristics so that they can switch between highly maneuverable and highly stable flight through morphing. Here we examine simple wing sweep as a morphing action to see its vibration properties to determine the stability properties as a function of airspeed and sweep angle. We show that for certain sweep angles and airspeed combinations a wing will exhibit flutter. Our analysis was performed using this simplest possible aeroelastic model, thus our conclusion should be considered as one from oversimplified assumptions, and hence preliminary.

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High-Intensity Focused Ultrasound for Adhesion Testing and Delamination of Soft Materials

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Abstract: High-Intensity Focused Ultrasound (HIFU) research today primarily focuses on biomedical therapy applications, such as tissue ablation, histotripsy, and lithotripsy. In this study, we investigate the potential of using HIFU as a low-impact test for laminated materials. Specifically, we explore the delamination of adhesively bonded thin-film laminates with varying HIFU excitation conditions. HIFU is attractive in nature due to its ability to generate high-strain-rate pulses in a non-contact, localized manner. More specifically, we used these features to study the damage on the thin films by gradually exploring various levels of power intensity and duration of the pulse. Our thin film laminates are made of Kapton polyimide layers bonded using epoxy. By varying the excitation intensity of HIFU, we create shock waves of different pressure levels to interact with our test specimen. Our experimental results show that the regions of HIFU excitation on the thin films display different ring/circular pattern-like damages and visible color changes based on the location, power intensity, and bond conditions. The morphological details of HIFU-induced areas on the thin film laminates are studied using optical profilometry and micro-computed tomography. These tools, when assisted with image processing algorithms, can allow us to establish a correlation between the HIFU transducer's power intensity, duration, and position with the size and shape of the damage. In addition, we extend this relationship to the laminate's bond condition as a measurement of adhesion strength. The developed procedure is then compared with traditional materials science techniques, such as the peel testing, for characterizing adhesion strength of the adhesively bonded thin-film laminates. Numerical simulations (using finite-element software) are conducted to corroborate our findings and further understand the potential effects of the temperature distribution generated by the HIFU transducer. This study further expands our understanding of HIFU-induced effects on the strength, failure, and damage mechanisms of adhesively bonded thin films.

Focused Ultrasound-Actuated Shape Memory Polymers for Biomedical Devices

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Abstract:

Focused ultrasound (FU) has emerged as a noninvasive and remotely controlled approach for triggering shape memory polymers (SMPs) in biomedical applications. This presentation gives a thorough examination of two critical issues that are key for the successful integration of SMPs in biomedical devices. (1) In response to the need for smaller biomedical device, our research team has succeeded in manufacturing fibrous acrylate-based shape memory polymers using electrospinning technology. The addition of non-resorbable, biocompatible, high-molecular-weight polystyrene (PS) improves the SMPs' structural and functional qualities. This study explores the complex relationships between fiber morphology and process parameters and solution properties, explaining how these relationships affect shape recovery performance. We demonstrate precise control over shape deformation through adjustment of the electrospinning parameters, setting the stage for customized SMPs with improved capabilities. (2) For the use of SMP devices in aqueous biomedical settings, it is critical to understand how water absorption affects shape recovery performance to guarantee dependable device operation. The response of hydrophilic and hydrophobic photopolymerized thermoset SMP networks to HIFU activation in an aqueous environment are compared in this presentation. The presence of absorbed water molecules appears as a critical component, improving SMP performance in terms of shape memory capacity during HIFU activation. This comparative investigation not only improves understanding of the effect of water uptake on shape memory behavior, but also provides useful insights for improving SMP performance in fluid environments. Understanding the interaction between water uptake and HIFU-actuated shape recovery is critical for optimizing SMP performance in aqueous environments and extending their use in a variety of medical applications. In summary, this study takes a comprehensive approach to the development of HIFU-actuated shape memory polymers for biological applications. This study's findings have the potential to considerably contribute to the evolution of highly functional and efficient SMP-based biomedical devices.

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Joint Input-State Estimation for Inelastic Structural Systems Subjected to Extreme Dynamic Input

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Abstract: This work outlines a robust approach for online joint input-state estimation tailored for inelastic multiaxial structural systems subjected to extreme dynamic inputs. Towards that goal, a novel nonlinear estimator is designed through the conjunction of the Extended Kalman Filter (EKF) and the Finite Input Covariance with Input Updating (FICIU) estimator, to yield the extended-FICIU (eFICIU) estimator. The resulting eFICIU estimator incorporates an online input updating routine, enabling recursive updates of the input covariance matrix, and reducing the reliance on the input statistics that are unknown a-priori. Furthermore, to accurately model the system dynamics in the presence of hysteresis or plastic deformation, a suitable constitutive model is carefully selected and modified. The chosen constitutive model integrates additional degrees of freedom to represent the hysteretic deformation and model the inelasticity at the macro-level. The nonlinear behavior of the aforementioned hysteretic degrees of freedom is modeled using a first order evolution equation, conducive for an estimation framework. Specifically, the chosen constitutive model is simplified to reduce the number of unknown degrees of freedom and enhance computational efficiency. This simplified constitutive hysteretic beam model is then integrated into the proposed eFICIU estimator using a finite element framework. The efficacy of the approach is demonstrated through numerical simulations of a fixed-fixed beam subjected to an unknown impact at its midspan. The estimation results highlight the eFICIU estimator's capability to provide robust estimates of both input and state variables in the presence of nonlinear structural behavior. Finally, to facilitate experimental validation of the proposed system identification approach, a comprehensive laboratory test setup is devised, and preliminary tests are conducted. An array of sensors is instrumented to maximize data collection and explore the minimum sensor requirements for optimal results in the case of material inelasticity. A description of the experimental setup, instrumentation employed, and preliminary experimental data are presented, together with the plan to validate the proposed eFICIU estimator with the experimental data.

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On the Dynamic Response of a Smart Bistable Plate

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Abstract: This paper examines fundamental concept of bistable material composite with an eye for morphing applications. The dynamic response of a smart bistable plate is modelled as a single degree of freedom oscillator with quadratic and cubic nonlinearities. The quadratic nonlinearity reflects the fact that the static equilibrium positions are initially curved, and the cubic nonlinearity reflects the relatively large amplitude due to the geometric nonlinearity. Investigating the equation of motion, one realizes that two parameters need to be experimentally identified: the static tip deflection x_0 and the cubic nonlinearity coefficient α. The static displacement can be measured from the equilibrium shapes at the room temperature of the bistable laminate. Moreover, the parameter α can be identified by measuring the natural frequency of the plate. Stability is caused by arrangements of composite fibers in the traditional sense. However, we examine previous work that used piezoelectric material to cause the bistable behavior. Traditional stability gives two modes, which are, asymmetric, however what's useful and morphing would be if you could make a plate such that bistability causes the free end to curl up and then curl down. Previous work has shown how this can be done by a particular layering. Here we take his analysis and try to validate it with experimental test using a simple single degree of freedom model.